

## Applying Plankton-index of Biology Integrity to Assess Aquatic Ecosystem Health of River Network in Hangzhou Bay New District, Ningbo

<sup>1</sup>Pei Shi, <sup>2</sup>Shilin Xu, <sup>2</sup>Guoer Zhan, <sup>2</sup>Wei Liu, <sup>2</sup>Dapeng Tan and <sup>1</sup>Pingsha Huang

<sup>1</sup>College of Biology and Environment, Zhejiang Wanli University, Ningbo 315100,

<sup>2</sup>Ningbo Environment Protection Research and Design Institute, Ningbo 315012, China

**Abstract:** Using the field sampling data obtained in November 2012, the aquatic ecosystem health of river network in Hangzhou Bay New District in Ningbo was assessed with Plankton Index of Biology Integrity (P-IBI). In these samples, 125 species of phytoplankton and 19 species of zooplankton were identified and the dominant phytoplankton species of each sampling sites were almost pollution indicator species. Through the judgment of 17 candidate metrics reflecting plankton community structure characteristic, algae diversity index, the proportion of edible algae and the abundance ratio of cyanobacteria to total algae this three candidate metrics were selected to assess the aquatic ecosystem health of the river network in Hangzhou Bay New Zone in Ningbo. P-IBI was calculated by using ratio scoring method, the assessment result showed among the 14 sampling sites, the aquatic ecosystem health of 4 sampling sites were excellent, 7 good, 2 inferior and 1 poor.

**Keywords:** Hangzhou bay new district, health assessment, index of biology integrity, plankton

### INTRODUCTION

Located in the South Bank of Hangzhou Bay and under governing of Ningbo municipality, Zhejiang Province, Ningbo Hangzhou Bay New District is an important area of the Hangzhou Bay wetland. As a part of the tidal estuary wetland at North Asia tropical coast along the East Asia Pacific, Hangzhou Bay wetland is one of eight major wetlands in China (Jiang *et al.*, 2007). The climate of Hangzhou Bay wetland belongs to the southern monsoon climate of northern subtropics (Shao *et al.*, 2011). Since regular alternation of cold and warm air mass, the regional climate is mild and humid with abundant rainfall. The region is composed of a large number of rivers, ponds and reservoir. Different water bodies form a complex river system. The local industry and agriculture have been developed rapidly since the last three decade; the population has increased as well. All of the human activities have had a certain influence on the regional water environment.

The physical and chemical indicators, the microbial indicators, or a single biological indicator and other means have been used to assess water environment for many years, but less attentions have been paid for ecosystem health of the water body (Shen *et al.*, 2012). The achievements resulted from environmental biology researches have showed that the ecosystem health is an important indicator to reflect the ecosystem safety. The

evaluation process should also be one of the important links in environmental monitoring, assessment and environmental health management (Wang *et al.*, 2006).

As a comprehensive index, Index of Biological Integrity (IBI) could reflect the degree of environmental health by combining biological component and structure information (Wang *et al.*, 2006). Therefore this index could be used to analyze the relationship between the human disturbances and biological characteristics quantitatively with sensitive responses (Ode *et al.*, 2005). The index was consisted of fish originally (Karr, 1981). Later on, benthic animal, algae, plankton and periphyton were taken into consideration (Kerans and Karr, 1994; Jungwirth *et al.*, 2000; Eugene and Oh, 2004; Griffith *et al.*, 2005).

Being the main primary producer, phytoplankton plays an important role in the material cycle and energy exchange in water ecosystem. The species composition and community structure of the phytoplankton can imply the water health directly or indirectly. In the last decades, the ecology and environmental biology research about Hangzhou Bay wetlands have been reported (Wu, 2004; Gao, 2006; Lv *et al.*, 2011), but there were rarely reports related to the planktonic communities in this wetland. In this study, the aquatic ecological health of the Hangzhou Bay wetland was assessed by calculating the index of biological integrity composed of plankton.

