2002 International Year of MOUNTAINS

Global Environment Facility

UNEP WCMC

Mountain watch

environmental change and sustainable development in mountains

Mountain Watch provides a new map-based synthesis of information on environmental change, and its implications for sustainable development, in mountains. It is designed to assist achievement both of the Millennium Development Goals, which aim to ensure environmental sustainability and improve people's livelihoods, and the Plan of Implementation of the World Summit on Sustainable Development, agreed in Johannesburg, South Africa, in 2002.

Mountain Watch profiles methods to assess mountain ecosystems, the pressures that affect them and the services they provide to people. A new analysis of global data is supplemented by regional and local case studies drawn from around the world. Tools are provided for decision-makers to ensure that development sustains mountain environments and the people who depend on them.

The report is designed to support an assessment process, launched at the Bishkek Global Mountain Summit during the International Year of Mountains, 2002. This will involve a series of regional workshops, bringing together many stakeholders living in and visiting mountain regions, and will lead to the production of a *World Atlas of Mountain Environments*.

Mountain Watch was compiled by UNEP-WCMC and the UNEP Mountain Programme, in collaboration with the GEF, UNEP Regional Offices, UNEP GRID Centres and other partners, as a contribution to the International Year of Mountains, for which FAO is the lead UN agency, in collaboration with governments, UNEP, UNDP, UNESCO and other partners.

UNEP World Conservation Monitoring Centre
219 Huntingdon Road, Cambridge CB3 0DL,
United Kingdom
Tel: +44 (0) 1223 277314
Fax: +44 (0) 1223 277136
E-mail: info@unep-wcmc.org
http://www.unep-wcmc.org

UNEP Mountain Programme
15 Chemin des Anemones,
CH-1219, Chatelaine, Geneva,
Switzerland
Tel: +41 22 917 8273/8481
Fax: +41 22 917 8004
E-mail: mountains@unep.ch
http://www.globalmountainsummit.org

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www.unep.org
United Nations Environment Programme
P.O. Box 30552 Nairobi, Kenya
Tel: + 254 2 621234
Fax: +254 2 623927
E-mail: cpiinfo@unep.org
Website: www.unep.org

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environmental change & sustainable development in **mountains**

UNEP

Mountain watch

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UNEP-WCMC

Mountain watch

environmental change & sustainable development in mountains

UNEP-WCMC

Simon Blyth, Brian Groombridge, Igor Lysenko, Lera Miles, Adrian Newton

Global Environment Facility

UNEP WCMC

International Year of Mountains 2002

UNEP World Conservation Monitoring Centre
219 Huntingdon Road
Cambridge CB3 0DL, UK
Tel: +44 (0) 1223 277314
Fax: +44 (0) 1223 277136
E-mail: info@unep-wcmc.org
Website: www.unep-wcmc.org

Director: Mark Collins

THE UNEP WORLD CONSERVATION MONITORING CENTRE is the biodiversity assessment and policy implementation arm of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organization. UNEP-WCMC aims to help decision-makers recognize the value of biodiversity to people everywhere, and to apply this knowledge to all that they do. The Centre's challenge is to transform complex data into policy-relevant information, to build tools and systems for analysis and integration, and to support the needs of nations and the international community as they engage in joint programmes of action.

Sponsors
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Mountain Watch

Project manager
Adrian Newton
UNEP World Conservation
Monitoring Centre (UNEP-WCMC)
E-mail: adrian.newton@unep-wcmc.org

UNEP Coordinator
Andrei Iatsenia
Coordinator
UNEP Mountain Programme
E-mail: iatsenia@unep.ch

Production, analysis, cartography
UNEP-WCMC
Simon Blyth, Brian Groombridge,
Igor Lysenko, Lera Miles

Neville Ash, Jared Bakuza,
Philip Bubb, Mark Collins,
Mary Cordiner, Florence Jean,
Valerie Kapos

Contributors
Agricultural University of Norway
Mariel Flores, Ingunn Vistnes

CGIAR - CIAT, Colombia
Glenn Hyman

CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion), Lima, Peru
Hector Cisneros, and associates
Coen Bussink, Pablo Arturo Sánchez,
Carlos Cerdán, and Jorge Reinoso

University of Geneva, Switzerland
Remote Sensing Unit and GIS
Walter Silverio

Global Environment Facility, Washington DC, USA
Fumiko Nakao

International Centre for Integrated Mountain Development (ICIMOD)

LCSES - Colombia LO, Colombia
Juan Pablo Ruiz Soto

King Mahendra Trust for Nature Conservation, Nepal
Siddhartha B. Bajracharya

University of Melbourne, Australia
Kerrie Wilson

University of Minnesota, USA
Lilian Pintea

NASA, USA
Research Division,
Office of Earth Science
Woody Turner

Norwegian University of Science and Technology, and International Peace Research Institute, Oslo, Norway
Halvard Buhaug

UNEP (DEWA), Nairobi, Kenya
Kofoed Jesper

UNEP GRID, Geneva Switzerland
Pascal Peduzzi

UNEP GRID Arendal, Norway
Hugo Ahlenius, Christian Nelleman

UNEP GRID, Sioux Falls, USA
Mark Ernste

UNEP Post-Conflict Assessment Unit, Geneva, Switzerland
Peter Zahler

UNEP Regional Resource Centre for Asia and Pacific (RRC.AP), Asian Institute of Technology (AIT), Bangkok, Thailand
Surendra Shrestha,
Mylvakanam Iyngarararasan

UNF, UNEP, KWS,
University of Bayreuth, WCST
Christian Lambrechts

USGS, Cascades Volcano Observatory, USA
Michael Poland

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Institute of Ecology and Conservation Biology
Michael Gottfried, Georg Grabherr,
Harald Pauli

WWF-Austria, Vienna, Austria
Thomas Kaissl

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Messages

Klaus Töpfer
Executive Director
United Nations Environment Programme

I AM EXTREMELY PLEASED TO INTRODUCE THIS IMPORTANT NEW REPORT, *Mountain Watch*. The initiatives launched during the International Year of Mountains, 2002, have led to enhanced international cooperation, and the development of many fresh partnerships, supporting the sustainable development of Earth's mountain regions. *Mountain Watch* exemplifies this spirit of partnership including, as it does, information from more than 30 contributors with experience of mountains worldwide. In this way *Mountain Watch* has played a role in fostering international collaboration, by gathering information from the many contributing organizations and mountain stakeholders in a wide variety of different regions.

UNEP has greatly welcomed the opportunity to coordinate this initiative, together with partners including the Food and Agriculture Organization of the United Nations, the United Nations Educational, Scientific and Cultural Organization, the United Nations Development Programme, the Consultative Group on International Agricultural Research, the International Centre for Integrated Mountain Development, and the Mountain Forum.

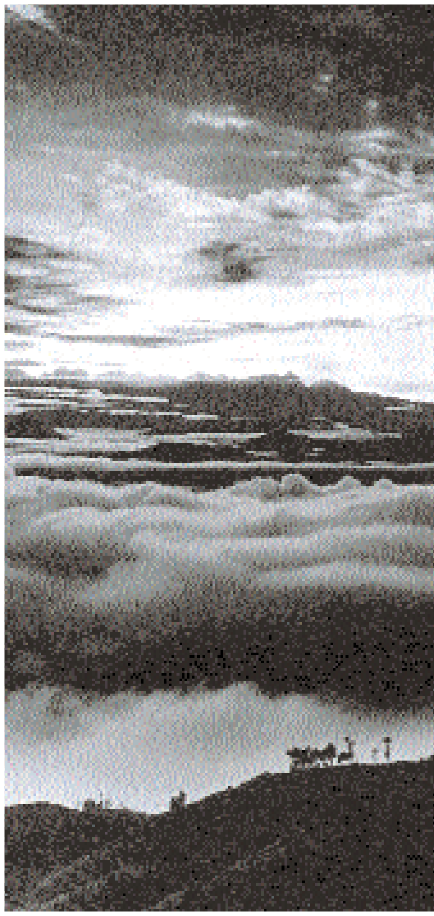
I also welcome the opportunity to thank the sponsors of this report and the project of which the *Mountain Watch* process forms a part, including the Global Environment Facility, the Swiss Development Corporation, the Aga Khan Development Network, the United Nations University, the United Nations Educational, Scientific and Cultural Organization, the Asian Development Bank, the Government of Kyrgyzstan, the Government of Italy, the Government of Germany and the Food and Agriculture Organization of the United Nations.

I am confident that *Mountain Watch* will help not only UNEP but all the partners in the International Year of Mountains to identify and focus on the implementation of priority activities for sustainable development in mountain regions worldwide.

Mohamed T. El-Ashry
Chairman and CEO
Global Environment Facility

THE STATE OF THE EARTH'S MOUNTAIN ENVIRONMENT may mean enrichment or impoverishment to more than half of humanity. The Global Environment Facility is proud to be working with governments, non-governmental organizations, private companies, communities, and individuals to conserve and sustainably develop mountain areas. Our hope is that *Mountain Watch* will contribute to the critical need for accessible and accurate information on mountain ecosystems.

Foreword *'We are all Mountain People'*



The message *'we are all Mountain People'* has been widely adopted during the International Year of Mountains 2002 – and rightly so. As *Mountain Watch* demonstrates through its maps, analyses and case studies, healthy mountain ecosystems are vital not only to mountain communities, but also for services to lowland peoples, including clean water, energy, food, recreation, and protection from environmental catastrophes such as avalanches and floods. *Mountain Watch* also shows us how mountains, often seen as everlasting and immutable, can indeed be vulnerable to human-induced impacts including climate change and ecosystem degradation.

With these principles in mind, *Mountain Watch* is designed directly to address two of the key aims of the International Year of Mountains 2002: to raise awareness of the importance of mountains in the development and quality of life of people everywhere, and to build partnerships that will seriously address the challenges to mountain environments.

To raise awareness, we intend to make key data from *Mountain Watch* freely available through a special website:

http://www.unep-wcmc.org/mountains/mountainwatch

In addition, plans are being laid for preparation of a full-scale *World Atlas of Mountain Environments.*

The International Year of Mountains 2002, the springboard for action on mountains, has benefited from the World Summit on Sustainable Development (WSSD), which also took place in 2002. This conference addressed mountains on a wide front, tackling environmental degradation, poverty, inequities adversely affecting women, indigenous peoples and mountain communities, diversification of economic investments and new ways of sharing benefits. Moreover, through the International Partnership for Sustainable Development in Mountain Regions launched at WSSD, many new projects and cooperative agreements are in train.

Amongst its many initiatives the International Partnership will promote environmental assessment in mountains, to build knowledge and to monitor programmes of action. *Mountain Watch* establishes a foundation for a network of mountain centres of excellence, working together to communicate achievements and inevitable setbacks, share experiences and technologies, and inform the world of what is being done to conserve mountain environments to the benefit of people, ecosystems and biodiversity everywhere.

Mountain regions cover one quarter of the Earth's terrestrial surface. They deserve the level of concern afforded to other global ecosystems, such as wetlands, forests and coral reefs. *Mountain Watch* will, we hope, become the guardian of mountain environments, the voice of mountain peoples, and a cornerstone for new partnerships and networks for mountains across the world.

Mark Collins
Director
UNEP World Conservation
Monitoring Centre

Andrei Iatsenia
Mountain Programme Coordinator
UNEP Regional Office
for Europe

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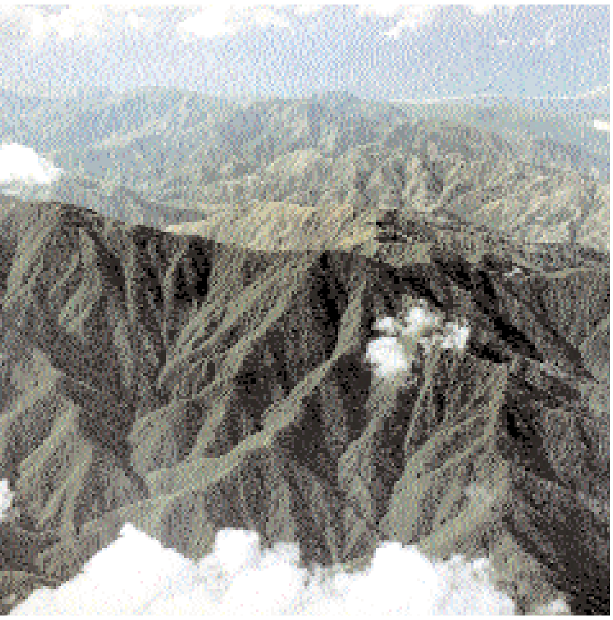


Executive summary

Mountain environments cover some 27 per cent of the world's land surface, and directly support the 22 per cent of the world's people who live within mountain regions. Lowland people also depend on mountain environments for a wide range of goods and services, including water, energy, timber, biodiversity maintenance, and opportunities for recreation and spiritual renewal.

Especially at higher elevation and outside the humid tropics, mountain people face an environment in which everyday physical demands are great, natural hazards are significant and agricultural production is constrained. Only about 3 per cent of land ranked as highly suitable for rainfed agriculture is within mountains, highlighting the restricted livelihood opportunities available to many mountain people. Difficult access, with economic and political marginalization, compound the problems.

Many mountain environments have been degraded by excess use of natural resources, inappropriate infrastructural development, deforestation, and the impacts of natural hazards. These changes affect the provision of ecosystem services and the livelihoods of people dependent upon them. Despite the importance of environmental change in planning for sustainable development, information has until now been lacking on how mountain environments might be affected by such change in the future.

Mountain Watch provides the first map-based overview of environmental change in mountain regions and its implications for sustainable development. New global maps are presented to illustrate selected values of mountain ecosystems and many of the pressures that are causing environmental change.

The global analyses are supported by a range of case studies from different mountain regions, illustrating how environmental assessments can inform the sustainable development of mountain regions. Particular emphasis is given to the use of remote sensing and geographic information system (GIS) technologies, and how these approaches can be used to provide practical tools for decision-makers, to ensure that development sustains mountain environments and the people that depend on them.

In this way, *Mountain Watch* aims to support implementation of policy initiatives focusing on sustainable development of mountains, including Chapter 13 of Agenda 21 and the Plan of Implementation of the World Summit on Sustainable Development (WSSD).

HIGHLIGHTS

A map indicating the biodiversity value of different areas shows that almost every area jointly important for plants, amphibians and endemic birds is located within mountains.

Analysis of seismic hazards, fire, climate change, land cover change and agricultural conversion, infrastructural development, and armed conflict, has allowed the distribution of these pressures in the world's mountain regions to be assessed. Many regional differences have emerged, for example:

- the proportion of mountain area that may be affected by severe climate change is substantially higher in the northern hemisphere than in the other regions considered;
- African mountains contain a considerably higher proportion of land that is suitable for rainfed crops than any other region;
- the proportion of mountain area affected by violent human conflict is substantially higher in Africa than in the other regions considered, although substantial areas have also been affected in Eurasia and Southeast Asia.

Four of the six pressures considered affect a higher proportion of mountain areas in Africa than in any other region. With all pressures combined, mountains in Eurasia and in Australasia-Southeast Asia experience a combination of multiple pressures over a larger percentage of land area than other mountain regions.

By overlaying the biodiversity map with the integrated pressure dataset it was possible to identify mountain areas that support high biodiversity and also experience severe environmental pressures. Among areas of particular concern are:

- the North-Western Andean moist forest and Magdaleña Valley of South America;
- the Caucasus mixed forests ecoregion;
- montane ecoregions in California.

These regions are priority candidates for global conservation action in the world's mountains.

Purpose and approach

This *Mountain Watch* report has been compiled by the UNEP World Conservation Monitoring Centre and the UNEP Mountain Programme, in collaboration with the Global Environment Facility (GEF), UNEP Regional Offices, UNEP GRID Centres and a number of other partners. The report was produced as a contribution to the International Year of Mountains (IYM), for which the Food and Agriculture Organization of the United Nations (FAO) is the lead agency in collaboration with governments, UNEP, the United Nations Development Programme, UNESCO and other partners.

Mountain Watch provides the first systematic assessment of mountain ecosystems, using a geographic information system (GIS) analysis of global data, presented as a visual, map-based overview of:

- the ecological and social values of mountain ecosystems;
- current and potential pressures facing mountain environments and people;
- tools and approaches for sustainable development in mountain areas.

A general aim is to assess the potential impacts of environmental change on mountain ecosystems and the services that they provide to people, and a key objective is to identify those mountain regions that are at particular risk of such impacts occurring in the future. A new analysis of global datasets is supplemented by regional and local case studies drawn from around the world. The report profiles methods that have been developed to help decision-makers assess the condition of mountain ecosystems and to plan effective management.

This *Mountain Watch* report is designed to support a new assessment process launched at the 2002 Bishkek Global Mountain Summit in Bishkek, Kyrgyzstan. The process will involve a series of regional workshops to be organized during 2003, which will involve many stakeholders including mountain residents.

This process will lead to production of a book entitled *World Atlas of Mountain Environments*, which will provide a highly detailed source of information on mountain environments, and identify best practice in the sustainable development of mountain ecosystems. UNEP-WCMC has many years of experience of producing conservation atlases, including most recently the *World Atlas of Coral Reefs* and the *World Atlas of Biodiversity*, both published by the University of California Press.

The *World Atlas of Mountain Environments* will be produced in close collaboration with a range of partners involved in assessment and sustainable development of mountain environments. Organizations or individuals interested in contributing to the assessment process, leading to production of the *Atlas*, are encouraged to contact the UNEP Mountain Programme office and UNEP-WCMC.

The draft conceptual framework developed by the Millennium Ecosystem Assessment (MA) (http://www.millenniumassessment.org/) has guided preparation of *Mountain Watch*. The MA is an international process launched by United Nations Secretary-General Kofi Annan in June 2001, and is designed to meet the needs of decision-makers and the public for scientific information on the consequences of ecosystem change for services essential to human well-being, and options for responding to those changes. Ecosystem services are the benefits that people obtain from ecosystems. These include provisioning, regulating and cultural services that directly affect people, and supporting services needed to maintain these (Table 1).

The MA conceptual framework differentiates between indirect and direct pressures or causes of change. Indirect pressures include demographic, social and political forces, as well as wealth distribution and technological developments. These indirect pressures may influence direct pressures, such as climate and land cover change, which directly affect ecosystems. This report focuses largely on a selection of direct pressures (including natural hazards, climate change, land use change, infrastructural development) and their impacts on mountain ecosystems and the services they provide to people.

Sets of spatial data on the drivers of environmental change of

Table 1: Ecosystem services being considered by the Millennium Ecosystem Assessment, which are of particular importance in mountain regions

SERVICE CATEGORY	SERVICE PROVIDED
Provisioning	Freshwater
	Food
	Fibre, timber, fuel
Regulating	Atmospheric and climate regulation
	Flood and storm protection, and erosion prevention
Cultural	Spiritual, amenity
Supporting	Nutrient cycling and soil fertility

particular importance in mountains have been compiled and mapped as the basis for this *Mountain Watch* assessment. Using GIS, these global data were then analysed in relation to a map of mountain areas defined by formal topographic criteria. The interpretation of these analyses differs between pressures. In some cases (such as armed conflict or fire), the map illustrating the pressure indicates where particular impacts have occurred in the past. The assumption is made that the risk of future impacts is higher in those areas where impacts have occurred in the past. In other cases (such as climate change), the map illustrates where particular impacts might occur in the future, according to a scenario of future change.

Scenarios are increasingly being used as tools in environmental assessments such as the MA. These are not attempts to 'forecast' the future, which is highly uncertain. However, they may illustrate possible future impacts according to current trends, by drawing on modelling approaches. They are also designed to provide decision-makers with a better understanding of the potential consequences of decisions they take today.

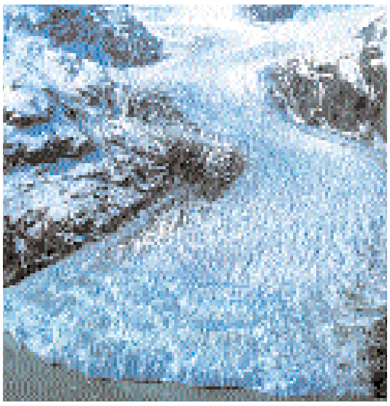
Finally, the different maps are combined to provide an integrated analysis of different pressures on mountain regions. In addition, this section illustrates how the spatial analyses presented in this report may be used to inform decision-making in support of sustainable development. Again, the focus is on the use of spatial data in the development of appropriate decision support tools.

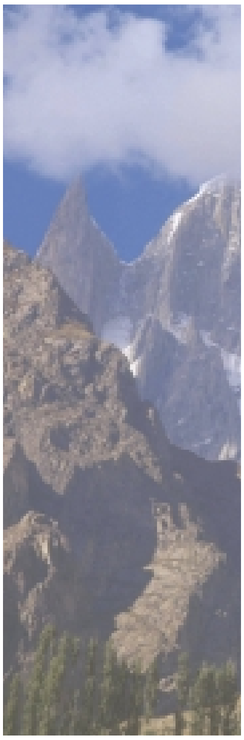
This report is the first attempt to assess mountain ecosystems in this way. It is designed primarily to stimulate further discussion rather than to be definitive. It should be recognized that any environmental assessment is subject to a high degree of uncertainty, particularly where potential future impacts are addressed. Available data are uneven in quality, quantity and resolution. For example, when pressure data were at a coarser scale than the mountain map, they were simply superimposed onto it. This implies an assumption of homogeneity within the larger grid cell, which in fact may contain a mix of mountain and non-mountain cells. This downscaling could be improved by correlating the map data with pressures at a finer scale, to better distinguish areas affected.

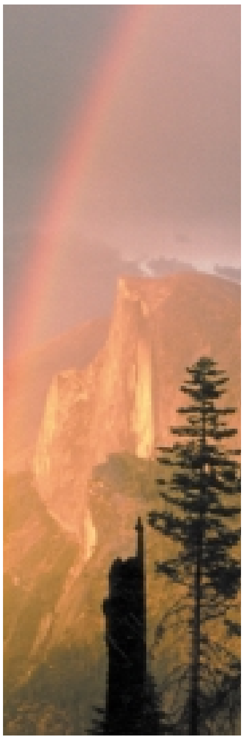
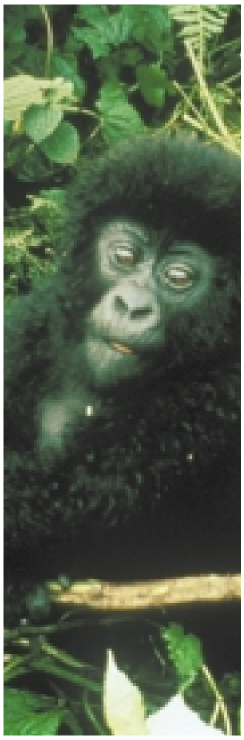
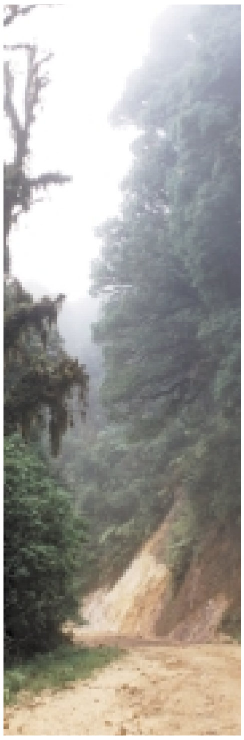
It is hoped that tools that can assist in the assessment of uncertainty will be employed as the process of assessing mountain ecosystems develops.

Table 2: Indirect pressures being considered by the Millennium Ecosystem Assessment, which are of particular importance in mountain regions

PRESSURE SUB-GROUP	PRESSURE
Demographic	Spatial distribution of population
	Globalization
Economic	Economic structure
	Consumption patterns
	Trade policy
	Income
	Wealth distribution
	Policy towards agriculture, forest and fisheries (including land tenure)
Global biophysical	Climate
Socio-political	Governance
	Attitude towards gender
	Involvement in conflict and/or war
Technological	Agricultural innovations
	Changes in cultural beliefs and practices
	Technological disasters





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.

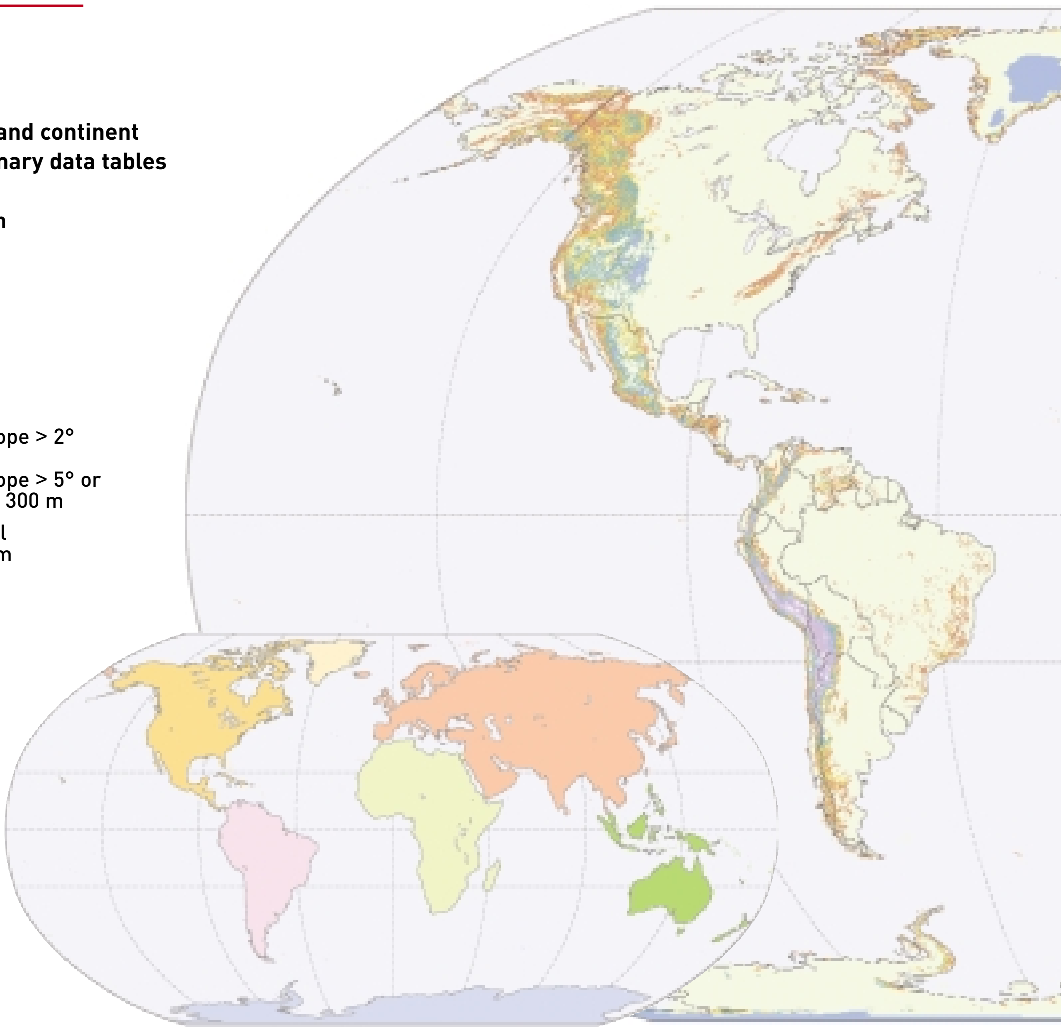
Truly horizontal or vertical surfaces are both rare on the Earth's surface. In the world's lowlands, slope may be imperceptible or of little practical consequence. As slopes increase in steepness and change direction more frequently, the physical aspects of everyday social and economic life become increasingly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

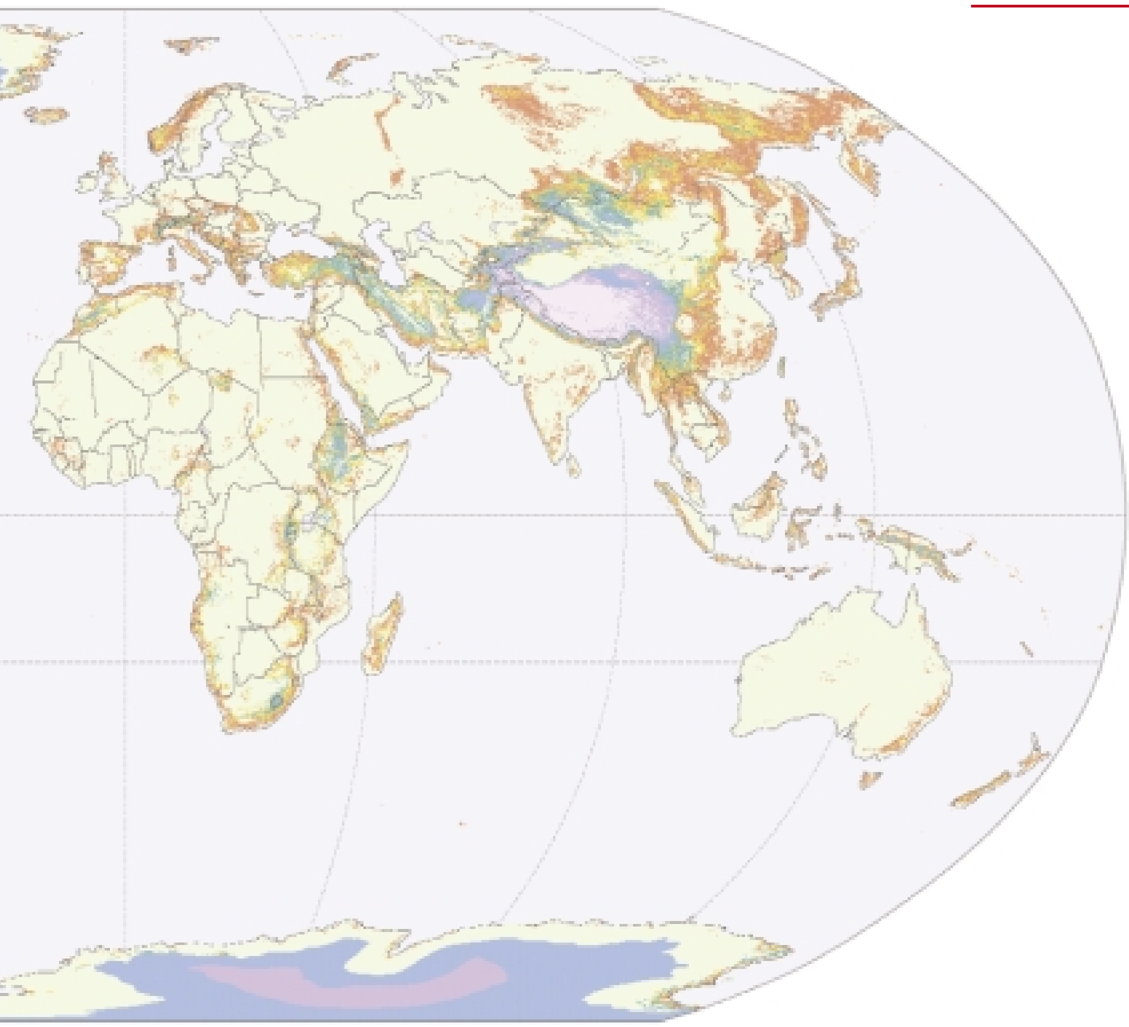
the effects of latitude and continentality on climate and local weather patterns, so that some mountains are almost permanently wet, others dry, and others highly seasonal. Geological substrate adds a further dimension of diversity by influencing the soil type and the potential for erosion.

