

Conservation Issues: Mountain Ecosystems

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Mountains constitute some of the most striking, awe-inspiring landscapes in the world. They provide inspiration and renewal for artists, travelers, and adventurers. They also are settings where people may seek to appreciate nature or wilderness, where people know spirits to be present, or where a sense of communion with the divine is sought. It should be no surprise therefore that most conservation issues in mountain regions are not only ecological or technical, but also have major human, socio-cultural dimensions (see Stone, 1992; Price et al., 2004; Wymann von Dach et al., 2016).

Encompassing 32 million square kilometers, or 22% of the world's land area (Romeo et al., 2015), mountain systems directly affect at least a quarter of humanity, that is, the people who live in or near these rugged and often marginalized lands (Meybeck et al., 2001; Price, 2015). Over half of the global population depends on mountain resources, especially water, for survival.

With high levels of biodiversity present in mountain ecosystems, and also given their extreme fragility as well as an increasing impact of human action on mountains from local to global levels, our communal wellbeing depends on maintaining functional ecosystems—including both the goods (natural resources, biodiversity) and the irreplaceable ecosystem services that are derived from mountain biodiversity.

Additionally, the preservation of cultural traditions and livelihoods that have developed over many generations in mountain social–ecological systems also may contribute to environmental conservation through maintenance of traditional (local) knowledge as well as the genetic resources inherent in local domesticated crops and livestock.

This article seeks to answer fundamental questions such as *Why do mountains matter? What threats do mountains face? What role can (or should) local mountain communities play in the conservation and sustainable use of mountain resources?*

A selection of further readings (references) about the most critical conservation issues in mountain social–ecological systems also is provided.

Mountain Systems of the World

Where are the mountains? Traditionally, mountains have been defined on the basis of three basic criteria: their relative altitude, slope, and prominence in the landscape (i.e., cultural perceptions). However with recent development in global digital datasets and elevation models (c.2000), a more nuanced global assessment of mountain systems is now possible. On this basis, a quantitatively derived map of the world's mountains that is based on broadly agreed criteria of altitude and slope (Kapos et al., 2000; Romeo et al., 2015) and on relief (i.e., topographic roughness) has been developed, most clearly illustrating the extent of the world's mountains (Fig. 1).

Inclusion of landscape roughness to describe mountain areas also helps to tie together some natural characteristics of mountains with their social or human dimensions. As is well known, intrinsically if not always explicitly, mountain systems (as social–ecological systems) do not need to be particularly high or with very steep slopes (see, e.g., the Appalachian Mountains or the Highlands of Scotland) to exhibit fundamental “mountain characteristics”—including weak economies dependent on poor or limited agricultural land, poor access, limited extent of social services, or high exposure to natural hazards and socio-political



Fig. 1 Mountain systems cover 24% of the Earth's land surface. Map based on the digital elevation model (spatial resolution 500 m) derived from USGS Global Multi-resolution Terrain Elevation Data 2010. Map produced by Mr. Evgenii Shibkov, Mountain Societies Research Institute, University of Central Asia. Mountain area data downloaded from <http://www.mountainpartnership.org/our-work/focusareas/foodsecurity/en/>.

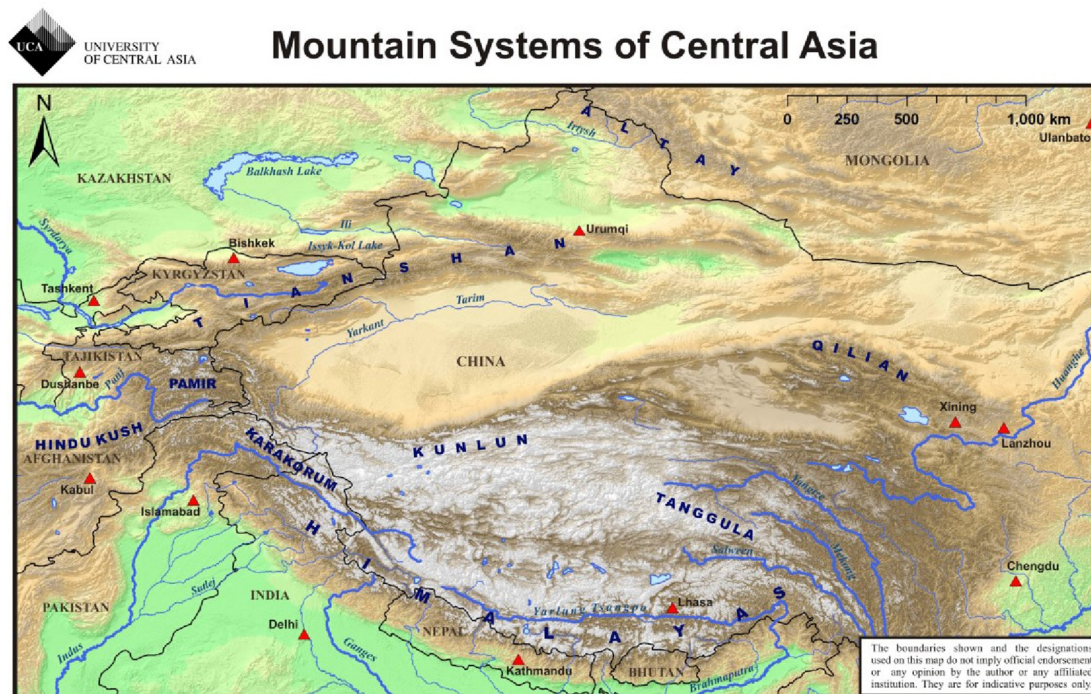


Fig. 2 Mountain Systems of Central Asia. Map designed by the author and developed by Mr. Evgenii Shibkov, Mountain Societies Research Institute, University of Central Asia.

marginalization. A view of mountains that incorporates roughness (and consequently, *de facto* remoteness) along with relative altitude and slope may thus provide a more accurate depiction of this globally important social–ecological system.

