

# Assessment of ecosystem health based on fish assemblages in the Wei River basin, China

Wei Wu · Zongxue Xu · Xuwang Yin · Depeng Zuo

Received: 2 July 2013 / Accepted: 21 January 2014 / Published online: 18 February 2014  
© Springer International Publishing Switzerland 2014

**Abstract** In the Wei River basin, the ecosystem is gradually deteriorating due to the rapid growth of the population and the development of economies. It is thus important to assess the ecosystem health and take measures to restore the damaged ecosystem. In this study, an index of biotic integrity (IBI) for fish was developed to aid the conservation of the ecosystem based on a calibration data set. An index of water and habitat quality (IWHQ) was calculated based on environmental variables and habitat quality (QHEI) to identify the environmental degradation in the studied sites. The least degraded sites ( $IWHQ \leq 2$ ; W1, W5, W10, W12, W13, W14, and W16) were chosen as the reference sites. Six metrics that are sensitive to environmental degradation were utilized to differentiate the reference and the impaired sites using statistical methods. These metrics included the number of species (P1), the total biomass (P2), the number of *Cobitidae* species (P8), the proportion of species in the middle and low tiers (P10), the proportion of individuals that were classified as sensitive species (P25), and number of individuals in the sample (P39). A continuous scoring method was used to score the six metrics, and four classes were defined to characterize the ecosystem health of the Wei River

basin. The fact that the overall IBI scores were negatively correlated with the index of environmental quality (IWHQ) based on the validation data set indicated that the index should be useful for biomonitoring and the conservation of biodiversity. According to the results, more than half of the sites were classified as poor or very poor. The ecosystem health in the Wei River was better than that in the Jing River and the Beiluo River, and this study will be a great reference for water resources management and ecosystem restoration in the Wei River basin.

**Keywords** Index of biotic integrity · Index of water and habitat quality (IWHQ) · Principal component analysis (PCA) · Fish assemblages

## Introduction

In response to growing concerns about water pollution, flow regulation, and land use changes on aquatic ecosystems, the assessment of ecosystem health and the monitoring of biotic responses to environmental changes have received increasing attention from scientists and catchment managers worldwide. The index of biotic integrity (IBI) has been widely used for ecosystem health assessments across the world since it was developed by Karr (1981). Fish communities are effective indicators of ecosystem health because these integrate environmental variability with different spatial scales (Oberdorff et al. 2002), these are relatively easy to identify, and their position at the top of the food chain

W. Wu · Z. Xu (✉) · D. Zuo  
College of Water Sciences, Beijing Normal University,  
Beijing 100875, China  
e-mail: zongxuexu@vip.sina.com

X. Yin  
College of Fisheries and Life Science, Dalian Ocean  
University,  
Dalian 116023, China

helps provide an integrative view of the watershed environment (Karr 1981; Simon and Lyons 1995).

The original IBI method was developed based on the biological conditions in the Midwestern United States by Karr (1981). It was later modified according to the characteristics of different basins. Oberdorff and Hughes (1992) modified and adapted the IBI to the main stem of the Seine River and its major tributaries in France. This successful modification of the IBI to a considerably different fish fauna on a different continent further supports its wider range of use outside the Midwestern United States. Casatti et al. (2009) applied a fish-based index of biotic integrity to lowland streams in a highly deforested region of the Upper Paraná River basin, and revealed that the biological integrity of 91 % of the studied streams was classified as poor or very poor. The IBI method is considered an acceptable tool for the evaluation of ecosystem health and has been widely used in the USA (Dauwalter and Jackson 2004; Tejerina-Garro et al. 2006), Europe (Breine et al. 2004; Siligato and Böhmer 2001), Brazil (Bozzetti and Schulz 2004; Casatti et al. 2009), New Zealand (Joy and Death 2004), and other countries (Ganasan and Hughes 1998; Kleynhans 1999; Qadir and Malik 2009). In addition, several studies have been conducted to evaluate the ecosystem health based on fish assemblages in eastern China such as in the Yangtze River (Liu et al. 2010; Zhu and Chang 2008) and the Liao River (Pei et al. 2010). However, neither an “index of biotic integrity” nor any other quantitative measure of biotic integrity has been applied to the Wei River.

A major reason for this is the intensive human disturbance in the Wei River. Over the past 30 years, intensified human activities have made a huge negative impact on the Wei River basin, which is characterized by decreasing annual runoff, heavy pollution, and a high sediment concentration (Song et al. 2007; Wu et al. 2012). All of the above changes have led to a marked deterioration in the ecosystem function, such as reduced fish richness, shrunk wetland, and decreased forest vegetation. The second reason is the scarcity of published biological community data from the Wei River. Little historical information is available to quantify the influence of human disturbance on the biotic integrity of the Wei River. The most recent investigation of fish assemblages in the Wei River basin was conducted in the

1980s (Xu and Li 1984), and this previous study was the first comprehensive investigation on fish assemblages. However, the changes in the fish assemblages that resulted from the huge human disturbance are still unknown, and few studies have focused on this field in the Wei River. The lack of ecological and life history information on most fishes of the Wei River basin, such as their uncertain functional role in the fish community, have also made it difficult to develop an IBI for the Wei River. In addition, there is a great variability in the environmental conditions caused by natural processes, such as precipitation, soils, and geology. The Wei River basin consists of three rivers: Wei River, Jing River, and Beiluo River, which are the first and second largest tributaries of the Wei River basin. These rivers flow through Loess Plateau, which consists of hyperconcentrated sediment, and are the main source of the sediment concentration in the Wei River basin (Song et al. 2010). The tributaries in the south bank originate from the Qinling Mountains, which are characterized by high flow and low sediment concentrations. The significant geographical features result in major natural difference in the species composition in the whole basin (Xu and Zhang 1996), which produces new challenges in the development of an IBI for the Wei River.

The previous studies on the Wei River basin mainly focused on the alteration of the hydrological regime (Wu et al. 2012), water quality assessments (Lu et al. 2010), and studies on the high sediment concentration in the river (Song et al. 2010). No study has evaluated the ecosystem health based on fish assemblages. The community structure and IBI of the fish assemblage are good indicators of human disturbance. Therefore, it is necessary to identify the ecosystem health based on the fish assemblage under the pressure of human disturbances. It is worth studying whether this tool is suitable for the assessment of ecosystem health in the Wei River. The flexible approaches used for the IBI in the Yangtze River and Liao River (Pei et al. 2010; Zhu and Chang 2008) are a good reference for the study area.

A method was proposed to develop a preliminary index of ecosystem health through three steps: (1) calculate the index of water and habitat quality (IWHQ) to identify the degraded situation of the sample sites, (2) select metrics sensitive to disturbance, and (3) construct a preliminary index of ecosystem health by scoring the identified metrics.

**Materials and methods**

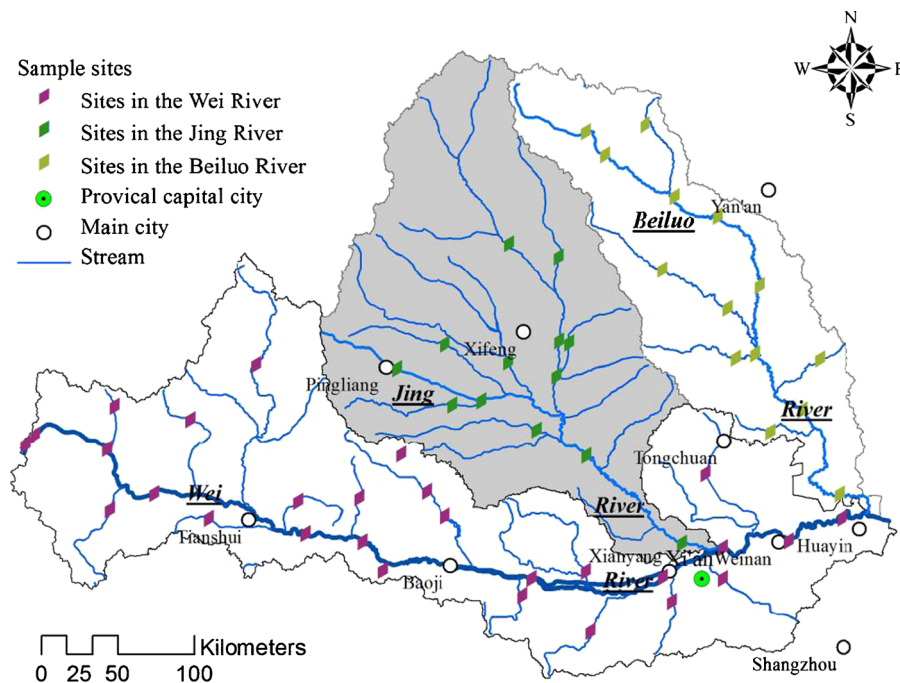
**Fish sampling methods**

In the present investigation, 55 sites were sampled across the whole basin in October 2011 and April 2012 (Fig. 1). The data were divided into a calibration data set and a validation data set. The calibration data set consists of 45 sites (23 sites in the Wei River, 13 sites in the Jing River, and 9 sites in the Beiluo River). In addition, 49 sites were used as the validation data set, and 38 of these sites were sampled twice. The validation data set was used to verify the effect of the preliminary IBI. Fishes were collected for 30 min in three habitats (i.e., pools, riffles, and runs) within 200 to 300 m of all sites, and the individuals in the three habitats were combined to represent each site. In the wadeable streams, the fish collection was performed by a two-person fish collection team, i.e., one individuals used the backpack electrofisher with two handheld electrodes and one was responsible for netting fish with dip nets (Barbour et al. 1999). In the unwadeable streams, seines (mesh sizes of 30 and 40 mm) were used for fish sampling by boat, and electrofishing equipment was employed to ensure a good representation of the fish at the site. All of the individuals (with a total length longer

