Mountain futures: pursuing innovative adaptations in coupled social–ecological systems

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Despite their importance to human well-being, mountains have only recently come into sharper focus in international policy efforts that seek to protect the benefits they provide to people and nature. Mountains cover ~12.5% of the Earth's terrestrial surface (excluding Antarctica; there is, however, some debate on how mountains are defined – see discussion in Körner et al. 2017). Montane areas provide over 50% of global fresh water, offer habitat for some 33% of terrestrial biodiversity, harbor half of all global biodiversity hotspots, and have irreplaceable cultural and spiritual value for a diversity of peoples around the world (Figure 1; Martín-López et al. 2019). Approximately half a billion people live in montane ecosystems globally; food insecurity impacts the majority of mountain communities in the developing world, a proportion that is continuing to expand (FAO and UNCCD 2019). This increase is due in part to land degradation and the impacts of climate change at higher elevations. Moreover, research shows that ~1.9 billion people (~23% of the global population) currently depend on fresh water originating from the world's “water towers” (Immerzeel et al. 2019), a figure expected to increase in the foreseeable future.

Ecosystem services provided by mountains will become even more essential in the future as land-use transformations continue and climate change accelerates. Historical trends are clear. Following the 1992 Earth Summit in Rio de Janeiro, Brazil, the first international meeting to focus solely on mountains was held in Austria in 2000, and work on the Millennium Ecosystem Assessment over the 2001–2005 period generated the first publication integrating mountain science and human development (Körner and Ohsawa 2005). Since 2002, when the UN declared an International Year of Mountains and established the Mountain Partnership advocating for sustainable development in mountains, progress on meeting international policy goals for montane regions has been slow, however. It took 6 years (1998–2004) for the Convention on Biological Diversity (CBD) to move from establishing a focus on mountains to crafting a specific program of work, which remains unfinished. Inclusion of mountains in the CBD’s Post-2020 Global Biodiversity Framework is still being negotiated, and although mountains were included in the UN’s Agenda 2030 Sustainable Development Goals, highlands figure explicitly in only three of the 169 targets. In addition, among the signatory nations of the Mountain Partnership, only one – Andorra – has formally included mountain sustainability as foundational to national development planning (Makino et al. 2019).

In a nutshell:
• The world’s mountainous regions have great social and ecological importance, including cultural and spiritual value for diverse peoples, and are the primary source of fresh water for nearly one-quarter of the global human population.
• While progress toward achieving global policy goals for mountain systems has been limited, several major reports on mountains were released by multiple international agencies in 2019.
• These reports recognize links between social–ecological systems in mountains, and call for transformative solutions to problems of sustainability.
• We review several major research partnerships focused on mountains, and pay particular attention to the Mountain Futures Initiative, a package of innovative efforts across different scales to link science with livelihood support for mountain communities.

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Fortunately, international policy recognition of highland areas appears to be progressing, and 2019 could later be considered the year when awareness of the critical role mountains play in conservation fully arose. Early in 2019, the most comprehensive social–ecological assessment of a single mountain region, the Hindu Kush Himalaya, was released (Wester et al. 2019); then, in June 2019, the Food and Agricultural Organization (FAO) of the UN published a major report on mountain agriculture in Asia (FAO 2019). This was followed by the UN Environment Programme's (UNEP's) release of a policy brief designed to elevate the standing of mountains for the initial CBD Open-Ended Working Group meeting to discuss development of the Post-2020 Global Biodiversity Framework (UNEP and GRID-Arendal 2019; UNEP et al. 2020). A month later, the Intergovernmental Panel on Climate Change (IPCC) issued the first-ever global assessment of Earth's oceans and cryosphere, which included a chapter on mountains (Hock et al. 2019), with the FAO releasing an update on food insecurity in mountains soon after (FAO and UNCCD 2019). In October 2019, an urgent Call to Action was issued by the World Meteorological Organization-led High Mountain Summit, a meeting designed to identify priority actions to address the effects of climate change in mountains (https://highmountainsummit.wmo.int/en/call-action). Finally, mountains were featured as one of ten foci of climate science in a publication released at the UN Climate Change Conference of the Parties (COP) 25 in Madrid, Spain, in December of that year (Pihl et al. 2019).

