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The tempo-spatial variations of phytoplankton diversities and their correlation with trophic state levels in a large eutrophic Chinese lake

Bin Yang[a], Yu-Jiao Jiang[a,1], Wei He[a], Wen-Xiu Liu[a], Xiang-Zhen Kong[a], Sven Erik Jørgensen[b], Fu-Liu Xu[a,*]

[a] MOE Laboratory for Earth Surface Processes, College of Urban & Environmental Sciences, Peking University, Beijing 100871, China
[b] Section of Toxicology and Environmental Chemistry, Institute A, University of Copenhagen, University Park 2, DK-2100 Copenhagen Ø, Denmarka

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ABSTRACT

Lake Chaohu is one of the most eutrophic lakes in China. Research on this lake's seasonal and spatial variations in phytoplankton diversity is needed to understand the distribution of eutrophication, as well as to find appropriate comprehensive biodiversity indices to assess the eutrophication status of the lake. The present study indicated that the Margalef index of all samples was as low as 0.799 ± 0.543 in summer (August 2011) and as high as 1.467 ± 0.653 in winter (February 2012). The Margalef index of the river samples had a high mean value and substantial variation compared with the lake samples. The Peilou index of the lake samples was higher than that of the river samples in summer and autumn (November 2011) but lower than that of the river samples in winter. In spring (May 2012), the Peilou index of the western samples was lower than that of the eastern samples. The spatial distribution of the Shannon–Wiener index was more similar to that of the Peilou index in autumn and winter, while in spring and summer, the spatial distribution was affected by both species richness and evenness. High eutrophication levels occurred in the western lake in spring and summer, whereas high levels occurred in the eastern lake, especially in the middle of the lake, in autumn and winter. The total trophic state index (TSI) in all samples exhibited a significant negative correlation with the Margalef ($r = -0.726$) and Peilou ($r = -0.530$) indices but a significant positive correlation with the Shannon–Wiener ($r = 0.654$) index. The partial correlation analysis results implied that these phytoplankton biodiversity indices could serve as synthetic ecological indicators to assess the eutrophication condition of Lake Chaohu.

1. Introduction

Lake eutrophication is the abnormal structure and function of an aquatic ecosystem and the obvious deterioration of the water environment due to the change observed in dissolved oxygen and water transparency when a lake contains excessive nutrients, such as nitrogen and phosphorus (Jin et al., 1990). One major aspect of lake eutrophication is the abnormal proliferation of specific phytoplankton species. Because of phytoplankton's position at the base of aquatic food webs and basic nutritional needs, phytoplankton communities provide unique information about the condition of the ecosystem (McCormick and Cairns, 1994). Phytoplankton responds rapidly and predictably to a wide range of pollutants, thus, the composition and diversity of phytoplankton can provide potentially useful early warning signals of deteriorating conditions, as well as clues to the possible causes. The use of phytoplankton as indicators of ecosystem conditions has historically focused on the effects associated with organic enrichment and other forms of cultural eutrophication (Patrick, 1977). Given the close correlation between phytoplankton and eutrophication, further consideration of the interactive effects of nutrient enrichment on phytoplankton diversity is needed.

The Carlson's trophic state index (TSI) (Carlson, 1977), based on transparency, and the modified Carlson's TSI (Aizaki et al., 1981), based on chlorophyll-a concentration, are most commonly used for lake eutrophication assessment. Later TSIs based on more biological, chemical and physical indicators were calculated (Jin et al., 1990; Primpas et al., 2010; Swanson, 1998; Xu et al., 2001) in an attempt to offer a more suitable and acceptable method for evaluating lake eutrophication. With the exception of chlorophyll-a concentration, ecological indicators, such as phytoplankton cell number, species number, biomass and some form of diversity index, have been involved in both univariate and multivariate approaches

* Corresponding author. Tel.: +86 10 62756122; fax: +86 10 62756122.
E-mail address: xufl@urban.pku.edu.cn (F.-L. Xu).
[1] Co-first author.

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in assessing eutrophication conditions in aquatic environments (Danilov and Ekelund, 1999; Washington, 1984; Watson et al., 1997; Xu et al., 2001). Most of the related studies on the relationship between phytoplankton diversity and eutrophication assessment focused on the ability of various diversity indices to distinguish between levels of eutrophication (oligotrophic, mesotrophic and eutrophic) and the selection of suitable indicators to identify descriptive classifications for lake trophic states (Danilov and Ekelund, 1999; Karydis and Tsirtsis, 1996; Spatharis and Tsirtsis, 2010). However, the continuous seasonal and spatial distribution of eutrophication levels is equally important in developing a complete picture of the trophic state of a lake. The correlation between typical phytoplankton diversity indices and continuous numerical classes of lake trophic states was analyzed in this paper.

The persistent dominance of Cyanophyta throughout all seasons remained unchanged since the 1980s, which may indicate a new tendency of the response of phytoplankton to eutrophication in Lake Chaohu (Deng et al., 2007; Jiang et al., 2014). Research on seasonal and spatial variations in phytoplankton diversity in Lake Chaohu, a typical eutrophic shallow lake, is necessary for understanding the distribution of eutrophication and finding appropriate synthetic biodiversity indices to assess the level of eutrophication. The objective of the present study was to analyze the feasibility of using phytoplankton diversity as an ecological indicator for assessing lake eutrophication states. It would be beneficial to have an integrated index to appropriately describe and measure the seasonal and spatial variations of eutrophication in Lake Chaohu.