than 20 mm) collected were identified by species, counted, examined for external anomalies (i.e., deformities, eroded fins, lesions, and tumors), measured (standard length to the nearest millimeter), and recorded on field data sheets. Moreover, individuals with a total length shorter than 20 mm were not identified or included in the standard samples. When a large number of individuals of any one species were encountered in a sample, the biometric characteristics (e.g., body length) of a representative subsample of 30 individuals were measured. Specimens that could not be identified in the field were preserved in a 10 % formalin solution and stored in labeled jars for subsequent laboratory identification. The fish were identified according to fishes in the Qinling Mountains area (Chen et al. 1987).

**Environmental measurement**

The habitat conditions of each sample site were assessed during the sampling period using a qualitative habitat evaluation index (QHEI). The habitat quality assessment process based on visual observation requires rating the ten habitat parameters as “optimal,” “suboptimal,” “marginal,” or “poor.” Given the ecosystem situation in the Wei River, the habitat parameters in this study were modified based on that provided by Ohio’s EPA



**Fig. 1** Location of the sample sites in the whole basin. The *rose*, *green*, and *light blue* points represent sites in the Wei River, Jing River, and Beiluo River, respectively. The *white* and *green* circles represent the main city and the provincial capital in the basin

(Barbour et al. 1999). The following parameters were studied: substrate, habitat complexity, velocity/depth regimes, bank stability, channel alteration, channel flow status, vegetation protection, water quality, anthropogenic alterations, and riparian land use. The habitat conditions were assessed through the sum of the scores obtained for the ten parameters.

The following environmental variables were measured in situ at each sample site. The altitude (Alt) was determined using a GPS, i.e., Magellan eXplorist 200. The physicochemical variables, including pH, dissolved oxygen (DO), salinity (Sali), saturation (Satu), conductivity (Cond), and total dissolved solids (TDS), were measured by YSI Pro Plus 85 in the field. Other physicochemical variables, including alkalinity (Alk), chemical oxygen demand using  $\text{KMnO}_4$  ( $\text{COD}_{\text{Mn}}$ ), water hardness (hardness), total nitrogen (TN), total phosphorus (TP), suspended solid (SS), and  $\text{SiO}_3$ , were tested in the laboratory according to standards from the State Environmental Protection Administration of China (2002).

#### Selection of reference sites

The reference condition is representative of a group of minimally disturbed sites that were chosen based on selected physical, chemical, and biological characteristics (Reynoldson et al. 1997). The choice of an appropriate reference condition is a major problem in ecological assessments (Hughes 1995). Sample sites that are undisturbed by humans are ideally chosen as reference sites. However, nearly all of the rivers in China have been seriously disturbed by human activities, and it is impossible to find a pristine river. In this paper, the IWHQ was used to assess the environmental quality at each site. IWHQ is a hybrid indicator that integrates the habitat condition with the water quality. The original proposal by Lyons et al. (1995) selected the lower quality score (either water or habitat). Schmitter-Soto et al. (2011) combined both criteria to attain a qualitative scale of 10 points, i.e., IWHQ. IWHQ was later correlated with the final IBI to estimate the latter's performance. We presume that a lower IWHQ reflects a better environmental quality, which indicates relatively fewer disturbances by human activities. Thus, those sites with better environment quality were selected as the reference sites.

In this paper, the IWHQ was modified based on the previous studies. There are many physiochemical

variables in this analysis, and the correlation between some of the variables may be high. To simplify the calculation, principal component analysis (PCA) and Pearson correlation were applied to identify the primary physiochemical variables. The primary water quality variables and QHEI were scored through a single factor water quality identification index proposed by Xu (2005a, b), which is based on five levels of water quality standard in China (Table 1).

The minimum values of some of the variables, such as  $\text{COD}_{\text{Mn}}$ , SS, Cond, and TP, are indicative of the best water quality. The score can then be calculated as follows:

$$\text{IWHQ}_i = \begin{cases} 1 & C_i \leq S_{i,1} \\ j + \frac{C_i - S_{i,j-1}}{S_{i,j} - S_{i,j-1}} & S_{i,j-1} \leq C_i < S_{i,j}, \quad j = 2, 3, 4, 5 \\ 6 + \frac{C_i - S_{i,5}}{S_{i,5}} & C_i \geq S_{i,5} \end{cases}$$

In contrast, the maximum values of some of the other variables, such as DO and QHEI, are indicative of the best water quality. In this case, the score can be calculated as follows:

$$\text{IWHQ}_i = \begin{cases} 1 & C_i \geq S_{i,1} \\ j + \frac{S_{i,j-1} - C_i}{S_{i,j-1} - S_{i,j}} & S_{i,j} \leq C_i < S_{i,j-1}, \quad j = 2, 3, 4, 5 \\ 6 + \frac{S_{i,5} - C_i}{S_{i,5}} & C_i \leq S_{i,5} \end{cases}$$

**Table 1** Scoring criteria of the physiochemical variables and QHEI in the five classes

Primary environmental variables	1	2	3	4	5
Cond	200	400	800	1,000	1,500
DO	7.5	6	5	3	2
SS	20	70	300	800	1,000
TDS	200	300	600	800	900
TP	0.02	0.1	0.2	0.3	0.4
$\text{COD}_{\text{Mn}}$	2	4	6	10	15
$\text{SiO}_3^{2-}$	7	11	14	16	18
QHEI	140	120	100	90	70

The scoring criteria of DO, TP, and  $\text{COD}_{\text{Mn}}$  refer to the standards from the State Environmental Protection Administration of China (China 2002). The scoring criteria of Cond, SS, TDS, and  $\text{SiO}_3$  were determined by the 5, 25, 50, 75, and 95 % percentile of the calibration data set. The scoring criteria of QHEI were determined by the 95, 75, 50, 25, and 5 % percentile of the calibration data set. Variable abbreviations are used in the following tables and figures

where  $C_i$  is the observed value of variable  $i$ ,  $i=1, 2, \dots, n$ ,  $n=8$ ;  $S_{ij}$  is the  $j$  class value of variable  $i$ .

The final IWHQ is the average scores of all of the variables:

$$\text{IWHQ} = \frac{1}{n} \sum_{i=1}^n \text{IWHQ}_i$$

According to the study conducted by Xu (2005a), the environmental quality is categorized into three classes: least degraded ( $\text{IWHQ} \leq 2$ ); medium degraded ( $\text{IWHQ} \leq 4$ ), and highly degraded ( $\text{IWHQ} > 4$ ). The sampling sites with  $\text{IWHQ} \leq 2$  were chosen as the reference sites.

### Metric systems for index of biotic integrity

Considering the present situation of the Wei River ecosystem and the application of the IBI (Karr 1991; Oberdorff and Hughes 1992; Pei et al. 2010; Simon and Lyons 1995), 40 metrics (Table 2) were calculated as candidate metrics. A statistical analysis (Baptista et al. 2007; Wang et al. 2005; Zhang et al. 2007) was applied to select the metrics that are sensitive to human disturbance. First, a metric was eliminated if the values for the metric at 90 % of the total sites are zero. Second, the fish community distribution may change with different altitudes (Ding et al. 2012). Certain characteristics of fish assemblages are expected to change with stream order (Yan et al. 2010). To distinguish the effects of stream order, altitude, and environmental quality on the fish assemblage characteristics, the Kruskal–Wallis test was applied to validate the distinction of different stream orders and altitudes based on the reference sites. For those metrics in which the altitude and the stream order did not contribute significantly to the analysis, a Mann–Whitney  $U$  test ( $p=0.05$ ) was used on the same metrics, and the environmental quality was the only independent classification variable used in this analysis. The sensitivity of each metric that exhibited an obvious difference between the reference and the impaired sites was then judged according to the degree of interquartile overlap in box and whisker plots (Barbour et al. 1999). The Pearson's correlation was then calculated for the retained metrics. For two metrics with an obvious correlation ( $r \geq 0.7$ ), one will be retained to simplify the index because that one metric sufficiently represents the

pattern of information. The retained metrics constitute the core index of biotic integrity.

