Ecological Indicators 61 (2016) 179–187

Contents lists available at ScienceDirect

Ecological Indicators

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

# Structure and spatial patterns of macrobenthic community in Tai Lake, a large shallow lake, China

Di Li[a,b], Richard A. Erickson[c], Song Tang[d], Yong Zhang[b], Zhichun Niu[b], Hongling Liu[a], Hongxia Yu[a,*]

[a] State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing, Jiangsu 210023, China
[b] Jiangsu Environmental Monitoring Center, Nanjing, Jiangsu 210036, China
[c] Upper Midwest Environmental Sciences Center, U.S. Geological Survey, La Crosse, WI 54603, USA
[d] School of Environment and Sustainability, University of Saskatchewan, Saskatoon, SK S7N 5B3, Canada

## ARTICLE INFO

*Article history:*
Received 5 March 2015
Received in revised form 12 July 2015
Accepted 25 August 2015
Available online 11 November 2015

*Keywords:*
Cluster analysis
Diversity
Eutrophication
Macrobenthos
Microcystin

## ABSTRACT

Tai Lake (Chinese: *Taihu*), the third-largest freshwater lake in China, suffers from harmful cyanobacteria blooms that are caused by economic development and population growth near the lake. Several studies have focused on phytoplankton in Tai Lake after a drinking water crisis in 2007; however, these studies primarily focused on microcystin bioaccumulation and toxicity to individual species without examining the effects of microcystin on macrobenthic community diversity. In this study, we conducted a survey of the lake to examine the effects of microcystine and other pollutants on marcobenthic community diversity. A totally of forty-nine species of macroinvertebrates were found in Tai Lake. *Limnodrilus hoffmeisteri* and *Corbicula fluminea* were the most abundant species. Cluster-analysis and one-way analysis of similarity (ANOSIM) identified three significantly different macrobenthic communities among the sample sites. More specifically, sites in the eastern bays, where aquatic macrophytes were abundant, had the highest diversity of macrobenthic communities, which were dominated by *Bellamya aeruginosa*, *Bellamya purificata*, *L. hoffmeisteri*, and *Alocinma longicornis*. Sites in Zhushan Bay contained relatively diverse communities, mainly composed of *L. hoffmeisteri*, *C. fluminea*, *L. claparederanus*, *R. sinicus*, and *Cythura* sp. Sites in the western region, Meiliang Bay and Wuli Bay had the lowest diversity, mainly composed of *L. hoffmeisteri*, *C. fluminea*, *Branchiura sowerbyi*, and *Rhyacodrilus sinicus*. In addition, the relationships between macrobenthic metrics (Shannon–Wiener, Margalef, and Pielou) and environmental variables showed that community structure and spatial patterns of macrobenthos in Tai Lake were significantly influenced by chemical oxygen demand ($COD_{Cr}$), biochemical oxygen demand ($BOD_5$), lead (Pb), and microcystin-LR (L for leucine and R for arginine). Our findings provide critical information that could help managers and policymakers assess and modify ecological restoration practices.

## 1. Introduction

Macrobenthic communities perform crucial ecosystem services through nutrient cycling and pollutants detoxification, and these organisms provide food for humans and are deemed as an important source of food for fishes and birds as well (Snelgrove, 1999; Thrush and Dayton, 2002). However, they are subject to degradation from pollutions (Covich et al., 1999; Salas et al., 2004; Blanchet et al., 2008). These communities respond to different environmental conditions and changes in environmental quality may affect community structures, dominant species, species abundance, and species diversity (Chapman and Peter, 1990; Dauer, 1993; Vaughn and Hakenkamp, 2001; Chainho et al., 2006; Zalmon et al., 2011). Economic development and population growth are two stressors that may affect macrobenthic communities (Gray, 1997). These stressors often cause native species to decrease in relative abundance and invasive species to increase (Keller et al., 2011; Erba et al., 2015). Changes of salinity, sedimentation, and eutrophication in estuaries and coasts have been shown to shift community structure (Posey et al., 1998; Mistri et al., 2001; Mucha et al., 2004; Lamptey and Ayaa, 2008; de Juan and Cartes, 2011; Pereira et al., 2012; Verissimo et al., 2012; Borja et al., 2013; Schroder et al., 2015). However, previous studies on macrobentic communities have mainly focused on marine ecosystems (Outridge, 1987; Camargo, 1993; Dauvin et al., 2012; Faupel et al., 2012; Daief et al.,

