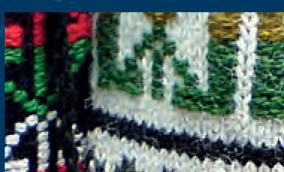
Mountain Biodiversity and global change



Contents

Foreword

Mountains offer vertical environmental gradients for life otherwise only seen over several thousands of kilometers of latitudinal distance. A gravity shaped extremely diverse topography provides opportunities for additional diversification of life, leading to unbeaten biodiversity. Mountains are cradles and refuges of organismic diversity and given their coverage of such a wide spectrum of environmental conditions they are key to conservation in a changing world. Over thousands of years people have modified parts of these natural mountain landscapes and created a multitude of cultural landscapes, especially in mountain regions. Mountain people have adapted and have taken advantage of the different climatic and thus ecological belts. Striving for a secured and better livelihood, mountain populations have contributed to the creation of thousands of plant varieties and animal breeds as a result of genetic selection efforts. Similarly, various land use management practices such as irrigated agriculture using sophisticated water transport systems, agro-silvo-pastoralism and seasonal transhumance further enhancing the multitude of small-scale habitats with a highly diversified and locally adapted flora and fauna.

Ongoing socio-economic changes cause a dramatic reduction in traditional landcare and overexploitation of easily accessible terrain. In many regions of the world traditional mountain landscapes disappear, and with these the associated wild and domesticated species and breeds. From a development perspective, where poverty alleviation and improvement of livelihoods are core concerns, efforts thus need to be undertaken to preserve biological diversity as an important asset of mountain populations. These are often characterised by a multitude of distinct societies and cultures that belong to the most disadvantaged and vulnerable rural communities to be found on our globe.

In this sense the Convention on Biological Diversity (CBD) of the United Nations requires the support of development cooperation. Maintaining biodiversity by empowering mountain communities to act as custodians of cultural and natural landscapes as mankind's heritage, serves both the needs of the CBD as well as of development cooperation. Such an aim recognizes the value of the efforts of hundreds of generations who have shaped a fascinating environment under harsh natural conditions, also bearing attraction for tourists. This objective also provides mountain inhabitants with the option of remaining where their roots are and thus not surrendering to urban migration. Their continued presence and activity is vital given the importance of the ecosystem services provided by mountains, such as the provision of fresh water that depends upon appropriate natural resource management in the highlands.

The present brochure has been prepared as a contribution to the International Year of Biodiversity IYB 2010 and the Conference of Parties of the CBD (COP10) in Japan in October 2010. It aims to highlight the role and importance of mountain biodiversity for the whole of humanity. With its attractive photographs, the publication also intends to sensitize its readers to the beauty of diversity. The ultimate goal and hope, however, is that it may contribute to trigger the necessary changes both in attitude and behaviour that will be required to secure mountain biodiversity and its genetic resources for future generations.

Daniel Maselli, Eva Spehn, and Christian Körner

Mountain meadow at Furka Pass, Switzerland, 2500m | Photo: Christian Körner

1
Mountain biodiversity – a global heritage

Mountain biodiversity – a global heritage

Mountains are storehouses of global biodiversity. They support approximately one-quarter of terrestrial biological diversity; half of the world's biodiversity hotspots are concentrated in mountains. Mountains are rich in endemic species, i.e. plants and animals that occur nowhere else. In addition to supporting a great diversity of species and habitat types, the world's mountains encompass some of the most spectacular landscapes and harbor a significant portion of distinct ethnic groups, varied remnants of cultural traditions, environmental knowledge and habitat adaptations.

High biodiversity in high ecosystems

A complete biological inventory of the world's mountains does not yet exist. About 12% of the terrestrial land area is mountains; the alpine belt, the treeless life zone of mountains, (see Fig. 1) covers ca. 3% of the global land area. Around 10 000 alpine species are confined to this alpine life zone and comprise about 4% of the global flowering plant species. Therefore, the alpine life zone is richer in plant species than might be expected from the size of its area (Körner 2004). Based on total mountain land area only, a conservative estimate of the world's mountain plant species is 50 000 species of flowering plants (out of a total of ca. 260 000). Given the inclusion of tropical lowland mountains in the above definition, the number may well be twice as high.

On average, a single mountain system such as the Alps, the Pyrenees, the Scandes, the Colorado Rockies, or the New Zealand Alps hosts a few hundred (often 500–600) different species in the alpine belt alone. There are no such estimates available for animals, invertebrates (e.g. insects) in particular, but a common estimate for temperate to cool climates is a 10-fold higher animal than plant species diversity. Climates rated as hostile to life by humans often exhibit a surprising species richness. One may find more than 30 plant species in an alpine fellfield on an area the size of this page.

Why are mountain biota so diverse?

There are several reasons for high plant species diversity in mountains:

- → The compression of climatic zones over short distances. Different climatic conditions that stretch over thousands of kilometers in the lowlands may be located on a single mountain slope. This compression of life zones, each with its characteristic biological inventory, creates an assembly of contrasting biota on mountains.
- → The great diversity of habitats resulting from topographic diversity driven by the forces of gravity. Mountain biodiversity mirrors topographic diversity. Exposure and inclination of slopes and relief lead to a multitude of microclimatic situations which, in combination with substrate types and associated water and nutrient regimes, create a great variety of microhabitats, each with characteristic organisms.
- → Habitat isolation and fragmentation, leading to local or regional diversification. Mountains have been compared to archipelagos, surrounded by an "ocean" of lowland life conditions which are hostile for most mountain species.
- → Mountains often offer migratory corridors, such as the east-west connection along the southern slopes of the Himalayas.
- → Moderate disturbances such as landslides, avalanches, grazing by large herbivores and/or wildfires tend to further increase habitat differentiation and diversity.

Alpine flowers, Caucasus, 2100 m | Photo: Christian Körner

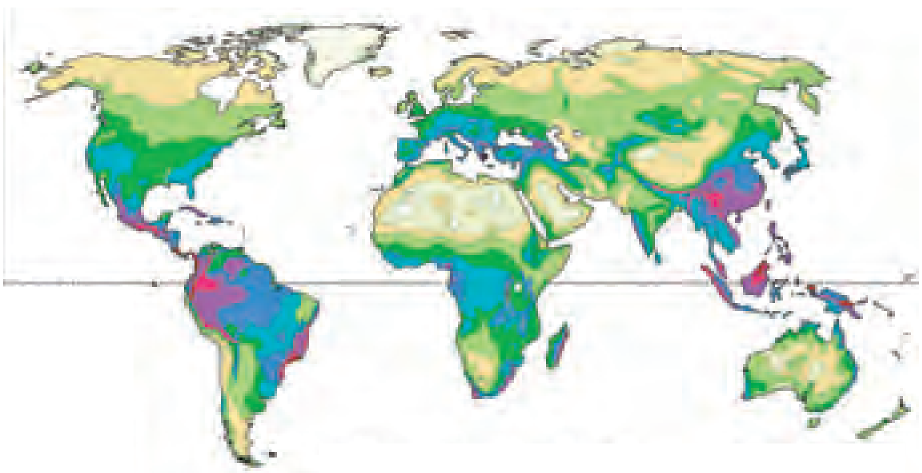
- Finally, at the community level, high altitude vegetation above tree line is diverse on small scales simply because of the small size of the species. Quite often one can find half of the plant species of a large area on a few square meters of dense ground cover.

Patterns of global mountain biodiversity

Major centres of plant species diversity are in tropical and subtropical mountains: Costa Rica and Panama, tropical eastern Andes, subtropical Andes, the Atlantic forests in Brazil, the eastern Himalaya-Yunnan region, northern Borneo, New Guinea, and East Africa (Mutke & Barthlott 2005, Barthlott et al. 2007). The mountains of tropical and subtropical America harbor a huge diversity of plants. Epiphytes, such as mosses and ferns, are an important component of this richness: Total moss diversity in the five tropical Andean mountain countries is estimated to be over 7 times higher than for the entire Amazon basin. Secondary centers of biodiversity are found in the Mediterranean mountains, the Alps, the Caucasus, and Southeast Asia. Mountains are also important centers of agro-biodiversity with a great variety of locally adapted crops and livestock, an important genetic resource and an asset for assuring food security for a growing global population.

Among mountain forests, cloud forests are hot spots of diversity, not necessarily in absolute numbers of species, but in numbers of very rare and endangered species (e.g. in Peru 30% of the 272 species of endemic mammals, birds and frogs are found in the cloud forest). Extremely endangered species, for instance the mountain gorilla, find specific habitat needs exclusively in mountain forests, the type of forest most rapidly disappearing.

Figure 1
Global Biodiversity: Species numbers of vascular plants.
W. Barthlott, G. Kier, H. Kreft, W. Küper, D. Rafiqpoor & J. Mutke 2007
Nees Institute for Biodiversity of Plants, University of Bonn, Germany
© W. Barthlott 1996, 2007



Diversity Zones: Species numbers of Vascular Plants per 10 000 km²

1: < 20
2: 20–200
3: 200–500
4: 500–1000
5: 1000–1500
6: 1500–2000
7: 2000–3000
8: 3000–4000
9: 4000–5000
10: > 5000

What is a mountain?

Mountains are conspicuous elements of the landscape, but a scientific definition of a mountain is nearly impossible. Intuitively, for most people a mountain is either steep or cold or both. However, mountains cannot be defined by climate, given that any cold category would include Arctic and Antarctic lowland, and tropical mountains that range from equatorial rain forests to Arctic conditions near their summits. Nor can mountains be defined by elevation alone. There are elevated plateaus, such as the North American prairies at around 2000 m elevation, the vast plateaus in central Asia, and steep coastal ranges rising a few hundred meters above sea level. The only common feature of mountains is their steepness (slope angle to the horizontal), which enables them to intercept rainfall and to create all those habitat types and disturbances which make exposure a driving factor of life.

How big is the mountain area globally?

An early attempt to answer this question considered all land above 300 m a.s.l. but excluded the major plateau area, and decided that 24.3% of all land area outside Antarctica belongs to mountain classification (Kapos et al. 2000). This definition still includes tropical lowland forests, hot desert terrain as well as some upland tundra in the polar region. In the Millennium Ecosystem Assessment, Körner et al. (2005) tested a 1000 m lower limit, irrespective of latitude but again excluding all plateaus, arriving at a 15.5% calculation for global mountain area (Fig. 1). The definition of a mountain suffered in both cases from the inappropriateness of a fixed elevation threshold across all latitudes.