## MATERIALS AND METHODS

**Study area:** The study area of the article is Hangzhou Bay New District in Ningbo, which is located on both sides of Hangzhou Bay Bridge in Ningbo. The eastern boundary of Hangzhou Bay New District is Shuiyun Pu (121°41'), the Western boundary is to the wetland protection area (121°39'), the southern boundary to Qitong Road (30°28') and the north boundary is to Sizaopu Reservoir (30°34'). The area is about 242 km<sup>2</sup>. In this region, a plenty of small rivers are running across each other and form a network to communicate with each other. Water in these rivers is affected by the tide due to it located in Hangzhou Bay along the seashore.

According to the basic characteristics of the river network, the terrestrial surrounding and humane landscape in study area, 14 sampling sites were set up (Fig. 1).

**Sampling and sample treatment:** The samples were collected in 2012 November. At each sampling site, 5 L water at 0.5 m below the surface was taken out with a semi-automatic water sampler. The water sample was fixed immediately by formaldehyde solution with a final concentration of 4%. The preserved water samples were brought back to lab, after setting up to 48 h the water samples were precipitated and concentrated to 50 mL.

**Identification and counting of planktons:** The phytoplankton identification in the samples were based on references (Guo and Qian, 2003; Hu and Wei, 2006; Li and Qi, 2010), meanwhile, the zooplankton identification were according to the references (Shen *et al.*, 1990; Zhang and Huang, 1991). The counting of the plankton in samples was followed as the method suggested by Zhang and Huang (1991). During the counting, two sub-samples were used and the average value was final result.

## Data treatment and P-IBI development:

**Reference site selection:** Considering the habitat conditions, human activity of each sampling site and the overall planning and layout made by local government in the study area, Sites 6, 9, 10 and 12 were selected as reference sites during data analysis and development of P-IBI and other 10 sites were considered as impaired sites. The reference sites were located in the places where are far from the industrial/residential/commercial area, with less impact of human activities and better vegetation condition.

**Candidate metrics:** According to literatures (Jiang *et al.*, 2007; Demott and Moxter, 1991) and the actual situation of this study, 17 candidate metrics of plankton community structure indicators, which can reflect the disturbance of stress sensitively, were proposed as the alternative metrics. These metrics are: species number of phytoplankton, species number of plankton, species number of rotifer, species number of cladocera and copepoda, Shannon-Wiener's index of phytoplankton, abundance of phytoplankton, abundance of zooplankton, abundance of rotifer, abundance of cladocera and copepoda, abundance ratio of cyanobacteria/total algae, diatom quotient, abundance ratio of water bloom algae/total algae, abundance ratio of potential toxic algae/total algae, abundance ratio of inedible algae/total algae, biomass ratio of zooplankton/phytoplankton, average algae weight and average zooplankton weight.

**Metrics selection:** Referring to the criteria suggested by Barbour *et al.* (1996), the candidate metrics were analyzed and identified by comparing the reference sites to the impaired sites for each candidate metric with interquartile box overlapping degree. In this process, higher overlap degree (>75%ile) means that the metric is not sensitive to the change of environment and lower (<25%ile) overlap degree imply that the metrics is sensitive to the environmental changes. All

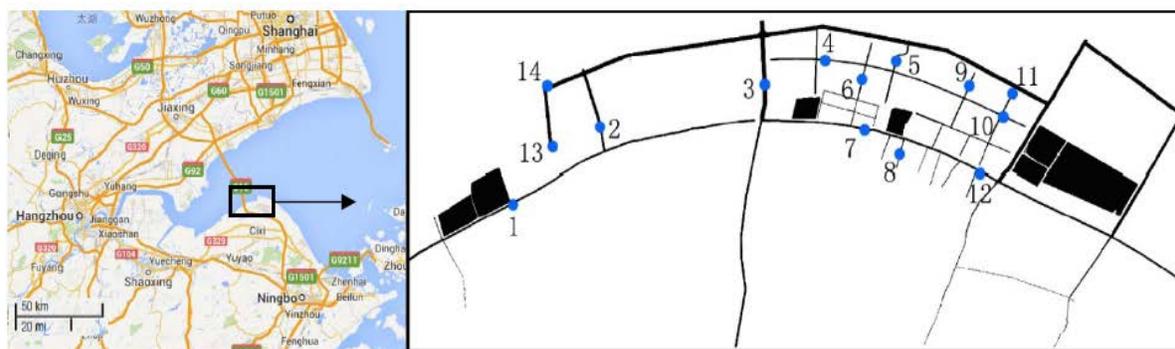


Fig. 1: Sketch map of sampling sites in Hangzhou Bay New District in Ningbo

candidate metrics were selected initially due to lower overlap degree in this study. After selecting of metrics, the Pearson correlation analysis was performed for testing the independence of each metrics.