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

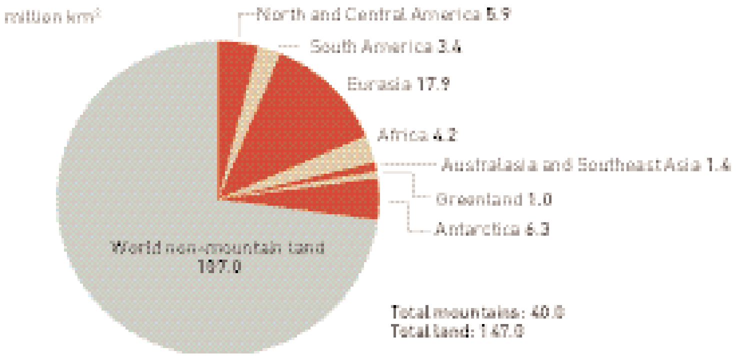


Figure 3: Mountain areas by latitude zone

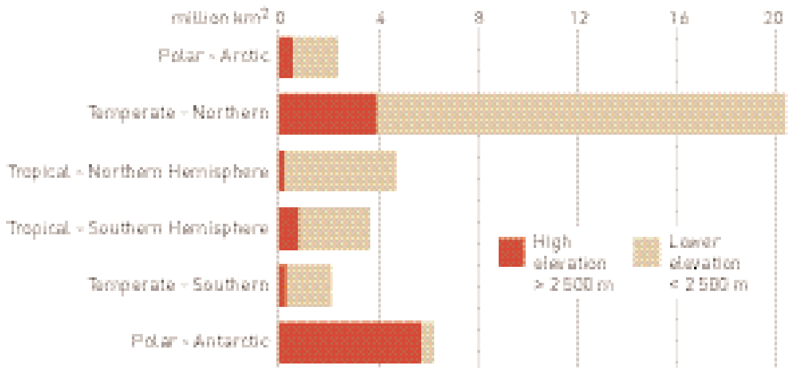
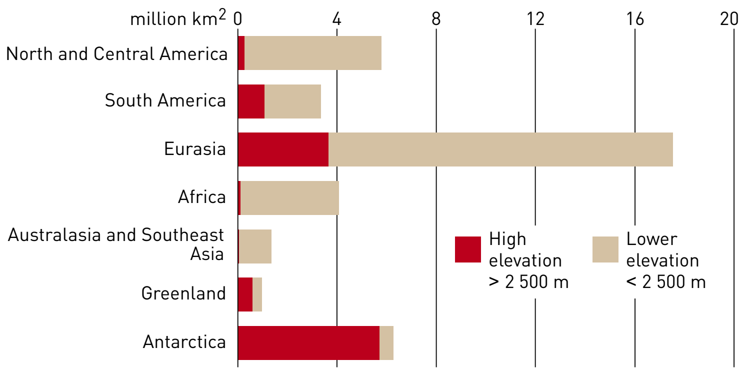


Figure 4: Mountain areas by continent group



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

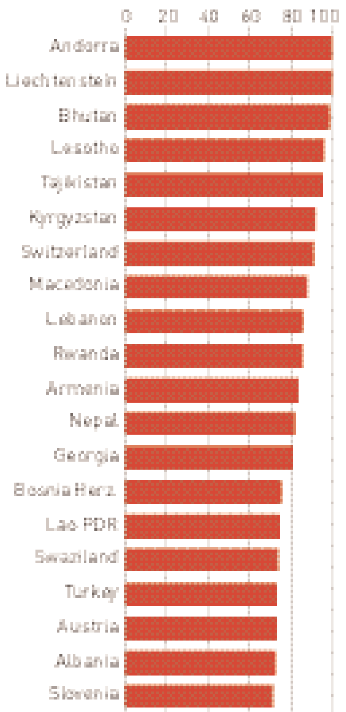


Figure 6: Area of high mountains
Top 20 sequenced by high mountain area

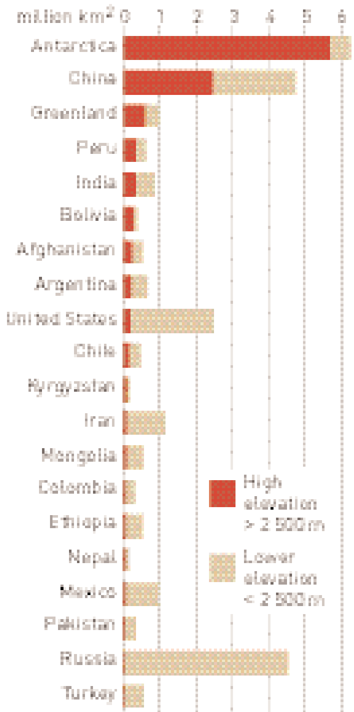


Figure 7: Total mountain area
Top 20 sequenced by total mountain area

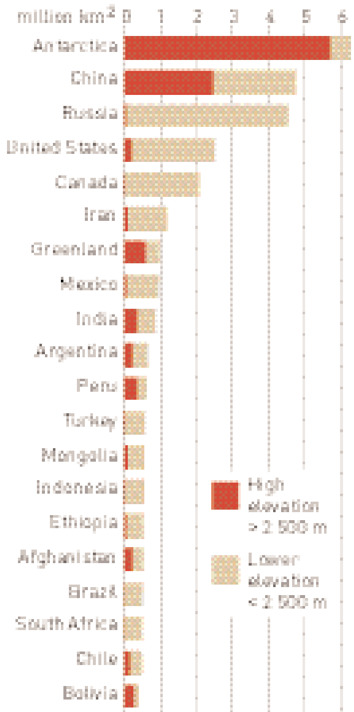
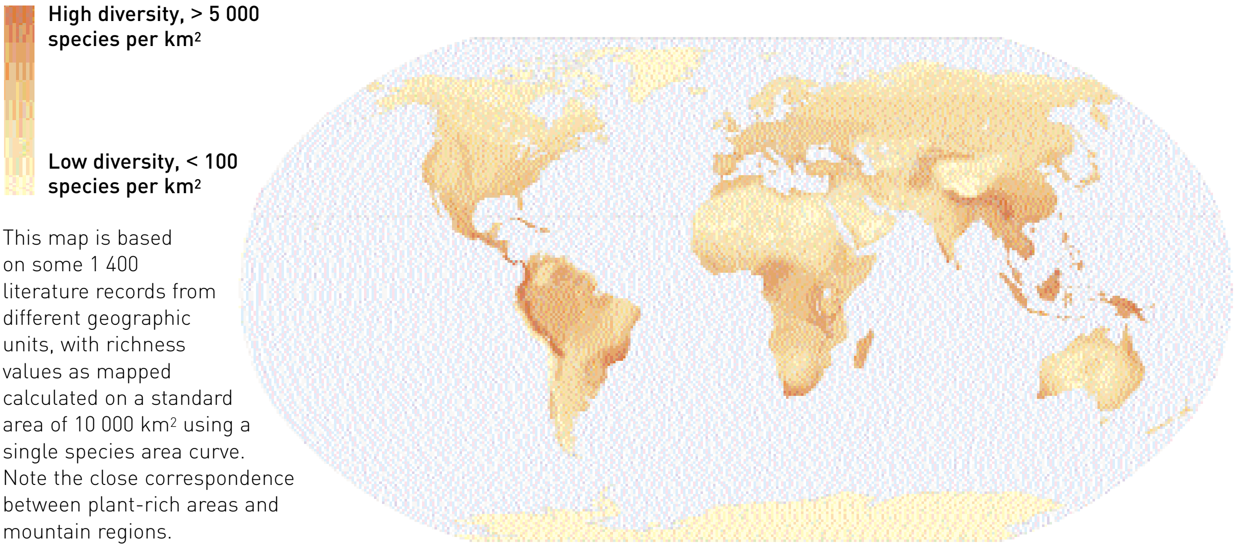


Figure 8: The diversity of vascular plants



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

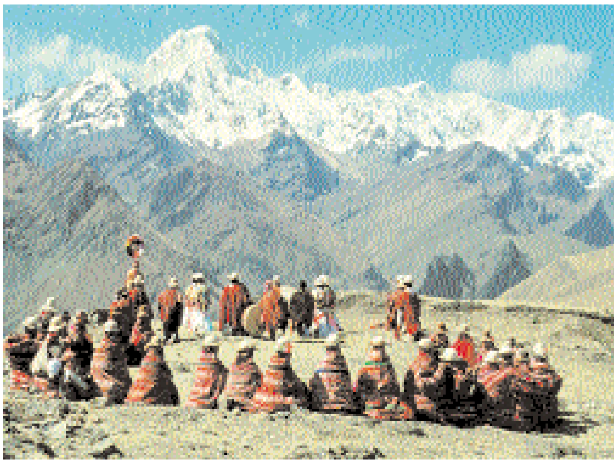
In most mountain regions, people have based their livelihoods on agriculture, pastoralism, and use of forest resources (timber, fuelwood, fodder). This remains widely true, although very marked changes have occurred in some mountain areas, gathering pace from the mid-20th century onward, with supplementary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



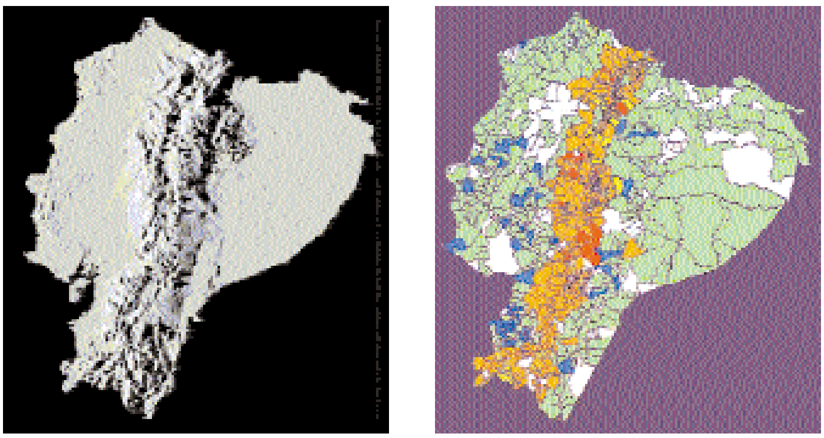


Figure 9: Linking topography and malnutrition in Ecuador

Percent of population malnourished

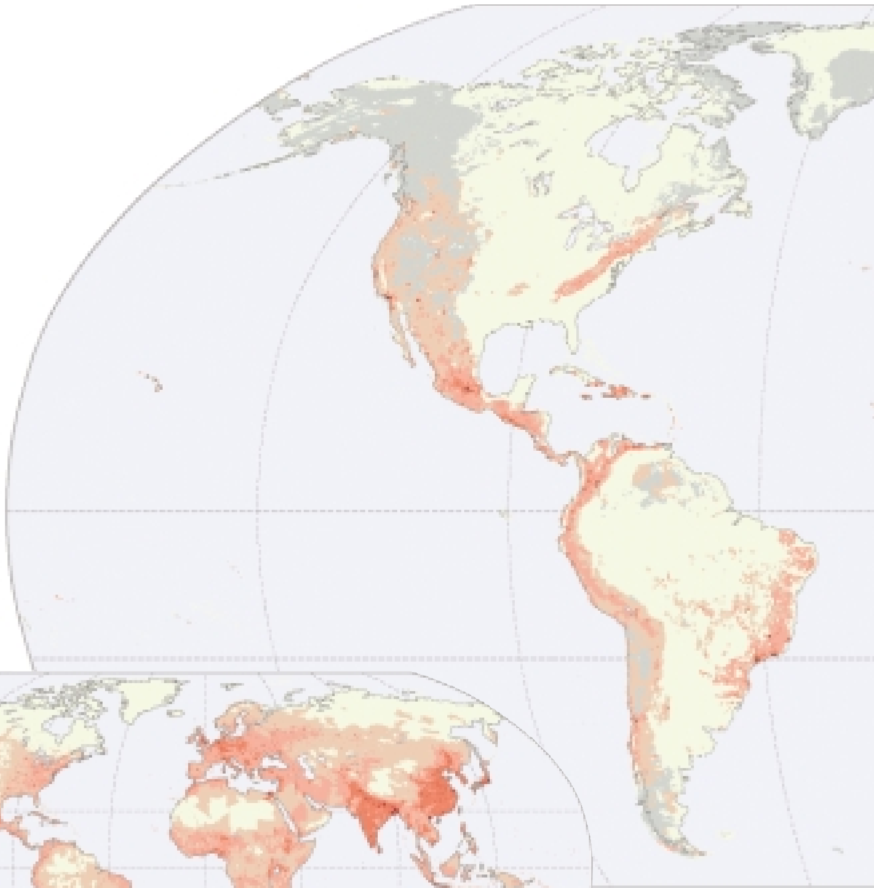
- < 40
- 40 – 50
- 50 – 60
- 60 – 70
- 70 – 80
- Insufficient data

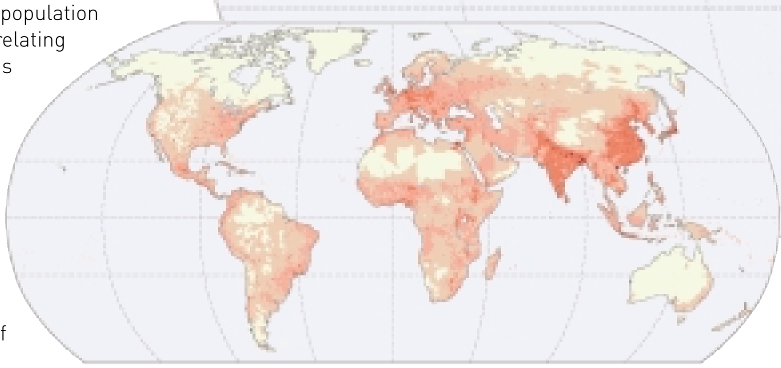
Source: Glenn Hyman, CGIAT-CIAT, using information from the National Statistics and Census Institute (INEC) and the National Development Council (CONADE), Ecuador

Figure 10: Human population in mountain regions and worldwide (inset)

People per km²

- 2 500 – > 63 000
- 1 000 – 2 500
- 100 – 1 000
- 10 – 100
- < 10
- Mountain region





This map, representing human population density (based on census data relating to administrative units of various sizes), shows that human distribution is not determined by topography alone. Some mountain regions at lower latitudes are more densely populated than nearby lowlands. Globally, the population within mountains is somewhat lower than would be expected given the proportion of land that is mountainous.

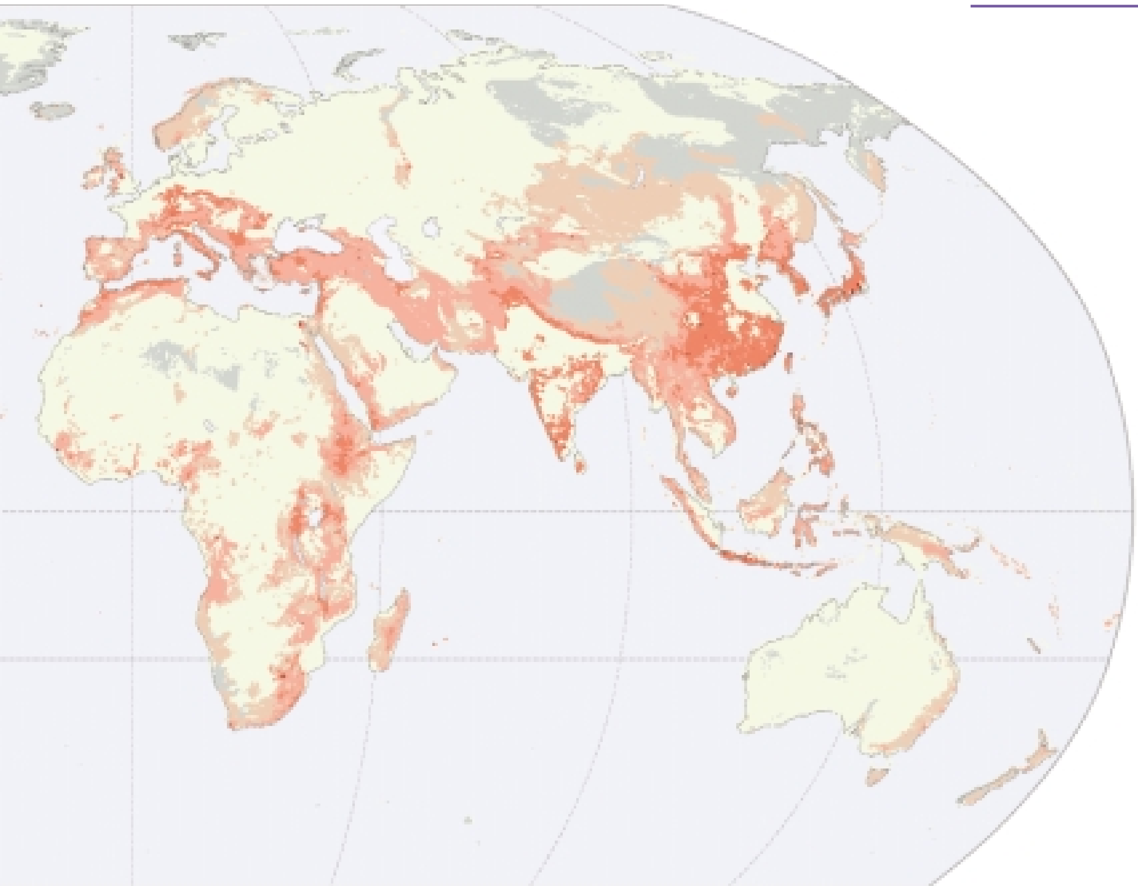
Human population

Archaeological evidence shows that humans were present in some mountain areas in prehistoric times. Some groups, such as the Sherpas in Nepal or the Berbers in Morocco, may have moved into their present mountain sites within the last few hundred years.

In some regions, such as the European Alps, mountain inhabitants are ethnically or culturally hardly or not at all different from people in the surrounding lowlands. In others, the mountain people are ethnically, culturally or in other respects significantly different from adjacent lowland people. Communities in this category often inhabit spatially restricted areas, sometimes in low population numbers. Where this is a common tendency, mountains can be regions of very high cultural diversity.

The physical seclusion of high mountain valleys, and a possible tendency for subordinate or minority groups to retreat to areas free from disturbance, may both in different instances contribute to such increased cultural diversity. On the other hand, some mountain peoples are relatively widespread, such as the Tibetans or the Quechua-speaking Indians of the central Andes. In some instances, for example the Incas in the central Andes, and in Ethiopia, the dominant culture was centred in mountains as opposed to lowlands.

Around 22 per cent of the world's human population occurs within mountains (as defined in this report). Population density per unit area may be very low, down to just a few individuals per km² in demanding high elevation environments such as parts of the Tibet Plateau. In many mountain areas, productive resources tend to be increasingly fragmented by inheritance patterns, and additional sources of income (e.g. tourism or mining) are often needed to support current numbers. Elevation limits arable activity and the crop types that can reliably be grown in any particular locality. As a result, land holdings tend to be vertically oriented, with grazing pastures at the highest level: a pattern widely characteristic of mountain agriculture. In parallel with seasonal changes, production activities, particularly those concerned



Source: CIESIN, Gridded Population of the World, version 2, data available at http://sedac.ciesin.org/plue/gpw/index.html?main.html

with livestock maintenance, commonly tend to shift up or downslope, making use of different categories of land type over the year.

The maps above represent human population density according to the CIESIN Gridded Population of the World (version 2) dataset, with the main map representing population density in mountains. With the exception of Australasia-Southeast Asia and Greenland, South America has a smaller area of mountainous land than the other continent groups used in this report, but has by far the highest proportion of its population in mountain regions, density being very low over Amazonia and other lowlands.

Population density within mountains is moderately high over large areas of Mexico and Central America, the Ethiopian Highlands and rift mountains to the south, the foothills of the Himalaya, many parts of central and south India, Java, and over enormous areas of central and eastern China. The global inset map suggests that human population density is not highly correlated with relief type alone. Both flat lowlands and high mountains may in different parts of the world each have relatively low or high population density.

Table 3: Population distribution (millions)

REGION	IN NON-MOUNTAINS	IN MOUNTAINS	% IN MOUNTAINS
North and Central America	353	90	20.3
South America	221	95	29.9
Eurasia	3 061	815	21
Africa	546	166	23.4
Australasia and Southeast Asia	239	75	23.8
Greenland	< 1	< 1	9.6
Antarctica	0	0	
GLOBAL VALUES	**4 421**	**1 240**	**21.9**

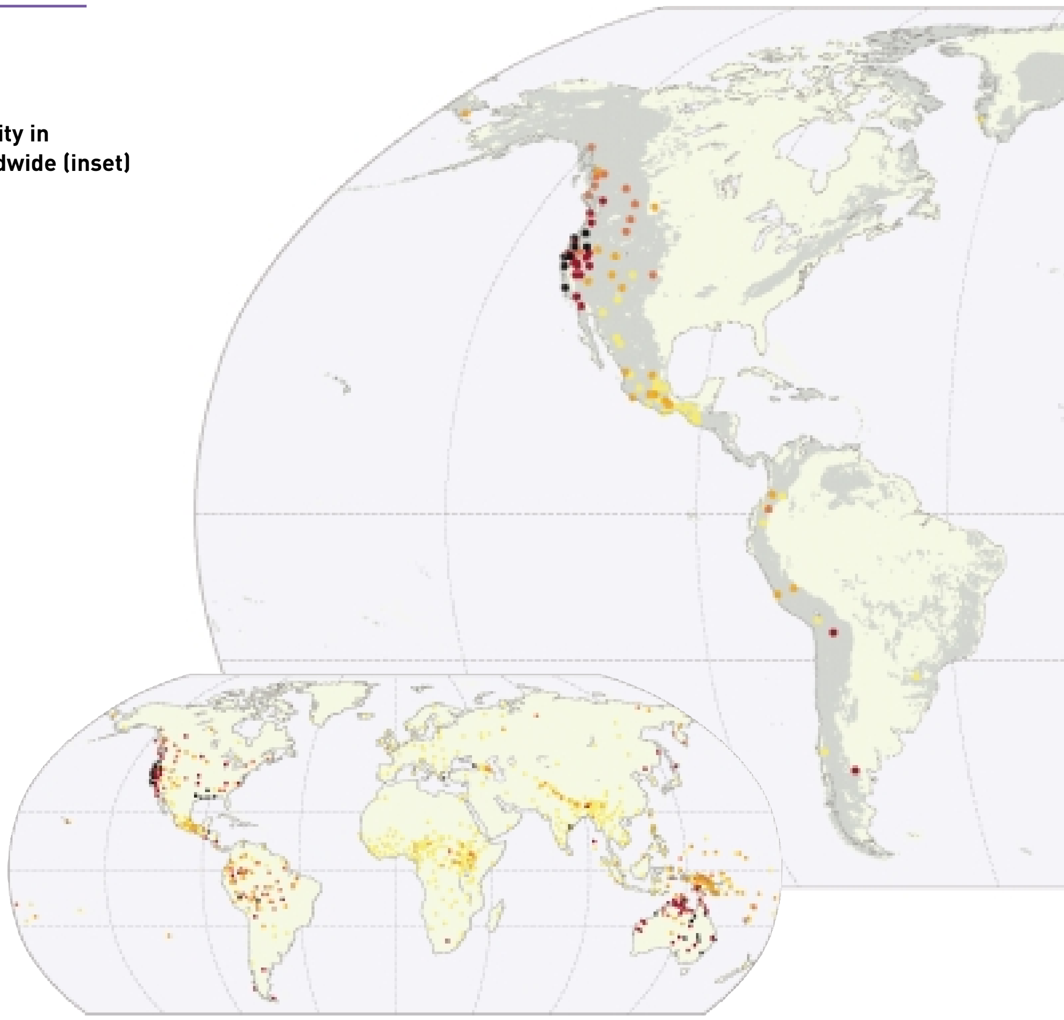
Mountain area (including Antarctica) as percent of global land: 27.2

Note: Numbers calculated from gridded population density map

Figure 11: Language diversity in mountain regions and worldwide (inset)

Number of speakers

- 0 – 1
- 2 – 100
- 100 – 1 000
- 1 000 – 10 000
- 10 000 – > 86 000 000
- Mountain region



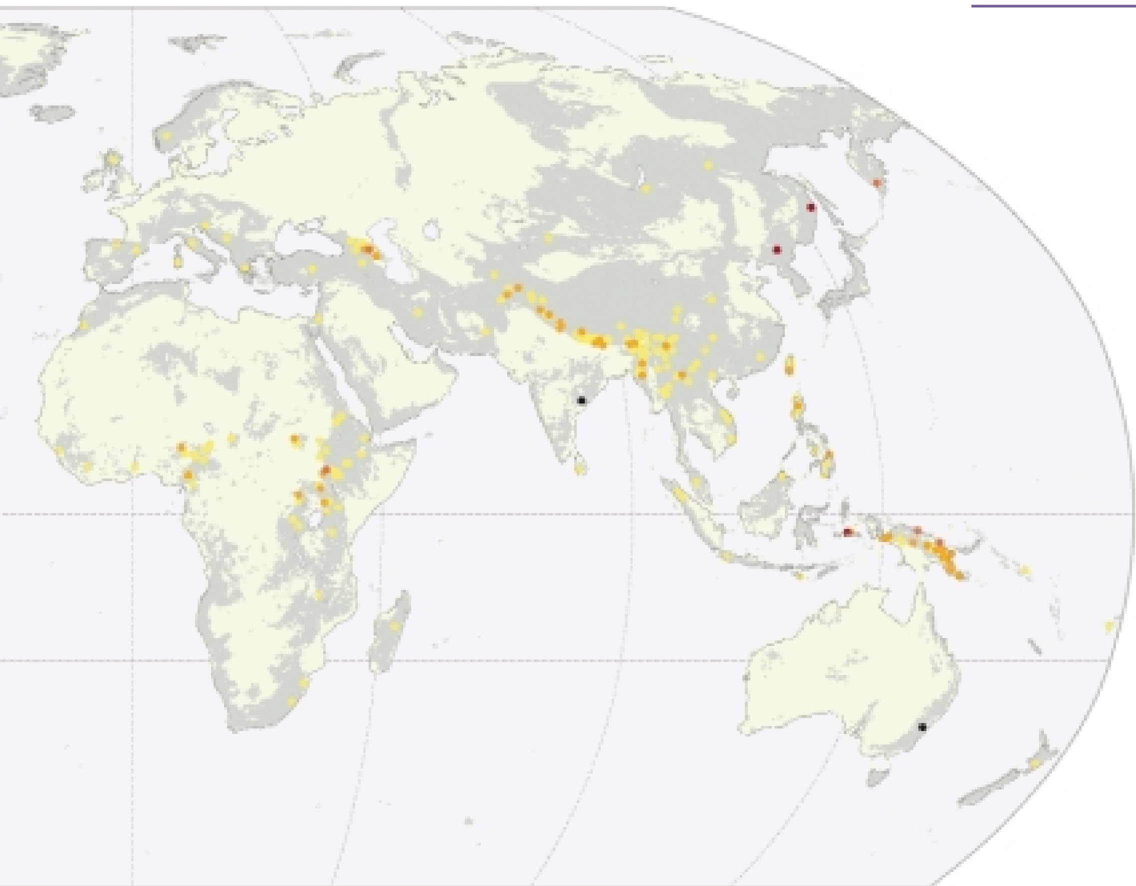
Languages are here represented by symbols placed at their core distribution area and graded according to number of speakers. More of the languages in the sample mapped are within mountain regions than would be expected, given the proportion of land that is mountainous.

