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Editorial

Why Watershed Ecology?

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Water is a fundamental natural resource underpinning life, ecosystems, and human society [1]. Although freshwater bodies cover less than 1% of Earth's land surface, they support about 10% of all known animal species and one-third of all vertebrate species [2]. Freshwater ecosystems are deeply interwoven with the material, cultural, and ecological dimensions of human life [3], with more than 50% of people living within 3 km of a freshwater body [4]. However, high-intensity production and daily activities—such as dam construction, water abstraction, pollution, land development, and species introductions—have profoundly altered freshwater ecosystems across watersheds [2]. The rate of freshwater biodiversity decline now far exceeds that observed in terrestrial and marine ecosystems [5].

If the global network of water systems and their watersheds is considered a whole system, it effectively blankets the Earth's land surface. Consequently, wherever people live, they reside within a watershed. A watershed can be divided into downstream waterbodies, upstream highlands, and the intermediate riparian ecotone. People living within a watershed do not merely obtain ecosystem services from a single ecosystem (such as freshwater alone), but rather they need to acquire various ecosystem services from the entire interacting ecosystem across the watershed. To achieve sustainable development of human society, it is necessary to regulate the spatial distribution and intensity of human activities from the perspective of the catchment or watershed

Since the beginning of the 21st century, human society has faced intertwined challenges—climate change, resource depletion, and biodiversity loss—leading to severe global ecosystem degradation. The depletion and pollution of water resources, together with the continued deterioration of terrestrial and aquatic ecosystems, seriously threaten the sustained provision of ecosystem services. This poses major risks to environmental protection, human well-being, and the achievement of the United Nations Sustainable Development Goals (SDGs). Progress on key indicators such as SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 2 (Zero Hunger), and SDG 13 (Climate Action) has slowed or stalled [6,7]. In fact, the global temperature has risen by 1.1 °C. Further increases in temperature will further exacerbate these changes, and the adverse climate impacts will be more profound and extreme than expected [8,9]. 75% of the world's population lives in 101 countries experiencing sustained freshwater decline; with climate change, droughts are projected to become more frequent and severe, increasingly affecting agriculture, ecosystems, and water security. Nearly two billion people may face substantial disruptions in water availability [10–12]. Climate change and biodiversity loss are now the foremost challenges to ecosystem health and Nature's Contributions to People (NCP). By mid-century, climate change will likely surpass land-use change as the dominant driver of biodiversity loss.

Restoring biodiversity and ecosystem services, and optimizing the rational use of water and biological resources, are essential pathways to achieving the SDGs holistically. This necessitates integrated watershed ecosystem management. The diversity, spatial unevenness, and selective use of ecosystem services mean that, under the joint influence of human activity, environmental variability, and climate change, relationships among services now exhibit both trade-offs—where increases in one come at the cost of another—and synergies—where services reinforce each other [13,14]. Consequently, it is crucial to clarify material cycles, energy flows, species movement, and information exchange among ecosystems and their components [1,15,16]. Particularly important are cross-ecosystem resource subsidies—the fluxes of materials and energy that connect ecosystem processes. These form critical linkages among

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ecosystems, underpin the dynamics of ecosystem services, enable sustainable watershed management, and constitute a focal theme in meta-ecosystem research [17,18].

The meta-ecosystem concept provides a theoretical framework for examining how local and regional resource flows shape ecosystem dynamics [19]. It underscores the importance of spatial exchanges of energy and information among ecosystems for watershed- and regional-scale processes. Extensive research has yielded a rich theoretical foundation [20–26]. The next crucial step is to translate these ideas into practice. Watershed ecosystems are, by their very nature, archetypal meta-ecosystems: geographically explicit, hierarchically nested, and ideally suited for integrative research and innovation. China's "Yangtze River Simulator" exemplifies such translation. Focusing on the Yangtze River Basin and using the watershed-wide water cycle as its connective thread, the simulator integrates upper, middle, and lower reaches and links lakes, reservoirs, shorelines, and urban agglomerations. It promotes coordinated flood control, hydropower generation, and aquatic biodiversity conservation, and emphasizes harmonizing conservation and development. By integrating monitoring, modeling, assessment, early warning, decision-making, and regulation, the system couples natural and socio-economic processes and has provided significant decision support for conserving the Yangtze River and advancing China's contributions to the SDGs [27].

Since its inception, watershed ecology has consistently emphasized using the watershed as the fundamental unit for investigating the flows of matter, energy, and information among upland, riparian, and aquatic ecosystems [16,28–30]. It is a branch of ecosystem ecology well-suited to both the practical needs of integrated watershed management and the implementation of meta-ecosystem concepts. In response to the rapid environmental changes of the new century, watershed ecology—by virtue of its vantage perspective—is poised for rapid development. Future development should focus on the following topics:

1. Investigate diverse watershed patterns to elucidate the distribution of geodiversity + biodiversity within and across watersheds.
2. Conduct long-term, networked monitoring at the watershed scale and develop integrated ecohydrological models to analyze dynamic relationships among multiple ecosystems within watersheds—particularly aquatic–terrestrial linkages. Building on a clear understanding of patterns/processes, monitoring/assessment, and mechanisms, advanced research in planning/design, technology/process, and engineering/demonstration.
3. Understand coupled social–ecological interactions and assess how future socioeconomic development and climate change will affect biodiversity and ecosystem services. Ecosystem services are key nodes linking natural capital and societal development. Starting from the bidirectional feedback between nature's services and human interventions and regulation [13,31,32], elucidate the dynamics and drivers of ecosystem services within watershed meta-ecosystems.
4. Use the watershed as the operational unit to implement multiscale actions, including integrated watershed management, to protect and enhance the service functions of watershed meta-ecosystems. Given regional differences in environmental conditions and socio-cultural contexts (and their vulnerabilities), consider inter-system relationships and the linkages among human health, ecosystem health, and planetary health; build effective science–society interfaces; integrate feedback channels between social and ecological systems; and implement multiscale response actions [1,9,33].

In summary, aiming for sustainable watershed development and focusing on watershed meta-ecosystems, we should advance the integration and innovation of ecological theory from a watershed perspective and build a scientific and technological system for watershed ecological and environmental protection and management. This is the development direction of watershed ecology. Accordingly, we have established the Journal of Watershed Ecology, an international, interdisciplinary, peer-reviewed platform for sharing advances in watershed ecology and related research, policies, and methodological innovations. We also encourage watershed researchers and managers to work together to further advance the field.

Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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