A new definition of mountains by the Global Mountain Biodiversity Assessment (Körner et al. 2010) is using ruggedness as a simple and pragmatic proxi for steepness. This definition forms the basis of the Mountain Biodiversity Portal. Ruggedness is defined here as the maximal difference of at least 200 m in elevation among nine neighboring grid points on the 30" (c. 4×4 km at the equator) grid of the WORLDCLIM database. Using this definition, 16.5 Mio km^2 or 12.3% of the terrestrial surface is rugged and therefore mountain terrain. This is now considered the most reliable figure for the global mountain area outside of Antarctica.

As elevation increases, mean temperature decreases. Mountains are thus stratified into thermal belts, each with a characteristic flora and fauna (Fig. 2). The land below the natural climatic limit of trees (the tree line) is called the "montane" belt, the land above the tree line is called "alpine", which by definition has no trees. The uppermost part, where snow can fall and stay year round, is called the "nival" belt, which is still inhabited by a great number of species settling in favorable microhabitats. The climatic tree line, in reality not a sharp line but a transition zone (also called the "tree line ecotone"), is found globally at roughly the same mean temperature during the growing season, 6.5 ± 0.8°C, irrespective of season length beyond a minimum of 94 days (Tab. 1: Körner

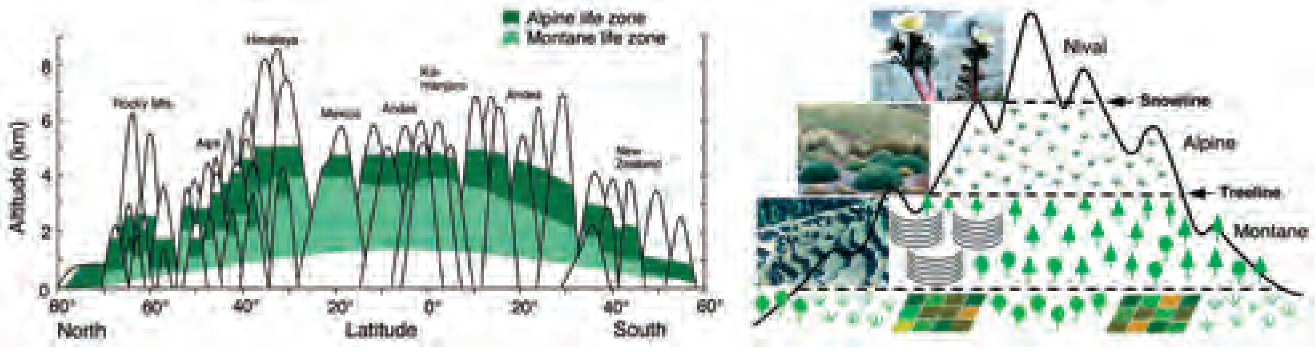


Figure 2
Left: a modern version of Humboldt's classical profile across the world's mountains. Bioclimatically similar belts are found at different elevations, depending on latitude.
Right: the biogeographical nomenclature of elevational belts. Reproduced from Körner 2004.


Giant Lobelia *(Lobelia rhynchopetalum)* in the Sanetti Plateau in the Bale Mountains of Ethiopia | Photo: Michele Menegon

& Paulsen 2004 and newer data by GMBA). Hence, at this mean growing season temperature, we find the tree line at 4500–4900 m a.s.l. in parts of the subtropical Andes (Bolivia, Chile) and the eastern Himalayas (China), on mountains near the equator at 4000 m, or at 700 m near the polar circle, thus permitting global comparison for land areas with similar temperatures and thus biota. The alpine and nival belts represent the only life zones on the globe that occur at all latitudes, although at different altitudes, which makes them very attractive for global comparisons of biodiversity and climate change effects.

Tab. 1. Terrestrial land area (Mio km^2) outside Antarctica (134.6 Mio km^2) subdivided by different thresholds of ruggedness (in meters). **As** Asia, **Eu** Europe, **Af** Africa, **N-A** North America, **S-A** South America, **Gld** Greenland, **Aus** Australia and New Zealand, **Oce** Oceania (including the islands of SE Asia). Körner, Paulsen & Spehn 2010. Based on the Digital Elevation Model used by Worldclim.org (Hijmans et al. 2005)

Ruggedness (m)	**Continent/Region**									
	As	**Eu**	**Af**	**N-A**	**S-A**	**Gld**	**Aus**	**Oce**	**Total**	**%**
All	44.6	9.8	30.0	22.1	17.8	2.1	7.7	0.5	134.6	100.0
<50	23.5	6.7	23.5	14.0	11.8	1.8	6.8	0.1	88.2	65.5
⩾50<200	12.2	2.2	5.3	5.2	3.8	0.2	0.8	0.2	29.9	22.2
⩾200	8.9	0.9	1.2	2.9	2.2	0.1	0.1	0.2	16.5	12.3

Tab. 2. The global area (Mio km^2) of bioclimatic mountain belts (rugged terrain only), as defined for the GMBA Mountain Biodiversity Portal (www.mountainbiodiversity.org). Temperatures refer to season mean air temperatures: **M(%)** = percent of total mountain area (100%=16.5 Mio km^2); **T(%)** = percent of total terrestrial area outside Antarctica (100%=134.6 Mio km^2). Source: Körner, Paulsen & Spehn 2010.

Thermal belts	**Area(Mio km^2)**	**M(%)**	**T(%)**
Nival (<3.5°C,season <10d)	0.53	3.24	0.40
Upper alpine (<3.5°C, season >10d <54d)	0.75	4.53	0.56
Lower alpine <6.4°C, season <94 d)	2.27	13.74	1.68
Treeline			
Upper montane (>6.4 ⩽10°C)	3.39	20.53	2.51
Lower montane (>10 ⩽15°C)	3.74	22.64	2.78
Remaining mountain area with frost (>15°C)	1.34	8.11	0.99
Remaining mountain area without frost (>15°C)	4.49	27.22	3.34
Total	**16.51**	**100.00**	**12.26**

GMBA – the Global Mountain Biodiversity Assessment of DIVERSITAS

GMBA is a crosscutting network of DIVERSITAS, the international biodiversity programme, founded in 2000. GMBA main task is to explore and synthesize findings from research on the great biological richness of the mountains of the world and to provide input to policy for the conservation and sustainable use of biodiversity in mountain regions.

GMBA-DIVERSITAS conference, Chandolin, Juli 2010 | Photo: Peter Imboden

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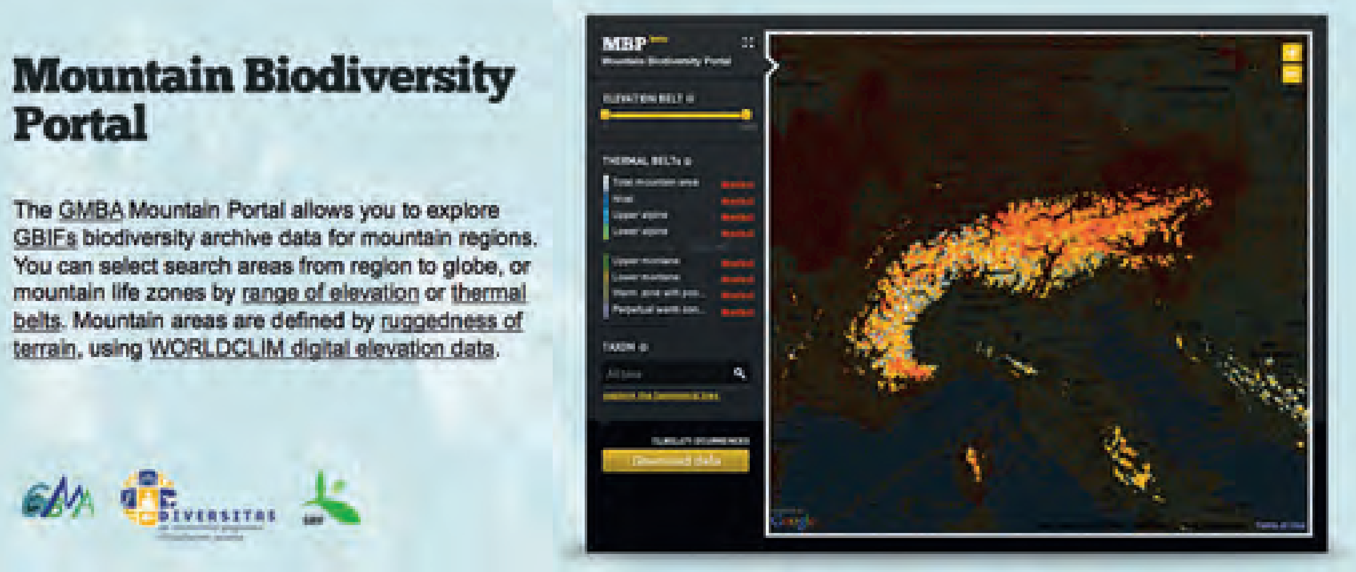
GMBA documents and synthesizes knowledge on mountain biodiversity and communicates these findings to international policy fora and interested institutions. It acts as a platform for international mountain biodiversity research, organizes conferences and workshops and promotes participation in projects on mountain biodiversity. It has also developed internationally accepted research guidelines for specific fields and has published three synthesis books. At present, it has a network of about 400 researchers and policy makers who work in the field of mountain biodiversity on all major mountain regions of the world; more than 1000 members from 71 countries are subscribers.

GMBA looks at three dimensions: the horizontal, biogeographic dimension with a zonal emphasis on the global scale; the vertical bioclimatic dimension with elevation transects on a regional scale; and the temporal dimension looking at past, present, and future situations by revisiting sites and using modeling. In cooperation with the Global Biodiversity Information Facility (GBIF), GMBA, encourages a worldwide effort to mine geo-referenced databases on mountain organisms, underscoring the conviction that accurate geographical coordinates and altitude specifications (georeferences) of observed or collected biological species are the vital link between biological data and other geophysical information.

More information at: http://gmba.unibas.ch/index/index.htm

The Mountain Biodiversity Portal: a gateway to biodiversity data in mountains

Geo-referenced archive databases on mountain organisms are promising tools for achieving a better understanding of mountain biodiversity and predicting its changes. The GMBA Mountain Biodiversity Portal allows specific searches for primary biodiversity data provided by the Global Biodiversity Information Facility in a mountain-specific context.



