Science of the Total Environment 616–617 (2018) 296–304

Contents lists available at ScienceDirect

Science of the Total Environment

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

Carbon and nitrogen burial in a plateau lake during eutrophication and phytoplankton blooms

Changchun Huang [a,b,c,*], Linlin Zhang [a,b,c], Yunmei Li [a,c,d], Chen Lin [b], Tao Huang [a,d], Mingli Zhang [a], A-xing Zhu [a,c,e], Hao Yang [a,d,*], Xiaolei Wang [f]

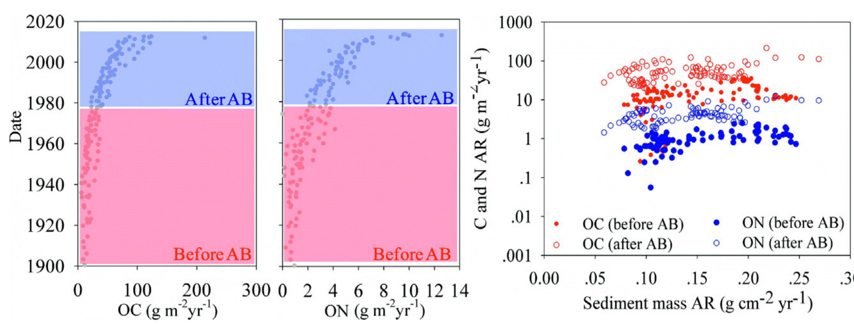
[a] Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing Normal University, Nanjing 210023, China
[b] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210023, China
[c] Key Laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing 210023, China
[d] School of geography science, Nanjing Normal University, Nanjing 210023, China
[e] Department of Geography, University of Wisconsin, Madison, Wisconsin 53706, USA
[f] School of Biochemical and Environmental Engineering, Nanjing Xiao Zhuang University, Nanjing 210046, China

HIGHLIGHTS

- Phytoplankton blooms increased the OCAR by a factor of 4.55.
- The total loss rate of TOC and TON can reach to 90% and 95%.
- The final burial rates of TOC and TON in old sediment are relatively low.

GRAPHICAL ABSTRACT

Increased OCAR and ONAR vs the sediment mass accumulation rate before and after algal blooms (AB).



ARTICLE INFO

Article history:
Received 16 August 2017
Received in revised form 29 October 2017
Accepted 30 October 2017
Available online xxxx

Editor: G. Ashantha Goonetilleke

Keywords:
Carbon cycling
Mineralization of OC and ON
Accumulation rate of OC and ON
Sediment
Dianchi Lake

ABSTRACT

Organic carbon (OC) buried in lake sediment is an important component of the global carbon cycle. The impact of eutrophication on OC burial in lakes should be addressed due to worldwide lake eutrophication. Fourteen ^{210}Pb- and ^{137}Cs-dated sediment cores taken in Dianchi Lake (China) in August 2006 (seven cores) and July 2014 (seven cores) were analyzed to evaluate the response of the organic carbon accumulation rate (OCAR) to eutrophication and algal blooms over the past hundred years. The mean value of OCAR before eutrophication occurred in 1979, 16.62 ± 7.53 (mean value ± standard deviation), increased to 54.33 ± 27.29 g m^{-2} yr^{-1} after eutrophication. It further increased to 61.98 ± 28.94 g m^{-2} yr^{-1} after algal blooms occurred (1989). The accumulation rate of organic nitrogen (ONAR) is coupled with OCAR. The high loss rate of OC and organic nitrogen (ON) leads to a long-term burial efficiency of only 10% and 5% of OC and ON. However, this efficiency can still lead to an increase in OCAR by a factor of 4.55 during algal blooms in Dianchi Lake. Dianchi Lake stored 1.26 ± 0.32 Tg carbon and 0.071 ± 0.018 Tg nitrogen, including 0.94 ± 0.23 Tg OC and 0.32 ± 0.14 Tg inorganic carbon, 0.066 ± 0.018 Tg ON, 0.002 ± 0.001 Tg nitrate nitrogen (NO_3-N) and 0.003 ± 0.001 Tg ammonium nitrogen (NH_4-N) between 1900 and 2012.