In addition to their timeliness, what is common to all of these reports is a growing recognition of the links between social and ecological systems in mountains, encompassing such factors as biodiversity, ecosystem services, human livelihoods, institutions, and governance. This reflects the influence of transdisciplinary efforts to understand complex nature/cultural systems (eg social–ecological systems [Bennett et al. 2015], nature's contributions to people [Diaz et al. 2018]). Representing more than the latest trends in collaborative research, these frameworks are the result of practitioners acknowledging a fundamental truth: that transformative solutions to problems of sustainability in mountains (and elsewhere) involve sociopolitical decisions made by people. These decisions often depend less on accumulation of scientific data and more on complex social relations among diverse actors at many levels that lead to both barriers and bridges to change (Ellis et al. 2019). No matter how much we learn about nature and culture through scientific research, it is human influence and agency that moves the world toward or away from sustainability.

● Partnerships for mountains

Improving knowledge of montane social–ecological systems across traditional academic disciplines is challenging. Below, we briefly review major mountain research and advocacy partnerships at global and regional levels. We then scale down to regional and local levels using the lesser-known Mountain Futures Initiative (hereafter, MFI) as an example of the use of a social–ecological framework to test and implement research results on the ground.

One of the first scientific groups to focus primarily on montane areas was the Global Mountain Biodiversity Assessment Network. This consortium – initiated by the Swiss Academy of Sciences in 2000 as a platform for international collaboration on assessment, conservation, and sustainable use of mountain biodiversity – emphasizes natural sciences research in mountains and hosts the Mountain Portal for Biodiversity (www. gmba.unibe.ch/services/mountain_portal).

A second global consortium concentrating on mountains is the Mountain Research Initiative hosted by the Centre for Development and Environment at the University of Bern, Switzerland (www.mountainresearchinitiative.org). This group, which also arose during the 1990s and early 2000s, serves to connect the global mountain research community, and has played an important role in bringing scientific research on mountains to the attention of international policy actors like the CBD and the IPCC.

Both of these organizations are members of The Mountain Partnership, a long-standing global advocacy group that emerged from the 2002 UN Sustainable Development Summit. With a Secretariat hosted by FAO, the Partnership now has 370 members, including 60 countries (www.fao.org/mountain-partnership/en). In terms of linking research to policy and practice, several intergovernmental members stand out, particularly the Consortium for Sustainable Development in the Andean Ecoregion (CONDESAN), the Alpine Convention, and the International Centre for Integrated Mountain Development (ICIMOD). These three groups are performing exemplary regional work to put social–ecological research results into practice in the Andes, Alps, and Himalayas, respectively (see examples below).

Another international partnership for research and practice in mountains is the Global Lands Program (GLP; Providoli et al. 2017). Featuring eight regional offices and multiple working groups, GLP is an interdisciplinary community of
researchers fostering the study of land systems and the co-design of solutions for global sustainability (https://glp.earth; Figure 2). Beginning in 2017, this consortium has hosted a specific working group on Land Systems for Mountain Futures, the genesis of which can be traced back to MFI’s founding in 2016. MFI shares many of the concerns of these montane partnerships, with a special emphasis on working with local communities to identify solutions to livelihood problems (Xu et al. 2018).

Although the majority of these partnerships rely on a systems approach to collaborative work on mountains, a recent overview of international policies for mountains, while spotlighting important knowledge gaps, reported that there is “little information on how land use in mountains is changing” and that studies are either fragmented or “focused on highly specific locations” (Makino et al. 2019). In fact, due in part to the groups described above, there exists a rich literature portraying multiple aspects of global land use and adaptations to change in mountains. In addition, the gathering of site-specific information is warranted given complex montane land-use and human settlement patterns that together create highly specific social–ecological outcomes and the need for place-based innovative solutions.

