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ORIGINAL ARTICLE

Effects and underlying mechanisms of damming on carbon and nitrogen cycles and transport in rivers of Southwest China: project introduction

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Abstract Southwest China is the primary area for damming rivers to produce hydroelectric energy and store water. River damming has changed hydrodynamic, chemical, and biological processes, which are related to sinks and sources of greenhouse gases and carbon and nitrogen fluxes of different interfaces. Here, I provide an introduction to a river damming-related foundation, the National Key R&D Program of China (2016YTA0601000). Supported by the foundation, we carried out research on multi-processes/multi-interfaces of carbon and nitrogen biogeochemical cycles in a dammed river system and have produced important results, as presented in this issue of the journal.

Keywords Damming · Carbon and nitrogen cycles · Southwest Chinese rivers

Rivers contribute a lot of nutrients to the ocean via their pivot position between terrestrial and marine ecosystems, thus playing an important role in the global material cycle. For decades, human society's demand for hydropower and water resources has accelerated the development and utilization of rivers. The unprecedented scale of damming and intercepting has had an environmental impact that gradually developed from a regional to global scale. Damming not only changes the watershed topography and the hydrological and ecological processes of rivers but also disturbs the original carbon and nitrogen cycle processes and flux balance between the land and sea, resulting in global scale environmental aftereffect.

In the past decade, greenhouse gas emissions from reservoirs located in polar and tropical regions—and their global estimation—have attracted special attention because of the carbon effect caused by damming interception. While the environmental impact of hydropower production is widely debated, the carbon emissions of reservoirs are exaggerated. Studies have shown that there is clear temporal and spatial heterogeneity in the carbon effect of the reservoir. However, the scientific community lacks a comprehensive understanding of the carbon effect of reservoirs. In addition, the absence of standardized measurement techniques and evaluation methods has further limited the accumulation of knowledge on the carbon emissions from reservoirs. The International Hydropower Association (IHA) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) first launched the "greenhouse gas program of freshwater reservoirs" a few years ago, which promoted a comprehensive and systematic global study of greenhouse gases from reservoirs. The carbon effect of river interception is also characterized by the carbon burial of the reservoir. The conservative estimate of this flux is 40–50 Tg $year^{-1}$ (estimated from Vörösmarty et al. 2003), which may be similar to the estimation of carbon emissions from reservoirs (Barros et al. 2011). These estimates indicate that there remains uncertainty regarding the quantities of carbon emissions from reservoirs.

In addition, in the aforementioned global carbon cycle study, the carbon cycle process of terrestrial hydrological systems has been ignored. A re-evaluation of this process is

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therefore needed. It is estimated that the total carbon output in the terrestrial hydrological system is nearly twice as high as the total carbon input (2.70 Pg C $year^{-1}$) (estimated from Regnier et al. 2013; Battin et al. 2009; Aufdenkampe et al. 2011; Tranvik et al. 2009). Moreover, the carbon exchange between water and gas is always neglected in carbon cycle calculations, with the most recent estimate being 2.10 Pg C $year^{-1}$ (Raymond et al. 2013)–3.28 Pg C $year^{-1}$ (Aufdenkampe et al. 2011), which is much higher than the carbon flux from rivers into the sea. The imbalances between the total carbon output and input are probably due to the lack of accurate quantification of the carbon flow path and intensity in the river system, and the strongly disturbed river processes caused by damming interception in the past few decades. The carbon cycle process of inland water should be further studied to reconstruct the carbon balance with a comprehensive consideration of a variety of factors and processes. Thus, the combination of SCOPE and IGBP research programs, named the "Global Carbon Program (SCOPE-13)", specifically set up a project entitled, "freshwater cycle of carbon". However, the current research on this key topic is still relatively limited.

Nitrogen is one of the key nutrients that affect terrestrial and marine ecosystems. At present, the quantity of anthropogenic active nitrogen emissions (mainly from industrial nitrogen fixation and fossil fuel combustion) has been comparable with that of natural nitrogen fixation (Kulkarni et al. 2008). This process leads to the nitrogen saturation of terrestrial hydrological systems. The rapid increase in the active nitrogen flux from rivers into the sea results in various environmental problems afflicting coastal areas (e.g., water acidification, water eutrophication, and N_2O release). The nitrogen cycle process of the river is further complicated by damming interception. The reservoir acts as a "converter" for the river's transport of material, developing a critical interface with a significant difference from that of rivers. The effects of damming interception on the nitrogen cycle are not only manifested in nitrogen flux changes but are also reflected by the transformation of nitrogen forms around the interface associated with the N_2O release and the environmental behavior of nitrogen. It is estimated that the particulate nitrogen output is reduced by 1 to 1.5 Tg $year^{-1}$ because of the damming interception, and only 30%–40% of the "new nitrogen" from anthropogenic sources are transported by rivers into the ocean each year (Seitzinger et al. 2010). In addition to the nitrogen accumulation in the terrestrial ecosystem, the storage and transport of nitrogen caused by the damming interception of reservoirs may be a key factor in creating the imbalance of "new nitrogen". The current understanding of the processes of nitrogen retention and loss in the impounded river system is limited, especially in cascade developing rivers in which nitrogen may show more complex accumulation or magnification effects due to the associated relations among water quantity, water power, and material transport.