At continental scale, Eurasia includes the highest and most extensive mountain region in the world—including the 2400 km Himalayan Range and the high, rugged mountains of Central Asia, along with numerous lesser-known mountain areas on the Tibetan Plateau and in Mongolia (Fig. 2). All of the world's mountains with summits over 7000 m are situated in Asia. South America possesses the second largest areal extent of mountains, also at very high elevations. Significant mountain regions also exist

on every continent—sometimes connected (e.g., the *Pamir Knot* in Central Asia), sometimes in isolation (e.g., Atlas Mountains in Morocco). The high rugged Himalayas, Rocky Mountains, and Andes are all geologically very young. Other mountain areas are very old, such as the eroded (lower, smoother) Appalachian Mountains in eastern USA, the Scottish Highlands, and an array of mountains in southern Africa and in Australia.

In all cases, though, the fundamental climatic and biotic characteristics of mountains are determined mainly by altitude, slope, aspect, and geographic position, including latitude and distance from ocean (i.e., continentality). Latitude affects both temperature and seasonality due to changes in day length (or not) throughout the year. Proximity to large expanses of water attenuates variations in temperature due to the high thermal inertia of water bodies. In addition to such variations in climatic and biotic environments due to geography, three main vertical zones can be identified in the majority of mountain regions: (i) a *montane belt*, which extends to the upper limit where forests can grow; (ii) an *alpine belt*, the treeless area between the upper (potential) limit of forests and the snowline; and (iii) a *nival belt*, all terrain situated above the snowline (defined as the lowest elevation where snow is commonly present year round). In terms of habitat or vegetation, these three zones are broadly characterized, respectively, by presence of forest, then grasslands and/or small shrubs, and areas with relatively little or no plant or animal life.

Why Mountains Matter

Mountains matter for many people, for many reasons. Like all ecosystems, mountains have both intrinsic (inherent, absolute) and extrinsic (utilitarian) values. Recognized as *social–ecological systems*, the fundamental features or elements of mountains that must be considered include biodiversity and other ecosystem services as well as cultural diversity, traditional and local knowledge, and socio-economic realities. As strongly *tele-coupled systems*—that is, complex social systems with persistent, long-distance linkages between different groups of people or sectors of society—we are simultaneously compelled to consider the wellbeing, and expectations, of both local (mountain dwelling) and nonlocal populations (i.e., cities provisioned by mountain resources). An example of such a tele-coupled system is the combination of lowland agricultural and urban populations who depend on water that originates in distant upstream mountain regions, and mountain dwellers affected by the development policies and programs that are designed or initiated from afar, in the more densely populated urban areas. Such social–ecological systems are clearly multiscale and they incorporate natural, social, and political dimensions. Achieving equitable and sustainable development in mountain ecosystems is thus a challenging endeavor—yet crucial for the wellbeing of humanity.

There are many specific natural and socio-cultural values of mountain ecosystems. The broadest values or benefits, which affect nearly all people, include the following:

- As *water towers of the world*, mountain areas supply both local and downstream communities—more than half of the world’s population—with essential water for drinking, irrigation, and energy. This crucial fact alone should be sufficient for all development stakeholders to understand and agree the significance of mountains for human wellbeing (Körner et al., 2005a,b; Viviroli et al., 2011).
- Mountains are *centers of global biodiversity* with unique assemblages of wildlife including many endemic, rare, or endangered species, as well as places of origin of many domesticated plants and livestock species (Körner and Spehn, 2002). Half the world’s biodiversity hotspots are situated in mountain areas. In light of this, c.17% of mountain areas (outside of Antarctica) are formally designated as protected areas (Hurni, 2013). In addition, overall “indigenous and community conserved areas” (ICCAs) (*sensu* Kothari et al., 2012; Borrini-Feyerabend and Hill, 2015) encompass around 13% of the world’s terrestrial area (ICCA Consortium, 2016), and a significant proportion are situated in mountains.
- Mountains also are major suppliers of *renewable energy* (through hydropower) and most of the world’s strategic *nonferrous and precious metals* (Byers et al., 2013). In a globalized world, even distant urban populations are now almost entirely dependent on electricity including hydropower (the most common form of renewable energy) and on rare metals sourced from remote mountain regions.
- *Cultural and ethno-linguistic diversity* is particularly high in mountain areas, due to their remoteness, and consequently limited access and poor communications. Traditional knowledge and cultural identities themselves may be considered as mountain assets to be protected. The same is true with mountain farming and pastoralism—socio-cultural systems that have uniquely evolved in mountain regions and that contain proven “seeds” of sustainability within this context. Mountain cultures and livelihoods are generally well adapted to the harsh, unpredictable weather conditions, as well as to opportunities that may be present in these diverse and biologically rich ecosystems.
- *Recreation and tourism* are among the special development opportunities that are offered by mountains. Diversified and enriched economies can contribute to the wellbeing of mountain communities, and visitors’ lives also may be enriched by the experience of wilderness, adventure, and cultural encounters.
- Mountains also are *sentinels of change*—highly susceptible to climate variations and anomalies, such as elevation dependent warming (Pepin et al., 2015).
- Finally, *healthy, functioning mountain ecosystems* can help to regulate the impact of extreme climatic events and contribute substantially to the protection of rural communities and cities (i.e., infrastructure) from mountain hazards such as avalanches,

landslides, and flooding. Ecosystem-based adaptation to climate change should be sought together with engineering-oriented solutions for risk mitigation. While the risk of such geohazards always will be a part of mountain life, maintaining the integrity of ecosystems can help reduce their frequency or intensity and simultaneously can contribute to successful agricultural development and socio-economic wellbeing.