**Metric scoring:** The metric scoring criteria were done by the ratio scoring method (Blocksom *et al.*, 2002). Because the ratio scoring method can eliminate the effects of subjective factors on the scores, the accuracy of evaluation results is better than other scoring methods (Wang *et al.*, 2005). After calculating the distribution range score was 0 to 1, more than 1 was recorded as 1. Each selected metric was calculated with ratio scoring method and the P-IBI equaled to the sum of ratio scoring of each metric. The range of P-IBI value is divided into four equal parts and the P-IBI value at each site is in one of the four parts. If the P-IBI value of one site is in the part of maximum rang the health of this site is excellent. If it is in the part of the minimum range the health is poor. Similarly, good and fair health could ascertain respectively by the P-IBI value.

## RESULTS

**Species number and abundance of plankton in Hangzhou bay new district:** In all samples, 125 species of phytoplanktons and 19 species of zooplanktons were found. The most species number of phytoplankton appeared at Sites 7 and 9 (43 species) and the least species number of algae presented at Site 11 (25 species). Meanwhile, the most species number of zooplanktons was found at Site 12. There were no any zooplanktons to be found at Sites 4, 5, 6, 9 and 14. In terms of the abundance, the highest abundance of phytoplankton ( $13616 \times 10^3$  ind./L) presented at Site 9, the lowest abundance appeared at Site 11 ( $2000 \times 10^3$  ind./L) and the highest abundance of zooplankton was found at Site 12 ( $1.8 \times 10^3$  ind./L).

**Metric selection:** According to the meaning of each metric and combined with the species and abundances of planktons identified, 6 metrics were selected preliminarily from the total 17 candidate metrics. These 6 metrics have significant distinguish, for examples, average algae weight ( $A_1$ ), Shannon-Wiener index of algae ( $A_2$ ), the biomass ration of zooplankton/phytoplankton ( $A_3$ ), abundance ratio of inedible algae/total algae ( $A_4$ ), abundance ratio of water bloom algae/total algae ( $A_5$ ) and abundance ratio of cyanobacteria/total algal ( $A_6$ ). Among these 6 metrics,  $A_2$  belongs to the species richness parameter,  $A_4$ ,  $A_5$  and  $A_6$  belong to the community structure parameters and other two metrics belong to the community trophic structure parameters. Box-plots of the 6 candidate

Table 1: Pearson's correlation matrix of the selected metrics

Metrics	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$
$A_1$	1					
$A_2$	-0.287	1				
$A_3$	0.668	-0.330	1			
$A_4$	0.640	-0.266	0.759	1		
$A_5$	-0.668	-0.759	0.330	-1	1	
$A_6$	-1	0.287	-0.668	-0.640	0.668	1

$A_1$ : Average algae weight;  $A_2$ : Shannon-Wiener index of algae;  $A_3$ : Biomass ration of zooplankton/phytoplankton;  $A_4$ : Abundance ratio of inedible algae/total algae;  $A_5$ : Abundance ratio of water bloom algae/total algae;  $A_6$ : Abundance ratio of cyanobacteria/total algal

Table 2: The selected metrics response to the disturbances

Metrics	Response to disturbances
Shannon-Wiener index of algae ( $A_2$ )	Decline
Abundance ratio of inedible algae/total algae ( $A_4$ )	Decline
Abundance ratio of cyanobacteria/total algal ( $A_6$ )	Raise

Table 3: Criteria of health assessment of P-IBI for river network in Hangzhou Bay New District of Ningbo

Health assessment	Poor	Fair	Good	Excellent
P-IBI	0-0.732	0.732-1.4641	1.4641-2.1962	2.1962-2.9282

metrics between reference and impaired sites were showed in Fig. 2.

