



United Nations
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Mountain Ecosystem Services and Climate Change

A Global Overview of Potential Threats and Strategies for Adaptation





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A Global Overview of Potential Threats and Strategies for Adaptation

Prepared for the UNESCO Programme Climate Change Impacts in
Major Mountainous Regions of the World: Multidisciplinary Network for
Adaptation Strategies (Africa, Asia, Latin America and Europe)

Editors

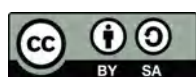
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Note from the coordinators

This document is an outcome of discussions based on an overview paper presented at regional workshops in Africa, Asia, Latin America (2013) and a final workshop held in Paris (2014) in the context of a Project on “Climate Change Impacts in Major Mountainous Regions of the World: Multidisciplinary Network for Adaptation Strategies (Africa, Asia, Latin America and Europe)”.

The International Hydrological Programme (IHP), in cooperation with the Man and Biosphere Programme (MAB), UNEP, ICIMOD and the Mountain Partnership Secretariat at FAO organized three regional workshops to gather inputs from Asia (Kathmandu, Nepal, March 2013), Latin America (San Jose, Costa Rica, August 2013) and Africa (Nairobi, Kenya, September 2013).

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Executive summary

Mountains provide vital resources to a significant proportion of the global population, particularly as the 'water towers' of the world, and as a result of their high biological diversity at genetic, species and ecosystem levels. As well as benefiting people and industries in lowland areas, these ecosystem services (ES) form the basis of most mountain livelihoods. However, despite providing such an unprecedented abundance of ES, mountains remain among the poorest documented ecosystems in this regard. Greater use of the ES framework can help provide a large-scale view of the unique 'multifunctionality' of mountains.

Given the immense threats to mountain systems posed by climate change, sensitive management of ecosystems can help promote climate change adaptation, and an emerging approach has been explored in a number of mountain areas, in the form of ecosystem-based adaptation. Inherent in this approach is the sustainable use of biodiversity and

other ES as a means to foster the adaptive capacity of mountain socio-ecological systems in response to anticipated climate change.

This paper presents a review of potential climate change and anthropogenic pressures on mountain ES, particularly focusing on water resources scarcity and increasing water demand due to rapid increases of population and utilisation of mountain ES. Adaptation strategies and supporting policy recommendations are also presented. An overview is presented on a global basis, but analysis also focuses on how mountain ES may be differentially affected due to key regional specificities in major mountain systems of the world. Existing policy and international frameworks of relevance to climate adaptation are examined in detail. Based on this, recommendations are presented on future policy directions, to support adaptation measures explicit to mountain ES using an ecosystem-based approach.



Perito Moreno Argentina © Marcela Fibiger Mountain Partnership at FAO

1. Introduction

Mountains occupy 22% of the Earth's surface, and 915 million people live in them: 90% in developing countries (Romeo *et al.* 2015). They are also the sources of the world's major rivers (Viviroli *et al.* 2007, 2011). Thus, mountains provide vital resources to a significant proportion of the global population. This globally critical reliance on the goods and services provided by mountains implies an urgent need for research and monitoring, in order to sustainably maintain their resources and protect them from the combined impacts of growing demands deriving from increasing human populations and climate change (e.g., Gleeson & Greenwood 2015; Singh & Thadani 2015). The conceptual framework of ecosystem services (ES) (the direct and indirect goods and services provided by ecosystems) offers a standardised approach to classifying and quantifying these resources in ways that are meaningful in both ecological and socio-economic terms. The impetus provided by the largest assessment ever undertaken on the global health of ecosystems, the Millennium Ecosystem Assessment (MEA – Reid *et al.* 2005), has served to popularize the ES concept within both scientific and policy-making domains. The use of the framework, starting with a specific chapter in the MEA (Körner *et al.* 2005) has helped to provide a large-scale view of the unique 'multifunctionality' of mountains in comparison to other terrestrial habitats, increasing the recognition that mountains have gained on the global agenda over the past two decades (Debarbieux & Price 2008). Despite growing recognition of the essential importance of mountains, however, the concept of ES, and of anthropogenic pressures on ES, has not been widely used within published literature referring to mountains. This situation is in stark contrast to the global and manifold importance of mountains, and must be remedied as part of integrated efforts towards sustainable development focused on the livelihoods of mountain communities and taking into account increased demands for food, fodder and other rangeland products, timber and other forest products, water, tourism, cultural, and industrial development.

Given the emerging recognition of ES provided by mountain systems, and the extent to which not only mountain communities but also lowland populations rely on these, the degree to which global change – including both climate change and global demographic and economic driving forces – may drastically alter these ES presents real threats. In particular, climate change is influencing mountain ecological and geosystems at a faster rate than other terrestrial habitats globally (Nogués-Bravo *et al.* 2007), and due to the rapid rate of deglaciation in the mountain cryosphere worldwide, mountain glaciers have themselves become key indicators of global climate and its warming. Already, climate change is clearly affecting the capacity of mountains to provide vital ES, which requires balancing between the potential of mountain regions to provide ES and the increasing demands for them. Thus, due to their high sensitivity, mountain ecosystems can serve as global early warning systems (Björnsen Gurung 2010). The potential medium- to long-term impacts of climate change in mountain areas are predicted to herald considerable and unprecedented change to their inherently fragile ecosystems, which are likely to be further exacerbated by various human interventions. Anticipation of these changes can provide the first step in the formulation of local- to regional-level adaptation strategies to address all aspects of global change, as a component of much-needed mountain-specific planning and policy. A key element of this must be to strengthen the political relevance of, and attention to, the ES concept.

This paper is based on literature review, as well as three regional workshops held during 2013, organised in Africa, Asia, and Latin America in collaboration with UNEP, ICIMOD and the Mountain Partnership Secretariat, and a global workshop in 2014. The paper presents a review of potential climate change and anthropogenic pressures on mountain ES, focusing particularly on water resources scarcity and increasing water demand, due to rapid increases in population and subsequent utilisation of mountain ES. An overview is presented on a global basis, but analysis

also focuses on how mountain ES may be differentially affected due to key regional specificities in major mountain systems, illustrated by case studies (boxes) deriving from the regional workshops. Existing policy and international frameworks of relevance to climate

adaptation are examined in detail. Analysis of these frameworks leads to recommendations on future policy directions, to support adaptation measures explicit to mountain ES using an ecosystem-based approach.

