Ecological Indicators 40 (2014) 162–174

Contents lists available at ScienceDirect

Ecological Indicators

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

Relationships between ecological risk indices for metals and benthic communities metrics in a macrophyte-dominated lake

Lulu Zhang, Jingling Liu*

State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China

ARTICLE INFO

Article history:
Received 9 September 2013
Received in revised form 15 January 2014
Accepted 17 January 2014

Keywords:
Heavy metals
Ecological risk index
Periphyton community
Benthic macroinvertebrate
Structural and functional metrics

ABSTRACT

With the aim of evaluating and comparing the correlation relationship between metal pollution and benthic structural and functional metrics, we carried out samplings of three anthropogenic disturbance levels at eight sites located in the Lake Baiyangdian that are strongly influenced by wastewater discharge (Sites 1 and 2), aquaculture and densely populated villages (Sites 3, 6, and 8), and the least human disturbances (Sites 4, 5, and 7). Benthic communities were studied in eight sample sites, and Cu, Ni, Pb, Zn, Hg, Cd, and Cr were simultaneously determined. The potential ecological risk index (RI) was calculated by Hakanson's methodology. The results showed that the RI for all three habitats was lower than 94, and they are in decreasing order: Habitat 1, Habitat 2, and Habitat 3. When the three sampling seasons were compared, August appeared to show the highest risk, followed by April and November. For the periphyton metrics, the best correlation was detected between chlorophyll *c*/chlorophyll *a* (Chl *c*/*a*) ratio and Eri Hg ($r = -0.851$, $p < 0.01$); for the benthic macroinvertebrate metrics, the best correlation was established between Eri Hg and community similarity index (CSI) ($r = -0.983$, $p < 0.01$). When periphyton and benthic macroinvertebrate metrics were compared, benthic macroinvertebrate metrics appeared to be more sensitive, especially the metrics of number of diptera taxa (NDT), community loss index (CLI), and CSI. Our results suggest that the benthic community would be used in biomonitoring for heavy metal pollution in the Lake Baiyangdian, China.

1. Introduction

Lakes are extremely important freshwater storage on the earth's surface. However, due to the increasing impact of anthropogenic activities over the last few decades, the heavy metal pollution of the lake ecosystem was increased (Long et al., 1995; Ali et al., 1999; Burton, 2002; Liu et al., 2009; Su et al., 2011). Heavy metals may change from non-biologically available forms to bioavailable ones with high toxicity, which can also be bioaccumulated in organisms and magnified through the food chain (Clearwater et al., 2002; De Schamphelaere et al., 2004; Zhou et al., 2008a,b), thus threatening ecological health. Therefore, increasing attention has been paid to the wide occurrence of metal pollution in freshwater ecosystems (De Jonge et al., 2008; Ancion et al., 2010; Tlili et al., 2011). Chemical analysis of environmental matrices is the most direct approach to reveal the heavy metal pollution status in the environmental compartments, but this technique with many disadvantages, such as cannot provide meaningful information regarding the possible toxicity to organisms and ecosystems (Zhou et al., 2008a,b), and not feasible when intensive and large scale samplings are needed (Blasco and Picó, 2009). Under such circumstances, a chemical-driven strategy for assessing the ecological risk from pollutants based on a combination of both biological responses and chemical data is necessary to explore and to develop new risk assessment strategies (Rodriguez-Mozaz et al., 2006; Gonzalez-Martinez et al., 2007; Brack et al., 2008; Fernandez et al., 2009; Ginebreda et al., 2010; Pesce et al., 2010).

Compared with conventional physical and chemical analyses of the aquatic environment, biomonitoring exhibits some advantages, including high sensitivity, high integration, and wide practicability (Zhou et al., 2008a,b). The typical method for biomonitoring is largely based on bioindicators, which are highly useful in biomonitoring and recording biological responses. In freshwater environments, benthic communities possess many of advantages as bioindicators: they are widely distributed, play an important role in nutrient cycling (Griffith et al., 2005; Gabriels et al., 2010), and are sensitive indicators of changes to pollution (Morin et al., 2008; Kröncke and Reiss, 2010). However, the differences in physical and chemical tolerances among taxa, differences in life-history (Wallace and Anderson, 1996; Hill et al., 2000), recolonization mechanisms, and biogeography of taxa among these assemblages

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* Corresponding author. Tel.: +86 10 5880 5092; fax: +86 10 5880 0397.
E-mail addresses: zhanglulu19850703@163.com (L. Zhang), jingling@bnu.edu.cn (J. Liu).

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http://dx.doi.org/10.1016/j.ecolind.2014.01.021

(Barbour et al., 1999; Angermeier et al., 2000) may affect their responses to changes in aquatic ecosystem quality (Townsend and Hildrew, 1994).

Although few field studies have been reported on characterization of benthic communities in response to short-term metal contamination and possible toxicity of heavy metals to benthic communities in the ecosystem (Gold et al., 2002; Ancion et al., 2010), the metal pollution in aquatic ecosystems can have a toxic impact on the structure and function of the biological community (Medley and Clements, 1998; Ivorra, 2000). Most of these studies were focused on the structural metrics (De Jonge et al., 2008; Morin et al., 2008); by contrast, functional metrics are often neglected in assessing the ecological status (Fechner et al., 2010; Feio et al., 2010). In addition, few studies have compared different benthic indicators as measures of freshwater ecosystem status, especially in the lake ecosystem (Townsend and Hildrew, 1994; Barbour et al., 1999; O'Connor et al., 1998; Hatzenbeler et al., 2004; Griffith et al., 2005; Lear et al., 2009; Justus et al., 2010).

