Ecological Indicators 50 (2015) 35–43

Contents lists available at ScienceDirect

Ecological Indicators

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

Predominance of terrestrial organic matter in sediments from a cyanobacteria- blooming hypereutrophic lake

Xiaoguang Xu[a,b], Wei Li[a], Megumu Fujibayashi[a], Munehiro Nomura[a], Osamu Nishimura[a,*], Xianning Li[c]

[a] Graduate School of Engineering, Tohoku University, Aoba 6-6-06, Sendai 980-8579, Japan
[b] Department of Chemical Engineering, Tokyo University of Agriculture and Technology, Naka-cho 2-24-16, Koganei, Tokyo 184-8588, Japan
[c] School of Energy and Environment, Southeast University, Nanjing 210096, PR China

ARTICLE INFO

Article history:
Received 2 June 2014
Received in revised form 13 October 2014
Accepted 21 October 2014

Keywords:
Organic matter
Source identification
Fatty acid biomarker
Hypereutrophic
Lake Taihu

ABSTRACT

Although an understanding of the quantity and quality of sedimentary organic matter (SOM) pools is necessary to design sound environmental management strategies for lacustrine systems, the characterization of organic matter sources and the assessment of their relative contributions to eutrophic and inland lake sediments remain insufficient. In this study, the contribution of potential organic matter sources to sediments in shallow and hypereutrophic lake Taihu, China was assessed on the molecular level using source-specific fatty acid biomarkers. The results indicated that SOM was composed mainly of terrestrial plants with a maximal contribution of 45.3 ± 2.4% to the total organic carbon, which accounted for approximately 66% among the determined organic matter sources. Evidence suggests the terrestrial plants remained in a fresh state in surface sediments: the correlation ($R^2 = 0.62$, $p < 0.05$) between bacterial and terrestrial plant carbon was strong. On the other hand, aquatic plant and bacterial carbon contributed 5–15% to the total organic carbon, which was followed by the faint contribution (<5% of total organic carbon) of algae-derived organic carbon including cyanobacteria, diatoms, and dinoflagellates. The results provided details of the contributions of SOM sources, illustrating the usefulness of fatty acid biomarkers in discriminating organic matter sources within lake environments. Although organic matter sources of sediments varied in spatial and temporal patterns, the strong correlation between terrestrial plant and total organic carbon ($R^2 = 0.60$, $p < 0.05$) indicates that terrestrial plants were the dominant source in lake sediments.

1. Introduction

Lake sediments generally receive organic matter from allochthonous (e.g., terrestrial plants, riverine inputs, and anthropogenic sources) and autochthonous sources (e.g., phytoplankton and microphytobenthos). A detailed breakdown of the sources and composition of SOM in shallow lake ecosystems is very important as it is related to current environmental problems such as the occurrence of eutrophication, the reduction of aquatic plants and the decline of benthic animals (Omesová and Helešic, 2010; Schultz and Urban, 2008; Wijck et al., 1992). On one hand, the degradation of SOM accompanied by the release of nutrients is a major contributor to the eutrophic state; on the other hand, the habitat for aquatic plants and the food quality of benthos are significantly influenced by the sources and composition of SOM. Recent studies about the origin of sediments have mainly focused on the estuarine, coastal and marine ecosystems (Cook et al., 2004; Dubois et al., 2012; Dunn et al., 2008; Hu et al., 2006; Woszczyk et al., 2011), whereas information from eutrophic lakes, as well as from large and shallow lakes, is scarce.

In eutrophic lakes, endogenous organic matter is overwhelming dominant, and this is particularly true of phytoplankton. One of the most typical cases of hypereutrophic lakes around the world is the large and shallow lake Taihu in China, with its characteristic hydrology and hypereutrophic state (Chen et al., 2008). Heavy blooms of *Microcystis* have occurred annually over the past few decades, and were most pronounced from spring to autumn, with maximal chlorophyll-*a* (Chl-*a*) concentrations of up to 1 mg L^{-1} during prolonged hypoxic/anoxic events (Qin et al., 2007, 2010). When the deposition of *Microcystis* colonies after they collapse occurs rapidly and in large amounts, the sediment system is unable to tolerate it. The balance between microbial degradation and

* Corresponding author. Tel.: +81 22 795 7470; fax: +81 22 795 7471.
E-mail address: osamurajp@gmail.com (O. Nishimura).

http://dx.doi.org/10.1016/j.ecolind.2014.10.020

continuous inputs becomes tilted toward the latter (i.e., accumulation). Additionally, one of the most vital factors that promote the ecological success of *Microcystis* is its biphasic life cycle, which includes pelagic and benthic stages. In the aftermath of groundbreaking research by Preston et al. (1980), who reported that bloom-forming cyanobacterium *Microcystis aeruginosa* overwintered on sediment surface, numerous studies have indicated that *Microcystis* can survive in the sediment anywhere from a few days to more than six years (Latour et al., 2007; Misson et al., 2012). In addition to these widely varying time scales, the spatial distribution and preservation of *Microcystis* has also been determined, with some reports reporting it as a surface sediments and others placing it depths of up to 10–12 cm (Rinta-Kanto et al., 2009). These observations indicate that cyanobacterial organic matter is likely to be a large accumulation in sediments because of the contributions from benthic and pelagic die-off cyanobacteria. However, the nature of relative recalcitrance and the longtime persistence in the bottom of lakes, which has been received a great amount of attention in intensive studies (Carpenter et al., 2005; Devesa-Rey and Barral, 2012; Pace et al., 2004; Tam et al., 1990), suggests that exogenous organic matter by catchment exports also should not be underestimated. In the case of lake Taihu, the drainage basin covers an area around 36,500 km^2 with more than 200 input sources and 7.6 billion m^3 discharged water each year ranging from streams to canals and rivers (Chen et al., 2003). Large amounts of terrestrial organic matter are probably carried by these inflows and then accumulate in the bottom of the lake.

