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Response of organic carbon burial to trophic level changes in a shallow eutrophic lake in SE China

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ABSTRACT

Lakes are an important component of terrestrial carbon cycling. As the trend of eutrophication in many lakes continues, the mechanisms of organic carbon (OC) burial remain unclear. This paper aims to understand the distribution of OC and the effect of trophic level changes on OC burial in Chaohu Lake, a shallow eutrophic lake located in the lower reaches of the Yangtze River, SE China. Two hundred and one surface sediment samples (0–20 cm) and 53 subsurface samples (150–200 cm) from the lake were collected. The OC accumulation rates (OCARs) are relatively low, with an average of 10.01 g/m^2/year in the surface sediments. The spatial distribution of the OCARs is similar to that of allochthonous OC. The difference in total phosphate (TP) content between the surface and subsurface sediments (ΔTP) is significantly correlated with the autochthonous OC, suggesting that TP loading is a critical limiting nutrient for the lake's primary productivity. It is concluded that allochthonous OC is the dominant source of total OC in surface sediments compared to autochthonous OC. The primary productivity of Lake Chaohu increased due to increasing nutrient loading. However, the autochthonous OC contributed 11% of the total OC in the surface sediments. This could be ascribed to strong mineralization in the water column or surface sediments.

Introduction

Organic carbon burial in freshwater bodies is of critical concern due to its important role in global carbon cycling. Lakes are active places for producing, transporting, transforming, and sequestering organic carbon, disproportional to their spatial extent, because of the high organic carbon reserves compared to soils. It has been reported that the annual organic carbon burial in freshwater is three times higher than that in the ocean (Tranvik et al., 2009). Because of its important role in global carbon cycling, organic carbon burial in lakes is receiving increasing attention, and most of the work has focused on estimating the carbon stock at a global or regional scale and the primary driving factors behind carbon balance (Cole et al., 2007; Gudasz et al., 2010; Gui et al., 2013; Heathcote and Downing, 2012; Kortelainen et al., 2013). Organic carbon burial in lakes usually varies with climate, basin morphology, and the trophic status of the water body (Gudasz et al., 2010; Heathcote and Downing, 2012; Kortelainen et al., 2013).

The sequestration of total organic carbon in lake sediments is controlled essentially by the balance between inputs, *i.e.*, from the primary productivity and the allochthonous organic matter from its catchment, and the outputs, including

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the mineralization and outflow of organic carbon (Yu et al., 2007). Normally, small lakes in warm climates with high trophic conditions have a relatively high organic carbon burial rate (Yu et al., 2014). Eutrophication is a worldwide problem for lake systems, mainly due to the increasing nutrient load in the face of increasing human activities. However, the mechanisms of organic carbon burial in eutrophic lakes are still unclear. In North America, it was reported that the increasing nutrient load resulting from land-use changes enhanced organic carbon sequestration in lakes (Anderson et al., 2013; Heathcote and Downing, 2012). However, in the boreal zone, it was reported that nitrogen/fertility may have undermined the role of lakes in landscape carbon sequestration (Kortelainen et al., 2013). Furthermore, because previous studies have mainly focused on boreal zones and North America, more studies in other regions are needed to better understand the mechanisms of organic carbon burial in lakes (Gui et al., 2013).

The lower Yangtze River floodplain is characterized by a temperate to subtropical climate. There are a number of shallow lakes, most of which have been undergoing severe eutrophication during the past few decades due to the dense population and intensive agricultural activities. This suggests that organic carbon burial will have increased as the result of increased productivity. However, the rates of organic carbon burial in lakes of the middle and lower reaches of the Yangtze River appear to be substantially lower than those of most eutrophic lakes elsewhere (Dong et al., 2012; Gui et al., 2013). In lake surface sediments, the organic carbon (OC) either originates from in-lake primary production (autochthonous OC) or is imported from its catchments (allochthonous OC). The OC from difference sources have contrasting properties, which is reflected by their susceptibility to microbial decomposition (Gudasz et al., 2015). Generally, the sediment OC dominated by autochthonous OC mineralizes faster than that dominated by allochthonous OC (Gudasz et al., 2012). The distribution of OC sources strongly influences the dynamics and quality of OC in the surface sediment. The mechanisms of organic carbon burial in this region are still highly uncertain. In this work, Lake Chaohu, a shallow eutrophic lake in the lower reaches of the Yangtze River, was studied with the following aims: to (1) estimate the spatial distribution of organic carbon accumulation rates and organic carbon sources, and (2) identify the relationship of organic carbon and nutrient change (total nitrogen (TN) and total phosphate (TP)).

