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Review

People, pollution and pathogens – Global change impacts in mountain freshwater ecosystems

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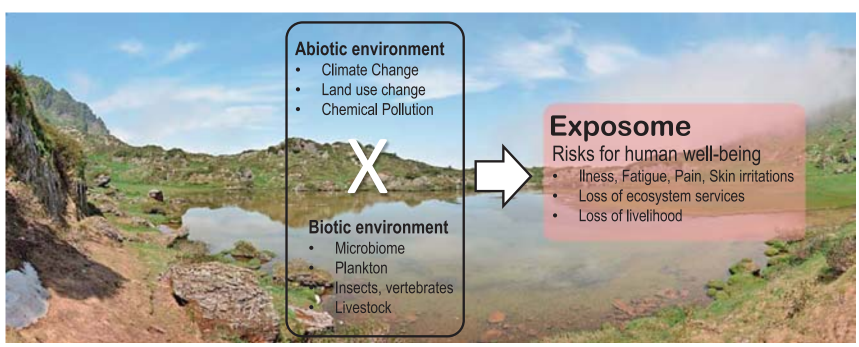
HIGHLIGHTS

- Mountain freshwater ecosystems are sensitive to global change.
- Microbiome composition indicates water quality.
- Dynamics of plankton reflects ecosystem health.
- Loss of ecosystem services
- Risks for human society through increased pathogen pressure

GRAPHICAL ABSTRACT

Interactions between the abiotic and biotic environment impact on human well-being in mountain freshwater ecosystems.



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ABSTRACT

Mountain catchments provide for the livelihood of more than half of humankind, and have become a key destination for tourist and recreation activities globally. Mountain ecosystems are generally considered to be less complex and less species diverse due to the harsh environmental conditions. As such, they are also more sensitive to the various impacts of the Anthropocene. For this reason, mountain regions may serve as sentinels of change and provide ideal ecosystems for studying climate and global change impacts on biodiversity. We here review different facets of anthropogenic impacts on mountain freshwater ecosystems. We put particular focus on micropollutants and their distribution and redistribution due to hydrological extremes, their direct influence on water quality and their indirect influence on ecosystem health via changes of freshwater species and their interactions. We show that those changes may drive pathogen establishment in new environments with harmful

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Chemical micro-pollutants
Potential harmful trace elements
Pesticides
Pathogens
Human impact
Pollution legacy
Anthropocene

consequences for freshwater species, but also for the human population. Based on the reviewed literature, we recommend reconstructing the recent past of anthropogenic impact through sediment analyses, to focus efforts on small, but highly productive waterbodies, and to collect data on the occurrence and variability of microorganisms, biofilms, plankton species and key species, such as amphibians due to their bioindicator value for ecosystem health and water quality. The newly gained knowledge can then be used to develop a comprehensive framework of indicators to robustly inform policy and decision making on current and future risks for ecosystem health and human well-being.

Contents

1. Introduction

Mountain catchments provide freshwater for more than half of humankind, provide the living space for an important number of animal and plant species, and have become a key destination for tourist and recreation activities globally (Grêt-Regamey et al., 2012). However, all forms of anthropogenic disturbance are damaging for freshwater biota (Lake et al., 2000; Revenga et al., 2005; Sala et al., 2000). For freshwater ecosystems, human activities causing water pollution, habitat loss and degradation, overexploitation, flow modifications and alien species invasions are common threats on all continents (Dudgeon et al., 2006; Malmqvist and Rundle, 2002) and contribute to quantitative and qualitative decreases of freshwater resources. All these activities interact to give rise to the two large-scale phenomena of biodiversity loss and climate change (Vitousek et al., 1997), the latter recognized as a major threat to wetlands worldwide (Schindler, 1981; Schindler and Hilborn, 2015). In mountains, freshwater ecosystems are key hotspots for climate vulnerability and ideal ecosystems for climate change studies, as they are influenced not only by altered average environmental conditions but also by climate and hydrological extremes (Millenium Ecosystem Assessment, 2005).

The importance of mountain catchments for the livelihood of humans asks for a higher effort to investigate and monitor biogeochemical and ecological processes. Particularly small but very numerous waterbodies (size between 1m^2 and 500 m^2) show a high susceptibility to climate change and hydrological extremes due to their shallow depth and low water volumes (Smol and Douglas, 2007; Smol et al., 2005; Wissinger et al., 2016). Such small waterbodies, especially when they are part of highland peatlands, play crucial roles in the biochemical cycling and retention due to their high productivity (Céréghino et al., 2008). Despite their high number and important role in freshwater catchments these water bodies remain largely understudied, especially in comparison to large mountain lakes, which they outnumber 100 to 1 (Birck et al., 2013; Hoffman and Huff, 2008; Oertli et al., 2005). Research on changes to the natural flow regimes, eutrophication, increasing temperature, and habitat loss in small mountain waterbodies and their microbial, plankton, plant and animal diversity is therefore important (Fenwick, 2006; Hudson et al., 2006; Johnson et al., 2010a; Middelboe et al., 2008; Okamura et al., 2011; Scholthof, 2006). More so, as small aquatic ecosystems, due to their susceptibility to climate events and increasing temperature, may also function as sentinels for long-term effects on larger aquatic systems, including whole catchments (Céréghino et al., 2008). Increasing temperatures, for example, may lead to changes in local and regional species richness with increased colonization events in mountain ponds due to an upward shift of species with a wide temperature tolerance and extinctions of stenothermal species (Oertli et al., 2008).

Research on change in mountain freshwater biodiversity and on the drivers and pressures causing those changes has a high value to inform policy and decision-making of local and regional stakeholders and administrations about the risks of climate change and the potential impact on human well-being. Here, we review current knowledge on the anthropogenic impact on mountain freshwater ecosystems, how anthropogenic pollution affects biodiversity (the eco-exposome) in mountain ecosystems and how those alterations may impact on human well-being (exposome) (Lioy and Smith, 2013).

2. Pollution through chemical micropollutants

Chemical micropollutants consist of mineral (=inorganic) as well as organic molecules. Micropollutants occur in low to very low concentrations (pg/l to ng/l) in water and their impact on freshwater ecosystems is much less understood in comparison to macropollutants (concentrations from mg/l or higher), such as acids, salts, nutrients, and natural organic matter (Schwarzenbach et al., 2006). However, the contamination of freshwater with chemical compounds is a key challenge humanity is facing, as it is closely linked to climate change and climate extremes (Whitehead et al., 2009). Global change, including climate change, plays a key role in the re-distribution of chemical micropollutants and is assumed to enhance release of micropollutants stored in ice, soils or sediments through e.g. flood events (Rockström et al., 2009). Also a range of other climate variables, such as rainfall, snowfall, length of growth season, and wind patterns may play an important but little understood role in distribution and re-distribution of micropollutants (Ferrario et al., 2017; Pavlova et al., 2014; Steffens et al., 2015). For example, temperature dependent partitioning between air and atmospheric particles, snow surface, or water droplets determine dry and wet deposition rates that may lead to a fractionation and preferential deposition of different compounds at different altitudes (Blais et al., 2006; Blais et al., 1998; Le Roux et al., 2008; Lei and Wania, 2004; Wania and Mackay, 1993; Weathers et al., 2000; Zhang et al., 2013). Mountain topography and land cover may further support the formation of hotspots of micropollutant concentrations, for example in snow fields, forest edges and wetlands (Bacardit and Camarero, 2010; Bacardit et al., 2012). Generally, the accumulation and release of micropollutants in the mountain watershed may be variable depending on the controlling parameters that include topography, dominating winds and type of vegetation (Le Roux et al., 2008; Lovett and