Although a biological inventory of the world's mountains does not yet exist, data mining of existing archives of biodiversity offers new avenues to assess mountain biodiversity. The GBIF (http://www.gbif.org) offers a data portal that connects more than 174 million single species occurrence records (from various data providers, such as natural history museum collections). The Global Mountain Biodiversity Assessment has a thematic web portal, launched in May 2010, as a contribution to the Mountain Programme of Work of the Convention on Biological Diversity (CBD) and the International Year of Biodiversity. This electronic portal to "open access" biological information provided by GBIF is designed to become a standard tool for conservationists and managers of mountain areas, as well as the global change research community. Mountain areas are defined by ruggedness of terrain, used by WORLDCLIM digital elevation data (see mountain definitions, p.10). Users can select mountain areas and specify them by elevation or bioclimatic life belts (such as the treeless alpine belt) and search and download biodiversity information on a regional or global scale.
The Mountain Biodiversity Portal is available at: www.mountainbiodiversity.org

Amphibians as indicators of change in Ethiopian highlands

Indicator species are important for revealing ecosystem changes. In Ethiopian mountain forests, habitats change rapidly or may even be destroyed due to land use of formerly pristine forest. Changes in upland ecosystems are examined using amphibians as indicator species to inform on conservation management priorities.

Treefrog *Afrixalus* sp. found at high altitude (right) in the Bale Mountains, Ethiopia | Photos: Michele Menegon

The Bale Mountains in southeastern Ethiopia have some of the largest areas of continuous Afroalpine and Afromontane forest habitats in Africa; the highlands in the southwestern part of Ethiopia contain the largest surviving patches of "pristine" montane forest on the continent. However, natural habitats are increasingly being lost in Ethiopia at an alarming rate. Amphibians are highly diverse in this region and have good potential for use as indicator species because of their relatively narrow environmental tolerance. Almost one-third of the world's ca. 6000 amphibian species are threatened with extinction; 168 species have been recently listed as extinct, often due to habitat change. Ethiopian amphibians display a comparatively high diversity for Africa, particularly in the mountain regions. Preliminary evidence from the Bale Mountains suggests that there has been significant recent change to forest habitats and potentially to amphibian communities. By examining species distributions across Ethiopian highland habitats and assessing how land-use changes have impacted biological communities, we aim to assist in assessing conservation priorities. The project aims to contribute quantitative data on physical and biological systems to help toward mitigation and adaptive strategies in the conservation of mountain ecosystems.

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Iranian mountains: a great place to see plants you never have seen before

Iran is a mountainous country harbouring an extraordinary vascular flora including many rare and endemic plant species in the alpine zone. Alpine regions are above timber-line, a divide not easy to recognize since aridity is prominent in most regions.

Damavand Mts. (5671 m), highest mountain peak of Iran with big *Papaver bracteatum* in the subalpine zone | Photo: Jalil Noroozi

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More than 100 mountain peaks can be found in Iran, some in the Zagros and Alborz mountains which reach altitudes of more than 4000 m. The upper limit of vascular plants is 4800 m, the highest point where a plant has been found in Iran. A first evaluation of the vascular flora shows that 682 species belonging to 193 genera and 39 families are known from the alpine zone. This zone is characterized by many species of hemicryptophytes and thorny cushions; species numbers decline strongly as altitude increases (Noroozi et al. 2008). The mountain flora of Iran is exceptional. The Iranian mountains are situated between Anatolia/Caucasus and the Hindu Kush; their flora contains elements from both regions. However, more than 50% of these species are endemic to Iran (they occur nowhere else) and some are remarkable relic species, primarily local endemics with a narrow ecological range. These plants need strong conservation and protection management, not only because they are rare but because the ecosystems where they live are fragile, often very restricted, small and isolated in high elevation areas. These plants adapted to the cold are particularly vulnerable to the impacts of climate warming and intensive grazing over large parts of Iran's mountains is expected to exert additional pressure on them. Many of these plants are potentially endangered and vulnerable species, and their threatened status should be assessed according to the International Union for the Conservation of Nature (IUCN) criteria.

River in Kangding, Sichuan, China | Photo: Christian Körner

2

Functional significance of mountain biodiversity

Functional significance of mountain biodiversity

Mountain environments cover about 12% of the world's land surface, and directly support those 22% of the world's people who live within mountain regions and their immediate forelands. Mountain biodiversity provides basic ecosystem services such as freshwater, timber, medicinal plants, and recreation for the surrounding lowlands and their increasingly urbanized areas. By preventing erosion, mountain plant diversity secures livelihoods, traffic routes and catchment quality. More than 50% of mankind benefits from mountains as the world's water towers. They host some of the world's most complex agro-cultural gene pools and traditional management practices.

Why should one care about biological diversity, genetic diversity within populations of species, the diversity of organismic species, the variety of their assemblages with a multitude of biotic interactions such as pollination, symbiosis or mutual benefits (facilitation), and the diversity of ecosystems and landscapes? The most fundamental of all arguments is the ethical one, which implies the right to exist for any species and, even the right to exist well. This has been the foundation of most conservation initiatives. However, science can contribute good reasons to care for mountain biodiversity.

Mountain biodiversity as life insurance?

Biodiversity is nature's insurance system. Security comes from multiple players that mitigate the risk of losing system integrity or functioning. This insurance principle of biodiversity may remain hidden for a long time and only become evident under extreme environmental conditions. The more diverse a system is, the more likely there will be organisms that can cope with extreme events such as storms, droughts, fires, pest outbreaks, and the spread of pathogens or invasive species. Sometimes a single "keystone" species can sustain an ecosystem function; its absence or presence may be vital to ecosystem or agronomic success.

Steep mountain slopes secured by diversity

In steep terrain, more than anywhere else, ecosystem integrity and functioning depends on a structurally diverse plant cover. Slopes are only as secure as the soils and plants that hold them in place against the forces of gravity. Biodiversity research has shown that a diverse set of taxa is more likely to provide complete ground cover year around than a depleted set of taxa that exposes open ground at times (Pohl et al 2009). Similarly important, species respond rather differently to disturbances such as grazing and trampling by pasture animals. These responses depend on moisture conditions at the time of the disturbances and on the nature of the substrate. Since these are unpredictable, a diverse set of taxa will more likely secure this most basic function of plant cover in mountain terrain and insure against complete system failure, i.e. the loss of substrate on mountain slopes. A single application of fertilizer or the employment of a different breed of domestic animal, could cause certain taxa to fail and disappear, thus exposing the ground during certain periods and leading to erosion or even landslides. The encroachment by shrubs on pastures may also change slope stability through water infiltration.

Why care for mountain biodiversity?

Beyond driving evolution and the ethical imperative (the right to exist), three motives to care about biodiversity deserve wider attention: the cultural, the ecological, and the economic. Hu-

Examples of the benefits of mountain biodiversity and ecosystems

Provisioning services: extractive resources that primarily benefit lowland populations (e.g. water for drinking and irrigation, hydropower, timber) and ecosystem production (agriculture for local subsistence and for export; pharmaceutical and medicinal plants; non-timber forest products);

Regulating and supporting services: including watershed and hazard prevention, climate modulation, migration (transport barriers/routes), soil fertility, soil as storage reservoir for water and carbon;

Cultural services: spiritual or heritage sites, recreation, cultural and ethnological diversity.

Each of these mountain ecosystem services makes specific contributions to lowland and highland economies (Körner et al. 2005).

Market in Cajabamba, Ecuador | Photo: Beat Ernst, Basel

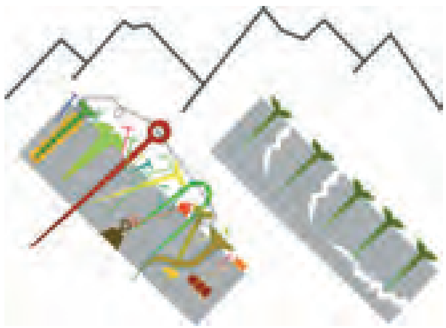
mans have shaped the biosphere and left fingerprints of genetic diversity on a landscape that can be seen as a cultural heritage, producing a living inventory with an immense variety of domesticated plants and animals. The cost of losing the services provided by mountain biodiversity are huge – both in ecological and economic terms. These benefits exceed those directly related to land use (agriculture, forestry) by securing watersheds from slope failure (erosion, mud flows, avalanches). Mountain freshwater supplies, which are crucial for all downstream areas, greatly depend on stable and intact vegetation in catchments. A highly structured, diverse ground cover with different root systems is probably the best insurance for slope stability and for securing railway lines, roads and settlements worth billions of dollars. Of major importance is the fact that mountain biodiversity also ensures the basis for the production of healthy food needed for expanding markets worldwide.

The economic motive

Biodiversity provides ecosystem goods and services directly used by humans, including high-elevation medical plants, mountain crops, timber and other montane forest products. It ensures a steady flow of clean water, provides an unpolluted and healthy environment for residents and offers attractive landscapes for visitors. The benefits and the services provided by mountain biodiversity are huge, in economic, political and social terms.

A cradle for species and a source of medicines

A large fraction of the world's most precious gene pools (for agriculture and medicine) are preserved in mountains. Major crops (maize, potatoes, barley, sorghum, tomatoes, beans and apples) have been diversified in mountains and an array of domestic animals (sheep, goats, yaks, llama and alpaca) have originated or been diversified in mountains. Other crops, such as wheat, rye, rice, oats and grapes, have found new homes in the mountains and evolved into many varieties. Coffee and tea, with their roots in Ethiopia and the Himalayan region, are mountain crops as well. Medicinal plants are one of the most valuable resources from high altitudes. For example, 1748 species from the Indian Himalayas are used for local medicinal treatment or in a trade that involves the pharmaceutical industry. Roughly a third of them grow in the subalpine or alpine zone. Cultivation of medicinal plants, instead of the harvest of wild plants, and local processing, instead of exportation of the raw material, are two strategies that can ensure the sustainable use of medicinal plants and increase the income of mountain dwellers. Some species that are important for ecosystems, are also charismatic for humans, providing symbols of the impressive variety of life. These include increasingly rare animals such as gorillas, mountain lions, and the majestic tahr or strikingly beautiful plants such as orchids and lobelias. Species such as these draw tourists, as well as scientists, to observe them.



Human land use increases or decreases biodiversity (symbolised by nails and screws, i.e. the functional tools of plants on steep slopes), and affect ecological integrity of alpine ecosystems (water catchment value, erosion risk). The GMBA initiated Bio-CATCH network in Austria, Switzerland and France assesses land use change impacts on plant diversity and their consequences on water dynamics from single plant traits to landscape and catchment level.

2

Keystone species control erosion edges in the Central Caucasus and the Swiss Central Alps

Grassland biodiversity in high mountain pastures is insured against soil erosion by a keystone species, the graminoid *Festuca valesiaca*. The otherwise inconspicuous grass species is able to brave the harsh conditions at erosion edges and thus prevent further degradation.

Festuca valesiaca at the boarder of large erosion gullies in the Central Caucasus | Photos: Riccarda Caprez

On the slopes in many European mountain regions, the grass *Festuca valesiaca* would hardly stand out in the species-rich pastures. However, surveys in the Central Caucasus (Rep. of Georgia) as well as in the Swiss Central Alps discovered the otherwise unremarkable grass species to be crucial in securing steep slopes against erosion. The investigated slopes are characterized by large erosion gullies (Central Caucasus) and surface erosion (Swiss Central Alps), consequences of excessive land management.