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[*] Corresponding author at: School of the Environment, Nanjing University, Nanjing, Jiangsu 210023, China. Tel.: +86 25 89680356; Fax: +86 25 89680356.
*E-mail address:* yuhx@nju.edu.cn (H. Yu).

http://dx.doi.org/10.1016/j.ecolind.2015.08.043
1470-160X/

2014; Gillett et al., 2015) and little attention was placed on freshwater ecosystems (Huang et al., 2015) and more specifically large shallow lakes. Furthermore, previous studies have mainly analyzed the relationships between macrobenthic community indicators and conventional water quality parameters, such as longitude, season, pH value, dissolved oxygen, and heavy metals (Courtney and Clements, 1998; Lu, 2005; Leunda et al., 2009; Mandal and Harkantra, 2013; Pereira et al., 2012). Effects of cyanobacterial microcystins (MCs) on macrobenthic communities are seldom studied in freshwater environments (Lance et al., 2010).

Large shallow lakes are important resources for aquaculture, tourism, recreation, shipping, and drinking. In the last 30 years, eutrophication has led to cyanobacterial blooms which can produce toxins such as MCs. Microcystin-LR (MC-LR; L for leucine and R for arginine) is the one of the most common toxins and has both a wide distribution and high toxicity. Francis (1878) first showed that water containing poisonous MC caused the deaths of livestock and poultry. Microcystin has not only been found in fish (de Magalhaes et al., 2001; Djediat et al., 2010), but also in crayfish (Kankaanpáá et al., 2004), shellfish, clams (Yokoyama and Park, 2003; Cazenave et al., 2005; Freitas et al., 2014), and even in vegetables (McELhiney et al., 2001; Cordeiro-Araujo et al., 2015). Understanding the relationships between environmental variables, especially MC-LR, and macrobenthic indicators is crucial to both conservation biology and the restoration and maintenance of freshwater ecosystems.

Tai Lake, the third-largest lake in China, is an important drinking water source for several populous cities including Shanghai, Suzhou, Wuxi, and Huzhou. It has been under numerous economic and population pressures, and cyanobacterial blooms (*Microcystis* spp.) occurred throughout the entire year, with the exception of January and February, from 1998 to 2007. The frequency and duration of cyanobacterial blooms have increased over recent years (Duan et al., 2009). A drinking water crisis during the summer of 2007 (Qin et al., 2010a,b) prompted a number of studies that focused on phytoplankton and microcystin in Tai Lake (Zhang et al., 2013a,b; Jiao et al., 2014). These studies mainly focused on bioaccumulation and single species toxicity of microcystin; however, the impacts of MC-LR on macrobenthic communities in Tai Lake have not been examined to date.

In this study, we surveyed the macrobenthic communities and measured environmental conditions in this large shallow lake. Our objectives were (1) to explore the potential impacts of environmental stress on macrobenthic organisms; (2) to analyze the relationships between environmental variables and macrobenthic metrics; (3) to identify the factors altering the structure of macrobenthic community; and (4) to provide baseline data for ecological and environmental protection in the future.

