Status and trends of high mountain biological diversity

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Contents

I. INTRODUCTION

1. Human land use has largely influenced today's environment from lowlands to many high mountain tops. The perceived all-pervasive imperative of development is likely to cause further major alterations and degradation of many high mountain ecosystems. Biodiversity loss and nature conservation are recognised issues, however, their relative importance in relation to development issues is low. It is illuminating that a recent mountain think-tank publication on mountain area development, designed to complement Chapter 13 of Agenda 21 devoted a combined 5% to biological and cultural diversity and protected areas (Anonymous 2002).

2. Genetic diversity, species richness and assemblages are the three main levels at which biological diversity is usually described (Secretariat of the Convention on Biological Diversity 2001). Species richness has had the longest history of study (Gaston 1996); its study and those of assemblages and their landscape-scale patterns and functional attributes in the alpine zone have recently been reported (Nagy et al., 2003a; Beck et al., 1984; Chapin and Koerner 1995). Genetic diversity is an important aspect and its investigation has gained popularity (e.g. Till-Bottraud and Gaudeul 2002), however, the interpretation of genetic diversity in the context of assemblages is difficult (Wilson 2000). Likewise, the relationship between species richness and ecosystem functioning has been the subject of many debates (e.g. Schulze and Mooney 1993; Lawton 2000).

3. The term 'mountain' has been used in a rather broad sense in the literature and issues discussed in an all-encompassing mountain framework can involve many interests. The definition of mountain is therefore crucial in determining what a document on mountain biological will contain. As there is no universally accepted definition of what constitutes a mountain (e.g. Kapos et al., 2000; Debarbieux 1999; Gerrard 1990), and no one which would serve all purposes, this document proposes a framework for classifying mountain environments. It is suggested that mountain biodiversity issues are discussed according to bioclimatic zonation of vegetation, which is the composite outcome latitude, altitude and topography. Accordingly, two broad zones are distinguished: montane and high mountain (alpine). Most discussion concerns high mountains (Gerrard 1990), where a considerable proportion of inland water is stored in the form of glacier ice (Anonymous 2002) and the high-energy status of these mountains provides potential for energy generation and has many hazards (Messerli and Ives 1997). Their distinguishing ecosystem features (upper montane - subalpine forest zone or its natural or anthropogenic substitute, and their areas lying above the climatic treeline - alpine with its numerous regional variants, e.g. afro-alpine, páramo), which set them apart from low and middle mountains are emphasized. The features common with middle (and low mountains with lower montane forest) are touched on in discussing the inter-connectedness of elevation zones in a watershed context. The nature of the natural vegetation and anthropogenic derivates of the lower montane and lowland zones, which have been largely exploited by man through agricultural production and forestry, are covered in relevant CBD programmes (Secretariat of the Convention on Biological Diversity 2001).

4. High mountains have landforms, soil processes and plant cover characteristics similar to those in the high alpine zone of the European Alps (Gerrard 1990). Following a latitude pattern, these landforms and vegetation features are also found at lower (at high latitudes) or higher (e.g. in the tropics) elevations than those in the Alps (e.g. Koerner 2001; Koerner 1995). About 3% of the terrestrial surface of the Earth is covered by high mountain ecosystems, where about 4% of the Earth's flora is found (Heywood 1995). The montane zone is c. 14% of the Earth's surface with montane forest cover being c. 11% of the total global forest cover in 2000 (FAO 2001; Table 1); some estimates for forest cover according to arbitrary elevation ranges is found in (Kapos et al., 2000).

II. STATUS OF MOUNTAIN BIOLOGICAL DIVERSITY

1. Features of mountain biological diversity

5. The most conspicuous feature in mountain areas is the concentration of species diversity, i.e. the existence, along a vertical projection, of a number of compressed latitudinal life zones, which, in the tropics in particular, may

encompass the full array of climatic conditions from the equatorial perhumid lowland to the ice-dominated arctic. The lowland zone and montane forest zones have already been treated by various thematic programmes of the CBD (e.g. the biological diversity of forests, the natural vegetation in non-arid lowland environments, and man-made agricultural ecosystems which replaced forests; Secretariat of the Convention on Biological Diversity 2001).

6. Biological diversity at high elevations is the results of the multitude of contrasting mosaics of habitat conditions such as microclimate, parent rock, hydrology and land use. Adaptation to high mountain conditions results in a variety of 'strategies'. Plant adaptation to low temperature and low available nutrients in temperate alpine conditions include the initiation of growth before, and rapid growth after snowmelt, a life cycle completed over > 1 season, early burst of growth using stored carbohydrates - mostly in below-ground organs, see high root-shoot ratio , selection of life form (chamaephyte and hemicryptophyte), and morphological features such as flower shape (parabolic shape concentrates heat in the middle of the flower), pubescence (protection against temperature and water stress), short stature (cushion, prostrate shrubs) (Wielgolaski 1997) see also (Koerner 1999; Koerner 2001). In tropical alpine environments, adaptation has evolved to cope with cold, drought and fire (Rundel et al., 1994).

7. Insects and other arthropods have adopted a variety of ways to live in temperate high mountain conditions (Soemme 1997). They may include cold hardiness, supercooling or rarely tolerance of freezing, anaerobiosis in response to ice crusting, increased rates of metabolism, and resistance to desiccation. There are specialists who make use of winter habitat differences associated with snow cover and in turn temperature. Morphological adaptations include reduction in size, wing reductions, melanism and thermoregulation, nocturnal activity (to avoid overheating in melanistic species). Life cycles may be prolonged (Carabids, Acari, Pardosa of Arachnidae) or favourable microhabitat occupancy may be taken advantage of to complete life cycles in one year (see contrasting examples within the genus Pardosa). Alpine aquatic invertebrates, especially those living in glacier-fed waters represent another example of specialisation (Fuereder 1999). In tropical mountains, shelter seeking is characteristic, e.g. in scree or in senescent leaves of giant rosette plants such as Espeletia spp. (Andes) or Senecio spp. (Africa); there is a limited number of freezing tolerant species and different degrees of desiccation tolerance exist. Specialist predators and scavengers with well-developed thermal and moisture regulation use aeolian environments (e.g. Loope and Medeiros 1994).

2. Characteristics of high mountain habitats

8. The appearance of a mountain landscape is shaped by denudation processes (weathering, mass movement, glacial and fluvial action). Landscape features largely determine ecological conditions, which, in turn, determine vegetation.

Under this simplistic approach lies, however, a much complicated suite of dynamic abiotic and biotic interactions. In general, mountains have steep ecological gradients which can be interrupted by movements of high energy material, including water, and influenced by animals.

9. In most areas of the world, high mountains do not form a continuous landscape and alpine habitats occur as sporadic and isolated 'islands' (see e.g. Coe 1967 for its plant evolutionary consequences in the East African mountain arc and Hedberg 1992 for a comparison between East Africa and the Andes).

10. High mountains fall into two broad categories: humid alpine type high mountain and arid mountains (e.g. Atlas, Zagros, Andean Front Ranges, MacDonnell Range). Features of alpine environments include seasonally low temperatures and a short growing season in temperate high mountains and large daily temperature amplitudes (which may cause heat or drought stress during the day and cold exposure at night) at tropical latitudes. Arid mountain environments have desert-like habitats and their plant and animal life usually has a different evolutionary history from that in humid alpine environments (e.g. Varga 2003).

11. Large areas lie at high altitudes which lack the typical high mountain landforms (Gerrard 1990; Koerner and Spehn 2002). For example, high plateaux extensively occur in the Ethiopian Highlands, Pamir, Tibet and in the Andes. Most of these areas offer better conditions to human occupancy than steep high mountain sides and have a long history of use. From a topographical point of view these areas are not mountains, however, from an ecological point of view they are part of a high altitude ecosystems.

12. Middle mountains are typically defined as less than 1500 m in altitude and low mountains below 1000 m. In this document, as emphasized above, elevation and latitude together are considered to be of importance for determining mountain character and mountains with glacial landforms and alpine vegetation are considered high mountains.

3. Distribution of the worlds mountain ecosystems (horizontal biogeographic dimension, including map)

13. High mountains occur on all continents (Messerli and Ives 1997; Kapos et al., 2000; Fig 1; Table 3.) {Idrisi map - being developed}

(a) Tropical regions

14. According to estimates published by FAO (2001), in the tropics, 3.4% of the Earth's area falls in the montane and alpine (including nival) zones (Table 1). (Note that in the literature 1000 m is normally considered as the upper limit of lowland tropical evergreen forest. The lower limit of montane forest is put at c. 1500 m with 500 m in between being considered as a transition zone –

sometimes called submontane.). The largest areas are found in South America (Tropical Andes: 9 N – 18 S), followed by Africa (Mt. Kenya, Mt. Kilimanjaro, Mt. Meru, Mt Elgon, Aberdares, Ruwenzori, Virunga, Ras Dashan of Ethiopia) and Asia (Malaysia and New Guinea: Mt. Kinabalu, Mt. Jaya, Mt. Trikora, Mt. Wisnumurti, Mt. Madala, M.t Wilhelm). There are relatively smaller areas in North and Central America (Cordilleras de Talamanca and Central; Guatemalan Highlands, Mexican Highlands) and in Oceania (Hawaiian Islands). The typical sequence of vegetation along elevation is the lower-, mid- and upper montane forest (cloud forest), tropical alpine vegetation with giant rosette plants (páramo or afro-alpine), grassland, and frost desert (Gerrard 1990). A classification of the mountains of the tropics encompasses a wide variety of geology, geomorphology, soils, climate, and natural vegetation (Fig 1 - map being developed; Table 3). They range from comparatively flat highland plateaux (Ethiopia) through the eroded glaciated volcanic peaks of East Africa and acid high ranges (Andes) to limestone and ultramafic high mountains with patchily scant vegetation (Mt. Kinabalu). There are striking differences in climate from wet tropical to arid within the Andes chain alone.

(b) Subtropical mountains

15. The largest montane and alpine areas in the subtropics are found in Asia, with far smaller areas in North and Central America, Africa, South America and Europe - the Mediterranean mountains of Europe (Table 1). Many (seasonally) arid high mountains belong to subtropical high mountain environments. For example, the most notable feature of the Mediterranean alpine (or cry-oromediterranean) zone is the presence of thorny cushion communities. Nival plant assemblages of endemic cushion plants and short grasses are found in the Sierra Nevada of Spain above 2800 m (Grabherr et al., 2003).

