

Research on the Carbon and Water Cycle in Aquatic Ecosystems

Kun Sun *  and Junjie Jia

Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; jiajj.16s@igsnr.ac.cn

* Correspondence: sunk@igsnr.ac.cn

1. Introduction

Carbon (C) and water are two of the most fundamental and tightly coupled components of the earth system [1]. Inland waters play a disproportionately important role in the global C cycle despite covering only a relatively small fraction of the Earth's surface [2–4]. The movement, transformation, and storage of C in aquatic ecosystems are profoundly regulated by multiple biological, chemical, geological, and physical processes from different interfaces between land, water, and atmosphere [5,6]. The Special Issue entitled “Research on the Carbon and Water Cycle in Aquatic Ecosystems” was organized in Water to document recent advances in aquatic C cycling research under natural and anthropogenic influences. The scope of this Special Issue encompasses greenhouse gas emissions, aquatic C metabolism, hydrological regulation, nutrient cycling, C source–sink transitions, reservoir and river biogeochemistry, and multi-interface C exchange processes across diverse aquatic ecosystems.

Since the call for papers was announced, five peer-reviewed papers have been accepted for publication. Although these contributions focus on different aquatic environments and research scales, they collectively emphasize the critical role of hydrological processes, ecosystem metabolism, and environmental regulation in shaping aquatic C cycling and associated biogeochemical dynamics. The major findings and scientific implications of these studies are summarized below.

2. Overview of the Contributions

The first contribution, by Han et al. [Contribution 1], examines phosphorus sources and release potential within the water-level fluctuation zone of the Three Gorges Reservoir, China. Although the study focuses on phosphorus rather than C directly, it provides important insights into the hydrological regulation of aquatic biogeochemical processes. Using particle source fingerprinting together with phosphorus release potential analysis, the authors identified the dominant phosphorus sources in two representative water-level fluctuation zones and demonstrated that their relative contributions varied with reservoir operation periods. They further showed that phosphorus originating from slope soils exhibited the highest release potential, highlighting the importance of controlling terrestrial phosphorus inputs to protect reservoir water quality. Beyond its implications for nutrient management, the study illustrates how hydrological regulation governs elemental cycling in reservoir ecosystems, providing an important biogeochemical context for understanding C cycling in regulated inland waters.

Moving from nutrient dynamics to greenhouse gas exchange, Zhou et al. [Contribution 2] investigated the spatial and temporal dynamics of CO₂ partial pressure (pCO₂) along a mountainous river–barrier lake–reservoir continuum in the upper Minjiang River, China. Based on



Received: 15 July 2026

Accepted: 31 July 2026

Published: 3 August 2026

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high-frequency field observations, the study demonstrated that river reaches consistently functioned as atmospheric CO₂ sources, whereas the downstream reservoir exhibited pronounced seasonal shifts between source and sink. The study further identified the environmental factors associated with these variations and demonstrated that transitions along the aquatic continuum substantially influenced atmosphere–water CO₂ exchange. These findings improve our understanding of C cycling in regulated river basins and provide valuable evidence for refining regional C budgets.

Complementing these freshwater studies, Bezhin et al. [Contribution 3] extended the perspective to marine environments by investigating the distributions of radionuclides (²¹⁰Pb and ²¹⁰Po) in the Sea of Japan, the Sea of Okhotsk, and the northwestern Pacific Ocean. Using radionuclide disequilibrium as a tracer of particle export, the authors quantified suspended particulate matter (SPM) and particulate organic carbon (POC) fluxes across contrasting oceanic environments. Their results identified distinct sedimentation and recycling regimes between productive coastal waters and oligotrophic open-ocean regions and provided the first estimates of POC export for the Sea of Okhotsk. These findings improve our understanding of the biological pump and demonstrate the importance of particle transport processes in regulating long-term C sequestration within marine ecosystems.

Recognizing that aquatic C cycling is also influenced by atmospheric processes, Tona and Demir [Contribution 4] investigated long-term trends in atmospheric acidifying pollutants and their potential impacts on aquatic C stability in the Konya province of Türkiye. The study revealed increasing trends in nitrogen oxides and air temperature and discussed their potential implications for aquatic C cycling in this semi-arid region. By highlighting possible linkages between atmospheric forcing and aquatic C dynamics, the study emphasizes the importance of integrating atmospheric processes into C budget assessments across the land–ocean aquatic continuum.

The final contribution, by Guo et al. [Contribution 5], investigated diel CO₂ and CH₄ exchange across different aquatic vegetation habitats in a shallow subtropical lake using continuous high-frequency measurements. The study revealed pronounced diel variability in greenhouse gas fluxes, with enhanced daytime CO₂ uptake and elevated nighttime CH₄ emissions, while demonstrating that aquatic vegetation exerts distinct controls on greenhouse gas exchange. These findings highlight the importance of incorporating both vegetation heterogeneity and diel variability into estimates of lake–atmosphere greenhouse gas exchange and aquatic C budgets.

3. Conclusions

Taken together, the studies published in this Special Issue provide valuable insights into the coupled dynamics of C and water cycling across diverse aquatic ecosystems, including shallow lakes, mountainous rivers, and large regulated reservoirs. Despite spanning different environments and research scales, they collectively reinforce several common perspectives. First, hydrological processes serve as a primary regulator of aquatic biogeochemistry by controlling material transport, residence time, and biogeochemical transformations. Second, biological processes—including ecosystem metabolism, vegetation dynamics, and the biological pump—play fundamental roles in determining whether aquatic ecosystems function as C sources or sinks. Third, advances in observational approaches, such as high-frequency monitoring, isotope tracers, and long-term environmental datasets, are substantially improving our ability to quantify dynamic C processes and reduce uncertainties in aquatic C budgets.

Nevertheless, important challenges remain. Future research should strengthen integrated observations across the entire land-to-ocean aquatic continuum, combine field

measurements with remote sensing and Earth system modeling, and further investigate the coupled cycling of C, nutrients, and water under changing climatic and anthropogenic conditions [7]. Particular attention should also be paid to the impacts of extreme hydrological events, reservoir regulation, land-use change, and ecosystem restoration on aquatic C dynamics [8]. Such interdisciplinary efforts will be essential for narrowing uncertainties in regional and global C budgets and for supporting sustainable management of aquatic ecosystems under future environmental change.

As Guest Editors, we sincerely thank all authors for contributing their high-quality research to this Special Issue. We are equally grateful to all reviewers for their thoughtful evaluations and constructive suggestions, which greatly improved the quality of the published papers. We hope that this Special Issue will serve as a valuable reference for researchers investigating aquatic biogeochemistry, hydrology, and C cycling, and that it will stimulate further interdisciplinary studies on the interactions between C and water across the land-to-ocean aquatic continuum.

Author Contributions: Conceptualization, K.S.; investigation, J.J.; writing—original draft preparation, K.S.; writing—review and editing, J.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: All the individual authors are acknowledged for their contributions in this Special Issue.

Conflicts of Interest: The authors declare no conflicts of interest.

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