Therefore, to obtain a more complete picture of the potential of benthic communities as bioindicators for ecological health assessment, the objectives of this paper were to: carry out an ecological risk assessment of the heavy metals present in Lake Baiyangdian; calculate the values of structural and functional metrics based on benthic communities; establish and compare the relationship between risk indices and bio-metrics; and select the most appropriate metrics for ecological risk assessment.

2. Materials and methods

2.1. Study sites

Lake Baiyangdian ($38^\circ 44'$–$38^\circ 59'$N, $115^\circ 45'$–$116^\circ 06'$E) covers an area of approximately 366 km^2 and is located in the city of Baoding in Hebei Province, China (Fig. 1). It is a typical macrophyte-dominated shallow lake with an average water depth of 2–4 m surrounded by roughly 143 connected lakes with 36 villages and 67 km^2 of reed marshes on the Northern China Plain. The water area of the lake changes according to hydrological conditions and seasonality. Annual precipitation is 350–750 mm in the area, and annual evaporation is 1750 mm. Because of rapid population growth, urbanization and economic development in the drainage area of the lake during recent decades, this region has suffered from intensive anthropogenic disturbances, particularly due to the Fu River serving as the only inflow river, which brought in a large quantity of pollutants and intercepted runoff from the dam established along its upper reaches. In addition, non-point source pollution arising from the daily lives of residents, aquaculture, farming, and villages causes excessive amounts of nutrient-rich wastewater to be discharged directly into the lake. Lake Baiyangdian has been designated mesotrophic-eutrophic, a category that is associated with severe negative effects on the ecosystem health of the lake.

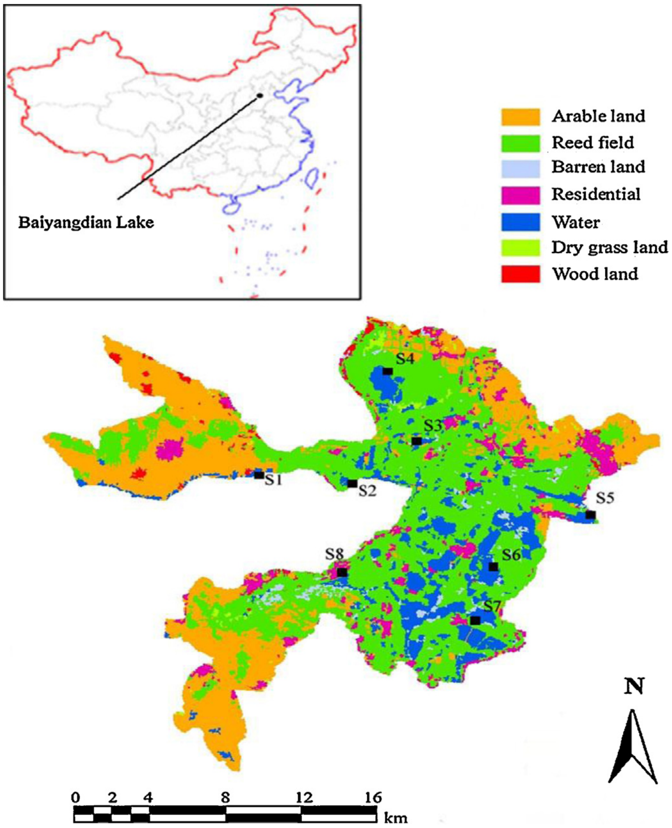

Fig. 1. The sampling sites of Lake Baiyangdian in this study (S1 – Fuhe inlet, S2 – Nanliuzhuang, S3 – Wangjiazhai, S4 – Shaochedian, S5 – Zaolinzhuang, S6 – Quantou, S7 – Caiputai, and S8 – Duancun).

According to the characteristics of land use, eight study sites were included in this study with water depths between 1.11 and 2.01 m, the study sites can be subdivided into 3 anthropogenic disturbance levels: greatly influenced by wastewater discharge (Sites 1 and 2), impacted by aquaculture and densely populated villages (Sites 3, 6, and 8), and the least human disturbances (Sites 4, 5, and 7) (Table 1). Sampling dates were selected depending on biological community development and were collected in late April 2009 (maximum vegetation), late August 2009 (maximum periphyton and benthic macroinvertebrate), and early November 2009 (minimum vegetation).

2.2. Physical and chemical characteristics of the study sites

Five 4 L samples of lake water were collected in low-density polyethylene containers, filtered (0.2 μm filter), and preserved in a cooler in the field and then refrigerator in the laboratory until

Table 1
Impaired conditions of the sampling sites.

Sampling site	Anthropogenic disturbance level	Coordinates	Land-use characteristics
S1	Habitat 1	N38.9044° E115.9238°	Greatly influenced by wastewater inflow from Baoding City
S2		N38.9045° E115.9348°	Greatly influenced by wastewater inflow from the Fu River, minor aquaculture, small village
S3	Habitat 2	N38.9177° E116.0114°	Major aquaculture, dense village
S6		N38.8604° E116.0282°	Major aquaculture, near to village
S8		N38.8470° E115.9506°	Major aquaculture, dense village
S4	Habitat 3	N38.9407° E115.9997°	Minor aquaculture
S5		N38.9021° E116.0804°	The outlet of the Baiyangdian, minor human disturbances
S7		N38.8249° E116.0102°	Minor aquaculture, small village