(c) Temperate regions

16. The largest areas of montane and alpine areas are found in the temperate zone (Table 1), of which, those in Asia are the largest (56%), followed by North and Central America (27%), Europe (13%), and South America and Oceania (2% each). Temperate mountains are snow-rich and extended snow cover provides protection from deep frost, but shortens the growing season, resulting in a distinctive mosaic of plant communities. Temperate alpine vegetation consists of dwarf-shrub communities at, and immediately above, the treeline. Most areas of the alpine zone are occupied by a variety of graminoid-dominated sedge heaths. In Europe, nival summits are clustered in the Alps and the Caucasus, along with a few peaks in the Pyrenees. In the nival zone, scattered assemblages of cushion plants, small rosette plants, and small grasses grow in favourable sites (Grabherr et al., 2003).

(d) Boreal regions

17. Boreal montane and alpine areas occur in Europe (Scandes, Urals) and North America (Alaska Range and the Mackenzie Mts.). Boreal high mountains are special in that they grade into zonal arctic tundra at high latitudes. Boreal

and arctic alpine environments receive moderate snow in winter and are characterised by severe frosts leading to cryoturbation, solifluction and gelifluction, resulting in patterned ground over large areas. In the summer, long days result in an extended light period which may selectively favour certain adapted species. Mixed dwarf-shrub heath and dwarf birch willow scrub cover dominate in the treeline ecotone. Above this, ericaceous dwarf-shrub heath grows, replaced at higher elevations by fell-fields with small cushion plants and prostrate dwarf-shrubs, sedges and rushes. Glaciers cover most of the nival zone (Grabherr et al., 2003).

4. Landforms

18. Whilst altitude zones (temperature) are important determinants of the types of ecosystems that occur, landforms can largely influence their use by humans. {Perhaps here is the schism between how natural scientists and socio-economists look at mountains: in oversimplified terms, for a socio-economist type observer, anything that's not flat is a mountain.} Landforms can largely influence drainage, and thereby natural vegetation, and their associated soil microbial and animal life. In any altitudinal zone where temperature does not inhibit human land use, landforms have had high importance in determining the type of land use. Flat lands are preferred for crop production; however, as they are rare, large tracts of mountain sides have been affected by human land use, varying from extensive pasturing or gathering to over-intensive agriculture. The extensive highlands of tropical and subtropical mountain chains may be more comparable with lowlands from an agriculturalist's point of view than with high mountains. Conversely, low mountains (hilly lowlands) with steep slopes may pose the same challenges in terms of, for example, tillage, harvest and erosion control, than cultivated fields in the montane zone of middle or high mountains. When assessing environmental impacts of land use, slope may be used as a common denominator for example, to compare hydrological and soil properties and processes, however, slope alone does not exhaust the properties of mountains - steep terrain alone does not constitute a mountain; climate (elevation)-related hydrological, soil and biological processes and relevant landforms together do.

5. Vertical ranges of mountain ecosystems (vertical bioclimatological dimension)

{Note: maybe 'Natural and semi-natural mountain ecosystems following altitude zones'}

(a) Alpine Life Zone (including Nival and Aeolian life zones)
19. Mountain ecosystem zones largely correspond to temperature isolines, e.g. the 6 oC isoline of the warmest 3 months of a year corresponds broadly with the natural, non-topography limited treeline, i.e. the lower limit of the alpine

(see scheme for the vertical altitude limits of the alpine zone change with latitude in Koerner (1995).

20. The floristic diversity of the alpine zone results from both long and recent past climate changes and recent - in terms of geological time - human land use. Whilst in life form and morphology there are similarities between high mountains, local species composition is related to biogeography, the length and degree of isolation and speciation. The common vegetation formations are ericaceous dwarf-shrub heaths, sedge heaths and grasslands, and habitat specialist (azonal) assemblages (e.g. scree, exposed rock, springs and rills, soligenous mires) with tussock grasses, prostrate dwarf-shrubs and cushion plants. A unique feature of tropical mountains is the giant rosette plants (Espeletia spp. in the New World and Senecio spp. and Lobelia spp. in Africa).

21. High elevation aeolian life zone is present where unweathered substratum or arid climate prevents the functioning of biogeochemical cycles towards organic matter production. In aeolian ecosystems, organic matter input is via wind transport, adaptations to which have developed highly specialised local faunas (e.g. Loope and Medeiros 1994).

22. Nival or sub-nival environments represent life at the edge. The season available for plant and animal growth and reproduction is extremely short, nutrients are in short supply and successful adaptation is a key to survival. Glacial retreat prompts rapid vegetation and animal succession (see examples for plants in e.g. Koerner 1999; for animals see Kaufmann 2002). Ongoing research at the alpine-nival ecotone in the Austrian Alps concerns vegetation dynamics, phenology and the role of herbivores (both invertebrates, e.g. Kaufmann 2002 and vertebrates, e.g. H. Pauli et al. pers. comm).

(b) Tree-line Ecotone or its phytogeographic equivalent

23. The treeline ecotone, the transition zone between the upper montane forest limit and the alpine zone, is an ill-defined zone, which shows much altitude oscillation, often with forest creeping above the alpine in favourable sheltered valleys. In oceanic and arid mountain environments, the treeline may be suppressed in comparison with alpine mountains. In arid mountains, there is usually a lower and an upper treeline, with a girdle forest in between in a sufficiently humid altitude zone (e.g. Messerli 1973). Although locally one or very few tree species grow in the upper montane forests and the treeline ecotone, and form the treeline in Europe, there is much variation with regard to species at the continent-wide scale (Nagy et al., 2003b). Upper montane forest and current treeline ecotones are far more species-rich in the Andes of Central America, where above 3000 m, Compositae and Melastomataceae are the most diverse families followed by Ericaceae and Myrsinaceae (Gentry 1995). The natural treeline forming tree species in much of the tropical Andes is thought to be Polylepis spp. at about 4000 m elevation (Kessler 2002). In the Eastern African high mountains, e.g. on Mt. Kenya, there is a bamboo zone

above the montane forest zone, followed by a Hagenia-Hypericum tall scrub, which together with tall-growing Ericaceae in sheltered locations (Coe 1967) can be taken for a local treeline ecotone. However, the dwarf ericaceous vegetation above is thought to be a fire-induced and fire-maintained type of vegetation, indicating a suppressed treeline (Wesche et al., 2000).

(c) Upper Montane Forest or substitute vegetation
24. Estimates of the extent of 'mountain' forest world-wide vary (FAO 2001; Kapos et al., 2000; Table 4). The upper montane forest is the uppermost part of the closed forest zone (grading into open forest, sometimes referred to as subalpine forest). Its altitude varies with latitude, for example in the European Alps it is between c. 900 and 1500-2000 m (Adler et al., 1994) and in Tropical South America it is between c. 2500 and 3500 m (Webster 1995), or 3800 together with the subalpine rainforest, between 3500-3800 m (Lauer 1989).

25. The natural treeline has, in many places, been lowered e.g., tree cutting at and near the treeline is used to open up the forest for grazing or to clear land for cultivation (e.g. potato in the Andes) in the Tropics. For example, Joergensen et al. (1995) reported a life form composition from páramo vegetation between 3400-4000 m in Ecuador similar to forested areas, implying anthropogenic lowering of the treeline. Cutting at the treeline (3800 m) in the Central Colombian Cordillera led to the lowering of the treeline, independent of grazing intensity; cutting and grazing at lower altitudes (3400 m) could result in forest regrowth at low to moderate grazing, or at high grazing, in permanent pastures (Kok et al., 1995).

26. The lower bounding line of the montane zone follows a similar curve to that proposed for the alpine, it being at c. 1500 m on the Equator, descending to c. 800 m at 47 N (temperate) and down to c. 300 m at the Arctic Circle.

6. Other elements in the mountain landscape

(a) Wetlands
27. Wetland ecosystems are associated with watercourses (springs and rills) and areas where topography, impaired drainage and excess irrigation (from snow / ice melt, rain, or upwelling ground water) provide all-year round waterlogged conditions. Wetlands have a distinct species composition at any elevation where they occur, much different from those of other ecosystems, because of the specific life conditions they offer. Not wetlands in a strict sense are areas of regular snow accumulation (snowbeds), where species need to adapt to varying degrees of snow packing and late melting of snow.

(b) Dry-lands and deserts
28. In arid high mountains usually there are two treelines, a lower and an upper one. Tree growth below the lower treeline is limited by water shortage, while the upper treeline may be a combination of water shortage and low

temperatures. Tree growth occurs in a belt which coincides with cloud belts (e.g. 3400-3900 m in the Hunza Karakoram, Troll 1973; c. 2000-3000 m in the Atlas, Messerli 1973). Above the upper treeline, conditions are usually akin to those of a desert.

(c) Lakes and rivers

29. Alpine lakes are affected by ice formation and breaking up, level changes through inflow, outflow, drainage and evaporation. Long-term sedimentation yields important information about past environmental conditions. Alpine lakes are naturally oligotrophic and support a specialist flora and fauna (Sommaruga and Psenner 2001). Banderas-Tarabay (1997) reported 105 species and subspecies of algae belonging to 50 genera from a Mexican high altitude lake. Eutrophication through human activities and acidification from pollution can seriously affect species composition, as can introduction of alien (invasive) plants and animals (Cammarano and Manca 1997).

30. High mountain streams and rivers are the place where runoff concentrates and they are characterised by rapid responses to precipitation and evaporation. They are fast flowing, in usually deeply cut beds, and supply a large amount of sediment downstream. The biology of these oligotrophic cold waters is characterised by few specialist species. There are clear downslope patterns among aquatic invertebrates, altitude affecting assemblage composition, probably more than richness (e.g. Monaghan et al., 2000). A latitudinal pattern for European macrobenthic invertebrate richness in glacier fed streams was reported by (Castella et al., 2001): three taxa (families for insects, higher units for non-insects) in Svalbard vs. 29 taxa in the Pyrenees.

7. Genetic and species diversity in high mountain biomes

N.B. Always include plants, animals and microorganisms (as far as possible) and information on population and community structures as well as on migrating and invasive alien species

31. The little information about genetic diversity in the alpine zone suggests that there is no reduction in genetic variability with altitude, i.e. alpine species are as well equipped to respond to climate change impacts as montane species (Till-Bottraud and Gaudeul 2002). Most available studies concluded that reproductive biology (selfing vs. outbreeding) is more important than elevation.