The continuous scoring method (CALU), which produced the best overall index for this set of metrics and data according to the study conducted by Blocksom (2003), was applied to assess the ecosystem health at 45 sample sites. The continuous scoring method uses the 95th or 5th percentile value as the best expected value. The metric scores are truncated to a range between 0 and 100, and the ratios greater than 100 are set to 100. The total score of the IBI at each site was calculated as the sum of all of the metric scores.

The integrity classes were classified into four groups: good, fair, poor, and very poor. The 25th percentile of reference site values was calculated to separate the good and fair conditions (Klemm et al. 2003), and the other two thresholds were obtained by trisecting the 25th percentile to define very poor, poor, and fair conditions (Zhang et al. 2007). To validate the index, the overall IBI scores were correlated with the IWHQ to estimate the performance of the IBI in the Wei River based on the validation data set.

### Statistical analysis

The PCA, Pearson correlation (two tailed), Kruskal–Wallis test, and Mann–Whitney  $U$  test were performed using the SPSS 16.0 software. The Origin 8.0 program was used for the box and whisker plots. The canonical correspondence analysis (CCA) was conducted using the Canoco 4.5 software program.

## Results

### Water quality analysis and selection of reference sites

The PCA of the physiochemical variables was used to select the primary variables. The first PCA axis accounted for approximately 30 % of the variance (eigenvalue=3.91, Table 3) and Cond, sali, and hardness, which indicate the inorganic pollution, exhibited the highest contribution, and had the highest positive loadings. The second PCA axis accounted for 19.5 % of the variance (eigenvalue=3.91) and saturation, DO,  $\text{COD}_{\text{Mn}}$ , and  $\text{SiO}_3$ , which indicate the organic pollution, exhibited the highest contribution to the second axis. The third and fourth axes explained 12.8 and 9.6 % of the variance with eigenvalues of 1.66 and 1.25,

**Table 2** Candidate metrics used in the assessment of fish communities

Category	Metrics	Abbreviation
Species composition and richness	Number of species	P1
	Total biomass	P2
	Shannon–Wiener index	P3
	Number of Siluriformes species	P4
	Number of Cypriniformes species	P5
	Number of Perciformes species	P6
	Number of Cyprinidae species	P7
	Number of Cobitidae species	P8
	Proportion of pelagic species	P9
	Proportion of species in the middle and low tiers	P10
	Proportion of benthic species	P11
	Proportion of individuals as pelagic species	P12
	Proportion of individuals as species in the middle and low tiers	P13
	Proportion of individuals as benthic species	P14
Trophic composition	Proportion of individuals as carnivore species	P15
	Proportion of individuals as omnivore species	P16
	Proportion of individuals as herbivore species	P17
	Proportion of individuals as filter-feeding species	P18
	Proportion of carnivore species	P19
	Proportion of omnivore species	P20
	Proportion of herbivore species	P21
	Proportion of filter-feeding species	P22
Tolerance	Proportion of sensitive species	P23
	Proportion of tolerant species	P24
	Proportion of individuals as sensitive species	P25
	Proportion of individuals as tolerant species	P26
	Proportion of demersal eggs species	P27
Reproductive guild	Proportion of viscid eggs species	P28
	Proportion of pelagic eggs species	P29
	Proportion of rafting eggs species	P30
	Proportion of species with special spawning	P31
	Proportion of species guarding eggs and larvae	P32
	Proportion of individuals as demersal eggs species	P33
	Proportion of individuals as viscid eggs species	P34
	Proportion of individuals as pelagic eggs species	P35
	Proportion of individuals as rafting eggs species	P36
	Proportion of individuals as species with special spawning	P37
	Proportion of individuals as species guarding eggs and larvae	P38
Abundance and individual condition	Number of individuals in samples	P39
	Proportion of individuals with diseases, tumors, fin damage and other anomalies	P40

Metrics abbreviations are used in Fig. 3

**Table 3** Weights of the first four principal components

Physiochemical variables	Axis 1	Axis 2	Axis 3	Axis 4
pH	-0.065	-0.202	-0.345	-0.026
Cond	<i>0.472</i>	0.119	-0.043	0.057
Sali	<i>0.482</i>	0.079	0.008	0.032
Satu	-0.014	<i>-0.473</i>	-0.110	-0.161
DO	-0.019	<i>-0.560</i>	-0.119	-0.194
SS	-0.032	-0.005	<i>0.630</i>	0.030
TDS	0.070	0.162	0.011	<i>0.710</i>
TN	-0.188	0.044	0.112	0.473
TP	-0.008	-0.006	<i>0.624</i>	0.024
Alk	0.204	0.360	-0.012	0.416
Hardness	<i>0.490</i>	-0.029	0.060	-0.081
COD <sub>Mn</sub>	0.049	<i>0.435</i>	-0.252	0.370
SiO <sub>3</sub>	0.034	<i>0.472</i>	0.022	-0.441

The italic numbers indicate the primary variables in each principal component. Abbreviation of physiochemical variables were shown in environmental measurement

respectively. SS, TP, and TDS were the three primary physiochemical variables for these two axes. The redundancy in these ten variables was evaluated via Pearson correlation coefficients. Those metrics with a correlation coefficient *r* greater than or equal to 0.7 were considered redundant. Because salinity and hardness were redundant with cond, cond was retained to represent the first axis. Saturation was redundant with DO and was thus excluded. DO, COD<sub>Mn</sub>, and SiO<sub>3</sub> were retained to represent the second axis. After the correlation analysis, Cond, DO, SS, TDS, TP, COD<sub>Mn</sub>, and SiO<sub>3</sub> were used to represent the water quality, and QHEI was added to calculate the IWHQ.

The environmental quality was evaluated, and the IWHQ was scored as summarized in Table 4 and Fig. 2. In the whole river basin, only seven sites were categorized as least degraded (IWHQ≤2). These sites (W1, W5, W10, W12, W13, W14, and W16) were chosen as the reference sites. These seven sites were all located in the tributaries of the Wei River basin. Twenty sites were classified as the medium disturbed condition (IWHQ≤4), and the remaining 18 sites, which is nearly half of the number of sites, were classified as highly disturbed (IWHQ>4). In the Wei River, seven sites were in the least degraded condition, ten sites were in the medium degraded condition, and six sites were in the highly degraded condition. In the other two rivers,

the environmental quality was much worse than in the Wei River. There was no site classified as least degraded. Seven of the 13 sites in the Jing River were in the highly degraded condition (IWHQ>4). A similar phenomenon was found in the Beiluo River, in which five of the nine sites were in the highly degraded condition. Thus, the environmental quality in the Wei River was better than that in the Jing River and Beiluo River.

IWHQ for variables exhibited spatial difference in the three rivers. The IWHQ of DO was lower, except for W2 and W7, and the W15, W18, W21, and W23 sites, which are located downstream of the main stem in the Wei River, exhibited a higher IWHQ of DO, which indicates that DO was the main polluted variable in the downstream part of the river. The TP of W15, W18, W21, and W23, which are located downstream of the main stem of the Wei River, exhibited a higher value. The SS in the Jing River and Beiluo River was of higher IWHQ than that in the Wei River, and the greatest values reached 5,778 mg L<sup>-1</sup> (L3) and 5,516 mg L<sup>-1</sup> (J9), respectively. A similar trend was observed with TDS and Cond with lower IWHQ in the Wei River compared with that in the other rivers. The statistical analysis showed that the SS and TDS in the Jing and Beiluo Rivers were significantly higher (*p*<0.01). A higher Cond was measured in the Jing and Beiluo Rivers. However, W2, W6, and W7 were outliers with markedly higher TDS and Cond, and a similar phenomenon was found in the Jing and Beiluo Rivers. The COD<sub>Mn</sub> and SiO<sub>3</sub><sup>2-</sup> in the three rivers exhibited slight differences (*p*>0.05). The TP in the other rivers were markedly higher than that in those four sites (Fig. 2c). In addition, the QHEI in the three rivers also exhibited slight differences (*p*>0.05).

