Science of the Total Environment 613–614 (2018) 907–918

Contents lists available at ScienceDirect

Science of the Total Environment

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

Sedimentary lipid biomarker record of human-induced environmental change during the past century in Lake Changdang, Lake Taihu basin, Eastern China

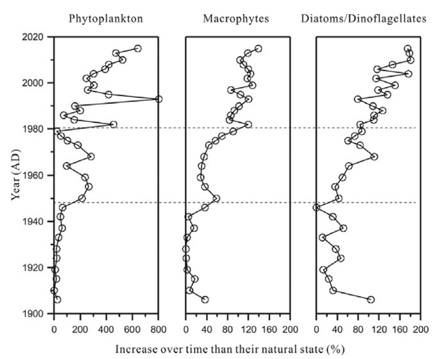
Yongdong Zhang [a,*], Yaling Su [a], Zhengwen Liu [a,b,**], Kaihong Sun [c], Lingyang Kong [a], Jinlei Yu [a], Miao Jin [a]

[a] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography & Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[b] Department of Ecology and Research Center of Hydrobiology, Jinan University, Guangzhou 510632, China
[c] College of Chemical Engineering, Nanjing Forestry University, Nanjing 210037, China

HIGHLIGHTS

- Lipid biomarkers and other geochemical proxies were analyzed in a sediment core from a lake in Lake Taihu basin.
- Phytoplankton and aquatic macrophytes have remained low in productivity before the 1950s, reflecting a natural state.
- Geochemical signs indicated a minor eutrophication of the lake in ca. 1950–1982, perhaps driven by agricultural growth.
- The acceleration of lake eutrophication in ca. 1982–2016 is a consequence of local urbanization and industrialization.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 May 2017
Received in revised form 30 August 2017
Accepted 18 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Lipid biomarker
Eutrophication
Human activities
Nutrients
Lake Changdang

ABSTRACT

During the past hundred years, the Lake Taihu basin has been greatly impacted by human interventions. The undesirable changes in water quality of lakes, presumably caused by the human activities, remain relatively undescribed in this area. In order to investigate these anthropogenic effects, a ^{210}Pb dated sediment core from a relatively small lake in the upper reaches of Lake Taihu known as Lake Changdang was subject to a detailed lipid biomarker study and other geochemical analyses including quantification of biogenic silica (BSi), nutrients and heavy metals. Based on the results, the recent environmental history of Lake Changdang can be divided into three periods. The first period from approximately 1906 to 1950, represents a natural state, with minimal anthropogenic impact on the lake. Human induced environmental change is recorded in the following stage, ca. 1950–1982, during which the trophic status of the lake increased slightly in response to inputs of agricultural waste and nitrogen (N) and phosphorus (P) based fertilizers. In particular, the signs of eutrophication during this phase accelerated from ca. 1973, perhaps owing to large-scale using phosphate based chemical fertilizer around the lake at the time. A second phase of nutrient input in the most recent stage, ca. from 1982 to 2016, initiated by wastewater discharge from rapid urbanization and industrialization of the catchment, greatly enhanced the nutrient level in the lake. However, the central zone of the lake has yet to reach a phytoplankton-dominated stable state, with both algae and aquatic macrophytes tracking an increased trend in productivity driven by intermediate nutrient levels in the water of this zone.

* Corresponding author.
** Correspondence to: Z. Liu, Department of Ecology and Research Center of Hydrobiology, Jinan University, Guangzhou 510632, China.
E-mail addresses: ydzhang@niglas.ac.cn (Y. Zhang), zliu@niglas.ac.cn (Z. Liu).

https://doi.org/10.1016/j.scitotenv.2017.09.185
0048-9697/

1. Introduction

Lake Taihu basin is located in the lower reaches of the Yangtze River, which has been among the most economic developed, population dense areas of China for thousands of years (Liu et al., 2007; Qin, 2008). As part of the rapid development of the Chinese economy since the 1980s, the Lake Taihu basin area has undergone intensive urbanization, industrialization and agricultural development (Deng et al., 2016), such that it is now responsible for approximately 14% of Chinese Gross Domestic Product (GDP), despite occupying just 0.4% territorial land area (Qin, 2008). Unfortunately, the unbridled development has placed increasing demands on aquatic and terrestrial ecosystems and has profoundly affected water environment of lakes in this area (Wu et al., 2007). A variety of anthropogenic interventions including forest clearance, land reclamation, the use of agricultural fertilizers, industrial waste-water discharge and raw sewage input have been found to influence water quality (Jin et al., 1990), most obviously, accelerating eutrophication of the lake (Qin and Zhu, 2006; Dong et al., 2012). The consequences of eutrophication include excessive plant production, blooms of harmful algae, increased frequency of anoxic events, fish kills (Carpenter, 2005; Parsons et al., 2006; Naeher et al., 2012), and thereby causing a significant loss of resource functions of lakes such as water supply, aquaculture and tourism (Wu et al., 2007). Understanding the response of lake environments to human disturbance is fundamental for environmental management (Bragée et al., 2013). For example, assessing the trophic evolution of impacted lakes may provide valuable baseline information with which to inform and improve management protocols and strategies for restoration (Smol, 2008).