32. It is estimated that there are about 250000 flowering plants species in the world. A large number of areas of high species diversity coincide with high mountain areas (Davis et al., 1994; Barthlott et al., 1997; Table 5). The major centres of species diversity (estimated by using vascular plant diversity > 4000 species 10000 km-2), which are centred around or include high mountains, are Costa Rica, tropical eastern Andes, eastern Himalaya-Yunnan region, and

northern Borneo and New Guinea (Barthlott et al., 1997). Other species-rich mountain areas with 2000-3000 vascular plant species km-2 include the Mediterranean and arid mountains, parts of the Rockies, the Atlas and Central Asia.

33. The Neotropics are especially species-rich (> 90000 species of flowering plants; c. 45000 in the highlands), with epiphytes being particularly important (Gentry and Dodson 1987). In Ecuador, 50% of total flora occurs in the 10% area of the cloud forests (Balslev 1988). There is a lower alpha diversity of woody plants than that in lowland forest, but a higher beta diversity caused by topography, disturbance, and elevation-climate (Gentry 1988), resulting in very high degrees of speciation. In the Andes, there are 139 genera of 72 families between 2500-2900 m and 57 genera of 36 families above 3000 m (Gentry 1995) of trees > 5? cm dbh. The most important (species-rich) plant families are Lauraceae, Melastomataceae, Compositae, Solanaceae, Myrsinaceae, Aquifoliaceae, Rubiaceae, Araliaceae, Guttiferae, Ericaceae and ferns; other families, on average are represented by less than two species (for some data on woody species richness see Table 6). The forests from Mexico to Guatemala are different from those further south, with many genera reaching their southern extension there. The forests are similar at the genus and family levels from Costa Rica to Bolivia, however their species composition is very different. There is a higher level of endemism than in lowland forests hence the need for conservation. Total species richness of Ecuador is c. 20000 species; that of the Ecuadorian high Andes (> 2400 m) being 4868 species (1119 genera, 200 families); the montane forest between 2400-3000 m has 3411 species (17000 km2), 300 species more than the lowland Amazon area of 70000 ha (Joergensen et al., 1995; Table 7). The total vascular plant species richness of the Andean páramo ecosystem (which occurs above the upper montane zone, above altitudes of c. 3500-3800 m in the Andes between 11 N and 8 S) is estimated to be between 3000-4000 with c. 60% them being endemic (Luteyn et al., 1992; Table 8). The estimated number of species in Europe's alpine areas, excluding the Caucasus, is 2500 species and subspecies (Vare et al., 2003); the exclusively alpine zone species for the Alps are estimated to be 800-1000 species (Ozenda and Borel 2003). This is in stark contrast with the afro-alpine zone, above the ericaceous zone on the isolated mountains of east Africa, where vascular species richness varies between 77-182 (Hedberg 1992).

34. There is a rich cryprogam flora too in the Neotropics. For lichens - 415 species between 2400-3200, 232 between 3200-4000 and 101 between 4000-4800 m in Colombia - (Sipman 1995) estimated the total for 2400-3200 m in the neotropics at being 1500-2000 species. The richness of non-moss bryophytes (Hepaticae and Anthocerotae) at Santa Rosa de Cabal, Colombia was 192 (2400-3500 m), decreasing to 88 at the upper reaches of the montane forest (3600-3700 m); (Gradstein 1995), over half the species being epiphytes. Extrapolating the data of Churchill (1991), that in Colombia c. 50% of the whole countries moss flora occurred in the zone between 2600-3300 m, the combined total of

mosses for Venezuela, Colombia, Ecuador and Peru and Bolivia is estimated to be around 1000 species.

35. For data on biological diversity of the Qingzang Plateau, China, see Tables 9-10).

36. A recent account in Europe found no non-native species in the alpine zone of the high mountains. In the Giant Mts of Czechia (middle mountains), about 14.5% of the plant species are introduced (Jenik and Stursa 2003).

37. {The summary report from a GMBA conference on invertebrates of early September is expected. A short account will be compiled on that basis.} Information on invertebrates is usually available from well-studied local accounts (Table 11), such as the European Alps (Meyer and Thaler 1995; Thaler 2003), or the African high mountains e.g. (Beron 1997; Beron 2000; Kotze and Samways 2001; Kotze and Samways 1999). Aquatic invertebrates are being intensively studied, particularly in glacier fed streams and rivers (e.g. Brittain and Milner 2001; Burgherr and Ward 2001). A literature review of soil organisms in alpine and arctic soils in Europe was given by Broll (1998).

III. MOUNTAIN ECOSYSTEM FUNCTIONING AND INDIRECT SERVICES OF MOUNTAIN ECOSYSTEMS

1. Mountain ecosystem functioning

38. The Unesco Man and Biosphere programme yielded much information about ecosystem functioning in the upper montane and alpine zones of European high mountains, especially those in the Alps. However, information is more scant from the tropics. Nevertheless, studies of the nitrogen cycle showed similar primary productivity in the alpine vegetation of the European Alps and in Afro-alpine vegetation (Rehder 1994). Recently, Theurillat et al. (2003) discussed the numerous factors and their interactions (e.g. space availability, species interactions, productivity, habitat heterogeneity, competitive exclusion) which had been put forward to explain species richness and its decline with altitude. Although general hypotheses have been offered, with regard to species richness increases or decreases and ecosystem function (e.g. Ehrlich and Ehrlich 1981; Lawton and Brown 1993; Vitousek and Hooper 1993), it is yet to be established how these diversity changes affect the functioning of biogeochemical cycles. Ample empirical evidence shows though, that, whatever the exact nature of biodiversity and ecosystem function relationship is, perturbation of high mountain ecosystems can cause irreparable damage - way beyond the relevance of any link between biodiversity and ecosystem function - with serious consequences (e.g. decreased slope stability and increased flood frequency / intensity) for montane and lowland regions (Koerner 2002).

(a) Protection against natural hazards – traditional flood and avalanche control measures
39. The high-energy nature of the environment in high mountains increases natural hazards such as rockfalls, avalanches (ice, snow), debris flow, landslide, and erosion (fluvial, wind, soil). These usually manifest more severely in heavily perturbed environments (e.g. after deforestation in combination with high altitude development). For example, close correlation has been shown between the historical increase in deforestation in Tyrol and the increase in areas affected by avalanches and heavy erosion (Aulitzky 1974, cited in Ozenda 1994). Traditional avalanche protection has been provided by the successive vegetation zones from alpine to lower montane zone, the settlements being principally in the lowlands or in the lower montane zone.

40. Further protection function of montane forest concerns hydrology, slope stability and sediment yield. The protective functions of montane forest were recognised early in the human settlement history of the mountains, however, formal legislation (designation and legal prescription) of protecting forests is relatively recent (Hamilton et al., 1997).

(b) Genetic reservoirs
41. High mountains often harbour a specialised flora and fauna with many endemic species, which have developed because of historic isolation or other forms of speciation. For example, in the tropics, an important altitude zone with regard to taxonomic diversity is where highland and lowland meet. This interface zone appears to be a significant region of speciation for a number of plant taxa in the Neotropics (Churchill et al., 1995). There are numerous widespread crops which originate from, and which have a very high number of varieties cultivated in the upper montane / páramo zones of the New World. These and their wild relatives may have important potential for crop genetics and breeding.
(c) Separation between biomes (prevention of species invasion)
42. The alpine zone of the high mountains reaches elevations where only specialised life forms can survive. These high mountains form a break to natural species distributions and control the spread of species which are usually associated with human activities. Introduced species therefore are rare in the high mountain zone. Differences in topography and surface properties (e.g. long smooth ridge type slopes vs. scree slopes) of high mountains are important for determining the rate of colonisation and lead to differential degrees of establishment of plants upslope (e.g. Grabherr et al., 1994; Pauli et al., 2003).
(d) Climate influence
43. Mountains may not have a range of latitudinal climate zones arranged along altitude, and have a diverse array of microclimates arising from their varied topography, but they can locally modify climate (which is largely determined by latitude, altitude and oceanity-continentality). Some major extensive highland plateaux such as the Tibetan and the Andean are large enough to have their own climate. High mountains can intercept moist air masses and create a

rain shadow in areas lying opposite from the prevailing wind direction. In arid mountains, clouds may form around a mountain core and cause the girdle forests. In addition, mountains can give rise to local wind systems (Barry 1992).

(e) Water and soil retention, including role as water reservoirs for lowland ecosystems
44. High mountains store and release a large amount of water in a dynamic manner. Precipitation falling as snow accumulates and fast flowing watercourses carry melt water from snow and ice. These high-energy rivers often used for generating electricity and are supplies of drinking water for urban lowland areas (e.g. Eastern Alps supply Vienna). The supply from high mountains is often important where there are seasons of low precipitation in the lowlands.

45. Soil retention properties are largely influenced by perturbation. Morainic deposits after glacier melt (akin to very young skeletal soil), overgrazed high mountain pastures, and deforested, cultivated steep montane fields are less stable than natural or lightly disturbed areas. Extreme precipitation events can cause landslides and soil creep, especially when the hydrological properties of the soil have been negatively affected by human land use. Surface run-off is enhanced by soil compaction and can result in soil erosion, especially in heavily perturbed areas. The importance of retaining soil on mountainsides is important for both mountain dwellers and lowland societies. Degraded mountainsides offer little in the way of agricultural productivity and have many hazards. For lowlands the importance is two-fold: without a soil-vegetation system hydrological regulation largely breaks down which can result in flash floods after major rainfall events. Soil carried off the mountain becomes deposited in low-lying areas which can silt up rivers; in extreme cases catastrophic mass events such as mudflows may occur.

2. Direct uses of mountain ecosystems

(a) Role of mountain ecosystems for the protection of human livelihoods - an historic perspective
46. Agricultural lands fall into grazing land, shifting and permanent cropland. Agricultural production in mountains is limited by the specificity of the environment (which results in restricted accessibility, ecosystem fragility, marginal returns, high landscape diversity) and associated social costs (Jodha 1997). Nonetheless, certain forms of agriculture have a long history in many high elevation areas and resulted in major changes in the vegetation and habitats (e.g. Mohamed-Saleem and Woldu 2002; Sarmiento et al., 2002). There is a pattern of differential use of the different elevation zones (Table 12). Crop production by shifting and permanent agriculture is most widespread in the lower and middle montane zones, however, it is of importance in the upper montane zone in the tropics. For example, Kappelle and Juarez (1995)

classified agroecological zonation as potato zone (2300-2700 m), followed by a charcoal zone (2700-3000 m) in Costa Rica.