The Pearson correlation analysis of these 6 metrics was showed in Table 1 for finding out the independence metrics. When the  $|r| > 0.75$ , Pearson's correlation means two metrics are significantly correlation. It implied that their corresponding metrics were not independences (Maxted *et al.*, 2000; Wang *et al.*, 2005). Following this principal, it can be found that  $|r|$  between  $A_4$  and  $A_5$  was 1, so that one of them can be eliminated optionally. Here,  $A_4$  was kept. In the same way,  $|r|$  between  $A_1$  and  $A_6$  was 1 as well,  $A_6$  was kept.  $|r|$  between  $A_3$  and  $A_4$ , between  $A_2$  and  $A_5$  was 0.759,  $A_3$  and  $A_5$  was eliminated; finally, only 3 metrics ( $A_2$ ,  $A_4$  and  $A_6$ ) were used for the index of biological integrity evaluation due to their independent relatively.

**Evaluation results:** Response to environmental disturbance from 3 independent metrics is listed in Table 2.

The largest score of P-IBI in this study was 2.9282 after the calculation. According to ratio scoring method, the criteria of health assessment for river network in Hangzhou Bay New District of Ningbo was listed in Table 3.

With the criteria listed in Table 3, an aquatic ecosystem health of Hangzhou Bay New District of Ningbo was evaluated and the results were listed in Table 4. The results showed that at Sites 3, 5, 6 and 12, the water health could be excellent relatively; at Sites 1, 2, 4, 7, 8 13 and 14, the water health could be good relatively, the water health of Sites 9 and 11 would be fair and at Site 10, the water condition would be poor.

