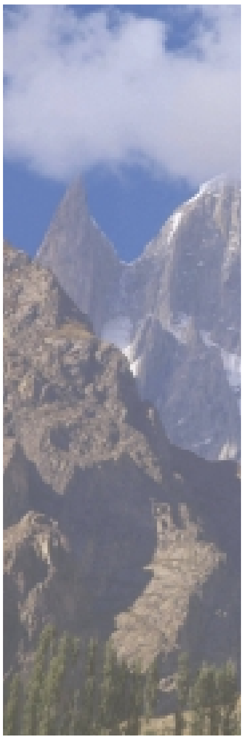
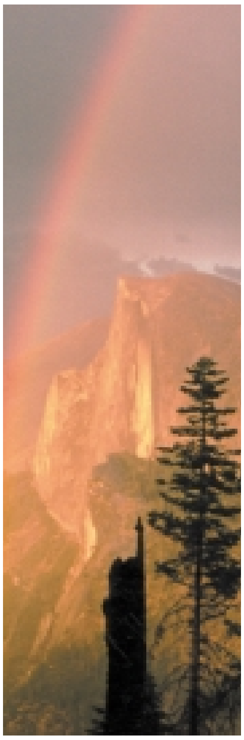
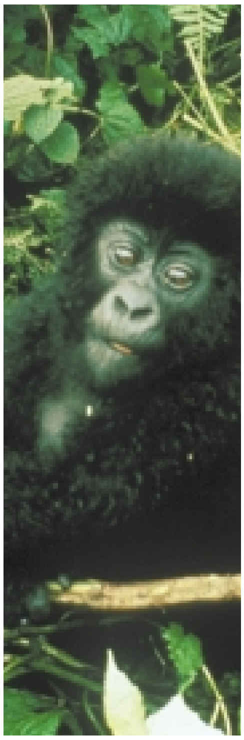
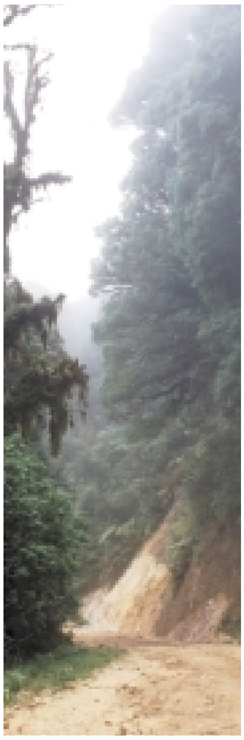


MOUNTAIN ENVIRONMENTS

Many of the subject areas covered by individual chapters of Agenda 21, or by the Convention on Biological Diversity or other international agreements and programmes, relate to all parts of the world regardless of topography and climate. Mountains, however, demand an individual approach, essentially because the effects of slope and elevation – or 'verticality' – add a unique dimension to the challenges present in the lowlands. Tropical uplands can have some production advantages, such as favourable humidity and soil conditions or the absence of certain pests and pathogens, and agricultural production is more marginal in the world's extensive temperate mountains. In all mountain regions, natural risks are high and the effects of poor land use practice are particularly severe.

Nearly 20 km separate the deepest ocean trench from the highest point above sea level, the summit of Chomolungma, or Mount Everest. This is roughly equivalent to the thickness of a fine pencil line forming the circumference of a circle 15 cm wide representing the Earth. The world's terrestrial mountain zones span less than half of this distance.

Despite such seeming physical insignificance at the planetary scale, the world's mountains encompass some of the most awe-inspiring landscapes, a great diversity of species and habitat types, and distinctive, tenacious and often disadvantaged human communities.