A preliminary index of biotic integrity

Of the 40 metrics calculated for the sites, seven metrics (P4, P18, P22, P29, P30, P35, and P36) were eliminated before the next procedure because more than 90 % of these sites exhibited a value of 0 for the metrics. The Kruskal–Wallis test indicated that the distinguishing of the stream order and the altitude was not significant based on the remaining 33 metrics in the reference sites (*p*>0.05). Based on the Mann–Whitney *U* test, the metrics of P1, P2, P5, P8, P10, P13, P23, P25, and P39 exhibit a marked difference between the reference sites and the impaired sites (*p*<0.05). These nine metrics were confirmed to exhibit no or little overlap between

**Table 4** Scores of the index of water and habitat quality (IWHQ) and ecosystem health for the calibration data set in the Wei River basin

Site	Cond	DO	SS	TDS	TP	COD <sub>Mn</sub>	SiO <sub>3</sub> <sup>2-</sup>	QHEI	IWHQ	Disturbance	IBI scores	Ecosystem health
W1	2.37	1.00	3.37	1.00	1.00	2.57	1.00	2.60	1.86	R	67.43	Good
W2	7.62	4.00	2.32	1.00	2.16	4.14	2.48	5.85	3.70	M	0.00	Very poor
W3	6.53	1.00	2.64	1.00	2.69	3.35	2.28	2.35	2.73	M	67.00	Good
W4	3.93	2.07	2.08	3.33	2.25	3.46	2.44	3.65	2.90	M	30.69	Poor
W5	2.07	1.00	2.20	1.00	2.03	2.45	2.28	3.00	2.00	R	57.05	Fair
W6	6.76	7.70	4.17	7.73	2.04	7.18	7.14	5.20	5.99	H	0.00	Very poor
W7	7.28	3.45	3.25	8.07	2.34	4.95	3.18	4.80	4.67	H	0.00	Very poor
W8	2.70	1.00	3.00	2.14	2.51	3.04	4.50	3.05	2.74	M	39.59	Fair
W9	4.43	1.00	4.08	3.59	2.31	3.29	2.74	2.55	3.00	M	33.63	Poor
W10	2.23	1.00	1.00	1.00	2.65	2.77	2.74	2.55	1.99	R	68.59	Good
W11	4.46	2.01	4.97	3.57	2.68	2.71	2.71	3.75	3.36	M	28.54	Poor
W12	1.00	1.00	1.00	1.00	2.70	2.60	2.88	2.55	1.84	R	63.72	Good
W13	2.40	1.00	2.28	1.00	2.31	2.02	2.51	2.50	2.00	R	65.29	Good
W14	1.00	1.00	2.12	1.00	1.00	3.94	2.70	2.95	1.96	R	65.73	Good
W15	2.72	3.32	3.74	2.28	4.03	3.50	3.80	3.50	3.36	M	19.37	Very poor
W16	1.00	1.00	2.08	1.00	4.42	2.56	2.60	1.00	1.96	R	59.02	Good
W17	3.28	2.60	7.48	2.16	4.35	4.01	4.35	5.60	4.23	H	28.84	Poor
W18	3.12	4.08	3.35	2.34	7.18	4.05	3.87	4.70	4.08	H	27.66	Poor
W19	2.86	2.75	3.09	1.00	6.99	3.33	3.37	4.50	3.48	M	40.50	Fair
W20	2.71	2.15	2.60	1.00	7.07	4.04	2.71	3.60	3.24	M	38.17	Poor
W21	3.48	4.08	3.00	2.96	7.15	1.00	3.37	3.90	3.61	M	30.87	Poor
W22	3.20	2.65	7.46	2.74	6.91	3.44	2.66	5.85	4.36	H	11.70	Very poor
W23	3.45	4.34	3.36	3.03	7.47	4.19	3.03	5.35	4.28	H	15.09	Very poor
J1	3.76	1.00	3.23	2.69	2.23	2.90	2.68	3.85	2.79	M	33.73	Poor
J2	4.15	2.69	6.39	8.71	2.44	3.98	2.31	3.50	4.27	H	54.82	Fair
J3	3.13	1.00	4.80	3.36	2.19	4.33	2.83	2.85	3.06	M	54.26	Fair
J4	3.41	2.24	7.08	7.08	2.31	3.27	1.00	3.90	3.79	M	52.94	Fair
J5	3.21	2.61	7.72	3.61	2.35	3.19	4.48	2.55	3.71	M	44.26	Fair
J6	3.15	2.67	2.32	3.91	4.41	4.08	2.45	3.20	3.27	M	41.06	Fair
J7	4.31	1.00	1.00	2.29	7.10	4.17	2.41	1.00	2.91	M	12.52	Very poor
J8	5.74	2.65	4.06	3.33	7.34	2.79	3.30	3.90	4.14	H	18.47	Very poor
J9	4.11	2.65	10.52	3.42	8.79	2.67	3.85	2.05	4.76	H	31.14	Poor
J10	3.02	2.46	8.84	3.21	8.40	2.98	3.62	2.85	4.42	H	35.31	Poor
J11	6.51	3.02	4.48	3.37	7.33	3.04	3.33	3.30	4.30	H	12.06	Very poor
J12	5.74	2.05	4.38	2.49	7.15	3.71	3.25	4.20	4.12	H	12.10	Very poor
J13	7.19	2.33	4.17	3.03	7.73	2.48	3.40	5.35	4.46	H	0.00	Very poor
L1	3.18	2.49	2.52	2.64	2.39	2.22	3.53	4.00	2.87	M	46.02	Fair
L2	7.68	2.19	3.67	2.49	3.26	1.00	3.18	6.35	3.73	M	0.00	Very poor
L3	3.82	2.21	10.78	3.68	7.67	2.23	2.53	5.60	4.81	H	26.50	Poor
L4	6.03	1.00	8.71	3.92	7.00	2.65	2.33	4.10	4.47	H	22.72	Poor
L5	4.27	1.00	4.15	3.63	6.87	4.09	2.55	3.45	3.75	M	23.65	Poor
L6	5.69	2.41	4.34	2.39	7.09	4.46	2.20	5.10	4.21	H	55.77	Fair
L7	2.87	2.07	4.61	7.45	7.68	3.46	1.00	4.60	4.22	H	7.43	Very poor
L8	3.81	2.38	3.79	4.14	6.89	3.42	1.00	2.70	3.52	M	25.44	Poor



**Table 4** (continued)

Site	Cond	DO	SS	TDS	TP	COD <sub>Mn</sub>	SiO <sub>3</sub> <sup>2-</sup>	QHEI	IWHQ	Disturbance	IBI scores	Ecosystem health
L9	3.91	2.86	4.41	8.14	7.46	3.15	2.11	5.50	4.69	H	6.25	Very poor

R reference condition, M medium degraded, H highly degraded

the reference sites and the impaired sites through the box and whisker plots. P5 was redundant with P1. P13 and P23 were redundant with P10 ( $r > 0.7$  and  $p < 0.01$ ). Thus, six metrics were selected as the primary metrics for the IBI (Fig. 3): P1, P2, P8, P10, P25, and P39.

The overall IBI was the sum of the individual scores for these six metrics, and it potentially ranged from 100 points, which indicates the best possible ecosystem health, to 0 points, which indicates the worst possible ecosystem health. Table 5 provides the thresholds for the four ecosystem health statuses. The IBI scores for the 45 sites in the calibration data set ranged from 0 to 68.59 points (Table 4).