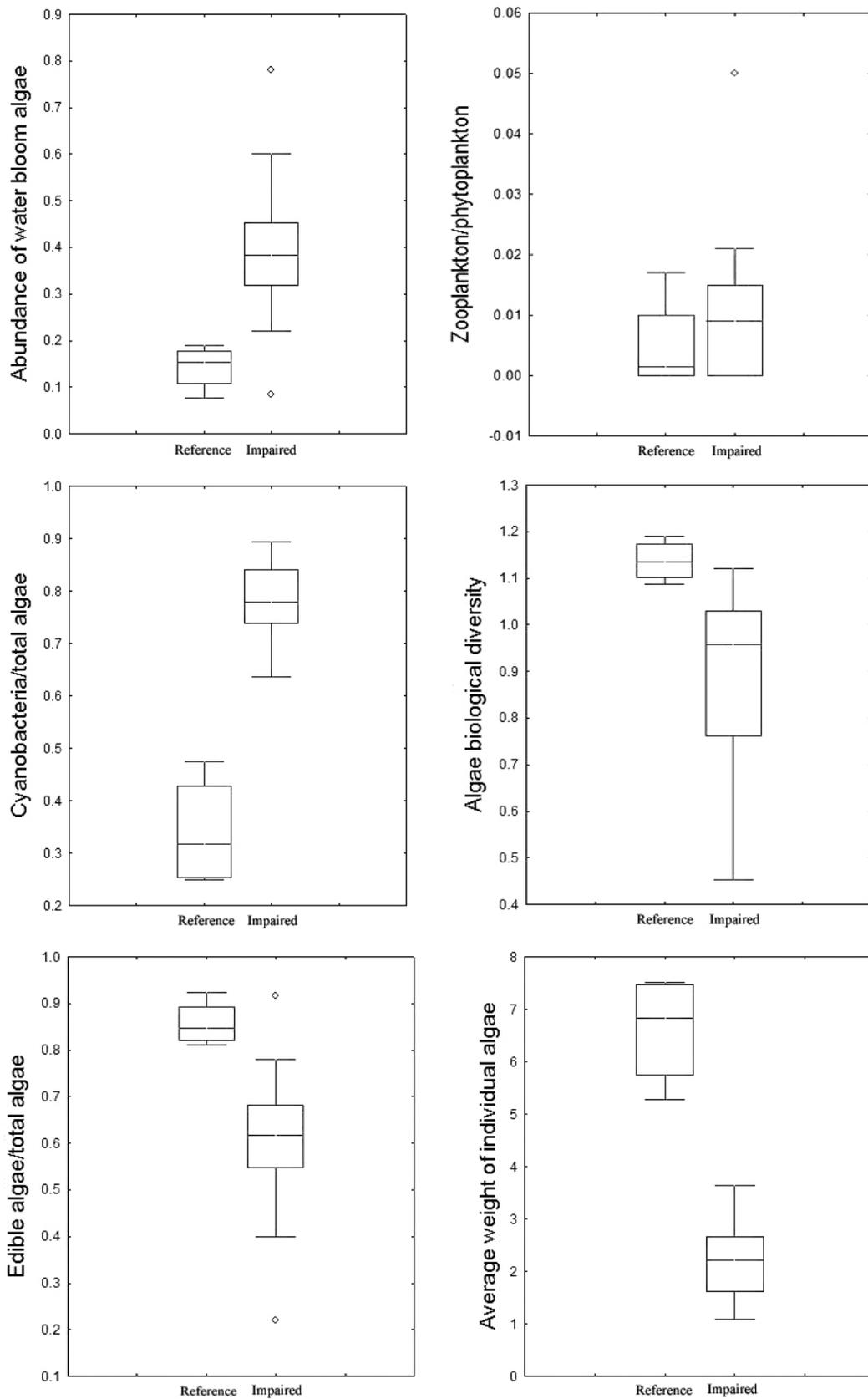


Fig. 2: Box-plots of candidate metrics between reference and impaired sites

Table 4: P-IBI scores for each sampling site of Hangzhou Bay New District of Ningbo

Sites	Shannon-Wiener index of algae A <sub>2</sub>	Abundance ratio of inedible algae/total algae A <sub>4</sub>	Abundance ratio of cyanobacteria/total algae A <sub>6</sub>	P-IBI	Health assessment
1	0.7848	0.6927	0.0516	1.5291	Good
2	0.8587	0.6350	0.2081	1.7018	Good
3	1	1	0.8027	2.8027	Excellent
4	0.9598	0.7417	0.4006	2.1021	Good
5	0.9547	0.9062	0.9967	2.8576	Excellent
6	0.9915	0.9367	1	2.9282	Excellent
7	0.7031	0.9977	0.2206	1.9214	Good
8	0.8664	0.8496	0.2785	1.9945	Good
9	0.6345	0.5969	0.0986	1.33	Fair
10	0.3883	0.2396	0	0.6279	Poor
11	0.6519	0.4357	0.2425	1.3301	Fair
12	0.9323	0.8833	0.6556	2.4712	Excellent
13	0.9590	0.7080	0.147	1.814	Good
14	0.8818	0.6535	0.0829	1.6182	Good

## DISCUSSION

The methods of river health assessment can be divided into two categories; one is the prediction model, including the river invertebrate prediction and classification system (RIVPACS) and Australian River Assessment (AUSRIVAS) (Wright *et al.*, 2000). RIVPACS can predict an existed biomass more accurate in theory, but if the environmental change did not reflect on the changes for the selected species, it could affect on the authenticity of evaluation. So RIVPACS has some limitations. For Australian rivers, AUSRIVAS is modified based on RIVPACS in the collection and analysis of data for evaluation (Wu *et al.*, 2005). The second category is multi-index evaluation methods. It included in Swedish channel and environmental conditions (RCE) (Petersen, 1992), Rivers State Index (ISC) (Ladson *et al.*, 1999), British river habitat survey (RHS) (Raven *et al.*, 1997), River Health Plan (RHP) (Wadson and Rowntree, 1994) and IBI (Karr, 1981). RCE can quick make an overall evaluation for the river health within a short time, but the selected index covers a very wide scope, so it requires a higher level of professional ability and skill for the analysis. ISC needs to combine the main status indicators of river together, but with a subjective selection on the reference sections. Both RHS and RHP are better ways to connect the biological indexes and physical indexes, but some data used for assessment by RHS and RHP is difficult to obtain. In IBI, it is focused on the biological community structure and function in the water bodies, including a series of sensitive indexes to environmental changes. This method was considered to be a simple, sensitive and efficient health assessment method for water ecosystem health (Hou and Zhang, 2007).

At the same time, some single index methods, such as diversity index, biological pollution index or algae pollution index, had still been used to assess the aquatic ecological health. Because limited information of environmental changes was reflected only, these methods were not comprehensive and overall, although it was fast.