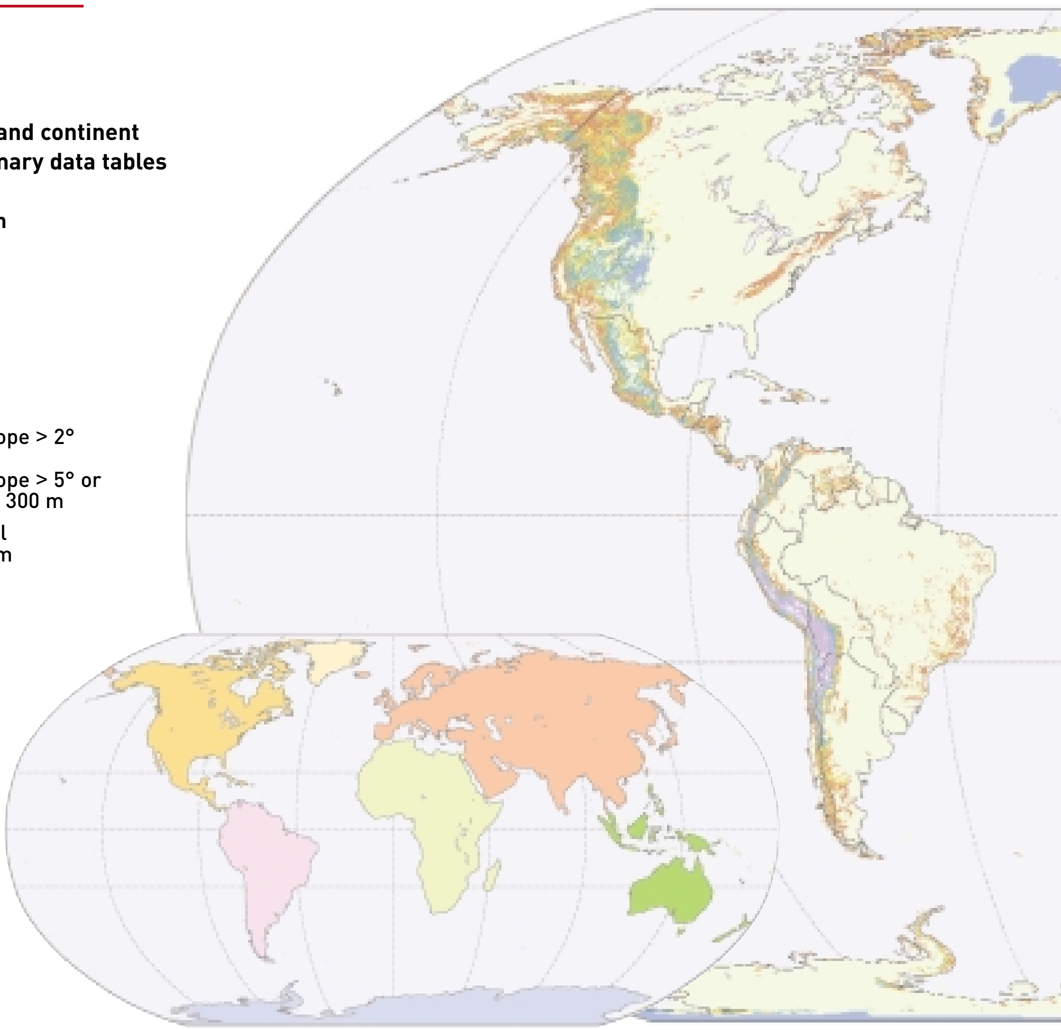
Truly horizontal or vertical surfaces are both rare on the Earth's surface. In the world's lowlands, slope may be imperceptible or of little practical consequence. As slopes increase in steepness and change direction more frequently, the physical aspects of everyday social and economic life become increasingly difficult.

Slope and ruggedness of the terrain, together with absolute altitude, determine many of the fundamental characteristics of mountain environments. Position on the Earth's surface imposes further diversity on these basic features, primarily through

Figure 1: World mountains and continent groups (inset) used in summary data tables

Categories of mountain terrain

- ‡ 4 500 m
- 3 500 – 4 500 m
- 2 500 – 3 500 m
- 1 500 – 2 500 m and slope > 2°
- 1 000 – 1 500 m and slope > 5° or local elevation range > 300 m
- 300 – 1 000 m and local elevation range > 300 m



The main map shows the location of mountain land estimated from a digital elevation model using criteria based on elevation alone (the upper three classes: > 2 500 metres) and at lower elevation, on a combination of elevation, slope and local elevation range.

