

Editorial

High-Mountain Lakes, Indicators of Global Change: Ecological Characterization and Environmental Pressures

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Abstract: Though mountain lakes are generally much less influenced by human activities than other habitats, global and local anthropogenic threats can alter their natural condition. The most alarming threats are climate change, water exploitation and abstraction, alien species introduction, and the medium-long range atmospheric transport of contaminants. Moreover, tourism and mountain farming are two other major sources of organic pollutants that can pose a threat to local aquatic biodiversity. Papers submitted to this Special Issue should be original contributions, with a focus on ecological and morphological characterization, environmental pressures (i.e., alien species introduction, environmental contaminants), and the use of bioindicators/tracers to inform adequate management plans.

Keywords: environmental contaminants; climate change; hydrochemistry; alien species; biotic components; bioindicators; paleolimnology

1. Introduction

High-mountain lakes are remote and extreme ecosystems subject to harsh climatic conditions. Due to the extreme winter temperatures, only alpine prairies or sparse vegetation can grow above the tree line [1]. During most of the year (from October–November to June–July), snow and ice cover the lakes, blocking sunlight from penetrating the underlying water column [2]. Without the penetration of light, photosynthesis cannot take place and the lakes remain in darkness [3], becoming heterotrophic systems isolated from the surrounding area until the ice cover breaks. When the snow melts in early summer, the lakes quickly shift from extremely low to extremely high solar irradiance, with increasing levels of UV radiation directly correlated to altitude [4]. The light can penetrate deeply owing to the low attenuation coefficient of clear water [5]. The ice-free season lasts for a few months, generally from mid-June to late October. During this brief period of ideal conditions, aquatic organisms can complete their life cycle before the snow covers the lakes again.

Harsh environmental conditions limit the biodiversity of these ecosystems [6]. Starkweather [7] underlined a negative correlation between altitude and species richness: high-altitude communities have scarce resource availability, lower habitat complexity, and exist under extreme physicochemical conditions.

The hydrochemistry of Alpine lakes is conditioned by the chemical composition of atmospheric deposition and by climate factors [8,9], making them early response indicators of climate change [10], atmospheric deposition, and air pollution [11]. Though they are generally much less influenced by human activities than other habitats, global and local anthropogenic threats to mountain lakes can alter their natural condition. The most alarming threats are water abstraction and exploitation [12],

alien species introduction [13–15], climate change [9,16], and the medium-long range atmospheric transport of contaminants [17,18]. Moreover, tourism and mountain farming are two other major sources of organic pollutants that can threaten local aquatic biodiversity [19].

1.1. Water Exploitation and Abstraction

Water level fluctuation and exploitation can have huge effects on mountain-lake biodiversity [12], particularly on macroinvertebrates, planktonic communities, and littoral vegetation. Furthermore, the construction of mountain dams has favored the introduction of fish for sport fishing [12]. Moreover, water abstraction can alter the hydrological regimes of outlet rivers, with consequences for freshwater biodiversity downstream [12,20].

1.2. Climate Change

Among the ecosystems most sensitive to climate change, mountains are affected at a faster rate than other terrestrial habitats [21–23]. Increased air temperature means a shorter snow cover and an earlier snowmelt [24]. The impact of climate change poses a serious threat to ecosystem services and the organisms depending on them [23]. Temperature affects numerous aquatic ecosystem functions, influencing metabolic rate, mixing the dynamics of primary productivity and of the entire food web [25–28], and causing loss of biodiversity [29]. Rogora et al. [16] observed the negative effects on Alpine and Apennine freshwater lakes of increases in solutes, decreases in nitrates, and changes in plankton phenology and benthos communities.

1.3. Alien Species Introduction

Mountain lakes are sensitive to the ecological damage caused by the invasion of alien species [30]. The low taxon richness of high-mountain freshwaters reflects the fact that these habitats are not species-saturated and are susceptible to invasive species or species that are expanding their ranges due to climate change [31]. The threat to their biodiversity is greater due to the low diversity and structure of such communities [32].

The lakes were originally fishless because they are isolated ecosystems [33], but their fish stocking with salmonid species is a widespread practice worldwide [34]. The release of fish for recreational fishing has a huge impact on the ecology of amphibians, macroinvertebrates, and zooplankton [19]. Paleolimnology provides ideal opportunities for studying global change and ecological changes in mountain lakes over time [35]. For example, Perilli et al. [36] highlighted significant differences in subfossil chironomid communities before and after fish introduction and between subfossil and modern communities, with a notable recent decrease in the biodiversity of a high-mountain lake in the northwestern Alps.

The introduction of fish may also cause sanitary risks to native aquatic biodiversity [15]. Furthermore, transhumance can act as a driver of pathogens in these remote ecosystems. Animal excrement from cows and sheep grazing on meadows around the lake shoreline can introduce pathogenic bacteria into the lake water and harm susceptible species [15].

1.4. Medium-Long Range Atmospheric Transport of Contaminates

Human emissions have changed the chemistry of the atmosphere. High-mountain ecosystems are areas of regional convergence of atmospheric pollutants: due to their high elevation, mountains intercept the flux of chemicals coming from the lowland [37]. Moreover, the deposition of volatile compounds by condensation is favored by the lower temperature at the summit compared to the valley bottom [37]. Environmental studies have largely investigated nitrogen and sulfur oxide emission into the atmosphere [38], trace element contamination [39–42], organohalogenated and polybrominated diphenyl ether compounds [43–45], and organochlorine pesticides [45,46].

High-mountain lakes are considered “natural laboratories” where global changes in water quality and biodiversity can be investigated [16,31] and the large-scale effects of anthropogenic activities assessed [47].

Diversity has dedicated a Special Issue to high-mountain lakes, with a focus on their ecological characterization and environmental pressures. Contributions should be original articles on the following topics:

- morphological characterization of mountain lakes by means of conventional or new methods and technologies (unmanned aerial vehicles and unmanned surface vehicles);
- hydrochemistry;
- ecological characterization using bioindicators (e.g., phyto-zooplankton, diatoms, ostracods, macroinvertebrates, fish);
- environmental DNA (eDNA), which is being increasingly used for assessing the presence and relative abundance of aquatic organisms (i.e., elusive organisms);
- environmental pressures: alien species introduction and environmental contaminants;
- the use of new bioindicators/tracers of environmental contamination;
- the condition and structure of amphibian populations;
- fish diseases, bacteria or parasites isolated in aquatic organisms;
- paleolimnological studies: lake sediments can serve as an archive for paleoclimatic-paleoenvironmental reconstruction.

The aim is to stimulate and collect new research data from high-mountain lakes from around the world. Although most of the core information is derived from the Pyrenees and the Alps, we encourage the submission of data from wherever the high-mountain lake is a valuable concept.

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