47. Many crops are grown as part of agroforestry systems in the montane zone. The upper montane zone and the treeline ecotone are mostly used for pasturing. In Europe, the use of upper montane forest for grazing land dates back to the ninth century (e.g. Bruenig 2002) and because of abandoning pasturing in the second half of the twentieth century forest cover has increased (e.g. Grabherr 1997). The ancient civilisations of the New World have modified the tropical highland landscape through agriculture in a localised manner, particularly around the ancient indigenous centres and their associated villages. There are still large areas under low intensity cultivation or in pasture, where agricultural techniques differ little from those employed 100–200 years ago, particularly in steep mountainous regions, where smaller towns and villages still rely on local plants for various uses (Churchill et al., 1995). On the other hand, since the European conquest, many montane ecosystems have been degraded with the increase of human populations in the highlands. For example, a study of c. 4.1 M ha area in the Eastern Colombian Andes estimated that c. 22% of the original forest cover remained (mostly above 3000 m, Etter and Villa 2000).

48. Estimates as to how many people live in mountains vary. It is thought that about 2% of the world's population are high mountain dwellers (sensu stricto), with another 8% living in highlands and middle mountain regions (Baatzing et al., 1996). Most of these people are found in developing countries where they have lived off subsistence farming for many generations. Traditional farming systems characteristically are/were small-scale and location-specific; amelioration measures included terracing (the abandonment of which may result in increased erosion and land / habitat degradation, Inbar and Llerena 2000) and ridging with drainage management, and sometimes irrigation. Agriculture was part of an overall agro-forestry system. Traditional farming systems at low population density have been found effective in sustainable resource use in high mountain systems (Jodha 1997). Crabtree et al. (2001) quoted OECD (2001) 'that the traditional management of landscapes provides a wide range of valued public goods varying from landscape features to soil protection and biodiversity. Agriculture is the key activity and tourists a principal beneficiary'.

49. One feature of subsistence farming is the maintenance of a large number of varieties of species of crop plants, used as an insurance against crop failure. The Neotropical montane region is one of 12 major world crop gene centres (maize, potato, tomato, lima bean, common bean, peppers, and tobacco). However, the origin, distribution, and life history of New World crops in the montane-alpine region, and in particular, their wild relatives, which may have important potential for crop genetics and breeding has been little investigated

(Churchill et al., 1995). Potential new crops include protein-rich cereals, edible tubers, and fruits from the Andes.

50. Low intensity agriculture can temporarily increase biological diversity on the landscape scale by introducing species and creating favourable conditions for species typical of secondary vegetation; it is when a (yet to be defined) threshold is exceeded that biological diversity declines through local species extinctions. A comparison of secondary vegetation after potato cultivation / grazing showed a decrease in trees, epiphytes, mosses and pteridophytes and an increase in grasses and herbs in (Kok et al., 1995), a largely generalisable pattern. Secondary vegetation comprising grassland, shrub and secondary forest in the Cordillera de Talamanca, Costa Rica had 132 vascular plant species at 2800 m (Kappelle et al., 1994). In another study, (Kappelle et al., 1995) recorded a total of 176 terrestrial vascular species in 122 genera and 75 families. They found that at ca 3000 m, terrestrial species richness was highest in early secondary forest (145), followed by late secondary forest (130) and primary Quercus forest (96) in plots of 0.1 ha.

(b) Current agricultural production

(i) Intensive agriculture

51. There are different current trends in agricultural land use in the world's high mountains (Hamilton et al., 1997). In Europe, the concentration of livestock farming since about the 1960s has meant larger stock in certain areas whilst abandoning other traditional grazing lands (MacDonald et al., 2000; Olsson et al., 2000; Fjellstad and Dramstad 1999). In the developing world, the agricultural sector has greatly expanded following a large population increase (e.g. Himalaya see Ives and Messerli 1989).

52. The fundamentals of modern agricultural production are based on concentration of land (cultivation of large fields) and, as a result of globalisation, the monopolistic imposition of cultivation technologies (including the provision of seed, implements and chemicals through financial arrangements) on producers. The technologies require intensive practices such as fertilizer, heavy machinery and pesticide application for producing marketable commodities. The application of such agricultural production in high mountain environments is much restricted by the prevalent natural and socio-economic conditions, i.e. limited accessibility, fragility of the ecosystem, marginal productivity of land, and topography and related diversity (Jodha 1997). The main limits relate to scale (field size), the responsiveness to inputs (of fertilizer and pesticides), the limited scope for the development of infrastructure, the market rewarding the surplus product. Demand for land and the loosening of traditional community bonds have been favourable in causing increasingly the abandonment of small-scale agriculture in favour of large-scale measures such as externally financed (sometimes by misguided development agencies) irrigation schemes and infrastructure development, implemented without proper assessment of impacts. During transition from small-scale to

large-scale farming the wide range of crops and varieties used in traditional systems have become replaced by a few widely grown and marketable commodities and resource regeneration (fallowing) has been reduced. Modern agricultural production systems are not suited for mountain environments, whilst traditional production at high population density is equally unsustainable. The use of pesticides (often excessive or indiscriminate) can not only results in environmental damage but also can have deleterious impacts on human health.

(ii) Agro-forestry

53. Agro-forestry systems usually comprise a mosaic of forest in an agricultural land matrix with much variation in forest stand or woody species cover and spatial arrangement. ICRAF defines agroforestry as a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (http://www.icraf.cgiar.org/ag_facts/ag_facts.htm#systems).

54. There are two main types of agroforestry systems distinguished on the basis of simultaneity of crop and tree growth on a parcel of land: (1) simultaneous and (2) sequential, where crops and trees are grown in a time sequence on the same piece of land. Simultaneous systems include boundary plantings, contour hedges, live hedges and fences, hedgerow, intercropping (alley cropping), parkland systems, silvopastoral systems, agroforests, shaded perennial crops, and windbreaks. Sequential systems comprise shifting cultivation, relay intercropping, improved fallows, and taungya systems. In mountain areas, agroforestry systems are of importance for soil, water and nutrient conservation for sustainable agricultural production (Sharma et al., 2001). Many agroforestry units reflect the natural progression in land use change from forest to agriculture, initiated by small holders. Recently adopted systems have been developed to counter unsustainable agricultural practices and help maintain or restore low input agricultural production systems. For example, the rehabilitation of degraded agricultural land has been proposed by adopting agroforestry systems (e.g. Shi and Li 1999; Thapa 1996).

55. Agroforestry systems as eco-systems, mimic forests (or scrub) and are structurally more diverse than equivalent size agricultural lands, and therefore are likely to harbour a larger number of species. Nonetheless, their biological diversity is less than those of forests' are and their main role is to serve as a buffer against large-scale or abrupt land conversion (Noble and Dirzo 1997). Historically a dynamic balance has been achieved between agricultural land and forest, after an initial extensive reduction in forest area, both in lowlands and in mountains, until reaching a critical low before the forest area is increased (Hamilton et al., 1997).

(iii) Pasturing or range us

56. Grazing at low intensities has no appreciable negative impacts on ecosystems and is the essential food source for ungulate wildlife and domestic livestock. It has been reported that low-moderate grazing resulted in the varied plant life of the alpine meadows in the European Alps (e.g.), and the abandonment of grazing resulted in decrease species richness (alpha diversity). However, areas heavily used by livestock develop nitrophilous tall herb vegetation and are likely to take a long time to increase in species richness after the abandonment of grazing. Heavy grazing causes simplification of ecosystem structure, life forms, and species richness and leads to overgrazing, which manifests in impaired ecosystem functioning (e.g. grazing associated trampling can cause or exacerbate erosion). Grazing associated vegetation change can affect invertebrate species richness and abundance (Tontini et al., 2003).

(iv) Major pressure factors and their impacts on mountain biological diversity

Intensification and expansion into new areas

57. To satisfy the food requirement of an ever-increasing population agricultural land use has largely expanded and now low quality marginal lands are being brought into cultivation. The opening up of mountain dwelling societies to external influences (e.g. through globalisation) has increased the demand for material goods. To produce marketable surplus, agricultural production has intensified (permanent large production units, use of chemical fertilizers and pesticides, irrigation schemes). It is easy to extrapolate from the examples of how intensification of lowland agriculture affected the environment to high mountains, where there is an added sensitivity to environmental and ecological processes. Beyond their local impacts on biodiversity, both intensification and extensification have wider environmental consequences. Excess fertilizer and pesticide leachate and outwash causes contamination including eutrophication of water resources (Vitousek et al., 1997; Ferber 2001; Sampat 2001). The soil resource is being put under pressure - changes in soil structure impact on hydrological properties, which, in turn, have consequences for downhill hydrological balance.

58. The environmental damage (cost) caused by the cultivation of marginal land is likely to far outweigh the benefits local farmers may derive.

(c) Forestry

(i) Role of mountain forests – an historic perspective

59. Traditional multi-purpose and multi-resource social forestry has been practiced over more than two millennia. It characterised the origins of forestry in classic Greece and the Roman Empire (e.g. Theophrastus, Plato, Cicero and Plinius the Elder). In Central Europe, social forestry was evident at least as early as 800 A.D., but was weakened during the mercantilistic feudal and then the early capitalistic industrial periods, only to be revived in the early twentieth century (Bruenig 2002). In the lowlands, population growth and decline in agricultural productivity resulted in large-scale forest clearances.

(The evident consequences of forest resource depletion and deforestation in the Greek, Roman and Chinese classic periods were recognised and the Greeks and Romans took steps toward sustainable forest management. However, forest destruction continued, driven by the need for food and fuel.) In the developing countries, forest clearance for agricultural land is an ongoing process, whilst there is an opposite tendency in developed countries.

60. Montane forest use has traditionally involved the lowering of the treeline through pasturing, small scale extractive uses in the upper montane and montane zones (fuel wood; non-timber products), and heavy extractive use in the montane zone, combined with the conversion of the hill foot areas from forest to agriculture and settlements. Agriculture and forest use in mountains is therefore closely connected. Montane forests offer a number of commodities (timber, fish, game, grazing land) and additional 'services' (hydrology, ecosystem diversity, hazard protection, amenity). Major uses of forests include extraction for construction timber, fuel wood collecting and non-timber products, with non-timber forest products accounting for a large share of all benefits derived from the forest (e.g. p. 293 in Hamilton et al., 1997). For an historical perspective, see e.g. Bruenig (2002).