2. Mountain Ecosystem Services

2.1 Ecosystem goods and services from mountain areas

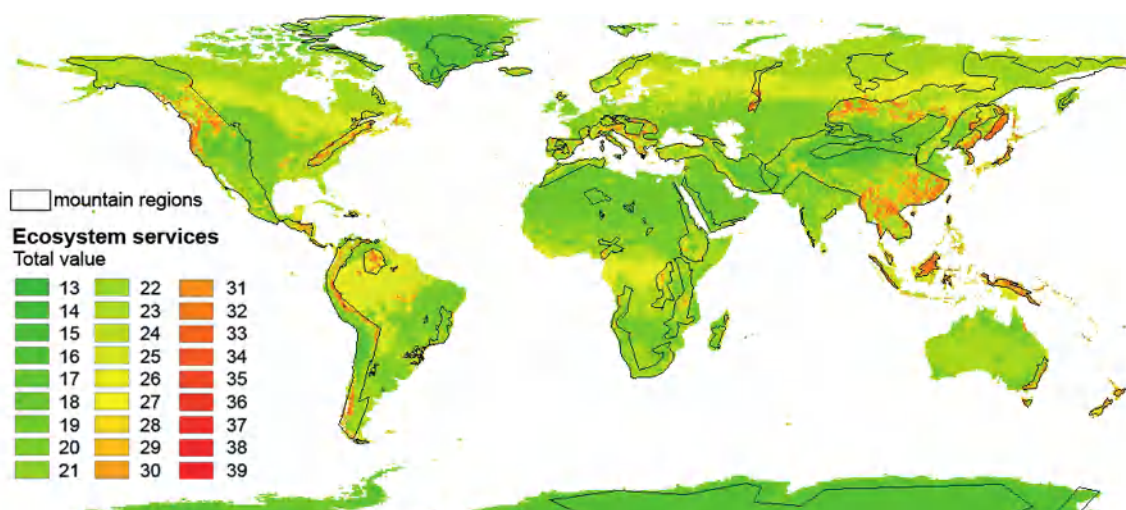
Mountain systems are widely distributed across all continents, from tropical to arctic latitudes, and thus support vastly differing biota, livelihoods, and human population densities. Despite such inherent differences, it is possible to derive global generalizations of the importance of mountains as sources of ES. The conceptual framework of ES was mainstreamed in the first product of the Millennium Ecosystem Assessment (MEA) in 2003 (Alcamo & Bennett 2003), in which 24 such services were defined and classified under the categories of provisioning, regulating, and cultural services (as well as supporting services which underpin each of these). On a global basis, while mountains provide very high levels of ES, the potential for deriving benefits from these largely remains underutilized. Mountain areas ranked very high in a study which examined the capacity of ecosystems to supply 15 selected ES, mostly provisioning and regulating (Grêt-Regamey *et al.* 2012). As highlighted in Figure 1, the vast majority of geographic areas identified as providing the highest levels of all 15 of these ES are in mountainous regions, as defined by Kapos *et al.* (2000).

These findings are supported by a qualitative assessment of European terrestrial and freshwater ecosystems (Harrison *et al.* 2010), which found that, of all habitat types evaluated, mountains provided the most diverse and numerous sources of ES. In most instances, mountains provided key contributions to ES and, of the 24 services assessed, there were none to which mountains did not contribute. However, not

all mountain ES were sufficiently known to allow more than preliminary assessment. Although qualitative in nature, the assessment allows for relative comparisons amongst habitat types, which has both revealed the importance of mountains and highlighted ES categories which are poorly known and in need of greater elucidation in future studies.

Despite providing such an unprecedented abundance of ES, mountains remain among the poorest studied ecosystems in this regard. Although the scientific literature with an explicit primary focus on mountain ES is growing, it remains very limited. By 2010, only 26 studies in mountains had included some form of valuation of ES and their links to human well-being (Grêt-Regamey *et al.* 2012). One basis for this finding was that improper use and interpretation of the concept of ES had been common: more than 80% of studies which purportedly featured mountain ES topics did not progress beyond descriptions of ecosystem functioning. While additional studies have since been published (e.g., Kakuru *et al.* 2014) this challenge must be addressed in order to uphold the integrity and functionality of the ES concept in mountain research, less it become superficial and functionally meaningless in both the scientific and the public sphere. UNESCO's biosphere reserves present particular opportunities for such studies (Box 1).

Figure 1. Classification of terrestrial habitat to provide 15 ES at 1 km² grid resolution. ESScap is a proxy for the capacity for the land in any 1 km² cell to provide ES and correlates strongly with the richness of ES in a cell. Mountains (highlighted by the bounding line) provide the most numerous ES (Grêt-Regamey *et al.* 2012).



Box 1: Biosphere reserves as learning places for the sustainable use of ecosystem services

The importance of mountains and the ES that they provide is reflected in the distribution of UNESCO biosphere reserves throughout the world. Today, of the 669 Biosphere Reserves in 120 countries, more than 60% are entirely or partly comprised of mountain ecosystems. These sites aim to improve human livelihoods while protecting their ecosystems. They promote innovative approaches to economic development that both environmentally sustainable and socially and culturally appropriate. Biosphere reserves can be seen as 'learning places for sustainable development', where interdisciplinary approaches can be tested to understand and manage changes and interactions between society and ecosystems. This is why biosphere reserves can be a useful tool to test practical methods of integrating conservation, restoration and sustainable use of ES.

Utilisation of most ES in mountain areas is usually disproportionately focused on a range of services related to forestry, water resources, agriculture, biodiversity, and tourism, some of which have been over-exploited (e.g., Ndanyalasi *et al.* 2007). However, the remoteness and under-developed levels of connectivity and infrastructure that characterise many mountain areas have worked both in favour of preservation of ES and to the disadvantage of indigenous mountain communities, who could potentially benefit from the greater release of the potentials offered by mountain ES that have not yet been realised fully, if at all. For example, both infant and maternal mortality rates are generally higher in mountain areas, due to hunger and micronutrient

deficiencies (Romeo *et al.* 2015). Gender aspects can also play a large role in terms of access to and the disproportionate use of mountain ES, as a function of sociocultural norms (Kideghesho & Msuya 2010); not all of which may be viewed as equitable. The following sections take a greater look at each ES category, detailing the most important services that mountains provide globally. Table 1 indicates the relative importance of the various ES provided by mountain ecosystems.

2.1.1 Provisioning Services

The key provisioning services provided by mountains include freshwater, food and fibre, medicinal plants,

fodder, timber (as a source of fuel/energy), habitat, and genetic resources. Across most of the world’s ecosystems, provisioning services have generally been enhanced at the expense of other categories, in particular regulating and supporting services. Mountains prove no exception to this trend, and trade-offs due to the enhanced production and extraction of goods and services are evident through impacts on the structure, functioning and natural capacity of mountain ecosystems.