* Corresponding authors at: Department of Geography, Nanjing Normal University, Wenyuan Road 1#, Qixia District, Nanjing, Jiangsu Province, China.
E-mail addresses: huangchangchun@njnu.edu.cn (C. Huang), yanghao@njnu.edu.cn (H. Yang).

https://doi.org/10.1016/j.scitotenv.2017.10.320

1. Introduction

Lakes play an important role in the global carbon cycle via the transport, mineralization and burial of organic carbon derived from terrestrial and aquatic ecosystems. Deposited organic carbon (OC) at the water–sediment interface is either buried in the lake sediment or emitted (mineralized) as CO_2 and CH_4 into the atmosphere. Increasing carbon input is accompanied by a growing emission of greenhouse gases (Heathcote and Downing, 2012; Anderson et al., 2014; Ferland et al., 2014; Sobek et al., 2014; Weyhenmeyer et al., 2015). Previous studies have proposed that the influx of carbon in inland water from terrestrial ecosystems reaches 5.7 PgC yr^{-1} (Le Quéré et al., 2015), and the emission of CO_2 from inland water is likely to be 2.1 PgC yr^{-1} (Raymond et al., 2013). Carbon burial in sediment could increase to 1.1 PgC yr^{-1} from 0.6 PgC yr^{-1}, according to a study by Tranvik et al. (2009). The current increase of carbon burial in lake sediments may be due to human activities, global warming (Larsen et al., 2011; Xu et al., 2013; Anderson et al., 2013; Heathcote et al., 2015) and lake eutrophication, which is known to increase primary productivity and OC burial in lake sediment (Heathcote and Downing, 2012; Anderson et al., 2014). The OC accumulation rate in lake sediment also varies with the lake's morphology, trophic state, vegetation, climate and watershed (Larsen et al., 2011; Dong et al., 2012; Kortelainen et al., 2013; Anderson et al., 2014; Mendonça et al., 2016; Leithold et al., 2016).

Long-term OC accumulation (after the OC mineralization process) and permanent burial of OC in the sediment is the net result of several processes (mineralization, accumulation, etc.) and refers to burial efficiency (Ferland et al., 2014). Short-term OC accumulation (during the OC mineralization process) involves a large amount of un-mineralized OC and may not represent long-term carbon accumulation due to the time dependence of the carbon loss rate (Sobek et al., 2014). The OC mineralization process, which is a long-term process that coincides with OC accumulation, reduces the OC burial effect in sediments. The mineralization of OC is very strong during the first few years but gradually weakens and terminates after decades or centuries (Gälman et al., 2008). The OC mineralization rate has been regarded as increasing with temperature (Gudasz et al., 2010) and oxygen exposure (Sobek et al., 2009). The source of OC is another important factor that strongly controls OC mineralization and the subsequent loss of sedimentary OC, with autochthonous OC degrading at a higher rate than allochthonous OC (Gudasz et al., 2012; Watanabe and Kuwae, 2015; Chmiel et al., 2015). As the worldwide trends in lacustrine eutrophication continue, lakes may fix large amounts of CO_2 via hydrophyte photosynthesis. Meanwhile, the elevated loss rate of autochthonous carbon under mineralization will return massive amounts of carbon to the atmosphere. However, the effects of eutrophication on OCAR, as well as the effects of high carbon evasion in sediment on the increase of CO_2 in the atmosphere are still unclear. Further understanding of these processes may be useful for developing strategies to mitigate climate change (Battin et al., 2009; Hanson et al., 2015; Chmiel et al., 2016). Thus, OC burial in lake sediment has received increasing attention in the fields of geochemistry and the global carbon cycle (Sobek et al., 2014; Huang et al., 2014; Fang et al., 2014).