Cultural diversity

Mountain communities tend strongly to develop and defend a distinctive cultural identity. Although social and economic dimensions are significant, language is frequently an important element, and a key marker of community identity, often tribal in nature. The livelihood of indigenous communities that retain their cultural identity, whether in highlands or lowlands, is often based on systems of 'traditional ecological knowledge'. Such knowledge, with associated beliefs, behaviours and land management practices (trenching, terracing, irrigation systems designed for low or seasonal rainfall) is especially important for low intensity production systems in high mountains.

Because of the close association between language and culture or ethnicity, linguistic diversity can serve as an indicator of human diversity more broadly. The evolution of language forms is in some respects analogous to the evolution of lineages of organisms, and the classification (taxonomy) of language faces similar problems to those arising in the taxonomy of organisms. As with subspecies and species in biological taxonomy, there is no unique operational method of distinguishing, for example, a dialect from a distinct language. However, for practical purposes, more than 5 000 current languages are widely recognized, and although several isolates exist, most can be grouped within one of a few dozen or so ancestral language families.

The available data (e.g. www.ethnologue.com) show that some parts of the world have a far higher diversity of languages than others. This diversity appears to have resulted from a mosaic pattern of human dispersal and settlement through time, with replacement in some areas, and frequently the isolation of communities in remote areas, sometimes serving as refuges from dominant lowland cultures. Regions of particularly high concentration include West Africa, the Caucasus, the wider Himalaya, Southeast Asia, the Philippines, New Guinea and Central America. Some 50 distinct languages occur in the Caucasus, including Indo-European, Altaic and indigenous Caucasian forms. New Guinea, with



Source: Based on data collated by Matthew Dryer (University at Buffalo) at http://linguistics.buffalo.edu/people/faculty/dryer/dryer/atlas.locations; number of speakers from Ethnologue (2001)

around 1 000 languages on a land area of around 900 000 km² has the highest known language density in the world. Deeply dissected mountain terrain provides an important topographic foundation for the generation and maintenance of language diversity in all these regions (except West Africa), often reinforced by strong tribal identity and social factors, such as feuding. These same terrain elements, and the consequent opportunities for isolation of populations, appear to contribute strongly to patterns of biological diversity which, as Figures 8 and 15 show, is also concentrated in mountain regions.

The location of 871 languages is plotted in Figure 11, classified by number of speakers. This is not a comprehensive dataset, but shows that languages with relatively few speakers occur in both lowland (e.g. Australia, Amazonia) and highland (western North America, Caucasus, New Guinea) regions. The number of local languages distributed along the Hindu Kush-Himalaya axis, and their apparent absence from the high elevation Tibet Plateau, is striking. Large areas of Tibet and the Andes support relatively homogenous human communities. If it is assumed that a low number of speakers is indicative of human cultures in decline or at risk, these data suggest that mountainous South America is of far less concern in this respect than parts of Africa, Southeast Asia and Eurasia, and much less so than North America, where many languages once spoken by Native Americans are already extinct.

The percentage of global endangered languages found in mountain regions is relatively high because more languages are found in mountain regions, rather than because mountain languages are inherently more endangered (10 per cent endangered) than non-mountain languages (15 per cent endangered).

Table 4: Endangered languages in mountain regions

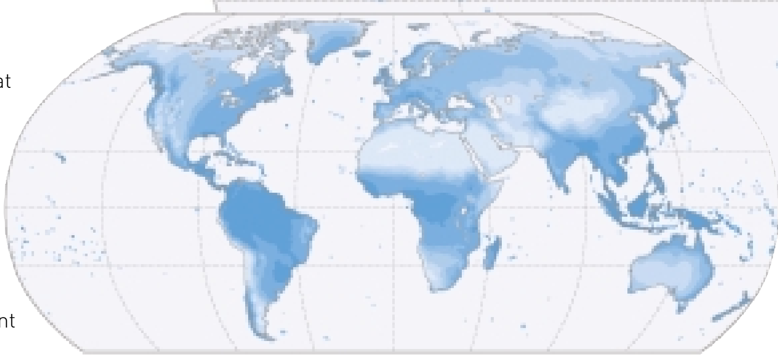
REGION	% ENDANGERED*
North and Central America	78
South America	6
Eurasia	9
Africa	0
Australasia and Southeast Asia	2
Greenland	0
GLOBAL VALUES	
% of endangered languages worldwide that occur in mountain regions	28

* Here defined as 1-100 speakers

Figure 12: Mean annual precipitation in mountain regions and worldwide (inset)

Millimetres per year, 1960-1998

- 0 – 150
- 150 – 300
- 300 – 500
- 500 – 750
- 750 – 1 500
- 1 500 – > 7 500



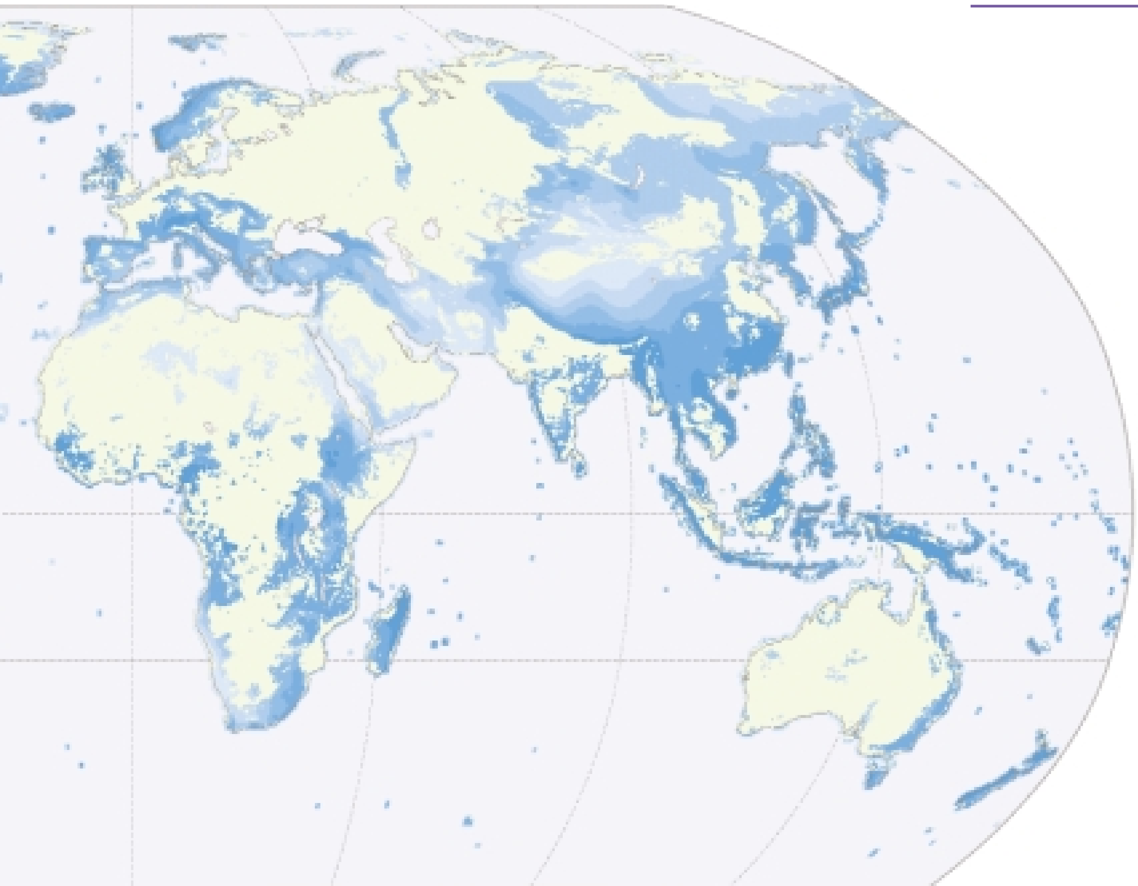
Although these data suggest that at global scale about as much precipitation falls outside mountain regions as within them, this can largely be attributed to the high values in humid tropical lowlands. At regional and local scales, mountains generally experience higher precipitation than adjacent lowlands.

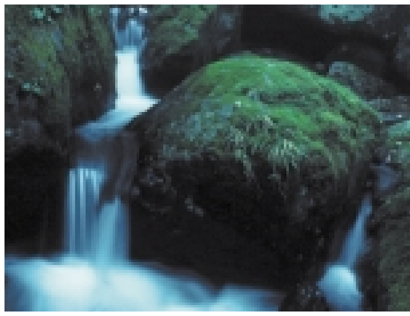
Water resources

Mountains, where virtually all the world's major rivers originate, play a central role in the global hydrological cycle. Water falling in high mountains may have its passage downslope moderated by mountain forest or other upland ecosystems. If falling as snow, it may be stored for part of the year until it joins the drainage system as meltwater, or it may become incorporated in icecaps or glacier ice, and stored perhaps for many centuries. In many areas, meltwater release is available when lowlands are at their driest.

By analogy with the man-made structures, mountains have been called the 'water towers' of the world's lowlands, highlighting one of the most important ecological services they provide for humans. Although many lowland regions, especially in the humid tropics – notably Amazonia and the Congo basin – have very high precipitation, estimates suggest that more than half the world's population depends on water that started the terrestrial phase of its cycle in mountain regions. Mountains also help to determine flow patterns and hydrological processes in many of the world's lake, river and wetland ecosystems.

Water intercepted at altitude in mountains is at some stage transported under gravity to surface drainage systems or underground aquifers, where it may be accessible to downstream users. Mountain water transported by river systems is a critical resource in the many arid and semi-arid regions, both high and lowland, that receive little direct precipitation. For example, many cities and other settlements in Central Asia depend on meltwater forming the Amu Darya and Syr Darya rivers arising in the Pamir and Tien Shan, respectively. Excess withdrawal, mainly for cotton irrigation, has led to severe shortages in many parts of this extensive basin and to drying of the Aral Sea. Most of Pakistan's inhabitants depend on the largest irrigation network in the world, based on the waters of the Indus that arise in the Karakorum and adjacent ranges. On the Iranian plateau, labour-intensive subterranean channels have traditionally been constructed to access mountain aquifers and transport water downslope to cropland.





Source: Based on 1960-1998 mean, from annual sum maps compiled in raster format by Yadvinder Malhi, from dataset interpolated by New et al. *(1999, 2000), Climatic Research Unit, University of East Anglia*

Table 5: Precipitation in mountain regions

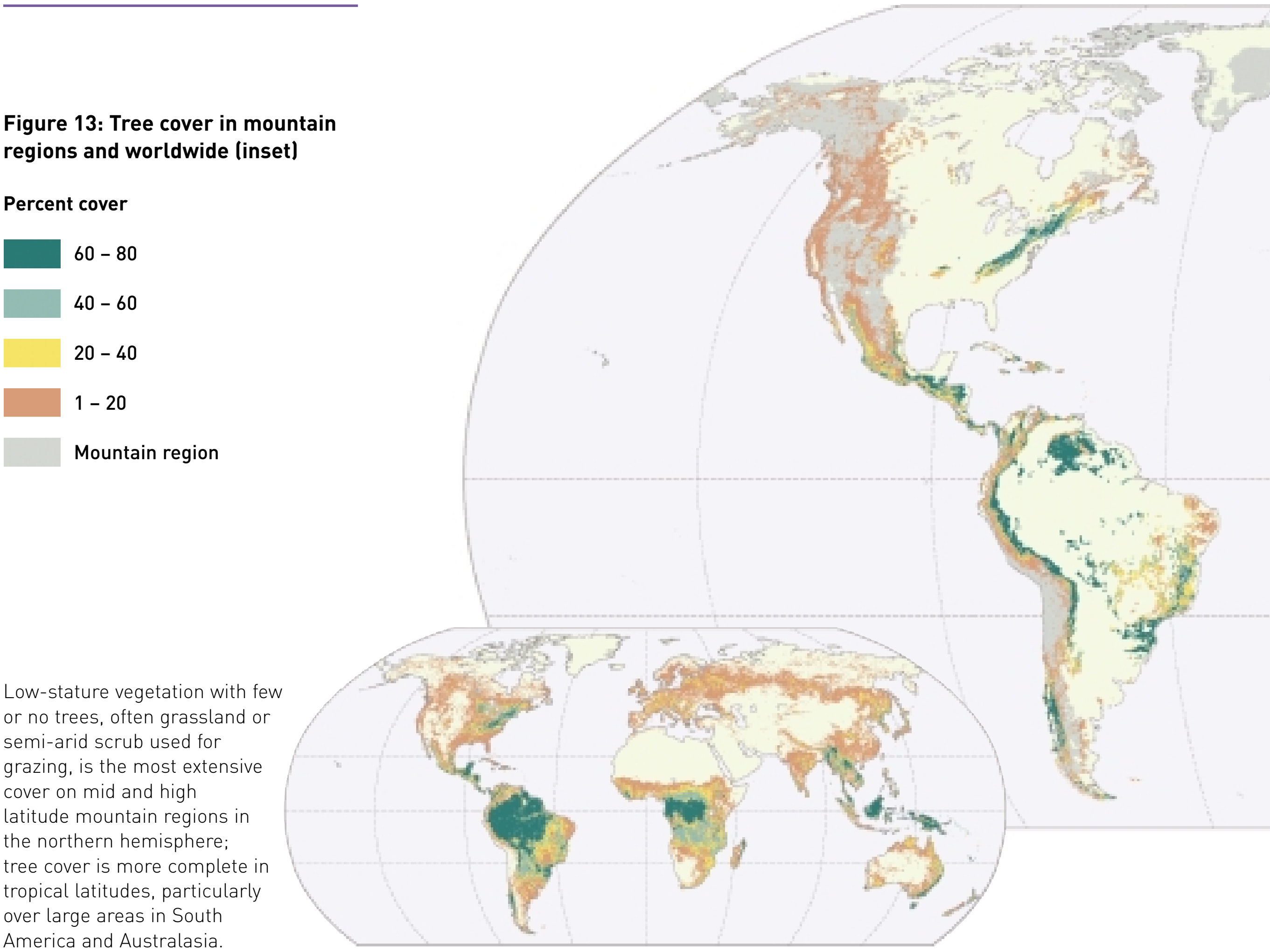
REGION	% OF GLOBAL PRECIPITATION	RATIO OF % PRECIPITATION TO % LAND AREA
North and Central America	4	0.90
South America	3	1.30
Eurasia	11	0.84
Africa	3	1.06
Australasia and Southeast Asia	3	3.21
Greenland	1	0.97
GLOBAL VALUES		
% of terrestrial precipitation falling in mountain regions (except Antarctica)	24	1.03

Natural or artificial lakes can extend the water storage capacity provided by glaciers and winter snow cover. These are frequently used to supply water for irrigation or other purposes, to regulate flow for flood control, or for hydroelectric power generation. Schemes for micro-hydropower, often used for local agricultural processing, can have low impact, but larger dams and reservoirs have commonly entailed the development of roads and other infrastructure, and a more extensive disruption of aquatic ecosystems.

Many cases demonstrate the widespread need for implementing integrated catchment-level planning and management, particularly for international basins, where agreements based on good hydrological data are needed to minimize the risk of conflict over water supplies.

The maps represent mean precipitation on land, with station data for 1960-1998 interpolated as a function of latitude, longitude and elevation. This suggests that at global scale, about as much precipitation falls directly on mountains as it does elsewhere, and regional variation is marked: mountain regions in Australasia tend to receive more rainfall than non-mountain regions, and those in Eurasia tend to receive less. These data take no account of 'rain shadow' effects and other local variations.

Figure 13: Tree cover in mountain regions and worldwide (inset)



Low-stature vegetation with few or no trees, often grassland or semi-arid scrub used for grazing, is the most extensive cover on mid and high latitude mountain regions in the northern hemisphere; tree cover is more complete in tropical latitudes, particularly over large areas in South America and Australasia.

Forest resources

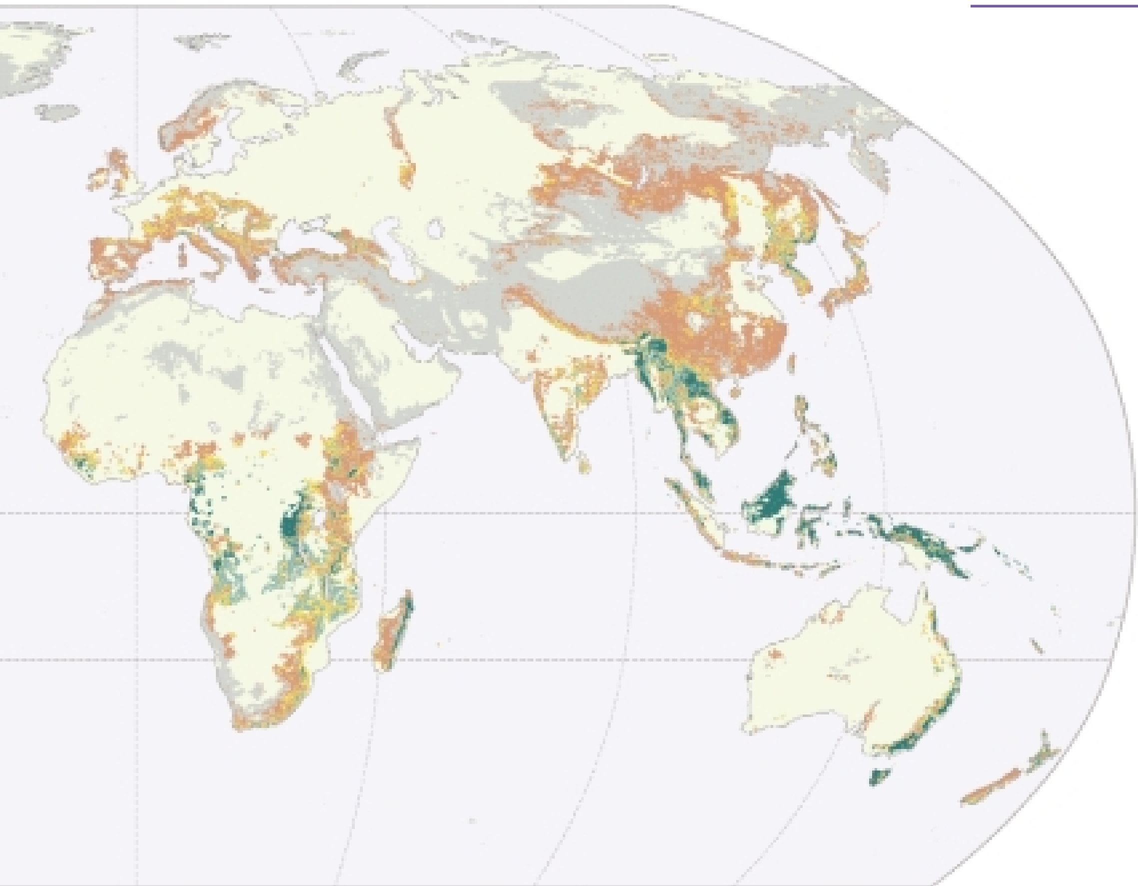
Mountain forests provide a range of services to mountain communities and to people outside mountain areas, and have a key role in the maintenance of global biodiversity. Species richness, density and forest height tend to reduce with increasing altitude; the boundary between forest vegetation and more open ground cover at higher elevation – the treeline – is an ecological marker signifying the transition to more extreme climatic conditions. Herbaceous vegetation near or above the treeline provides grazing resources in many mountain areas. At high latitudes the treeline is close to sea level, while at lower latitudes it extends to almost 5 000 m in a few areas, such as the central Andes, where the quenal *Polylepis* almost reaches the treeline.

Most traditional mountain cultures have been based on agriculture, pastoralism or forestry, often in combination. Forests make an important contribution to the spiritual, scenic or amenity values attached to many mountain regions. They provide fuelwood, timber and non-timber forest products for subsistence or for trade use by people living in mountain areas.

Fuelwood, by providing heat for food, the living space and water purification, is key to human physical well-being in what may be a very demanding environment. Timber is used for construction, or may be a commodity for trading. Other forest products include bamboo, fungi, fruit, nuts and other foods, and medicinal plants.

Mountain forests have generally been managed under a form of communal property system, with the associated social norms and penalties varying from place to place, often with a degree of flexibility according to circumstance. Local management is widely perceived to be more beneficial than state control, which may prioritize the interests of lowland constituencies.

Upland forests can protect communities and transport infrastructure against rockfall, landslides and avalanches by the simple physical presence of treetrunks and flexible branches that can absorb the impact of snow masses. In many countries,



Source: MODIS 1-km resolution percent tree cover data set, courtesy of University of Maryland Global Land Cover Facility

montane forests are conserved by schemes designed to maximize this protective role. Recent avalanches and extreme weather events in Europe, for example, have highlighted the need for such approaches. The total forest area in Switzerland has increased by around 60 per cent over the last 150 years, taking up former agricultural land. Much of this is maintained primarily for hazard protection, and government support has been available to cover the high management costs.

Mountain forests also contribute to water resource regulation. While there is marked species and site-specific variation, runoff is generally lower from forested areas than from areas with less vegetation and, except on steep slopes with high sediment yield, erosion is often lower where natural forest occurs. In many situations dry season flow is believed to be enhanced by maintenance of forest cover, though this is an area of ongoing research.

Table 6: Forests in mountain regions with tree cover greater than 20 per cent

REGION	% OF GLOBAL FORESTS	% OF MOUNTAIN AREA FORESTED
North and Central America	3	17
South America	5	46
Eurasia	8	14
Africa	4	31
Australasia and Southeast Asia	3	77
Greenland	0	0
GLOBAL VALUES		
% of forest worldwide occurring in mountain regions	23	

The main map shows tree cover in mountain regions classified by percentage, based on interpretation of data gathered by the airborne Moderate Resolution Imaging Spectroradiometer (MODIS). The most extensive areas of high percentage tree cover occur mainly at low to moderate elevations in the humid tropics, but extend also to temperate latitudes.

Figure 14: Tropical montane cloud forest

Cloud forest

Mountain region

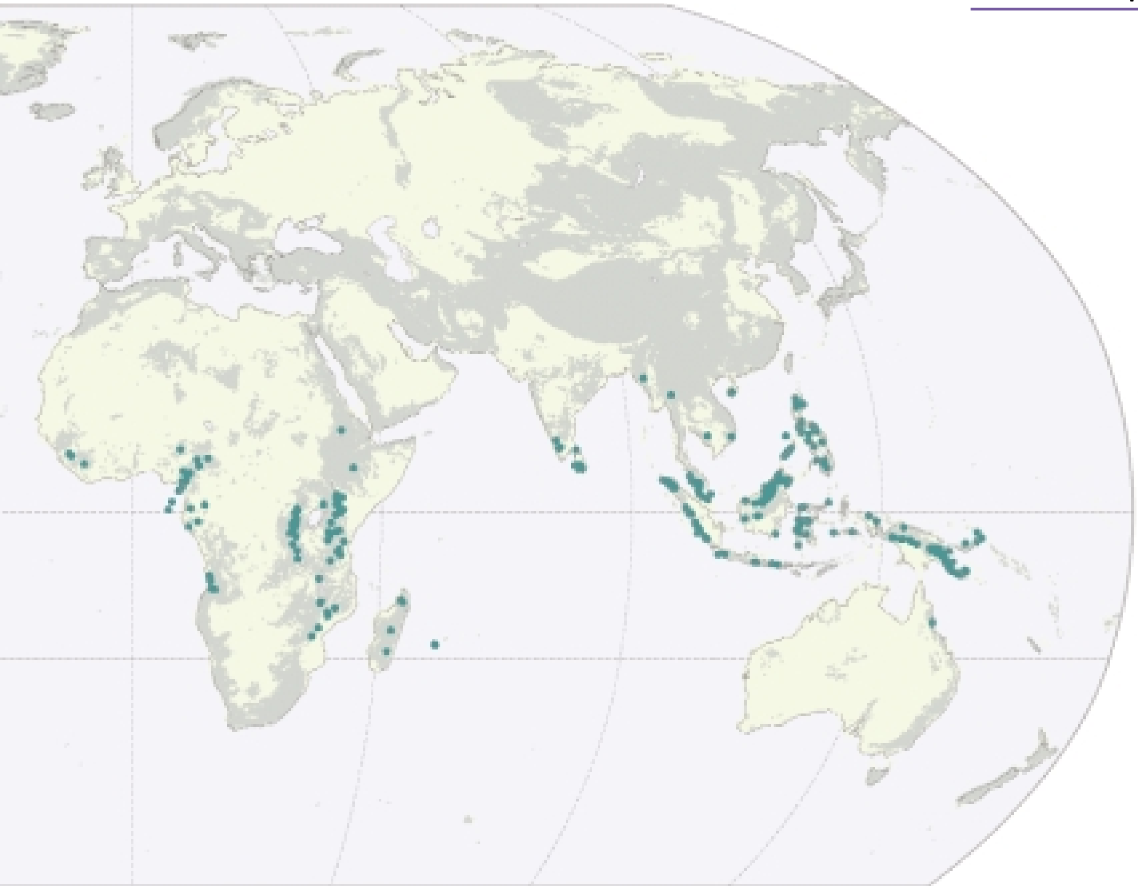
Sites known to hold tropical montane cloud forest are plotted on this map. Map symbols represent the location of the forest and bear no relation to forest area. The transition from lowland to montane forest tends to occur where average minimum temperature drops to less than 18° C, often at an elevation of 1 200-1 500 m near the equator. Tropical montane cloud forest may be present between this elevation and up to 3 000 m, although often at lower elevation on islands.