Water is perhaps the most critical ES provided by mountains, particularly in terms of its supply to more densely populated adjacent lowlands. The great importance of mountains as sources of freshwater

has justified their label as the ‘water towers’ of the world (Vanham and Rauch 2009; Viviroli *et al.* 2007), as it is estimated that at least half of the world’s population depends on water originating from mountain headwaters. As a function of their hydrology (higher relative rates of precipitation) and cryosphere (seasonal snow, permafrost, glacial and lake ice meltwaters), mountain areas contribute to the provision of this vital resource, contributing disproportionate amounts of runoff to nearly all of the world’s major rivers (including the Amazon, Yangtze, Niger and Mississippi-Missouri systems) and many minor rivers, and as origins and storage locations of groundwater.

Table 1. Mountain ecosystem services and their relative importance. Adapted from Harrison *et al.* (2010) & Körner *et al.* (2005). Services highlighted in bold indicate services of key importance that are also poorly known.

Contribution	Provisioning	Regulating/Supporting	Cultural
Key	<ul style="list-style-type: none"> • food & fibre/fodder • genetic resources • freshwater • timber 	<ul style="list-style-type: none"> • climate • air quality • water flow • erosion • natural hazard 	<ul style="list-style-type: none"> • education • recreation • sense of place • cultural heritage • aesthetic values
Some	<ul style="list-style-type: none"> • ornamental resources • biochemicals/medicinal plants 	<ul style="list-style-type: none"> • pollination • pests • seed dispersal • diseases • water purification 	<ul style="list-style-type: none"> • spiritual & religious values
None	-	-	-
	Very important	Very important	Important

Globally, 23% of mountain areas are essential to downstream water supply; another 30% support this supply to some extent (Viviroli *et al.* 2007). People and industries in downstream areas and adjacent lowlands rely heavily on mountain water not only as a source of freshwater for consumption, but also for economic activities, including for agricultural irrigation and in various industrial sectors (Box 2). Mountain rivers are also used for the generation of hydroelectricity, with dams and power stations located both in the mountains and downstream. As demands for energy are set to rise dramatically over the coming decades as the global population and economy increase, it is

clear that hydroelectricity generated from mountain rivers will play an important part in meeting these demands at all scales, from micro-hydro to cascades of dams along river systems.

Mountains have also long been recognized as globally- and regionally-important centres of biodiversity (Mittermeier *et al.* 2011), many of which are directly used by people. Given the often extreme variations of climate and topography over relatively short geographic distances, mountain regions commonly exhibit both high rates of endemism and great biological diversity at genetic, species and

ecosystem levels. For mountain people, this rich biodiversity provides a rich variety of provisioning ES in the form of food, fibre, medicinal plants, genetic resources, and timber and non-timber products from mountain forests (which constitute 28% of global forest area: Kapos *et al.* 2000). In addition to supporting the livelihoods of mountain communities, which commonly depend primarily on such natural resources, mountains have provided global benefits as the original source of diversification and/or domestication for many of the world's major crop

species (e.g. maize, barley, potatoes, sorghum) and several domestic animals (e.g. sheep, goats, domestic yak). Mountains continue to remain valuable in this regard as part of modern breeding and bioprospecting initiatives, and as vital gene pools for agriculturally and pharmaceutically important plants, wild crop relatives, and horticulturally valuable ornamentals. However, despite this noted importance, the prospect and knowledge of genetic resources as sustainable mountain ES generally remain poorly known.

Box 2. Good governance for local delivery of watershed services – case studies from the Hindu Kush Himalaya

While it is acknowledged that payment for ecosystem services (PES) can serve as a valuable instrument that can underpin ecosystem-based adaptation (EbA), good examples of PES-type schemes that operate successfully at the local level are still few. Nevertheless, the concept of payments for watershed services is seen as an important innovation, as part of the wider goal of integrated watershed management. In the context of climate change, better management of water resources (including infrastructure development) in upper mountain catchment areas of the Hindu Kush Himalaya will be vital in order to enhance water security and the adaptive capacity of downstream users.

Practical projects from Nepal – such as the Dhulikhel water supply project (implemented by the local municipality) and the Kanchanpur irrigation project (facilitated by the District Forest Office) – have highlighted the importance of strong local governance and institutional leadership in such processes. A collaborative approach to project development, in which both local and upstream mountain communities are embedded, has been a common thread pivotal to successful implementation. This success has been evidenced in provision of a reliable and high quality water source to the town of Dhulikhel, 20 km east of Kathmandu; whereas in Kachanpur, downstream irrigation users pay a nominal fee to upstream Community Forest User Groups (CFUGs) – and, in return for deriving this much-needed economic benefit, the CFUGs ensure adequate conservation and maintenance works on the Haldekhel River.

The development of specific local-level policy and governance practices can help foster wider adoption of such 'community-to-community' models, which have the power to improve watershed services in linking communities through PES or other incentive-based mechanisms. Supporting actions by local government and institutions should anticipate the likely need of communities for legal and contractual flexibility in PES schemes, as well as their potential high vulnerability to a market-based approach – particularly where there is extensive private-sector involvement.

2.1.2 Regulating & Supporting Services

Mountain systems not only provide ecosystem goods and services but, critically, also regulate factors which underpin their provision. The regulating and supporting services provided by mountain systems can be divided between the physical and biological elements. The physical regulating services are deemed most critical. These include the regulation of climate, air quality, water flow, and erosion and natural hazards. In comparison, relatively less is known on the biological importance of mountain systems in

regulating or supporting ES such as pollination, seed dispersal, and the regulation of pests and diseases.

In addition to providing invaluable sources of water to downstream communities, the processes of regulation and purification of water flow in seasonal hydrological cycles are key ES provided by mountains. The hydro-biosphere of mountain environments constitutes a tightly integrated series of systems which ultimately affect water provision and quality characteristics. Much research has been

conducted into the linkages between these systems, including interactions between precipitation rates, buffering effects of vegetation, storage capacity of soils, and formation of surface runoff. The regulation of both flow and purification of mountain water is highly dependent on human activities in upstream watersheds which may influence any, or all, of these system dynamics. In particular, links have been established between land use change – especially deforestation and the degradation of rangeland – and soil erosion in certain upland areas, driving increased sedimentation and irregularity of water flow in downstream areas. However, given the complexity of mountain ecosystems, and the large spatial scales at which such processes typically play out, establishing such causality and linkages between upstream and downstream areas may not always be straightforward. Healthy functioning mountain ecosystems also contribute to protection against natural hazards and the impacts of extreme events, particularly hydrological events such as floods and droughts. These regulating ES are especially critical to downstream areas, where the impacts of such events are often greatest, sometimes several hundreds of kilometres away.

