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Editorial

Special Issue Editorial: Mountains under Pressure

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Mountains are highly significant regions in the context of climate change and sustainable development; they are situated at the intersection of accelerated climate warming, changes in moisture regime and support a large population that depends on mountains for their livelihoods, either directly or indirectly (Adler et al., 2022 [1]). Montane forest and alpine ecosystems are rich in biodiversity and endemism (Rahbek et al., 2019 [2]) and are an important global carbon store (Cuni-Sanchez et al., 2021 [3]). Despite their importance and impact on multiple downstream communities, mountain ecosystems are increasingly threatened by climate change, population growth, and land-use change (Adler et al., 2022 [1]). Mountains provide an ideal natural laboratory to investigate the evolution of social–ecological systems, and to assess the current challenges and opportunities that this evolution has created (Thorn et al., 2021 [4]). Mountains have been centres of past development and conduits for the spread of crops, populations, and technologies. They were, and remain, a locus for cultural interaction, in many parts of the world through pastoral–agricultural–urban interactions over access to space and resources, particularly water. As outlined in the special Cross-Chapter on 'Mountains' of the latest IPCC report (Adler et al., 2022 [1]): 'Observed climate-driven impacts on mountain ecosystem services, agriculture and pastoralism are largely negative in most mountain regions through increased exposure to hazards such as droughts and floods, changes in the onset of seasons, the timing and availability of water, increasing pests and decreasing pollinator diversity. These impacts are challenging the adaptative capacity of mountain communities with knock on impacts at lower altitudes as drought induced degradation of rangelands and pastures and decreasing yields of important cash and subsistence crops such as maize, rice, tea and coffee, respectively'.

Amani et al. (2022) [5] and Kaganzi et al. (2021) [6] approach the topic of the impacts of climate change on mountainous socio-ecological systems, focusing on mountains in Africa that have limited long-term meteorological data. In addition to providing insight into their specific case studies, these manuscripts raise the much wider challenge of missing or incomplete basic data, such as data on climate or hydrology. The potential of indigenous and local knowledge to identify the impacts of climate change and formulate adaptation measures has been demonstrated and is being increasingly recognized (e.g., Petzold et al. 2020 [7]; Schlingmann et al. 2021 [8]). Both Amani et al.'s (2022) [5] and Kaganzi et al.'s (2021) [6] studies administered semi-structured questionnaires to smallholder farmers to identify their perceptions of climatic changes, the impacts of these changes in the biophysical domain, and the adaptation strategies already being used by these farmers. Whereas Kaganzi et al. (2021) [6] focused on two mountains in Tanzania (Mount Kilimanjaro and Udzungwa Mountains) Amani et al. (2022) [5] focused on two different ethnic groups living in the Itombwe Mountains in eastern DR Congo. The respondents in all these mountains reported numerous climatic changes beyond changes in rainfall and temperature, and impacts on their crops, livestock, and even human health. Farmers in these mountains

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were implementing several adaptation strategies, but several factors were constraining their adaptation options.

Garcia-Amorena et al. (2021) [9] also explore climate change impacts but focus on specific plant species: providing an analysis of the potential future distribution shifts of *Pinus hartwegii*, a tree species native to the very high altitudes of the mountains of Mexico, Eastern Central America, and Honduras. These authors combined satellite images, species distribution models, and connectivity analysis to disentangle the effects of climate change and anthropogenic land use change on the habitat availability for this species in Izta-Popo National Park in Mexico. Their approach proposes solutions to overcome the limitations of field-based observations in areas that are difficult to monitor or are unsafe due to ongoing conflict. Indeed, mountains often form the boundary between nations and can be the focus of conflict.

Beyond the impacts of climate change, invasive plant species are known to threaten mountain ecosystems. Canavan et al. (2021) [10] assessed the status of alien plants in South African mountains by determining the sampling efforts, species compositions, and abundances across the six major mountain ranges in South Africa. These authors showed that most alien species were woody plants with broad ecological tolerances and were characterised by long distance seed dispersal, contributing to the trend of woody plant encroachment across South African mountains. They also showed that more data are urgently needed for four of the six mountains they targeted. This is a common thread throughout the special issue—for the effective execution of informed decisions around ecosystem management, ecological restoration, and how to maximise the potential of nature-based solutions to deal with these challenges, we must have more data from mountain regions to make evidence-based decisions.

One of the key challenges for understanding mountain ecosystems and the impacts of their change is their sheer taxonomic diversity. This problem is particularly acute as resources for descriptive taxonomy and biodiversity inventories have substantially declined over the past decades, and they are also globally unequally distributed, which can result in a decline in the quality of biodiversity data, reducing the utility and reliability of inventories (Ahrends et al., 2011 [11]). The Andean forests support a strikingly high diversity of plants, making it difficult to understand the main drivers of species assembly. However, trait-based approaches can help overcome some of the challenges associated with high taxonomic complexity, providing insights into the main drivers of species coexistence. The roles of climate, soil fertility, and symbiotic root associations and how these shape the assembly of six of plants' functional traits (leaf area, specific leaf area, dry leaf matter content, leaf thickness, leaf toughness and wood density) are evaluated along an elevational gradient in the species-rich northwestern Andean forests of Colombia by Ochoa-Beltrán et al. (2021) [12]. The study shows how trait-based approaches can help in overcoming some of the challenges associated with high taxonomic complexity in the Colombian Andes; methods that could be applied to other highly diverse tropical montane forest ecosystems.