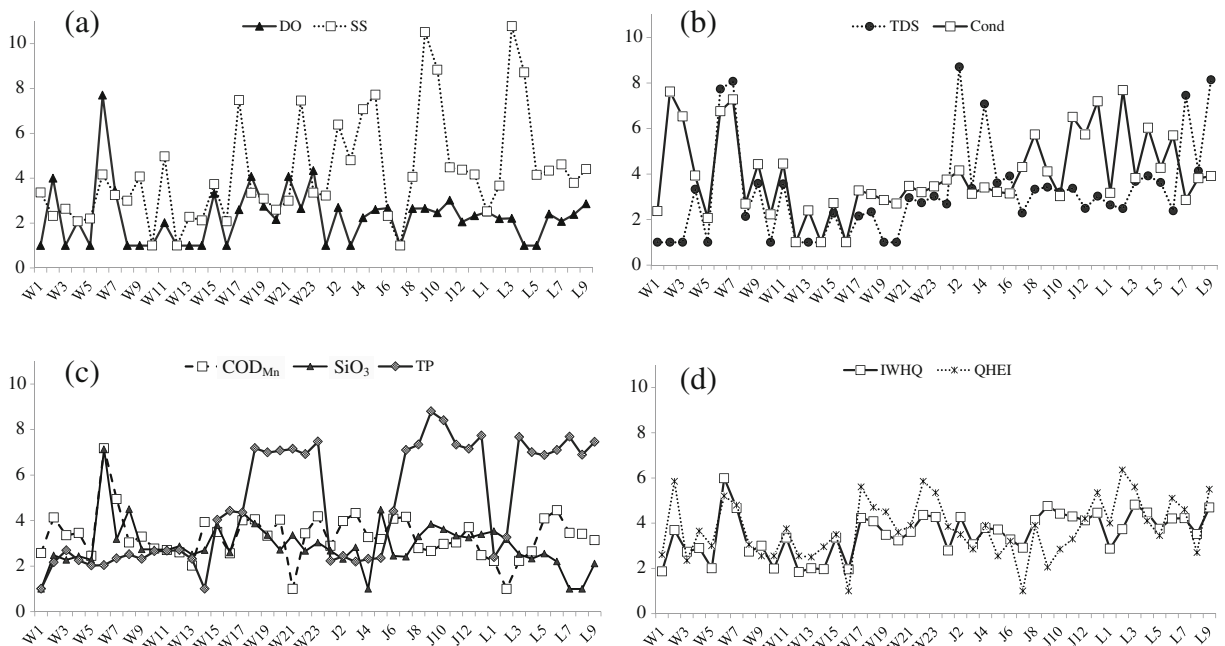
Validation of the IBI method

The adaptability of the IBI was validated through the correlation of the IBI scores and the IWHQ based on the validation data set. The overall IBI scores were

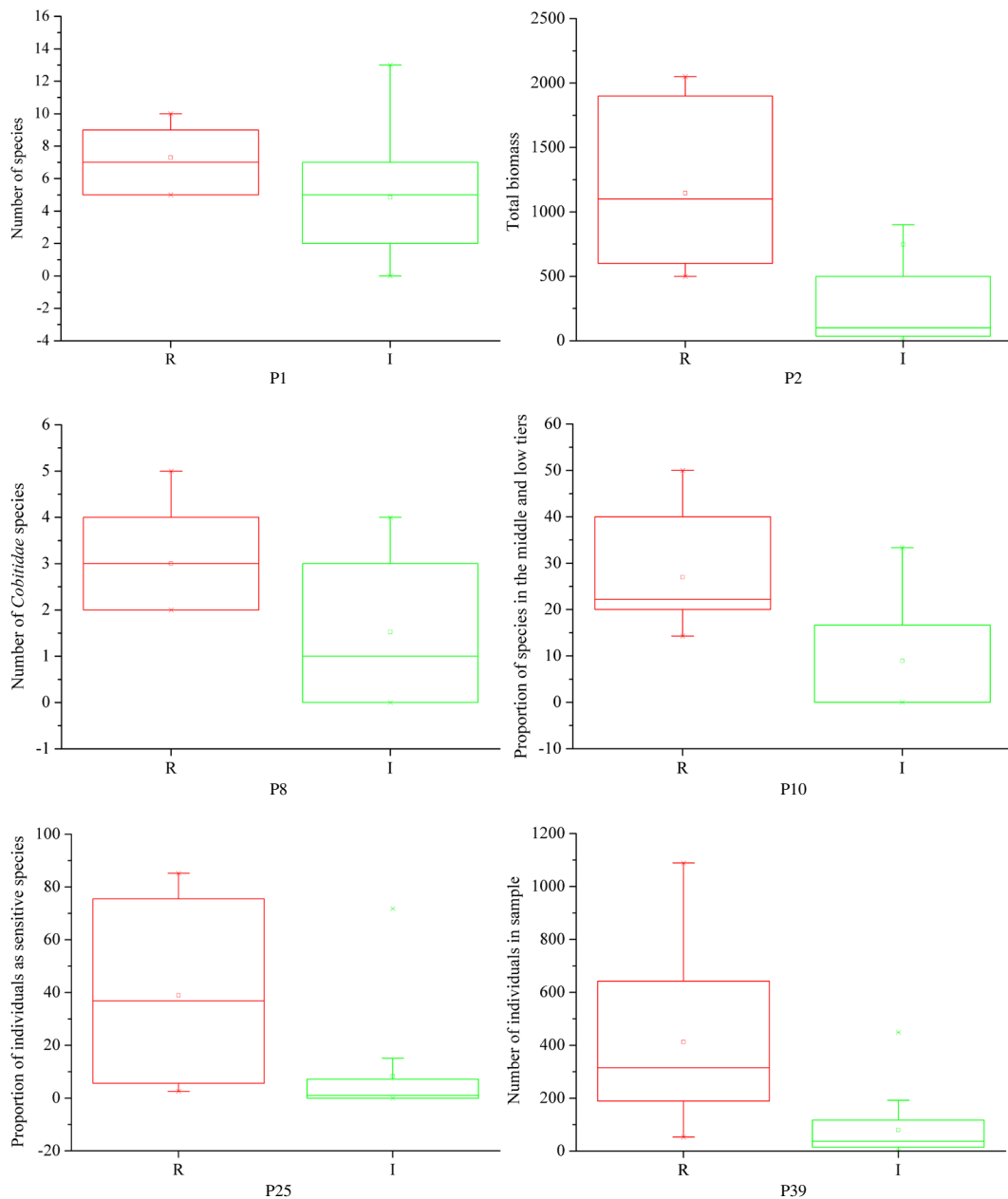
negatively correlated with the index of environmental quality (IWHQ) (Pearson correlation =  $-0.64$ ; Fig. 4), which indicates that the index should be useful for biomonitoring and the conservation of biodiversity. The IBI scores decreased linearly with the IWHQ. In addition, the validation in Fig. 5 also showed good discrimination between the reference sites and the impaired sites, which further illustrated the robustness of this index.

Ecosystem health in the whole basin

The index of biotic integrity exhibited large variation in the whole basin based on the validation data set (Fig. 6). For the 23 sites in the Wei River, five sites (W1, W10, W12, W14, and W25) were in good condition, five sites (W3, W11, W16, W19, and W26) were in fair condition, eight sites (W0, W5, W8, W9, W15, W17, W20, and W21) were in poor condition, and five sites (W4, W18,



**Fig. 2** The IWHQ at the sample sites in the whole river basin. **a** IWHQ scores of DO and SS. **b** IWHQ scores of TDS and Cond. **c** IWHQ scores of COD<sub>Mn</sub>, SiO<sub>3</sub><sup>2-</sup>, and TP. **d** IWHQ scores of QHEI and the final IWHQ



**Fig. 3** Box and whisker plots showing the nine candidate metrics that were sensitive to environmental changes. *R* (green boxplot) and *I* (red boxplot) represent the reference sites and the impaired

sites, respectively. The lines in the boxplot from top to bottom represent the 95, 75, 50, 25, and 5 % percentile. The dot denotes the mean value of all the reference or impaired sites

W22, W24, and W27) were in very poor condition. The ecosystem health in the Jing River showed a significant difference between all sites ( $p=0.000$ ). Two sites (J6 and J10) were categorized to be in good condition, four sites (J3, J4, J5, and J9) were in fair condition, two sites (J11 and J8) were in poor condition, and five sites (J1, J2, J7,

J12, and J13) were in very poor condition. No fish were obtained at site J13, which was classified as very poor. The sites in the Beiluo River exhibited the worst ecosystem health, and their IBI values ranged from 2.87 to 32.88. Thus, the ecosystem health was judged as poor or very poor. However, L2, with an IBI score of 2.87,

**Table 5** Score interpretation for IBI values in the Wei River

	Good	Fair	Poor	Very poor
IBI	≥59.02	39.35–59.02	19.67–39.35	≤19.67

exhibited the worst condition in this river. In this site, only three specimens were captured, which resulted in the low score. The ecosystem health of the Wei River was better than that of the Jing River, and the ecosystem health in the Beiluo River was the worst. Of the 49 sites, 13 sites were in very poor condition, 20 sites were in poor condition, 9 sites were in fair condition, and only 7 sites were in good condition. The sites in poor or very poor condition accounted for 67.35 % of the total sites. In summary, the ecosystem health of the whole basin was not good, but the ecosystem health in the Wei River was better than that in the Jing River, and ecosystem health in the Beiluo River displayed the worst condition.

