A Global Assessment of Mountain Biodiversity and its Function

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1. Introduction

The montane and alpine regions of the world cover about 10% of the terrestrial area, a life zone ca. 1000 m above and below the climatic treelines in temperate and tropical latitudes, including some of the biologically richest ecosystems. The alpine life zone above the climatic treeline hosts a vast biological richness, exceeding that of many low elevation biota and covers 3% of the global terrestrial land area (Körner 1995). The overall global vascular plant species richness of the alpine life zone alone was estimated to be around 10,000 species, 4% of the global number of higher plant species. No such estimates exist for animals but based on flowering plants, high elevation biota are, as a general rule, richer in species than might be expected from the land area they cover.

Within the alpine zone, the total plant species diversity of a given region commonly declines by about 40 species of vascular plants per 100 m of elevation (Fig. 1). The upper montane forest, its substitute pastureland, and the often fragmented treeline ecotone also host a wealth of organismic diversity, often exceeding that in the alpine life zone.

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1.1 Causes of high biological diversity in mountains

The causes of this high biological diversity at high altitude are manifold. Mountain terrain is commonly highly fragmented and topographically diverse and this high geodiversity is strongly related to biological diversity, as it reflects the multitude of life conditions in a given area. Patterns of snow distribution reinforce landscape diversity by influencing soils, length of growing season, and microclimate. Selective microenvironments, for example habitats with insufficient or excessive snow cover, are characterized by specialist communities of organisms that may exist in close proximity to one another. In the European Alps, communities with moderate snow cover are richer in species than strongly exposed communities or snowbed sites (Virtanen et al. 2002). High plant diversity in mountains may be attributed in part to the small size of alpine species. Alpine plants are on average one tenth of the size of their closest lowland relatives (Körner 1999), which increases the likelihood of a diverse suite of taxa occurring in a small area. Another important cause of high biological richness in mountains is a moderate disturbance regime. Disturbance can either be related to the dynamic state of the physical environment, which keeps plant communities at an early successional stage or by domestic livestock and/or natural grazing. Although alpine species are usually long-lived, strongly reliant on reproduction by vegetative growth, and often geographically isolated, their genetic diversity within populations is usually surprisingly high due to effective genetic and breeding systems (Körner 1999; Till-Bottraud and Gaudeul 2002).

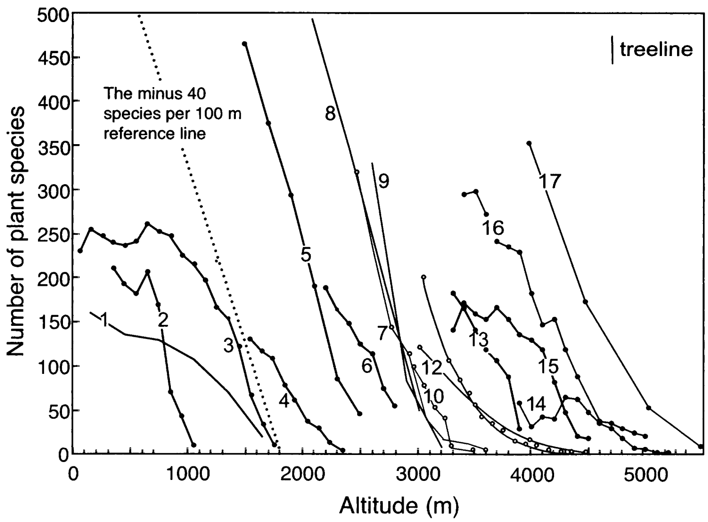

Figure 1: Examples of the elevational reduction in plant species diversity in different mountain ranges. (1) E-, NE-Greenland; (2) Clova, Scotland; (3) Aurland, S-Norway; (4) Jotunheimen, S-Norway; (5) Tatra Alps; (6) Olympus, Greece; (7) Swiss Alps; (8) Bernina, Swiss Alps; (9) West Alps; (10) Bernina, Swiss Alps; (11) Oetztaler Alps, Tyrol; (12) Montafon, Alps; (13) Oytagh, Karakorum; (14) K2-North, Karakorum; (15) Batura, Karakorum; (16) Nanga Parbat, Karakorum; (17) Hindukush. For references see Körner (2002). Figure reproduced with kind permission of the Parthenon Publishing Group.