(ii) Current use: intense harvesting

61. Mechanisation of forestry operations (especially those of harvesting and transporting) requires a large initial capital layout. Consequently, forestry operations need to be made on an industrial scale to ensure revenue. Clear felling and large-scale extraction of commercial species characterises today's industrial timber harvesting. Schemes, where selective logging is operated, particularly in the tropics, are often unsustainable as the levels of extraction of commercially valuable trees (allowable cut and return cycle) are such that they inevitably lead to forest degradation. The degraded state of forests (labelled as wasteland after commercial timber has been removed) is then often used as an excuse to the convert forests to commercial monoculture plantations. Where there is proper forest estate management, maximising profit from harvesting is used to offset the expenditure incurred over the long cycle of forest growth (forestry is a low interest earning investment, and, in the absence of subsidies or tax incentives, may be loss making). In developing countries, more often than not management of primary forests in reality concerns timber harvesting only, with no regard to after care. Approaches which are concerned with profit maximising without taking into account the many associated environmental issues and environmental values are bound to cause lasting environmental damage.

62. Large-scale logging and the associated timber extraction activities have many local and downslope consequences. The removal of forest cover removes protection from the incidence of high-energy mass movements, such as rockfalls and avalanches (the estimated value of protection functions, such as flood and avalanche control, protection against erosion, and conservation of

water quality, of montane forests in Austria is ATS 1,800 billion - 4,000 billion, (OECD 2001). Slope stability may suffer as increased water availability may penetrate deeper and cause earth flows. Surface run-off increases cause erosion and loss in soil fertility. Sedimentation of streams is an additional negative effect of large-scale logging.

63. Integrated forest management is necessary to successfully maintain all functions (timber production, non-timber products and protection), a good indicator of which is biological diversity.

(iii) Major pressure factors and their impact on mountain biodiversity: Deforestation and unsustainable management of mountain forest diversity
64. Logging, indirectly, has largely contributed to forest loss in developing countries. The opening up of forest has often prompted an influx of settlers, using the road system established for timber extraction. The logged forest has then been rapidly converted to agricultural land (shifting cultivation or permanent estates, pastures). Where land use change is prevented, natural forest is often cleared for monoculture plantations (usually using exotic species). The rate of forest destruction has been such that it has been estimated that over 50% of all species may be lost by 2100 (Anonymous 1994).

65. Communal forests that serve local communities for their construction timber and fuelwood, medicinal plant, game etc. supply often become depleted in those resources which are in greatest demand. For ecosystem functioning the removal of trees may have the largest effect by impacting on soil water availability, changing microclimate and habitat fragmentation. Forest fragmentation can change the rates of predation, pollination, seed dispersal and parasitism. In the tropical montane zone, also, deforestation will have the largest effect on biodiversity, on plant diversity by removing the rich epiphytic component, and animal diversity, by removing habitat. In temperate-boreal forest the removal of trees alone will have relatively little effect on plant diversity, which, on the local scale, may even increase (e.g. establishment of alpine grassland species in the upper montane zone after forest clearing). Nonetheless, the structural changes will exclude many animal species.

66. Afforestation or reforestation with exotic species (which are usually unsuitable as they have a high resource demand) has affected large areas, especially in Central and South America. These monocultures are the antithesis of diversity, whether they are planted for commercial industrial forestry or being initiated through the advocacy of carbon credit trading.

(d) Hunting and gathering
(i) Historical perspective
67. Over history, traditional hunter-gatherers have contributed to changing their environment by selectively favouring or 'cultivating' certain plant and

animal species (e.g. Zent and Zent 2002). In agro-forestry ecosystems hunting has been an important source of meat for locals.

(ii) Current use

68. In modern societies in industrialised countries, hunting survives as a recreational activity and, in the absence of natural predators, a means of control of population growth of ungulates. Hunting can serve ceremonial purposes in third-world mountain societies, whilst some sought after commodities make some species endangered by overhunting.

69. Gathering of medicinal plants for local use and trade is part of mountain dwelling peoples' heritage. A large number of species are collected e.g. in the Andes (), or in the Himalayas ().

(iii) Major pressure factors and their impacts on mountain biological diversity: Extraction of keystone species

70. Today's use or management of non-wood forest products is closely related to the issue of forest use. Hunting is largely controlled in developed countries, whilst, in developing countries, although they may have laws related to wildlife management, they are rarely enforced. In most developing countries subsistence hunting is being replaced by commercial (often illegal) hunting which threatens the populations of many prey species (e.g. Hamilton et al., 1997; Anonymous 1998). It is somewhat ironic that meanwhile, in some of the European (and North American) mountain ranges, large re-introduction programmes are being carried out at a high cost to bring back formerly hunted out species.

71. Over collecting of some medicinal plant species occurs for supplying tradable goods. Certain species are being over collected for fuel in areas where population increase has exceeded the carrying capacity of the environment (e.g. Qingzang Plateau, China, Anonymous 1998).

(e) Recreation use

(i) Conventional tourism and Ecotourism (expansion and improved access to fragile areas)

72. Mountain tourism, since its beginning in the European Alps in the nineteenth century, has developed into a major earner of income in many high mountain areas of the world (e.g. Mountain forum ref in Williams et al., 2001; Godde et al., 2000), however, not without cost (e.g. Rai and Sundriyal 1997). Traditional tourists enjoyed scenery, local amenities, air quality, and, as there were relatively few who left the villages to venture into the hills, their impact was low on ecosystems initially. The large increases in disposable income, particularly in the developed world, have led to an explosion of tourist numbers and tourist resort development. Ecotourism is perceived as a relatively recent branch of conventional tourism, although it probably reflects more the increase in number of those who are willing and can afford to take to the mountains to explore their natural history. A recently published volume

gives an overview of alpine ecotourism (Williams et al., 2001) and regional case studies are available from Central and South America (Weaver 1998c), Africa (Weaver 1998a) and the Indian subcontinent (Weaver 1998b).

73. The growth of tourism has been one of the fastest of all industries. One estimate put the share of unspecified 'mountain tourism' at 15-20% (Mountain Agenda: Mountain Tourism 1999). For example, the number of visitors using the French Alps for outdoor activities increased twenty-fold between 1950 and 1997, IFEN, unpublished cited in (Loison et al., 2003). Many of the tourist activities have the potential of disturbing wildlife and changes in habitat use patterns, impacts on the condition of the animals and their reproductive success may result (Loison et al., 2003).

74. One of the most dynamically growing branches of tourism is the so-called ecotourism. It is often hailed as a potential saviour of biological diversity through its contribution to local economies, however, in reality, it is a potentially most harmful branch of tourism if the fragility of high mountain ecosystems is ignored. Undoubtedly, ecotourism generates income and as such, it is most welcome by governments of third world countries which view it as an alternative to devoting their own limited resources to sustainable mountain resource use. The principal objects of ecotourism, at the mercy of market forces, are unlikely to be long sustained and short-term profit chasing may actually destroy the very objects of tourist interest (be it of natural or cultural). Fragile ecosystems may easily become overburdened by increases in tourist numbers through ecosystem impacts caused by trampling, extra resource use, increased waste generation and disposal, causing pollution. For discussion on socio-economic impacts see Anonymous (2002). (Interestingly, economic valuations of biodiversity have used the ‘travel cost’ approach to assign a value to ‘biodiversity’ – a travel cost to the individual tourist (how much one is willing to spend on reaching a destination), but not a cost to the environment. Why? Undoubtedly, it would reveal the over-exaggerated nature of the economics of tourism. The environmental costs of international and local transportation, infrastructure development alone would cancel out much of the cash income arising from visitors’ spending, the generation of income for which would have incurred high environmental costs in the first place. See Section 4 a and Table 14 below.)

(ii) Winter Sports

75. Winter sports (e.g. skiing, snow boarding etc.) are very popular (e.g. in the European Alps there are 145 ski resorts offering a variety of activities, http://francais.cipra.org/). Ski resort development involves major earth moving operations to prepare the slopes and requires an extensive infrastructure (service and approach roads, service buildings and cafes, restaurants and hotels) the construction of which all involve a major disturbance to plant and animal life. Recovery of vegetation cover after ski piste bulldozing and ski lift installation is a lengthy period and the original

structure and composition is rarely achieved (e.g. Grabherr 2003). An additional threat to biodiversity is the use of ski lifts and cable cars to transport tourists to high elevations outwith the skiing season, when vegetation is especially susceptible to trampling. Trampling alone can much alter the composition of vegetation, locally reduce species richness, and initiate erosion.

(f) Settlements and Urban areas

76. Settlements at high elevations are concentrated on the extensive plateaux, especially those in Central and South America, and in the densely populated Himalayas. Rural settlements in high mountain environments have traditionally been established in the hill foots and in the montane zone, however, population pressure meant that in many areas, especially in the tropics, there are rural settlements in the upper montane zone. A relatively recent type of settlement is that associated with tourism and winter sports. They consist of a number of hotels, service areas and service buildings. Both traditional and recreational settlements require power, access roads, and waste disposal facilities. They pose formidable challenges for developers.

77. Power generation is usually through hydro-electric development for urbanised areas; rural settlements in the developing world are often without electricity and rely on the use of nearby forest for fuel wood. Road construction often increases the hazard of erosion and landslides by interfering with the hydrology and stripping vegetation (see Section j).

78. Settlements usually are centres of introduced species and natural plant and animal life is much reduced.

(g) Industrial uses

(i) Hydropower (transformation of ecosystems and watersheds)

79. High mountains are high-energy environments and many hydroelectric developments have taken place to harness the energy of the rivers. The construction of dams changes the ecology of the flooded area altogether, turning terrestrial habitats into lake bottoms. Dams can interfere with species exchange between up and downriver. Small-scale developments for local use are favoured in contrast to large-scale developments, which have raised many environmental concerns (Anonymous 2002).

(ii) Mining

80. The bulk of mining takes place in the lowlands, however, a large proportion of many non-ferrous and precious metals (e.g. copper, lead, zinc, tin, gold) are mined in high mountains. Major non-ferrous and precious metal deposits are being mined in the Andes (Bolivia, Chile, Peru), Sierra Maestra (Mexico), Western Ranges (U.S.A.), Magadan Ranges (Russia), New Guinean mountains (Papua New Guinea, Indonesia) (Fox 1997). The impacts result from disposal of mining waste (overburden, tailings, mine water), processing (smelting, refining, leaching), inadequate management of tailings and reservoirs (pollution of water). Mining developments can have devastating results on the landscape, vegetation and water resource far down slope from the mines (see

e.g. Freeport copper mine at Mt. Carstens, Indonesian New Guinea). For an overview of mining in mountains, see (Fox 1997).