The single species *Festuca valesiaca* plays no spectacular role in the intact pasture, but becomes vital at the edge of the eroded areas, where most other taxa fail. Its ability to cope with the harsh life conditions at the edge, mainly due to its dense root system and drought resistance, engineers an environment that prevents or delays the progression of the erosion process. Such a key role of a single species often only becomes apparent when environmental conditions change, e.g. as a result of intense land use or climate change. The more diverse a system is, the more likely there will be a species (or a functional trait) that can cope with extreme conditions and compensate for the failure of other species. Thus, highly diverse plant communities, with a higher probability of "hidden" keystone species, are important for the integrity of high mountain ecosystems.

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Honeybees and Ecosystem Services in the Himalayas

Honeybees are very effective and important pollinators and, therefore, essential for the production of food and the maintenance of biodiversity. A pollinator decline led to loss in the yield and quality of apples in Maoxian County (Sichuan, China) and forced farmers to pollinate their apple flowers manually.

Indigenous honeybee *(Apis dorsata)* pollinating a wild flower | Photo: Surendra R. Joshi

Lady pollinating apple flowers by hand in Maoxian County, China | Photo: Uma Partap

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More than 75% of the major world crops and 80% of all flowering plant species rely on animal pollinators. Bees are the principle pollinators of crops and natural flora and are reported to pollinate over 70% of the world's cultivated crops; among the different types of bees, honeybees are the most effective and efficient pollinators.

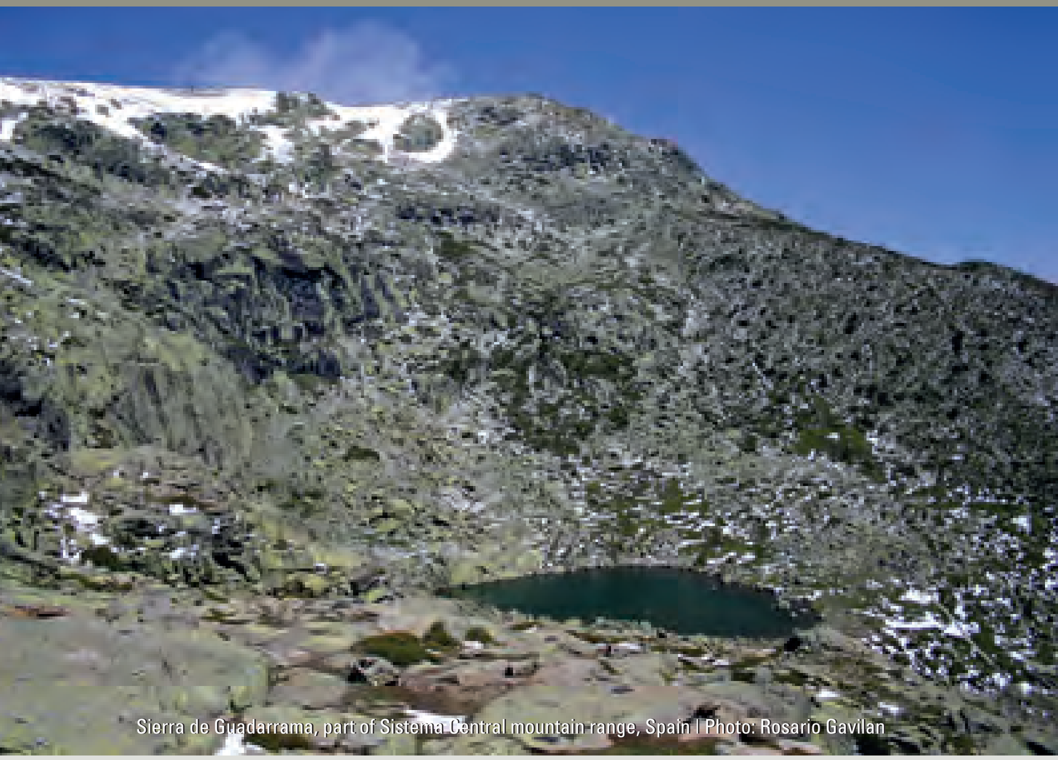
The Hindu Kush-Himalayan (HKH) region is blessed with a diversity of honeybee species, including five indigenous species. For example, the Himalayan cliff bee, *Apis laboriosa,* is a valuable pollinator of high mountain crops and other plants, while *Apis dorsata* and *Apis florea* pollinate agricultural crops and natural flora in low hill and plain areas. However, the populations of indigenous honeybees are threatened for a variety of reasons: loss of habitat; reduced availability of foraging, nesting and hibernation sites; ongoing expansion of monoculture; reduced diversity of forage resources; extensive use of pesticides and other agro-chemicals; increased honey hunting; promotion of honey hunting-based tourism and the competition from exotic *Apis mellifera.*

The pollinator decline has had an adverse impact on agricultural productivity and biodiversity in the HKH region, and is clearly evident in apple farming valleys. The increasing decline in the yield and quality of apples due to the lack of pollinators has forced farmers in Maoxian County (southwestern Sichuan province) to pollinate their apple flowers manually.

The "Indigenous Honeybees Programme" at ICIMOD is making efforts to reverse the decline of populations of indigenous honeybees. For two decades the programme has promoted beekeeping to farmers, and highlighted the importance of bees and their pollination "services" to policy and planning institutions.

Facilitation: an important outcome for alpine Mediterranean biodiversity

Interactions among species are generally accepted as important processes shaping alpine communities. In the alpine zone, positive interactions between species (facilitation) seem to be more important than negative interactions (competition), at least in exposed sites.



Sierra de Guadarrama, part of Sistema Central mountain range, Spain | Photo: Rosario Gavilan

Minuartia recurva | Photo: Rosario Gavilan

Facilitation means that some species profi t from others; in alpine areas this effect is often stronger than competition for resources. The mechanisms involved in facilitation are diverse and include provision of shelter or shade, attraction of pollinators, protection from herbivores, and improvement of soil. Some species receive more visits from pollinators when accompanied by other species than when alone. Some plants protect seedlings or small plants from predators by shading them and/or preventing animals from reaching and eating them.

Bare ground with no vegetation impairs establishment
of plant seedlings: the soil is overheated by the sun and seedlings may suffer from freezing of the ground on clear nights. Nutrient-poor, loose substrate can be stabilized and enriched with humus by specialist species (clonal plants, cushion plants) that form their own compost. They can then “nurse” other species. Cushion plants are typical in the alpine life zone and facilitate co-occurring plant species. For example, alpine Mediterranean vegetation in the central Iberian Peninsula is organized in mosaics of vegetation surrounded by open areas. Those patches are composed of perennials such as cushion plants (Silene elegans, Jasione centralis, Minuartia recurva or Plantago alpina). The conservation of this natural vegetation in the Mediterranean mountains (and elsewhere) guarantees slope stabilization and prevents erosion processes that could exert a strong negative infl uence on the capacity of water reservoirs downhill. The area shown here is only 60 km from Madrid (Sierra de Guadarrama) and one of the regions where water is collected for inhabitants of the city of Madrid, the third most populous city in Europe with over three million inhabitants and more than six million in the Greater Madrid area.

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Erosion of crop genetic diversity in mountainous regions of Georgia

Agriculture has a long history in the mountainous country of Georgia and has led to a great diversity of local landraces and varieties of cultivated plants. Now this diversity is under threat for several reasons. More info: Akhalkatsi et al. 2010.

Local variety of soft wheat *Triticum aestivum* var. *ferrugineum* in the living collection of Georgian cultivars in Tsnisj, Georgia | Photo Maia Akhalkatsi

The main threat to agrobiodiversity in Georgia is the loss of ancient crop varieties. These traditional cultivars which are adapted to local climatic conditions and often disease resistant, have been largely replaced by introduced crops with higher yields. Imported modern agricultural machines that are adapted for the widely distributed, imported crops cannot be used to harvest local cultivars.

Until the 1990s, genetic erosion of ancient crop varieties was not a problem. The mountain areas of Georgia contained local crop varieties of wheat, barley, rye, oat, common millet, traditional legumes, vegetables, herbs, and spice plants adapted to mountain conditions. These depositories in local mountain communities preserved a traditional way of life and socioeconomic structures. Traditional agricultural equipment, used on a large scale until the 1990s, still is used to cultivate areas on steep slopes and at high elevations, where modern tractors cannot be used; some old landraces of wheat and barley are still being used to prepare bread and beer for religious rituals. However, many endemic and native representatives of crop plants are in danger of extinction due to the population decline in mountain regions, harsh economic conditions and lack of modern infrastructure. International nature conservation institutions and Georgian scientific and nongovernmental organizations are preserving the genetic resources of local cultivars by setting up gene banks and living collections in Georgia, or maintaining ex situ germplasm collections in research centres.

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2

Llamas and alpacas grazing on wetlands (bofedales), Sajama National park, Bolivia | Photo: Eva Spehn

3

The dramatic impact of land use change

The dramatic impact of land use change

Natural disasters in the form of landslides, floods, and avalanches strike mountains each year, affecting only small areas but also habitat diversity and ecosystem dynamics. These natural disturbances result in surprisingly fast natural regeneration of plants. In contrast, human impact dominates large areas, and its effect is often irreversible. Land use effects can be more dramatic than natural disasters or climatic change

Human interaction with regional species and climatic drivers has shaped mountain biodiversity for centuries. Many traditional upland grazing systems are classical examples of sustainable management. Animal husbandry for meat, milk, or wool production represents the major use of highland biota around the globe. In recent decades, however, road construction has made access easier, population pressure has grown, and migration has led to the collapse of traditional modes of land and resource use in mountain areas worldwide. Mining, industrialization, intensification of agriculture and tourism have all led to pressures on biodiversity that were unknown before. Moreover, poverty has caused upslope migration and forced farmer to use inappropriate land e.g. on erosion-prone slopes for agriculture, leading to significant biodiversity or soil losses in fragile mountain ecosystems.

How fire affects mountain biodiversity

Cultivation of formerly pristine montane areas and intensification of agriculture in inappropriate ways may provide a few harvests, but destroy the land-use potential – and biodiversity – forever. Both practices are most severe in the tropics and subtropics. In many of these regions, fire is used to clear land or renew forage, and is often followed by erosion, decline of catchment value and floods. When appropriately handled, fire can be used as a sustainable management tool that might increase biodiversity. For example, in the Maloti-Drakensberg Mountains between Lesotho and South Africa, species richness is higher in areas with a biennial spring burn than in those with annual burning and regions protected from fire. Grazing and fire provide open space for colonization that, in turn, can modify species diversity, promote some seedling establishment, and change the general structure of the community.