Cloud forest

Tropical montane cloud forest (TMCF) occurs on mountains where there is frequent cloud or mist. These evergreen forests are characterized by the presence of tree ferns and an abundance of mosses, orchids and other plants growing on every trunk and branch. The vegetation intercepts moisture from the frequent presence of clouds, and so adds water to the ecosystem over and above normal direct rainfall. This clean water is fundamental to the economies and well-being of local communities and cities in the lowlands, especially in the dry season.

TMCFs are also of global importance because they contain exceptionally high levels of species that are endemic or restricted to local areas. In Mexico, for example, TMCF covers less than 1 per cent of the country but contains about 3 000 species or 12 per cent of the country's flora, of which up to 30 per cent are endemic to the country. In western Ecuador a single cloud forest ridge was found home to about 90 plant species apparently endemic to a forest area of only 20 km^2. The mountain gorillas in Rwanda and Uganda and the resplendent quetzals in Central America are cloud forest species and major tourist attractions. TMCFs also harbour the wild relatives of many major crops, such as the tomato, beans, potatoes, the avocado, and the tree from which quinine was originally extracted.

TMCFs are increasingly becoming fragmented islands of evergreen montane forests surrounded by agricultural landscapes. Clearance for land by resource-poor farmers is the dominant pressure on TMCFs around the world. In South America extensive cattle ranching is a major pressure on TMCFs. In Africa they are also being degraded, by fires in the dry season and the hunting of game species. In some Southeast Asian



Source: Aldrich et al. *(1997)*

countries commercial logging is a particular pressure.

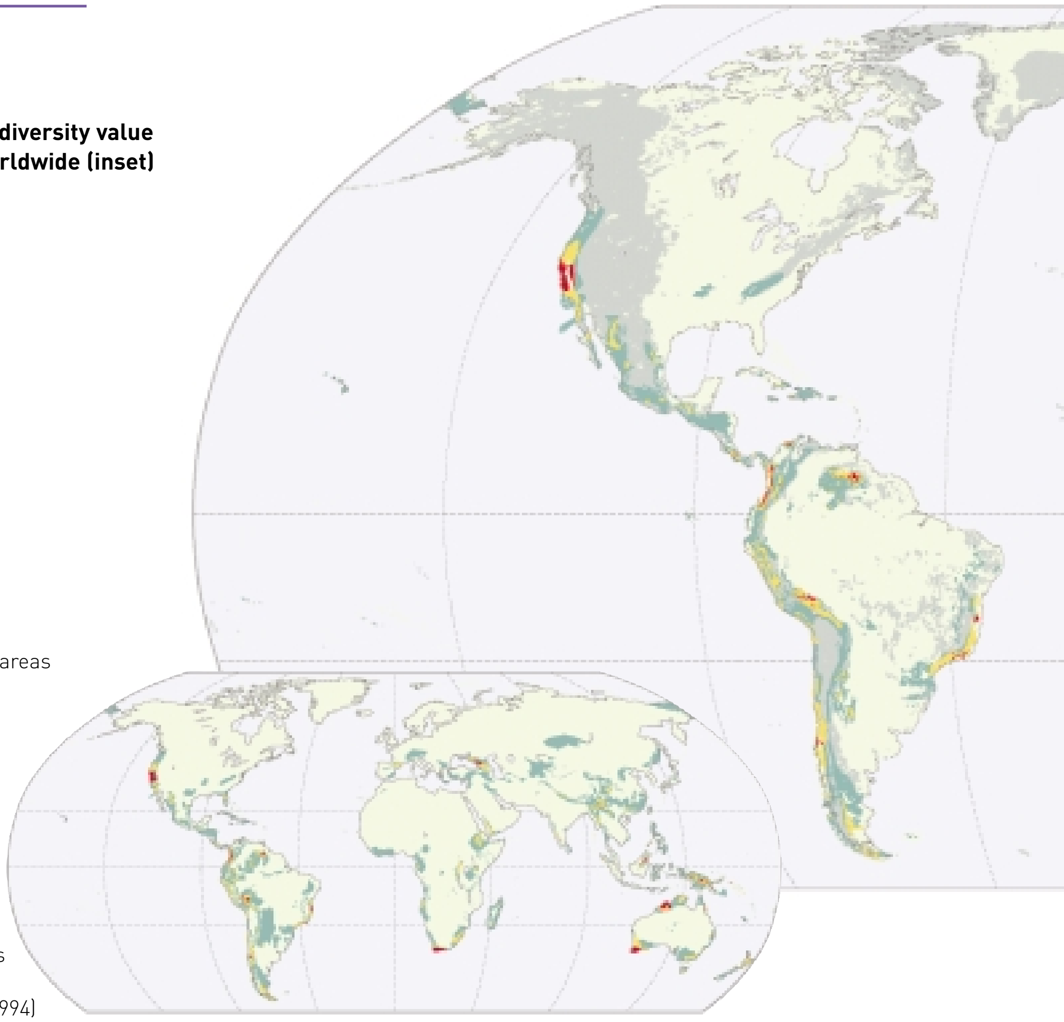
TMCFs are also uniquely susceptible to climate change. There is evidence that global warming can cause a lifting of the cloud base above the altitude of the forest. The consequent drying out of the forest has been linked to the extinction of the golden toad and other amphibians and to declining stream flows in the Monteverde cloud forest in Costa Rica.

Ensuring the maintenance of the biodiversity, water and other ecosystem values of TMCFs requires a range of responses, including increasing public and political awareness of the unique values of TMCF; support for sustainable farming and livelihoods in TMCF regions; and developing innovative funding mechanisms for TMCF watershed conservation through payments for water supplies from TMCFs.

Figure 15: Areas of high biodiversity value in mountain regions and worldwide (inset)

Number of groups

- 3
- 2
- 1
- Mountain region



The maps show the location of areas identified as globally important for species in one, two or three of these groups: plants*, amphibians, restricted range birds. As different methods have been used to analyse these groups, this compilation is indicative only.
* The dataset is based on that developed for the Centres of Plant Diversity study, but differs in some respects from the version published (WWF-IUCN 1994)

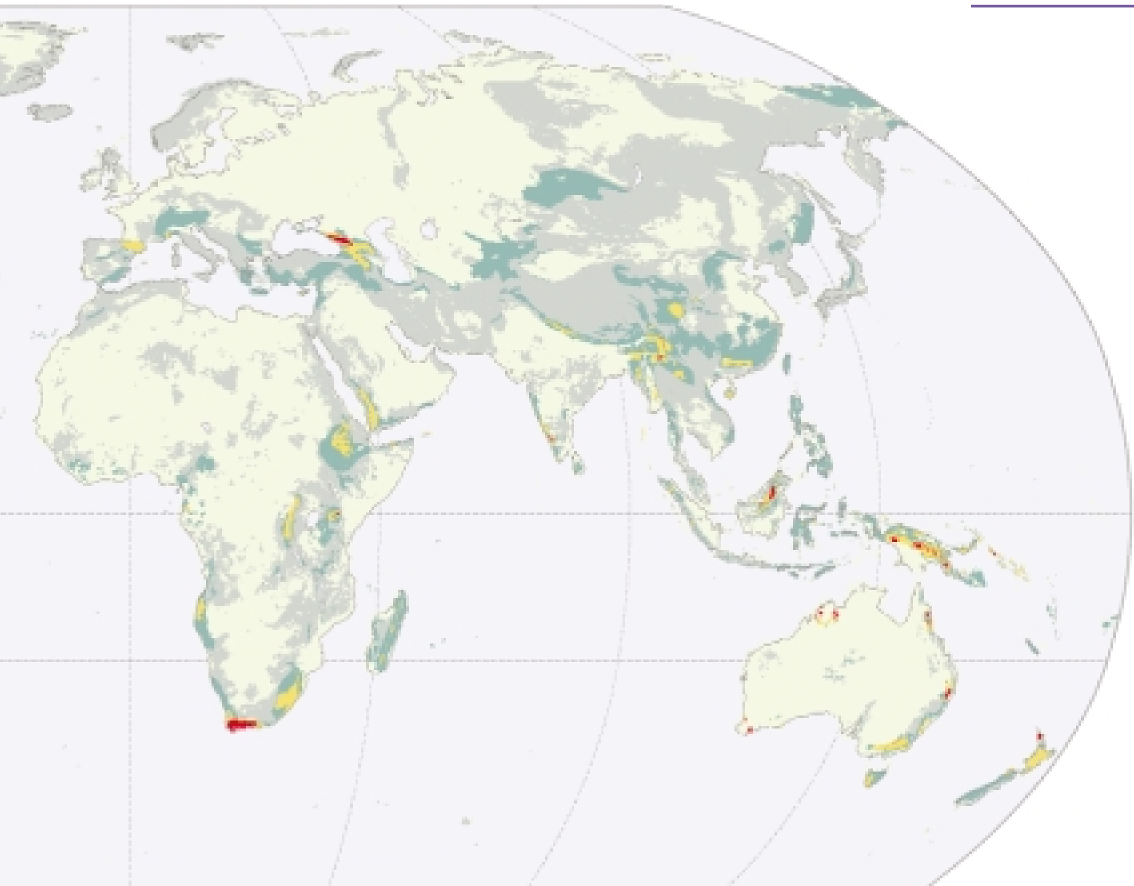
Biological diversity

Many mountain ecosystems have high biodiversity, in terms of species richness and degree of endemism, in comparison with adjacent lowlands. In more developed regions, this difference is accentuated by the extensive modifications that have been made to lowland ecosystems for agriculture, settlement and infrastructure.

At large scales, mountains at lower latitudes can support exceptional biodiversity, probably a result of the way that different life zones tend to succeed one another with increasing elevation, thus compressing a wide range of ecosystems into a relatively short horizontal distance. Mountains also often provide islands of suitable habitat, isolated from unfavourable surrounding lowlands, and endemism is often high in a range of taxonomic groups, particularly on mountains at medium elevations in the tropics and warmer temperate zones. For some taxa, mountains appear to have acted as refuges from environmental change or competing species, or in other cases to have been sites of *in situ* speciation. Mountain species with narrow habitat tolerance, particularly higher elevation forms and those with low dispersal capacity, are likely to be at high risk from the environmental effects of climate change.

Despite the coarse-scale richness of most mountains compared with lowlands, species richness in both plants and animals tends consistently to decline with increasing elevation, as also with increasing latitude; in a sample of alpine sites, plant richness decreases by about 40 species for each 100-m rise in elevation.

High plant richness at patch scale may be attributed in part to the small size of most species, and the dynamic state of the physical environment which keeps plant communities at an early successional stage. Slope dynamics alone plays a part in this, but livestock grazing is a significant driver of sward diversity in many alpine regions. Flower-rich alpine meadows are an important cultural heritage that is coming under increasing threat as traditional grazing practices decline. High sward diversity can also be an important factor



Source: WWF-IUCN; Stattersfield et al. *(1998); Duellman (1999)*

promoting stability on steep slopes prone to slippage.

Data on mountain biodiversity that can be readily used for comparative analysis are sparse, and very few globally comprehensive sets of data exist. In this report, information on areas identified as important for biodiversity in three different groups of organism has been used. The WWF-IUCN Centres of Plant Diversity project used expert information to identify semi-quantitatively a set of areas of key significance for global plant diversity. A set of areas significant for global amphibian diversity has been identified in a similar, but less formal, expert opinion approach. The most structured and objective global analysis remains that by BirdLife International, in which distribution data on restricted range bird species were analysed to identify a set of Endemic Bird Areas.

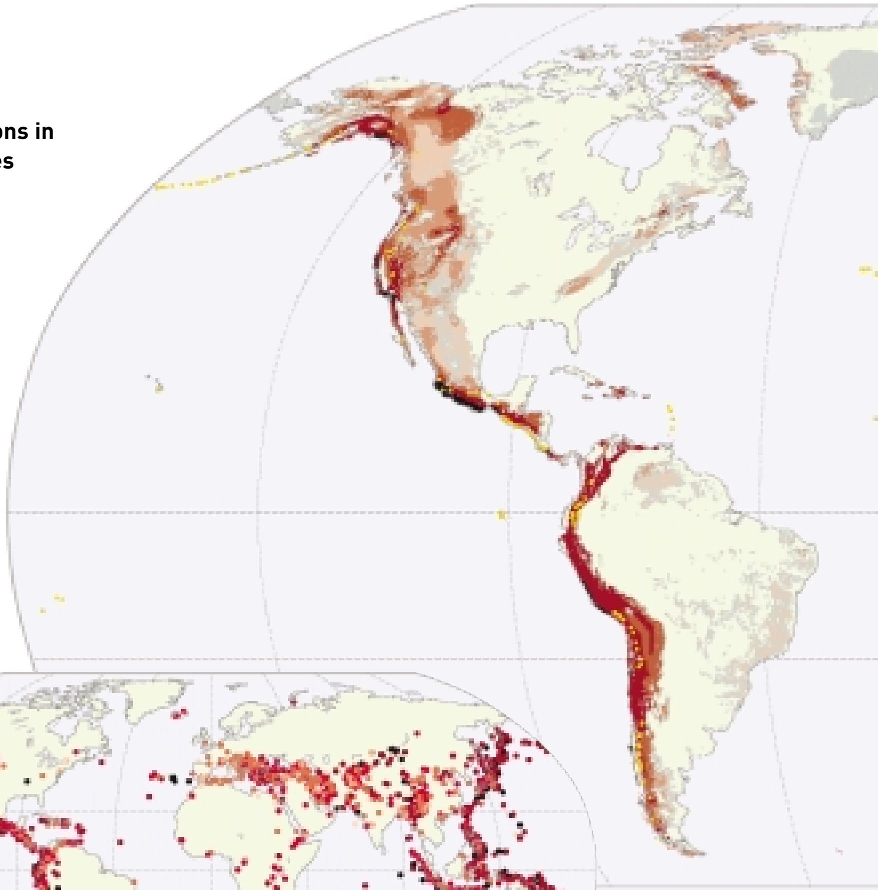
The maps (Figure 15) are simple overlays of areas delimited by these three studies, in which each grid cell is scored according to the number of groups (0 to 3) for which it has been identified as 'important'. This is only a preliminary attempt to make use of existing datasets, but the very high similarity between the main map, showing important areas for biodiversity within mountains, and the inset, showing important areas globally, serves to confirm the extremely high biodiversity value of mountain ecosystems.

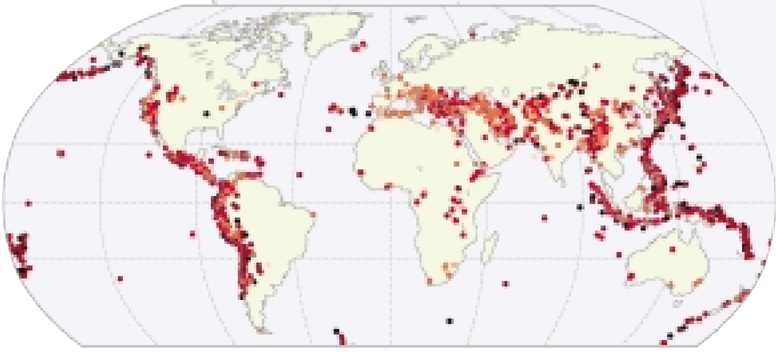
Mountains are also extremely important centres of biodiversity in agricultural resources. Mountains extend over large parts of the five principal centres of early agricultural development, and several crops – maize, potatoes, barley, sorghum, tomatoes, apples – originated in mountains; others have further diversified in mountains. A large proportion of domestic mammals – sheep, goats, domestic yak, llama and alpaca – originated in mountain regions. Genetic diversity in these resources tends to be higher in mountains, perhaps associated with cultural diversity and the extreme variation in local environmental conditions. Some high altitude communities in the Andes maintain more than 150 distinct potato varieties, and mountain farmers in central Africa cultivate beans as mixed populations of up to 30 varieties. Such diversity would tend to reduce the impact of failure in any one variety, and provide adaptability for future change. The global trend is for genetic diversity to be eroded as local varieties are replaced by modern varieties or cash crops, but the rate of loss appears to be slower in some mountain areas than in the world's lowlands.

Figure 16: Seismic hazard and volcano locations in mountain regions, and significant earthquakes worldwide, 1900-2001 (inset)

Earthquake with 10% risk of occurrence in 50-year period

- Annihilating
- Devastating
- Destructive
- Very strong
- Strong
- Volcanic eruptions (79–2000 AD)
- Mountain region





A high proportion of land in most mountain areas is susceptible to destructive earthquakes. According to this analysis, the mountain region at highest risk is South America, with approximately 88 per cent of land area considered susceptible.

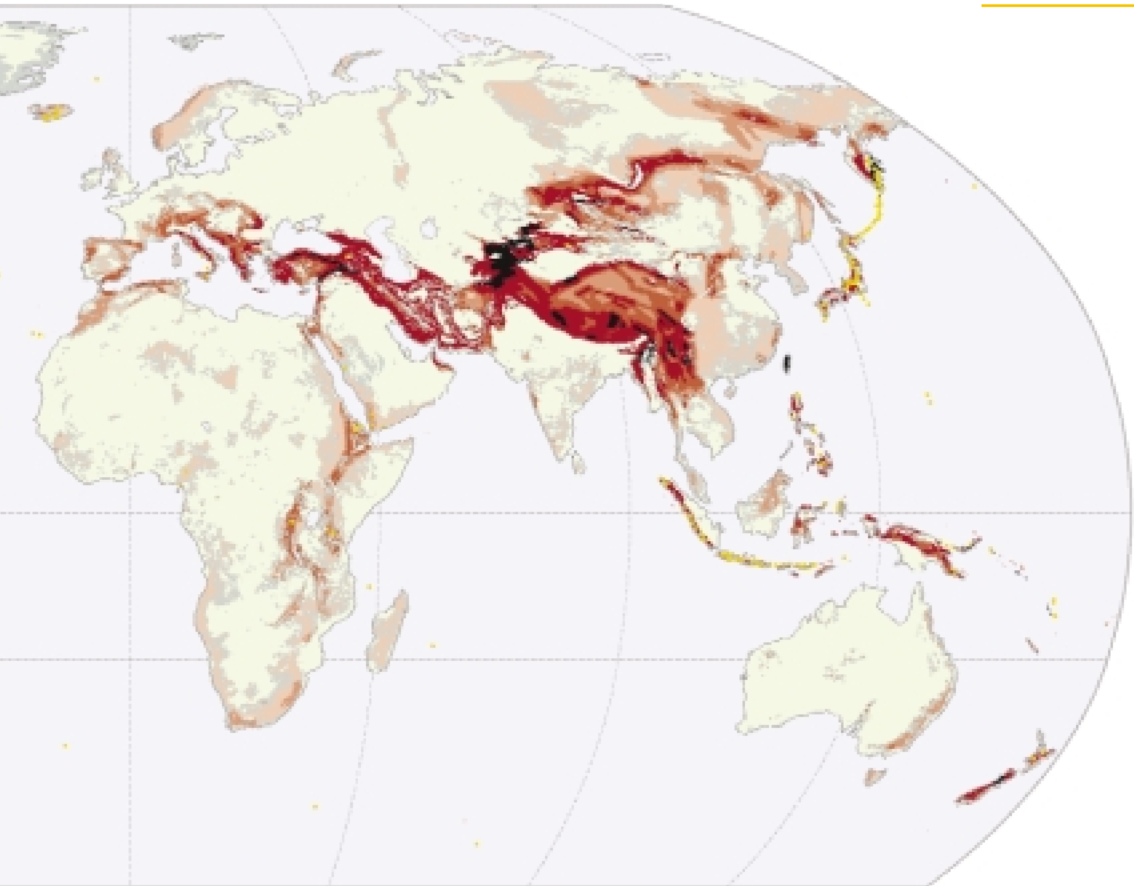
Seismic hazards

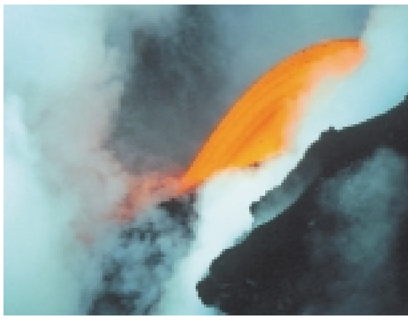
Mountain regions are dynamic environments, subject to major tectonic processes. Many mountain chains lie along the boundaries of continental plates, increasing the likelihood of earthquakes and volcanic eruptions. The steep slopes and high precipitation common to many mountain areas promote the downslope movement of rocks, soil, water and snow. Sudden events such as earthquakes and storms increase the risk of catastrophic events including landslides, rockfalls, floods, snow and ice avalanches, as well as the more gradual processes of weathering and soil erosion.

Seismic hazards may interact with other causes of environmental change. Volcanic eruptions are a natural source of fire, and can trigger the migration of people, leading to shifting patterns of resource exploitation and increased social tension. Patterns of land use and development of infrastructure can influence the occurrence of catastrophic events; for example, deforestation in mountain areas can increase the likelihood of floods and avalanches, as well as promoting soil erosion. Climate change could affect the frequency and intensity of catastrophic events by influencing the seasonal distribution of precipitation and the positioning of storm tracks.

Volcanic eruptions and earthquakes represent a direct threat to human life, but also influence the provision of environmental services to people. Agricultural and forest resources can be severely affected by events such as landslides and avalanches, and any increase in soil erosion is likely to reduce agricultural productivity. These processes can also affect biodiversity and other important resources such as water.

Mountain communities often have a deep understanding of natural hazards and have sometimes found ways of reducing the likelihood of catastrophic events, for example through the use of traditional land use practices such as terracing. However, volcanic eruptions and earthquakes are very difficult to predict, severely constraining the processes of both risk assessment and environmental planning, which are key tools for sustainable development.





Sources: left: Dunbar et al. *(1998); above: seismic hazard, Giardini* et al. *(1999); volcanoes, Dunbar (2002)*

A growing population in many mountain areas, coupled with infrastructural development and agricultural intensification, is increasing the potential loss of life and property that can result from natural hazards.

Often, the impacts of catastrophic events are most severe in valleys, where agricultural land, human settlements and infrastructure tend to be concentrated. The effects of such events can extend beyond mountain regions, to include the floodplains of rivers that originate in mountain areas.

SPATIAL DATA

Consideration of natural hazards is here restricted to seismic hazards and volcanic eruptions. The likelihood of hazards such as landslides, floods and avalanches could potentially be analysed in a similar way, for example by integrating data on the amount of precipitation, degree of slope and geomorphology. Data describing storm tracks, which could be overlaid on maps of mountain areas to provide a risk assessment, are also available.

The seismic hazard map (Figure 16) was compiled from a set of regional hazard analyses (Giardini *et al.* 1999). The substrate through which the earthquake shock waves travel was defined as rock everywhere but North America, which assumed rock or firm soil. An improved map would take variation in soil type and depth into account to model differences in the transmission of seismic waves. The data for location of volcanoes were derived from Dunbar (2002) and refer to those that erupted during the period 79-2000 AD.

The inset shows earthquake occurrence data (Dunbar 1998) of the type used to generate the seismic hazard map.

Table 7: Percent of mountain area susceptible to destructive earthquakes*

REGION	%
North and Central America	45
South America	88
Eurasia	61
Africa	27
Australasia and Southeast Asia	71
Greenland	2

GLOBAL VALUES	
% of susceptible area worldwide that occurs in mountain regions	31

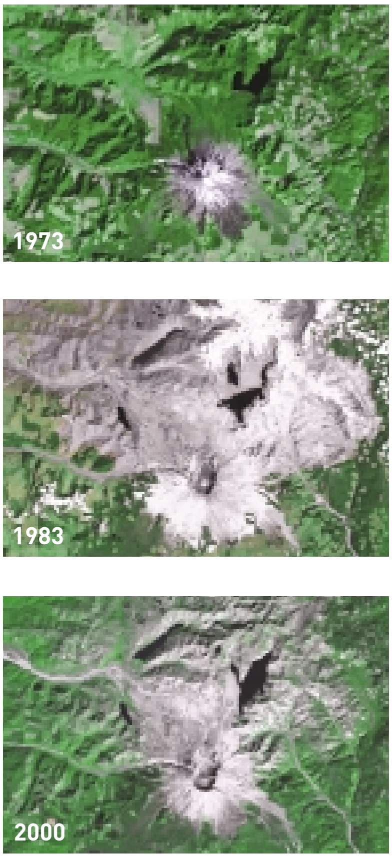
There is a significant difference between the 55% of mountain land and the 36% of non-mountain land that is susceptible.

* Level VIII or greater on the Modified Mercalli scale

Mount St Helens

Mount St Helens and Spirit Lake, two years after the 1980 eruption.

Figure 17: The changing extent of vegetation at Mount St Helens, showing ecosystem recovery after the 1980 eruption



The Cascade Range of western North America contains several recently active volcanic mountains. The 1914-1917 eruption at Lassen Peak had been the latest until Mount St Helens erupted in 1980, having last done so in 1857. The mountain had been a quiet retreat and a popular location for skiing, hiking, camping and fishing. Following two months of seismic unrest, during which its northern flank bulged increasingly (sometimes at 1.5 m a day), a massive landslide and catastrophic eruption occurred on 18 May. The entire north flank of the mountain collapsed into the Toutle River valley, reducing the height of the summit by nearly 400 m, with devastating mudflows entering several drainages. The eruption killed 57 people, flattened 600 km^2 of trees, and left the area barren and nearly devoid of life. A vertical eruption column persisted for nine hours, sending a stream of ash and pumice 25 km into the atmosphere. In the years that followed, a dome of viscous lava formed on the crater floor, eventually reaching a height of more than 300 m when it stopped growing in 1986. In addition, two new lakes, Castle and Coldwater, formed where tributaries of the Toutle River were dammed by the landslide debris.

Many geologists and biologists speculated that it would take hundreds of years for the region to recover, but this has proved mistaken. Wind-blown seeds germinated in the landslide deposit and soon shrubs and grasses were growing. Elk, rodents, insects and other animals followed the plants, and today, 22 years after the eruption, a thriving ecosystem exists. Groves of box alder trees surround quiet ponds in the landslide deposit, where a thriving fir forest had stood before the eruption. The river valleys, which were choked with mud and debris in 1980, still bear scars from the eruption, but the mud is slowly being colonized by grasses and box alders, and the effects of the eruption are becoming less discernable.

Although the Mount St Helens eruption devastated a landscape, it granted biologists an unprecedented view into the colonization and recovery of natural systems. Future eruptions of other volcanoes in the Cascade Range are inevitable, and lessons from Mount St Helens will help such activity to be predicted and its ecological impacts anticipated. The eruption also resulted in the recognition of two previously unknown volcanic hazards: debris avalanches and lateral blasts.

Mount St Helens during the May 1980 eruption.

Source: Michael Poland, Research Geophysicist, USGS - Cascades Volcano Observatory
Landsat imagery: Mark A. Ernste, UNEP Sioux Falls, USA

Avalanche in Peru

The increased risk from environmental hazards in mountain regions is exemplified by the long record of disaster and loss of life in the Cordillera Blanca, central Peru. The vicinity of Yungay, southwest of the twin peaks of Huascarán, has been affected by two catastrophic events since the mid-20th century.

In 1962 an avalanche of rock, ice and snow broke loose from the higher, northern peak of 6 768 m, the highest point in Peru. Sweeping down the Río Santa valley, it wiped out several villages and killed more than 3 000 people.

Less than a decade later, on 31 May 1970, a severe earthquake (magnitude 7.7 on the Richter scale) occurred in the region. This induced a rock and snow avalanche, again originating from the northern peak of Huascarán. The avalanche started as a sliding mass of glacial ice and rock about 1 500 m long. It grew rapidly in mass, picking up glacial debris as it sped downslope at an average speed estimated to have been around 200 km/hr. The debris buried the towns of Yungay and nearby Ranrahirca, about 15 km from its source, and eventually extended some 25 km in total. The debris avalanche claimed around 18 000 lives, and the death toll from the earthquake was approximately 48 000.