81. Large-scale destruction of habitats occurs at opening mines developments. The immediate impacts on biodiversity are temporary annihilation, which may be followed by recolonisation by certain species. At mining developments, artificial revegetation is carried out sometimes, using species with the best colonising abilities.

(h) Road construction (Traffic, especially transit traffic and impacts along the major transportation routes)
82. The construction of new roads and an increase in mountain road use by heavy goods vehicles has dramatically increased worldwide. For example in the French Alps and the Pyrenees, there was an estimated 300% increase between 1984 and 1995 (IFEN unpublished). Road construction can directly affect the local survival of species, can cause habitat fragmentation, and can have serious wider consequences by initiating soil erosion. Habitat fragmentation, together with other impacts can speed up local extinctions. In the case of animals, it can, for example, disrupt migration routes for amphibians and prevent natural exchanges of ungulates between mountain massifs (Loison et al., 2003).

83. Roads provide improved access to previously less or inaccessible areas and thereby can indirectly contribute to the major and rapid spreading of agents detrimental to biodiversity and to the wider environment.

(i) Invasive species
84. Invasive species are organisms (usually transported by humans) which successfully establish themselves in, and then overcome, otherwise intact, pre-existing native ecosystems (http://www.issg.org/index.html#Invasives). Species introduced to new environments sometimes become more successful than native species and may become invasive, threatening the existence of some rare native species. The impact of biological invasions by non-native species has been best documented on agriculture, forestry, fisheries, and other industries, as well as on human health. Their impact on native ecosystems and species is less well understood. However, from a review by (Simberloff 1981) of more than 850 plant and animal species introductions it emerged that (1) less than 10% of all introductions led to local extinction of species, (2) islands appeared particularly susceptible to extinctions, and (3) where extinction occurred predation was by far the most important factor, followed by habitat change and competition.

85. Perturbations to ecosystems by human activities such as road construction, mining, logging and agriculture make these ecosystems susceptible to invasion (see e.g. Kitayama and Mueller-Dombois 1995). Introduced plants may become invasive if their establishment and spread is facilitated by the existence of potential mutualistic partners (e.g. generalist frugivores and pollinators,

mycorrhizal fungi with wide host ranges, rhizobia strains with infectivity across genera) and if environmental conditions are conducive for the establishment of various alien/alien synergisms (Richardson et al., 2000).

86. Some islands with a large proportion of mountain areas (e.g. Hawaii, Madagascar) are among those which have been most affected by invasive alien species. Introduced / alien species have invaded ecosystems in most life zones (see Table 13), with the exception of the alpine and arctic, where adaptation to harsh environment is required.

87. Recent initiatives set up to systematically collect information on invasive alien resulted in a major international effort, with a major input by CBD, led by the Global Invasive Species Programme (GISP). As a result of the efforts of GISP a manual on invasive alien species management has been published recently (Wittenberg and Cock 2001).

(j) Pollution
88. Air-borne pollution (NOx and SOx, causing acidification and N input) in industrialised countries has affected plant and animal communities in the upper montane forest zone (Jenik 1997; Bytnerowicz et al., 2001). The intensification of agriculture in third-world countries is increasingly becoming a source of eutrophication and pesticide pollution harming soil microbial and plant and animal life. Mining is a major pollutant of water with far reaching consequences in downslope areas. Traffic and tourism related untreated waste is also contributing to pollution.

3. Other biophysical causes of loss or degradation of mountain biological diversity

(a) Climate change
89. The clearest evidence of climate warming is the accelerating rate of retreat of glaciers in the high mountains worldwide. It is climate warming that has been attributed to an increase in species richness on high mountain summits in the Alps (Grabherr et al., 1994). In general, models predict an upward shift of vegetation zones (and habitats for animals) and thereby montane, incl. upper montane forest is predicted to advance at the expense of alpine grasslands and sub-nival vegetation types. This is a coarse approximation as in many locations topography, or soil- and hydrology-related features are likely to prevent advances. For examples of likely effects of climate change see: Kappelle et al., (1999) general, Foster (2001) cloud forests, Kienast et al., (1998) mountain forest, Villers-Ruiz and Trejo-Vazquez (1998) Mexican mountain forests, Theurillat and Guisan (2001) Alps, Guisan et al., (1995) Alps and Fennoscandia, Haeberli and Beniston (1998) glaciers, Hauer et al., (1997) fresh water ecosystems, Tulachan (2001) Hindukush-Himalaya, and Barry and Seimon (2000) climate warming and expanding agriculture in the Andes.

(b) Ozone layer depletion

90. Stratospheric ozone is being depleted because of industrial pollution (CFCs), causing an increase in UV-B radiation, especially at high latitudes (Sonesson and Molau 1998). UV-B can affect ecosystem functioning in number of ways. For example, it can enhance the breakdown of plant litter which is directly exposed to sunlight (Moorhead and Callaghan 1994), whilst in closed canopy vegetation it can have the opposite effect by modifying tissue composition and directly eliminating certain decomposing organisms (Gehrke et al., 1995). The exact impacts of ozone depletion are difficult to assess as enhanced UV-B will be accompanied by changes in temperature and CO_2 concentration and all these factors together will determine biodiversity impacts.

4. Underlying (socio-economic) causes of the loss and degradation of mountain biological diversity

(a) Broader macroeconomic, political and social causes, e.g. poverty, population growth, displacement

91. All the benefits humans derive from direct uses of mountain ecosystems (see Sect. 3.2.) can potentially negatively impact on biological diversity and other indirect ecosystem services. All human activities, which impact on biodiversity and broader environmental quality, need to be seen in a wide context which encompasses historical background, world-wide economic, political, and social issues (Table 14). Once examined in such a context, it becomes obvious that biological diversity and its maintenance, unfortunately, is largely a no-concern issue for the large majority of the human population as Gadgil (1996) has eloquently demonstrated it.

(b) Institutional and social weaknesses, e.g. property rights (access, use, right to alter, right to alienate), institutional enforcement, governance structures etc.

92. Until the primary underlying causes (Sect. 4. a) are openly and adequately addressed efforts expended on improving institutional (governance) issues will yield little in the way of environmentally sustainable long-term assured existence of the human population. Only then, can the necessary revamping of governance structure work towards sustainability. Anonymous (2002) has considered governance issues at five levels: global, national, regional and provincial, local, and through non-governmental organisation and civil society. The role of global institutions is overarching and in need of a major overhaul and revitalisation. National governments can make things work for the environment and China's example in using Agenda 21, with an apparent improvement in the state of the environment, for their land allocation policy is often quoted. It would be good to see other national (as well as provincial and local) government follow suit. (See Table 15 for a list of all major issues and research priorities identified in the Abisko Agenda, Anonymous 2002).

(c) Market and economic failures

93. Market values of goods and services depend on a large number of factors and can much vary or be transitory. They absorb the economic cost of producing those goods and services, however, the environmental cost is not considered. Therefore, a market-based regulation of the environment or environmental services (which is taken for grated for everybody's benefit) is unlikely to succeed. Apart from abstract values, which are hard to monetise, produce from far-lying mountains is usually undersold, as it is more cost effective to produce similar commodities in the lowlands. There are many examples from mountain regions in developed countries which show that agriculture and forestry need subsidies to pay for environmental services (see examples in Section IV).

(d) Policy failures

94. Policy failures are largely connected to major policy makers' serving a group interest at all levels. EU and World Bank policies have been especially heavily criticised for destroying agriculture and the environment (Bond 1996).

IV. APPROACHES TO THE VALUATION OF MOUNTAIN ECOSYSTEMS, INCLUDING ECONOMIC VALUATION

95. Perlman and Adelson (1997) differentiated between values (human values, sensu Kellert 1995) and worth (economic value) concluding that worth is essentially the reflection of values that individuals or society hold. Biodiversity is a non-value neutral concept as it values different species according to their rarity or commonness or natural or introduced status for example (Pilou 1995). The list of rationales offered by Perlman and Adelson (1997) for protecting biodiversity is open to criticism, but serves to illustrate the breadth of topics considered by conservationists (Table 16).

96. The three major categories of values (conservation value or worth) arising from biodiversity as discussed, though not completely agreed, by economists after Price (2002) are:

1. Instrumental value comprises contributions to material well being that could acceptably be provided by other means. For example, net photosynthesis by forests reduces atmospheric CO_2; but as far as global climate is concerned, the reduction could just as well be achieved by reduced use of fossil fuels.
2. Interest value is the source of pleasure to people which habitats or species themselves provide. This rather superficial-sounding term is also intended to embrace deeply felt cultural and spiritual values attributed to sites and species.

3. Intrinsic value is whatever good is held to subsist in the very being of the habitats or species, independent of any human experience or knowledge of them.

97. The instrumental value of biodiversity is probably best summed up in Chapter 12 of (Heywood 1995): 'The use value of biodiversity is generally an indirect use value, and derives from the role of the mix of species (habitat value) in supporting either individual organisms (give upper montane and alpine examples) or ecological services (the value of ecosystem functions = ecological functions, protection functions, waste assimilation, microclimate effects, and C storage)'. The various values associated with ecosystems are summarized in Table 17.

98. Biodiversity valuation issues are rather hypothetical and rarely applied alone. Monetising biodiversity may be called for during policy formulation or as part of an advanced form of cost-benefit analysis called environmental cost-benefit analysis. Environmental cost-benefit analysis, in addition to the profitability of a proposed project, takes into account the likely costs and benefits to the wider environment (e.g. Kuuspilo in Price 2002). A recent example of valuing the ecological functions of a mountain forest is that by (Xue and Tisdell 2001) and (Crabtree et al., 2001).

99. Depending on the approach, valuation method and context, very different monetary values can be arrived at. In Austria for example, they may vary from a few billion ATS (e.g. from the ecological accounts and people's willingness to pay for properly managed cultivated landscapes) to over ATS 1,000 billion (technical costs for replacing the function of forests to provide protection against natural disasters) (OECD 2001). Whilst there is a large variation in monetising ecosystem benefits, it has been suggested that economic valuation of non-market benefits 'underline the special importance of biodiversity conservation and maintenance and to relate the ecosystem functions to other economic activities, so as to provide a basis for public responsibilities and intervention in general and also for strategic discussions' (OECD 2001). From a systematic survey on the economic value of biodiversity (Nunes and van den Bergh 2001) concluded that for monetary valuation to make sense it was necessary that '(1) a clear life diversity level is chosen, (2) a concrete biodiversity change scenario is formulated, (3) a multidisciplinary approach seeking the identification of direct and indirect effects of the biodiversity change on human welfare is used, and, (4) the change is well defined and not too large'. So far, relatively few valuation studies have met all these requirements and from the review of the economic valuation studies it is clear that the assessment of biodiversity values does not lead to a univocal, unambiguous monetary indicator (Nunes and van den Bergh 2001).