Organic matter (OM) in lake sediments can provide valuable information about environmental variation within and around the lake when lacking long-term monitoring data (Meyers and Ishiwatari, 1993; Routh et al., 2004; Enters et al., 2006; Routh et al., 2007; Muri et al., 2013; O'Beirne et al., 2015). Lipid biomarkers typically constitute <1% of total sediment OM and may not be representative of the total material (Meyers, 1997). However, their biogenic specificity makes them a sensitive indicator for variation in OM input over time (Meyers, 2003; Das et al., 2009; Xing et al., 2011; Xu et al., 2015). Compared to the bulk OM proxy, geochemical proxies based on lipid biomarkers provide a better understanding of various biogeochemical process, trophic state shifts, and natural or human-induced effects in lake environments (Meyers, 1997; Muri et al., 2004; Routh et al., 2009; Lu and Meyers, 2009). For example, short-chain *n*-alkanes (*n*-C15, *n*-C17 and *n*-C19), which indicate algal and photosynthetic bacterial input, might be expected to increase in abundance in sediments at times of elevated nutrient status in the overlying water (Meyers, 1997, 2003; Lu and Meyers, 2009; Xiong et al., 2010). Middle-chain *n*-alkane (*n*-C21, *n*-C23 and *n*-C25) in sediments are commonly derived from submerged and floating macrophytes (Das et al., 2009), and may exhibit a complex variation in abundances as a result of nutrient input. On the one hand, the abundance can exhibit an increasing trend because low to moderate nutrient loading favors a primary producer community dominated by submerged and floating macrophytes (Schelske et al., 2005; Brenner et al., 2006; Xu and Jaffé, 2009). On the other hand, a declining trend of the abundance was also found in lakes (He et al., 2015) when macrophyte-dominance gives way to phytoplankton-dominance at high levels of nutrient enrichment (Scheffer et al., 1993; Schelske et al., 2005; Sayer et al., 2010). The dinosterol/brassicasterol ratios in sediments reflect the variation of OM input from dinoflagellates relative to diatoms (Volkman et al., 1998; Schubert et al., 1998; Zimmerman and Canuel, 2002), which would turn to a declining trend when soil silicon input to the lake increased during catchment agricultural expansion (Zimmerman and Canuel, 2002; Zhang et al., 2015). In addition, the relative abundance of short-chain *n*-alkanes over long-chain homologues in sediment can reflect historical variation in the input of autochthonous versus allochthonous OM, which closely relates to the past nutrient status in the lake and the human-induced change in the catchment (Zimmerman and Canuel, 2002; Meyers, 2003; Lu and Meyers, 2009; Xiong et al., 2010).

Lake Changdang is the third largest lake in the Lake Taihu basin, located in the upper reaches of the catchment. The lake is important for aquaculture, tourism and transportation, and serves as a backup reservoir for drinking water for cities including Jintan and Liyang (Zhuge, 2000). During the last few decades, the lake has been polluted by agricultural fertilizers, industrial and domestic wastewater and excess feed and waste from aquaculture enclosures (Zhang et al., 2002). The average chlorophyll *a* (Chl *a*) concentrations recorded in 2009 and 2010 were up to 50 μg/L (Wang et al., 2012), equal to or higher than those in the huge, highly eutrophic body of nearby Lake Taihu, now infamous its summer blooms of cyanobacteria (Wu et al., 2007; Zhang et al., 2017). Thus, the water quality of Lake Changdang is now greatly declined, facing the threat from cyanobacterial bloom (Wang et al., 2012), but for which little is known of earlier limnological conditions, the start point and cause of eutrophication due to the limited scope and time period covered by instrumental records. In particular, the paucity of data on human modification to the lake precluded the efforts for further protection and sustainable use of the lake resource. The current study aims to garner retrospective insights into human-induced environmental change in the lake over the last 100 years by conducting a stratigraphic analysis of lipid biomarkers, BSi, nutrients and trace elements in a 50-cm sediment core. This study deepens our understanding of the process of cultural eutrophication in lakes and provides evidences for environmental assessment and designing strategies for lake restoration. Moreover, the result may also contribute to the debate on the environmental evolution of nearby Lake Taihu.

2. Methods and materials

2.1. Geographical location and sampling

Lake Changdang (31° 33′–31° 40′ N and 119° 30′–119° 37′ E) is located in the Lake Taihu basin (Fig. 1). The lake is 16.0 km in length, 5.6 km in width, with an area of about 90 km^2, a mean depth of 0.8–1.2 m and water retention time of approximately 55 days. Local hydrology is complex, with 12 connecting rivers and tributaries, largely flowing into the lake from the west and draining it to the east into Lake Gehu and from there to Lake Taihu (Wang et al., 2012). The primary inflow rivers include the Sudu, Xinjian, Xinhe, Dapu, Baishi and Houdu, and the important outflow rivers are the Huangli, Beigan and Zhonggan (Deng et al., 2016). Direct water column monitoring in Lake Changdang started in 1997, and in the period of 1997–2012 revealed a variation of the year average values for total nitrogen (TN) from 0.363 to 7.685 mg/L and for total phosphorus (TP) from 0.046 to 0.317 mg/L (Fig. 2) (Wang et al., 2012). Spatially, water quality in the central zone of the lake was much better than elsewhere (Zhang et al., 2002). The sediments in the marginal zone of the lake were strongly disturbed by direct human intervention, such as the activities in enclosure aquaculture. In contrast, the sediments in central zone of the lake, a habitat conservation area, were not influenced by human activities to a significant extent. For this reason, only one sediment core (CD-1) with length of 50 cm was collected from the central zone using an UWITEC gravity corer with a 90-mm-diameter coring tube in July 2016. Care was taken to minimize disturbance while obtaining the core. The CD-1 core was sub-sampled at contiguous 0.5 cm intervals and refrigerated at −20 °C prior to geochemical analysis and dating. Dating analysis was conducted at 0.5 cm-intervals through the core. Geochemical analysis was conducted at 1 cm-intervals for the sediments in the upper portion (0–20 cm) of the core and at 2 cm-intervals for the left.