1.2 Biodiversity provides insurance

Mountain biodiversity is perhaps the best indicator of the integrity of mountain ecosystems. Traffic routes, settlements, streams and lakes, but also water reservoirs depend on the integrity of upslope systems and mountain hydrology is strongly influenced by the type of vegetation and its stability. Diverse mountain forests offer sustainable physical barriers that provide protection from natural hazards and therefore prevent major ecosystem disturbances by mechanical forces (e.g. by avalanches). Ecosystem integrity on steep mountain slopes and in high elevation landscapes is in general a question of soil stability, which in turn depends on plant cover and rooting patterns (Körner 2002). A highly structured, diverse ground cover with different root systems is probably the best insurance for the maintenance of intact slopes that are subject to gravitational force. The many and varied manifestations of alpine environments require different mechanical solutions. Alpine vegetation must cope with physical disturbances such as the impact of heavy rainfall or hail on the ground surface, the disruptive force of surface runoff, mass movements of surficial material on unstable slopes, and snow gliding, and at the same time maintain exploitation of deep substrate moisture, and resist the effects of trampling and grazing by large herbivores. A multitude of plant structures can and do provide a maintenance function when operating in a concerted manner. Yet, natural diseases, divergent life cycles, and varying sensitivity to stress and disturbance may eliminate different players, at least periodically. The more morpho-types of plants co-occur the less likely will extreme events lead to vegetation failure and soil erosion (insurance hypothesis). Although intuitively plausible, this is a research field that is poorly supported by data and the insurance hypothesis is therefore a prime topic in the research promotion agenda of the Global Mountain Biodiversity Assessment.

2. Impacts of global change on mountain biodiversity

2.1 Impacts of climate change on mountain biodiversity

Global warming will reduce available land area for cold adapted organisms and therefore, it will be a threat to mountain plant species richness, especially in isolated ranges where high alpine plants are often restricted to small summits (Wohlgemuth 2002). The uppermost vegetation zones or the uppermost ecotones often host species, which are only uncommonly found in the zones below and are therefore distinguished as nival from the other alpine species. As a consequence of earlier snowmelt and/or climatic warming, typical alpine species may migrate into the nival niche, exerting competitive pressure on the nival flora and potentially leading to biodiversity losses (Gottfried et al. 2002).

With predicted higher temperatures, longer summers with greater incidence of drought are expected in many mountain regions. Recent drought events led to significant losses in the diversity of plant communities in the Cumbres Calchaquies of NE Argentina (Central Andes) (Halloy 2002). In the Cape Fold Mountains in

South Africa, increased incidence of fires is threatening the fynbos (macchia-like) plant communities in many moist highland and marginal arid localities. Substantial plant species replacements are possible (McDonald et al. 2002). Increasing summer temperatures, predicted for this century, are also likely to cause a loss of species in the Australian mountains (cf. Williams et al., this volume), and a stochastic loss of species from surviving alpine islands, related to increased isolation and decreased area, are expected (Kirkpatrick 2002). The responses of mammals and birds to a 30% reduction in snow cover in the Snowy Mountains of Australia over the last 45 years already caused a higher abundance of feral mammals in alpine/high subalpine areas, along with the prolonged winter presence of browsing macropods (Green and Pickering 2002). The predicted impacts of global warming on snow cover will result in a significant change in distribution of animal communities both spatially and temporally.

2.1 Impacts of land use changes on mountain biodiversity

Although global climatic changes can dramatically affect the distribution of plant species in the alpine zone, these changes will most likely be superseded by heavy anthropogenic impacts, such as overgrazing and inappropriate land management in the short term. Of all global change impacts on mountain biodiversity, land use is the most important factor. It is encouraging that traditional upland grazing systems and land management has contributed to the establishment of rich biota in a sustainable way. One example is the Andringitra Massif in south-central Madagascar, which is known as a biodiversity hotspot and is characterized by a high degree of local endemism (Bloesch et al. 2002). Traditional land-use appears to be the key to the preservation of this hotspot of mountain biodiversity, as it replaces former natural drivers of biodiversity, such as fire and (extinct) large herbivores. This traditional knowledge is currently threatened by population pressure and poverty combined with the disappearance of traditional land-use methods and may be lost (Körner 2002). Thus, different approaches to alleviate increasing human pressure on mountain ecosystems and its consequences on biodiversity are needed.

Sarmiento et al. (2002) demonstrated that the traditional long fallow system in the paramo, located in the upper belt of the Northern Andes, reduces the local biodiversity and generates a low economic income for the Andean farmers. Currently, high land use pressure is pushing up the agricultural frontier into the pristine paramo, representing a risk to plant diversity conservation. The paramo is characterised by a very diverse flora with many endemics and particular adaptations to these cool tropical environments.

The best theoretical alternative to retain or enhance both the local biodiversity and the economic profit is to conserve large areas of natural vegetation and to manage the remaining land with a sustainable, but intensive system. In the East African mountains, the natural vegetation has vanished except for a few patches. In regions such as those, human population growth and survival needs exceed land carrying capacity, and biodiversity protection becomes a low priority. A four-year test with different grazing regimes, including exclosures, revealed that high stocking rate pasturing is not necessarily detrimental to species richness and ground cover (Mohamed-Saleem and Woldu 2002). There is also evidence that a certain level of forest use in tropical montane forests in Bolivia is compatible with the conservation of endemic plant taxa (Kessler 2002), where endemism reaches a maximum in moderately anthropogenically disturbed forests at about 3500 m a.s.l.