Innovation for mountains

Although we continue to be engaged with several of the partnerships described here (Mountain Partnership, ICIMOD, MRI, GLP), in the rest of this paper we spotlight MFI (our current focus) as a prime example of researchers engaging with local peoples. Partners in MFI are active globally and have published extensively; below, we briefly present a representative sample of studies that depict regional work on mountain systems that may have global applications. We then scale down to spotlight work in progress at the Honghe Innovations Centre for Mountain Futures, a recently established demonstration center in southern Yunnan Province, southwest China, cosponsored by MFI that is testing practices with a strong emphasis on working with local partners in ways that may influence broader global innovation.

Three projects involving the participation of MFI partners and others offer exemplary regional work linking mountain research with practical applications. In the Andes Mountains of South America, Mathez-Stiefel et al. (2017), with input from CONDESAN, constructed a comprehensive research framework for use in capturing interactions between ecological and social systems. This framework includes social knowledge goals, such as how to work better with diverse stakeholders on participation, equity, and justice issues. Transformational knowledge is also accentuated, including exploration of governance and institutional barriers to change. These researchers suggest that scientists collaborate with partners from other disciplines, given that social and transformational knowledge goals often present challenges to those who lack cross-disciplinary training.

In Europe, the Alpine Convention countries and the EU recently released a strategic roadmap to building a carbon-neutral green alpine economy by 2050 (Palenberg et al. 2019). This plan is rich in detail and is noteworthy for being the first mountain-oriented planning framework to embed climate emission reduction targets within social–ecological goals. Moreover, it emphasizes the need for transboundary partnerships among montane countries, a continuing obstacle for many governments around the world. The plan is also unique in that it addresses the role of young people in building a sustainable mountain future for the Alps.

On the other side of the world, a team composed of hundreds of researchers led by ICIMOD, with participation by many MFI researchers, comprehensively assessed the state of knowledge of social–ecological systems across one of the world’s most important mountain regions, the Hindu Kush Himalaya (Wester et al. 2019). The goal of this work was to reduce fragmented knowledge and influence the direction...
of decision making for sustainable development in the Himalayas (Figure 3). This benchmark report offers not only evidence of how the Himalayas are being increasingly influenced by regional and global drivers of change, but also a suite of coordinated transnational policies for Himalayan nations to consider.

Numerous other regional and local studies conducted by MFI partners illustrate lessons learned about multiple aspects of sustaining ecosystems and livelihoods in mountains in the face of environmental change. Several examples of those with global implications are detailed here. In the Asian Highlands extending from China to Pakistan, Xu and Grumbine (2014) reported on how local mountain communities have begun to shift away from dependence on traditional knowledge in adapting to climate-change impacts, with many farmers now basing land-use decisions on hybrid forms of knowledge that blend site-specific mixes of “bottom-up” traditional knowledge, “top-down” government support, and market information. However, smallholders (farmers who work less than 2 ha) would greatly benefit from more site-specific, targeted government support to improve market access, and to develop agricultural extension services and water use infrastructure, among other needs.

Rao et al. (2019), working at six montane sites in Asia and Africa, explored gender-associated vulnerabilities and factors that may reduce women’s decision making in adapting to climate change. These workers learned that environmental stressors could reduce the ability of women to make climate-adaptive decisions, even when general social conditions and household norms are supportive. They also discovered that increased access to nonlocal economic markets is not a panacea, and does not always strengthen agency or reduce adaptation risks for women as well as for men.

Providoli et al. (2017) reviewed the establishment and effectiveness of watershed partnerships in the Ethiopian Highlands and water resource user associations in Kenya and Tanzania. They found that these grassroots projects led to reduced erosion and downstream siltation, increased community participation in regulating water use, and consequently reduced water-related social conflicts. The results suggested, however, that partnerships among researchers, development workers, and local governments must be maintained over time to ensure success.

In an examination of the effects of improved market access on farmers’ land-use choices and livelihoods at villages in northern Laos, Thanichanon et al. (2018) reported that greater market access can lead to increased planting of cash crops for export at the expense of household food crops. However, low-cost government policies directed toward land availability and market participation were shown to support farmers’ adaptation to change if governments expanded their engagement with the needs of local people.