A number of approaches are available for estimating the contributions of organic matter from various sources to sediments. Carbon stable isotope ratios ($^{13}C/^{12}C$) have been used to evaluate the relative contributions of terrestrial and marine sources to SOM pools in many isotope studies (Cook et al., 2004; Dunn et al., 2008; Volkman et al., 2008). However, this approach is a simplification using a mixing model of two end members and gives little information about the type of marine or terrestrial organic matters. Additionally, its limitation makes it unsuitable for use in lake ecosystems since multiple organic matter sources are involved in the sediments and the differences in their stable isotope ratios are relatively small. To assess the major sources of SOM in shallow (Dunn et al., 2008) or even the deepest lake in the world (Matsumoto, 1994), fatty acids have been proven to be useful biomarkers. They are considered molecular biomarkers and it is believed they could provide insight into the detailed of SOM composition and distribution due to their structural diversity, source specificity and relative stability (Zimmerman and Canuel, 2001). Considerable studies have used fatty acids as biomarkers for cyanobacteria (Hayakawa et al., 2002), diatoms (Alfaro et al., 2006), dinoflagellates (Alfaro et al., 2006), terrestrial plants (Dunn et al., 2008), and bacteria (Rajendran et al., 1993).

To properly manage the quality of sediments in eutrophic lakes, SOM accumulation processes need to be understood and evaluating the relative contributions of potential sources is the first step. The main objectives of this study are to reveal the relative contributions of potential organic matter sources to the SOM pool and to test the relative importance of terrestrial organic matter vs. cyanobacteria in eutrophic lake Taihu using fatty acid biomarkers. The spatial and temporal variations of potential source contributions to SOM were also traced to elucidate the influence of the seasonality of riverine inflows, phytoplankton development, and meteorological conditions.

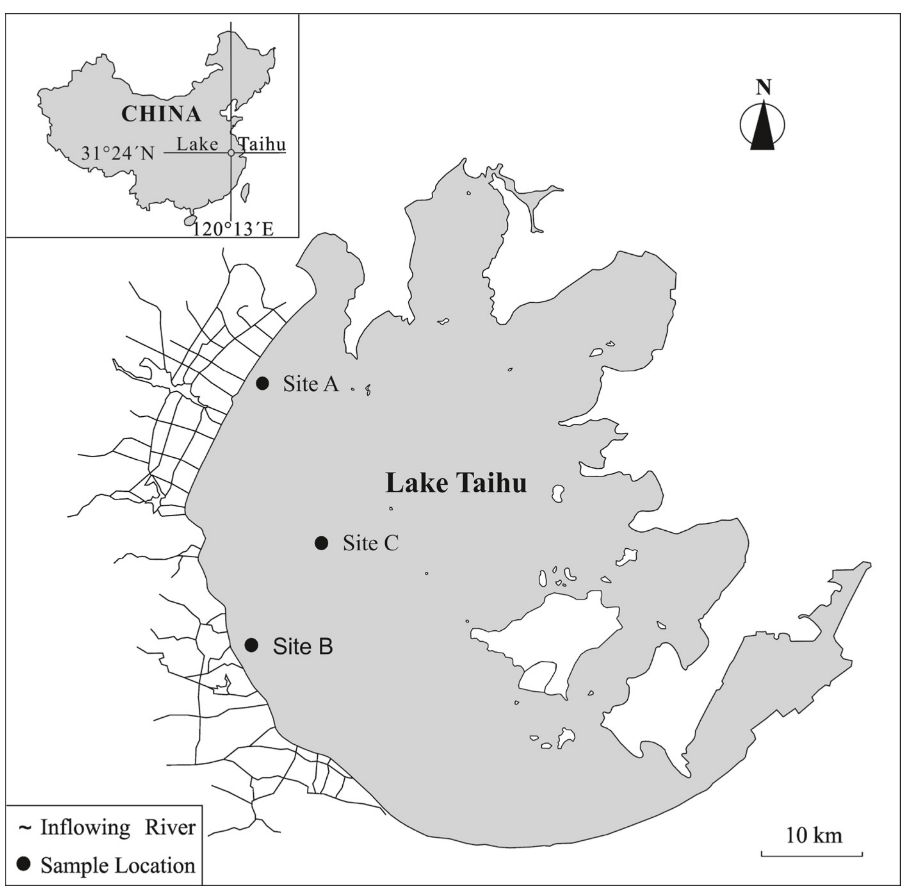

Fig. 1. Map of lake Taihu, China and the sampling sites in the western region with many nearby inflow networks.