V. CONCLUSIONS ON STATUS AND TRENDS IN MOUNTAIN BIOLOGICAL DIVERSITY

1. Loss of ecosystems/habitats, species/communities and populations and genetic diversity (essentially tables and diagrams, showing changes over time and in different locations)

{Information from WCMC - Mountain watch document in mid-September with relevant data};

100. At the time of drafting this document, there was no comprehensive dataset available for inspection. In general terms, it can be said that there has been a sustained loss of biological diversity at all levels, especially so in developing countries as witnessed by land use change (e.g. FAOSTAT, http://apps.fao.org/page/collections). For two specific examples in high mountain and montane areas in the Andes and East Africa see Table 18). In Scotland, from the 1940s to the 1980s there was an expansion of features associated with urbanisation, agricultural intensification and afforestation, and a consequent reduction of long-established or semi-natural features (SNH, National Countryside Monitoring Scheme).

2. Mountain agro-ecosystems (essentially expansion in the form of tables or diagrams as representation of the global distribution)

101. The exact rate of expansion of agro-ecosystems is not available yet. {FAO statistics – contacted Douglas McGuire / Thomas Hofer - have been waiting for reply}

3. Assessment of the impact of climate change

102. It is difficult to assess how climate change, superimposed on other driving forces such as land use, pollution, will affect biodiversity. Kappelle et al., (1999) identified six areas of interest: (i) spatial and temporal distributions of taxa; (ii) migration and dispersal potentials of taxa; (iii) genetic diversity and viability of (meta) populations of species; (iv) physiological tolerance of species; (v) disturbance of functional interactions between species; and (vi) ecosystem processes. van der Hammen (1995) assessment on climate change on cloud forest emphasized the importance land use interactions with climate change. He postulated that climate change along continuous gradients acting alone would be slow, however, together with habitat fragmentation it could cause rapid extinction of susceptible species by interrupting potential migration routes. As a result, ideally, conservation/protected areas should encompass complete large-scale gradients from lowland to alpine habitats, encompassing areas rich in endemism.

103. Land use aside, there are large uncertainties associated with climate change scenarios and the generated ecosystem responses (Anonymous 2002). The assessment of Foster (2001) of possible climate change impacts on cloud forests included biodiversity loss, altitude shifts in species' ranges and

community composition, and possible forest death. Possible species losses were attributed to unsuitable climate for specialist species, lack of available space to colonise and differences between migration / establishment rates vs. climate change rates and new species interactions. Epiphytic species, frogs and lizards are thought to be particularly susceptible and recent cloud forest animal redistributions, notably frog and lizard disappearances, may have been caused by climate changes. At the landscape scale, fire, drought and plant invasions can potentially increase the effects of climate change associated changes in the cloud forest.

104. For high mountain vegetation, the area is likely to be reduced and within the remaining alpine zone large re-arrangement of species distribution patters may take place. The reduction in area may mean the end of existence for small isolated alpine outposts. A large number of taxa may become locally extinct, and many endemics altogether. Changes in precipitation and temperature regimes or patterns have significant potential effects on the distribution and abundance of plants and animals. For example, enhanced drought is likely to be a major force in the Andes, the South African mountains and in the Australian Snowy Mountains (Spehn et al., 2002).

105. Aquatic ecosystems are likely to undergo marked transformation, too. Stenothermic species may become extinct from formerly cold waters and increasing temperatures may confine cold-water fishes to headwaters (Hauer et al., 1997).

106. Climate warming, where it does not involve extreme changes in precipitation patterns, may increase the productivity of agro-ecosystems in the upper montane and high mountain zones.

107. However, there are concerns about possible shifts in hazards caused by changes in permafrost, which, in turn, will affect snow characteristics, avalanche activity, slope stability and soil water (Anonymous 2002).

4. Implication for declining trends in mountain biological diversity

108. In mountains, the decline in biological diversity has been the most pronounced and extensive in the montane zone, where land use has been most concentrated (Table 12). In high mountain ecosystems, a decline would have occurred on the high altitude plateaux, around local installations, and locally around footpaths. …

5. Information and knowledge gaps

109. Inventories are incomplete for most mountain areas in developing countries and the available data are not generalisable, or usable for monitoring. Data on soil micro-organisms is especially scant (Broll 1998).

Further field data collection should be made for a global database for monitoring (including existing data) (Anonymous 2002). The lack of knowledge about wild species with potential uses should be rectified and the species identified should be preserved (Anonymous 2002; Churchill et al., 1995). Although it is beyond doubt that human land use has greatly altered mountain ecosystems, the exact nature of changes is yet to be established. This is important for monitoring changes in view of sustainability of land use systems (e.g. Mohamed-Saleem and Woldu 2002; Sarmiento et al., 2002) and for restoration (Anonymous 2002). Areas earmarked for research by the Abisko Agenda include in situ and ex situ conservation of animals and plants, ecosystem restoration, the potential of sacred mountains for biodiversity conservation, and through better understanding of traditional livelihood systems, the identification of possible mitigating actions (Anonymous 2002).

{Note: For final document compile a table on information gaps and research needs}

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Tables:

Table 1. The percentage of the earth's surface classified as mountain ecosystems (montane, alpine and nival) by FAO (2001)

Continent	Tropical (> 1000 m)	Subtropical (> 800-1000 m)	Temperate (> 800 m)	Boreal (> 600 m)	Total
Africa	1.1	0.3	0.0	0.0	1.4
Asia	0.7	2.6	3.1	0.0	6.4
Europe	0.0	0.1	0.7	3.8	4.6
North and Central America	0.2	0.4	1.5	0.9	3.0
South America	1.4	0.2	0.1	0.0	1.7
Oceania	0.1	0.0	0.1	0.0	0.2
Total	3.4	3.7	5.5	4.7	17.3

Table 2. Altitude zones (incomplete, being developed)

		Tropical	Subtropical	Temperate	Boreal
Subnival - Nival	Africa Asia Europe N & C. America S America Oceania	4300-4700	-	2900-	1500-
Alpine	Africa Asia Europe N & C. America S America Oceania	3000-4400	2100 (2200)-	2000-2900	700-1500
Upper montane (to treeline)	Africa Asia Europe N & C. America S America Oceania	2300-3500 2400-4000	1600-2200	1300-2000	700-1200
Montane	Africa Asia Europe N & C. America S America Oceania	1700-2700 1500-2400	1000-1800	600-1500	?

Table 3. Mountain systems by continent.

Today's mountains originate from three major mountain building episodes: the oldest are those of the Caledonian of the mountain system (e.g. Scotland and Scandinavia). A second phase was the Hercynian (Variscan) / Appalachian when today's west and central European worn-down mountains (Central Massif, Vosges, Black Forest) and the Appalachian Mts. were formed. The youngest are the extensive chains of the circum-Pacific and the Alpo-Himalayan-Indonesian mountain belts. {If judged useful contents will be filled in}

Mountain system	**Mountain chains/ranges**	**Geology**	**Origin**	**Geomorphology**	**Extent**	**Mean (highest) elevation**
Appalachian - Quachita			Caledonian/Hercynian		New England - Texas	
North American Cordilleras			Alpine		Alaska - California	
Caribbean Arc			Alpine		Guatemala - Andes	
Venezuelan Cordillera and Caribbean ranges			Alpine			
High Cordillera			Alpine		Colombia – Tierra del Fuego	
Buenos Aires ranges			Variscan?			
Caledonian	Scottish Highlands, Scandes, Spitzbergen, Greenland		Caledonian		Ireland – Scandinavia - Greenland	
Hercynian	Iberian Meseta, Massif Central, Vosges, Ardennes, Harz		Hercynian		Iberia - Harz	
Alpine	Pyrenees, Iberian, Cantabrian, Jura, Alps, Carpathians, Balkan Mts., Caucasus; Elburz, Apennines, Dinarids,		Alpine		N: Alps-Caucasus; S: Apennines – Taurus – Mts of Oman	

	Hellenids, Taurus, Mts. Of Oman, Mts. Of Baluchistan					
Atlas			Alpine			
Cape			Hercynian			
East Africa			Volcanic			
Himalayan	Anatolia, Crimea, Elburz-Zagros, Baluchistan, Afganistan, Pamir, Karakoram, Himalayas		Alpine			
Hindu-Kush-Pamir-Karakoram						
Baikal			Cambrian			
Ural						
Tien Shan-Altai-Nan Shan						
SE Asian						
Indonesian						
Verkoyansk-East Siberian			Alpine			
Sikhote-Alin-East Mongolian Arcs						
Koryat-Kamchatka						
West pacific Arcs	Japan, Taiwan, Philippines					
Adelaide-Flinders-MacDonnell			Cambrian			
East Australia					Cape York - Tasmania	
Papua-New Caledonia-New Zealand Arc						
New Guinea-						

Solomons-Fiji-Tonga-New Zealand Arc						
Victoria Land Mountain						
Marie Byrd Land						
Scotia Arc						

Table 4. The area of land (M ha) classified as belonging to mountain ecosystems (montane, alpine and nival) with the percentage of forest cover in parentheses.