Land-use change is another major threat to both natural and cultural mountain landscapes. Three empirical studies from different continents (Africa, Asia and Europe) in this issue focus on this topic. Mpanda et al. (2021) [13] assess land cover dynamics in the Uluguru Mountains of Tanzania. They show an overall net increase in forest cover across the entire 25-year study period, which they attribute to a trend towards intensified tree-based farming systems. Qu et al. (2021) [14] investigate the spatio-temporal differentiation pattern in gully production following the expansion of agriculture in the Chinese Loess Plateau. They report shifts in the agricultural elevational area in the past 20 years; a common trait of many mountain areas driven by social and economic factors. Dax et al. (2021) [15] study the risk of land abandonment in mountain regions in Europe and show that this risk is three times higher in mountain areas than in non-mountain areas. These authors attribute this high risk to the high disparity in agricultural competitiveness between regions (at a fine geographical scale) and call for policy reform. Ehrlich et al. (2021) [16] also provide data on another important threat to mountain socio-ecological systems and more broadly to their functioning: population growth. They provide estimates for population changes in mountain regions between 1975 and 2015. They show that the global mountain population has increased from over 550 million in 1975 to over 1050 million in 2015, and that 34% of this growth is in mountain cities.

Given the importance of water resources, particularly as a connection between mountain and lowland communities, our Special Issue also includes two papers on water, one from an ecological and one form a social perspective. Sumner and Venn (2021) [17] conducted a quantitative systematic review and meta-analysis of the effects of an altered water supply on plants from high elevation ecosystems. They report that the responses to decreases in water supply appear to be related to the magnitude of the change in the water supply, the form of plants' growth and to the measured response attributes. Yu et al. (2021) [18] study the characteristics and challenges facing rural mountain settlements in southwestern China. They report that in their study area, 8.7% of rural settlements are situated in high-risk and medium risk areas and discuss the implications of their findings for both revitalisation activities and the site selection of rural mountain settlements.

Our Special Issue also includes two papers on cultural aspects. Laković et al. (2020) [19] investigate seasonal mountain settlements for summer cattle grazing (katuns) in the Kuči Mountain in Montenegro. Although these are now obsolete, the density of these settlements and the architectural and constructional characteristics show the high importance they had for the local population up until the last third of the 20th century. More broadly, this paper showcases the importance of taking a historical perspective for a greater understanding of change and the evolution of mountainous social-ecological systems. Wan et al. (2020) [20] investigate farmers' environmental perceptions in the Huanjiang Karst Mountain Area of China. Through a survey administered to 379 farmers following a government intervention policy to enhance the livelihood of mountain communities in this area, they report farmers' high satisfaction with their living space, average for their ecological space, but low for their farming production space.

Finally, three papers examine the impacts of more action-oriented approaches to developing sustainable mountain futures for people and biodiversity. Carbutt and Thompson (2020) [21] present insights into how new investments that build on the Long-Term Ecological Research (LTER) in South Africa can help to optimise catchment management through sound water policy. It is suggested that this new investment marks a renaissance period of global change research in South Africa, which takes greater cognisance of the social context. This diversity of initiatives will generate a more robust knowledge base from which to draw conclusions about how to better safeguard the well-being of people and biodiversity in the region and help balance livelihoods and environmental sustainability in complex, socio-ecological mountain systems. In addition to underlining the necessity of further data, there is also a need for new tools to visualise and connect science and practice. Giupponi and Leoni (2020) [22] introduce the VegeT: a tool to classify and inform the management of Seminatural Grasslands of the Italian Alps, through techniques such as the timing of pastoral mobilisation. Mackay-Smith et al. (2021) [23] present a framework for reviewing silvopastoralism in Oceania by comparing poplar (*Populus* spp.)—the most commonly planted silvopastoral tree in their study area—and the endemic kānuka (*Kunzea* spp.) tree. The insights from the research provide a formalised tool for reviewing and generating research priorities for silvopastoral trees and provides clear research directions for silvopastoral systems worldwide.

All the authors whose work comprises this Special Issue are engaged to bring new empirical insights to bear on these growing and important topics and ensure an evidence-based approach to finding solutions facing mountains throughout the world. Our aim in this Special Issue of Land is to showcase the breadth and depth of mountain research from around the world; the articles present the results of case studies from Central and South America, Europe, Africa, Asia and Oceania. We hope that the relevance and impact of this Special Issue on mountains transcends academia. Increasingly, practitioners, organisations, policy-makers, and managers charged with addressing the challenges of global change and finding solutions to crafting future sustainable pathways need information and data-based insights on the dynamics and changes in social-ecological systems to aid in the design and implementation of appropriate management strategies for the sustainable future of mountains, and this need is particularly acute in this United National International Year of Sustainable Mountain Development.

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