2.1.3 Cultural Services

A remarkably high proportion of the world's cultural and ethno-linguistic diversity is found in mountain areas (Stepp *et al.* 2005), representing the legacy of human habitation in these challenging environments, typically over many centuries, if not millennia. The immense significance of mountain areas in terms of intangible services such as cultural heritage, aesthetic, and spiritual values is widely acknowledged and celebrated. The general remoteness and inaccessibility of mountains has, in many parts of the world, especially in least developed countries, allowed for the preservation of unique indigenous mountain cultures and associated traditional knowledge and production systems. Despite the intangibility of mountain cultures, they may contribute to economically relevant activities, not only through the maintenance of traditional practices for the management of land, plants, animals and other resources, but also by contributing to other resources, such as high-quality

foods and attractive cultural landscapes, that attract tourists into these otherwise remote areas.

Most mountain areas provide ample and diverse recreational opportunities, especially for hiking, climbing, and winter sports, though the extent to which these opportunities are realised varies greatly at all spatial scales in all mountain areas (Debarbieux *et al.* 2014). The importance of tourism and recreation is evident to the extent that they form the basis of local economies in many mountain areas worldwide, often making significant contributions to national economies, though a general lack of infrastructure often limits greater development in less developed regions. The sacredness of many mountains and mountain locations around the world has not only ensured the preservation of certain species, ecosystems, and landscapes (Verschuuren *et al.* 2010), but has also been a driver for the development of infrastructure into and through many mountains for centuries: pilgrimage is one of the oldest forms of tourism (Pohner *et al.* 2009). Today, while the image of mountains for many lowland people is one of 'purity' and close relationships between respectful people and the environments in which they live; it is the aesthetics of mountain landscapes that draw the most tourists, often from parts of the world with very different cultures, to mountain areas.

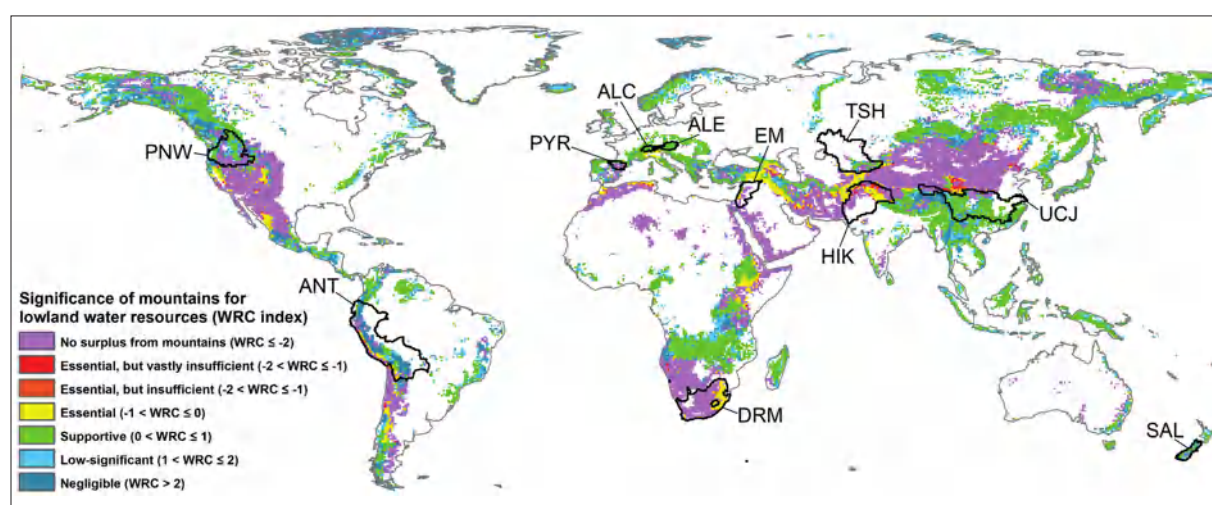
2.2 Global patterns – key similarities and regional differences

Mountain areas differ in their potential to provide ES. While it is useful to generalize discussion on ES provided by mountain systems, in the broad sense, the specificities and differences both between and even within mountain regions globally must be acknowledged. A comprehensive global definition of mountains was not established until 2000, using three types of criteria: slope, elevation, and terrain roughness. Global or regional comparisons of mountain ecosystems were therefore, until recently, limited by lack of such a definition; and such comparisons are few and often limited by the lack of globally-consistent information or data to be used for analysis.

As discussed in 2.1.1, at the global scale, water resources are probably the most critical of all ES provided by mountain systems. However, the provision of this ES highlights one of the largest disparities between mountain regions, as the significance of freshwater to surrounding downstream areas varies dramatically: first, as a function of demand due to population densities in the mountains and downstream; and,

second, according to physical factors relating to not only the climatic zone in which a mountain range is located (e.g., tropical, sub-tropical, temperate, boreal, or arctic), but also finer-scale intrinsic factors (such as extent of elevation and significance of glaciers), and specificities of prevailing local weather patterns (e.g. precipitation, oceanicity, seasonality, wind direction, existence of rain shadows) (Figure 2).

Figure 2. Significance of mountains for lowland water resources (Viviroli *et al.* 2011). ALC = Alps (Central), ALE = Alps (East), ANT = Tropical Andes, DRK = Drakensberg Mountains, EM = East Mediterranean, HIK = Himalaya Karakoram, PNW = Pacific Northwest, PYR = Pyrenees, SAL = Southern Alps, TSH = Tien Shan, UCJ = Upper Changjiang River/Tibetan Plateau.



Comparisons between regions on this basis show that, on average, mountains located in arid zones deliver a very high share of total discharge (66.5%) compared to the proportion of the watershed (29.8%). Mountain regions deemed critically important in this regard are found in South Africa (Drakensberg Mountains), the Middle East, and parts of the Andes and Rocky Mountains (Viviroli *et al.* 2011). Water resources from the Western Himalaya and the Tibetan Plateau also have a high associated importance (Archer *et al.* 2010). In contrast to arid and semi-arid zones, mountain ranges located at higher temperate latitudes (e.g. European Alps), and particularly in the humid tropics, generally have either less critical (though mainly still supportive) or negligible significance for lowland water resources.

While climatic factors contribute to the unique characteristics of each mountain region, disparities

between developed and developing regions represent another key difference between mountain ranges. This disparity is perhaps best highlighted in terms of the level of capacity for sustainable management of water resources and other provisioning and regulating mountain ES. Generally, high physical water stress has been associated with low adaptive capacity due to poor economic development, though there are notable exceptions such as the Pyrenees and Drakensberg Mountains, where well-developed water management has helped adaptation to an otherwise high mean water stress (Viviroli *et al.* 2011).

