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Editorial

Ecological indicators for aquatic biodiversity, ecosystem functions, human activities and climate change

A B S T R A C T

Inland aquatic ecosystems, such as streams, rivers, ponds and lakes, play an important role in maintaining global aquatic biodiversity and ecosystem services. They have been increasingly influenced by environmental change such as global warming, dam construction, habitat fragmentation, eutrophication and urbanization. However, our understanding of the impact of global change on aquatic biodiversity and ecosystem functions remains elusive. The aim of this special issue is to highlight the ecological indicators of aquatic biodiversity and ecosystem functions under global change. The special issue comprises 18 papers including both review and research articles. These papers cover a wide range of research topics, including testing ecological theory, environmental indicator development, biodiversity monitoring and bioassessment. By covering a broad taxonomic range from bacteria and phytoplankton to fish and spanning large spatial (much of Eurasia) and temporal scales (from one season to 25-years observations and 100-years paleo-reconstruction), these articles provide an overview of ecological phenomena from population and community perspectives. Several important implications emerged from these studies: (1) The studies of the long-term succession of biotic community provide important insights into the impacts of human activities and climatic changes on conservation and management of aquatic ecosystems; (2) Anthropogenic activities strongly affect aquatic biodiversity via modifying aquatic habitats and reducing habitat heterogeneity; (3) Biotic assemblages are valuable to for assessing the ecological status of freshwater ecosystems; (4) Aquatic ecosystems have unique characteristics different from other ecosystems, as the underlying drivers and assembly mechanisms of community structure in these ecosystems are highly distinct. Together, the selection of studies reinforces the importance of long-term monitoring, ecological indicator development, and applications of ecological theory in helping us to understand the response of aquatic biodiversity and ecosystem functioning to global change.

Environmental changes, such as climate change and human activities, are jointly causing loss of aquatic biodiversity, threatening species extinction from microscopic to macroscopic organisms in inland waters and further affecting ecosystem functions and services. The theoretical developments and methodological approaches in research on aquatic biodiversity and associated ecological indicators are evolving rapidly. It is thus important (1) to provide an overview of the new developments for up-to-date biodiversity and ecological indicator studies, (2) to integrate taxonomic, phylogenetic, and functional dimensions of biodiversity and associated indicators, (3) to understand interactions and feedbacks among these biodiversity facets, and (4) to gather interdisciplinary groups of researchers together to address complex environmental change impacts on biodiversity of different organism groups.

Originating from the 34th Congress of the International Society of Limnology held on the 19–24 August 2018, Nanjing, China, this special issue brings together researchers and conservation scientists addressing aquatic environments around the world to evaluate the state-of-the-art methods, poses key questions for aquatic biodiversity and associated indicator research and discuss the on-going directions and themes of biodiversity research in a changing world.

This virtual special issue covers 16 research articles and 2 review articles. Studies span much of Eurasia and incorporate a variety of spatial scales from a single lake or a mountain to large-scale observational studies of aquatic ecosystems (Li et al., 2020; Liu et al., 2020), of temporal scales from one season to 25-years monitoring observations (Guo et al., 2019) and to over 100-years paleo-reconstruction studies (Klamt et al., 2020; Yan et al., 2019). Eurasia covers temperate to Arctic regions, and different aquatic realms, such as streams, rivers, lakes, reservoirs and coastal habitats. These include the streams within the Cangshan Mountain, Southwest China (He et al., 2020), the low mountain streams in central Germany (Li et al., 2020), the streams and lakes in Finland (Vilmi et al., 2019) and Sweden (Pajunen et al., 2020), the freshwater lakes in a city Nanjing, China (Zeng et al., 2019), the freshwater lakes including two large lakes Lake Poyang and Lake Tai of Mideastern China (Guo et al., 2019; Liu et al., 2019; Zhang et al., 2019), the Yangtzi River in the Yangtze River Basin, China (Zhang et al., 2021), the Koshi River in Koshi River Basin, Nepal (Paudel Adhikari et al., 2019), the reservoirs in the Pearl River Basin in Southeast China (Liu et al., 2020), the medium-size lakes in Southwest China (Klamt et al., 2020; Yan et al., 2019), and the Jiangsu Coastal Zone in Mideastern China (Yu et al., 2019). These articles also consider various taxonomic groups from small to large, including bacteria (Zeng et al., 2019), diatoms (He et al., 2020; Pajunen et al., 2020; Vilmi et al., 2019), cyanobacteria (Yan et al., 2019), phytoplankton (Guo et al., 2019), zooplankton (Liu et al., 2020), macroinvertebrates (He et al., 2020; Li et al., 2020; Zhang et al., 2019), and fish (Liu et al., 2021; Tóth et al., 2019; Zhang et al., 2021), and research approaches from morphological identification (e.g., Vilmi et al., 2019) to molecular sequencing (e.g., Zeng et al., 2019). The two review articles by Gal et al (2019) and Cantonati et al (2020) address the effects of urbanization on freshwater

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macroinvertebrates, and on the combined field ecohydrogeology for integrating the disciplines of ecology and hydrogeology in studying groundwater-dependent ecosystems, respectively.