Glacial lakes are sometimes impacted by ice avalanches, and the resulting floods are known in Peru as *aluviones.* These can have similar effects to the glacial lake outburst flood (GLOF) events (see page 41), but have a different origin. They occur with little or no warning and are composed of liquid mud, transporting large boulders and ice blocks. These were a component in the 1962 Huascarán avalanche. More than 20 catastrophic flood events have been recorded since the start of the 18th century, with settlements being destroyed and many lives lost.

The Peruvian Government has attempted to prevent or mitigate floods from glacial lakes by artificially draining them. Great care is needed to avoid uncontrolled outflow, and the very high elevation of 4 000 m or more makes construction work difficult.

Source: Walter Silverio, Remote Sensing Unit, University of Geneva; additional material, USGS

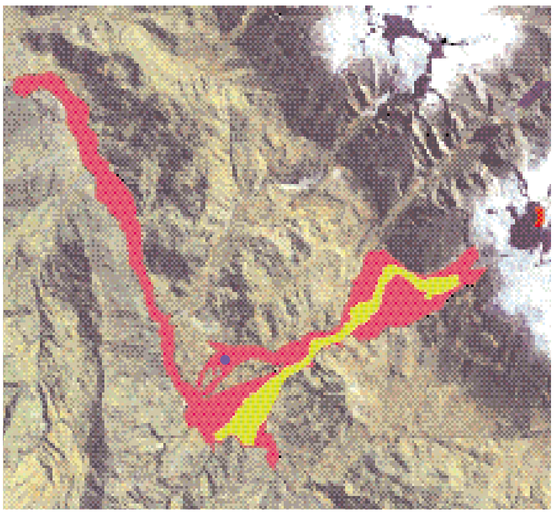


Figure 18: Two avalanche events in the Río Santa valley within a decade

- Source area of 1970 avalanche, Mount Huascarán
- Extent of 1970 avalanche
- Extent of 1962 avalanche
- Yungay town

Figure 19: Aerial view of Yungay in 1962 and in 1970, when the town was destroyed by a debris avalanche caused by earthquake

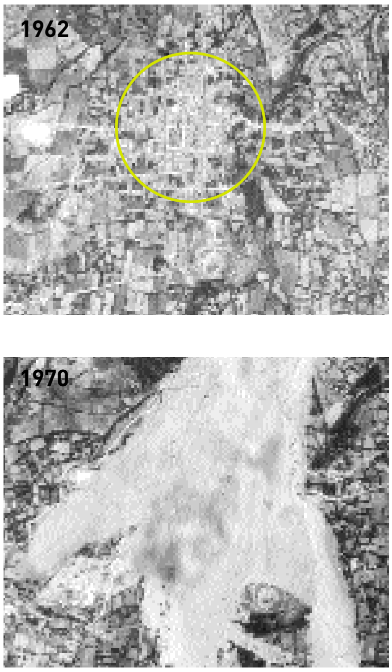


Figure 20: Hot areas in mountain regions and worldwide (inset) observed at night

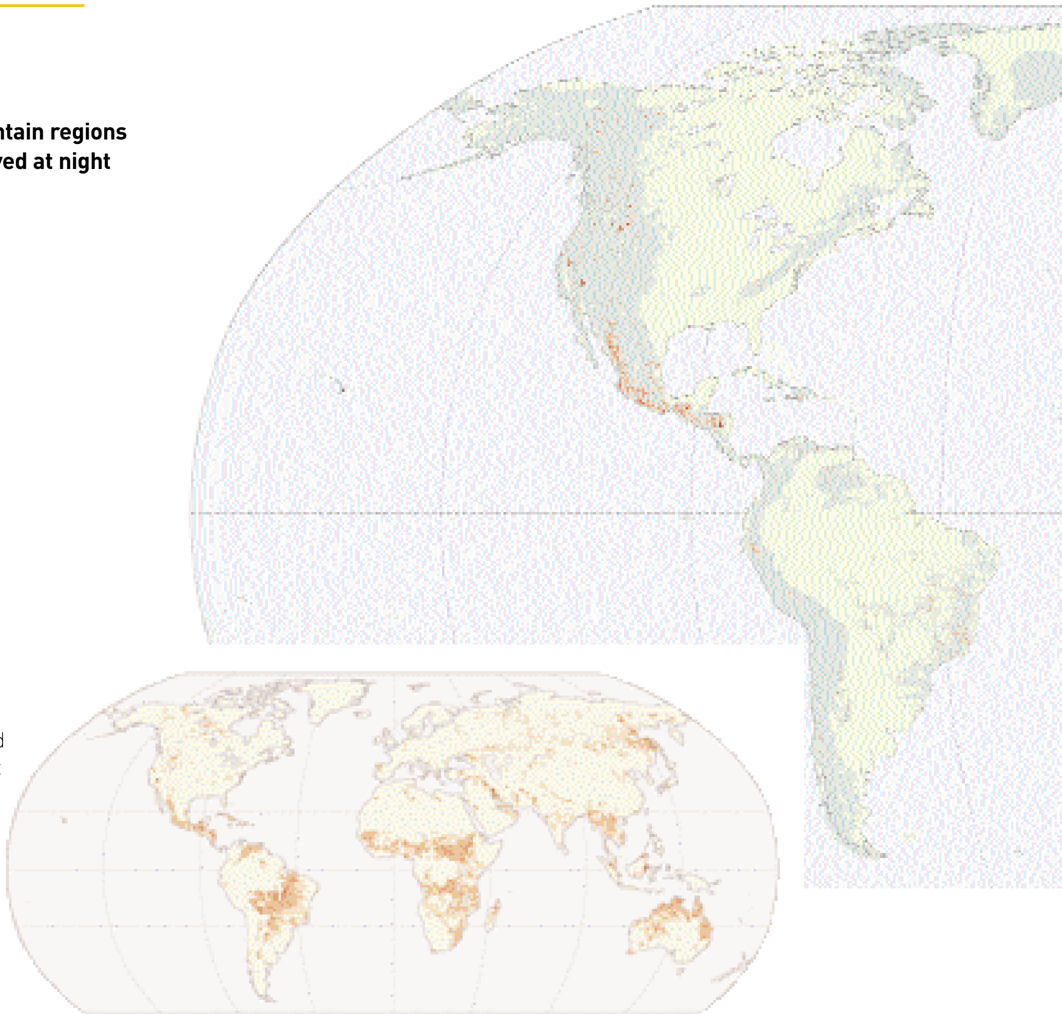
Number of fires, 1998-2000

> 50

6 – 50

1 – 5

Mountain region



Almost a quarter of fires recorded worldwide during the assessment period occurred in mountain regions. A substantially higher proportion of mountain land was affected by fire in Africa than in the other regions. Central America, Eastern Asia and Southeast Asia have also been characterized by a relatively high fire frequency.

Fire

Fire has a major influence on the structure, functioning and composition of many ecosystems, including grassland and forest communities. Fires may arise naturally through processes such as lightning strikes and vulcanism. Fire also often forms part of traditional approaches to land management in some areas, for example fire may be used to promote the availability of food for grazing animals or to clear the ground of vegetation prior to planting of agricultural crops.

In recent years, fire has become a major environmental issue on a global scale, following the extensive fires in South America and Southeast Asia, and their potential impact on global climate. In these areas, fire is being used to rapidly convert extensive areas of forest to agriculture.

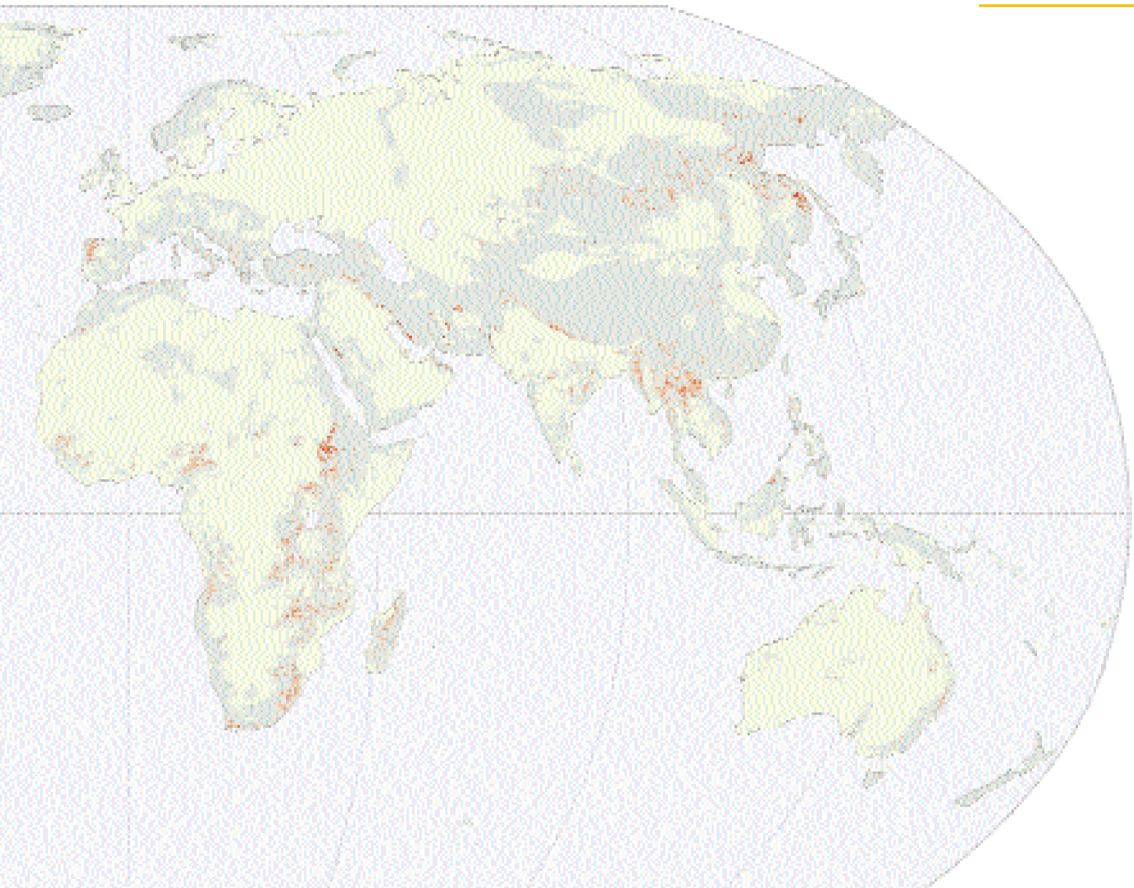
Fire can be viewed as a significant agent of land use change, and the incidence of fire is often promoted by the development of infrastructure. The risk of a fire outbreak is influenced by rainfall patterns and affected by land use practices. Changes in livestock grazing, timber harvesting and fire suppression policies can influence the frequency and intensity of such outbreaks. Climate change is also likely to have a major influence on the probability of fires occurring in many areas.

Fires can influence the provision of many ecosystem services, and threaten biodiversity in those areas such as moist forests where species are not adapted to fire. Fires also have a direct impact on human health, for example through the inhalation of smoke and smog.

SPATIAL DATA

The fire maps are based on remote sensing data provided by the ATSR satellite, which measures thermal energy (Figure 20). The data are 'hot spots' detected at night during the three years from 1998 to 2000, at a resolution of about 1 km^2. A few sources of extreme heat such as industrial plants and oil rig flares are visible as well as the fires.

The satellite visits all areas at least every three days. It visits those at higher latitudes more often, which introduces a bias to the detection

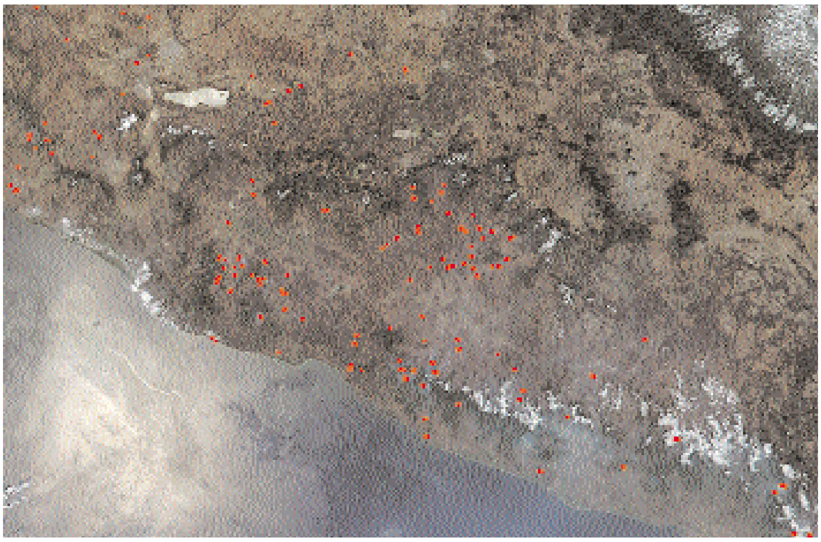


Source: Copyright ESA 1999, ESA/ESRIN ATSR World Fire Atlas Project (algorithm 2), with support from the IGBP-DIS Office

Table 8: Percent of land affected by fires in mountain regions

REGION	%
North and Central America	0.23
South America	0.12
Eurasia	0.20
Africa	0.53
Australasia and Southeast Asia	0.16
Greenland	0.00
GLOBAL VALUES	
% of all fires worldwide that occur in mountain regions	24

Figure 21: The Pacific coast of Mexico, showing fires in April 2002



Satellite imagery: MODIS Response System, NASA Goddard Space Flight Center

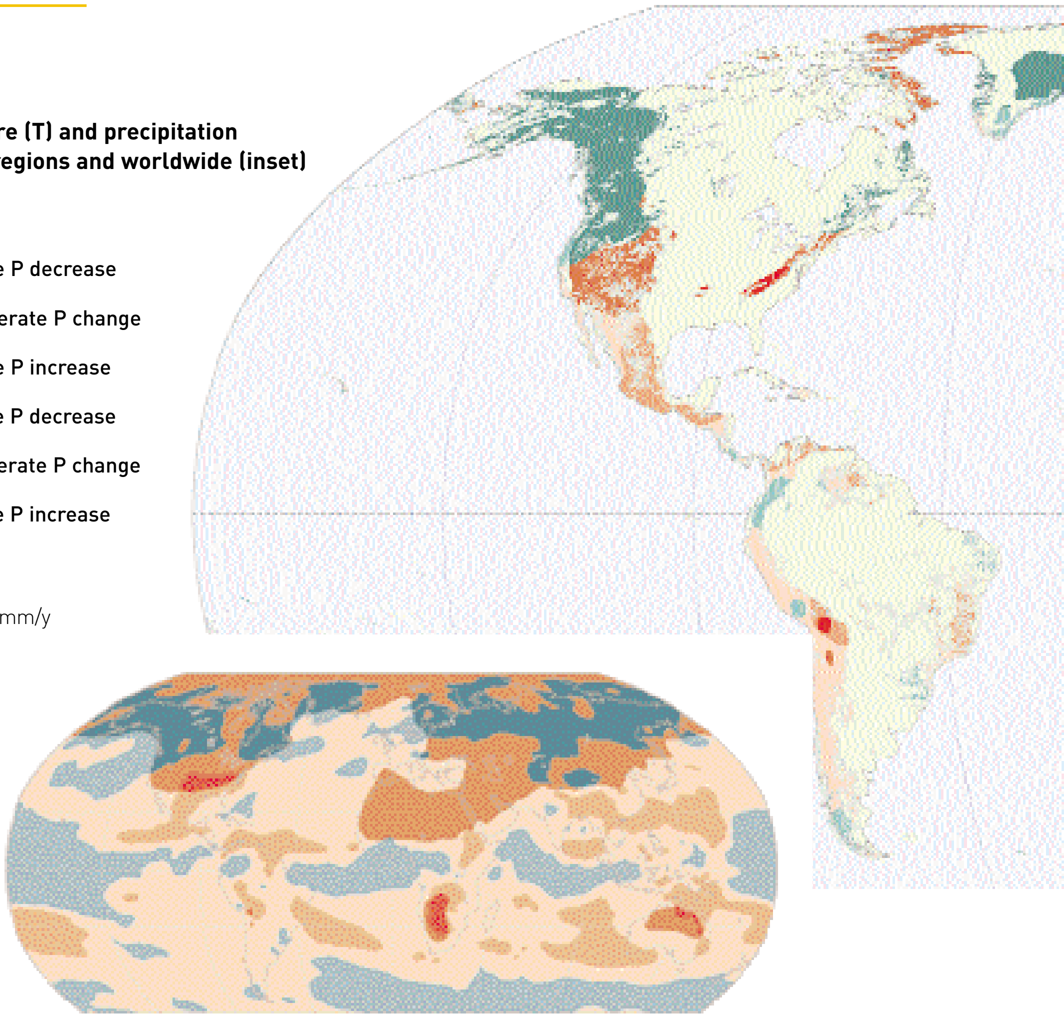
rate. The maps could be improved by adjusting for the visit frequency and identifying non-fire heat sources. Ground-truthing of these data indicated an under-detection of fires in boreal regions, but was otherwise generally found to be accurate (Arino and Plummer 1999).

Figure 22: Mean temperature (T) and precipitation (P) anomalies in mountain regions and worldwide (inset)

Estimated change, 2040-2069

- Small T increase; large P decrease
- Small T increase; moderate P change
- Small T increase; large P increase
- Large T increase; large P decrease
- Large T increase; moderate P change
- Large T increase; large P increase
- Mountain region

Moderate P change = -50 to +50 mm/y
Large P increase = > 50 mm
Large P decrease = > 50 mn
Small T increase = < 2.5° C
Large T increase = > 2.5° C



The proportion of mountain that may be affected by seve climate change is substanti higher in North and Centra America, Eurasia and Greenland, than in the othe regions. This is a result of t widespread warming simula the northern hemisphere.

Climate change

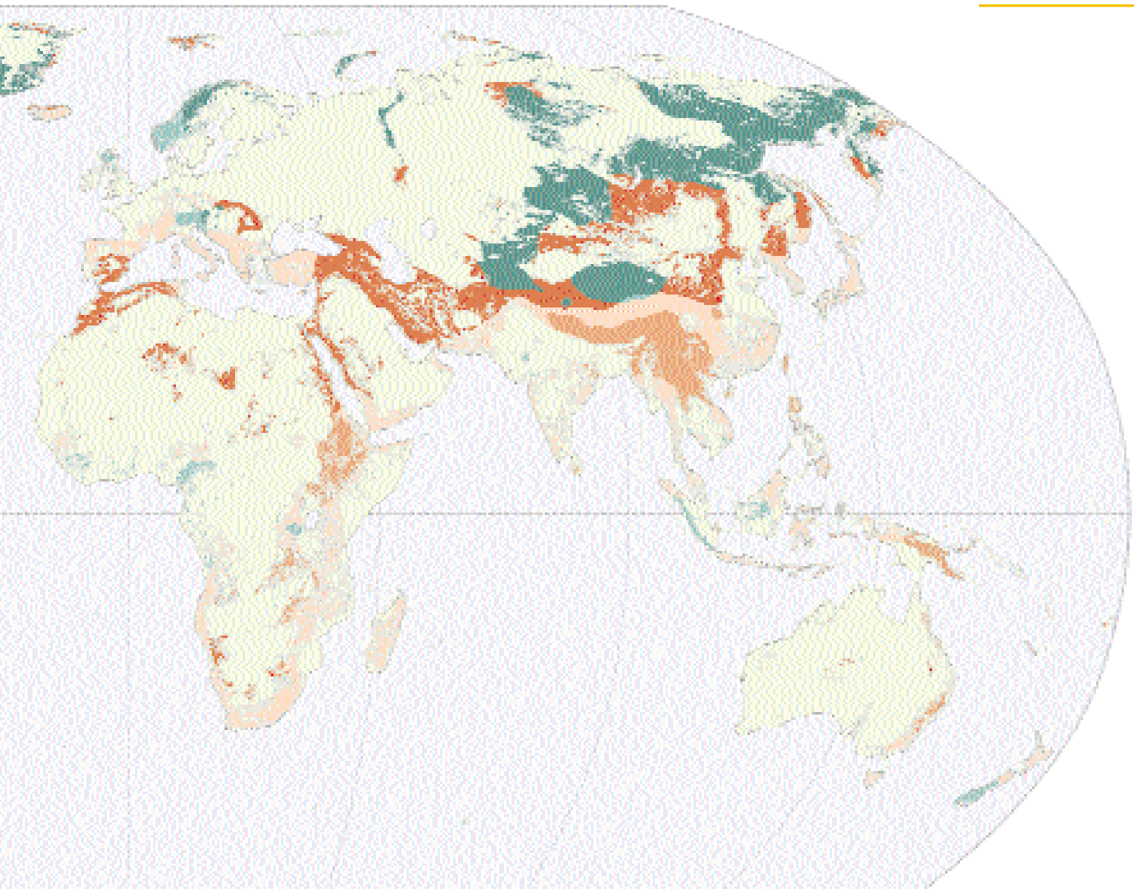
The Earth's climate has varied throughout its history as a result of variation in the amount of solar radiation incident at the Earth's surface, the extent of vegetation cover, circulation of the oceans and other factors. A body of evidence suggests that the atmospheric concentration of 'greenhouse gases' has increased in recent decades as a result of human activity, and that this has led to an increase in global temperature. These changes have been accompanied by a decline in snow cover and ice extent, increased sea levels and changes in patterns of precipitation.

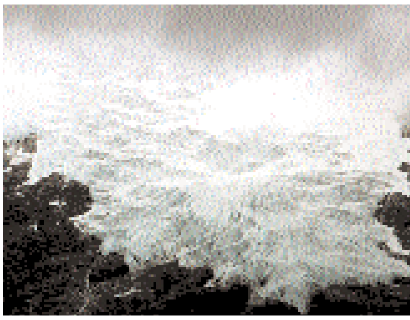
Production of the greenhouse gases responsible for climate change is largely attributable to combustion of fossil fuels. However, changes in land use, such as clearance of forest by fire, are significant sources of carbon dioxide emissions.

Climate change has significant implications for mountain environments as well as the people that depend on them. Temperature increases are associated with changes in rainfall and snowfall patterns, and may influence the frequency of extreme events such as floods, avalanches, landslides and fires. The major storm tracks that impact on mountain regions may shift, and snowmelt may occur earlier, as a result of climate change.

Biological diversity in mountains is particularly vulnerable to climate change. Most mountains are characterized by distinct zones of vegetation that vary with altitude. Climate change is expected to bring about range shifts for mountain species. All species are likely to suffer a decrease in available habitat as increasing temperature pushes their bioclimatic zone towards higher elevations, as the more elevated parts of a mountain have a smaller surface area.

Climate change is also likely to have major implications for sustainable development. For example, changes in the distribution of snowfall could significantly reduce ski tourism. However, it is possible that climate change may increase agricultural and forest productivity in some areas, and therefore patterns of land use change may be affected.





Source: Runs used - CGCM1 GSa3: Boer et al. *(2000); CCSR/NIES GSa1: Emori* et al. *(1999); CSIRO Mk2 GSa1: Hirst* et al. *(2000); GFDL-R15 Gsa1: Haywood* et al. *(1997); HadCM2 GSa1: Johns* et al. *(1997)*

SPATIAL DATA

The maps in Figure 22 illustrate the average patterns of temperature and precipitation change as simulated by five general circulation models (GCMs).

All models were run using the Intergovernmental Panel on Climate Change 'IS92a with sulphate forcing' scenario conditions. The climate mapped is the mean difference between the standard reference climate (1961-1990) and a future climate (approximately 2055) as simulated by each GCM (following Carter *et al.* 1999). Future climate values are based on mean monthly values for 2040 to 2069. The GCM values were interpolated to a 5' grid map using a spline function.

There is a very variable pattern in simulated change. Temperature anomalies generally increase with latitude, whilst precipitation tends to decrease at the equator and increase in northern areas.

It is impossible to predict with any precision how the climate is likely to change within any given mountain region, as climate is influenced by many complex, interacting variables. In addition, GCMs are designed to represent global to regional patterns rather than to provide local-scale accuracy.

A measure of the uncertainty involved in this analysis is provided by the level of consistency between the models in direction and amount of change. Results indicate that there is a high level of agreement between the models over most of the globe. In some tropical mountain regions, however, there is more concurrence between the mapped changes in temperature than in precipitation, while the opposite is true for Arctic regions.

Table 9: Percent of area affected by severe climate change* in mountain regions

REGION	%
North and Central America	77
South America	17
Eurasia	66
Africa	29
Australasia and Southeast Asia	17
Greenland	98

GLOBAL VALUES	
% of severe climate change simulated worldwide occurring in mountain regions	23

* 'Severe climate change' is defined as areas where either temperature increases by more than 2.5° C or precipitation decreases by more than 50 mm/y by 2055, averaged for the five GCMs.

Alpine plants

Schrankogel, the site of Austrian scientists' detailed studies of plant distributions, rises to 3 497 m in the Austrian Tyrol.

Many of the models and scenarios used to forecast global climate change predict that mountain regions will be strongly affected by rising temperatures and changing rainfall patterns. However, what climatic change will mean for mountain ecosystems is as yet poorly understood. It is likely that species distributions with respect to elevation will change, resulting in changing patterns of biodiversity. It is thought that some species from lower elevations will migrate to higher zones and that the plants of higher altitudes may be squeezed out by the arrival of these invaders. However, because such changes are slow, it is a difficult task to document them and determine their precise nature.

A team at the University of Vienna has used a variety of tools to clarify the changes that have occurred or may develop as a result of climate change in the high altitude ecosystems of the eastern Alps. They resurveyed plots on 30 alpine summits that were first studied by scientists between 50 and 100 years ago and found that 70 per cent of these areas now have markedly more plant species than when first studied. The additional species were plants from lower elevations that had moved upslope to invade the original vegetation.

In order to predict future changes and understand their implications for individual species, the scientists have been conducting detailed studies of plant distribution in a range of high altitude plant communities. They have inventoried plants in 1 000 1-m squares on the slopes of Schrankogel (altitude 3 497 m) in the eastern Alps. The species composition and cover in the plots were analysed in relation to elevation, aspect and a number of topographical characteristics such as slope and roughness.

Based on the relationships of species to particular plot characteristics, the scientists could predict the distribution of individual species over entire slopes. This showed that the transitional areas (ecotones) between different vegetation zones had the highest plant diversity. Data from the plots also showed that many species had very narrow tolerance

One thousand 1-m² plots were used to study plant distributions and environment in detail. The plots are permanent sites for long-term monitoring of change.

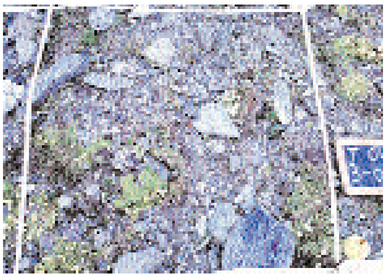
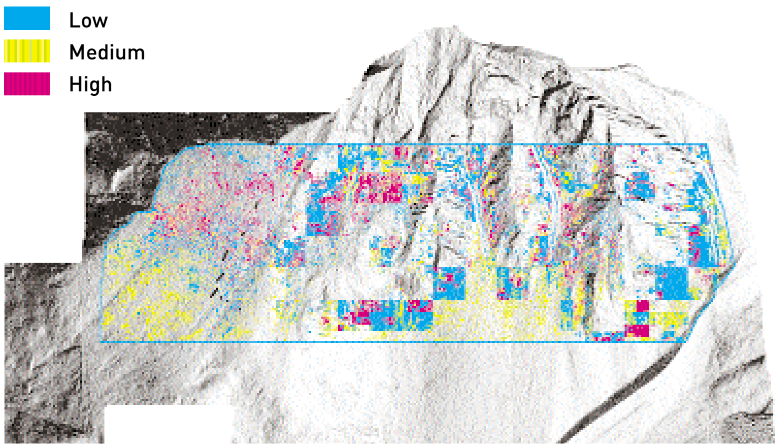


Figure 23: The occurrence of *Oreochloa disticha*, a pioneer species at the alpine-snowline transition, modelled from detailed plot studies



regarding topographic as well as climatic conditions, and allowed the scientists to define an 'environmental envelope' that described the growing conditions and preferred sites for each individual mountain plant species.