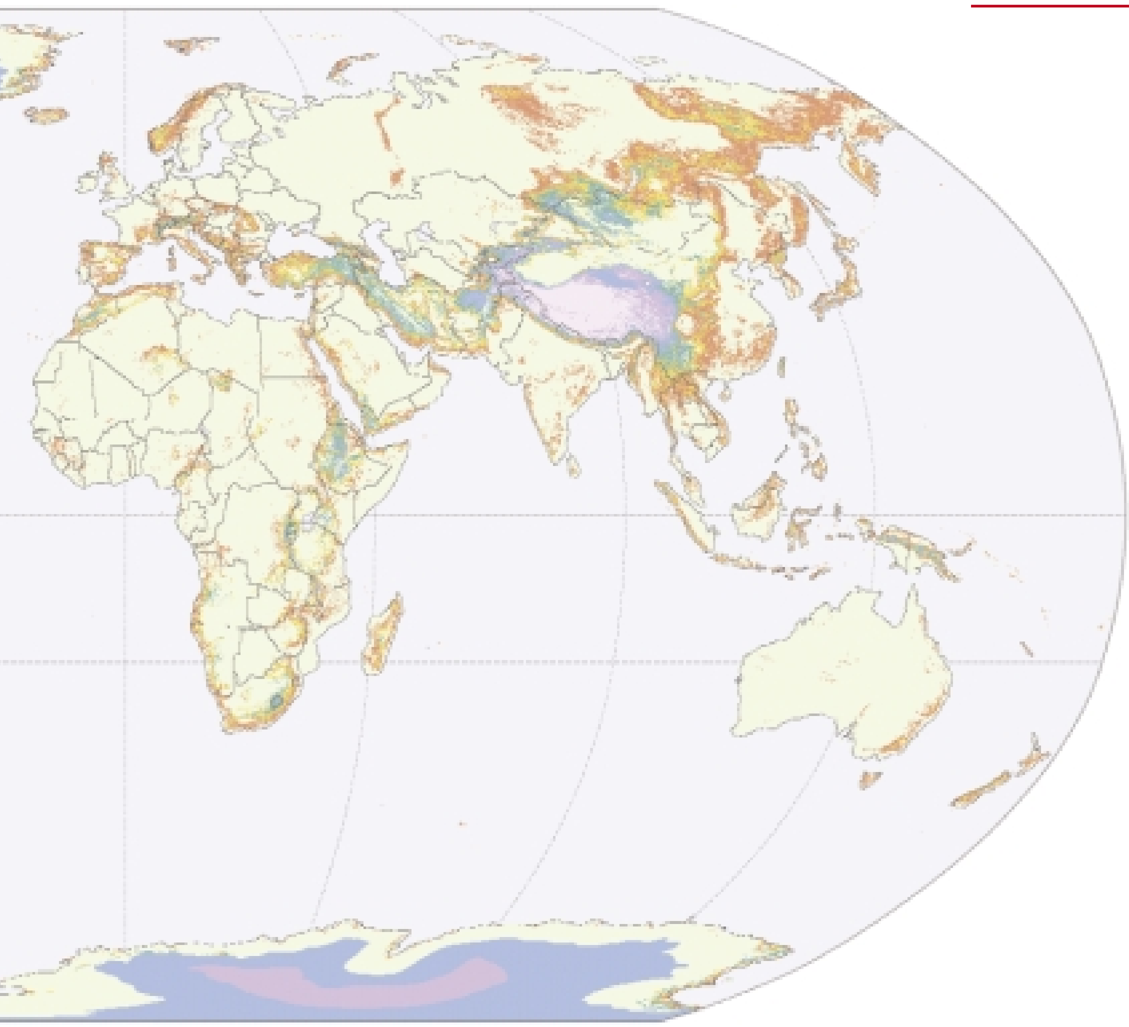
the effects of latitude and continentality on climate and local weather patterns, so that some mountains are almost permanently wet, others dry, and others highly seasonal. Geological substrate adds a further dimension of diversity by influencing the soil type and the potential for erosion.

Several factors, all of which influence life processes or living conditions, change predictably with altitude and underlie the marked environmental gradients typical of high mountains. Temperature, air pressure and humidity decrease with increasing altitude, while solar radiation (especially UV) and wind speed increase. The Earth's very highest mountain regions (above 8 000 m) are beyond the range of temperature and air conditions that most macroscopic living organisms can tolerate. In many other temperate high mountain areas, and those in drylands, conditions are marginal for people, their crops and livestock, and survival demands effort and special techniques to sustain agricultural production.

DEFINING MOUNTAINOUS TERRAIN

Most people would know a mountain when they see one: a significant landscape feature, relatively elevated, with more or less steep approaches. Elevation and slope are key elements, but producing a formal global definition is not simple. Absolute elevation alone cannot provide an adequate criterion; the nature of the terrain is also highly relevant, especially the degree of slope and how often it changes direction, i.e. how rugged the topography is. Such considerations have made it difficult for geographers to agree on a standard definition, although this would greatly improve the information base for integrated research and management in the world's mountains.