How grazing affects mountain biodiversity

Moderate-intensity grazing of temperate montane forests with cattle actually increases, rather than decreases, biodiversity. Unlike wild ungulates, cattle mainly feed on grass and profit from minor clearings intentionally opened by farming or selective logging. The complete banning of forest pasturing in temperate mountains is therefore not desirable, but stocking rates must be kept low and selective browsing by livestock such as goats must be avoided. However, in sub-tropical and tropical montane forests this mode of land use can be very destructive for biodiversity.

Grazing intensity and the type of grazing animals greatly affect mountain biodiversity. Plant communities in the Venezuelan páramo, for example, can lose up to 30 to 40% of their palatable biomass to grazers without losing any species. Grazing can even promote plant species diversity, because it can suppress some otherwise dominant species. However, when grazing intensity is enhanced beyond a certain threshold, already-existing dominant plant species tend to become

Tien Shan, Kasachstan, 2600 m | Photo: Christian Körner

more dominant, and biodiversity declines. Selectively-browsing animals, such as cattle, sheep, and alpaca, have much more impact on pasture quality and biodiversity than species with a broad food spectrum, such as llama. The more selective the animals are, the more restricted the effective pasture space becomes. This becomes most critical in periodically dry regions, where herds must be sustained on small areas with good ground moisture. Several studies have documented the key role of these wetlands in the Andes and in the dry inner parts of the Himalayas – they determine the carrying capacity of large regions for grazing animals (Spehn et al 2006).
In Australia, New Zealand, and the tropic alpine grasslands of New Guinea, the flora evolved without ungulates. Hence, mountain vegetation has not adjusted to grazing and trampling by animals. Early settlers nearly destroyed the Australian alpine vegetation with livestock grazing. It has been calculated that rehabilitation and re-vegetation of the eroded landscape has cost twice as much as the financial benefits of 100 years of pasturing, not counting losses in terms of clean water provision and hydroelectric energy (Costin 1967).

Recent land use changes: intensification and abandonment

In temperate mountain regions like the European Alps, clearing of forests and subsequent agricultural land use on a spatially small scale created a cultivated landscape of high biodiversity. Since the 1950s, agriculture has become more mechanized and the use of easily accessible land (usually near villages and at valley bottoms) has been intensified. Increased fertilization has led to biologically depleted grassland, and important landscape elements like single trees or hedges have been removed so that the landscape has become monotonous. At the same time, steep or more inaccessible land, with low yield and requiring considerable manual work, was abandoned and hay meadows were converted to pastures, both decreasing species and landscape diversity.
On the other hand, sub-tropical and tropical mountains offer striking examples of intensification of human pressure on montane areas, e.g in African mountains, humans have traditionally settled in uplands, where the climate is mild and the environment relatively disease-free compared to the arid or very humid lowlands. However, more recently, increasing population pressure has led to unsustainable land practices and upland use detrimental to biodiversity.
Mountain forests are among the most biologically diverse areas and contain the most threatened biota worldwide. For example, evergreen tropical cloud forests harbor a disproportionately large number of the world's species, including rich amphibian and invertebrate fauna and wild relatives that contain sources of genetic diversity of important staple crops, such as beans, potatoes and coffee. Uphill expansion of agriculture and settlements, logging for timber and fuel, and replacement by highland pastures all threaten these ecosystems.

Assessment and prevention of non-native plant invasions in mountains

Mountains may increasingly become threatened by invasive non-native plants due to climate change, increased anthropogenic disturbances, and the deliberate introduction of non-native species that are pre-adapted to a cold climate. The Mountain Invasion Research Network evaluates the threat of plant invasions to mountains globally.

Lupinus polyphyllus in the abandoned gold mining village of Kiandra in the Australian Alps | Photo: Keith McDougall

A harsh climate, isolation and limited human activities have made mountain ecosystems relatively resistant to plant invasions. However, in the future, climate change and increasing human pressures may make mountains as susceptible to invasions as other areas. The Mountain Invasion Research Network (MIREN, www.miren.ethz.ch) integrates on a global scale monitoring, experimental research, and management of plant invasions on mountains. The MIREN core program includes 10 mountain regions covering the major climatic zones and including continents and islands.

MIREN has identified almost 1500 plant taxa worldwide that are naturalized or invasive on mountains. The most widespread species are typical of European pastures and were introduced during the past few hundred years, many in association with livestock grazing. Most of these species appear to have had relatively little impact on biodiversity. However, some problematic invaders (e.g. *Hieracium* spp., *Cytisus* spp., *Salix* spp.) have appeared recently, as mountain land use has shifted in many regions from agriculture to tourism and recreation. These species have often been selected for cold adaptation and now pose an important threat to biodiversity. This threat is likely to grow, as deliberate introductions of non-native species expand and global warming allows invaders to reach higher altitudes.

Mountains are among the very few eco-regions not yet strongly altered by invasions; managers thus have the unique opportunity to respond in time to prevent invasions. Proactive measures, such as restricting the transport of likely invasive species and early detection surveys, may help to prevent invasions before they have major impacts.

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Management of an invasive plant species in the Australian Alps

MIREN documents case studies of plant invasion management in mountains worldwide to foster learning. The example of hawkweed management in the Australian Alps illustrates that eradication is very challenging once a non-native species spreads into a topographically complex mountain landscape.

A dense colony of Orange Hawkweed *(Hieracium aurantiacum)* in undisturbed snow gum woodland, Kosciuszko National Park, Australia | Photo: Keith McDougall

In the early 1990s, the Australian Alps were regarded as being at low risk of invasion by non-native plants because of their harsh climate. In 1999, the European orange hawkweed *(Hieracium aurantiacum)* was found to have naturalized from a ski resort garden. Its known invasive behavior and threat to biodiversity in mountain areas in New Zealand and North America alerted national park managers, leading to broader survey and the discovery of further populations and another hawkweed *(H. praealtum)*. Despite immediate removal of hawkweed plants using herbicides, both species spread rapidly, invading both disturbed and undisturbed environments and forming extensive colonies.

There is now a concerted and costly effort to eradicate hawkweeds in the Australian Alps involving state and federal governments and ski resort companies. The program comprises surveys utilizing volunteer labor, GIS mapping and modeling of spread, outreach, research into the reproductive biology of hawkweeds, and advice from researchers in New Zealand, where several hawkweeds are now intractable in montane grasslands. The Australian hawkweed program has demonstrated the new and potentially high impact of plant invasions on mountains. It is representative of an increasing focus on prediction and prevention (e.g. modeling species movements under climate change, assessing potential invaders from lowlands, and removal of horticultural species from ski resorts) and learning from experiences in mountains elsewhere. If effective, these management approaches will be far more cost-effective than reactionary management.

Ecological and hydrological consequences of green alder expansion in the Swiss Alps

Due to reduced farming activities, the massive encroachment of a single shrub species (green alder, *Alnus virdis)* into the upper montane, formerly a species-rich pasture land in the Swiss Alps, significantly reduces water quantity and quality for drinking as well its potential for hydroelectric use.

Green alder *(Alnus viridis)* is rapidly encroaching upper montane pasture land | Photo: Erika Hiltbrunner

With its N_2-fixing symbionts, *Alnus viridis* pumps enormous amounts of nitrogen into the ecosystem, promoting only a few lush, tall herbs in the understory | Photo: Christian Körner

The European Alps are the most intensively exploited mountain region in the world, inhabited by 13.6 million residents and visited by an estimated 120 million people every year. Primary resources are agriculture, tourism and hydroelectric power. In Switzerland, hydropower meets 56% of the country's electricity requirements. Despite exploitation, the Alps still host Europe's largest pool of plant species in highly diverse landscapes. Land use transitions, climatic changes and socio-economic processes are affecting ecosystem goods and services of alpine areas with vital impact on the forelands. Reduced farming activities have led to massive shrub and forest expansion into formerly open habitats. In particular, green alder encroachment leads to nearly mono-species stands in previously species-rich upper montane grasslands.

Besides negative impact on plant diversity, these land cover changes affect evapotranspiration and runoff (amount, quality), with hydrological consequences for both highlands and the adjacent lowlands. Leaves of dense alder stands intercept more precipitation and transpire more water. Therefore, there is less surface runoff and ultimately less water arriving in the creeks and rivers, thus decreasing the hydroelectric potential. With its N_2-fixing symbionts, *Alnus viridis* pumps enormous amounts of nitrogen into the ecosystem, promoting only a few lush, tall herbs in the understory. The system rapidly leaches so much nitrate from the soil that it creates risks to the local drinking water springs and adds nitrogen loads to the rivers. At the same time, this vigorous species-poor system replaces centuries-old, species-rich grasslands and allows little chance of tree establishment due to the lack of seed sources and the competitive vigour of alder and its lush understory vegetation.

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Land use and biodiversity in the Swiss Alps from the genetic to the landscape level

Hundreds of years of agricultural activity have shaped landscape diversity and biodiversity of grassland parcels in the Swiss Alps. Old cultural traditions have also shaped current landscape biodiversity. However, due to recent land use changes, biodiversity is currently declining.

Scattered barns on steep hayfields above Vals (1252 m a.s.l.), a traditional village: they were used until recently to store hay for the long winter | Photo: Jürg Stöcklin

Alpine grasslands harbour a great diversity of plant species, but only little is known about other levels of biodiversity: landscape diversity, diversity of biological interactions, genetic diversity, and the effects of recent land use changes on the different levels of biodiversity. Landscape diversity has been increased by differences in land use promoted by the old Romanic, Germanic, and Walser cultural traditions. High land use diversity within a village increases the total plant species diversity of the village. Plant species diversity per parcel is highest in unfertilized meadows compared with fertilized or grazed grasslands, and each land use type harbours a different set of species.

The studied grassland parcels contain a great diversity of biological interactions, as most plants are affected by herbivores and fungal leaf pathogens. Hundreds of years of agricultural land use have led to a genetic differentiation in the important fodder plant Alpine meadow-grass *(Poa alpina)*. An experiment comparing plants from mown and grazed sites shows that the plants are genetically different. Genetic diversity of the Alpine meadow-grass is higher in villages with higher land use diversity, analogous to the higher plant species diversity there.

The results of this study suggest that measuring plant species richness does not always adequately reflect biodiversity at different levels of biological integration. Overall, landscape diversity and biodiversity within grasslands are currently declining. Since the observed changes in land use are socio-economically motivated, financial incentives are needed to stop or at least slow down this development. The focus should be on promoting high biodiversity at the local and the landscape levels.