Apart from mountain water, particular differences between developed and developing countries in terms of the provision of mountain ES relate to biodiversity and the provision of food from mountain environments. The intensification of land use

practices and cultivation in mountain regions in most developing countries has been increasingly evident in recent decades. Conversely, mountain regions throughout Europe have seen a growing trend of land abandonment, particularly of extensively-used land. Both of these trends may result in net negative effects on biodiversity and related mountain ES. In particular, mountain biodiversity in Europe has benefited from sustainable low-intensity management practices over many generations, and declines where these practices cease on land that is then left unmanaged.

However, regardless of the level of development in a particular region, the FAO has estimated that 78% of the world's mountain area is either unsuited or only just marginally suited for agricultural production (Huddleston *et al.* 2003): grazing and forestry are more appropriate land uses, dominating in most regions. The mountains of Africa are a notable exception; due predominantly to their unique soil properties and underlying geology, they contain a significantly higher proportion of mountain land suitable for the cultivation of rainfed crops (Blyth 2002).

3. Climate Change Impacts

3.1 Climate change as a component of global change in mountains

Mountains are among the most sensitive regions to climate change, provide some of the clearest indicators of global warming and, in the 20th century experienced above-average warming, in comparison to the global mean (IPCC 2007; Nogués-Bravo *et al.* 2007; Kohler *et al.* 2014). While predicting and anticipating the effects of climate change on the capacity of mountain systems to supply vital ES is essential, an understanding of the wider context of global change as a whole is also important. Already, many of the interacting drivers of global change are influencing mountain environments globally: in addition to climate change, these drivers include globalisation, land-use change, economic policy, and population pressures. Large knowledge gaps on the effects of global change on ES still remain for mountain and other terrestrial habitats, due mostly to the high uncertainty in combining predictions of these various drivers, each of which is complex and not very well understood.

The only global analysis to date of the combined direct pressures of global change on mountain areas (Blyth 2002) showed that these are experienced most critically throughout the mountains of Africa, whereas those in Eurasia and Australasia-Southeast

Asia experience the largest total area of combined multiple pressures. These trends are likely to have continued subsequently; better understanding them, their drivers, and their interactions is a primary need for global change research in mountain areas (Björnson Gurung *et al.* 2012). With regard to climate change in particular, mountain areas in the northern hemisphere will generally be much more substantially affected by severe climate change than other regions. It is estimated that, for the European Alps, even an increase in warming by 2 °C (the current objective of international efforts to mitigate climate change) will not be enough to avoid significant alteration to at least several mountain ES (Elkin *et al.* 2013).

3.2 Specificities of climate change impacts in mountains

With climate change, various global circulation models (GCMs) predict potentially significant modifications to both mean values and variability of temperature and precipitation around the globe (IPCC 2013). Although considerable regional (and even local) variations in response are expected for mountain regions, there is a consensus that mean and extreme temperatures will increase, as will the frequency of extreme events. Changes in precipitation will vary regionally; however, dry areas are likely to become drier, and wet areas

wetter, and increasing temperatures will mean that the proportion of precipitation falling as snow will decrease. Mountain regions at high and medium latitudes are expected to see the greatest changes. The unique biophysical conditions that characterise mountain systems - mountain specificities, such as inaccessibility, fragility, marginality, heterogeneity - will be increasingly affected under growing climatic variability.

Glacier retreat is perhaps the most apparent sign of climatic warming, with the vast majority of glaciers worldwide shrinking and thinning, a trend which has been either continuing, or accelerating over the last century (Vaughan *et al.* 2013). The regulating function provided by glaciers in the form of water storage may thus be drastically altered in river basins where glacier melt provides a significant proportion of runoff. It has been estimated that 140 million people live in river basins where at least 25% of the annual flows come from glacier melts; this rises to 370 million people for a threshold of 10%. Most of these people live in High Asia (Schaner *et al.* 2012). When coupled to predicted intensification of the hydrological cycle, changes to drainage systems and water transfer will ultimately impact on the provision of freshwater and related ES, in the form of excesses during wet seasons, droughts of varying intensity during dry seasons, or both. Mountain livelihoods and infrastructure will be at increased risk from natural hazards and extreme events, which are set to increase in both magnitude and frequency (Oppenheimer *et al.* 2014).

The altitudinal shifting of mountain climatic belts under climate change is predicted to have significant negative impacts on biodiversity. As climates warm, mountain species may be able to move to more appropriate new habitats more easily than species living at lower altitudes, because the steep topography means that distances to move are generally less; however, there may no longer be appropriate habitat on mountain summits, leading to a high likelihood of extinction. This may also occur due to the narrow niche requirements of many mountain species (Scholes *et al.* 2014; Oppenheimer *et al.* 2014). Provisioning ES, and especially food production systems in mountains, may be adversely affected due to increased climatic

variability and extreme events, as well as potential increases in pest outbreaks and epidemics of disease-causing organisms. While a growing number of studies have highlighted the importance of insect pollinators (including social and solitary bee and non-bee species) in mountain agriculture (Verma 1992; Partap *et al.* 2012; Sharmah *et al.* 2015), quantifying the wider economic contribution of this regulating ES to crop productivity and yield stability is of outstanding importance, as well as the need to identify the threats posed by climatic and other environmental changes. This topic is also highly relevant from a food security perspective, given the high vulnerability of subsistence farming systems prevalent throughout most mountain regions of the developing world.

While climate change will potentially lead to dramatic negative alterations of the capacity of mountain ecosystems to maintain current ES, not all ES will be degraded under climate change, and anticipating ES which might possibly be enhanced will be key to developing adaptation strategies to increase the resilience of mountain livelihoods. For example, warming climates may lead to the potential to grow food crops (if soil and water are suitable), and to extend livestock grazing - but also to the potential for increasing conflicts between domestic and wild animals - at higher altitudes. Equally, increases in the elevation of tree line may enhance the provision of timber and Non-Timber Forest Products (NTFPs), and increase potentials for carbon sequestration, hazard mitigation, and recreation. Nevertheless, this may pose particular challenges when areas into which people might move have been designated as protected areas. Likewise, where water discharge is anticipated to increase (due to increases in glacial melt or precipitation levels), the potential for micro-hydropower may be enhanced, at least in the short term.



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4. Adaptation Strategies & Mountain-relevant Policy

4.1 Adaptation strategies in mountain communities

Vulnerability assessment & adaptation

Enhancing the ability of the mountain communities most at risk from climate change to adapt to its impacts is of high priority. A crucial element underpinning this process is to identify the areas and communities most at risk, and the key impacts, through vulnerability assessment. Vulnerability may be defined in either biophysical or socio-economic terms, or as combinations of these factors, in order to assess a diverse array of subjects ranging from human communities to endemic species. A distinct advantage offered to decision-makers is the temporal dynamic of these assessments, which can allow for a relatively robust scoping of how both current and future climate may influence vulnerability. However, despite the rise in the popularity of tools and methodologies for assessing vulnerability, the potential outcomes are often highly uncertain – or even unknown – due to factors such as complexity of the system under study, interactions amongst vulnerability drivers, and the particularly long-term timeframes often considered (Patt *et al.* 2005).