An operational quantitative definition, incorporating elements of both altitude and slope, has only become possible with the development of geographic information system (GIS) technology and digital elevation models (DEM). A DEM represents a three-dimensional model of conventional contour information, and GIS analysis allows the ups and downs of this model surface to be assessed against numerical criteria. The first such definition and global map of mountain regions was developed at UNEP-WCMC and is used throughout this report (see Figure 1 and page 74). Future work will aim to address variables, such as temperature and precipitation, that are not purely topographic and which help to deter-



Source: *Kapos* et al. *(2000)*

mine the conditions of life for human and other species.

PHYSICAL FEATURES OF MOUNTAINS

Physically, existing mountains have only slope and elevation in common, and the fact that all will ultimately be eroded into insignificance, while others will be created. They may be formed by uplift of extensive blocks of land around major faultlines, or by folding of rock strata, both of which result from continental movements, or by volcanic activity often associated with both faulting and folding. Any given segment of land may well have been affected by all three processes over the course of Earth history, and so, with the exception of volcanic cones, mountain ranges will often be composed of a variety of igneous, sedimentary and metamorphic rock types. Accordingly, there is wide variation in features that depend on rock type, such as erosion potential, slope stability and soil.

Mountains vary widely in age. One of the better known episodes of ancient folding affected rocks now within northwest Europe around 400 million years ago; geological evidence for this early mountain-building has been largely obscured by later earth movements and the levelling effects of erosion. Much of the folding involved in uplift of the Alpine-Himalayan chains took place around 35 million years ago, and these tend to retain the sharp peaks and ridges typical of younger mountain ranges. The Earth's very youngest peaks are volcanic in origin. Paricutin in Mexico, for example, had built a cinder cone about 500 m high within a year of its eruption in 1943 (total elevation about 2 770 m).

With the present configuration of continents, more than two-thirds of the world land surface is located in the northern hemisphere, and the area of land north of the Tropic of Cancer slightly exceeds that in the rest of the world put together. This in part explains why the northern temperate belt contains a far greater mountain area than any other zone (Figure 3). The Antarctic region comes a distant second in total mountain area, but owing to the immense extent and thickness of its icecap, it has the highest proportion of overall area defined as mountainous and the greatest surface area above 2 500 m (Figure 4).

Dividing the world's land by continental groups, rather than by latitude, shows unsurprisingly that the enormous Eurasian landmass has by far the greatest mountain area.

Eurasia also has the most extensive inhabited land area above 2 500 m elevation, in the Tibet (Xizang) Plateau and adjacent ranges. All of the world's mountains above 7 000 m in height are in Asia, and all the 14 peaks above 8 000 m are situated in the Greater Himalaya range extending along the southern rim of the Tibet Plateau.

After Eurasia, and excluding Antarctica, South America has the second most extensive area of high elevation land (Figure 4), formed by the mountains and basins of the Central Andes. The world's highest individual peak outside Asia is Aconcagua, which reaches an elevation of around 6 959 m in the southern Andes. A major part of Greenland is above 2 500 m, and this region resembles Antarctica in that much of the surface is composed of a deep icesheet; in both cases most of the very small human population is restricted to the coast.