The environmental after-effects of damming interception include the release of greenhouse gases, carbon burial and the flux changes of carbon and nitrogen from rivers into the sea. The essential end-result of these effects is a change in the law of material circulation. However, the current understanding of the key processes and cumulative effects of cascade reservoirs is still very limited, which makes it difficult to accurately grasp the material circulation law of carbon and nitrogen under damming. This, in turn, hinders our ability to deliver scientific answers to the question of what the carbon and nitrogen effects of reservoirs are, and what significance these effects have in global change; moreover, it is difficult to find effective countermeasures for the above problems in time. Future research for this topic should start from the case analysis of a single reservoir and then systematically build towards integrating research on cascade reservoir groups in a river basin. According to the detailed description of coupled carbon and nitrogen cycle processes, the interaction mechanisms between the interface of carbon and nitrogen in the biogeochemical cycle processes in the reservoir could be further revealed and mathematically quantified. A comprehensive model of integrated hydrological processes and biogeochemical cycle processes could then be established to assess its global change effects.

The essential end-result of the environmental aftereffect caused by damming interception is a change in the law of material circulation. The current understanding of the key processes and cumulative effects of cascade reservoirs is still very limited, which makes it difficult to accurately grasp the material circulation law of carbon and nitrogen under damming. In addition, what extent does this process affect material and energy transmission between land and sea, with carbon and nitrogen at its core, and how will it influence global environmental change? Such studies on global change have yet to be explored. This is also a great hindrance to developing scientific answers to the question of what the reservoirs' carbon and nitrogen effects are, and what their significance to global change is. Thus, effective countermeasures cannot be put forward in time. The forthcoming development orientation for this topic will switch from the case study of a single reservoir to the integration of cascade reservoirs in a river basin. Using the detailed description of coupled carbon and nitrogen cycle processes, the interaction mechanisms between the interface of carbon and nitrogen in the biogeochemical cycle processes in reservoirs could be further revealed and mathematically quantified, so that a comprehensive model of integrated hydrological processes and biogeochemical cycle processes can be established to assess its global change effects. As described below, there are three key scientific problems in this research field: biogeochemical mechanisms of multi-interface carbon and nitrogen cycles in different types of river-reservoir systems; quantitative identification of carbon and nitrogen flux variability in rivers following impacts of different reservoir types;and the impacts of the southwest China reservoir on carbon and nitrogen interception, greenhouse gas emission and mass transport in the Yangtze and Pearl River basins, as well as an assessment of its significance to global change.

In 2016, the national key research and development plan, "global climatic change and response," approved a research project on the river interception's influence mechanism and effect evaluation on the carbon and nitrogen cycles and transport in southwest China (No. 2016YFA0601000). Professor Xiao Huayun is in charge of the study plan, and the excellent academic members in this research plan are mainly from Tianjin University, Shanghai University, Hohai University, Wuhan Botanical Garden (Chinese Academy of Sciences), Institute of Geochemistry (Chinese Academy of Sciences), and Institute of Geographic Sciences and Natural Resources Research (Chinese Academy of Sciences). The project will be carried out from July 2016 to June 2021.

The following are the main scientific objectives of the project: (1) to reveal the key process evolution of carbon and nitrogen biogeochemistry in different types of reservoirs in southwestern China, and its multi-process coupling mechanisms at the basic theoretical level; (2) in support of the quantitative assessment, develop the ecohydrological models of the carbon and nitrogen cycles in reservoir-river systems, and its coupled models with biogeochemical cycles, to enhance the simulation and prediction of environmental effects of southwestern large-scale water conservancy projects; (3) in support of ecological regulation, propose the optimal control strategies of cascade reservoirs to reduce the negative impacts of reservoir dams on the basin's ecological environment and (4) in support of meeting national demand levels, provide the research cases and reserve policy for the scientific assessments of change trends in the catchment greenhouse effects, the carbon sink potential of damming interception in China, and the scientific basis for national participation in global climate control and international climate negotiations.