To facilitate the conservation and management of these aquatic ecosystems, the studies of the long-term succession of biotic communities could provide important insights into the impact of human activities and climatic changes on biodiversity. Based on 3-years observational datasets in Lake Poyang, Liu et al. (2019) showed the influence of water-level fluctuation on seasonal variations in phytoplankton total biomass, taxonomic and functional composition though direct (i.e., biomass dilution and mixing) and indirect effects (i.e., nutrient dilution and underwater light availability). Similarly, Guo et al. (2019) found that the phytoplankton community in Lake Tai shows significant temporal variation from 1992 to 2017 using the routinely limnological monitoring data and that the variance is explained by nutrient (i.e., ammonium, nitrate and phosphate) and climatic (i.e., air temperature and wind speed) variables. The authors further demonstrated the important roles of climatic factors in shaping the phytoplankton community and cyanobacterial blooms. When there is a lack of long-term monitoring data, reconstructing records of aquatic organisms from lake sediment using paleolimnological approaches provide an alternative to explore the impacts of climatic change and human activities in the long-term monitoring programs. For instance, Klamt et al. (2020) reconstructed the succession of phytoplankton community during the past 70 to 100 years in two lakes, and found that the historical events including extreme drought event and eutrophication are accompanied by the variations in the diatom community and homogenize their composition over time. Paleolimnological data further showed that the elevated cyanobacterial biomass during the past 100 years is closely linked with the increase in historical human activities such as nutrient inputs (Yan et al., 2019).

Anthropogenic activities strongly affect aquatic biodiversity by modifying aquatic habitats and reducing habitat heterogeneity. Tóth et al. (2019) investigated the stream fish community structure and diversity in three characteristic land use types (i.e., protected, agriculture and urban landscapes), showing that land use categories are poor predictors whereas local environmental gradients influence the community independently of land use type. Furthermore, regardless of significant heterogeneity among different case studies, Gál et al. (2019) in their *meta*-analysis found that urbanization has an overall negative effect on the diversity of macroinvertebrates in lotic ecosystems. Liu et al. (2020) also found that rapid urbanization enhances the process of homogenizing zooplankton communities in tropical reservoir ecosystems. Yu et al. (2019) evaluated the impact of human activities on five biological components (i.e., phytoplankton, microzooplankton, macrozooplankton, macrobenthos and nekton) along offshore areas in Jiangsu, China, highlighting the importance of protected areas in maintaining biodiversity values. Through scenario simulation and field sampling, Zhang et al (2021) demonstrated that the hydropower operation of the Three Gorges Dam impacts the spawning activities of the four main domestic carp species and Chinese sturgeon, with the spawning time advances by 1.3 days for the former and delays by 2.1 days for the latter, and that climate change adds to these negative impacts. In addition, Zeng et al (2019) found that eutrophication enhances the contribution of stochastic processes in controlling bacterial community assembly in the water and sediments of shallow lakes.

Increasing human activities and climate change highlight the importance and urgency of reliable assessments of the ecological status of freshwater ecosystems. Biotic assemblages reflect the environmental conditions and are used widely in bioassessment. Zhang et al. (2019) developed a macroinvertebrate-based multimetric index, comprising of three taxonomic and two functional metrics, to assess the influence of eutrophication on the ecological status of shallow lakes. Pajunen et al. (2020) developed a predictive model using diatom assemblage data as indicator of water chemistry (i.e., pH and total phosphorus) and climatic factors (i.e., growing degree days). The reliability of diatoms has more predictive power across regions owing to numerous factors, including region-specific differences in species realized niches, the compositions of species pools and the local adaptation of species.

Aquatic ecosystems have remarkable characteristics that distinguish them from terrestrial ecosystems; therefore, the underlying drivers and assembly mechanisms for biotic assemblages are distinct from different ecosystems. Adhikari et al (2019) investigated both the particle-associated and free-living bacterial communities along the mainstreams and tributaries of the Koshi Rivers in the southern slopes of the Himalayas, showing that geographical distance and water physicochemical properties are the main drivers of variations in bacterial communities. He et al (2020) investigated the diversity of stream diatoms and macroinvertebrates in streams in the Hengduan Mountains and showed that elevation, aspect and local environmental conditions jointly determine their diversities. Li et al (2020) found that local contribution to beta diversity (i.e., a measure of ecological uniqueness of biotic communities) negatively correlates with the dispersal capacity of stream macroinvertebrates, highlighting the importance of considering metacommunity dynamics in river management and conservation practice. Liu et al (2021) found that fish community structure in middle and lower sections of the Yarlung Zangbo River on the Tibetan Plateau substantially changes along the longitudinal gradient, which is driven by biotic and abiotic factors, including altitude, channel width and macroinvertebrates density. Vilmi et al. (2019) showed that there are positive occupancy-abundance relationships for both diatoms and macroinvertebrates in the littoral zone of a large (~305 km^2) highly-connected lake system, and that niche position is the main determinant of the variations in occupancy and abundance of both groups of organisms.

In sum, this special issue incorporates various topics on the influence of human activities and climate changes on aquatic biodiversity, and examines novel ways to assess the effects of human activities on different facets of biodiversity.

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