Figure 2: Mountain regions worldwide

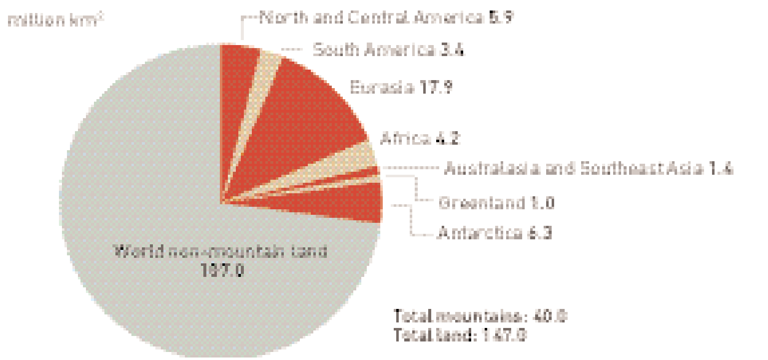


Figure 3: Mountain areas by latitude zone

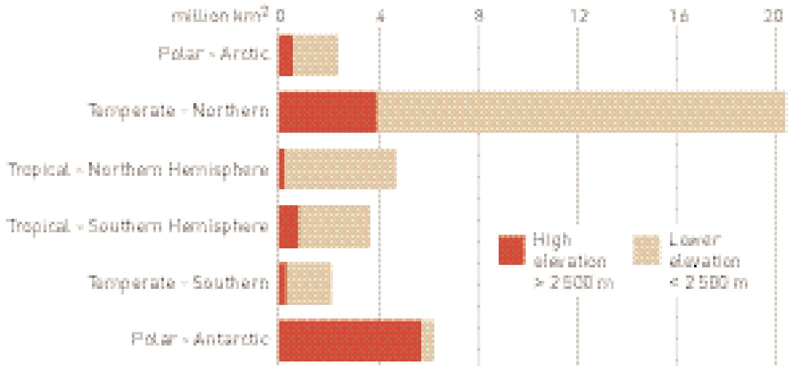
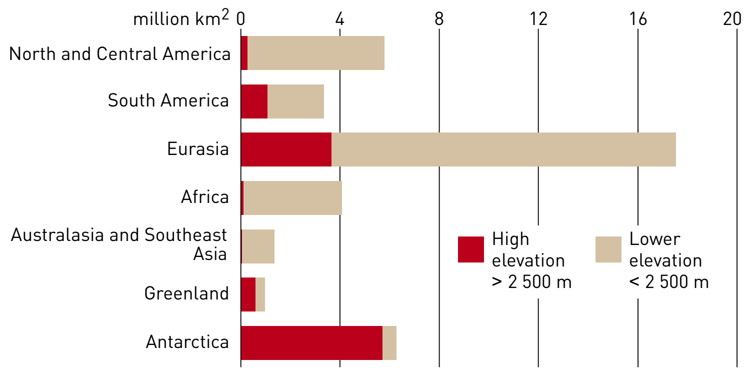


Figure 4: Mountain areas by continent group



KEY FEATURES OF MOUNTAINS

Local variation

There is immense variation in the nature of mountain environments despite their common basic physical conditions of elevation and slope. Much of this variation arises from differences in temperature and precipitation regimes associated with position on the Earth's surface – whether at high or low latitudes, whether deep within a continental landmass or subject to oceanic influence along the margin of a landmass. Mountains guide approaching air masses upward, and as temperature falls, the air is able to hold less water vapour, leading to increased rainfall on the windward side and a reduction on the lee side (the 'rain shadow' effect). More locally, conditions vary greatly according to aspect of slope (north- or south-facing), soil and local topography.

High energy, high erosion

Mountains are typically high energy environments, subject to strong winds, frequent freeze-thaw cycles at higher elevations, accumulation and melting of snow masses in some parts and heavy rainfall in others. Collectively, these agents speed up the process of weathering, while altitude and slope hasten the loss of erosional debris. Slope, thin soils, and the general absence of a permanently frozen subsoil, mean that water is similarly lost rapidly downslope, and mountain plants are often well adapted to drought conditions. The need to reduce erosion while improving soil and water conditions for crop plants is a key factor behind the widespread adoption of terracing by mountain agriculturalists. If wind velocity doubles, the force exerted increases fourfold; this has a direct physical impact on humans and other species (leading to the prostrate or cushion-like growth form of many high mountain plants), as well as a desiccating effect that adds to the risk of water stress.

Temperature

Air temperature on average decreases by about 6.5° C for every 1 000 m increase in altitude; in mid latitudes this is equivalent to moving poleward about 800 km. The dry dust-free air at altitude retains little heat energy, leading to marked extremes of temperature between day and night. In seasonal climates, daytime temperatures can rise sharply in sunlit mountain areas. In tropical climates, the sun is high overhead throughout the season, so that tropical mountains tend to have high temperatures and sometimes high rainfall throughout the year. Temperature is one factor determining the natural upper limit of tree growth (the 'treeline'), which varies locally and with latitude, from around 5 000 m in parts of the tropics to near sea level at high latitudes.

