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Opportunities for research on mountain biodiversity under global change

Davnah Payne, Eva M Spehn, Mark Snethlage and Markus Fischer

Mountains worldwide host very rich biodiversity, are home to hundreds of millions of people, and provide billions of upland and lowland inhabitants with vital ecosystem services. By altering mountain ecosystems and their biodiversity, global change modifies this picture substantially. We concisely review current knowledge and knowledge gaps on mountain biodiversity, ecosystem services, and human well-being under global change. We argue that our ability to understand, predict, and sustainably manage mountain biodiversity and to support human well-being requires concerted research efforts in natural and social sciences and comparative analyses of biological and social–ecological systems within and across mountain ranges. Specific examples illustrate how the Global Mountain Biodiversity Assessment will continue to support these efforts in the future.

Address
Global Mountain Biodiversity Assessment, Institute of Plant Sciences, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland

Corresponding author: Payne, Davnah (davnah.payne@ips.unibe.ch)

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Introduction

Because of their global occurrence across all latitudes [1••] (Figure 1) and the steep, small-scale environmental and climatic gradients characterizing them, mountains offer unique 'experiments by nature' for studying the mechanisms driving the evolution and maintenance of biodiversity and ecosystem functions in a changing world [2]. Yet, mountains are not only storehouses of biodiversity and intriguing study systems for natural scientists. Mountains and their biodiversity also serve as water suppliers and climate regulators [3], and support hundreds of millions of livelihoods locally (0.5–1.2 billion people in mountains only [1••,4]), and an even higher number in adjacent lowlands and urban areas, with vital ecosystem services [5]. Moreover, mountains around the world harbour an extremely rich ethnic and cultural diversity and are home to both extremely poor and marginalized inhabitants as well as to communities achieving high levels of life quality [6,7]. Mountains therefore offer complex and fascinating study systems for social sciences and take a prominent position in international science and policy agendas [4,6,8].

In recent years, natural and social scientists have increasingly participated in common initiatives [9] (e.g. Global Network of Mountain Observatories, G.N.O.M.O) and conferences (e.g. Perth III: Mountains of Our Future Earth) to work toward a holistic understanding of mountain systems. Accordingly, within the mountain research community, biases in thematic coverages toward natural sciences tend to decrease [10]. Yet, numerous opportunities still exist for interdisciplinary research on the socio-economic role of mountain biodiversity in a changing world and on the importance of biodiversity in achieving the United Nations' sustainability agenda in mountain regions.

Here we concisely review the state of knowledge on mountain biodiversity, ecosystem services, and human well-being in the light of global change. We then identify open research questions and outline future activities of the Global Mountain Biodiversity Assessment (GMBA)[1] in its role as a platform to foster international and cross-disciplinary collaboration on the assessment, conservation, and sustainable use of mountain biodiversity.

Global change in mountains

Climate change, land-use change, pollution, overexploitation, and alien invasive species are considered the most important drivers of biodiversity change [7]. Indications

[1] GMBA was formerly a DIVERSITAS project and is now a Future Earth global research project.

Figure 1

The >1000 mountain ranges of the world (central map [1••]) vary in their biophysical, geomorphological, socioeconomic, cultural, and political characteristics and in the extraordinary floristic and faunistic diversity they host. For their individuality and their worldwide distribution, mountains offer unique study systems for unravelling the tight relationship between biodiversity and human well-being. Top (left to right): mountains in Bolivia, Tanzania, Switzerland, Georgia, and Central Asia; right (top down) and left: mountain inhabitants of Georgia, Bolivia, Pamir, and Tanzania; bottom (left to right): mountain biodiversity of Georgia, Switzerland (incl. sheep), Bolivia (incl. lama), Tanzania, and South Africa. Pictures from V. Ralph Clark, Erika Hiltbrunner, Christian Körner, Eva Spehn, and Niklaus Zbinden.

of climate change in mountains include increases in temperatures above global averages (e.g. 0.5–0.7 °C per decade in the Alps [11] and the Colombian Andean Central mountain range [12]), changes in precipitation patterns (e.g. less in the summer and more in the winter in the Alps [11], more unusually heavy rainfalls in the Andes [12]), decreases in snow cover duration, changes in cloudiness and relative humidity, and the melting of glaciers [11,13]. Land-use changes include an increase in the intensity of land use and concomitant overexploitation (e.g. in (sub)tropical mountain ranges [14] and temperate mountain grasslands at and above the treeline [15]), a decrease in the intensity of land use accompanied by land abandonment and emigration (e.g. in temperate mountains [16]), and a higher likelihood of farmland abandonment in mountainous than in non-mountainous regions across the world [17]. Levels of pollution in mountains, including rates of nitrogen (N) deposition, are largely unknown (but see [18] for N deposition in the southern Rocky mountains). Occurrences of biological invasion are currently considered to be limited at the highest elevations [19] but observations of rapid upwards spread of non-native species in the Alps highlight that invasions into native alpine communities are likely to represent a growing pressure [20]. Evidence for the impacts of land-use change on climate (e.g. decreased cloud occurrence and precipitation with increasing deforestation at Mt Kilimanjaro [21]) suggests that coupled models will likely reveal additional interactions between global change drivers in mountains.

Beyond warming, detailed information about temporal changes in climate exists only for a subset of indicators and mountain ranges worldwide (e.g. European Alps [11], Sierra Nevada (Spain) [22], Rocky Mountains [23], Sierra Nevada (United States), see G.N.O.M.O), notably because of the general paucity of high-elevation observation stations. Accordingly, extrapolating climate patterns across scales and over time is difficult [24,25]. Remote sensing offers promising new approaches to obtain data [26], and emphasis on the validation of these data for high-elevation regions will greatly improve their