Since 1990's, IBI has been widely used to assess aquatic ecosystem health. It has been showed that the key index system of biological method for health assessment was based on IBI in Environmental Protection Agency of USA. In the actual operation, the metrics would be different with various biological significances. For example, Hill *et al.* (2000) developed a P-IBI assessment system with 10 metrics in Mid-Appalachian basin. There was different between watershed upland and lowland regions. In China, IBI system has been used for assessment of water health as well. It has showed that the assessment results for Hunhe river health with P-IBI were basically consistent with the results of the physic-chemical index system of habitat environment (Yin *et al.*, 2011). Recently, Shen *et al.* (2012) analyzed the aquatic ecological health of water sources in Zhejiang Province in China by a P-IBI system with 22 metrics. The results not only reflected the ecological health of water, but also displayed the eutrophication and algal bloom risk in these water bodies. The results of this study fitted the assessment results of physic-chemical index system.

## CONCLUSION

In this study, 17 candidate metrics had been chosen, but after analyzing and selecting by Pearson correlation, only 3 metrics showed finally to responses for environmental disturbance (Table 2). From the references, it could be found that there is a regular pattern, i.e., the more spatial differences of the sampling sites were and the more independent metrics were useful for the health assessment. It can explain that due to the strong homogeneity of the sampling sites in this study, there was less metrics with significance in the evaluation.

It is different with some reports in the references (Shen *et al.*, 2012; Wang *et al.*, 2005; Yin *et al.*, 2011; Li *et al.*, 2012) that river network in this study is a relatively independent system without upstream and downstream. Therefore there was no a typical reference site in upstream. Although the health evaluation was carried out within the river network system only, the

results showed objectively the health status in the river network and displayed the risk of the water eutrophication and algae bloom.

#### ACKNOWLEDGMENT

Thanks are given to and Ms. Jean Huang for her English improvement of this manuscript.