**Discussion**

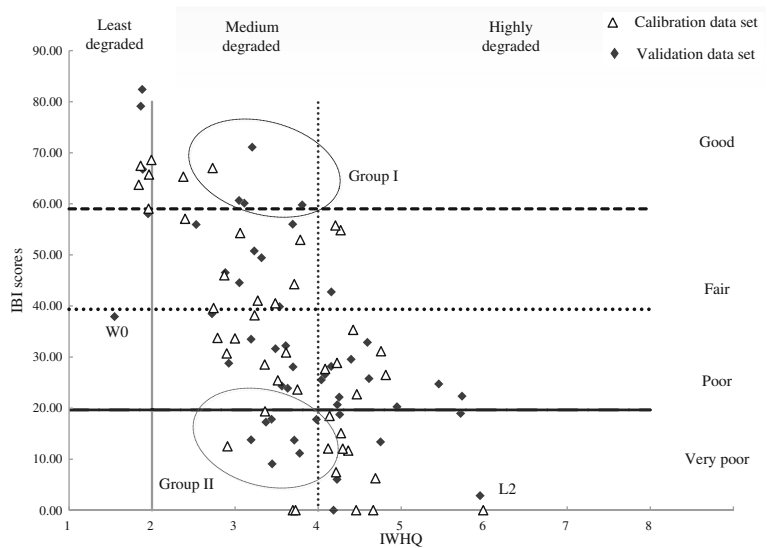
Spatial variation in the water quality

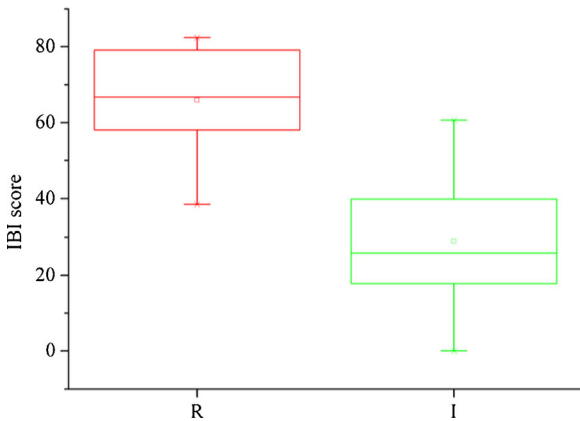
The water quality variables and QHEI exhibited different variations in the whole river basin (Fig. 2). Most of the sites with a lower IWHQ were located upstream or in the tributaries of the Wei River, where there is a low population density and high vegetation coverage. The

downstream sites in the Wei River, except W2, W6, and W7, exhibited markedly worse environmental quality with higher TP and COD<sub>Mn</sub>, and lower DO; this trend was particularly observed from Baoji to Weinan. It was common that a lower DO and higher TP and COD<sub>Mn</sub> was measured downstream of the main stem in the Wei River (W15, W18, W21, and W23). There are large cities with large population density, such as Tianshui, Baoji, Xianyang, Xi’an, and Weinan, located downstream of the Wei River, and these caused great nutrient and organic pollution, such as industrial wastewater effluents and domestic disposal plant effluents. This effect was demonstrated by Lu et al. (2010), who found higher COD<sub>Mn</sub> in the water from vicinal reach of Baoji, Xianyang, and Xi’an. A similar result was found in the Taizi River (Wan et al. 2013). However, W2, W6, and W7 were outliers with markedly higher TDS and Cond, and a similar phenomenon was found in the Jing and Beiluo Rivers.

The sites in the Jing River and Beiluo River, including J1–J13 and L1–L9, were characterized by high Cond, SS, TP, and TDS. These were mainly caused by three factors: (1) flowing through the Loess Plateau, which exhibits serious soil erosion and high suspended solid (Han 2003), (2) poor water quality in the natural state and characteristics of high total dissolved solids, saline, and hardness (Shi 2008), and (3) a massive development of the petroleum industry in the upstream of the Beiluo River and the Malian River, which is a tributary of the Jing River (Kang et al. 2008).

**Fig. 4** Regression of the IBI score as a function of the index of environmental quality (IWHQ) for the 49 study sites in the Wei River basin



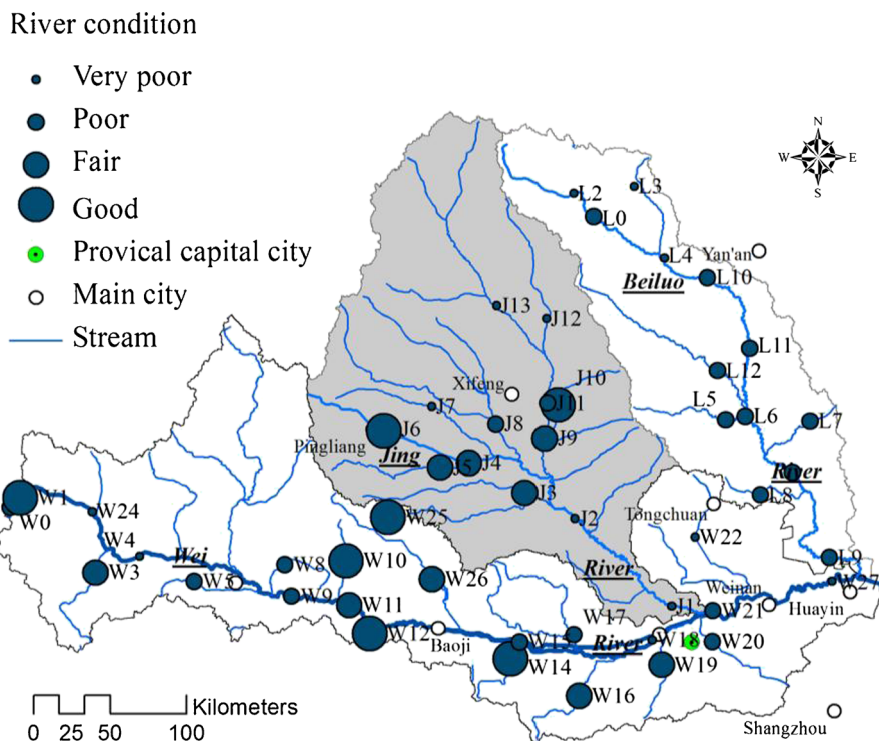


**Fig. 5** Ability of IBI scores to differentiate between the reference and the impaired sites in the whole basin. The abbreviations are denoted in Fig. 3

Selection of reference sites and development of IBI

The definition of the reference conditions establishes an appropriate benchmark for the assessment of the ecological status and the trends of wadeable streams. Therefore, the selection of reference sites is critical when the IBI is estimated. In many parts of the world, rivers in pristine condition are rare, and reference sites

have to be defined as the least affected sites (Tejerina-Garro et al. 2006). Historical data were suggested as an essential source to describe the reference condition, but it is impossible to collect these data. Particularly in the Wei River basin, the latest and comprehensive study on fish assemblages was conducted in 1984 (Xu and Li 1984) and consisted of the species richness and ichthyological fauna in the whole basin. Other studies have been performed, but these were focused upstream of the Wei River (Song and Wang 1983), Shaanxi Province, or some other regions (Xu and Zhang 1996; Liu et al. 2003). The scarcity of information made it difficult to select the reference condition through historical data. Many studies (Qadir and Malik 2009; Zhu and Chang 2008; Casatti et al. 2009) chose the least degraded sites as the reference sites, such as in the case of highly degraded basins, and environmental variables, such as the water and habitat qualities, were the main consideration. Casatti et al. (2009) selected the reference sites according to the physical habitat index, which identified good physical habitats as the reference sites. Pei et al. (2010) selected the reference sites based on their water and habitat qualities. Studies have shown a significant correlation between the fish assemblages and the



**Fig. 6** Ecosystem health in the whole basin. The circle size indicates the ecosystem health and bigger circle indicates better ecosystem health. The others are denoted as in Fig. 1

physical habitat condition (Casatti et al. 2006). It was possible to select reference sites based on the water quality and habitat quality.

In this study, the water and habitat qualities were calculated by the IWHQ, and those sites in the least degraded conditions ( $IWHQ \leq 2$ ) were identified as the reference sites. The selected reference sites were mostly located in the upstream reaches of the tributaries in remote, thickly forested mountains with less human disturbance. This result is similar to that reported by previous studies conducted by Qadir and Malik (2009) and Roth et al. (1998). Although these sites cannot characterize a pristine state, these exhibited the least degraded situation in the whole basin. In addition, all of the reference sites in the calibration data set, with the exception of W5, were rated as being in good condition. W5 exhibited a high IBI score of 57.05, which is near the good condition threshold. In the validation data set, all of these reference sites were also categorized as being in good condition. If a “reference site” consistently receives a fair or poor rating, then the site’s suitability for serving as a reference should be re-evaluated (Barbour et al. 1999). The assessment results in the calibration and validation data set indicated that the reference sites in this study were all classified as being in good condition, which confirms that the selected reference sites were suitable.