Regardless of the methods employed, mountain areas have been consistently assessed as having a high vulnerability to climate change, whether related to biophysical fragility and natural hazards (Papathoma-Köhle *et al.* 2011), social vulnerability and human livelihoods (Gentle & Maraseni 2012; Olsson *et al.* 2014), or biodiversity (Nagy & Grabherr 2009; La Sorte & Jetz 2010). Such assessments have permitted the relative comparison of vulnerability, usually within a defined geographic area. However, it is not valid (or meaningful) to compare areas assessed in different studies, which defined and parameterized vulnerability in numerous different ways. Hence, comparisons of vulnerability in mountains have been difficult to establish across larger national or regional scales.

For mountain regions in particular, which are typically characterised by great topographic complexity, higher degrees of error may occur at broad, as well as fine spatial resolutions, because variables with a wide range of values (such as elevation or slope) are 'averaged' out across each spatial unit. Moving forward, a strong collaborative approach is called for among governments and intergovernmental organisations in developing a standardized methodology for regional-scale vulnerability assessments of mountain areas, which includes defining and agreeing relevant parameters, reliable indicators, and optimal spatial extent and resolution. Notwithstanding differences in methodologies employed, consistent patterns have been observed for certain aspects of vulnerability in mountain systems – in particular the gender-specific impact of climate change. As in other ecosystems, women and children – both as occupants of mountain areas and those depending on mountain ES downstream – are more affected by water-related disasters and risks such as floods and droughts; and hence are most likely to comprise the majority of the victims (Pangare 2012). As such extreme events are anticipated to further intensify under climate change, further effort is needed to document gender-specific vulnerability in mountain regions, to establish adaptation measures specifically targeting women and other socially vulnerable groups (Khadka *et al.* 2015).

Ecosystem services & adaptation in mountains

Sensitive management of ecosystems can help promote climate change adaptation, and an emerging approach has been explored in a number of mountain areas in the 'EbA Mountain Programme', part of a wider global initiative in a range of ecosystems (Box 3). These ecosystem-based adaptation (EbA) methods can offer sensible means for protecting natural environments through increased resilience, but depend strongly on the identification and assessment of potential risks. Inherent in the EbA approach is the sustainable use of biodiversity

Box 3 Capacity development for ecosystem-based adaptation to climate change in the Andes

Much remains to be learned on how best to implement the principles of EbA in an applied context in mountain ecosystems. The 'EbA Mountain Programme', a partnership between UNEP, UNDP and IUCN supported by the German government, has set out to examine capacity development needs for implementing EbA within a number of developing countries. Utilising the Landscape Reserve Nor Yauyos-Cochas in the Peruvian Andes as a pilot study location, the project aims to implement activities and validate methodologies and tools for EbA decision-making in mountain areas. It is hoped these will then be scaled up for use nationally in Peru, through their integration into sub-national and national adaptation strategies and programmes. A noted focus will be on identifying 'no-regret' adaptation measures, which are capacity development mechanisms that possess benefits, regardless of whether these are specific to adaptation or not.

While intergovernmental organisations and regional institutes (such as UNEP, IUCN, ICIMOD, CONDESAN etc.) will continue to play a large role in developing best practice through the implementation of EbA pilot schemes, knowledge generation and exchange; capacity must also be developed more widely beyond the immediate sphere of influences of such organisations if the EbA approach is to be more extensively adopted. It is also important for future policy guidelines and/or legislation involving EbA that traditional mechanisms of mountain communities for autonomous adaptation to climate change are adequately taken into account, and not undermined.

and other ES as a means to foster the adaptive capacity of mountain socio-ecological systems in response to anticipated climate change. The promising role for ES as part of adaptation to climate change and disaster risk reduction has been optimistically noted (Munang *et al.* 2013). However, despite the vast natural capital often associated with mountain ecosystems, linking payment for ecosystem services (PES) with climate change adaptation has not progressed greatly beyond the conceptual framework level in mountain areas; greater policy-based action will be required to mainstream such initiatives.

Through the adoption of the Charter for World Mountain People (APMM 2003), as well as 'The Future We Want' (specifically, paragraphs 210-212) at the Rio+20 conference in 2012 (United Nations 2012), the international community has acknowledged the specific need to include often marginalised mountain inhabitants directly in decision-making processes. However, while high-level intervention is essential to support mountain PES initiatives, mountain communities should remain at the centre of all such schemes, as core stakeholders, and where feasible through greater adaptation of inclusive approaches to decision-making (Ariza *et al.* 2013). In addition, their knowledge of how to adapt and respond to climatic and other environmental hazards, even though this may be inadequate given the severity of extreme events under climate change, should be studied and

used to inform adapted new strategies. In this process, school children and young people could play key roles in collecting the necessary physical and cultural data.

4.2 Supporting policy and framework conditions

Global instruments for sustainable mountain development

At both national and international levels, sustainable development in mountain areas was not a priority until the early 1990s. The subsequent period has witnessed the rather rapid emergence of coordinated mountain-specific strategies and initiatives at the global level (Appendix 1; Schild & Sharma 2011). The Rio Earth Summit in 1992 and the International Year of Mountains in 2002 catalyzed the formulation of many national policies and strategies of relevance to mountain areas (Price and Kohler 2013). The momentum created by these and other events – with synergies catalysed by the Mountain Partnership, established at the World Summit on Sustainable Development in 2002 – has been instrumental in fostering dialogue at the global level, bringing together many organisations which, despite a specific or broader concern with mountain areas, had previously worked in relative isolation. In exploring the prospect for the future development and expansion of the global mountain agenda, it is thus important to gain an appreciation of the

Box 4 Safeguarding mountain provisioning & regulating services – a bottom-up approach to national legislation in the Kenyan Highlands

The Kenyan Highlands provide diverse and extensive ES to many mountain and lowland communities. In particular, regulating ES provided by these mountains (in the form of unique microclimatic conditions) form the basis of several economic sectors (agriculture, fishing, tourism, electricity), which are estimated to contribute 30-40% of national GDP. Entire industries such as coffee and tea cultivation are wholly dependent on the lush growth conditions provided at high elevation – and for instance, within the Aberdare Range, ca. 400,000 people depend directly on tea cultivation for their livelihoods. The high rate of orographically enhanced precipitation intercepted by the mountains also provides an essential source of freshwater, and dams situated throughout a major upper catchment of the Tana river generate nearly 50 % of Kenya's total electricity needs.