Beyond the values and benefits of mountain ecosystems recognized above, an introduction to the specific resources to be conserved is still warranted in order to better understand the most pertinent conservation issues in mountain areas.

Mountain Biodiversity and Ecosystem Services

The geology and topography of mountains, together with their inherent diversity of species, habitats, and ecosystems (aka biodiversity), provide humankind with a suite of ecosystem services that are generally categorized as provisioning, regulatory, cultural, and supporting services or processes (MEA, Millennium Ecosystem Assessment, 2005; Wall & Nielsen, 2012). A summary of these core “goods” and “services” (often referred to collectively as ecosystem services) is presented in Table 1. It is these ecosystem services (Harrison et al., 2010), including not only natural elements but also cultural dimensions, which must be conserved—for the wellbeing of both present and future generations.

In this framework, biodiversity is the sum-total of the goods or products derived from the mountain ecosystems (provisioning services; including inter alia fundamental soil biota, livestock and agricultural plant varieties, wild animals and plants, etc.) as well as their underlying genetic basis and the habitats and symbiotic assemblages that support them. Biodiversity also is part of each of the framework’s four subsystems. For example, diversity at the species level increases ecological resilience, that is, an ecosystem’s ability to recover from shocks, and thus also encompasses a regulatory function. In a similar way, special cultural values often are attributed to wildlife or to places (e.g., sacred sites; see Verschuuren et al., 2010; Chan et al., 2012). Conserving mountain ecosystems, therefore, means to conserve all aspects of ecosystem services; either through direct action, or mediated through livelihoods, socio-economic benefits, cultural values, or identity.

Mountains are generally recognized as hotspots of biodiversity, and they occur in all-life zones from humid tropics to extreme polar regions. With a widespread distribution and exceptional altitudinal gradients leading to high levels of environmental heterogeneity, they also encompass a very large portion of the world’s biota. Topographic features such as exposure and slope, as well as the regular occurrence of natural disturbances such as landslides, avalanches, and floods, also contribute to an underlying heterogeneity, which contributes to overall diversity (Kueffer, 2015). On Mt Namche Barwa in eastern Tibet, for example, biological zones transition from tropical rainforest to alpine habitats to rock and ice as one moves upward on a single mountain face from

Table 1 Four main categories of ecosystem services in mountain regions

1. Provisioning services

- Fresh water, fresh air, timber, renewable energy supply, local genetic resources
- Mountain agriculture including farming and pastoralism also provides subsistence (food products) for around half a billion people worldwide
- Biochemical resources (e.g., for natural medicines), ornamental plants, and mineral resources also may be present

2. Regulating services

- Key contributions include regulation of climate, erosion, water flow, natural hazards
- Some contribution also is made to water purification, pollination, and seed dispersal

3. Cultural services

- Mountain ecosystems have intrinsic spiritual value, especially for local inhabitants
- Biodiversity together with spectacular landscapes can provide great aesthetic value
- Traditional mountain ways of life often have created a strong sense of place and cultural heritage, which can translate into a deep and lasting sense of identity
- Mountains also are favored target regions for recreation and tourism

4. Supporting services

- Topographic and habitat heterogeneity provide enormous variety of environments for maintenance of both resident and migratory wildlife species
- Endemism and/or speciation facilitated by the presence of mountain habitats increase regional and global genetic diversity
- Family and community farming/pastoralism (as set of traditional land use practices)

Adapted from Harrison, P.A., Vandewalle, M., Sykes, M.T., Berry, P.M., Bugter, R., de Bello, F., Feld, C.K., Grandin, U., Harrington, R., Haslett, J.R., Jongman, R.H.G., Luck, G.W., da Silva, P.M., Moora, M., Settele, J., Sousa, J.P. and Zobel, M. (2010) Identifying and prioritising services in European terrestrial and freshwater ecosystems. *Biodiversity and Conservation* **19**(10), 2791–2821. doi: 10.1007/s10531-010-9789-x and Price, M.F. and Egan, P.A. (2014). Our Global Water Towers: Ensuring Ecosystem Services From Mountains Under Climate Change (Policy Brief). A Contribution to the VIIIth Phase (2014–2021) of the UNESCO IHP “Water security: Responses to Local, Regional and Global Challenges” Program. IUCN, UNESCO IHP, UNESCO MAB. Available at: <http://unesdoc.unesco.org/images/0023/002308/230850e.pdf> (Accessed: 16 April 2016).

750 m at the southern base all the way to its 7782 m summit—more than 7 km, vertical, over 50 km horizontal distance. Because of such compression of life zones on steep mountain slopes, there is greater biological richness per unit area than in any other terrestrial ecosystem (Körner, 2003). Mountains also may act as evolutionary engines due to isolation and are thus home to many endemic plant and animal species, which are sometimes restricted to single mountain systems (Nagy and Grabherr, 2009).

In terms of total numbers, Körner (2004) estimates around 50,000 species of flowering plants (of a total c.240,000 species globally) to be present in mountain areas. While less is known at a global scale about the diversity of other living organisms, it is at least clear that there is much greater diversity of life in mountains than would be expected based on area alone. More than 30 plant species may be found in some habitats in a small plot the size of a sheet of paper (25 × 35 cm). Habitat isolation (e.g., a single mountain) and fragmentation (e.g., lowland habitats separated by mountain ranges) can equally lead to speciation (Nagy and Grabherr, 2009). In other contexts, mountains also can serve as movement corridors (e.g., snow leopard moving through mountain habitat). But either way, mountain systems are biologically diverse and their natural wealth (natural capital) is extremely high. In terms of water provision, mountains also contribute 60–80% of the world's freshwater resources. Particularly in dry climate areas, up to two-thirds of the water flow in rivers comes from mountains.