Metrics that are sensitive to environmental changes were measured to assess the ecosystem health. The Kruskal–Wallis test indicated that the differentiation of the stream order and altitude was not significant in the reference sites ( $p > 0.05$ ), which indicated that the stream order and altitude exhibited a small effect on the metrics. Although the fish species changed gradually from headwaters to the main stem, the difference in their abundance may be related more to changes in the local microhabitat features than to any pervasive effect of stream order or longitudinal position in the stream system (Matthews 1986). In this basin, the altitude of these sites ranged from 2,400 to 360 m, although most were located at an altitude between 600 and 1,500 m; this variation in altitude caused some difference, but this difference was not significant. The primary metrics of the IBI consists of six metrics (Fig. 3): P1, P2, P8, P10, P25, and P39. Three of the primary metrics for the IBI (the number of species (P1), the proportion of individuals as sensitive species (P25), and the number of individuals in the sample (P39)) were the same or similar to the metrics used by the Karr (1981). Three metrics (the total biomass (P2), the number of *Cobitidae* species

(P8), and the proportion of species in the middle and low tiers (P10)) discriminated significantly between the reference sites and the impaired sites in the Wei River basin. *Cobitidae* are very common in the Wei River (Xu and Li 1984) and comprise the groups of fishes that thrive under conditions of high human disturbance.

#### Reliability of the IBI method

The IBI scores decreased linearly with the IWHQ, as shown in Fig. 4. All of the least degraded sites had high index scores, and most of the highly degraded sites had low scores. The box plot in Fig. 5 showed good discrimination between the reference sites and the impaired sites, which further illustrates the reliability of this method. The ecosystem health based on the IBI exhibited a large variation in the whole basin based on the validation data set and accurately reflected a known spatial pattern in the environmental quality of the whole basin. The ecosystem health of the Wei River decreased from upstream to downstream and was better than that of the Jing River and the Beiluo River, similarly to the trends found in the environmental quality based on the IWHQ.

However, two types of errors were displayed in Fig. 4. The ecosystem health measured through the IBI score was much better than that measured through the IWHQ, as displayed in group I, which is represented by W14, W25, J6, and J10. The ecosystem health measured through the IBI score was worse than that measured through the IWHQ, as displayed in group II, which is represented by W4, W18, J1, J2, J7, J12, and L3. These inconsistencies also appeared in the fish-based index of French Guiana (Tejerina-Garro et al. 2006). These errors were mostly focused on those sites with an IWHQ value between 2 and 4. Site W0, which is located at the headwater of the Wei River, was classified as least degraded ( $IWHQ = 1.55$ ) but exhibited an IBI score of 37.91 (fair condition). Four species and 24 individuals were collected in this site, and only one was a sensitive species, which resulted in a relatively low IBI score. W14 was in the medium degraded condition because of its slightly high TP but received a high index score based on the three species, 328 individuals and one sensitive species sampled. The TP of  $0.443 \text{ mg L}^{-1}$  appeared to have little impact on the fish assemblages in W14.

There were various reasons for these differences between the results obtained through the IWHQ and the IBI. First, the IBI was integrated from six metrics, which may react differently to different disturbances.

However, the interactions among these factors and the ways in which these factors affect the fish history are not yet clear. Additionally, these environmental variables exhibited different contributions to the fish community structure in different catchments. Rodríguez and Lewis (1997) indicated that the assemblage structure is predictably related to only four descriptors of lakes: transparency, conductivity, depth, and surface area. It was apparent that fish assemblages are not limited by a single factor such as pH or conductivity. Instead, an interaction among many variables is involved (Rahel 1984). Second, our classification of reference and impaired sites could be limited in some cases. The habitat quality was assessed at each sampling site using a QHEI, which is based on visual observation. Ten descriptors (substrate, habitat complexity, velocity/depth regimes, bank stability, channel alteration, channel flow status, vegetation protection, water quality, anthropogenic alterations, and riparian land use) were included in this index. This index was obtained on the basis of visual observation, and inevitably leads to some subjective errors. Some better method, such as physical form condition, is more suitable to reflect geomorphic condition. However, it is more cost-consuming and time-consuming assessments. Therefore, a more rapid visual-based physical form assessment was applied widely according to USEPA's RBP (Barbour et al. 1999).

## Conclusions

The preliminary attempt to calculate a fish index of biotic integrity for the Wei River basin has shown that the ecosystem health of the Wei River is better than that of the Jing River and the Beiluo River. The Wei River has been severely disturbed by human activities, such as untreated industrial wastewater and urbanization, which has had negative impacts on the fish assemblages and diversity. The results obtained in this study show that the IBI is a suitable assessment tool to evaluate the ecosystem health of the Wei River. The IBI is correlated with the water and habitat quality (IWHQ) and is therefore a good indicator of the ecosystem health. However, some limits exist in this index. First, the water and habitat quality may not have accurately measured some types of environmental degradation, such as alteration of the hydrological regime. Second, this preliminary index was established using limited ecological data, and it is necessary to thoroughly test the ability of this index to

assess the health of these rivers with an independent set of fish assemblage and environmental quality data. Third, although fish assemblages have been regarded as an effective biological indicator of environmental quality and anthropogenic stress in aquatic ecosystems since they are relatively easy to identify and their position at the top of the food chain helps to provide an integrative view of the watershed environment (Karr 1981), it is still incomplete for only using fish assemblages as the indicator. Biological assemblages respond to many kinds of disturbance, and assessments of biological condition would be based on multiple biological assemblages, thereby providing insight into the overall biological condition of an ecosystem (Carlisle et al. 2008). Some papers (such as Davies et al. 2010) also pointed out that ecosystem health is currently determined primarily on the basis of fish and macroinvertebrate condition, and recommend to include condition of vegetation in the future. Both macroinvertebrate and algae will be added to assess ecosystem health in the study area in the future. This investigation aimed to clarify the ecosystem health of the Wei River, where restoration activities are needed, and to monitor trends in ecosystem health over time.

**Acknowledgments** This study is supported by the Natural Science Foundation of China (91125015) and the Major Special S&T Project on Water Pollution Control and Management (2009ZX07012-002-003) of the Ministry of Environmental Protection of the People's Republic of China. In addition, the authors would like to thank their colleagues at the Dalian Ocean University for their help with the data analysis and the identification of the samples. The authors also appreciated the sampling team for their assistance with the field work.

## References

- Baptista, D., Buss, D. F., Egler, M., Giovanelli, A., Silveira, M. P., & Nessimian, J. L. (2007). A multimetric index based on benthic macroinvertebrates for evaluation of Atlantic Forest streams at Rio de Janeiro State, Brazil. *Hydrobiologia*, 575(1), 83–94.
- Barbour, M. T., Gerritsen, J., Snyder, B., & Stribling, J. (1999). *Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish* (2nd ed.). Washington: USEPA.
- Blocksom, K. A. (2003). A performance comparison of metric scoring methods for a multimetric index for Mid-Atlantic Highlands streams. *Environmental Management*, 31(5), 670–682.