Given this major reliance on natural resources, several government bodies are charged with responsibility for overseeing these (e.g. Kenya Forest Service; Kenya Wildlife Service; Water Resource Management Authority; National Environment Management Authority). While this sectoral approach offers many advantages, instances of conflicting national mandates and policies have proven unsatisfactory – especially where more integrated strategies are required, such as in the management of mountain ecosystems. Recognizing this, the Kenyan government has recently devolved responsibility for mountain-specific planning to county-level governments. Since 2010, long-term range-specific strategic management plans have been enacted for five of the main mountain ranges (or are in the final stages of stakeholder consultations): the Aberdare Range, Cherangani Hills, Mau Complex, Mount Elgon, and Mount Kenya. This entire process of national devolution of responsibility to more local levels of government, alongside the formation of mountain-specific legislation, provides exemplary lessons to other mountainous African countries (and indeed mountain regions worldwide), and has permitted a genuinely bottom-up-approach to management of mountain ecosystems nationally.

dynamics which have led to this global platform which we see today.

As recognized within six UN resolutions specifically on sustainable mountain development, most recently A/RES/68/217, adopted by the General Assembly in 2014, and 'The Future We Want', the outcome document of the Rio+20 conference (United Nations 2012), national-level action and legislation are considered key to effective and efficient progress concerning sustainable mountain development (Box 4). However, these documents also recognize that further institutional arrangements and mechanisms to enhance coordination and collaboration should be encouraged at both regional and international levels.

Mainstreaming mountain ES into climate change adaptation

In response to the increasingly apparent threat of climate change, there has been a noted drive amongst national governments to establish national adaptation programmes under the UN Framework Convention on Climate Change. At their heart, these programmes seek to outline a coordinated policy-led approach to the mitigation of both the environmental and the

socio-economic impacts of climate change. Although the wide level of political commitment to climate change adaptation has been commendable, the role of ecosystem management in underpinning such adaptation has not been as well recognized (Munang *et al.* 2013). Given the disproportionate effects of climate change observed in mountain ecosystems, and due to their critical linkages with downstream areas, national adaptation plans will benefit from continued critical appraisal and elaboration, where required, in order to adequately address these concerns in relation to mountain specificities.

While new policy directives concerning mountain ES will no doubt prove crucial, particularly at national level, strong evaluation and monitoring of relevant pre-existing policy instruments will remain of utmost importance. Reference to the multifaceted importance of mountains in "The Future We Want" reaffirmed the need for protection and management of the unique natural resource base of mountain ecosystems which are critical for both social and economic development. In spite of some criticism as to the effectiveness of evaluation mechanisms for sustainable development (Krchnak 2008), the appraisal and emphasis of key

achievements and successes obtained specifically in relation to mountain ecosystems, and their sustainable exploitation (e.g., Ariza *et al.* 2013), can continue to be valuable processes that will benefit future such endeavours and the evolution of policy. In particular, greater participation and involvement of women in these and related decision-making processes will be imperative, towards fostering a greater sense of gender equality.

Addressing knowledge gaps & uncertainties

Despite growing global recognition of the unique value of mountain ES, reconciling current initiatives towards PES with the diverse needs for climate change adaptation in mountain regions remains a significant challenge. To avoid over-selling the promise, careful and context-specific evaluation must be made of the potential economic returns which can be offered to mountain communities for ensuring the provision of ES (e.g. Rasul *et al.* 2011). In particular, efforts to evaluate the potential provision of ES in many ecosystems have generally placed an unfair emphasis on identification of synergies (and the extent to which multiple ES can be maximised), whilst overlooking trade-offs that may occur (Bennett *et al.* 2009); this is just as likely to apply to mountain ecosystems. Such biased assessment of ES can be damaging, and can arguably lead to unsustainable practices with a net degradation of mountain environments. To help avoid such scenarios, decision-support tools should be utilized more to gain a holistic picture of both synergies and trade-offs regarding ES in mountain areas. One example of such a tool for mapping, modelling and valuation of ecosystem services is the InVEST toolbox (Kareiva *et al.* 2011), which provides a modelling platform for assessment of trade-offs among ES at the landscape scale. The appropriate scale at which ES are evaluated and compensated has

to be carefully chosen in order to avoid jeopardizing complex production systems and/or creating imbalances in development, as this can result in the counterproductive and inequitable specialisation of certain favoured populations or segments of the community (e.g., landowners vs. tenant farmers; men vs, women) in providing particular ES.

Mountains typically possess high non-use values, relative to the limited economic activity they support on the ground (Table 2). However, there are few quantitative data describing such non-use values of mountain areas. Thus, comprehensive economic evaluations of mountain regions or habitats should give greater attention to distinguishing the direct value of various ES from other non-use or potential values. While good examples of studies of this kind exist at the local scale (e.g., Table 2), greater effort will be needed to fill such knowledge gaps at national and regional levels. Although the concept of a non-use value may appear somewhat abstract, its practical utility is evidenced by the growing emergence of pro-poor PES schemes in mountain regions, which seek to unlock novel means of sustainable development beyond a typical reliance on provisioning services.

Table 2.

Non-use value of mountain ecosystem services provided by the Mukura Forest Landscape, Albertine Rift Region, Rwanda, adapted from Kakuru *et al.* (2014). Non-use values were quantified using a contingent valuation (or willingness to pay) method. Amongst more ‘intangible’ elements, these included categories such as pharmaceutical value; which possessed a potential direct but as yet unexploited value. The total economic value of this mountainous forest area was estimated at US\$ 1,692,132, of which non-use values comprised a major component.

Ecosystem service category	Non-use value	Gross return from the resource (US\$)
Provisioning	Pharmaceutical value	2,697
Regulating/supporting	Carbon Storage & Sequestration	39,556
	Landslide and flood control	84,506
	Pollination	25,172
Cultural	Aesthetic Value/Ecotourism	647,280
	Existence Value	3,596
		802,807

Moving forward, two major challenges of serious political relevance facing scientific institutions are: 1) the need to reduce scientific uncertainty associated with climate change and its likely impacts, which will have knock-on effects for ecosystem-based adaptation initiatives; and 2) the need to generate baseline data to reduce key knowledge gaps in support of decision-making processes (Björnsen Gurung *et al.* 2012). Experience from initiatives which have sought to mainstream ES into policy in support of the ambitious targets set in the EU Biodiversity Strategy to 2020, has shown that data of sufficient coverage and resolution are critical for multi-scale mapping and assessment of ES (Maes *et al.* 2013). Where the fundamental basis for such data is missing, prioritization is called for at the political level to ensure the availability of this critical information. Whereas the notably high potential of mountains to provide ES has been acknowledged, it has also been noted that the contribution of several of these ES of potentially large importance remains unknown even in Europe (Harrison *et al.* 2010) and therefore inevitably in other regions and at the global scale, hence the pressing need for the necessary data.