1. Study area

Lake Chaohu, the 5th largest freshwater lake and one of the three most eutrophied lakes in China (Fig. 1), is an algae-dominant lake located in the lower reaches of the Yangtze River (31°25′–31°43′ N, 117°16′–117°51′ E). The surface area of the lake is 770 km^2, with a mean water depth of 2.7 m and 50–100 cm thickness of modern lacustrine deposits (Wang et al., 2004). The area of catchment is 12,938 km^2. The catchment has a subtropical to warm temperate monsoonal climate, with an annual average temperature of 16.1 °C and annual average precipitation of 900 mm. Metamorphic, clastic sedimentary and carbonate rocks are the main components of the bedrock in the catchment (Liu et al., 2012).

Over the past 30 years, Lake Chaohu has suffered seriously from pollution due to rapid urbanization and intensive agricultural activities (Xu et al., 2005; Zhang et al., 2006). In the north-western part of the lake, a large amount of untreated domestic and industrial wastewater is discharged into the lake from Hefei, the capital city of Anhui Province, via the Nanfei River and Shiwuli River. In the south-western part of its catchment, the Fengle River and Hangbu River contribute more than 60% of the annual runoff. The Yuxi River is the only outflow, and drains into the Yangtze River at the east of the lake. In 1963, a water gate was constructed on the Yuxi River, cutting off the connection of the lake level with the Yangtze River (Zan et al., 2012). The lake catchment consists of a highly developed irrigated agricultural landscape, with rice as the staple crop, except for the steep and wooded mountains in the south-western region.

2. Materials and methods

2.1. Sampling and analytical methods

Surface sediments at a depth of 0–20 cm were taken following a 2 km × 2 km regular grid sampling procedure. Subsurface sediments (150–200 cm) were taken based on a 4 km × 4 km grid. PVC tubes with a diameter of 50 mm were inserted vertically into the lake bed to retrieve sediment samples. A total of 201 surface and 53 subsurface sediment samples were collected in 2003.

TOC measurements were conducted with the wet combustion method using a mixture of potassium dichromate and concentrated H_2SO_4, followed by titration with a standard solution of ammonium ferrous sulfate (Lu, 1999). Contents of major and minor elements in sediment samples were determined by X-ray fluorescence spectrometry using pressed boric-acid-backed pellets of bulk samples. The accuracy of determinations was validated using certified internal reference materials. The organic carbon accumulation rates (OCARs, g/m^2/year) were calculated from

$$\text{OCARs} = \text{TOC} \times \text{MARs} \quad (1)$$

where, TOC (g/kg) is the content of total organic carbon, and MARs (g/cm^2/year) are the mass accumulation rates of sediment (Alin and Johnson, 2007; Muller et al., 2005). Chronologies used to calculate MARs were based on previous work (Chen et al., 2011; Gui et al., 2013; Xue and Yao, 2011; Zan et al., 2011).

In summary, the chronology analysis in Lake Chaohu was mainly focused on the middle of the west and/or the east lake, but the whole lake MAR was not estimated. Generally, the mean MAR in the surface sediments of the western portion of the lake was 0.21 g/cm^2/year, which is slightly lower than that in the eastern part of the lake (0.24 g/cm^2/year). However, soil erosion in its catchment was significant, and a previous study estimated that 198 × 10^4 tons/year was deposited in Lake Chaohu and mainly accumulated in the southwest and southeast (Xue and Yao, 2011; Zhang and Pan, 1990) (Fig. 1b). The average whole lake MAR was 0.257 g/cm^2/year. To obtain the MARs of the siltation section, Lake Chaohu was divided