#### REFERENCES

- Barbour, M.T., J. Gerritsen and G.E. Griffith, 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. *J. N. Am. Benthol. Soc.*, 15(2): 85-211.
- Blocksom, K.A., J.P. Kurtenbach and D.J. Klemm, 2002. Development and evaluation of the lake macroinvertebrate integrity index (LM II) for New Jersey lakes and reservoirs. *Environ. Monit. Assess.*, 77: 311-333.
- Demott, W.R. and F. Moxter, 1991. Foraging on cyanobacteria by copepods: Responses to chemical defenses and resource abundance. *Ecol. Soc. Am.*, 72(5): 1820-1834.
- Eugene, A.S. and I.H. Oh, 2004. Aquatic ecosystem assessment using exergy. *Ecol. Indic.*, 4: 189-198.
- Gao, X., 2006. Biodiversity and conservation of wetland of Hangzhou Bay. *J. Shenyang Normal Univ., Nat. Sci.*, 24(1): 92-95.
- Griffith, M.B., B.H. Hill and F.H. McCormick, 2005. Comparative application of indices of biotic integrity based on periphyton, macroinvertebrates and fish to southern Rocky Mountain streams. *Ecol. Indic.*, 5: 117-136.
- Guo, G.J. and S.B. Qian, 2003. *Flora Algarum Marinarum Sinicarum*. Science Press, Beijing.
- Hill, B.H., A.T. Herlihy and P.R. Kaufmann, 2000. Use of periphyton assemblage data as an index of biotic integrity. *J. N. Am. Benthol. Soc.*, 19: 50-67.
- Hou, J.Y. and Y.L. Zhang, 2007. Research on ecological health evaluating system of Hunhe River Shenyang section. *Environ. Protect. Sci.*, 33(3): 74-77.
- Hu, H.J. and Y.X. Wei, 2006. *The Freshwater Algae of China: Systematics, Classification and Ecology*. Science Press, Beijing.
- Jiang, J.R., J.D. Zhu and C.L. Fang, 2007. Preliminary strategy of wetland protection in Hangzhou Bay. *Anhui Agric. Sci. Bull.*, 13(14): 62-63.
- Jungwirth, M., S. Muhar and S. Schmutz, 2000. Assessing the ecological integrity of running waters. *Proceeding of the International Conference on Hydrobiologia*, 422/423: 245-256.
- Karr, J.R., 1981. Assessment of biotic integrity using fish communities. *Fisheries*, 6(6): 1-27.
- Kerans, B.L. and J.R. Karr, 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. *Ecol. Appl.*, 4: 768-785.
- Ladson, A.R., L.J. White and J.A. Doolan, 1999. Development and testing of an index of stream condition of waterway management in Australia. *Freshwater Biol.*, 41: 453-468.
- Li, G.C., X. Wang and L.S. Liu, 2012. Bioassessment of water quality based on diatom index of biotic integrity in the upstream of Liaohe River. *Res. Environ. Sci.*, 25(8): 852-858.
- Li, J.Y. and Y.Z. Qi, 2010. *Flora of Freshwater Algae in China, Bacillariophyta (Family Naviculaceae I)*. Science Press, Beijing.
- Lv, Y., S.Y. Yin, J. Howes and B.R. Zhu, 2011. Survey of waterbird resource in Cixi Hangzhou Bay wetland center in Zhejiang Province. *Chin. J. Wildlife*, 32(6): 312-315.
- Maxted, J.R., M.T. Barbour and J. Gerritsen, 2000. Assessment framework for mid-Atlantic coastal plain streams using benthic macroinvertebrates. *J. N. Am. Benthol. Soc.*, 19(1): 128-144.
- Ode, P.R., A.C. Rehn and J.T. May, 2005. A quantitative tool for assessing the ecological condition of streams in southern coastal California. *Environ. Manage.*, 35: 493-504.
- Petersen, R.C., 1992. The RCE: A riparian, channel and environmental inventory for small streams in the agricultural landscape. *Freshwater Biol.*, 27: 295-306.
- Raven, P.J., P. Fox and M. Everard, 1997. River Habitat Survey: A New System for Classifying Rivers According to their Habitat Quality. In: Boon, P.J. and D.L. Howell (Eds.), *Freshwater Quality: Defining the Indefinable? The Stationery Office, Edinburgh*, pp: 215-234.
- Shao, X.X., W.Y. Yang and M. Wu, 2011. Soil organic carbon content and its distribution pattern in Hangzhou Bay coastal wetlands. *Chinese J. Appl. Ecol.*, 22(3): 658-664.
- Shen, Q., J.J. Yu and H. Chen, 2012. Planktonic index of biotic integrity (P-IBI) for water source assessment. *J. Hydroecology*, 23(2): 26-31.
- Shen, Y.F., Z.S. Zhang and X.J. Gong, 1990. *Modern Biomonitoring Techniques Using Freshwater Microbiota*. China Architecture and Building Press, Beijing.
- Wadson, R.A. and K.M. Rowntree, 1994. A hierarchical geomorphological model for the classification of South African River Systems. In: Uys, M.C. (Ed.), *Classification of Rivers and Environmental Health Indicators*. Proceedings of a Joint South African/Australian Workshop. Water Research Commission Report No. TT63/94, Pretoria, pp: 49-68.
- Wang, B.X., L.F. Yang and B.J. Hu, 2005. A preliminary study on the assessment of stream ecosystem health in south of Anhui Province using benthic-index of biotic integrity. *Acta Ecol. Sinica*, 25(6): 1481-1490.

- Wang, B.X., L.F. Yang and Z.W. Liu, 2006. Index of biological integrity and its application in health assessment of aquatic ecosystem. *Chinese J. Ecol.*, 25(6): 707-710.
- Wright, J.F., D.W. Sutcliffe and M.T. Furse, 2000. *Assessing the Biological Quality of Freshwaters: RIVPACS and Similar Techniques*. Freshwater Biological Association, Ambleside.
- Wu, M., 2004. Current situation and conservation countermeasures of Hangzhou- Bay wetland. *Forest Resour. Manage.*, 6: 44-47.
- Wu, A.N., K. Yang and Y. Che, 2005. Characterization of rivers health status and its assessment. *Adv. Water Sci.*, 16(4): 602-608.
- Yin, X.W., Y. Zhang and X.D. Qu, 2011. Community structure and biological integrity of periphyton in Hunhe River water system of Liaoning Province, Northeast China. *Chinese J. Appl. Ecol.*, 22(10): 2732-2740.
- Zhang, Z.S. and X.F. Huang, 1991. *Method for the Study of Freshwater Plankton*. Science Press, Beijing.