Beyond the direct provision of habitats, wildlife, and fresh water, mountain ecosystems also provide resources and conditions suitable for people to develop viable livelihoods (e.g., farming, pastoralism, agro-forestry), domestic livestock breeds and crop varieties, wild food products, traditional knowledge, mineral resources, carbon storage, and energy (MP, Mountain Partnership, 2014; Wymann von Dach et al., 2013). All these are among the wealth of mountain systems.

The global economic value of mountain grasslands, forests, wetland, peatland, and other ecologically vital habitats is virtually inestimable; yet the human impact of their loss is beyond dispute. For example, pastoralism alone supports more than 200 million herders worldwide and contributes at least one-third of the agricultural GDP in many countries (Hatfield and Davies, 2006)—and immeasurably more if indirect benefits of grasslands and pastoralism also were included in economic valuations (IUCN, International Union for Conservation of Nature and Natural Resources, 2011; McGahey et al., 2014; SCBD, Secretariat of the Convention on Biological Diversity, 2010; WISP, World Initiative for Sustainable Pastoralism, 2008). Similar assessments exist for mountain forests (Price et al., 2011), wetlands (Brander and Schuyt, 2010), and protected areas (SCBD, Secretariat of the Convention on Biological Diversity, 2008; WCPA, Task Force on Economic Benefits of Protected Areas of the World Commission on Protected Areas of IUCN, in collaboration with the Economics Service Unit of IUCN, 1998).

Mountains as Cultural Landscapes

As outlined earlier, mountain ecosystems are not only biological or ecological systems, but also socio-cultural landscapes. Land use decisions, local people's perspectives, local and regional politics—all of these affect and shape mountain landscapes. Therefore, successful conservation will depend as much on human dimensions of resource governance and management as on geological or other biogeophysical realities. Additionally, mountain ecosystems both *influence* people and communities, providing them with opportunities and constraints, and they are dramatically *impacted* by their decisions and actions.

Local residents' sense of wellbeing and their hopes and aspirations for the future are very important, for these factors influence people's way of seeing the world and their daily, practical decisions. However socio-economic development in mountain regions often lags far behind the levels in lower lying, often more fertile, more accessible, and more powerful (politically connected) regions of the world. Several key features are common in the lives of mountain people around the world: high levels of poverty, food insecurity, unemployment and challenges of out-migration (as people search for jobs, and through which they may provide remittances to family members), marginalization in relation to regional economies, and a disproportionate exposure to natural hazards including landslides and floods. These outcomes are due largely to some fundamental "mountain characteristics" such as weak local economies dependent on poor or limited agricultural land, poor transportation and access to markets, limited range or extent of social services, and lives situated in national or regional socio-political peripheries.

In this context, mountain farming—including crop cultivation and pastoralism, usually in combination—is the primary livelihood of many mountain people around the world. New livelihood options also are emerging, such as the tourism sector and development of niche mountain products (supported, e.g., by development of a variety of "mountain labels" and associated marketing). However, even such interventions may be understood as subsumed under a *diversified* mountain farming framework. Additionally, as recently articulated by Wymann von Dach et al. (2013), such farming is almost always family farming. This means that local household- and community-level dynamics are predominant in decision-making (in contrast to larger, externally controlled businesses), and subsistence needs as well as local environmental and socio-economic realities are often the most relevant (though not always) in the operation of enterprises in mountain regions.

It is important to preserve such a local perspective for at least two reasons. First, local solutions are best tailored to the social and ecological environments in heterogeneous mountain regions. Over generations, local solutions have led even to the development of new genetic material, through purposeful or de facto breeding of livestock and crops. In a rapidly changing world, maintaining such variety of expression, genetic or otherwise, enhances resilience at multiple levels.

Second, the operation of smallholder (family) farms is not only an economic occupation, but sometimes also a personal and cultural way of life. Indeed, beyond the immediate or direct benefits of local adaptation, household-level farming also has other tangible and intangible values, as agriculture is not merely a means for production and market trade (see Hodges et al., 2014). Thus, neither development nor environmental conservation in mountain regions should fall into the trap of adopting the current dominant economic paradigm, namely neoliberalism. Although this perspective may be beneficial in many instances

(e.g., production of consumer goods such as cars and computers), it remains first and foremost a philosophical position—and one that is poorly suited to address or respond to the socio-ecological complexity of agricultural production systems. Rather, agricultural communities in mountain areas, including family level enterprises, should be supported both for inherent present day values and as a safeguard for the future. Conservation of biological and cultural diversity can enhance mountain communities' resilience to change, as well as our corporate (global) resilience to climate change.

As Wymann von Dach et al. (2013) have rightly stated, mountain farming tends to be family farming, and our global future could well depend on ensuring the sustainability of the land use practices of the long-standing custodians of the world's mountain resources. Family farming does not mean individuals or families working in isolation, but rather a prioritization of locally based interests (economic, social, political) combined with local resource assessments and decision-making, including the governance of common pool resources. With great wealth of site-specific knowledge, the values and perspectives of local mountain communities should be respected, including an appreciation for their own development goals and aspirations—even when money is not recognized as primary metric of development, success, or happiness.

Major Threats to Mountain Ecosystems

From the Andes in South America to the Himalayas in Asia, mountain ecosystems are distinct from lowlands—and they are invariably considered among the world's most vulnerable biogeographical domains. Additionally, nearly all the conservation issues in mountain areas relate to one or more of the following three major threats, or areas of concern, broadly driven by socio-economic, geophysical, and political dimensions:

- Loss or degradation of *biodiversity* and *ecosystem services*;
- Persistent or increasing *risk of natural hazards* (e.g., flooding); and
- Loss of *traditional knowledge* (including farming and pastoral livelihoods).