(Source: FAO 2001 http://www.fao.org/forestry/fo/fra/main/index.jsp?lang_id=1

Continent	Tropical (> 1000 m)	Subtropical (> 800-1000 m)	Temperate (> 800 m)	Boreal (> 600 m)
Africa	147 (11)	42 (4)	-	-
Asia	88 (46)	351 (16)	418 (8)	1 (76)
Europe	-	15 (38)	87 (67)	513 (53)
North and Central America	26 (55-65)	59 (54-74)	197 (47)	118 (36)
South America	190 (23)	24 (4)	8 (20)	-
Oceania	7 (55)	-	20 (36)	-
World total forest M ha (%)	154.8 (4)	116.1 (3)	116.1 (3)	425.6 (11)

Table 5. Examples of plant species diversity from WWF and IUCN (1994)

Site	Size (km^2)	Altitude (m)	Flora	Vegetation	Use	Threats
Afro-alpine region	3500	3500-5890	350	Giant rosettes, scrub, grassland, bog	Grazing, browsing, fuel	Overgrazing, fuelwood collection, fire, tourism
Mount Kenya	1500	1600-5199	800	Montane forest, bamboo,	Timber, fruit, medicinal plants	Logging, plantations, visitor pressure
Drakensberg alpine region	40000	1800-3482	>1750	Grasslands, shrub, scrub, savannah,	Forage grasses, grasses and	Overgrazing, Soil erosion, arable

				wetlands	sedges for thatching, rope, hats fuelwood	agriculture, invasive plants
Australian Alps	30000	200-2228	780	Grassland, woodland, shrub, alpine vegetation	timber	Tourism, grazing, hydroelectric development, fire, feral animals, exotic plants
Mountains SE Turkey, NW Iran, and N Iraq	147332	1400-4168	2500	Oak forest, alpine thorny cushion scrub, monatne steppe, alpine grassland, scree	Pears, almonds, hawthorns, gum tragacanth	Influx of refugees, re-afforestation, dam and irrigation schemes
Anti-Taurus Mts./Upper Euphrates	60000	700-3734	3200	Oak forest, steppe, montane steppe	Walnut, medicinal plants, dyes, cereal crop relatives	Dam construction, re-afforestation, rock climbing initiated erosion
Peruvian puna	230000	3300-5000	1000-1500	Grassland, scrub, wetlands, tropical alpine vegetation	Potato relatives, traditional Andean crops and medicinal plants, spices	Overgrazing, fire, soil erosion, mining, fuelwood cutting

Table 6. Tree species richness in some selected upper montane forests in Central and South America. Diversity of woody species including lianas, hemi-epiphytes and stranglers in sample plots of varying size in the neotropics. Data after Gentry 1995; Joergensen et al., 1995)

Country (sample n)	Elevation (m)	Number of families	Number of species
Mexico (1)	2250	26	44
Costa Rica (4) Total woody species****	2225-2775 2600-3200	17-34 60-c. 35	24-66 200-c. 75
Colombia (9)	2290-3050*	19-46	35-107
Ecuador (1) (4)	3010** 2400-	21**	35** (32-90)***
Peru (5)	2330-3000	20-42	36-96
Bolivia (1)	2450	33	91

*0.05 ha, ** 0.04 ha, *** 1 ha; **** total number of woody species

Table 7. Number of vascular plant species of from herbarium records in Ecuador (Jorgensen et al 1995)

Vegetation zone	Elevation (m)	Estimated area (km2)	Number of species
Desert paramo	4500-5000	1200	91
Shrub and cushion paramo	4000-4500	2800	464
Grass paramo and *Polylepis* forest	3400-4000	12000	1441
Upper montane forest	3000-3400	12000	2189
Montane forest	2400-3000	17000	3411
Amazon lowland	200-600	70000	3100
Coastal lowland	0-600	80000	6300

Table 8. Approximate numbers of families, genera, and species of plants in the páramo (after Luteyn et al., 1992)

	Families	Genera	Species
Mosses	45	120-140	> 300
Hepatics	?	c. 200	?
Lichens	?	?	?
Vascular plants	112	449	3000-4000

Table 9. Biological diversity of the Qingzang Plateau, China. Figures are total numbers for the region(s), values in parentheses refer to species numbers above 4000 m. Source: Anonymous (1998)

	Family	Genus	Species	
Flowering plants		1500	12000 (955)	Quinzang Plateau + Himalayas + Hengduan Mts.
Aquatic protozoan			458	Tibet
Rotifera			208	Tibet
Crustaceae			59	Tibet
Insecta	173	1160	2340	Tibet
Fish	5	45	152	

Other vertebrates		343	1047 (215)	

Table 10. Comparison of species diversity in the three main ecosystems of the alpine plateaux of Qingzang, China (Source Anonymous 1998)

	Dwarf-shrub - grassland	High altitude steppe	Cold desert
Flowering plants	500	>300	c. 100
Amphibians	7	-	-
Reptiles	3	3	-
Birds	103	118	17
Mammals	45	35	26

Threats: forest clearing; uncontrolled hunting and uprooting of plants for fuel; gold panning and associated disturbance; overgrazing and degradation;

Table 11. Species richness of carabids, butterflies and spiders in some regions of Europe. Figures are for regions including lowland areas, the alpine zone and individual habitats (from Brandmayr et al. 2003)

Taxon (Region)	Total number of species	Total number of species in the alpine zone with (% of total)
Butterflies (Italy)	275 (Tontini et al. 2003)	119 (43%)
Carabid Beetles (Italy)	1280 (Magistretti 1965, 1968)	180 (14%)
Carabids Fennoscandia)	354 (Lindroth 1949)	72 (20%) lower alpine 16 (4.6%) middle alpine
Spiders (Eastern Alps)	683 (Thaler 1998)	90 (c. 3%)

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Table 12. Human land use forms in the montane and alpine zones of mountains

	Montane	Upper montane	Alpine	Nival

Agriculture	Shifting, permanent, pasturing	Mostly pasturing; crops in tropics	Transhumance	
Forestry	Logging; building timber, fire wood, land clearing for agriculture	Fire control of scrub and trees for pasture maintenance		
Hunting and gathering	both	Both	both	
Recreation	Tourism, ecotourism	Tourism, ecotourism	Tourism, ecotourism	tourism
Settlements and urban areas	Numerous	Few	Rare	
Hydropower and mining	both	Both	both	
Road construction and traffic	High frequency - related to industries and settlements	Less frequent - can have high transit throughput	Infrequent - can have high transit throughput	
Invasive species	Yes	Rare	No	No
Pollution	Point source and regional background	Point source and regional background	Point source and regional background	Regional background

Table 13. Alien / invasive species in mountain environments

Impact on native flora and fauna	**Impacted habitat**	**Impacting factor**	**Impacted group of organism**	**Geographic region**	**Reference**
Insect diversity	montane grasslands	alien invasive plant species	insects	South Africa	[McGeoch, M. A. 2002 #3952]
Grazing	mountain grasslands	3 alien (non-invasive0 species		Argentina	[Marquez, S. 2002 #3951]
Competition and diseases		mountain goats (*Oreamnos americanus*)	native bighorn sheep (*Ovis canadensis*)	Rocky Mts	[Gross, J. E. 2001 #3955]
Range restriction	food availability (seed and insect larvae) in sub-	alien invasive plant and	*Loxioides bailleui*, a specialist	Hawaii	[Banko, P. C. 2002 #3950]

	alpine forest	animal species	seed-eater, endangered bird		
Habitat type and elevation	intermediate forest	34 invasive alien woody species		Seychelles	[Fleischmann, K. 1997 #3959]

Table 14. Environmental resource use by different groups of the world's population

Who	Local, traditional communities	Displaced rural people (poor)	Largely urban dwellers (affluent)
How	Subsistence	subsistence	Service economy
Where	Third world	Third world	Developed world; elite in third world
Numbers	Dwindling	Heavily increasing	Stable
Relation to local environment (biodiversity)	Dependent	No stake	Not dependent; leisure
Management and impact on environment (biodiversity)	Sustainable management; local impact	Exhaustive extractive use; heavy local-regional impact	Exhaustive extractive use of far away resources; heavy impact; conservation of selected interest features
Why	Dependent on particular ecosystems (forest dwellers, highland dwellers)	Internal population growth and external forces exerted by developed world and local elite interests	Maintenance of pleasant living environment and further increase living standards
Resource demand per individual	balanced	low	high
Resource use (demand x population size)	balanced	high	high

Table 15. Major issues and research priorities highlighted in the Abisko Agenda (Anonymous 2002)

Critical mountain issues	Research needs	Research approaches

Human insecurity	Population dynamics	Partnerships
Mountain glaciers	Glaciers	Capacity building
Water	Water security	Research networks
Sediments		Data generation and management
Nutrients and pollutants		Short and long-term research
Land use		Scales and scale jumps
Biodiversity	Biodiversity	Disciplinary, interdisciplinary and transdisciplinary research
Tourism		Knowledge transfer and sharing
Globalisation		
Governance	Governance, policy and law	
Energy and transport	Energy and transport	
Highland-lowland interaction		

Table 16. Rationales offered by [Perlman, D. L. 1997 #2526] to protect biodiversity

Existing elements of biodiversity have a right to continued existence by their moralistic and humanistic and religious values;

Threatened elements of biodiversity deserve protection for their naturalistic, ecological-scientific, symbolic, humanistic and moralistic values;

Ecosystems and species that provide important commodities deserve protection (e.g. timber, fish, raw material for industrial processes) for their utilitarian values;

Ecosystems deserve protection if they provide important services (e.g. carbon sequestration, watershed protection, flood control, and filtration) for their utilitarian values;

Charismatic, beautiful, and symbolically important species deserve protection for their naturalistic, aesthetic and symbolic value;

Ecosystems that have integrity, and elements of biodiversity that add to the integrity of ecosystems, deserve protection for their ecological-scientific, aesthetic, and naturalistic values;

Species that are taxonomically, morphologically, behaviourally, or physiologically distinct deserve protection for ecological-scientific and utilitarian reasons; and

Ecosystems containing many species deserve protection for their ecological-scientific, aesthetic and naturalistic values.

Table 17. Ecosystem direct-, indirect-, optional- and non-use values

Direct use	**Indirect use**	**Optional use**	**Non-use**
Extractive use	Ecosystem services	Drug sourcing	Bequest (future generations)
Timber/fuel wood	Effects on climate	Future ecosystem services	Existence
Mining	Water supply	Genetic resource (plant and animal)	
Gathering of plants	Hydrologic control		
Hunting/fishing	Avalanche control		
Non-extractive use	Soil erosion control		
Hydropower generation	Pest control		
Recreation	Ecological functions (biogeochemical cycles, net primary production)		
Tourism			
Economic cost-benefit analysis (income vs. expenditure) Easy to monetize	Replacement value Relatively easy but context and method dependent	Contingent valuation check this Heavily method and context dependent	Willingness to pay; Contingent valuation Heavily method and context dependent
Cash values			Moral values

Table 18. Figures from two case studies to illustrate trends in loss of ecosystems

	Potential area (km^2)	**Year**	
Paramo	14,400	? (1991)	Cavalier (1995)
Upper montane forest	68,800	20,370 (1991)	Cavalier (1995)

degraded UMF	0	800 (1991)	Cavalier (1995)
Eastern Arc Mountains, Africa, total forest cover	23,315	5,708 (1996; 75.5% loss)	Newmark (2002)
Eastern Arc Mountains, Africa, montane forest cover (> 1500 - 2800 m)	?	2696 (1996)	Newmark (2002)