- Bozzetti, M., & Schulz, U. H. (2004). An index of biotic integrity based on fish assemblages for subtropical streams in southern Brazil. *Hydrobiologia*, 529(1), 133–144. doi:10.1007/s10750-004-5738-6.
- Breine, J., Simoens, I., Goethals, P., Quataert, P., Ercken, D., Van Liefferinghe, C., et al. (2004). A fish-based index of biotic integrity for upstream brooks in Flanders (Belgium). *Hydrobiologia*, 522(1), 133–148.
- Carlisle, D. M., Hawkins, C. P., Meador, M. R., Potapova, M., & Falcone, J. (2008). Biological assessments of Appalachian streams based on predictive models for fish, macroinvertebrate, and diatom assemblages. *Journal of the North American Benthological Society*, 27(1), 16–37.
- Casatti, L., Langeani, F., Silva, A., & Castro, R. (2006). Stream fish, water and habitat quality in a pasture dominated basin, southeastern Brazil. *Brazilian Journal of Biology*, 66(2B), 681–696.
- Casatti, L., Ferreira, C. P., & Langeani, F. (2009). A fish-based biotic integrity index for assessment of lowland streams in southeastern Brazil. *Hydrobiologia*, 623(1), 173–189. doi:10.1007/s10750-008-9656-x.
- Chen, J., Xu, T., Fang, S., Song, S., & Wang, X. (1987). *Fishes in Qingling Mountain area*. Beijing: Science Press.
- China, S. E. P. A. (2002). *Monitoring and determination methods for water and wastewater*. Beijing: Environmental Science Press.
- Dauwalter, D. C., & Jackson, J. R. (2004). A provisional fish index of biotic integrity for assessing Ouachita Mountains streams in Arkansas, USA. *Environmental Monitoring and Assessment*, 91(1), 27–57.
- Davies, P., Harris, J., Hillman, T. J., & Walker, K. F. (2010). The sustainable rivers audit: assessing river ecosystem health in the Murray–Darling Basin, Australia. *Marine and Freshwater Research*, 61(7), 764–777.
- Ding, S., Zhang, Y., Qu, X., Kong, W., Liu, S., & Meng, W. (2012). Influence on the spatial distribution of fish in Taizi River Basin by environmental factors at multiple scales. *Environmental Science*, 33(7), 2272–2280.
- Ganasan, V., & Hughes, R. M. (1998). Application of an index of biological integrity (IBI) to fish assemblages of the rivers Khan and Kshipra (Madhya Pradesh), India. *Freshwater Biology*, 40(2), 367–383.
- Han, J. (2003). Speciality researching on water quality of the Jing River and the Wei River. *Journal of Northwest University (Natural Science Edition)*, 33(3), 341–348.
- Hughes, R. (1995). *Defining acceptable biological status by comparing with reference conditions biological assessment and criteria: tools for water resource planning and decision making*. Boca Raton: CRC Press.
- Joy, M. K., & Death, R. G. (2004). Application of the index of biotic integrity methodology to New Zealand freshwater fish communities. *Environmental Management*, 34(3), 415–428.
- Kang, Y., Yue, L., Xu, Y., & Sun, B. (2008). Impact of petroleum exploitation on water environment in the upper reaches of north Luohe River in northern Shaanxi. *Journal of Catastrophology*, 23(3), 71–75.
- Karr, J. R. (1981). Assessment of biotic integrity using fish communities. *Fisheries*, 6(6), 21–27.
- Karr, J. R. (1991). Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications*, 1(1), 66–84.
- Klemm, D. J., Blocksom, K. A., Fulk, F. A., Herlihy, A. T., Hughes, R. M., Kaufmann, P. R., et al. (2003). Development and evaluation of a macroinvertebrate biotic integrity index (MBII) for regionally assessing Mid-Atlantic Highlands streams. *Environmental Management*, 31(5), 656–669.
- Kleynhans, C. (1999). The development of a fish index to assess the biological integrity of South African rivers. *Water SA*, 25(3), 265–278.
- Liu, W., Huang, Z., & Liu, Q. (2003). Studies on the ichthyofauna of Maiji Mountain area in Gansu province. *Journal of Lanzhou University (Natural Sciences)*, 39(4), 68–70.
- Liu, M., Chen, D., Duan, X., Wang, K., & Liu, S. (2010). Assessment of ecosystem health of upper and middle Yangtze River using fish-index of biotic integrity. *Journal of Yangtze River Scientific Research Institute*, 27(2), 1–7.
- Lu, X., Li, L., Lei, K., Wang, L., Zhai, Y., & Zhai, M. (2010). Water quality assessment of Wei River, China using fuzzy synthetic evaluation. *Environmental Earth Sciences*, 60(8), 1693–1699. doi:10.1007/s12665-009-0303-2.
- Lyons, J., Navarro-Pérez, S., Cochran, P. A., Santana, E. C., & Guzmán-Arroyo, M. (1995). Index of biotic integrity based on fish assemblages for the conservation of streams and rivers in West-Central Mexico. *Conservation Biology*, 9(3), 569–584.
- Matthews, W. J. (1986). Fish faunal ‘breaks’ and stream order in the eastern and central United States. *Environmental Biology of Fishes*, 17(2), 81–92.
- Oberdorff, T., & Hughes, R. M. (1992). Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France. *Hydrobiologia*, 228(2), 117–130. doi:10.1007/bf00006200.
- Oberdorff, T., Pont, D., Huguény, B., & Porcher, J. P. (2002). Development and validation of a fish-based index for the assessment of ‘river health’ in France. *Freshwater Biology*, 47(9), 1720–1734.
- Pei, X., Niu, C., Gao, X., & Xu, C. (2010). The ecological health assessment of Liao River Basin, China, based on biotic integrity index of fish. *Acta Ecologica Sinica*, 30(21), 5736–5746.
- Qadir, A., & Malik, R. N. (2009). Assessment of an index of biological integrity (IBI) to quantify the quality of two tributaries of river Chenab, Sialkot, Pakistan. *Hydrobiologia*, 621(1), 127–153.
- Rahel, F. J. (1984). Factors structuring fish assemblages along a bog lake successional gradient. *Ecology*, 65(4), 1276–1289.
- Reynoldson, T., Norris, R., Resh, V., Day, K., & Rosenberg, D. (1997). The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. *Journal of the North American Benthological Society*, 16(4), 833–852.
- Rodríguez, M. A., & Lewis, W. M., Jr. (1997). Structure of fish assemblages along environmental gradients in floodplain lakes of the Orinoco River. *Ecological Monographs*, 67(1), 109–128.
- Roth, N., Southerland, M., Chaillou, J., Klauda, R., Kazyak, P., Stranko, S., et al. (1998). Maryland biological stream survey: development of a fish index of biotic integrity. *Environmental Monitoring and Assessment*, 51(1), 89–106.
- Schmitter-Soto, J. J., Ruiz-Cauich, L. E., Herrera, R. L., & González-Solís, D. (2011). An index of biotic integrity for shallow streams of the Hondo river basin, Yucatan Peninsula. *Science of the Total Environment*, 409(4), 844–852.

- Shi, H. (2008). *Environmental pollution and controlling suggestion in petroleum development region in Northern Yan'an*. Xi'an: Northwest University.
- Siligato, S., & Böhmer, J. (2001). Using indicators of fish health at multiple levels of biological organization to assess effects of stream pollution in southwest Germany. *Journal of Aquatic Ecosystem Stress and Recovery (Formerly Journal of Aquatic Ecosystem Health)*, 8(3), 371–386.
- Simon, T. P., & Lyons, J. (1995). *Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems biological assessment and criteria: tools for water resource planning and decision making*. Boca Raton: Lewis Publishers.
- Song, S., & Wang, X. (1983). Notes on fishes fauna of the upper reaches of Weihe River in China. *Journal of Lanzhou University (Natural Sciences)*, 19(4), 120–128.
- Song, J., Xu, Z., Liu, C., & Li, H. (2007). Ecological and environmental instream flow requirements for the Wei River—the largest tributary of the Yellow River. *Hydrological Processes*, 21, 1066–1073.
- Song, J., Xu, Z., Hui, Y., Li, H., & Li, Q. (2010). Instream flow requirements for sediment transport in the lower Weihe River. *Hydrological Processes*, 24, 3547–3557.
- Tejerina-Garro, F. L., De Mérona, B., Oberdorff, T., & Hugueny, B. (2006). A fish-based index of large river quality for French Guiana (South America): method and preliminary results. *Aquatic Living Resources*, 19(1), 31–46. doi:10.1051/alr:2006003.
- Wan, J., Bu, H., Zhang, Y., & Meng, W. (2013). Classification of rivers based on water quality assessment using factor analysis in Taizi River basin, northeast China. *Environmental Earth Sciences*, 69(3), 909–919. doi:10.1007/s12665-012-1976-5.
- Wang, B., Yang, L., Benjin, H., & Linna, S. (2005). A preliminary study on the assessment of stream ecosystem health in south of Anhui province using benthic-index of biotic integrity. *Acta Ecologica Sinica*, 25(6), 1481–1490.
- Wu, W., Xu, Z. X., & Liu, X. C. (2012). Impact of Baojixia water diversion works on the hydrologic regime in the Wei River basin. *Procedia Environmental Sciences*, 13, 1653–1662. doi:10.1016/j.proenv.2012.01.158.
- Xu, Z. (2005a). Comprehensive water quality identification index for environmental quality assessment of surface water. *Journal of Tongji University (Natural Science)*, 33(4), 482–488.
- Xu, Z. (2005b). Single factor water quality identification index for environmental quality assessment of surface water. *Journal of Tongji University (Natural Science)*, 33(3), 321–325.
- Xu, T., & Li, Z. (1984). Studies on fishes fauna of the Weihe River. *Journal of Xinxiang Normal College*, 4, 73–78.
- Xu, T., & Zhang, C. (1996). A study on zoogeographical division of the freshwater fishes in Shaanxi province, China. *Geographical Research*, 15(3), 97–102.
- Yan, Y., Zhan, Y., Chu, L., Chen, Y., & Wu, C. (2010). Effects of stream size and spatial position on stream-dwelling fish assemblages. *Acta Hydrobiologica Sinica*, 34(5), 1022–1030.
- Zhang, Y., Xu, C., Ma, X., Zhang, Z., & Wang, J. (2007). Biotic integrity index and criteria of benthic organisms in Liao River Basin. *Acta Scientiae Circumstantiae*, 27(6), 919–927.
- Zhu, D., & Chang, J. (2008). Annual variations of biotic integrity in the upper Yangtze River using an adapted index of biotic integrity (IBI). *Ecological Indicators*, 8(5), 564–572. doi:10.1016/j.ecolind.2007.07.004.