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Himalayan tahr, Sagarmatha (Mt. Everest) National park, Nepal | Photo: Som B. Ale

4
Climate change and its link to diversity

Climate change and its link to diversity

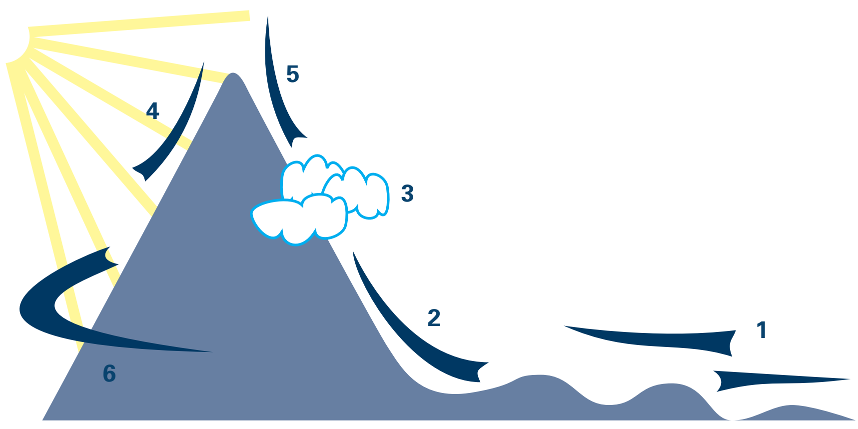
Global warming threatens mountain biodiversity by forcing life zones upslope, thus reducing higher land area for organisms specifically adapted to the cold. With higher temperatures predicted, longer summers with a greater incidence of drought are expected in many mountain regions worldwide. Although effects vary regionally and the extent of the increase of temperatures is debated, it is clear that the Earth has experienced an exceptional warming during the past century, one that cannot be explained by natural drivers.

Climate change in mountains

Climate change is linked to an increase in atmospheric concentrations of greenhouse gases (Carbon dioxide CO_2, Methane CH_4, Nitrous oxide N_2O, halocarbons) caused by human activities. Greenhouse gases affect the absorption, scattering and emission of radiation in the atmosphere and at the Earth's surface (IPCC 2007). Studies show that temperatures are very likely to increase more in the 21st century.
Rising temperatures are coupled to a decrease in mountain glacier area, shorter duration of snow cover at elevations below tree line in temperate and boreal latitudes, and increased annual precipitation with otherwise changing seasonality, i.e. not excluding periodic droughts in summer. It is expected that many small glaciers will disappear, while the volume of large glaciers will be reduced by 30% to 70% by 2050, with consequent reductions in discharge in spring and summer.

Earlier spring activities

Climate warming since the 1960s has led to a progressively earlier onset of spring activities below the tree line. Above the tree line, warming-associated increases of precipitation may enhance snow pack in some regions, and thus even delay spring. Plants show an earlier bud break or flowering, while increased temperatures have changed the timing of hibernation, breeding of animals and, in some cases, the dependence of predators on traditional prey. The effects of climate change on one species are likely to affect a cascade of other species in the food web.



Species responses to climatic warming. Mountains may be refugia (2, 4), traps leading to local extinction (3, 5), or a chance to escape climate warming by topography effects (6). Lowland species often have to move greater distances (1).

Vicuña *(Vicugna vicugna)* on the Bolivian Altiplano | Photo: Erika Hiltbrunner

Species migration with climate change

Another widely observed phenomenon related to climate warming is migration of plant and animal species. In the northern hemisphere, a northwards shift of bird and butterfly species has been observed as well as migration to higher elevations. Species already inhabiting cool summit regions cannot migrate further upslope when temperatures increase and species from lower elevations move up. Given that all mountains become narrower with elevation, more species will compete for the upper area and its limited resources. Rare species, or those adapted to the cold, may be outcompeted in the long term. However, co-existence of species with contrasting climate preferences is facilitated by the rich topography of mountain ecosystems that creates diverse microhabitats. While space for species living near summits today is diminishing, the overall situation in mountains is far better than the situation on the plains. Mountains are key environments for conservation of biodiversity during climatic change. They have always provided refuge for species, especially during postglacial cycles. This protective function may be enhanced by enlarging and connecting mountain areas based on scientific knowledge and maintaining wilderness corridors to the foothills and plains. Otherwise, low elevation organisms will have nowhere to go. One of the main problems presented by temperature increase concerns the speed of change: ongoing and expected climatic changes are much faster than what evolution and migration are commonly able to cope with. At the most rapid pace of plant species in the European Alps, uphill movement has averaged only about 10m per decade during the past century. Model simulations of climate change in mountain areas are very difficult due to the complex topography; so far, climate models have been inadequate to reflect the very large variations in microhabitats. A new thermographic study for alpine terrain in the Alps (Scherrer & Körner 2010) reveals major deviations in life conditions from what weather stations record. The study shows that only 4% of all habitat types are lost in a 2°C warmer world. The size of the cool habitats, however, will shrink significantly, leaving less space for more species.

Climate station on the Qinghai-Tibetan Plateau, China | Photo: Eva Spehn

Which species will be most affected by climate change?

Any environmental change will cause local native populations to either adapt or escape (migrate) to avoid extinction. This will probably occur through competitive exclusion rather than physiological limitations; the survivors will be those that compete successfully for basic resources such as light, water, space and food. Under natural conditions, most taxa can easily cope with a few degrees of warming. Mountain species often have a surprisingly high genetic diversity, which is a great pre-requisite for adaptation to new conditions. Also because of rapidly changing climatic conditions, from week to week and season to season, alpine organisms are able to rapidly acclimate to new conditions. Individuals have the ability to adapt either by physiological acclimation or, in the case of animals, behaviour. But this sort of "adaptation" of the phenotype is limited and not at all the same as evolutionary adaptation. In the timeframe of climatic warming, the evolution of new taxa is very unlikely and not an issue. New "adapted" communities usually assemble by replacement of species by other species migrating into the community (i.e. from lower elevations). When neither acclimation nor behavioural changes match the new demands, migration becomes inevitable, and in cases, where migration is not possible, species will disappear, at least locally.

Which sorts of species are we at risk of losing, given the rapidity of change that is anticipated? There is no simple answer, but a few general characteristics may serve as a guideline:

Likely losers:	**Likely winners:**
Large territorial animals	Small, highly mobile organisms
Late successional plant species (K-strategists)	Ruderal plant species (r-strategists)
Species with small, restricted polulations	Widespread species with large populations
Species confined to summits or the plains	Mid-slope species

Combining these partially overlapping categories, we would expect small, mobile, widespread ruderals, currently not confined to summits, to represent the winning group of plants. Large, slowly reproducing organisms with small populations would be expected to be on the losing side. Not surprisingly, plant species in higher elevations that belong to a generalist group of "weedy" taxa have an advantage. Some late successional plant species, however, are so resilient that they have hardly been affected by climatic changes. There are some species, mostly clonal, that have not changed position by more than a few meters over the past thousand years (Steinger et al. 1995). Others may escape problems by making use of the diverse mosaics of high elevation microhabitats. Usually, a temperature increase of 1–2°C exerts little short term change on

Great Aletsch (Switzerland), the largest glacier in the Alps | Photo: Katrin Rudmann-Maurer

alpine vegetation, due to the substantial natural inertia of high elevation plant species (Theurillat & Guisan 2001); more pronounced warming is likely to bring substantial changes. Because each species responds individually, new assemblages are expected, rather than a migration of established communities.

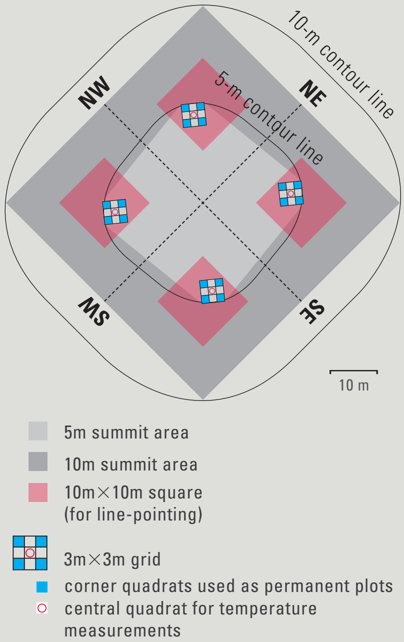
Changes in plant communities also imply changes in animal habitats. Especially for large species with a narrow geographic and climatic range, the risk of extinction increases with climate warming. Already threatened and endemic species are the most vulnerable. While mobile species can react very fast on changes in their environment, some slower moving species may show a delayed reaction. Their fate more strongly depends on the diversity of available microhabitats.

4

Impacts of climate change on mountain biodiversity: the global observation network GLORIA

The world's high mountain regions harbour a large number of highly specialised plant species that are governed by low-temperature conditions. Climate warming may force many of these species towards ever higher elevations and finally to mountain-top extinction. Long-term observation sites, therefore, are a crucial prerequisite for assessing the impacts of climate change in high mountain regions.

GLORIA field recording in the north-eastern Alps | Photo: Harald Pauli



The standardised GLORIA sampling design as applies on several 100 mountain tops distributed over 5 continents.

Climate change impact models have suggested serious biodiversity losses, and have indicated that plants in mountain regions may be among those most affected. Model projections, however, need to be verified by ground-based direct evidence. For this reason, the long-term observation network GLORIA (the Global Observation Research Initiative in Alpine Environments; www.gloria.ac.at) was established at the turn of the millennium. GLORIA focuses on plants in high mountain regions, i.e. the area from the cold-limit of tree growth to the upper limits of vascular plants. Such alpine environments occur at all latitudes from the tropics to the polar regions and, thus, have a great potential for monitoring large-scale ecological effects of climate change. The observation network uses the area around mountain summits at different altitudes for its basic and widely applicable monitoring setting. The standardised design includes permanent plots of different size (Figure 1#) on each of four summit sites per mountain region. Soil temperature is measured continuously at all sites. Currently, the network has sites in 80 mountain regions distributed over the continents of Europe, Asia, North America, South America, and Australasia.

GLORIA makes a direct contribution to the Global Terrestrial Observing System and collaborates with the Global Mountain Biodiversity Assessment and the Mountain Research Initiative. Support came from European Union research programmes, MAVA Foundation for Nature Conservation, UNESCO MAB, the Austrian Federal Ministry of Science and Research and a number of national and non-governmental organisations.