At the local level, the establishment of the Honghe Innovations Centre for Mountain Futures in China has, as mentioned above, created a public–private land-based laboratory where lessons learned about linking science with livelihood support and ecological restoration can be tested (Figure 4). The Centre is being built on 220 hectares of degraded semiarid mountain slopes at a cost of 21 million RMB (US$3.2 million) financed primarily by the Honghe County, provincial, and national governments. Initial projects include establishment of a series of on-site weather stations to generate local meteorological data that can be shared with smallholders. Several plants – including drought-resistant mango (Mangifera indica) and coffee (Coffea arabica), fast-growing Indian gooseberry (Phyllanthus emblica), and giant milkweed (Calotropis gigantea) for use as fiber and fodder (Ayemele et al. 2020) – are being assessed to determine what species are best suited to local conditions and farmers’ use. These species will provide biomass for soil development and ongoing site restoration. Farmers have also formed a cooperative to learn how to raise edible fungi by working with a local mushroom factory (Figure 5). The factory is partnering with scientists from the Honghe Innovations Centre to pioneer closed-loop recycling of wastes back into production using the circular agricultural principles of reduce, re-use, and recycle (Zhao et al. 2008; see Fan et al. [2018] for issues with deploying circular agriculture in China).

Workshops held at the Honghe Innovations Centre help farmers learn new business skills and information, such as how to access markets and the importance of value-added specialty products, which can assist farmers in increasing quality standards and connecting more directly with markets through the use of e-commerce platforms and smartphones. The farmers’ co-op is seeking social enterprise certification in 2021 so that responsible consumption and production can be more directly linked to mountain lifestyles (Warnecke 2018). This aligns with the overall themes of work at the Honghe Centre – connecting people to nature, to people, and to new technology. The primary goal is to strike an appropriate balance between FI partners illustrate lessons learned about multiple aspects of sustaining ecosystems and livelihoods in mountains in the face of environmental change. Several examples of those with global implications are detailed here. In the Asian Highlands extending from China to Pakistan, Xu and Grumbine (2014) reported on how local mountain communities have begun to shift away from dependence on traditional knowledge in adapting to climate-change impacts, with many farmers now basing land-use decisions on hybrid forms of knowledge that blend site-specific mixes of “bottom-up” traditional knowledge, “top-down” government support, and market information. However, smallholders (farmers who work less than 2 ha) would greatly benefit from more site-specific, targeted government support to improve market access, and to develop agricultural extension services and water use infrastructure, among other needs.

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growing food crops for local consumption and cash crops for markets, taking into account land restoration, climate impacts, and social equity.

At Honghe, innovative public–private partnerships support researchers and farmers. Future projects include experiments involving the restoration of degraded lands at locations that could also support agroforestry livelihood crops, and that could eventually be linked to off-site restoration efforts at the watershed-scale across the county. However, development of a wide range of pilot projects requires time, and creation of diverse partnerships is as challenging in southwestern China as it is elsewhere. Engagement with local people, particularly the poor, many of whom have limited education, voice, and power, requires that scientists and environmental professionals in all fields take time to share their perspectives and objectives with smallholders. Incorporating the interests of middle-class urban consumers is equally important. A Shanghai–Honghe Partnership for Precise Poverty Reduction has been established to link urban consumers with mountain farmers through market chains. Once these processes become operational, addressing off-site suppliers, investors, and other actors will pose additional challenges, yet this is where innovative practices remain to be explored in many global mountain livelihood systems (Meyfroidt et al. 2019). The primary issue the Honghe Centre hopes to address is what can be learned from these diverse experiments about restoring ecosystems and what assistance can be provided to local mountain partners to help them navigate land-use and livelihood changes in the future.