Many previous studies have focused on OC sequestration in different types of lakes, such as boreal lakes and lakes in the plains of Europe and the United States. The process of OC sequestration in these lakes is well understood (Battin et al., 2009; Sobek et al., 2014; Anderson et al., 2013, 2014; Isidorova et al., 2016). However, there is little acknowledgement of OC burial in sub-tropic plateau lakes, especially during the process of lake eutrophication, even though the global eutrophication of lakes has proven to be a stubborn environmental problem (Carpenter, 2005; Schindler et al., 2008; Anderson et al., 2014; Ni and Wang, 2015). The number and total area of sub-tropical lakes are second only to boreal lakes (Verpoorter et al., 2014), yet the OC cycle period in sub-tropical lakes is much shorter than in boreal lakes because of the high accumulation and loss rates of OC. This study of OC and nitrogen (N) burial in Dianchi Lake, the largest freshwater plateau lake in China, may improve our understanding of organic nitrogen (ON) and OC burial in lake sediment during the process of eutrophication and will also provide more information to accurately estimate the role of carbon sequestration in global carbon burial.

The objective of this study was to investigate variations in ON and OC burial rates in sub-tropic plateau lakes during the process of lake eutrophication and to elucidate the effects of human activities (economic development and urbanization), temperature and nutrients on ON and OC burial rates. An additional aim was to reveal the influence of mineralization on the final burial reserves of ON and OC.

2. Materials and methods

2.1. Study area

Dianchi Lake is the largest freshwater plateau lake in China. It is located in a fault depression between 24°01′ N–24°40′ N and 102°36′ E–102°47′ E on Yungui Plateau (Kunming, Yunnan Province; Fig. 1) and is shallow (mean depth of 5 m), with an area of 300 km^2. The land in the lake basin (area 2800 km^2) is mainly composed of forested, agricultural or developed land. The Haikouzi River (black arrow in Fig. 1) is the only outfall, thus the residence time of water in Dianchi Lake is 3.9 years. Kunming, the largest city on Yungui Plateau, with a population of 5.49 million and a 212.04 billion (China Yuan) gross domestic product (GDP) (statistical data from the statistical yearbook of the government of China in 2015), is located on the northern shore of Dianchi Lake. Approximately 90% of Kunming's wastewater is poured into the lake. Consequently, Dianchi Lake is severely polluted, with nitrogen and phosphorus levels of 2.37 ± 1.30 mg/L and 0.30 ± 0.14 mg/L in 2014 (unpublished data in our group). Eutrophication has been a major

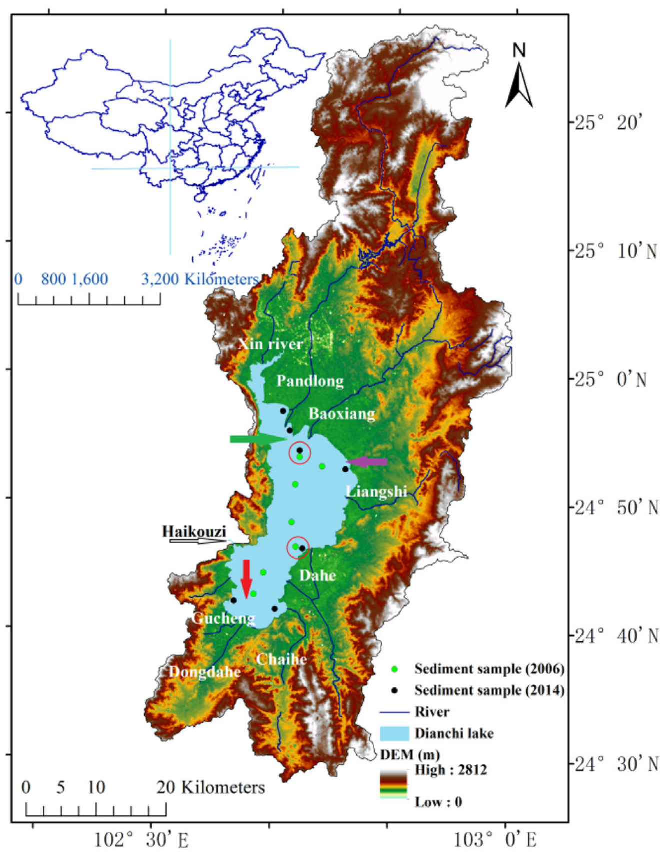


Fig. 1. Study area and sampling sites. Dianchi Basin is located on the Yungui Plateau of southwest China (blue cross in the top left corner). The dots represent sediment samples. The samples in the red circles are the coupling paired sites for 2006 and 2014.