Several core characteristics render mountain ecosystems particularly susceptible to damage or degradation, whether due to natural or anthropogenic pressures:

- Mountains by their nature are *fragile and highly susceptible to erosion*, leading to landslides and sometimes flooding. As dynamic environments, mountains are places of significant activity, more likely to be affected by lava flows, avalanches, earthquakes, and rock falls.
- In high altitudes, *rates of recovery* following disturbance also are slow, mainly due to climatic conditions. When habitat is disturbed, degraded, or lost, wildlife (flora and fauna, including soil biota) are generally very slow to return to their original condition.
- As *island habitats* in a sea of relatively intense human disturbance, mountain biodiversity cannot simply migrate or extend beyond the geographic limits of mountain areas. Most mountain habitats are, in effect, distinct and fragmented from each other. However, with less human disturbance than surrounding areas, and with their relative isolation compared to more densely populated lowlands, mountains also may serve as refugia for some species or provide conditions suitable to speciation—with consequent high levels of endemism in mountains.

The following more proximate threats to mountain systems also are widely recognized:

Deforestation in mountains, illegal logging and uncontrolled gathering of fuel wood lead to loss of resources, slope instability, increased erosion, changes in micro and regional climates—all of which equally are intertwined with and often exacerbate the poverty in communities dependent on a decreasing and degrading natural resource base.

Unsustainable livestock grazing in fragile alpine pastures, especially where land tenure and resource usage rights are unclear or uncertain, and *agricultural encroachments* due to population growth or uncontrolled demographic movements, also bring unnecessary pressures to fragile mountain systems, where resources already are maximally used.

Poorly conceived infrastructure projects including road construction and development of hydropower dams have often resulted in severe damage to the natural environment and people's livelihoods, both through direct loss of habitat and resources and the increased disturbance created by new access infrastructures, concurrently with poor or virtually nonexistent government legislation and limited capacities for its enforcement.

Improved access in particular has also contributed to a large increase in *illegal wildlife poaching* of both plants and animals. The remoteness and vast scale of mountain areas render difficult any monitoring and control of illegal activities, even more so as many mountain ranges constitute geopolitically sensitive international border areas.

Quarrying and mining can also take their toll on mountain ecosystems, due partly to the development of access routes (see above) and an influx of short-term residents, and partly to the risk of pollution—especially with the potential for accidental leakage into water ways, with obvious negative downstream impact for both wildlife and people.

Finally, *tourism development* is both a potential source of socio-economic benefit and of conservation awareness, and also a risk—the latter especially if tourism development is implemented too casually or with narrow economic interests focused on the benefit of people living or based outside of the mountains. Influxes of large numbers of short-duration visitors and service providers insufficiently vested in equitable development can lead to disastrous outcomes, with environmental degradation as well as increasing social disparities and cultural erosion.

In addition to the above direct and immediate threats to mountain ecosystems, with all their varied and interconnected social and ecological impacts, two other global issues that can constitute both threat and opportunity also stand out, namely *climate change* and *globalization*—cross-cutting, pervasive, and present for the foreseeable future.

Climate Change

Climate change is particularly noteworthy, as mountain systems are disproportionately affected by the changes undisputedly observed in the world's climate (Macchi, 2010; Price and Egan, 2014), even though their origin is for the most part outside mountain regions themselves. New or emerging climatic realities include a significantly increased frequency and magnitude of extreme events, changing precipitation patterns, and increases in temperature with consequent melting of glaciers—which itself also can lead to an increased frequency and severity of natural hazards faced by mountain peoples. Climate change is occurring more rapidly in mountains than in any other ecosystem outside of the polar regions (see Kohler and Maselli, 2009; Kohler et al., 2014).

While mitigation of the factors influencing current climatic trends is largely outside the control of the people and communities residing in mountain regions, adaptation to these observed or anticipated changes is both necessary and possible. Local mountain farmers and pastoralists have long practiced and adapted their resource management on a trial-and-error basis, with more or less explicit (conscious) observation of outcomes; leading to socio-cultural evolution over generations of their integrated resource use patterns. At higher levels, many countries are developing their national strategies for climate change adaptation. Long-term systematic monitoring of environmental conditions, and access to information in general, will increasingly be necessary to help monitor in detail the changes that are occurring, and thus monitor the impacts of adaptation strategies.

Globalization

Even in remote mountain regions, globally dominant development ideologies mediated by powerful socio-political systems are greatly impacting the lives of mountain peoples—often without their knowledge and rarely with their consent (also referred to as *free, prior, and informed consent*; in the case of indigenous or local peoples' participation in decision-making, see UNDRIP, UN Declaration on the Rights of Indigenous Peoples, 2008). Sometimes these ideologies fail to serve the best interests of the intended beneficiaries, for example, when development aid is offered on the basis of donor country priorities, or when business interests are assumed to supersede other needs, interests, or aspirations of mountain people themselves.

Given that local communities often have adapted their agricultural and other livelihood practices to their unique, often heterogeneous mountain environments (including local livestock breeds or plant cultivars), the agro-biodiversity they have developed over time could potentially play a significant role in future climate change adaptation. It is therefore particularly important to enable and to empower small-scale farmers, over and above larger external business interests (e.g., corporations)—rather than bypass or assimilate them into a more homogenous globalized world (Foggin, 2008; Hodges et al., 2014). The loss of family or community-oriented farming systems as well as communal pastoralist management systems (see McGahey et al., 2014)—and the ecological knowledge therein, accumulated over centuries—would be a fundamental loss to humanity, a loss of cultural heritage as well as of a diverse suite of tried-and-tested livelihood options that could help in our response and adaptation to climate change.

For further discussion of these and other anthropogenic threats to mountain systems, also see Messerli and Ives (1997) and Price (2015).