Medicinal plants are one of the most valuable resources at high altitudes. For example, a survey of the available literature reveals that about 2500 species from the Indian subcontinent are used for local medicinal purposes or commerce/trade, involving the pharmaceutical industry (Purohit 2002). 1748 of these species are from the Indian Himalayan region and 44% of these plants are from the sub-alpine and alpine zones. These are also the species with high economic returns. As this resource is more and more exploited, production- and/or processing-based strategies need to be developed to ensure the sustainable use of medicinal mountain plants.

3. The Global Mountain Biodiversity Assessment

The Global Mountain Biodiversity Assessment (GMBA), initiated by the Swiss Academy of Sciences in 1999, is a global research network dealing with biological richness, its function and change at the cool high elevation limit of the biosphere. GMBA is part of DIVERSITAS (Paris), an international global change research programme on biodiversity sciences.

The understanding of biological diversity in mountains requires a three-dimensional global approach. Firstly, a horizontal, biogeographic dimension with a zonal emphasis is necessary on a global scale (e.g. major mountain regions at different latitudes - from the tropics to the poles). Mountains provide an excellent opportunity for such a global network, as they exist in every climatic zone. Secondly, a vertical, bioclimatologic dimension is required on a regional scale, focusing on the alpine and montane zone (i.e. above and below climatic treeline) and on elevational transects along mountain slopes. Thirdly, a temporal dimension can explain how past environmental changes have shaped current diversity and provide potential analogues for future predictions of global change impacts.

The main goal of GMBA is to document the great biological richness of the mountains of the world and its change induced by both direct and indirect human influences ("global change"), to synthesize existing knowledge and to initiate new research activities with an emphasis on large-scale comparisons. These include cross- and intercontinental comparisons of the upper montane zone, the treeline ecotone and the alpine regions, as well as elevational transects. Another task is to shape a corporate identity, which will help to increase the political visibility of mountain biodiversity issues, and to create a global scientific community involved in mountain biodiversity research, in order to induce transfer of knowledge and cooperation between globally scattered mountain researchers. Most importantly, GMBA wants to investigate the human influence on natural and cultural landscapes in the mountains with the task to preserve mountain biodiversity and to encourage sustainable development of rural areas. To meet this objective, GMBA initiated a project on "High mountain biodiversity and sustainable land use in the tropics/subtropics" with two thematic workshops in Africa and the Andes.

4. Future research needs

Biodiversity research is often seen as an inventory effort, and we certainly need more and better (i.e. in terms of comparability) documents of what the biological richness of regional mountain biota is. Our current mountain biodiversity database has large gaps, with some groups of organisms missing completely for some regions. Therefore, rapid improvement of a mountain biodiversity database is an area of prime engagement of GMBA. Given different levels of development worldwide, a more even distribution of research efforts is needed to arrive at a more balanced understanding of biodiversity and conservation needs. Since we have neither the resources nor the time for a complete biological inventory of all mountain biota across the globe, groups of key stone organisms and taxonomic ratios between groups are promising tools in biodiversity assessments. Taxonomic ratios are based on the assumption that diversity within certain groups of organisms is closely linked with diversity in other groups. In addition, inventories of organismic taxa do not require the visitation of every square km of mountain landscape. 90% of the taxa and measures of overall biotic richness often can be retrieved in sample areas of 10-20 km^2 (or less) within a given biogeographic zone. A promising tool for up-scaling local inventories is remote sensing (satellite) data, offering new avenues of documenting habitat and community diversity over large areas (Braun et al. 2002).

Science needs to provide facts not only on mountain biological diversity itself, but also on its functional significance for mountain ecosystems. This scientific evidence is seen as an addition to, rather than a substitute for, other values of biodiversity, such as the general ethical, aesthetical and economic value. In other words:

1. Both present and future inventories of biological richness need to be analysed by quantitative methods and for functional significance.
2. We need empirical evidence for the insurance hypothesis, because sustained integrity of ecosystems provides the strongest scientific justification for the protection of biodiversity. The insurance hypothesis proposes that high biodiversity buffers the effects of environmental changes on ecosystem processes because different species respond differently to these changes, leading to functional compensations among species. In other words, less affected species can take over the ecosystem function of strongly affected species (e.g. soil protection against erosion).
3. Ecosystem services, such as productivity of upland pastures or erosion control, need to be demonstrated and quantified, which requires experiments.
4. Research needs to explore climate change and management scenarios, which serve both the sustained integrity of diverse mountain biota and human needs.

The current scientific basis on which the benefits of diversity and the potential drawbacks of change can be assessed is rather limited. Much of the current debate is based on observational, plausibility-oriented and theory-based reasoning. Future assessments of mountain biodiversity need to develop a deeper and more functionally oriented search for answers, one of the major tasks of the Global Mountain Biodiversity Assessment (GMBA) and its international networking activity.

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