2. Methods

2.1. Sampling sites and analytical methods

Lake Chaohu, the fifth largest freshwater lake in China, is located in central Anhui Province (30°25′28″–31°43′28″ N, 117°16′54″–117°51′46″ E). This lake has a flat bottom with an area of 770 km^2 and an average depth of 3.06 m (Xu, 1997). Lake Chaohu is a semi-enclosed lake and is artificially controlled by the Chaohu sluice gates. In this study, samples were collected from the surface water of Lake Chaohu and the main inflow rivers that drained into the lake (10 samples each) (Fig. 1). Sites L01-L05 were located in western Lake Chaohu (WL), while Sites L06–L10 were located in the eastern part of the lake (EL). Sites R01–R05 were located in the western part of inflow rivers around Lake Chaohu (WR), and Sites R06–R10 were located in the eastern part of rivers around Lake Chaohu (ER). Samples were collected every 3 months from August 2011 to May 2012, representing the water conditions in summer, autumn, winter and spring.

A sample of approximately 1 L of raw water was taken by plexiglass deepwater barrel sampler from each site controlled depth within 0.5 m to measure the concentrations of total phosphorus (TP), total nitrogen (TN), chemical oxygen demand (COD) and chlorophyll-a (Chl-a). Quantitative samples of the phytoplankton were collected using 10 L or 20 L of raw water samples concentrated to approximately 50 mL through a 25# plankton net (mesh diameter of 64 μm) in 100 mL vials, and preserved with 5 mL 37–40% formalin for subsequent species identification and counting under an optical digital biological microscope in the laboratory. Phytoplankton biomass (PB) was calculated by multiplying the approximate volume of all algae cells by the approximate density of algae cells (equal to 1 g/cm^3). The measurement of TP, TN and COD, as well as identification and counting of phytoplankton samples, was described in detail in Jiang et al. (2014). For the Chl-a measurement, a known volume $V1$ of raw water in a given sample was filtered through a 0.8 μm cellulose acetate membrane filter. Chl-a pigment was extracted by mixing the sample with a solution of acetone and absolute alcohol (2:1 in volume) after grinding membrane filter with calcium carbonate and quartz sand (Peng and Liu, 1992). After centrifugation, the supernatant was diluted with the mixing solution to 10-mL volume and mixed. Chl-a was measured at two wavelengths using a spectrophotometer and calculated as shown in Eq. (1):

$$Chla = (12.7A_{663} - 2.69A_{645}) \times \frac{10}{V1} \quad (1)$$

where $Chla$ is the concentrations of Chl-a (mg/L) and A is the corrected optical density (with 1 cm light path) at the respective wavelength.

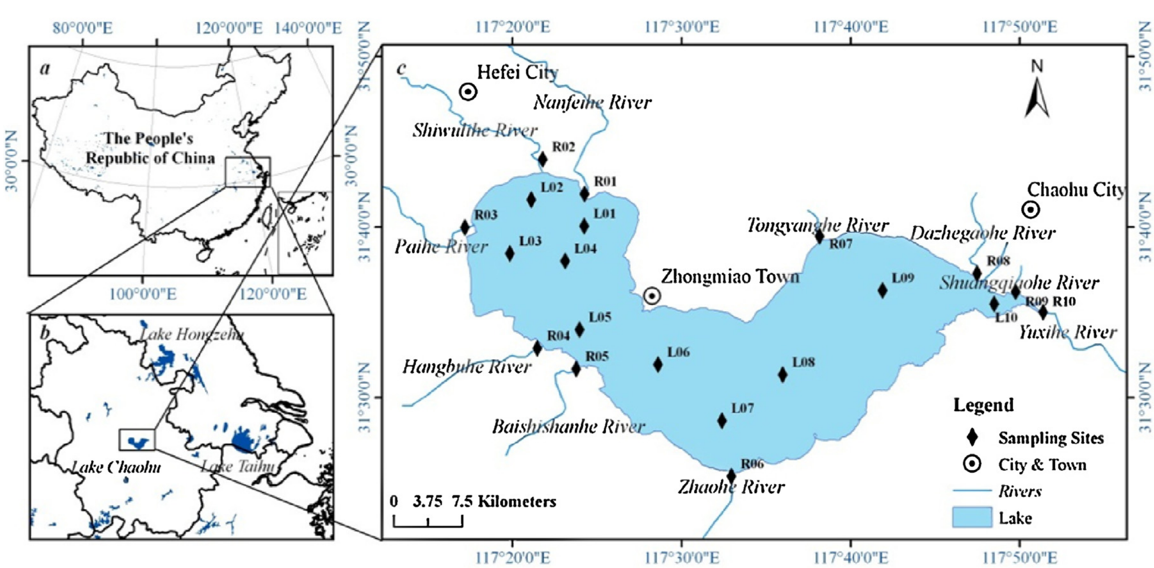

Fig. 1. Twenty sampling sites in and around Lake Chaohu. L01: Nanfeihe River mouth; L02: Tangxihe and Shiwulihe River mouth; L03: Paihe River mouth; L04: the middle of western Lake Chaohu; L05: Sanhe River mouth; L06: east of Mushan Island; L07: Zhaohe River mouth; L08: the middle of eastern Lake Chaohu; L09: Tongyanghe and Jiyuhe River mouth; L10: Shuangqiaohe River mouth; R01: Nanfeihe River; R02: Shiwulihe River; R03: Paihe River; R04: Sanhe River; R05: Baishishanhe River; R06: Zhaohe River; R07: Tongyanghe River; R08: Zhegaohe River; R09: Shuangqiaohe River; R10: Yuxihe River.