Air pressure and oxygen availability

As a consequence of decreasing air pressure, the partial pressure of oxygen falls with increasing altitude (partial pressure is the constant 21 per cent concentration of oxygen multiplied by the barometric pressure). At 1 500 m the partial pressure of oxygen is about 84 per cent of the value at sea level, falling to 75 per cent at 2 500 m and 63 per cent at 3 500 m (with minor variation with latitude and season). The consequence of this for humans and other animals is that with increasing altitude, less oxygen is obtained per volume of air inspired, and fewer oxygen molecules diffuse into the bloodstream to maintain cell function and support physical activity. Mountaineers and other temporary residents at high altitude can achieve limited acclimatization to oxygen shortage (hypoxia) over a period of days or weeks. Populations that live permanently at high altitude are subject to life-long hypoxic stress, and have in some instances evolved the metabolic capacity to maintain physical activity. Nevertheless, in human populations hypoxia has demonstrable adverse effects on birthweight and reproductive success.

MOUNTAIN ECOSYSTEMS

Mountains occur on all continents, in all latitude zones, and within all the world's principal biome types – from hyperarid hot desert and tropical moist

Figure 5: Percent of country classed as mountainous
Top 20

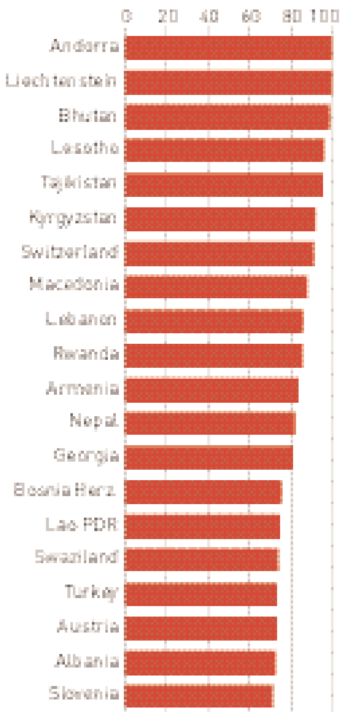


Figure 6: Area of high mountains
Top 20 sequenced by high mountain area

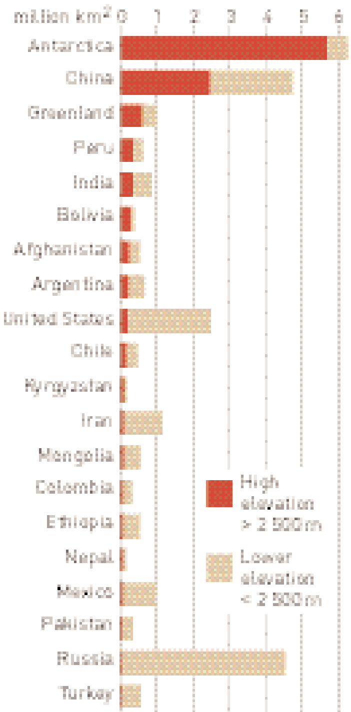


Figure 7: Total mountain area
Top 20 sequenced by total mountain area

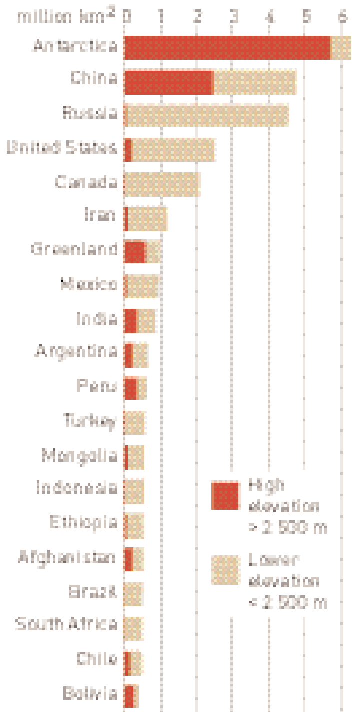
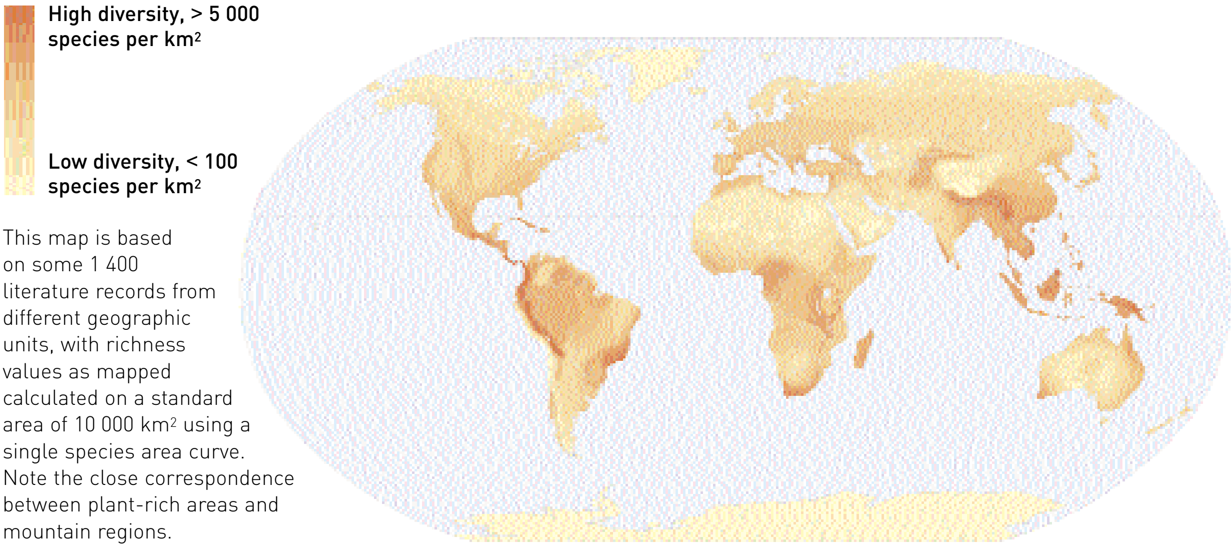


