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Editorial

Lake Management and Eutrophication Mitigation: Coming down to Earth—In Situ Monitoring, Scientific Management and Well-Organized Collaboration Are Still Crucial

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Lakes, together with rivers and subterranean aquifers, are indispensable natural resources for humans and other organisms. Globally, there are more than 100 million lakes [1], holding 87% of Earth's liquid surface freshwater [2] and covering an area of 4.2×10^6 km^2, including water bodies smaller than 1 km^2 [3]. Lakes not only play a crucial role in water supply, food production, and climate regulation [4] but also function as a cornerstone for socio-economic development.

During the last century, anthropogenic climate changes, especially seasonal climate alternations, intensified widespread use of agricultural chemicals (e.g., fertilizers and pesticides), and rapidly increasing urbanization, have dramatically changed regional watershed and hydrological patterns, exerting excessive pressure on lacustrine ecosystems [5]. As both air and water temperatures are key controlling factors of lake thermal regimes [6] and ecosystem metabolism [7], rising air temperatures and persistent nutrient input have direct effects on the physical and ecological properties of lakes [8], often resulting in nuisance algal blooms worldwide.

Harmful algal blooms affect ecosystem productivity and public health globally [9], and the costs are high. For example, primarily as a result of harm to drinking water supplies, aquatic food production, and diminished tourism, economic losses of more than a billion dollars occur annually in the United States alone [10]. During the last few years, the equivalent of tens of billions of US dollars have been allocated by the Chinese government to mitigate eutrophication of lakes. In Yunnan Province in southwestern China, conservation and pollution control of the so-called Nine Large Lakes (>30 km^2) alone has cost more than RMB 1.16 billion (~USD 180 million) during the last decade, but the situation is still serious.

For many years, scientists have spared no effort to understand algal blooms and have struggled to find effective measures to mitigate their harmful effects. Two of the main foci of the United Nations' Sustainable Development Goals are a commitment to water resources (Goal #6) and the impacts of climate change (Goal #13). These concerns are also essential components of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

People have long realized that satellites might play an important role in the scientific study and operational management of hydrology and water systems [11]. Space-based remote sensing was expected to revolutionize the monitoring of algal blooms and the water quality of large lakes [12], but it has proven difficult to draw statistically accurate pictures from such data [13]. Before the development of advanced technical equipment and practical theories, we must first focus on understanding lacustrine eutrophication and algal blooming [14]. In situ monitoring and sustained analyses of various samples are crucial, not only with respect to adequately understanding lacustrine systems themselves, but also to provide valuable background and crosschecks to ensure reliable application of advanced technologies in the future.

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Lakes themselves and their drainages involve many important systems and dynamic processes (Figure 1). Humans directly change both global and regional climate dynamics, catchment hydrological and transportation patterns and processes, lake eco-dynamics and deposition–evolution processes. Most importantly, serious disturbance of all these processes results in the shutoff of three critical interactions: depositional processes and geochemical and bio-geochemical interactions, which can lead to the deterioration or collapse of lakes' self-clarification ability and self-restoring capacity, effectively leaving them "dead."

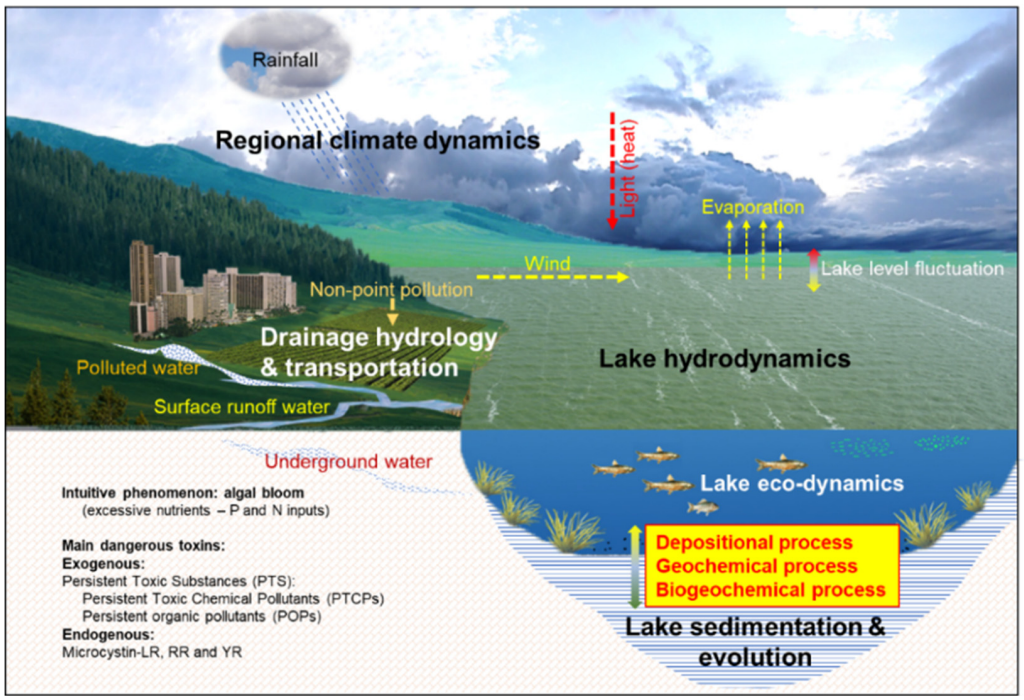

Figure 1. Watershed lake systems and main processes.

Strengthening anthropogenic environmental changes driving biodiversity loss decreases ecosystem stability [15]. Maintaining healthy biodiversity is crucial to stabilize ecosystem productivity [16–19], as greater biodiversity generally provides greater resistance to the extreme climate events [20].

Ongoing climate change is expected to accelerate hydrological cycles and thereby increase available renewable freshwater resources. However, changes in seasonal patterns and the increasing probability of extreme events may offset this effect [21]. This will inevitably induce fundamental variations in lake systems and their functions. In this expectation, we face the brutal reality that much more time and effort than expected are needed to restore polluted lakes to their health condition. In particular, (1) we must pay special attention and alert that the potential harmful effects and unrealized consequences of highly eutrophicated lake waters, e.g., novel hypertoxic viruses and new toxic chemical and organic compounds are overwhelming; (2) we should pay attention to the large long-distance trans-regional water drainage claimed to mitigate lake water pollution, as this process might result in abrupt changes in the established watershed ecosystems.

Lakes support a global heritage of biodiversity and supply key ecosystem resources. Securing a sustainable future for lakes ultimately lies in the scientific management of these treasured natural resources, and concerted efforts at the local governance through national and international levels. It is necessary to work from individual to regional clusters of lakes because the lake status varies depending upon the location, depth, area, agricultural and industrial intensity, and trophic status. "One alone is good," but only through close and

coherent collaboration can we successfully address global challenges, pursuing common goals to maintain and protect lake health synergistically.

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