4.3 Implementation – from science to policy to practice

Moving forward, effectively addressing the challenges to further develop, conduct and evaluate ecosystem-based adaptation initiatives aimed at increasing resilience of mountain communities will be vital. Increased dialogue and knowledge sharing amongst a range of players (from governmental, non-governmental, institutional and academic sectors, and mountain people) is required; a challenge that must be addressed by policy-makers, scientists and practitioners at regional to global scales in the context of sustainable development (Kohler *et al.*

2014), particularly through the 2030 Agenda for Sustainable Development (United Nations 2015). Two of the Sustainable Development Goals specifically mention mountains in relation to: the protection and restoration of water-related ecosystems (6.6); the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services (15.1); and the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development (15.4).

Policy-makers must seek to apply more standardized assessments of vulnerability, ideally applicable and comparable at a range of scales. Trans-boundary cooperation in initiatives within shared mountain regions is also vital, requiring political leadership that recognises particularly the need for good governance of headwaters to avoid water conflicts. For scientists, reducing the uncertainties of climate change and model downscaling for use at local scales will continue to form an important basis for EbA in mountains. Establishing empirical evidence for the 'deliverability' of mountain ES (such as land-use interventions to increase water quantity/quality) is a key need, and must be addressed in order to better inform PES schemes and confidence for market buy-in. In the drive for greater application of the EbA approach, practitioners are required to establish best practice in case studies – including local historically-developed strategies of adaptation to climatic hazards – and to share experiences which have failed, beyond merely highlighting successes. As part of this, realistic assessments of trade-offs between ES on the ground will be useful, in addition to noting the synergies identified in projects. Long-term monitoring and evaluation of impacts will help close the circle amongst policy-makers, scientists and practitioners.



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6. Appendix: A timeline of major global initiatives and mountain-relevant policy

Initiative/Policy	Year	Details
Mountain Research & Development	1981	Creation by the International Mountain Society of a dedicated journal to foster sustainable development in mountains by supporting interdisciplinary research, promoting policy dialogue, and strengthening the mountain community.
Rio Earth Summit (UN Conference on Environment and Development)	1992	Chapter 13 of the plan of action, 'Agenda 21', is titled 'Managing Fragile Ecosystems: Sustainable Mountain Development'. Two of the legally binding global Conventions, the Convention on Biological Diversity and the UN Framework Convention on Climate Change, specifically refer to mountain areas.
Mountain Forum	1995	The Mountain Forum was founded as a network of networks to provide mutual support, information sharing and advocacy for mountain peoples and environments.
Global Mountain Biodiversity Assessment (GMBA)	2000	The GMBA actively explores and explains the great biological richness of the mountains of the world, and provides input to policy makers and stakeholders for the conservation and sustainable use of biodiversity in mountain regions.
World Mountain People Association (WMPA)	2000	The WMPA was born out of the World Mountain Forum, an event which brought together 900 participants from 70 countries, to make the voice of mountain people and the expression of their desires heard.
Mountain Research Initiative (MRI)	2001	MRI promotes and coordinates global change research in mountain regions all over the world, with an aim to detect and define the consequences of global change, and to inform sustainable resource management in mountain regions.
Global Observation Research Initiative in Alpine Environments (GLORIA)	2001	GLORIA is a worldwide long-term observation network in alpine environments for discerning trends in species diversity and temperature.
International Year of Mountains (IYM)	2002	By resolution in 1998, the United Nations General Assembly proclaimed the year 2002 as the International Year of Mountains, to ensure the well-being of mountain and lowland communities by promoting the conservation and sustainable development of mountain regions.
The Bishkek Mountain Summit	2002	As the culminating event of the IYM, the Summit provided a framework for stakeholders and others to contribute, beyond the IYM, to sustainable development in the world's mountain regions, to improve the livelihoods of mountain people, to protect mountain ecosystems and to use mountain resources more wisely. The final document was the basis for a resolution of the UN General Assembly in 2002.
World Summit on Sustainable Development	2002	Chapter 42 of the Final Report specifically considers mountains.
Mountain Partnership	2002	The Mountain Partnership is a United Nations voluntary alliance of partners (currently including 56 national governments, 14 intergovernmental organizations and 192 major groups, and 5 subnational authorities) dedicated to improving the lives of mountain people and protecting mountain environments around the world.
UN General Assembly (UNGA) Resolutions on Sustainable Mountain Development	2003	Since 2003, the UNGA has adopted six resolutions on sustainable mountain development which, although not legally binding, have helped to emphasize the importance of mountain regions.
Global Change in Mountain Regions (GLOCHAMORE)	2003	GLOCHAMORE was an international project for research and knowledge exchange on global change in mountains. It concluded in 2005 and informed the long-term strategy of the Mountain Research Initiative.

Initiative/Policy	Year	Details
Charter for World Mountain People	2003	The Charter for World Mountain People was adopted following discussions by representatives of Mountain Territories from 40 countries in Quito (Ecuador).
Convention on Biological Diversity	2004	The Conference of the Parties to the Convention on Biological Diversity (CBD) adopts the Programme of Work on Mountain Biological Diversity (annex to decision VII/27) at its seventh meeting.
Millennium Ecosystem Assessment	2005	Chapter 24 of 'Ecosystems and Human Well-Being: Current State and Trends' considers Mountain Systems.
Convention on Biological Diversity	2010	The Conference of the Parties to the Convention on Biological Diversity (CBD) adopts a decision on Mountain Biological Diversity at its tenth meeting.
Rio+20 Earth Summit	2012	Paragraphs 210-212 of the final document 'The Future We Want' specifically concern mountains.
2030 Agenda for Sustainable Development	2015	Sustainable Development Goals 6 and 15 specifically refer to mountains.



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the Biosphere
Programme

FOR MORE INFORMATION:

International Hydrological Programme (IHP) Division of Water Sciences, UNESCO
<http://en.unesco.org/themes/water-security/hydrology>

Climate Change Impacts in Major Mountainous Regions of the World: Multidisciplinary Network for
Adaptation Strategies (Africa, Asia, Latin America and Europe)
<http://en.unesco.org/news/climate-change-impacts-major-mountainous-regions-world-0>

Man and Biosphere Programme (MAB) Division of Ecological and Earth Sciences, UNESCO
www.unesco.org/mab