Figure 8: The diversity of vascular plants



This map is based on some 1 400 literature records from different geographic units, with richness values as mapped calculated on a standard area of 10 000 km² using a single species area curve. Note the close correspondence between plant-rich areas and mountain regions.

Source: W. Barthlott, University of Bonn

forest to arid polar icecaps – and support a correspondingly wide variety of ecosystems.

Mountain ecosystems tend to be important for biological diversity, particularly in the tropics and warmer temperate latitudes (see Figure 8). Although richness declines with altitude, lower elevation slopes often hold a wide range of habitat types within a relatively short distance. Isolated mountain blocks are often rich in endemics.

Polar mountains may be entirely without vegetation; at other high latitude sites, mountains may bear only sparse tundra-like scrub. On low elevation mountains at lower latitudes, vegetation may be broadly similar to that of surrounding lowlands, often with coniferous or broadleaf forest. With increasing elevation, the effects of temperature, precipitation and wind combine to induce an altitude-related zoning in vegetation. As elevation increases, the availability of moisture – as rain or condensation from cloud or fog – tends to increase (up to a level that varies with latitude and between continents). In arid regions such as the Horn of Africa, this can allow tree growth near the top of mid elevation mountains that emerge from treeless semi-desert plains. In more humid regions, short-stature epiphyte-rich evergreen forest (cloud forest) may flourish above more seasonal forest types.

Ultimately, temperature and moisture availability decrease, and windspeed increases, to a point where tree growth cannot be sustained. Above this point, low herbaceous vegetation, often including tussock grassland, takes over, to be succeeded by largely bare rock or snow. Such montane grasslands are often important for livestock grazing, as exemplified by the *páramo* zone of the northern Andes. This is an extensive tract of grass and shrub, lying between the upper limit of cultivation (around 3 250 m) and the high summits (> 4 000 m). Distinctive giant forms of groundsel and lobelia (whose widespread relatives are small herbaceous plants) occur above the treeline on high mountains in tropical Africa, while giant bromeliads and large composites occur on the Andean *páramo*. In many hill and mountain regions the present treeline has been pushed downslope from its potential level by burning and agricultural activity.

The vegetation zones encountered with increasing elevation on an idealized tropical mountain tend to resemble the biome types found with increasing latitude. Vegetation types similar to those that succeed one another through more than 80° of latitude and 3 000 km distance – tropical moist forest, deciduous forest, coniferous forest, shrub and grassland, or ice – may be compressed onto the slopes of a mountain perhaps 5 000 m high. Despite superficial resemblance in vegetation, there are fundamental differences between elevational gradients in the tropics and latitudinal gradients. In tropical regions, the sun is high overhead throughout the year, whereas seasonality increases with increasing latitude. At high arctic latitudes, permafrost is common and there is little shortage of water during the short growing season, whereas alpine environments are less seasonal, with high light levels and daytime warming through much of the year. The absence of permafrost means that soil water is readily lost through downslope drainage, leading to water stress.

