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Organic carbon burial in Chinese lakes over the past 150 years

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ABSTRACT

Organic carbon (OC) accumulation and storage in lake sediments is considered to be an important component of global C cycling. However, the storage of OC in Chinese lakes is not well constrained, and its role in future global change processes has rarely been considered. Here, we analyzed the OC burial and its correlation with lake catchment properties in Chinese lakes that have experienced heavy anthropogenic influence over the last ~150 years. We compiled OC data from sixty-four lakes from the literature. The results showed that organic carbon accumulation rates (OCARs) in Chinese lakes ranged between 1.4 and 259.5 g m^{-2} yr^{-1}, with a mean of 22 g m^{-2} yr^{-1} over the past ~150 years, consistent with the global estimate of the carbon burial rate in lake sediments (11–26 g m^{-2} yr^{-1}). Extrapolated to the whole country, a total of 269.5 Tg OC (ranging from 138.9 to 690.4 Tg C) was stored in Chinese lakes over the past 150 years. Spearman analysis revealed that OCARs strongly depended on lake and catchment size, precipitation, temperature, longitude, altitude and anthropogenic activities. Moreover, OCARs showed an increasing trend, especially after the 1950s, coinciding with land use changes and lake nutrient level shifts.

1. Introduction

Carbon burial in lakes has been recognized as an important carbon sink at both regional and global scales (Cole et al., 2007; Tranvik et al., 2009). Organic carbon (OC) deposited in surficial lake sediment will be mineralized to CO_2 or CH_4 by heterotrophic microbes, or buried over geological timescales (Cole et al., 2007; Ferland et al., 2014). Although lakes only cover less than 2% of the area of the sea, they are estimated to store about 30–60% as much OC per year as does the ocean (Cole et al., 2007). Thus, lakes may play a central role in the global C cycling, and increasing attention has been paid to the C burial in these inland aquatic ecosystems (e.g., Alin and Johnson, 2007; Anderson et al., 2009; Cole et al., 2007; Dean and Gorham, 1998; Downing et al., 2008; Einsele et al., 2001; Heathcote and Downing, 2012; Kastowski et al., 2011; Prairie, 2008; Sobek et al., 2009; Tranvik et al., 2009).

To date, most of the related studies have been confined to boreal areas and North America (e.g., Anderson et al., 2009; Campbell et al., 2000; Dean and Gorham, 1998; Downing et al., 2008; Kortelainen et al., 2004; Molot and Dillon, 1996; Mulholland and Elwood, 1982; Sobek et al., 2006), while less attention has been paid in subtropical and temperate regions, where the climate and lake features are completely different. Climatic zones in China shift from the tropical-subtropical and temperate monsoon regions in the east to the arid region in northwest and the frigid region of the Tibetan Plateau. There are approximately 2693 lakes with surface areas larger than 1 km^2 in China, covering 0.9% of the country's total land area (Ma et al., 2011). Therefore, lakes in China have great C sequestration potential. Previous studies have estimated that the OC burial rate in Chinese lakes ranged from 7.7 to 49.9 g C m^{-2} yr^{-1} (Dong et al., 2012; Gui et al., 2013; Lan et al., 2015; Wang et al., 2015). However, all these estimates were based on one single lake or a few lakes. The only estimate of modern OC burial in lake sediments on a national scale in China (Duan et al., 2008) was the result of upscaling from 22 lakes, using lake area data from the first nationwide lake investigation (1960s–1980s). During 2007–2012, a project aiming to investigate lakes in China gave the most recent data of lake size and number based on satellite and field

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investigations. We compiled OC data from 64 lakes in different lake regions of China and estimated the C pool over the past ~150 years based on the latest lake survey results. Furthermore, the factors controlling OC burial of Chinese lakes still remain unclear, and we also tentatively assessed the factors affecting OC burial in Chinese lakes. The objectives of this study were (1) to estimate the OC burial of lakes in different regions of China over the past 150 years and (2) to reveal the underlying mechanisms affecting the spatial-temporal variability of OC accumulation.

2. Data and methods

2.1. Study regions

Large numbers of different types of lakes are distributed throughout China. Five lake regions can be categorized according to differences in climate and geography (Ma et al., 2011), namely, the Eastern Plain Lake Region (EPLR), the Northeast Mountain and Plain Lake Region (NMPLR), the Inner Mongolian-Xinjiang Lake Region (IMXLR), the Tibet Plateau Lake Region (TPLR) and the Yunnan-Guizhou Plateau Lake Region (YGPLR) (Fig. 1). The number of lakes and lake sizes in these five lake regions are summarized in Table 1.