The scientists then used computer models to test the effects of predicted climate change on the distributions of these conditions and site characteristics and thus predict the distribution of species after climatic change. The results showed that particular vegetation types and zones would not migrate upwards as whole communities, but the response of individual species would be affected by topographic barriers and variation in distinctive ways.

The models predict that migration of species from lower altitudes will alter species richness in many parts of the mountain ecosystems. Upward migration of species from alpine grasslands will increase competition. Only small patches of the high altitude vegetation in the roughest terrain will remain unaltered. Many high altitude species may be unable to migrate because of topographic constraints and may decline or even die out because of increased competition. Those higher altitude species that are able to migrate upwards may 'run out of space' on the upper slopes.

Continued monitoring of the network of plots on Schrankogel will provide detailed enough data to detect such vegetation changes over a decade, vastly enhancing our understanding in a relatively short time

Changes in plant communities will almost certainly cause changes in other components of the ecosystems that depend on them. Only by understanding and predicting such changes can action be taken to mitigate them and preserve these distinctive mountain species and ecosystems.

Source: Michael Gottfried, Harald Pauli, Georg Grabherr, Institute of Ecology and Conservation Biology, University of Vienna, Austria
For further information: http://www.pph.univie.ac.at/igbp/highres/schran/schran_highres.html

Figure 24: The effects of climate change on species richness

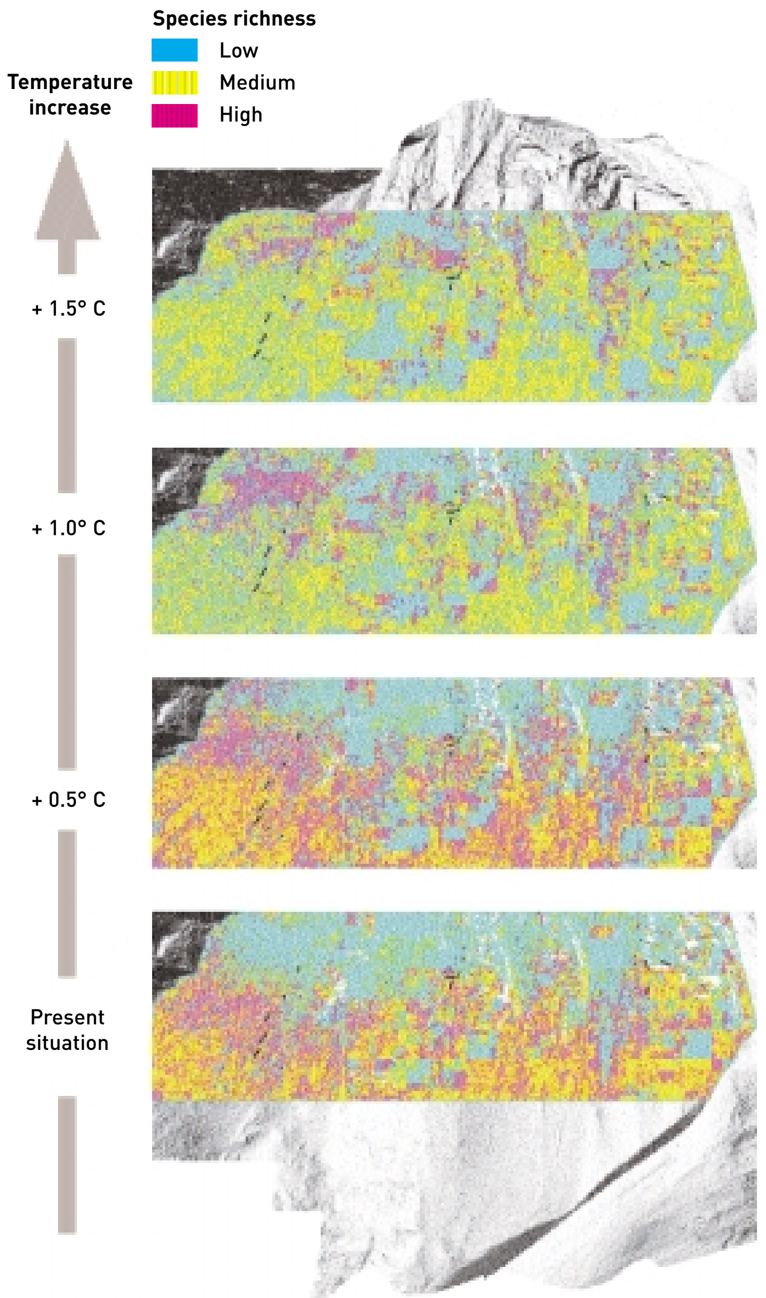
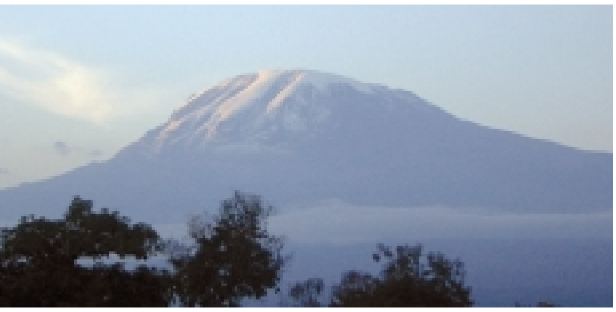
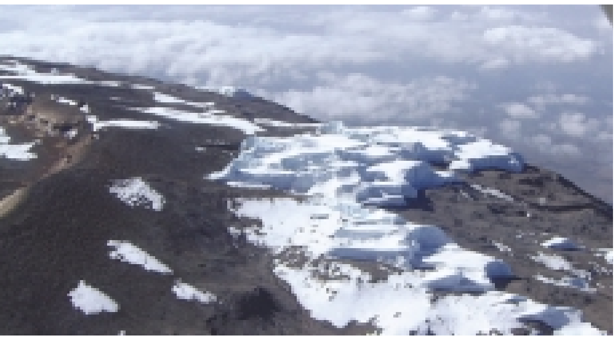


Figure 24: For 21 species studied, overall richness is currently greatest within the alpine-snowline transition zone, but computer models predict that richness will decline sharply with climate warming as different species become 'trapped' in particular terrain situations.

Retreating glaciers





The southeastern side of Kibo, the highest peak of Kilimanjaro (top) and remnants of the eastern side of the northern glacier of Kilimanjaro (above).

During the last ice age, glaciers covered more than 30 per cent of the world's land surface. With climatic warming over the subsequent 12 000 years these have now retreated to cover about 10 per cent of land. The mass of a glacier reflects the balance between ice accumulation and melting. A continuous record of mass balance data from the 1960s exists for about 40 glaciers, with less complete data for a few hundred. Such data, with historical records and recent satellite observations, confirm that while a very few glaciers have increased in bulk, most continue to retreat, and the rate of retreat is accelerating in many areas. This apparent increase may be linked to a recent rise in global mean temperature. Several cases of glacier retreat in the European Alps and North America are well documented; two less familiar examples are profiled below.

CORDILLERA BLANCA

Records show that glaciers in the Cordillera Blanca (Ancash, Peru) have been shrinking since at least the 1970s, amounting to a decrease in area of about 75 per cent over a 25-year period. This changing balance in water reserves stored in the form of ice could have significant impacts on water availability in the region, and could contribute to landslide hazard.

MOUNT KILIMANJARO

Reaching 5 963 metres above an undulating savanna plain, Mount Kilimanjaro is Africa's highest mountain. Named 'shining mountain' after its characteristic icecap, visible from afar when sunlit, it is located 300 km south of the equator in northern Tanzania. Glaciers on Mount Kilimanjaro are now much reduced, possibly a result of regional warming linked to global climate change. In the 38 years between 1962 and 2000, the glacier area was reduced by about 55 per cent. Studies by the Byrd Polar Research Center (Ohio State University) suggest that the icecap has diminished by 82 per cent since it was first carefully surveyed in 1912. If this rate of loss continues, the entire icecap may disappear a couple of decades into the 21st century.

Source: Cordillera Blanca: Walter Silverio; Kilimanjaro: Christian Lambrechts, UNEP-DEWA
Remote sensing image (bottom left): Walter Silvieri, University of Geneva

Figure 25: Remote sensing image of the Pasto Ruri glacier, Huascarán National Park, showing current ice extent in pale blue, with larger 1987 area outlined in yellow

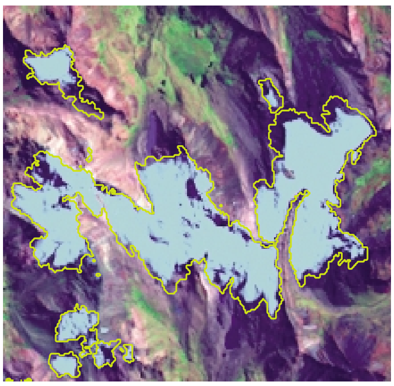
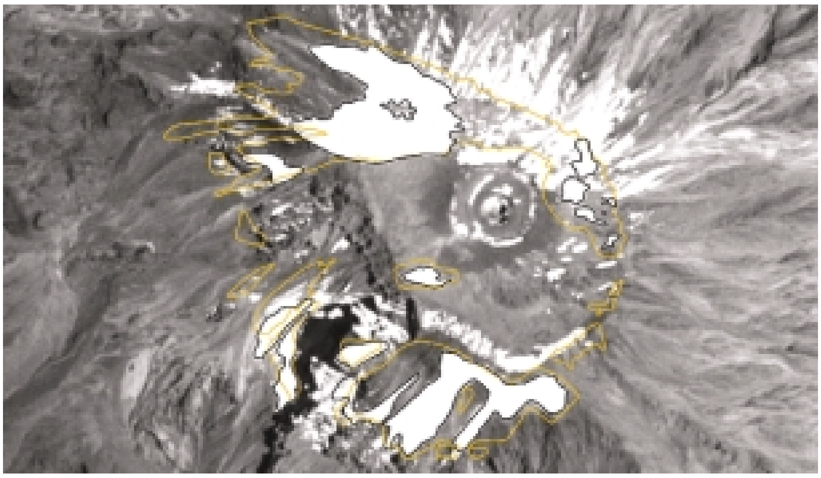


Figure 26: The Kilimanjaro icecap in 1962 (yellow), and 2000 (black outline)



Dangerous glacial lakes

As glaciers retreat, banks of erosion debris (moraines) are left behind, and recent melting has in many cases led to the formation of lakes behind them. With rapid melting, lake levels can rise over the containing bank, an event known as a glacial lake outburst flood (GLOF), making these high altitude lakes potentially very hazardous. Catastrophic flooding can be caused downslope, with serious damage to life, forests, farms and infrastructure.

Nepal and Bhutan are subject to the natural hazards associated with high mountain regions. Most of their major rivers are fed by snow and ice meltwater. At least 20 catastrophic GLOF events have been documented in the Himalaya region over the past 50 years. The 1985 outburst from Dig Tsho glacial lake in eastern Nepal destroyed the almost completed Namche Small Hydropower Plant, and led to identification of the GLOF phenomenon as a distinct and increasingly significant mountain hazard. GLOFs in 1957, 1969 and 1994 in the Lunana area of northwest Bhutan caused extensive damage to the Punakha Dzong, a religious and administrative centre. In October 1994 a GLOF was triggered in Bhutan by the partial breaching of the Lugge Tsho glacial lake.

Field investigation of glaciers and glacial lakes by conventional methods is extremely difficult, but satellite images and aerial photographs can be used to evaluate physical conditions with considerable accuracy. A multi-stage approach, combining remote sensing data with targeted field investigation can be highly effective. Visual and digital image analysis, together with GIS techniques and use of digital elevation models (DEM), have proved key to successful study of these features and the identification of potentially dangerous glacial lakes.

In collaboration with the International Centre for Integrated Mountain Development (ICIMOD), UNEP has initiated a collaborative study in the Hindu Kush-Himalaya region. Recent work has already identified 2 323 glacial lakes in Nepal and 2 674 in Bhutan, of which 20 and 24, respectively, have been assessed as potentially dangerous.

Source: UNEP/RRC-AP, ICIMOD;
For further information see
http:// www.eapap.unep.org/issues/glof/

Tsho Rolpa, 4 580 m, the most studied glacial lake in Nepal, in October 2000. The lake formed at the head of the Rolwaling Valley as the Trakarding Glacier retreated. It is dammed by an ice-cored moraine and now extends over 3 km and contains an estimated 80 million m^3 of water.

Figure 27: 1999 image of Tsho Rolpa, demonstrating how remote lakes can be visualized by draping remote sensing data over a digital elevation model

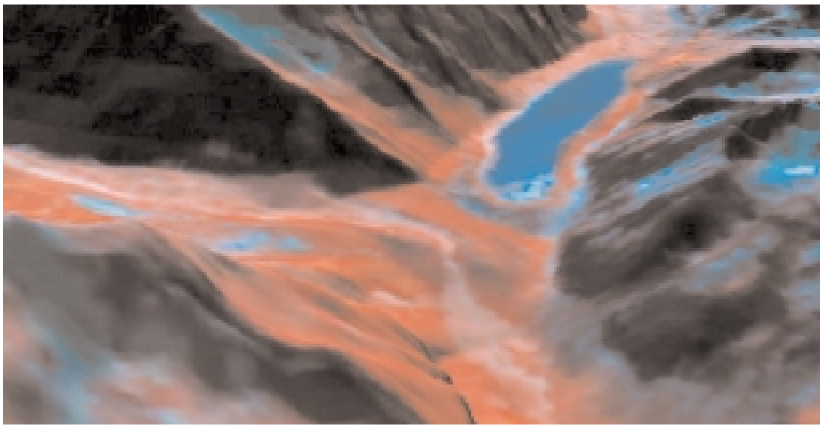


Figure 28: Measures to prevent glacial lake outburst floods can include canal construction, as here at Tsho Rolpa, to prevent excess water accumulating

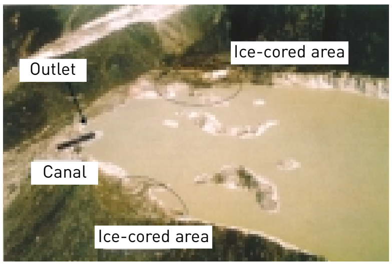
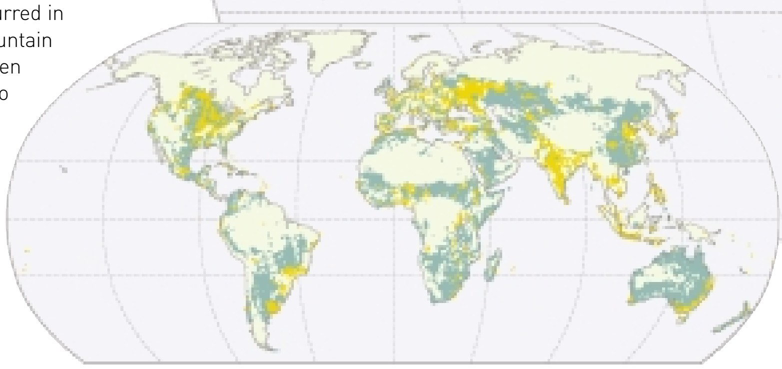


Figure 29: Land cover change in mountain regions and worldwide (inset)

Conversion during the period 1700-1990

- To cropland
- To grazing land
- Mountain region



The maps illustrate the extent of land cover change that has occurred in mountain areas. In general, mountain areas are more likely to have been converted to grazing land than to cropland, and non-mountain areas are more likely to have been converted than mountain areas. In terms of percentage land area, conversion to grazing land is highest in African mountains, whereas conversion to cropland is greatest in Australasia and Southeast Asia.

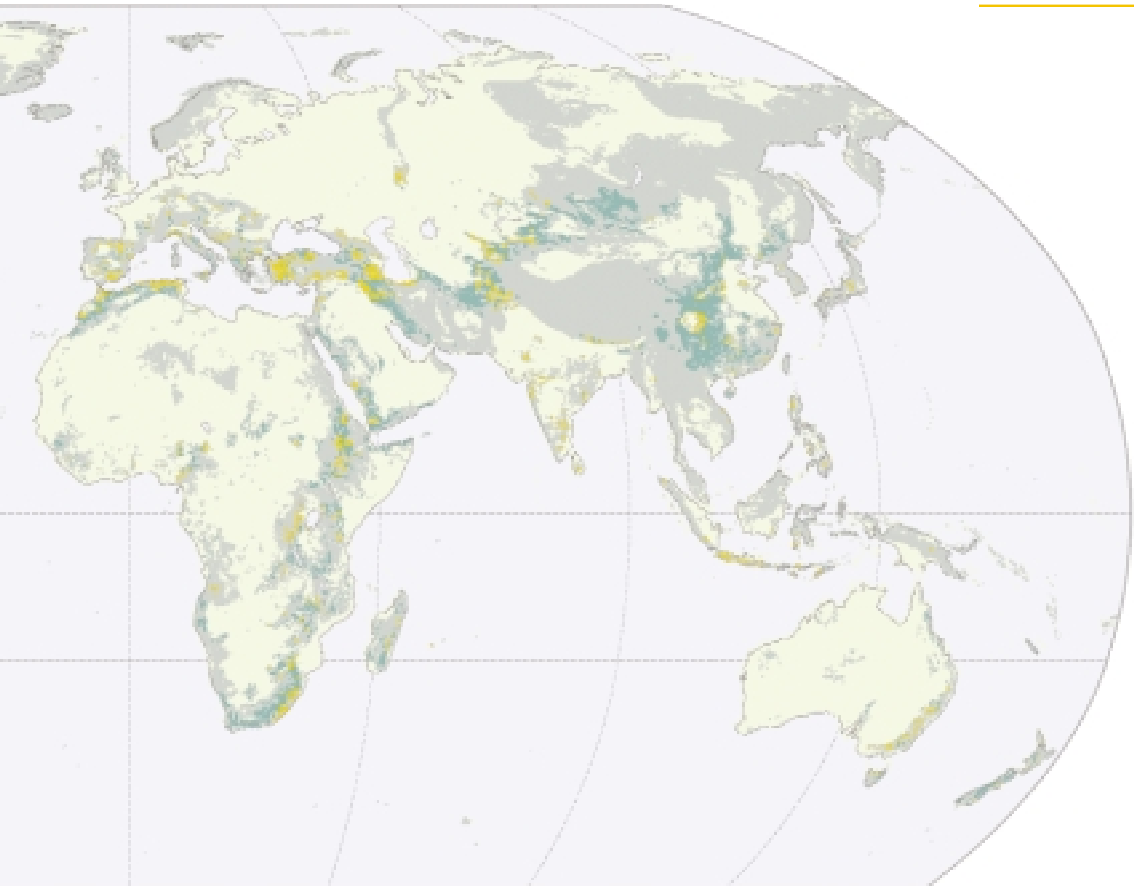
Land cover change

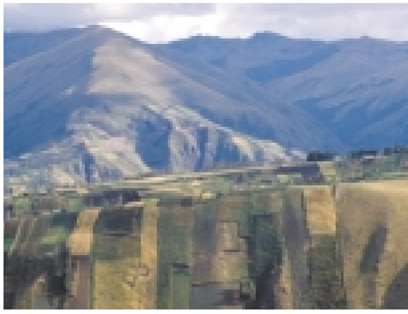
Rapid and extensive alteration of land cover as a result of human activity has been a major element of global environmental change over the past three centuries, although evidence for land cover alteration dates back many thousands of years. Changes in land use and land cover have occurred to such an extent that they significantly affect functioning of the biosphere, being one of the most important causes of biodiversity loss as well as climate change. Land use change is one of the primary causes of soil degradation, and has a major impact on the provision of ecosystem services to people.

The principal modifications of land cover that have occurred at the global scale include conversion of forests to cropland and grazing land, modification of rangeland, intensification of agriculture and urbanization. The extent and rate of land cover change is significantly influenced by global factors, which interact with institutional factors and the characteristics of local situations, to influence people's responses to economic opportunities. Political efforts to attract international capital, market conditions and the price of agricultural commodities have a major influence on decisions relating to land use. Rapid land use change often coincides with the incorporation of a region into the global economy.

Many ecosystems are maintained in their current state by human activities. For example, many tropical rangelands are maintained through management of grazing animals. The changes to traditional land use practices that are currently being experienced in many areas can have major effects on land cover.

Sustainable development requires that land cover change should not reduce the capacity of ecosystems to provide the services that support human populations. In practice it is often difficult to differentiate land cover changes that are irreversible, such as loss of biodiversity or soil degradation, from those that can be reversed. To achieve sustainable development, inappropriate interventions that give rise to rapid modifications of landscapes and ecosystems should be avoided.





Source: History Database of the Global Environment, as Goldewijk (2001)

SPATIAL DATA

The maps (Figure 29) show land use change from 1700 to 1990, based on the HYDE model (Goldewijk 2001). Only changes to agricultural cover are included. HYDE was developed to inform future land use change scenarios. It integrates available data on historical human population and migrations of people with land cover. Population was estimated through time for each map unit.

Present-day cropland and grazing land were defined according to the DISCover dataset (Loveland and Belward 1997). The estimated amount of crop or grazing land present in each country or state for a period was assigned to those map units of land use with the highest population densities at that time.

As not all historical food production was centred on areas of population density, this method could be improved by allocating agricultural land to grid cells in proportion to surrounding population density, instead of simply defining map units as having or not having agriculture. It would also be useful to incorporate a measure of agricultural suitability through time, as some areas have been degraded or improved. There is a significant difference between the 6 per cent of mountain and 9 per cent of non-mountain land farmed for crops, and between the 19 per cent of mountain and 22 per cent of non-mountain land used for pasture.

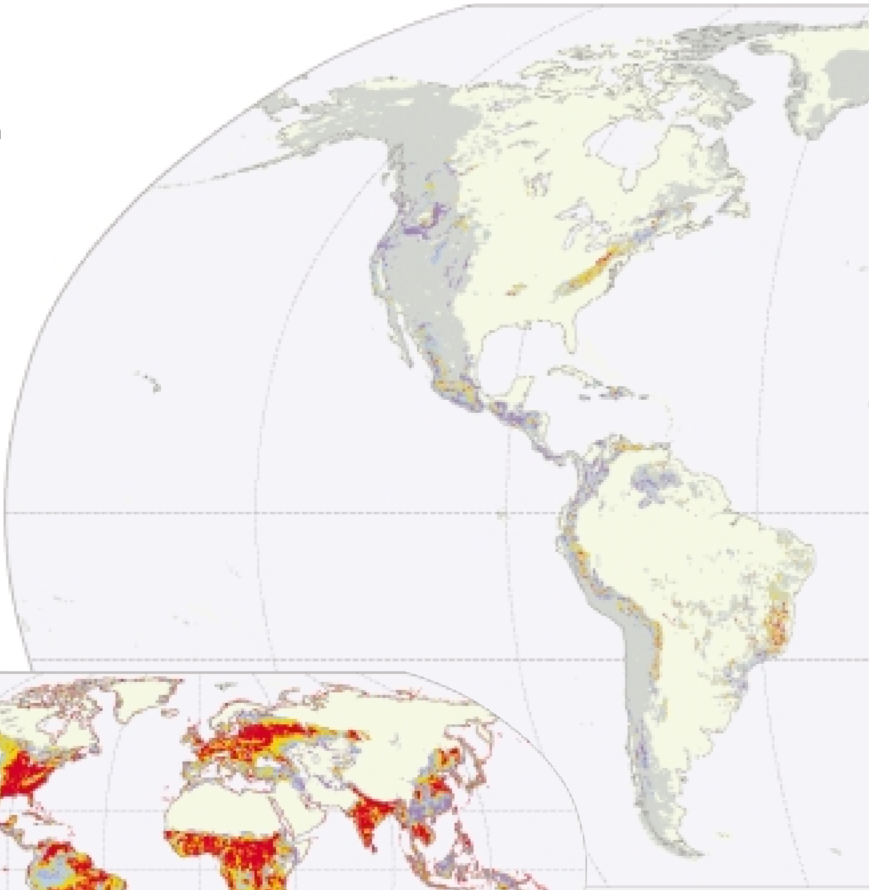
Table 10: Percent of mountain land converted to cropland and grazing

REGION	% TO CROPLAND	% TO GRAZING
North and Central America	5	9
South America	5	25
Eurasia	5	19
Africa	10	34
Australasia and Southeast Asia	12	10
Greenland	0	0
GLOBAL VALUES		
% of area converted to agriculture worldwide that occurs in mountain regions	16	21

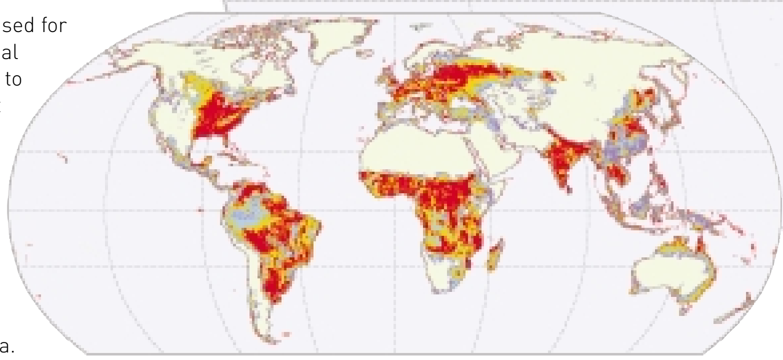
Figure 30: Suitability for rainfed agriculture in mountain regions and worldwide (inset)

Level of suitability

- Good to very high
- Moderate
- Marginal
- Very marginal
- Mountain region



Extensive mountain areas are used for livestock grazing. Some marginal lands have unrealized potential to support rainfed agriculture, but managing cropland in steep mountain environments is problematic. The risk of soil loss and the impact on biodiversity are high. Relatively large areas highly suitable for rainfed cropping occur in the Atlantic highlands of Brazil, in tropical Africa and central China.



Agricultural suitability

Suitability for agricultural production can be considered both as a potential service provided by mountain systems and a threat to existing biological diversity in mountain regions.

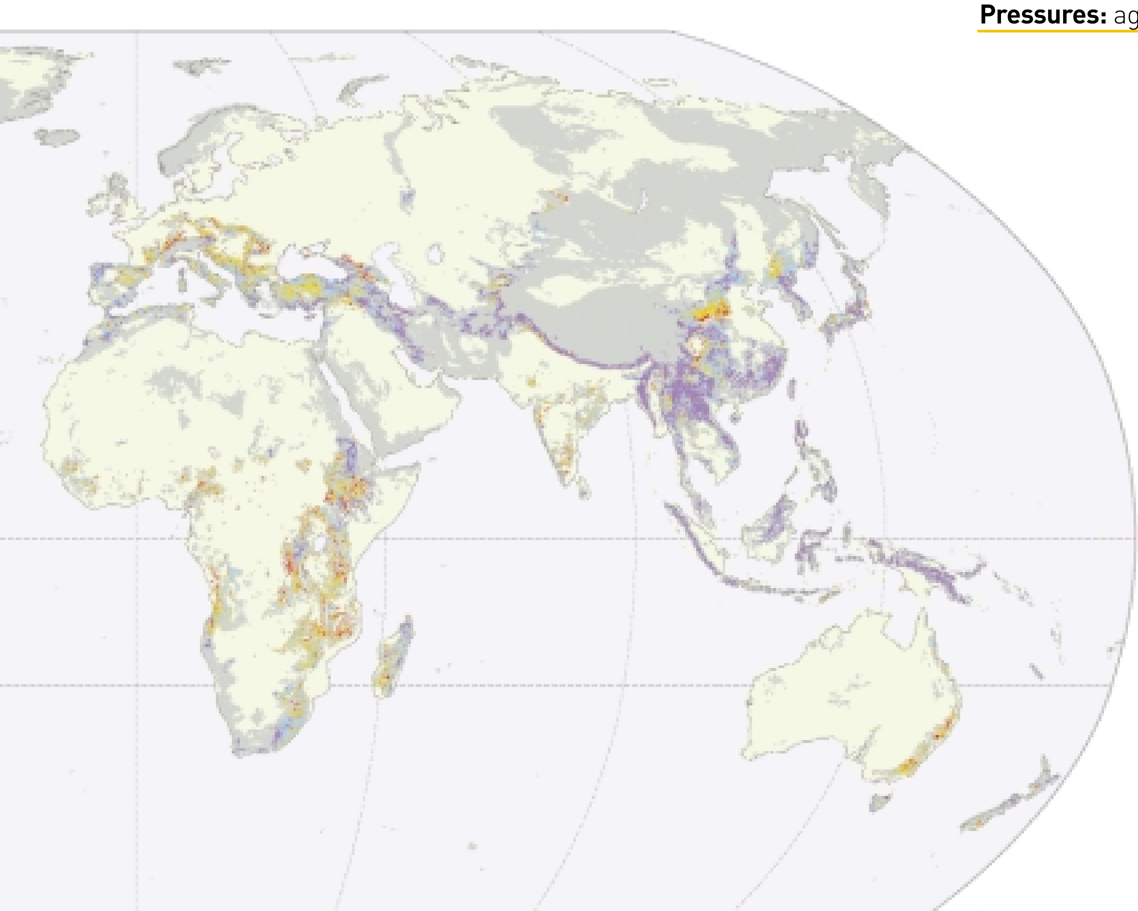
Soil erosion from mountain slopes can be rapid once the original vegetation cover is removed, particularly on sites where soils are immature with a low humus content. Complex terracing and irrigation systems have been developed in many mountain regions to retain soil and water that would otherwise be lost during cultivation. If deforestation upslope or an extreme event causes these systems to fail, devastating floods can occur, affecting populations both on the mountain slopes and in adjacent lowlands. In extreme cases of land degradation people may be forced to leave the mountain region to seek alternative employment.