PEOPLE IN MOUNTAINS

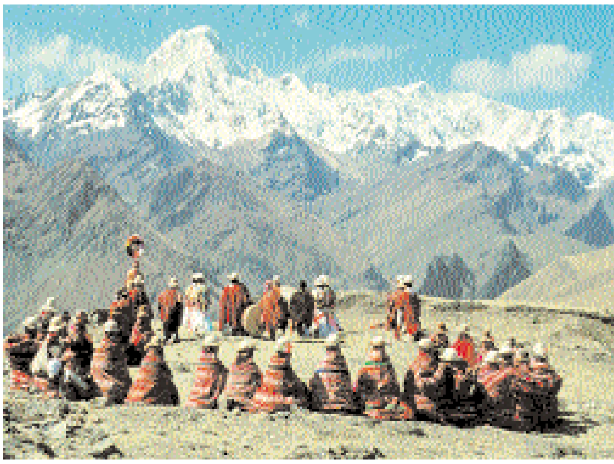
In most mountain regions, people have based their livelihoods on agriculture, pastoralism, and use of forest resources (timber, fuelwood, fodder). This remains widely true, although very marked changes have occurred in some mountain areas, gathering pace from the mid-20th century onward, with supplementary or entirely new sources of income, often located outside mountains proper, increasing in importance.

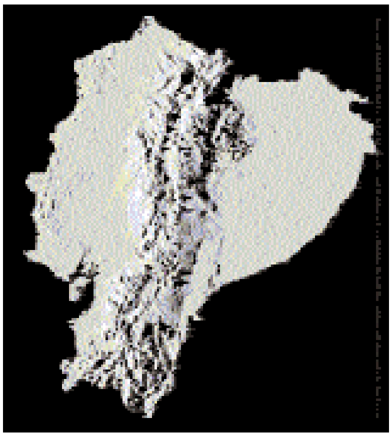
Traditional livelihoods in mountain environments, particularly outside the humid tropics, have typically been created with difficulty and at some risk of failure. The growing season is shorter at altitude, and the range of crops that can be grown tends to be narrow (exceptionally so at higher altitude), with increased risk of malnutrition (Figure 9). Physical hazards tend to be high relative to lowlands, and moving from place to place is difficult. The social and economic networks basic to development may be hard to access. Nevertheless, mountain people generally have evolved productive agro-ecosystems, often involving the creation and maintenance of slope terracing, field enclosures and irrigation systems, and effective trading relations with lowlanders.

Where valued minerals are exposed or accessible, mining has for centuries been an important local form of resource extraction in mountains, often with local adverse impacts on mountain ecosystems. Tourism is a more recent use of mountain landscapes with effects ranging from benign to damaging. Low intensity tourist use, such as adventure travel or trekking, can bring significant cash benefits to a region, but may have adverse impacts on local food, water or fuel resources. More intensive recreational activities, such as skiing, have economic benefits but are liable to result in infrastructure development and landscape-scale change to the mountain environment.

Marked demographic change in mountain communities is evident from historical records and contemporary observations, with growth and decline occurring in different areas. For example, economic migration and unsustainability of traditional livestock production methods have reduced numbers in many mountain communities in the Alps and Pyrenees, while tourism and incoming 'amenity migrants' have increased numbers in others. Local agricultural production, local social and cultural factors, and economic forces generated in the wider region, variously contribute to these changes, which remain difficult or impossible to predict.

The following pages outline some aspects of human demography and cultural diversity, and the ecosystem services that underpin them. Subsequently a number of important pressures that have affected mountain ecosystems or may do so in future, are introduced.





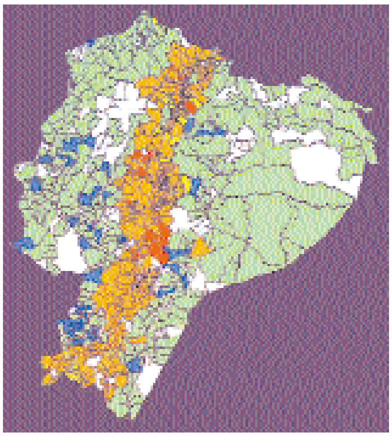


Figure 9: Linking topography and malnutrition in Ecuador

Percent of population malnourished

- < 40
- 40 – 50
- 50 – 60
- 60 – 70
- 70 – 80
- Insufficient data

Source: Glenn Hyman, CGIAT-CIAT, using information from the National Statistics and Census Institute (INEC) and the National Development Council (CONADE), Ecuador