The project targets the southwestern river-reservoir system in the Yangtze River and the Pearl River based on the above scientific issues and objectives, and the following three main research areas will be addressed: (1) carbon and nitrogen transport and transfer characteristics, as well as the control mechanisms in impoundment rivers; (2) the dynamic processes of the source and sink patterns, as well as income and expenditure changes of carbon and nitrogen in impounded rivers; and (3) the environmental impacts and global change significance of the material cycle variations in impounded rivers. In brief, 12 different types of reservoirs, classified according to water retention time (as the main variable), will be comprehensively analyzed to study the biogeochemical mechanisms of multi-interface carbon and nitrogen cycles in different types of river-reservoir systems and its coupled modes with hydrological processes. The study is expected to accurately characterize the mechanism of how multi-stage dam interception changes the key processes of carbon and nitrogen biogeochemistry. An estimate of the total budget of carbon and nitrogen in water storage rivers, and an identification of the influence of water conservancy projects on the amount of riverine carbon and nitrogen fluxes into the sea, could be achieved through the cross-section control of the main stream and tributaries of the Yangtze River and Pearl River, and combining the hydrological ecological model and the river Strahler classification model. This will not only make a significant contribution to effectively evaluating and predicting the impacts of dam interception on global change but also provide research cases and reserve policy for scientific assessments of change trends in greenhouse gas emissions and the carbon sink potential of damming interception in southwest China. Based on these results, eco-hydrological models of carbon and nitrogen cycles, and its coupled models with biogeochemical cycles, can be built into reservoir-river systems, which may significantly enhance the ability to simulate and predict the environmental effects of large-scale water conservancy projects in southwest China. At the same time, optimal operation strategies for reducing the negative impacts of reservoir dams on basin ecosystems will be proposed to provide the scientific basis for the national participation in global climate regulation and international climate negotiations and to pave the way to build a regional response to global change and development sustainably.

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References

Aufdenkampe AK, Mayorga E, Raymond PA, Melack JM, Doney SC, Alin SR, Aalto RE, Yoo K (2011) Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere. Front Ecol Environ 9:53–60

Barros N, Cole JJ, Tranvik LJ, Prairie YT, Bastviken D, Huszar VLM, del Giorgio P, Roland F (2011) Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. Nat Geosci 4:593–596

Battin TJ, Luyssaert S, Kaplan LA, Aufdenkampe AK, Richter A, Tranvik LJ (2009) The boundless carbon cycle. Nat Geosci 2:598–600

Kulkarni MV, Groffman PM, Yavitt JB (2008) Solving the global nitrogen problem: it's a gas! Front Ecol Environ 6:199–206

Raymond PA, Hartman J, Lauerwal R, Sobek S, McDonald C, Hoover M, Butman D, Strieg R, Mayorga E, Humborg C, Kortelainen P, Durr H, Meybeck M, Ciais P, Guth P (2013) Global carbon dioxide emissions from inland waters. Nature 503:355–359

Regnier P et al (2013) Anthropogenic perturbation of the carbon fluxes from land to ocean. Nat Geosci 6:597–607

Seitzinger SP, Mayorga E, Bouwman AF, Kroeze C, Beusen AHW, Billen G, Van Drecht G, Dumont E, Fekete BM, Garnier J, Harrison JA (2010) Global river nutrient export: a scenario analysis of past and futuretrends. Glob Biogeochem Cycles 24:GB0A08. doi:10.1029/2009GB003587

Tranvik LJ, Downing JA, Cotner JB, Loiselle SA, Striegl RG, Ballatore TJ, Dillon P, Finlay K, Fortino K, Knoll LB, Kortelainen PL, Kutser T, Larsen S, Laurion I, Leech DM, McCallister SL, McKnight DM, Melack JM, Overholt E, Porter JA, Prairie Y, Renwick WH, Roland R, Sherman BS, Schindler DW, Sobek S, Tremblay A, Vanni MJ, Verschoor AM, von Wachenfeldt E, Weyhenmeye GA (2009) Lakes and reservoirs as regulators of carbon cycling and climate. Limnol Oceanogr 54:2298–2314

Vörösmarty CJ, Meybeck M, Fekete B, Sharma K, Green P, Syvitski J (2003) Anthropogenic sediment retention: major global impact from registered river impoundments. Glob Planet Change 39:169–190