Conservation Efforts—Past and Present

In response to the above realities and the benefits that we may derive (or lose) from mountain ecosystems, a wide array of conservation practices and initiatives have been attempted over the past decades and centuries. While the following highlights are not an exhaustive list, they are some of the core approaches that have contributed to successful conservation in mountain ecosystems around the world. Additionally, it is noteworthy that such conservation responses have come from individuals and communities as well as government, and have operated across a wide range of spatial and temporal scales.

Protected Areas

“Protected areas” is a broad category of landscapes (and seascapes) that are recognized as locations or areas of particular natural, ecological, and/or cultural significance, and therefore have been designated as “protected” for the purpose of conservation. Many different categories and subcategories exist, though not all are held in common in all countries. However the protected area (PA) management categories provided by the International Union for the Conservation of Nature (IUCN)—the world's oldest and largest global environmental organization, with nearly 1300 government and NGO members and over 15,000 volunteer experts in 185 countries (IUCN, International Union for Conservation of Nature and Natural Resources, 2016)—generally are accepted as the global standard, including by the United Nations and many national governments.

Following IUCN's definition of PAs as “clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values,” there are many ways in which PAs may be operationalized, as indeed they have been across space and time. Probably the best-known

form of PA management is that of the national park system, initially launched in North America with the establishment of Yellowstone National Park in 1872, Banff National Park in 1885 and Yosemite National Park in 1890. These parks have served as models globally, and were exported around the world over the subsequent century. The main purpose of these parks, however, has been to promote tourism to allow the public to visit and appreciate nature in its pristine form. This, however, never was the reality of such places—as even “pristine” areas such as Banff and Yosemite had for a long time been managed and conserved successfully by local indigenous communities.

In the above cases, First Nations and Native American groups were forcibly removed from the land, in most reprehensible ways, to make way for the national parks (Dowie, 2009). It is of paramount importance, therefore, that we consider afresh the different roles and approaches that can be used in conservation and particularly protected area management; and duly involve all stakeholders in dialogue and decision-making to find more equitable solutions. While the history of national parks does have such a dark side, fortunately the inclusion of local and indigenous peoples in protected area governance has increased markedly in recent decades, demonstrated most recently on a global stage in the “Promise of Sydney” declaration (IUCN, International Union for Conservation of Nature and Natural Resources, 2014) issued by over 6000 participants at the IUCN World Parks Congress in Nov. 2014.

Working through a large variety of implementing partners, global institutions such as the Global Environment Facility (GEF)—established on the eve of the 1992 Rio Earth Summit to help tackle our planet’s most pressing environmental problems—also are strongly committed to improving the effectiveness and the equity of protected areas. More specifically, Chester et al. (2013) summarize the relation between mountains and PAs: “The formal establishment of protected areas in mountain regions is tightly inter-woven into the complex tapestry of conservation history. Notably, many of the world’s earliest protected areas were established in mountain environments. [Today] there are at least 21,400 protected areas in mountains . . . constituting roughly 32 percent of the global protected areas estate (Körner et al., 2005a,b) and covering 17 percent of the total mountain area outside of Antarctica (Rodríguez-Rodríguez et al., 2011; also see Hamilton, 2006).” Biosphere reserves are a special type of protected area that draws special attention to the connections and potential compatibility between people and nature, bridging conservation and development agendas (Price and Persic, 2013; Schaaf, 2009; Möller, 2011).

In the context of climate change (see above), national and regional PA systems—with their relatively undisturbed natural ecosystems as well as the traditions preserved in some instances—may equally serve increasingly important ecological functions. In particular, PA systems help to increase our adaptive capacities through their role—when suitably designed—as corridors for movement along or across mountain ranges for wildlife species forced to migrate or shift distributions due to changing environmental conditions (Worboys et al., 2010).

ICCAs—Recognizing Local Communities and Indigenous Peoples

One very important subset of PAs deserves special mention, namely “indigenous and community conserved areas” (ICCAs). These areas, or resource management systems, are among the oldest in the world. As Borrini-Feyerabend and Hill (2015) explain:

Governance by indigenous peoples and local communities is the oldest form of governance of land and natural resources and is still widespread, applying to all forms of ‘commons’—that is, land, water and natural resources governed and managed collectively by a community of people, settled or mobile. Throughout the world and over thousands of years . . . communities have been developing their livelihood strategies, responding to the opportunities and challenges of their environments.

Conservation by indigenous peoples and local communities in these often very large territories and areas, such as in the transboundary Kangchenjunga Conservation Area, may involve strict protection of an area in its so-called natural state, preservation of certain natural features, more “passive” shaping and maintenance of valuable landscapes, or sustainable and biodiversity-friendly use of natural resources (Borrini-Feyerabend et al., 2013). Globally, it is estimated that ICCAs cover approximately 13% of the land area (ICCA Consortium, 2016). IUCN and its constituent members now acknowledge such ICCAs through an expanded, comprehensive matrix of PA management categories and governance types, including governance by local/indigenous peoples (Dudley, 2008).

Whether specifically recognized as ICCAs or not, a large proportion of the world’s PAs is inhabited and/or used by local or indigenous peoples whose livelihoods and/or cultural and spiritual relation with the land are critically important to them. It is these people and communities who are among “the most concerned and best equipped to conserve the relevant territories and resources, if given a chance and the proper means (Ostrom and Nagendra, 2006)” (Borrini-Feyerabend and Hill, 2015). However, greater recognition of ICCAs and of the conservation value of local or indigenous communities is still needed in many parts of the world including mountain regions (Price, 2015).

For further description and up-to-date information about ICCAs, the reader is directed to Borrini-Feyerabend et al. (2004a,b, 2013, 2015) as well as to the online ICCA Forum, <http://www.iccaconsortium.org>.