Agricultural intensification includes greater use of existing land as well as conversion of new land. The most productive lands are typically cultivated first, with marginal lands being called upon when pressures increase, for example in the Hindu Kush-Himalaya region.

Intensification can be caused both by land scarcity in developing economies and by population growth. In market economies, intensification is driven by a combination of commercial opportunities and political subsidies. Collapses in product markets or subsidy programmes affect the economic viability of production systems, and can lead directly to major changes in land use. Urban development can have a major impact on land cover change in areas outside towns and cities by changing patterns of consumption and increasing the demand for resources.

SPATIAL DATA

The maps illustrate suitability for one type of agricultural production: rainfed crops. Crop-specific limitations of climate, soil and terrain resources were modelled under assumed levels of inputs and management conditions (Fischer *et al.* 2001). Yield calculations for each map unit were then based on mapped climate and soil characteristics. The set of maps was



Source: Data as Plate 46 (optimizing technology mix) from Fischer et al. *(2000, 2001)*

processed to identify units on the maps as: very suitable and suitable at high levels of agricultural input, very to moderately suitable at intermediate levels, and very to marginally suitable at low levels of input, for each of several crop types. Where areas are shown as very suitable, this may relate to suitability for any of the three input types, but where they are shown as marginal it always indicates low input conditions.

The marginal lands are areas where subsistence farmers would be able to plant crops producing low yields. If there are no 'very suitable' lands in an area, people are likely to use marginal lands for agriculture. For example, little good agricultural land remains vacant in the Comoros islands, and cultivation occurs on slopes greater than 60° (WWF 2001).

As pasture land, agroforestry and the effects of irrigation are not included in this analysis, an aggregated map of suitability for all forms of agriculture would cover a larger area.

In general, lands very suitable for agriculture are rare in mountain regions, owing to the combination of topography and extreme climates. There is a significant difference between the 2 per cent of mountain and 22 per cent of non-mountain land modelled as good to very suitable for rainfed crops. African mountains contain a considerably higher proportion of land that is suitable for rainfed crops than any other region.

Climate change may increase the viability of arable farming in some mountain regions. However, the expected increases in climatic variability in combination with ongoing deforestation may also bring about more major landslides and flooding events, thereby reducing agricultural potential.

Table 11: Percent of mountain land classed as having 'good to very high' suitablility for agriculture*

REGION	%
North and Central America	1
South America	4
Eurasia	1
Africa	7
Australasia and Southeast Asia	2
Greenland	0
GLOBAL VALUES	
% of suitable area worldwide that occurs in mountain regions	3

* The three highest classes in the analysis are grouped here as 'good to very high'

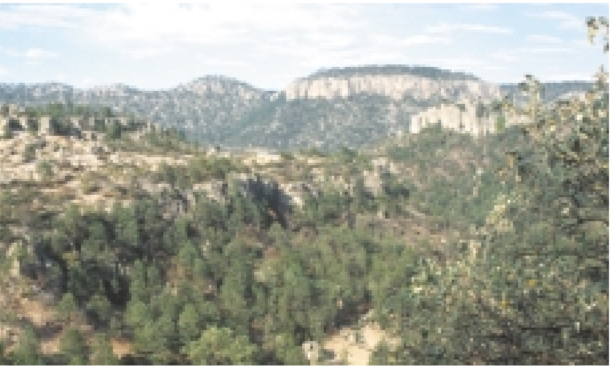
The Sierra Tarahumara

Imagery from the Landsat series of satellites has been used to demonstrate and measure change in forest cover over time within the Sierra Tarahumara.

This region is situated in Chihuahua state, Mexico, and forms part of the Sierra Madre Occidental range. It has high biodiversity value, with many endemic species, and lies within one of WWF's Global 200 Ecoregions, and a major Endemic Bird Area (EBA) identified by BirdLife International. The region extends over some 60 000 km^2. High plateaus, with a maximum elevation of about 3 000 m, are separated by deep canyons. Many of the region's rivers flow west to the Pacific; others flow eastward toward the Río Grande and the Gulf of Mexico, and support irrigated agriculture in much of northeast Mexico and Texas. The highest areas hold montane conifer forest, key to the forest products industry in Mexico; this intergrades with evergreen oak at lower elevation. The region is also the homeland of the Raramuri (or Tarahumara) indigenous people, now outnumbered at least sixfold by non-indigenous peoples.

More than 300 of the native plant species are used for food and medicinal purposes. Maize, squash and beans form the staple diet; although livestock are kept, animals may be most important for their manure, key to successful arable agriculture. Extractive industries have been the economic mainstay of the region since colonial times. Mining roads were precursors to the logging roads developed in the mid-20th century, and forestry is now a close second to mining in economic importance. With increasing domestic demand, Mexico has a large and growing trade deficit in wood and wood products.

Most forests in the Sierra Tarahumara are communal property held in cooperatives known as *ejidos*, intended to ensure that local residents (Raramuri and *mestizos*) had input to forest management and a larger share of the profits from their exploitation. In practice, a few powerful leaders and companies buying the wood benefit far more than communal *ejido* members. Illegal logging has been on the increase. Continued deforestation of the Sierra Tarahumara, whether conducted legally or illegally, does not appear to benefit the majority of the local people. In particular, Raramuri culture has depended upon the forests for food, shelter and medicine, and its survival is likely to track the health of these forests. New approaches to forest management are needed, taking full account of changing land cover and ecosystem conditions.



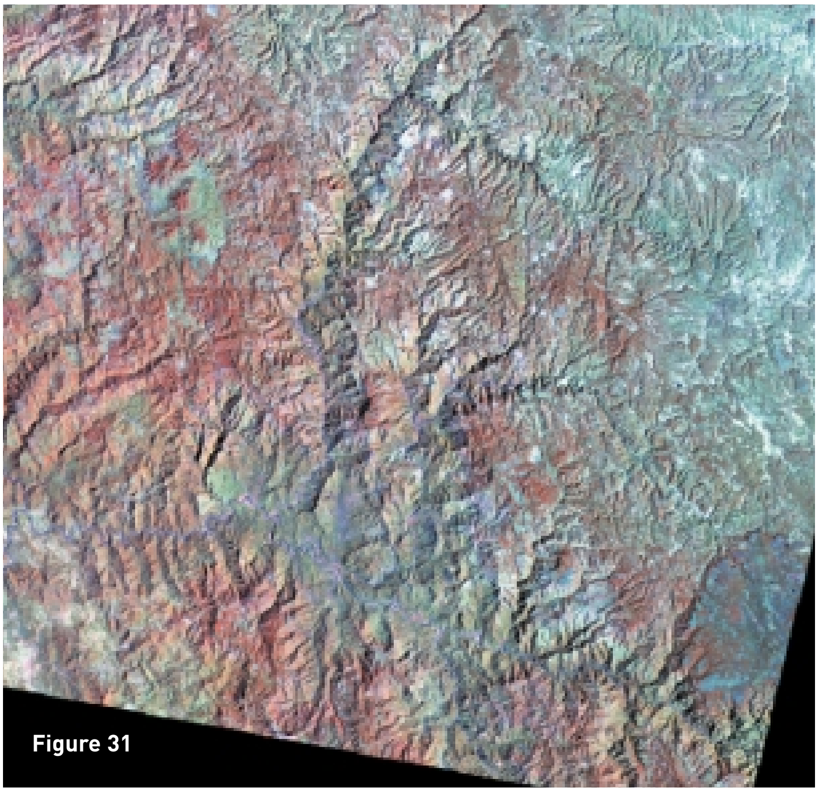


Figure 31

Table 12: Analysis of forest cover change, 1992-2000

CHANGE CLASS	N° OF PIXELS	AREA (KM2)	%
Forest to forest	4 271 970	3 469.9	19.02
Non-forest to non-forest	17 605 551	14 300.1	78.37
Deforestation	286 195	232.5	1.27
Reforestation	78 553	63.8	0.35
Shaded	143 524	116.6	0.64
Water	80 115	65.1	0.36
TOTAL	**22 465 908**	**18 248.0**	

Satellite imagery is an excellent tool for obtaining a synoptic view of land cover over a wide area. Detection of change typically involves viewing imagery of a particular area at different times and comparing the results. For this study, two Landsat scenes were used, the earlier scene dated 1 April 1992 and the later 23 April 2000. Shaded slopes, which are difficult to classify, are a problem when using this approach in areas with great topographic relief.

A comparison of cover between 1992 and 2000 shows that of around 18 250 km^2 analysed, approximately 19 per cent remains as forest, 78.3 per cent remains as non-forest, 1.3 per cent has been deforested, and 0.4 per cent reforested, with small areas shaded or water. This represents 6.3 per cent forest loss from 1992 to 2000, and 1.7 per cent reforestation, for a net deforestation rate of 4.6 per cent over the eight-year survey interval. This is cause for significant concern. Recent forest regrowth is not ecologically equivalent to a comparable amount of lost forest, given the different habitats provided by older and younger forests. The actual cause of the forest change from 1992 to 2000 cannot be determined from this study. Whatever action is taken must take into account the needs and desires of the Raramuri and *mestizo* peoples who are the longstanding stewards of the Sierra Tarahumara, if it is to succeed in preserving both biological and cultural diversity.

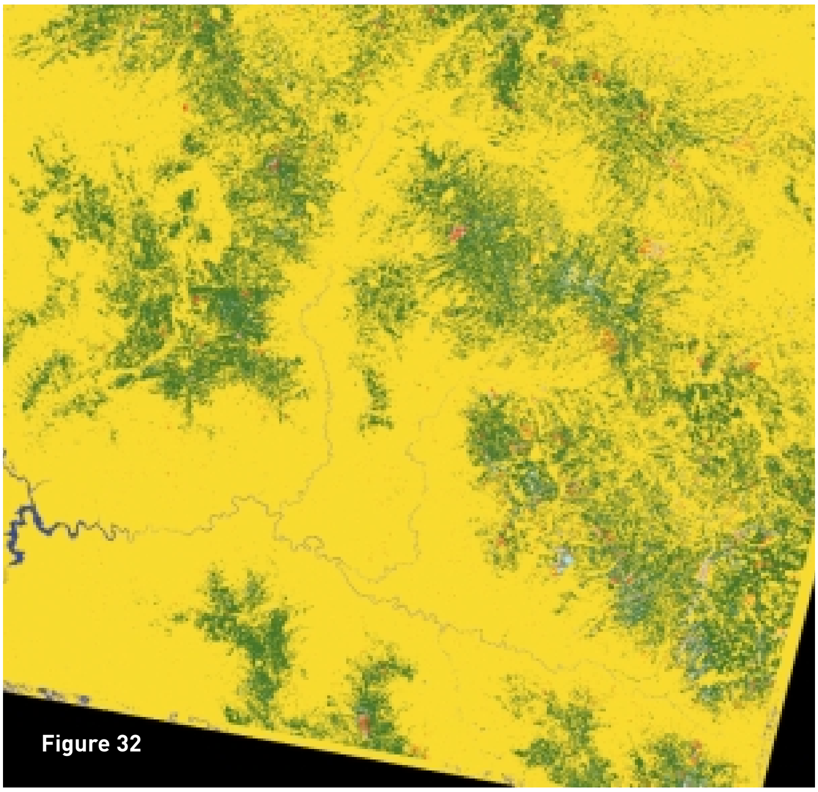


Figure 32

Figure 31 is an image of the study area from the Thematic Mapper on Landsat 4, in April (dry season) 1992. The channels are selected to show vegetation with a red tint and dry areas with a blue tint.

Figure 32 represents the change in land cover in the study area between 1992 and 2000. Red areas show forest loss, turquoise represents forest growth, green remained forest throughout the period and the yellow background remained non-forest. Rivers and other water bodies are in blue. Net deforestation over the period: 4.6 per cent.

Source: Woody Turner, who acknowledges assistance from the NASA Goddard Space Flight Center and the Washington, DC office of Conservation International

Gombe National Park

Mountain ecosystems are increasingly being fragmented into patchy 'habitat islands' as a result of human activity. This process of land cover change can be assessed using remote sensing data and geographic information system (GIS) approaches.

Gombe National Park is located on the east coast of Lake Tanganyika, western Tanzania. The park is part of the unique Albertine Rift biodiversity region and is known around the world for its chimpanzees, which have been studied intensively over a long period. Chimpanzees are threatened with extinction, primarily because of habitat loss and fragmentation. In 1960, the Tanzanian chimpanzee population extended along the eastern shore of Lake Tanganyika and was linked with populations in Burundi and Rwanda. Today, there are only small isolated fragments of woodland habitat in this area, separated by a matrix of human settlements, and cultivated and degraded land. These patches of habitat are critical for maintaining the viability of the chimpanzee population in the area and may act as refugia for some endemic species of the Albertine Rift region. To design effective conservation strategies there is a need for spatially explicit information on the trends in land use and land cover change.

A 30-year archive of Landsat satellite imagery now available worldwide can provide unique insights into land cover change in mountain areas. Analysis of the area adjacent to the Gombe National Park and along the major roads and settlements close to the Tanzania-Burundi border indicate major loss of forest area, which has apparently been caused by the harvesting of trees for charcoal production, and conversion of forest to farmland and oil palm plantations.

At Gombe, data on chimpanzee distribution and behaviour have been collected since 1960. GIS tools enable these data to be combined with historical information on habitat change at the local and regional scales. The success of linking chimpanzee point observations with remotely sensed habitat data depends upon the appropriate definition and partitioning of habitats at the spatial scales that are recognized by the chimpanzees. In west Tanzania chimpanzees use diverse habitats that vary from evergreen forests and woodlands to open grasslands and savannas, but

Figure 33 shows forest loss indicated by change over 1972-2001 in the normalized difference vegetation index (NDVI). NDVI is derived from Landsat MSS and ETM+ satellite data and provides a measure of chlorophyll density in living vegetation.

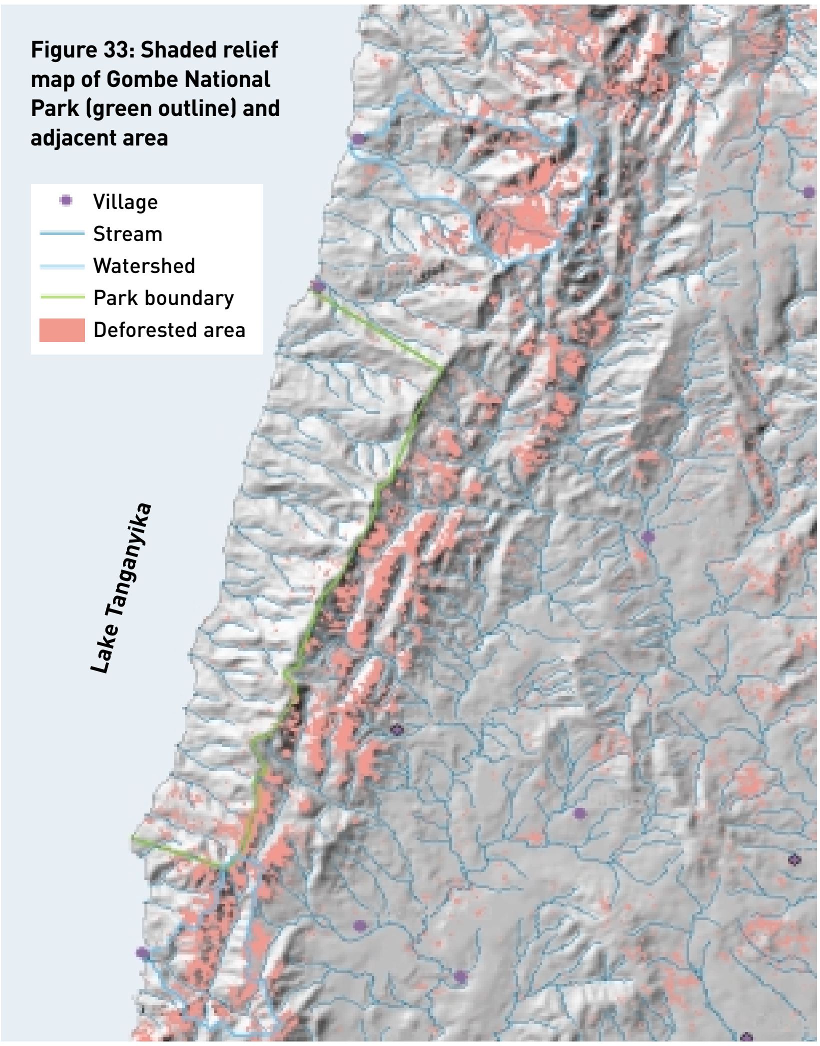


Figure 33: Shaded relief map of Gombe National Park (green outline) and adjacent area

always include at least a small percentage of evergreen forest.

At 30-metre Landsat TM/ETM+ type spatial resolution it is possible to differentiate habitat classes over hundreds of kilometres. The new high-resolution satellite images provided by IKONOS 1-m pan-sharpened data, combined with additional GIS layers, enable individual food patches such as trees to be visualized, as well as providing an assessment of habitat condition.

Analysis of remote sensing data for the Mtanga watershed in the Kigoma region of Tanzania (Figure 35) indicates that severe deforestation has occurred in this area. Most of the *miombo* woodlands on high slopes have been converted to farmland. In January 2001, a flash flood occurred in Mtanga village that resulted in dozens of human lives lost and destruction of households and village infrastructure. Reforestation of degraded watersheds such as this could provide a win-win opportunity to restore both chimpanzee habitats and decrease people's vulnerability to future disasters.

Source: Lilian Pintea, Jane Goodall Institute's Center for Primate Study, University of Minnesota
IKONOS satellite image courtesy of Space Imaging

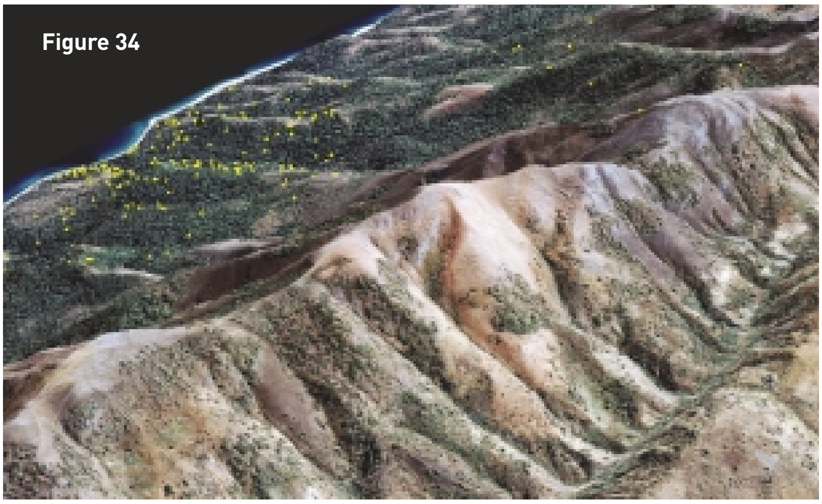


Figure 34 shows the distribution of an individual female chimpanzee's (Fifi) feeding sites in 1998 (yellow dots). These are overlaid on a natural colour synthesized and 1-m pan-sharpened IKONOS satellite image of part of Gombe National Park, draped over a digital elevation model (DEM) derived from 1:50 000 elevation contours. Forest cover remains extensive within the park between the ridge and Lake Tanganyika at upper left, but has largely been cleared outside the eastern park boundary running along the bare diagonal ridge.

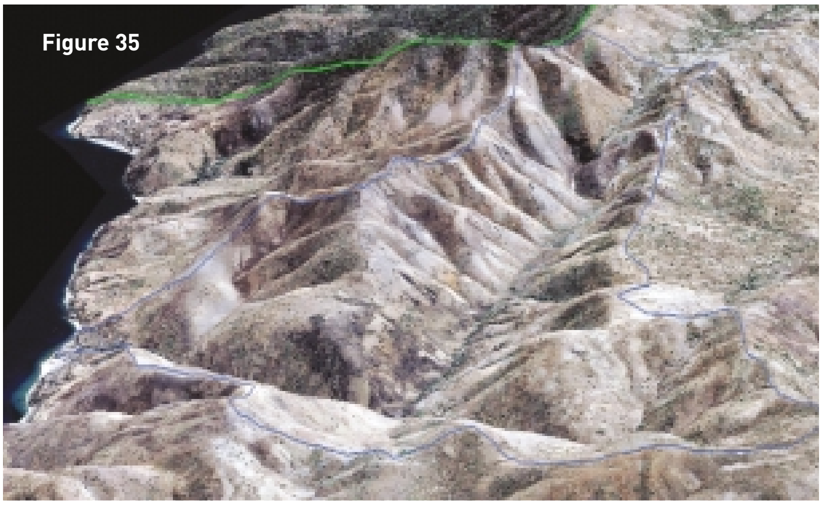


Figure 35 is an IKONOS natural colour satellite image from a point to the south of Figure 34, showing parts of the park (top) and the deforested Mtanga catchment to the south (watershed in blue). Deforestation may have contributed to the flash flood that swept down the valley (centre) and west through settlements at the lake shore.

Chile's temperate forests

Chile's extensive temperate forests occur between 36.5° S and 54° S, mainly on uplands, and isolated by physical and climatic barriers. Isolation has resulted in high endemism in plants and animals: almost 90 per cent of the 850-900 woody species in Chile are endemic to the temperate forest region. Although biologically rich, the native temperate forests are subject to high rates of loss, especially through conversion to plantations of exotic species, particularly of *Pinus* and *Eucalyptus*.

If the impact of future conversion is to be minimized, it is important to identify high priority areas of native forest, defined as areas that are both highly vulnerable to conversion and important for biodiversity maintenance. 'Vulnerability' can be represented as a function of two variables: exposure to the threatening processes and the ability to respond.

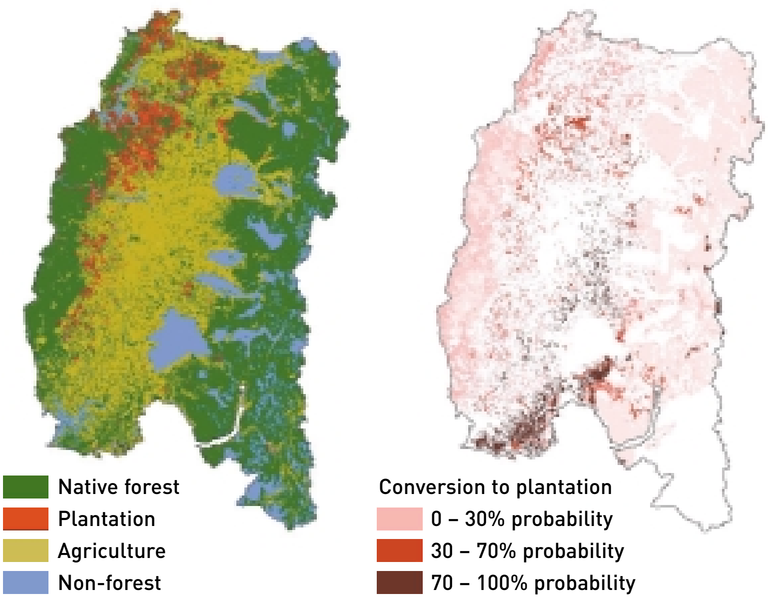
The study area for this vulnerability assessment comprises a subset area of Region X, between the coastal range and the Andes, from approximately 39.5° S to latitude 43° S. The study area covers some 4.2 million hectares.

The assessment identifies vulnerable areas as those with the highest probability of being converted to plantations at some stage in the future. The steps employed in this process are outlined below:

1: Identify variables that may function as proximate causes for the conversion of native forest to plantations; these include distance to nearest roads, soil type and climatic factors.
2: Use existing land cover maps to assess spatial distribution of plantation conversion in the recent past.
3: Develop a multivariate spatial model of plantation conversion to identify forest areas that are vulnerable to future conversion.
4: Generate a grid-based map output (see Figure 36), with each grid cell assigned a vulnerability rating representing the probability of conversion.

The results of this vulnerability assessment have been combined with an assessment of biodiversity elements to identify priority areas for conservation action in the study area.

Figure 36: Chile's forests and probability of conversion to plantation



Source: Kerrie Wilson. Abstracted from work in preparation: Incorporating data on uncertainty and vulnerability into systematic reserve selection. University of Melbourne, Australia; a contribution to the BIOCORES project with UACH, Chile

Lesotho highlands dam

Lesotho is a small land-locked country entirely surrounded by the Republic of South Africa. Most of the large rivers in the latter arise in the mountains of Lesotho. The Lesotho Highlands Water Project (LHWP) is designed to supply water to Gauteng Province in South Africa, and hydropower to Lesotho, otherwise dependent on its neighbour for energy, using some 40 per cent of the water in the Senqu (Orange) River system in Lesotho. With five large dams to be constructed, water will be diverted through 200 km of tunnels in the Maloti Mountains, to the Ash River in South Africa and ultimately the Vaal Dam south of Johannesburg. The LHWP is Africa's largest current infrastructure project and one of the largest in the world. With a contract between Lesotho and the apartheid government signed in 1986, the first dam (Katse) was closed in late 1995, and the second (Mohale) is nearing completion.

Lesotho depends almost entirely on South Africa for economic income, and many men are employed in South Africa's mines. With low returns from mining forecast in the late 1990s, the LHWP was a very welcome potential source of income, and further employment opportunities are anticipated if the project continues. Schools and clinics have been built, and other benefits introduced to the Lesotho highlands. Conversely, more than 20 000 people in the once remote highland communities have been affected by the first phase, losing either homes, communal grazing lands or farmland, and with only 9 per cent of Lesotho's land regarded as arable, any loss is nationally significant. Communities have been separated by the Katse reservoir, while at the same time, reportedly around 20 000 project workers and others have moved into the region, and AIDS is now a problem. Few grievances have been fully addressed.

Some water experts in South Africa believe that further dams could be postponed if demand-management measures are implemented in order to reduce wastage, and fear that moving forward with the second dam will stall such measures and needlessly increase the cost of water at a time when the Government is undertaking to improve water services to millions of South Africans in the townships.