## 2. Materials and methods

### 2.1. Study area

Located in the southern Changjiang (Yangtze) River Delta, Tai Lake (30°55′40″–31°32′58″ N and 119°52′32″–120°36′10″ E) is one of the most densely populated regions in China. Tai Lake has an area of 2338 $km^2$, with a maximum length and width of 68.5 and 56 km, respectively. The average depth is about 1.9 m. The average annual air temperature in Tai Lake is 16.0–18.0 °C. The average annual precipitation is 1100–1150 mm. In the current study, there were a total of 14 sampling sites (Fig. 1). Two sites were in Zhushan Bay (TH11 and TH12), one site was in Wuli Bay (TH9), one site was in Meiliang Bay (TH8), three sites were in Gonghu Bay (TH2, TH6, and TH7), four sites were in the eastern bays (TH10, TH1, TH14, and TH13), and three sites were in western region on the lake (TH3, TH4, and TH5). Sediments exhibit high spatial heterogeneity in Tai Lake. The northern bays (Gonghu Bay, Meiliang Bay, and Zhushan Bay) and eastern bays are covered with soft organic sediment, whereas the western region (mainly the open area) is covered with a thin layer of mud-sand sediment (Nanjing Institute of Geography & Limnology, 1965). Aquatic macrophytes are distributed in eastern bays and site TH2 of Gonghu Bay and are seldom found elsewhere in Tai Lake. Distributions of macrophytes in Tai Lake were based on data from Suzhou Municipal Environment Monitoring Center (Li et al., 2014).

### 2.2. Sampling

#### 2.2.1. Water sampling

Sampling was performed at 14 sites in both the spring and fall from 2011 to 2013. Water quality samples were collected in glass bottles 0.5 m below the surface at each site and for each period. Water temperature (WT), pH, dissolved oxygen (DO), transparency, and conductivity were measured using YSI water quality sondes (YSI Incorporated, 6600V2-4, Ohio, USA) following standard methods (EPA of China, 2002). In addition, water samples were collected in glass containers, stored at 0–4 °C in the dark, and brought to the laboratory within 12 h and processed immediately upon arrival in order to measure chemical oxygen demand ($COD_{Cr}$), permanganate index ($COD_{Mn}$), total phosphorus (TP), total nitrogen (TN), biochemical oxygen demand ($BOD_5$), ammonia nitrogen ($NH_4^+$-N), fluoride ($F^-$), arsenic (As), lead (Pb), copper (Cu), Chlorophyll a (Chl *a*), and MC-LR.

#### 2.2.2. Macroinvertebrate sampling

Triplicate benthic samples were collected using a Peterson grab sampler (0.0625 $m^2$ sample area) at each site for each period after water samples were collected. Each grab sample was carefully washed and sieved *in situ* through a 40-mesh nylon-membrane, and the retained materials were preserved in 70% alcohol, and then transported to laboratory at the same day (EPA of China, 2002).

### 2.3. Analytical procedures

#### 2.3.1. Environmental variables

Environmental variables including WT, pH, DO, transparency, and conductivity were measured by the YSI water quality sondes *in situ*. Analysis of $COD_{Cr}$, $COD_{Mn}$, TP, TN, $BOD_5$, $NH_4^+$-N, $F^-$, As, Pb, Cu, and Chl *a* in water samples were based on Water and Wastewater Monitoring Analysis Method (EPA of China, 2002). MC-LR was analyzed by Enzyme-linked immunosorbent assay (ELISA) following previously published methodologies (Rivasseau et al., 1999; Jarkko et al., 2002).

Synthesized trophic state index (STSI) for eutrophication of water quality was calculated for each water sample using transparency, $COD_{Mn}$, TP, TN and Chl *a*:

$$\mathrm{STSI} = \mathrm{TSI}\left(\sum\right) = \sum_{j=1}^{m} (W_j \times \mathrm{TSI}_j),$$

where $W_j$ is the entropy weight, $\mathrm{TSI}_j$ is the trophic state index for variable $j$, and m is the number of observations. The weight coefficient of each variable was calculated through entropy weight, which is a measure of fuzziness (Zedeh, 1965; Don, 1994; Qiu, 2001). Correlation between STSI and water quality is reported in Table 1.

Sediment substrate type was classified by the grain size of materials: sediments whose grain size is less than 4 μm were mud; grains ranging between 4 and 64 μm were mud-sand; and grains greater than 64 μm were sand.