The future of mountains

Ensuring future sustainability for people and nature in the alpine regions of the world is challenging. Although such impediments as limited data and incomplete understanding of how complex social–ecological systems function from ecosystems to economic markets are problematic, overcoming the political and cultural barriers that promote socioeconomic marginalization of mountain peoples represents, in many cases, a much larger task. Nonetheless, global change is accelerating; multiple lines of evidence from climate science indicate that the Earth’s mountainous regions (as well as other systems) are edging closer to planetary thresholds (Lenton et al. 2019; Höhne et al. 2020). For instance, along with the well-publicized loss of mountain glaciers, 27–29% of global permafrost stored in highlands is beginning to thaw (Biskaborn et al. 2019; Hock et al. 2019). Yet numerous countries are proceeding with plans to increase fossil-fuel consumption despite Paris Agreement commitments to maintain global average temperature increase at or below 2.0°C (SEI et al. 2019). The lack of progress in meeting international climate targets, the UN Sustainable Development Goals, and the Aichi Biodiversity Targets has led to increased calls for transformative change in the societal status quo to meet sustainability goals (Díaz et al. 2019; CBD 2020).

“Transformative change” implies extensive reorganization across all sectors of global society, but such processes will not occur overnight (Loorbach et al. 2017). To support emergence of such long-term changes in the mountainous areas of the world, what adaptations can be initiated at local and regional scales? Although only a small sample, the efforts we highlight above offer some initial suggestions; we summarize those with broad applicability in many mountain regions below (see also Klein et al. 2019; Martín-López et al. 2019).

To reduce risks and increase adaptive capacity to respond to water stress at local scales, many alpine communities would benefit from development of various kinds of water infrastructure, ranging from storage to irrigation depending on specific conditions.
site conditions. Local and regional governments should consider reducing institutional barriers to the creation of water user groups where such obstacles exist. In addition, greater participation (including equity, inclusivity, and gender) of local communities in decision making that affects their livelihoods is crucial.

To cope with climate-induced risks and increases in local-scale food security in mountains, smallholders in many areas urgently need better access to real-time meteorological information. Moreover, farmers generally would benefit from advice on circular agriculture practices, such as waste stream management, biomass recycling, no-till soil methods, cover crops, and drought-resistant crop varieties. Research indicates that many farmers may require multiple livelihood options in a changing world, and as such would benefit from improved knowledge of how to transition to more diverse mixes of cash crops, traditional crops, and nutrient-dense, climate-resilient foods (FAO 2019). The formation of farmer cooperatives, such as the one at Honghe, will likely amplify the collective voice of smallholders and facilitate greater understanding of how to access markets using inexpensive modern technologies.

Blending biodiversity and restoration goals with livelihood support requires planning for projects that can meet multiple objectives. Enhancing channels of communication between scientific and agricultural experts and local partners is essential. Prior to 2012, relatively little mountain-focused adaptation research captured the key concepts (eg vulnerability, resilience, governance, sustainable development) necessary to build strong actions, and incorporating these issues remains challenging for knowledge producers focused on highlands (McDowell et al. 2019). Scientists must ramp-up efforts to communicate project results to facilitate sharing of what was accomplished and how, and what did not work and why.

Although much can be accomplished through local projects, many sustainability issues in mountains are linked to scales at which local communities have little influence. But governments can do more. In mountain systems, transboundary problems require transboundary solutions; where warranted, nations must act to form regional partnerships to foster change. International efforts to link sustainable development, biodiversity, and climate-change goals have made some progress, but outside of the Alps and the Andes, regional cooperation among highlands nations continues to be the exception and not the rule. Governments could also increase funding to support adaptation research and action in mountain regions, as in the case of the Honghe Innovations Centre, but public–private partnerships in montane areas remain rare. Furthermore, given the increasing influence of transnational flows of products, energy, waste, and capital on mountain ecosystems and communities, governments must also address regional and international management of telecoupled flows of goods and services (Munro et al. 2019). The fate of mountainous areas will no longer be in the hands of local and regional actors alone.

In light of the formidable challenges that lay ahead, mountain communities will require increased support in order to anticipate and adapt to the environmental and social shifts prevalent in the Anthropocene (Bennett et al. 2016). Such “anticipatory adaptation”, in which society must adopt ways to stay out in front of the impacts of climate and social change, will be increasingly important as each “new normal” state shifts into yet another novel scenario. One bright spot in the Anthropocene is that people inhabiting the mountainous regions of the world have always done this, albeit perhaps not at the speed and scale that is becoming necessary. These inherent human skills must be bolstered at all scales in decision making about the future of global alpine environments.

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