National Rules and Regulations, Laws, Legislations, and Policies

Beyond the establishment of PAs per se, or wider recognition of ICCAs, a complementary tool for the conservation of resources has long been the development and application of rules and regulations, sometimes formalized into national laws, legislations, and

policies. Some legislation may apply specifically to PAs, however many rules and regulations in regard to resource management and environmental protection have been developed for specific development sectors such as agriculture, construction, or mining. Social norms also are created over the span of generations—whether by local (including indigenous) communities, or by nation-states—in order to guard against the overuse or degradation of natural resources. Not all laws or regulations, however, need be *legally* binding to be effective; such is the case in many ICCA scenarios, especially in remote areas (see, e.g., the experiences of pastoral communities in the Tibetan highlands; Foggin, 2000, 2005).

National governments also have developed many laws in support of their development goals and commitments, both independently and as part of the global community (cf. UN treaties and conventions). Much international development support is now focused on promoting or adapting/refining development policies and related legislation—and their implementation—to achieve broadly agreed development priorities such as the United Nation’s Sustainable Development Goals (SDGs). For a long time, though, the critical significance of mountains for humanity (especially through provision and regulation of water resources) was not adequately recognized. However, a general awareness of the need for a dedicated “mountain agenda” with a focus on the specificities of “sustainable mountain development” is now increasing (Wehrli, 2014). Mountains are specially referenced in 2 of the 17 goals in the post-2015 SDG framework (also known as the *2030 Framework for Sustainable Development*), in particular with a subgoal to ensure by 2030 “the conservation of mountain ecosystems, including their biodiversity, to enhance their capacity to provide benefits which are essential for sustainable development” (UNSDKP, UN Sustainable Development Knowledge Platform, 2016).

The major significance represented in these advances, from the Rio 1992 Earth Summit and the launch of the International Year of Mountains in 2002 to the present time, lies in the broad recognition within governments (and also intergovernmental institutions, as well as the development donor community) that mountain regions are distinct—and that mountain resources play a crucial role for both local and global development.

International Conventions for Conservation and Sustainable Development

Internationally, the UN framework provides the strongest basis for the development and for institutionalizing into government legislations a wide array of evidence-based norms and practices. **Table 2** provides a list of the major UN conventions, ratified by many countries, which are particularly relevant to mountain areas.

Several international mechanisms (e.g., Global Environment Facility) provide financial support for implementation of these UN conventions, as well as governments through their development aid programs (e.g., SIDA, SDC, USAID)—albeit the latter also are more attuned to individual (national) priorities, sometimes including trade relations. Intergovernmental organizations and a variety of wide-ranging partnerships also have been established in support of mountain development, such as the International Centre for Integrated Mountain Development (ICIMOD), with regional focus on the Himalayan and Hindu Kush mountain ranges, and the Mountain Partnership (comprised of NGOs, nation-states, and others) with its policy advocacy role and vision to protect mountains and to improve socio-economic conditions by empowering mountain peoples to become more fully engaged in decision-making. Among national government aid programs, the Swiss Agency for Development and Cooperation is exemplary in its recognition and support of mountain regions, especially as it incorporates considerations both of global climate change and local mountain voices.

Transboundary agreements also play a significant role in mountain conservation, as many international boundaries are marked by mountain summits or ridge lines. While such borders are often politically sensitive, sometimes disputed, scientific cooperation or joint management of protected areas (e.g., international peace parks) may help with rapprochement through increased collaboration and mutual understanding. Such transboundary approaches have been adopted by ICIMOD (see above) and also are relevant for UNESCO’s International Hydrological Programme and its World Heritage Program, including many transboundary mountain sites, as well as the IUCN World Commission on Protected Areas (Vasilijević et al., 2015; Puri and Aureli, 2009; UN Water, 2008).

As one of the primary funding mechanisms for a majority of the conventions listed in **Table 3**, the GEF has long been explicit in its recognition of mountain ecosystems as high priority (World Bank, 2002). In the present operational phase too (i.e., GEF-OP6), the increased risk to human populations and to ecosystems dependent on water resources as glaciers melt due to climate change also is noted, especially as 500 million people in Asia clearly are dependent on the waters originating in the Himalayas, Hindu Kush, and Tibetan plateau region. The significance of scaling-up sustainable land management (SLM) through adopting a

Table 2 Major United Nations Conventions that impact mountain ecosystems

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- Convention on Biological Diversity (CBD), incl. Access & Benefit Sharing (ABS)
 - United Nations Framework Convention on Climate Change (UNFCCC)
 - Stockholm Convention on Persistent Organic Pollutants (POPs)
 - UN Convention to Combat Desertification (UNCCD)
 - Montreal Protocol of the Vienna Convention on Ozone Layer Depleting Substances
 - Convention on Migratory Species (CMS)
 - Convention on Migratory Species (CMS)
 - Ramsar Convention on Wetlands
-

Table 3 Key concepts and approaches in conservation sciences*Key concepts:*

- Island biogeography
- Metapopulation dynamics
- Fragmentation and connectivity
- Biodiversity and ecosystem services
- Population viability
- Keystone species
- Role of disturbance
- Ecological resilience

Key approaches:

- Protected area systems
- Ecosystem-based management
- Multiple use management, adaptive management
- Sustainable land management
- Integrated watershed level management
- Multidisciplinarity, interdisciplinarity, transdisciplinarity
- Ecosystem-based adaptation to climate change

landscape approach is specially encouraged, in particular with “integrated watershed management, including wetlands, trans-boundary areas and mountainous regions where SLM interventions can improve hydrological functions and services for agro-ecosystem productivity” (GEF, *Global Environment Facility*, 2014). Through history as in the present time, mountains have long held a special significance for people—sometimes for their goods and services, sometimes also revered as holy places or where poets, artists, and musicians have sought and found inspiration.

