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Global lake primary productivity and carbon source-sink processes and their impact mechanisms

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Abstract: Inland lakes, as key components of the terrestrial-ocean aquatic continuum, play an important role in the global carbon cycle. However, quantifying their productivity and carbon fluxes across different scales and types remains highly uncertain. This study integrates long-term data, field surveys, remote sensing, and modeling to assess lake primary productivity and carbon fluxes at both global and regional scales, with case studies on the Qinghai-Tibet Plateau and a subtropical region. It reveals spatiotemporal patterns and explores how lake productivity and carbon dynamics respond to climate change and human activities.

Keywords: *primary productivity; inland lake; climate change; carbon source and sink.*

1. INTRODUCTION

Inland lakes, as primary functional units of terrestrial-ocean aquatic continuum, play a crucial role in the global carbon cycle. The annual primary productivity of global lakes reached 0.41 Pg C yr-1, 0.15 Pg C yr-1 buried in lake sediments and 0.32 Pg C yr-1 emitted into the atmosphere. However, there exists significant uncertainty in quantifying the productivity and carbon fluxes of lakes at different scales and types. Under global change, both natural and anthropogenic factors contribute to the complexity of CO_2 production and emissions processes, affecting the carbon source-sink dynamics of inland water bodies. Therefore, a comprehensive understanding of driving mechanisms of lake productivity and carbon source-sink dynamics is essential for achieving terrestrial ecosystem carbon neutrality.

2. METHODOLOGY AND RESULTS

This study, employing long-term data collection, field sampling, experimental analysis, remote sensing techniques, and model simulations, using global and two regional case studies (the Qinghai-Tibet Plateau and a subtropical region), comprehensively assesses global and regional-scale lake primary productivity and carbon fluxes. It also elucidates the spatiotemporal distribution patterns of lake primary productivity and carbon fluxes, and analyzes the response mechanisms of global and regional-scale lake primary productivity and carbon source-sink dynamics to anthropogenic activities and climate change. The main research progress are as follows:

(1) In the 2010s, global lake primary productivity (PPeu) (2.07±0.12 g C m-2 d-1) was significantly larger compared to the 2000s (1.71±0.11 g C m-2 d-1) and has continued to accumulate. Economic development has significantly contributed to increases in global lake temperatures and total phosphorus concentrations, thus stimulated increases in annual lake C productivity (i.e., from 1.53 Pg C yr-1 in the 2000s to 1.95 Pg C yr-1 in the 2010s). However, lakes with larger total phosphorus (TP) concentrations had significantly greater PPeu (3.16 g C m-2 d-1). Although lake water TP concentrations can reach 1 mg L-1, the global tipping point when peak (PPeu) was reached was 0.5 mg L-1. We show that exploiting the carbon sink potential of lakes requires knowledge of the environmental tipping points that control metabolic processes, but there is a lack of effective monitoring and evaluation of the highly heterogeneous and diverse autotrophic carbon fixation processes in inland waterbodies.

(2) Lake CO_2 exchange flux rates on the Qinghai-Tibet Plateau (QTP) show significant temporal differences where those in the 2000s and 2010s were significantly higher compared to the 2020s. Annual total CO_2 emission flux from QTP lakes has increased from 1.60 Tg C yr-1 in the 2000s to 6.87 Tg C yr-1 in the 2010s before decreasing to 1.16 Tg C yr-1 in the 2020s. Since 2000, the annual average primary productivity of lakes on the Qinghai-Tibet Plateau has fluctuated within the range of 0.48 to 0.62 g C m-2 d-1. Therefore, owing to the high uncertainties in the estimation of C exchange flux, the QTP lake C sink capacity has been largely underestimated.

(3) In the subtropical region, the spatial and temporal heterogeneity of phytoplankton primary productivity in a floodplain lake (Poyang Lake) varied significantly, fluctuating within the range of 0 to 1.52 g C m-2 d-1. During periods of high water levels, phytoplankton primary productivity was notably higher compared to other phases. From wet seasons to dry seasons, Poyang Lake acted as a steady carbon source. When accounting for the

drawdown zone, however, the whole floodplain-lake system shifted from a carbon source to a carbon sink. It is therefore necessary to integrate the drawdown zone into lake system qualification processes to ensure steady carbon source and sink states.

3. CONCLUSIONS

The average annual primary productivity of phytoplankton in lakes located in the subtropical regions of the Northern Hemisphere reaches 1.86 ± 0.14 g C m-2 d-1, which is generally higher than the mean primary productivity in QTP lakes and in the low-altitude floodplain lakes within the same latitudinal range. Over the past 20 years, QTP lakes have typically acted as C sources, although C emission fluxes have been gradually decreasing. However, considering the impact of ice-covered periods, some lakes on the QTP may have the potential to transition into C sinks. In low-altitude regions, the C source-sink characteristics of the floodplain lake vary significantly with seasonal and hydrological changes: it acts as a C source during the wet season and shifts to a C sink during the dry season. Therefore, regardless of whether in high-altitude or low-altitude regions, winter (the dry season or ice-covered period) is a critical time when C emissions are significantly reduced.

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