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Observed climate-related changes and risks of alpine biodiversity losses

Nevadensia purpurea, Sierra Nevada | Photo: Harald Pauli

The majority of alpine plants are slow-growing and long-lived. Therefore, climate-related changes in the number of species and their abundance are mainly a response to climatic changes over several years or decades rather than to short-term oscillations. GLORIA's permanent plots are resurveyed at intervals of 5 to 10 years. Preliminary results from the first reinvestigated sites confirm previous case studies showing an increase in species richness at high altitudes that most likely is a consequence of a warming-driven upward shift of mountain plants. Using European GLORIA data, an alpine plants/climate change indicator was developed to indicate if and to what degree the continent's high mountain vegetation already has experienced a transformation to a more thermophilic species composition. Monitoring data from the GLORIA master site Schrankogel in the Austrian Central Alps indicated that extreme high altitude plants experienced a significant decline within a decade. High mountain regions are outstandingly rich in different plant species. Many species with a very restricted distribution occur especially in Mediterranean mountains but also in parts of the Alps. These endemic species currently often live only in the uppermost elevation zones and, thus, are particularly prone to mountain-top extinctions.

4

Extinction threat to pygmy-possum from early snowmelt and late bogong moth arrival

Migratory bogong moths are a keystone species in the Snowy Mountains of Australia, as they are an important food source for a number of animals after a stressful winter. However, earlier snowmelt due to climate change is not being matched by earlier moth arrival, resulting in serious consequences for the endangered pygmy-possum.

Mountain pygmy-possum | Photo: Ken Green

Bogong moths congregating in mountain caves over summer | Photo: Will Osborne

Bogong moths *(Agrotis infusa)* are an important source of nitrogen and phosphorus for the alpine ecosystem in the Snowy Mountains of southeastern Australia, as well as a threat due to their importation of arsenic from lowland agricultural systems. With more than two billion arriving each year, bogong moths are also an important food source for hungry animals in spring after a stressful winter. Although animals are becoming active earlier because of an earlier snow melt, bogong moths are, in fact, arriving significantly later. This has a critical impact.

Since 1996 moths have arrived, on average, 25 days later than the date of snowmelt. This later arrival provides less time for moth numbers to build up to become a readily exploitable food source for animals emerging from hibernation. Resident mammals dependent upon this source of food in spring, at a time of high energy demand, include endangered mountain pygmy-possums *(Burramys parvus)*. A consequence of the late arrival of bogong moths is that the moth diet of feral foxes in spring fell from 60% to 20% over three years. Populations of all insectivorous small mammals crashed during this period. The shortfall in moths was compensated for by increased predation by foxes on small mammals, including pygmy-possums. It appears that climate change has altered the matched timing between spring migrating bogong moths and hibernating mountain pygmy-possums, with dire consequences for mountain pygmy-possums whose numbers continue to fall.

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Effects of changes in climate, land use and land cover in the High Atlas, Morocco

Moroccan mountain biomes are endangered due to climate change that directly or indirectly affects biodiversity, snow cover, run-off processes and water availability.

Alfa steppe, Ziz valley, Morocco | Photo: Mohammed Messouli

Collaboration among scientists, stakeholders and decisionmakers is important for an integrated assessment of climate change in the High Atlas Mountains of Morocco. Local-to-regional scale information on climate variables can be derived by downscaling statistical outputs from IPCC climate models. These data will be combined with socio-economic information such as the amount of water used for irrigation of agricultural land, types of agricultural practices and phenology, cost of water delivery and non-market values of produced goods and services.

A GIS-platform compiling gridded spatial and temporal information of environmental, socio-economic and biophysical data is used to map vulnerability assessment and risk levels of a large area of the southern High Atlas. Key climate indicators related to sustainable management of ecosystem goods and services will be determined for different scenarios in the near future (10–15 years). An Integrated Valuation of Ecosystem Services and Tradeoffs tool (InVEST), recently developed by the Natural Capital Project, will be used to assess interaction among ecosystem service principles. The aim here is to identify areas of high and low ecosystem service production and biodiversity across the mountains and illuminate tradeoffs and synergies among services under current or future conditions. Biodiversity in the High Atlas is threatened not only by climate change but also by land use and land cover change.

Cultivation has resulted in a high loss of plant communities in the lowlands and has threatened regional diversity. Grazing has increased in Morocco due to low labor costs and economic policies that provide incentives for cattle production, while forest cover has declined due to timber extraction and urbanization as well as cultivation and grazing.

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Tree crowns in the mist, in the montane forest of the Nyungwe National park, Ethiopia, at about 2300 m a.s.l. | Photo: Michele Menegon

5
Protecting mountain biodiversity

Protecting mountain biodiversity

Mountains are hot spots of biological richness. Their diversity of life zones and habitats leads to unique flora and fauna and to the exceptional cultural diversity of mountain people, making mountains especially important sites for conservation efforts and projects. In fact, one-third (32%) of all protected area, regardless of status and size, is in mountains, including 88 World Heritage Natural Sites, and 40% of all UNESCO MAB Biosphere Reserves. The total number of Mountain Protected Areas is 21,400, on a total area of 5,996,075 km² (Chape et al. 2008).

Management of mountain biodiversity has increasingly been recognized as a global responsibility. In the past 40 years, protected areas have increased six- to eight-fold, largely in mountain areas, expanding from 9% of total mountain area in 1997 to 16% in 2010. While protected areas are essential, they alone cannot ensure conservation of biodiversity or cultural heritage. Traditional indigenous communities often use and manage biodiversity in mountain protected areas, and may be even more threatened than biodiversity itself. Mountain regions where people live and work require innovative and respectful approaches to conservation; local people should be encouraged towards stewardship of both their natural and cultural heritage. Participation of mountain communities at all stages is crucial in the sustainable management and use of biodiversity. Stewardship, with its focus on community-based management and local leadership, holds great promise for conservation of those mountain areas around the world where the biological, cultural and scenic qualities of the landscape are the result of the interactions of people with nature over a long time. In the Hindu Kush region of the Himalayas for instance, conservation efforts now adopt participatory approaches, implement policies of decentralised governance for biodiversity management, and empower local communities toward achieving that goal (Sharma et al. 2010). A gradual paradigm shift in conservation policies and practices has included the acceptance of communities as an integral part of national conservation initiatives, and the integration of many global conventions.

Conservation landscapes are increasingly recognized for their potential to maintain high levels of biodiversity in combination with intensive, but diversified, small-scale agriculture in densely-populated mountain areas where the establishment or extension of formal protected wilderness areas is not feasible. These landscapes incorporate mixed crops, agropastoral and agroforestry approaches, and soil and water conservation. Mountain land users also may be compensated for the lack of on-site benefits through payment for environmental services (PES). Considerable experience from developing and industrialized countries shows that PES supports biodiversity management and is an innovative tool for resource transfer to upland communities, which are often more socially and economically disadvantaged than surrounding lowland areas.

The Harenna chameleon *(Chamaeleo harennae)* a species endemic of the Harenna forest at high altitude in the Bale Mountains of Ethiopia | Photo: Michele Menegon

Managing mountain biodiversity successfully under global change

Mountain biota are particularly vulnerable to climate change. Protected areas crossing several altitudinal belts are necessary to allow species to move upward as temperatures increase. To accommodate climate change and to protect biodiversity, mountain protected areas should be extended downslope to the lowlands and, in some places, to the sea ('Summit-to-Sea') (Hamilton 2006). For large territorial animals, mountain conservation areas ideally should be linked to each other to provide an escape corridor. Migration routes should also be kept open for refugee species from climate-change impacted areas. Because it is essential to preserve the full range of biodiversity, provision should be made for the protection of large and connected examples of natural ecosystems and of populations of plant and animal species. These could be supplemented by the protection of smaller areas representing a full local variety of species and ecosystems, including intra-specific genotypic variation. As far as possible these also should be connected with nature-friendly land uses (Hamilton and McMillan 2004).

Integrating sustainable use of biodiversity with conservation

Highly developed regions, such as the European Alps, and mountain regions that are still in a natural or pristine state, e.g. Patagonian Andes, need different conservation strategies. For the one, protected areas may be created; for the other, wilderness areas should be maintained. UNESCO's Man and Biosphere (MAB) program is successfully integrating sustainable use of biodiversity with conservation. In Mountain Biosphere Reserves, different protection zones meet the various needs of humans and biodiversity. These include core and wilderness zones, zones for recreational or other uses, and buffer or peripheral zones for production activities (such as harvesting of medicinal plants by locals). Those areas with species or ecosystems extremely sensitive to human interference (e.g. Tibetan chiru, Afro-montane cloud forests) should merit special protection status, such as strict nature reserves or wilderness zones.

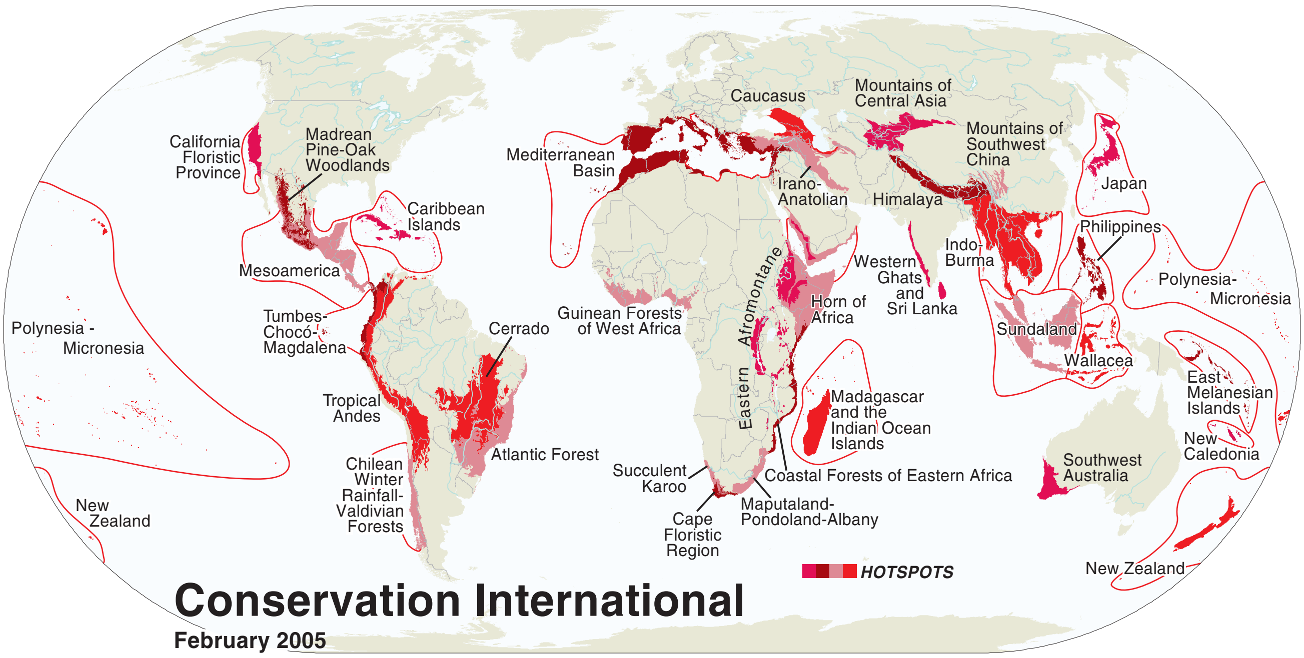
Identifying regions with high biodiversity value