The average annual precipitation and air temperature are relatively high and the average altitude is usually lower than 500 m a.s.l. at the EPLR. The vast majority of lakes in EPLR (85.5%) are located in the MLYB, including four of the five largest freshwater lakes in China. EPLR is dominated by shallow lakes (the average depth of most lakes is < 5 m). Most lakes here are recently eutrophic due to agricultural and industrial development. NMPLR mainly refers to lakes in Northeast China. This lake region is situated in a temperate humid and semi-humid climate zone, and also has been subject to intensive agricultural practices, resulting in significant changes of lake area and water quality (Yang et al., 2010). IMXLR is geographically located in the arid and semi-arid areas of the northern and northwestern part of China. Most lakes are hydrologically closed saline and semi-saline lakes (Wang and Dou, 1998). Intensifying human activities such as overgrazing and agricultural irrigation in cultivated areas have led to lake shrinkage over the past several decades (Tao et al., 2015; Zeng and Wu, 2010; Zhang et al., 2011). TPLR, which has long been known as "the roof of the world" or "the third pole of the earth", is the largest lake region in China. This lake region is dominated by saline or brackish lakes, and is less influenced by human disturbance (Li et al., 1998; Ma et al., 2011; Wang and Dou, 1998). YGPLR is dominated by deep and freshwater lakes. The region is mainly controlled by the south-western monsoon. Lakes near cities or farmland have undergone serious eutrophication processes due to agricultural development and sanitary sewage discharge (Yang et al., 2010).

2.2. Dataset and analysis

For the estimation of organic carbon accumulation rate (OCAR) in Chinese lakes, a high-quality chronology-depth relationship and corresponding total organic carbon (TOC) content from sediment cores are necessary. In this study, 64 lakes (Fig. 2, auxiliary material Table S1, Table S2, auxiliary material Fig. S1, auxiliary material Fig. S2) from the five lake regions were selected. The 64 lakes were all the available lakes with available data from the published literature to meet the requirements for estimating OCAR. These lakes vary from 1.2 to 4254.9 km^2 (the largest lake is Lake Qinghai). Approximately 70% of lakes in the dataset are between 10 and 1000 km^2, and eight lakes are larger than 1000 km^2.

The OCAR for each of the selected lakes were calculated by multiplying the dry mass accumulation rates (DMAR, g cm^{-2} yr^{-1}) by the estimated TOC content. For those lakes with no DMAR data, OCARs were calculated by multiplying the linear sediment rates (LSR, cm/yr) and the porosity (φ) and the dry sediment density (ρ, g cm^{-3}) (Alin and Johnson, 2007; Gui et al., 2013; Müller et al., 2005). For lakes in which TOC content data were not available, loss-on-ignition (LOI) and organic matter (OM) were used and converted to TOC using correction factors of 0.469 (Dean, 1974) and 1.724 (Tiquia and Tam, 2000), respectively. The equations are shown as follows:

$$\mathrm{OCAR} = \mathrm{DMAR} \times \mathrm{OC}(\%) \quad (1)$$

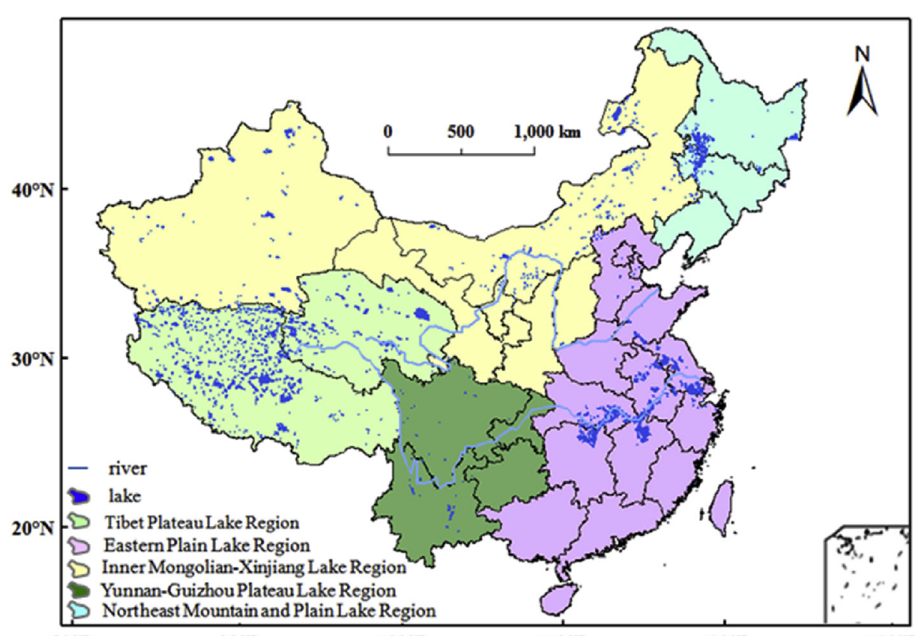

Fig. 1. The distribution of Chinese lakes.

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