Conservation Sciences: Key Concepts and Management Approaches

Finally, built into most conventions, protocols, best practice guidelines etc. are many conservation issues and concepts—relevant for mountain systems as for elsewhere—which have been identified or developed over the past several decades under the aegis of *conservation science* (or conservation biology) by practitioners and academics alike.

Many conservation texts already exist (e.g., MacDonald and Willis, 2013; Milner-Gulland and Rowcliffe, 2007; Sutherland, 2000), and many university courses are available. Some of the most significant advances in conservation sciences in recent years—key concepts and management approaches—are listed in Table 3. As a part of international endeavors to manage natural resources (biodiversity) sustainably, a variety of regional and global monitoring systems have also been developed in recent years. Data collected contribute to our corporate assessment of the current status and trends in the observed systems.

Current or recent global monitoring networks, and networks of professionals (e.g., WMF), with a special focus on mountain social–ecological systems include:

- Global Land Project (GLP)
- Global Change in Mountain Regions (GLOCHAMORE)
- Global Network of Mountain Observatories (GNOMO)
- Global Observation Research Initiative in Alpine Environments (GLORIA)
- International Geographical Union (IGU)—Mountain Commission
- IUCN-WCPA Mountain Protected Area Network
- Mountain Partnership
- Mountain Sentinels Collaborative Network
- World Mountain Forum (WMF)

In the end, there is need for integrative and empowering monitoring programs and conservation approaches that encompass both the natural and the social sciences and include local communities as partners. It is by working together to address large threats such as climate change and inequitable development paradigms that we can most effectively assess and respond to the conservation situation we face today.

For purposes of conservation, both social and ecological elements should be considered and incorporated into critical analyses, however all too often the focus of conservation research and monitoring remains primarily on the natural subsystems—even though the human dimensions of conservation are equally critical to long-term sustainability. There is clearly need for more

research to be undertaken on how people's knowledge, values, and behaviors influence and are affected by environmental management and conservation decisions, as well as on the interface of overlapping and sometimes competing "conservation" and "development" agendas (see [Chan et al., 2007](#)).

One of the anomalies of modern ecology is the creation of two groups, each of which seems barely aware of the existence of the other. The one studies the human community, almost as if it were a separate entity, and calls its findings sociology, economics, and history. The other studies the plant and animal community (and) comfortably relegates the hodgepodge of politics to "the liberal arts." The inevitable fusion of these two lines of thought will perhaps constitute the outstanding advance of the present century.

[Leopold, 1935](#)

Conservation actions are ultimately human behaviors, and it is vital to understand how social factors (e.g., markets, cultural beliefs and values, laws and policies, demographic change) shape human interactions with the environment and choices to exploit or conserve biodiversity.

[Fox et al, 2006](#)

Conservation problems are social and economic, not scientific, yet biologists have traditionally been expected to solve them.

[Schaller, 1992](#) (cited in [Bennett and Roth, 2015](#))

Closing Remarks

As outlined at the beginning of this article, key interventions required for conservation of mountain ecosystems include the protection of biodiversity, empowerment of local mountain communities, and elaboration of context-specific policy environments that support and enable sustainable mountain development. To achieve these, integrated management approaches are necessary to ensure that the complex realities of the world's mountain systems are understood—and preserved.

In order to address conservation issues in mountain ecosystems, clearly an *integrated, transdisciplinary approach* that spans the social and natural sciences as well as truly involving and partnering with all levels of stakeholders, including communities, must be adopted. Mountains matter—and they matter for all sectors of society, at all scales.

Since conservation is premised on the *sustainable use* of natural resources, and since the *human dimensions* of resource use likely constitute the most significant opportunities as well as the greatest challenges for conservation, it is not surprising that conservation depends not only on science, but also people's perceptions and on politics. In mountain areas, *politics of power* (or political ecology; e.g., the capture of natural resources by elite minorities, such as a ruling class) as well as relevant policy, legislative and enforcement issues are entangled. Such a web of conservation issues and options must be addressed in integrated manner, together with sound understanding of the biology and ecology of the species, habitats, and ecosystem of interest.

Development of mountain areas is often shaped by decisions taken in political and economic centres in lowland areas. The interests behind these decisions are short-term rather than long-term, and extraction of resources takes precedence over the sustainable development of mountain areas. To end political and economic marginalisation, mountain areas need to be recognised as equal partners in development. Strategies to achieve this goal include decentralisation, local institution building, recognition of local rights to natural resources, and establishment of platforms and collaborative networks to give mountain populations a "voice."

[Mountain Agenda, 2002](#)

Geographic location and inaccessibility equally are key features in most mountain areas, often leading to community (and sometimes cultural) disempowerment, marginalization, and poverty.

Mountain farmers are often a minority in their [own] countries. . . They live far away from the centres of economic and political power and decision-making, and are often marginalized in political, social, and economic terms. This is particularly true for communities with livelihoods and farming practices that deviate from global and national mainstreams, such as shifting cultivators or pastoralists, which are both prominent and important in mountain regions. One of the results of marginalization is widespread poverty.

[Kohler and Romeo \(2013\)](#)

Whether we consider land, soil, water, habitats, wildlife, or cultural complexes that have developed over generations in mountain regions—all are integral parts of the mountain conservation equation. Mountains are social–ecological systems, and their conservation requires that all component parts be preserved in reinforcing ways.

With a large portion of the world's water resources originating in mountain areas, and nearly half of the world's biodiversity hotspots and much cultural diversity being found there, mountains are among the most valuable biomes for the wellbeing of humankind. In addition, a diversity of spiritual values and our aesthetic appreciation of mountain ecosystems as well as livelihood, recreational, and other economic values are further reasons why mountains matter so much to us. Ultimately, however, it is their intrinsic value that most warrants our respect and their sustainable use and conservation.

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