One way to maximise conservation efforts is to identify protection areas with high biodiversity values. The WWF European Alpine Program provided a list of priority areas for biodiversity conservation in the Alps using available data on species and habitats, socio-economic information, and a gap analysis with existing protected areas. Based on this information and expert knowledge from all countries of the Alps, areas most important for different species groups (flora, insects, reptiles and amphibians, birds and mammals) and for freshwater ecosystems were drawn on maps and then the areas with the greatest overlap were identified. As a result, 24 conservation priority areas in the Alps with the largest number of animals, plants and ecosystems (Mörschel

The Hare Forest canopy in the Nguru Mountains of Tanzania at about 2200 m a.s.l. | Photo: Michele Menegon

2004) have been established. These protect extraordinary groups of plants and vegetation types unique and/or typical for the Alps; centres of endemic species; centres of rare species; large, continuous forest areas (refuges for rare species and corridors for large animals); distinct dry areas with drought-tolerant vegetation (e.g. grasslands with *Stipa* or *Festuca* in the dry valleys of the central part of the Alps); and habitats harbouring particular ecological phenomena special to the Alps, such as peat bogs or glacier forelands. In the case of mammals, special attention was given to the following groups: Large carnivores such as wolf, lynx, and brown bear; large herbivores such as the Alpine ibex, Alpine chamois, and red deer, whose traditional migration between winter and summer habitats mostly has been cut off by roads or settlements in the valleys. Additionally, special attention was given to small and medium-size mammals, especially endemic species (e.g. Alpine mouse, Bavarian vole), bats (vulnerable to disturbance) and otter.

Hotspots map from Conservation International. To qualify as a hotspot, a region must meet two strict criteria: it must contain at least 1,500 species of vascular plants (> 0.5 percent of the world's total) as endemics, and it must have lost at least 70% of its original habitat. More info: www.biodiversityhotspots.org



Black and White Colobus *(Colobus guereza)* of the Ethiopia highlands. | Photo: Michele Menegon

Transboundary connectivity for mountain biota

Mountains can also have a corridor function for biota, for instance connecting mesic, temperate lowland regions otherwise separated by hot or dry lowland climates, the case in the southern slopes of the Himalayas. Conserving connectivity corridors (and their associated transboundary protected areas) helps conserve habitats and the opportunities for species to evolve, adapt and to move. On a large scale, connectivity corridors provide additional opportunities for some species to survive in a world affected by climate change. Quite commonly, these corridors only became effective if they are permitted to cross political boundaries. Establishment of some large scale, cross-boundary conservation corridors in mountains is underway in the Himalayas, Altai-Sayan, Western mountains of USA and Canada, Australian Alps and the Albertine Rift Valley in Africa (Worboys 2009).

Implementing the Programme of Work on mountains

The Convention on Biological Diversity, signed by 150 governments worldwide, with its specific Programme of Work on Mountain Biodiversity, provides a set of actions to address characteristics and problems that are specific to mountain ecosystems. The review of the work programme and the International Year of Biodiversity 2010 present opportunities to promote action for the sustainable management of mountain biodiversity. Key elements of national action include awareness raising, participation and capacity building, and provision and implementation of laws and regulations that include benefit-sharing arrangements such as PES. National level action will be crucial for sustainably managing mountain biodiversity and finding lasting solutions to satisfy the needs of both mountain and lowland populations.

Expanding Long-Term Ecological Research to an Alpine network

The vast majority of studies in the ecological literature last less than three years, and only 10% of studies capture unusual events. To detect changes in high mountain ecosystems, long-term research is imperative for these areas are important bellwethers of global change.

Glacier foreland of the long-term monitoring site Rotmoosferner, Austria | Photo: Brigitta Erschbamer

The Long-Term Ecological Research (LTER) Network was established by the National Science Foundation, USA, in 1980 to support research on long-term ecological phenomena in the United States. Currently, efforts are underway to establish an alpine LTER network worldwide as part of GMBA. A working group is inviting participants to form a nucleus of core sites that will use common protocols to ensure comparability of data. This network will be able to capture slow processes or transient, episodic or infrequent events, reveal trends, multi-factor responses, or processes with major time lags. LTER relies on a secure and consistent funding base for instrumentation, observation (climate, vegetation, discharge), and for collaborators' costs. The alpine LTER network will expand beyond a project of individual investigators; the data collected by the network will be publicly available and also analysed and published in peer-reviewed journals. We consider the key to the success of long-term research to be information management. Long-term studies depend on databases that document project history, cross-site studies that require communication among the parties involved and the integration of their data. To facilitate the sharing of data, publicly accessible databases will be established.

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Examples of LTER in the USA and Europe

Niwot Ridge in the Colorado Rocky Mountains, USA, is the only multi-disciplinary, long-term field site for high mountain areas on the North American continent. As such, the site is an essential benchmark for any regional, national, and global network whose objective is to record the state of, and document the changes in, the abiotic and biotic environment, study the impacts of changes on ecosystem functioning and experimentally investigate the mechanisms for the relationships. The underlying rationale of an international alpine LTER is to convert long-term observations into

Mountain lake in Sierra Nevada | Photo: Ernesto Sofos Navero

Measuring climate data at the Niwot Ridge LTER site, circa 1956

process-based understanding of the controls of biodiversity. Data from such long-term observations are required to verify models that use long-term ecological data and suggest that amplification of drivers such as climate change, N deposition, and dust deposition in high mountain catchments may be "tipping" these ecosystems into states not experienced in modern times.
Austria has been actively involved in the international LTER agenda since 2002, when the LTER-Austria Society was founded with a total of 26 sites. Several areas in North Tyrol central Alps form the platform Tyrolean Central Alps'. Each of these regions hosts observation programmes on different spatial and temporal scales and have collected information on different processes and/or organism levels. Glacier research as well as climate and timberline studies have been undertaken for several decades; ecological monitoring using permanent plots has been carried out during the last two decades. The platform Tyrolean Central Alps' offers good examples of long-term studies that provide biodiversity baseline data and also essential data input for models and future observations. A continuation of these observation programmes is indispensable in order to analyse trends and to predict ecological consequences in the future.
In Spain, at the Sierra Nevada LTER site, effects of global change are monitored with more than 100 environmental variables. The main objective of this LTER site is to implement adaptive management in mountain ecosystems. To do this, we pay special attention to data management as a way to create useful knowledge to foster adaptive management. Data are managed with an information system and a metadata system that meets international standards so that it can be useful both to managers and scientists. Processed information is expressed as a set of pressure-status-response indicators of the ecosystem functions. Indicator values are shown for the past, present and future to facilitate ecological forecasts.

Biodiversity conservation through regional cooperation in Kailash Sacred Landscape

The Kailash Sacred Landscape (KSL) conservation initiative, a collaborative effort led by ICIMOD, UNEP and regional member countries (China, India, and Nepal), was launched in August 2009 to facilitate transboundary ecosystem management for biodiversity conservation and sustainable development.

Mt Kailash with surrounding landscape | Photo: Robert Zomer

The International Centre for Integrated Mountain Development (ICIMOD), with its partner institutions in the region, has prioritized transboundary landscape approaches for biodiversity conservation among its key areas of focus. Seven critical transboundary landscapes with globally significant biodiversity resources have been identified within the Hindu-Kush Himalaya (HKH), and meet the criteria for development of transboundary conservation and regional cooperation frameworks. These seven landscapes lie along altitudinal and bioclimatic gradients, from moist in the east to dry in the west, forming a representative sample of ecosystem diversity along the whole range of the HKH. These landscapes contain a remarkable diversity of peoples, cultures, languages, and livelihood strategies.

The Mt. Kailash region, in the remote southwestern portion of the Tibetan Autonomous Region (TAR) of China, spans a highly diverse array of mountain ecosystems, biomes and cultures, and represents a sacred site vital to hundreds of millions of people in Asia, and around the globe.

Each of the countries has completed a national and regional Conservation Strategy, a Comprehensive Environmental Monitoring Plan and Feasibility Assessment, which includes a gap and needs analysis, and an analysis of the policy-enabling environment in the country. The aim is to address the root causes of biodiversity loss, environmental degradation, and adverse impacts on the cultural integrity in the region, to enhance technical and scientific cooperation among the countries involved and to improve coordination among diverse actors involved in biodiversity and cultural conservation. More information at: http://www.icimod.org/ksl and http://books.icimod.org/index.php/search/publication/688

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The Carpathian Convention: implementation of the CBD at the ecoregional level

The Carpathian Convention, the Alpine Convention and the Convention on Biological Diversity (CBD) present an example of the synergistic implementation of the CBD work programmes on Mountain Biodiversity and on Protected Areas. Experience transfer and partnerships are facilitated between the Alps, Carpathians and other mountain regions of the world.

Piatra Craiului National Park, Romania | Photo: Mircea Verghelet

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The Carpathian Mountains, a natural treasure of beauty and high ecological value, are a reservoir of biodiversity, an essential habitat and refuge for many endangered species, and contain Europe's largest area of virgin forests. The Carpathian Convention, ratified by the Czech Republic, Hungary, Poland, Slovakia, Romania, Serbia and Ukraine, is an innovative regional governance tool for protection and sustainable development of this region. It supports local initiative and regional partnerships.

The Protocol on Biological and Landscape Diversity to the Carpathian Convention recently entered into force. National implementation is supported by regional or transboundary programmes, including the Carpathian Network of Protected Areas and the support of the Alpine-Carpathian ecological corridor. In partnership with the Ramsar Convention, the Carpathian Wetlands Initiative promotes the conservation and sustainable use of fragile mountain wetlands. EU and Swiss-funded projects promote sustainable regional development based on the integrated management of natural assets.

The Alps and the Carpathian networks benefit from an exchange of experience. For example, the Alpine Network of Protected Areas supports Carpathian cooperation, and benefits from knowledge gained in the Carpathians on how to manage large carnivores. The Alpine-Carpathian partnership is an example of best practices for ecosystems management and promotion of "green economy" in mountain regions. At CBD COP9, this cooperation culminated in the signing of a memorandum between the Alpine Convention, the Carpathian Convention and the CBD. With the support of the global Mountain Partnership, this cooperation will be extended to other mountain regions of the world.

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