Figure 37: Satellite imaging of the Senqu River

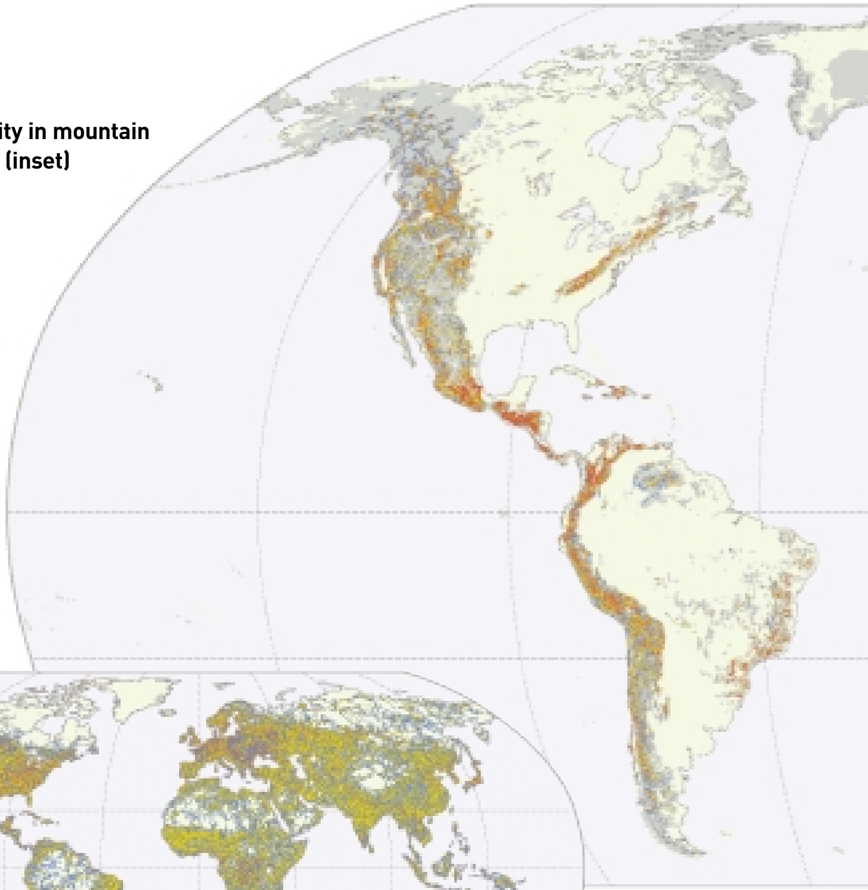
Figure 37 shows the Senqu River in northern Lesotho in its original condition (far left) and with the valley flooded over more than 30 km^2 (left) after closure of the Katse Dam. This water resource development will bring important benefits to many people, with some adverse effects on displaced communities.

Source: Kofoed Jesper, UNEP Division of Early Warning and Assessment (DEWA) Landsat imagery: Mark A. Ernste, UNEP Sioux falls, USA

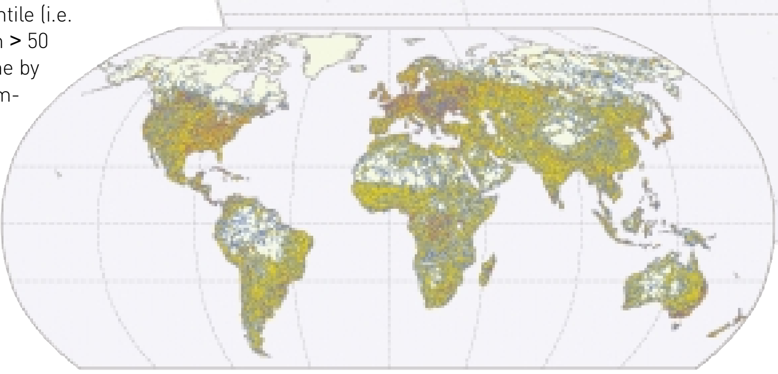
Figure 38: Impact of infrastructure on biodiversity in mountain regions for 2035, and current impact worldwide (inset)

Level of impact

- High
- Medium – high
- Low – medium
- Mountain region



Zones of impact were defined statistically based upon the distribution of declining species within different categories of distance to roads: 'high impact' = upper 50th percentile (i.e. the distance interval within which > 50 per cent of all species that decline by > 50 per cent are found); 'medium-high impact' = 25-50th percentile (the distance interval within which 25-50 per cent of all recorded species that decline by > 50 per cent are found), 'medium-low' impact = 1-25th percentile (the distance interval within which 1-25 per cent of all recorded species that decline by > 50 per cent are found).



Infrastructure

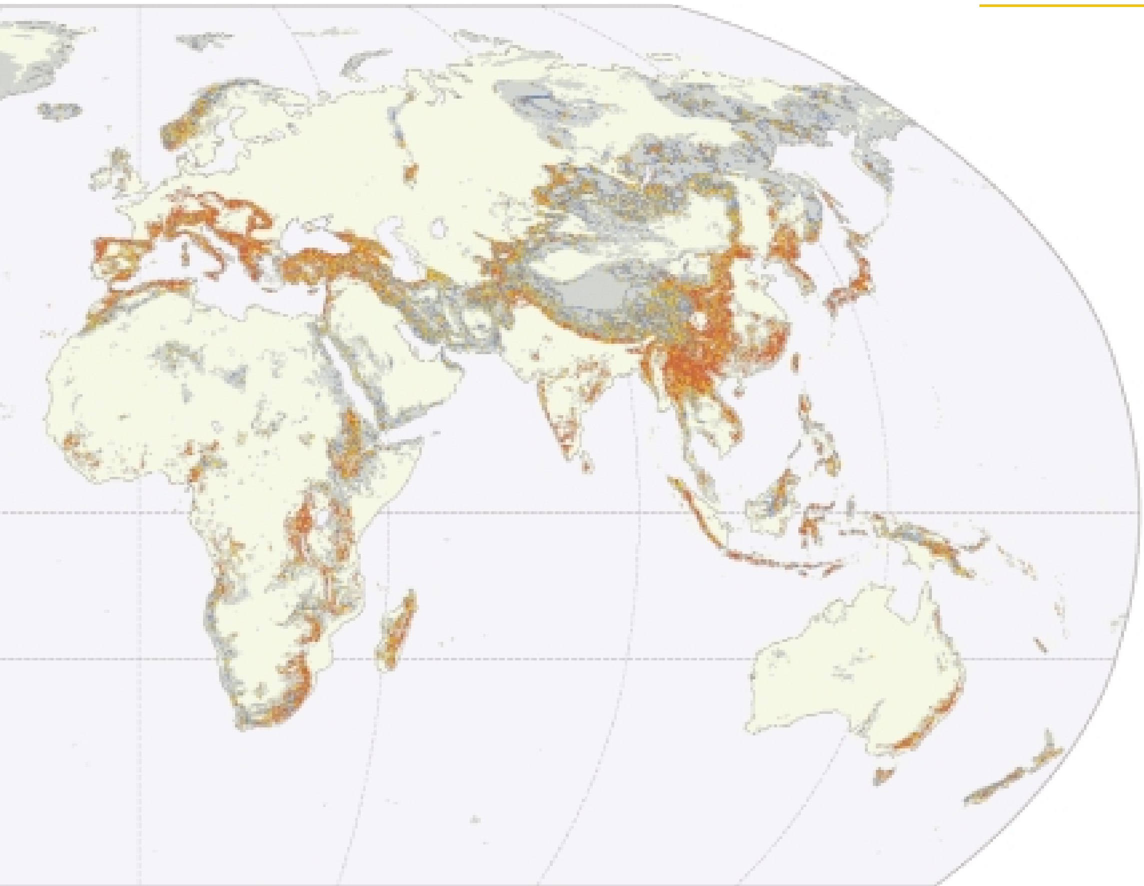
Economic growth is often supported by the development of infrastructure, including construction of roads, dams, pipelines and other industrial features. Such developments can improve access to resources and link communities to markets, potentially improving livelihoods in the process. Road construction facilitates the export of minerals, timber and other resources, increases access by tourists, and improves communication.

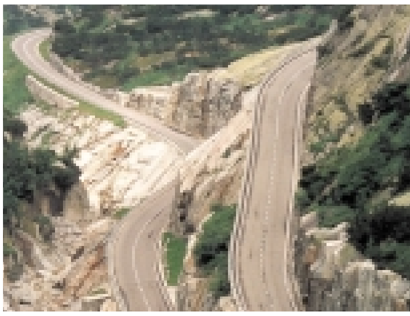
However, the development of infrastructure in mountain areas is often driven by the demands of lowland economies and political needs. The presence of major transit routes may benefit people living outside mountain areas more than local communities, which may suffer increased noise and air pollution.

Infrastructural development can have significant negative environmental impacts. Road construction can promote the overexploitation of natural resources and result in environmental degradation, for example through timber extraction and deforestation. Roads can also increase immigration into an area, resulting in increased use of resources, agricultural expansion and urban development. Dam construction has major impacts on the hydrology of mountain watersheds, and affects water flow and sedimentation downstream. Mineral extraction can lead to increased pollution, and sometimes causes social problems.

Development of infrastructure has a major influence on patterns of land use. Road construction can significantly increase the rate of forest conversion to agricultural land, and industrial development can alter the role of different land uses in local economies. Infrastructure can also influence the likelihood of human conflict. Improved access can facilitate law enforcement in areas remote from centres of government, but may also lead to immigration and an increased risk of social tension.

Infrastructure can have a major effect on biodiversity, as many species are unable to disperse across features such as roads and pipelines. Habitat fragmentation and the increased isolation of populations that results therefore increase the risk of extinction.





Source: GLOBIO data from UNEP/GRID-Arendal, as UNEP (2002)

Difficulties associated with terrain have previously limited the development of infrastructure in many mountain regions. However, technological advances coupled with a growing demand for resources are leading to increased infrastructural development in many mountain areas. In order for development to be sustainable, the adverse environmental impacts of infrastructure need to be minimized. This requires careful planning, for example by assessing the potential impacts of proposed development schemes.

Most mountain areas are susceptible to development under the assumptions of the GLOBIO model, with almost half the Australasian and Southeast Asian region being affected by 2035. North and Central American mountains were simulated as undergoing the least infrastructural impact under this scenario.

SPATIAL DATA

The infrastructure maps were produced using satellite remote sensing data. The GLOBIO model was used to assess the current impacts of infrastructural development [Figure 38 inset]. This is a spatial modelling approach based on the definition of buffer zones that indicate the probability of reduced abundance of wildlife occurring around infrastructure features such as roads, major trails, human settlements, industrial features such as power lines, dams, etc. These probabilities are derived from review of field research into the effects of infrastructural development (for further details consult http://www.globio. info).

The GLOBIO model was also used to develop scenarios of possible impacts, based on current trends in development of infrastructure [Figure 38, main map].

Table 13: Percent of mountain land with 'high impact' from infrastructural development for the year 2035

REGION	%
North and Central America	21
South America	27
Eurasia	27
Africa	33
Australasia and Southeast Asia	49
Greenland	0
GLOBAL VALUES	
% of all 'high impact' land to occur in mountain regions	24

Note: The model combines the amount of infrastructural development modelled for the region, and its likely impact on biodiversity.

Mapping the Alps

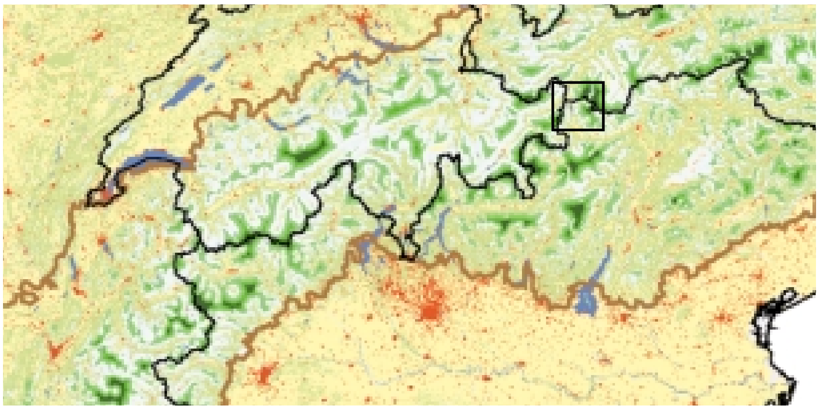
WWF-Austria has used geographic information systems (GIS) to assess and map relative wilderness values in the European Alps. This will support a range of conservation efforts and local planning activities under the WWF European Alpine Programme, and has already promoted cooperation between Alpine institutions, commercial companies and other relevant Alpine bodies.

The mapped wilderness quality measures the distance of any specified location from permanent structures such as settlements, roads and railways, associated with modern technological society. Increased remoteness from such infrastructure corresponds to higher wilderness values; Figure 39 shows particularly high values along the main Alpine crest as well as in existing protected areas. Wilderness areas in general have high naturalness, and are of great scientific and conservation interest, often providing refuges for rare or threatened species.

The wilderness analysis is now an important planning tool in continuing cooperation between WWF and the Austrian Federal Forestry Agency (Österreichische Bundesforste AG), the biggest landowner in Austria. Current discussion focuses on establishment of an IUCN Ib category protected area in the Ötztaler Alpen. Here, ÖBf ownership boundaries were mapped as an overlay on the wilderness plot, providing a shared information base for discussion. In another application, detailed conservation recommendations were produced for Austrian Cable Cars plc. (Österreichische Seilbahnen AG) in order to improve planning of future cable car lines and reduce impact on high wilderness areas. WWF will also use the analysis to calculate the economic benefit of wilderness areas in the province of Tyrol, Austria.

This GIS analysis provides an effective large-scale method to identify the most remote and undisturbed areas of the Alpine mountain ecosystem using scientifically sound and objective data. It provides an important tool for cross-border conservation in the Alps, particularly in support of WWF's European Alpine Programme, which aims to protect the remaining wilderness areas of the Alps and to stop further development within already heavily fragmented regions. The analysis can be regularly extended as new or improved data become available.

Figure 39: GIS analysis of the wilderness values of the Alps



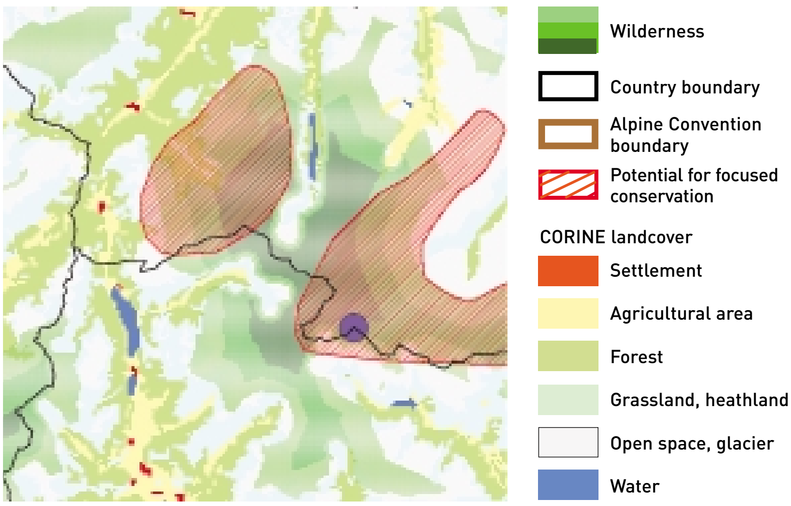


Figure 39: The upper map shows relative wilderness levels in the European Alps, the square outline showing location of the lower map, a larger scale view of the Ötztal region where the 'iceman' Ötzi was found (purple circle), now subject to conservation planning and wilderness preservation.

Source: Thomas Kaissl and Gerald Steindlegger; WWF-Austria Alps Campaign: Reichtum Alpen - gemeinsam sichern! www.wwf.at

Norway's reindeer

Over thousands of years, the mountain landscape in Norway has been modified by subsistence activities. In the past 50 years a vast network of logging roads has penetrated the mountain forests. Extensive hydropower development and mining have affected most mountains and drainage systems with an extensive network of roads and power lines.

The cumulative impacts have been substantial. By the end of the 20th century, nearly 90 per cent of the country was subject to the effects of infrastructure. More than 2 000 cabins have been built annually since the 1980s, resulting in extensive disturbance of wildlife in the mountain forests and subalpine areas. The last remaining population of less than 30 000 wild mountain reindeer *Rangifer tarandus tarandus* in Europe now share their range with the summer sheep population of over 2 million. The reindeer, dependent on migration between winter and summer ranges, have been fragmented into 26 isolated subpopulations. Maternal females in particular avoid the vicinity of roads and recreational cabins, so that traditional ranges are reduced and undisturbed sites far from development are overgrazed. As infrastructural development continues, predators and prey become concentrated in smaller fragments of former range, escalating both conflicts and management problems. The red fox *Vulpes vulpes*, a small generalist predator, has increased dramatically in numbers, while the specialized Arctic fox *Alopex logopus* is now threatened with extinction as a result of range fragmentation and competition from the red fox.

Decentralization of government control appears to have reduced strategic planning, promoting piecemeal development in favour of commercial and corporate interests, with resultant loss of wildlife habitats. Positive steps include a large reduction in sulphur (SO_2) deposition from Europe, and the establishment of more national parks. The potential merging of a series of proposed national parks, such as Breheimen, Jotunheimen, Reinheimen, Dovrefjell-Sunndalsfjella, Knutshø, and Rondane, may help protect the last undeveloped mountains and strengthen the only remaining corridor between the eastern and western range, a traditional migration route for reindeer that has now been interrupted by infrastructure for more than 80 years.

Figure 40: Reindeer populations

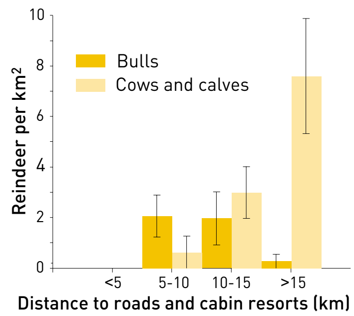


Figure 41: Wilderness loss in Norway

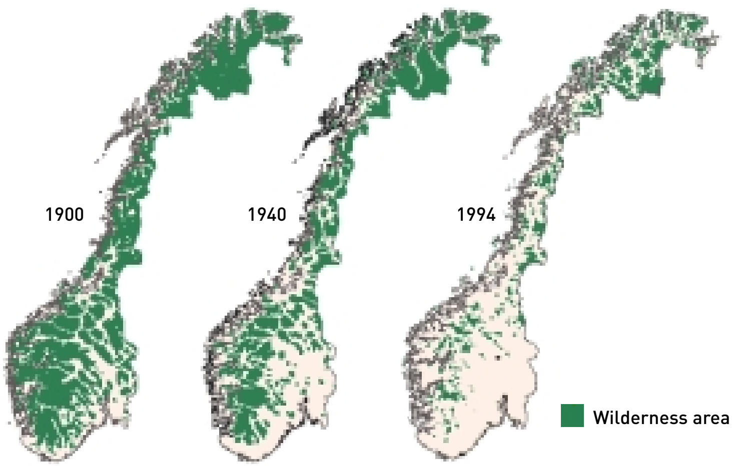


Figure 40 records reindeer females and young avoiding the vicinity of roads and cabins.

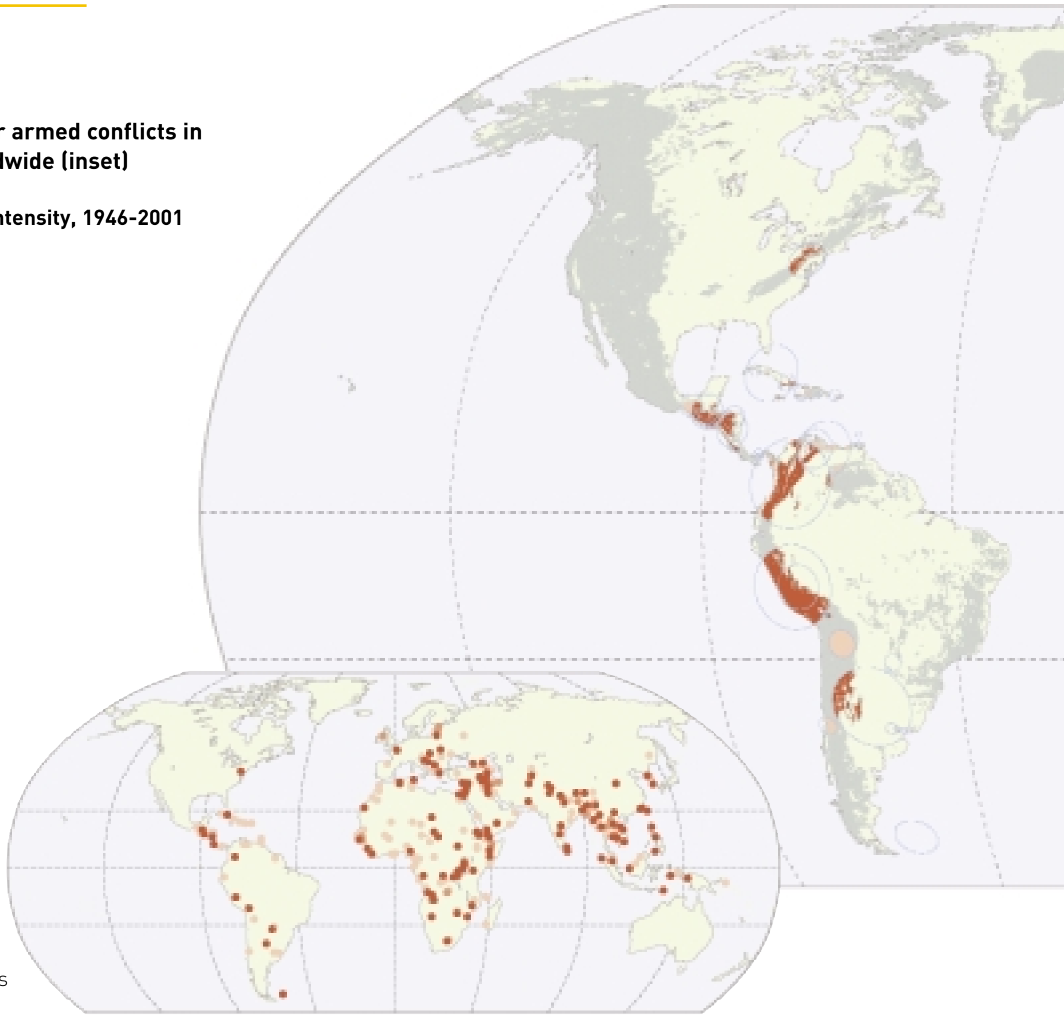
Figure 41 clearly shows the extreme decline in remote wilderness area during the 20th century.

Source: Christian Nelleman, Global coordinator, GLOBIO; UNEP GRID-Arendal, Norway
Further information: Vistnes, I, Nellemann, C, Jordhøy, P, and Strand, O. 2001. Wild reindeer; impacts of progressive infrastructure development on distribution and range use. Polar Biology *24: 531-537*

Figure 42: Location of major armed conflicts in mountain regions and worldwide (inset)

Level of impact at maximum intensity, 1946-2001

- High
- Intermediate
- Low
- Conflict ellipse
- Mountain region



Maximum intensity is mapped from conflict centre points with a radius of 50-km accuracy. High impact (war) = at least 1 000 battle deaths annually; intermediate impact = 25-1 000 battle deaths annually but more than 1 000 in total; low impact = 25-1 000 battle deaths annually, with less than 1 000 in total.

Armed conflict

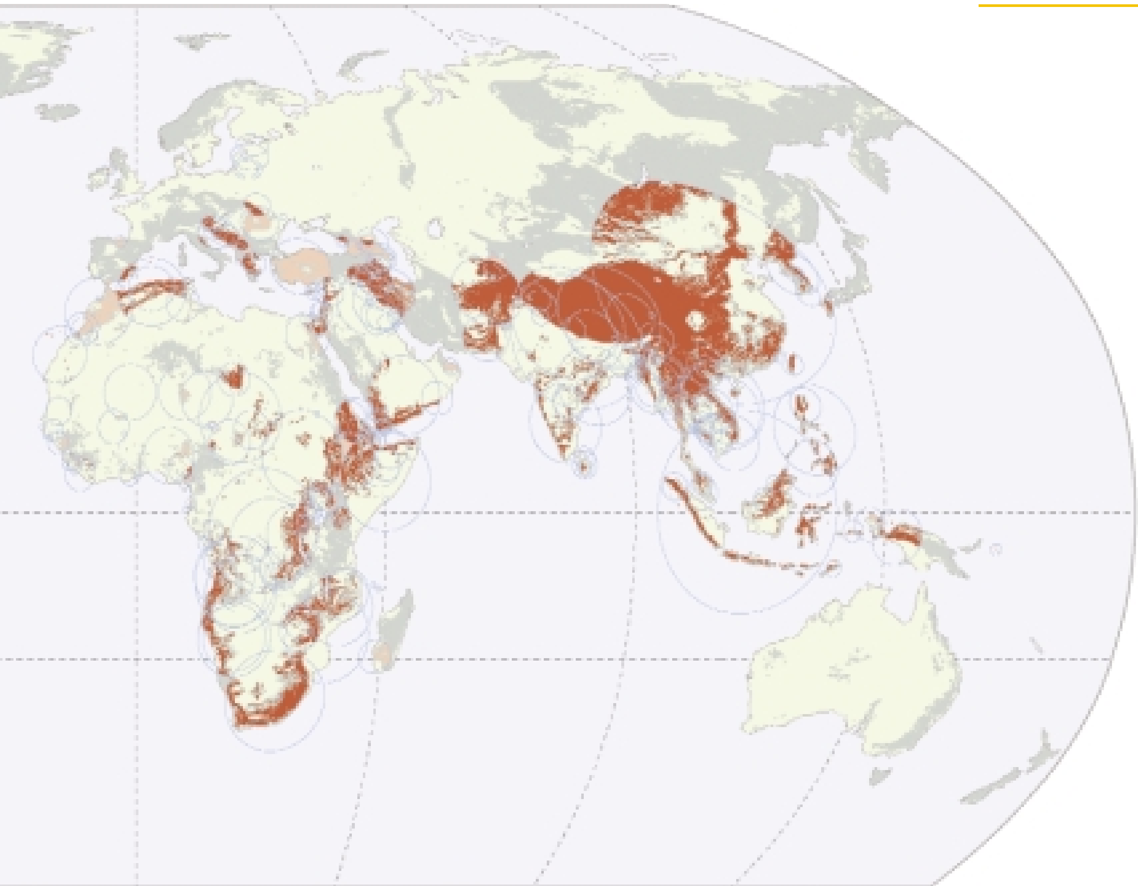
Conflict may be considered endemic to human society. Most conflicts are resolved by negotiation, bargaining or institutional processes. Violent conflict is relatively rare, but can result in serious environmental impacts, as well as causing substantial loss of human life.

Conflicts arise for social, political or economic reasons, but are often triggered by some form of injustice. However, the processes that determine whether or not conflicts become violent are poorly understood.

Although many national boundaries occur within mountain regions and can become the focus of interstate conflict, mountains also form a barrier to invasion, and are inherently easier to defend than lowland areas. Evidence suggests that civil wars, rather than interstate wars, may be more likely in mountain regions. Mountains give strategic advantage to insurgents by providing places of refuge. Mountainous terrain hinders road building, thereby restricting law enforcement. A lack of infrastructure can therefore make insurgent civil war more likely or prolonged.

Conflicts can also arise over competition for natural resources, which intensifies as populations increase and access to resources improves through the development of infrastructure. In countries dependent on natural resources for income, competition between powerful elites over 'lootable resources' such as timber and minerals can lead to prolonged civil strife. Many mountain areas are also centres of narcotics production, which can also lead to armed conflict. The role that mountain regions play in water provision may become the focus of increasing conflict in future.

The environmental impacts of wars can be substantial. Military operations can directly result in environmental degradation, overexploitation of natural resources and increased pollution. Wars also often result in the migration of large numbers of people, resulting in increased pressure on natural resources, for example around refugee camps. Conflicts can also have major impacts on biodiversity, as a result of habitat destruction, pollution, increased harvesting of species and disruption of migration routes.



Source: Based on PRIO/Uppsala Armed Conflict 1946-2001 v1.1; Buhaug and Gates (2002); Gleditsch et al. *(2002)*

Reduced ecosystem services owing to environmental change may increase competition for resources, raising the likelihood of conflict. Policies to prevent conflicts and rebuild post-conflict societies should seek to strengthen local decision-making and improve sustainable livelihood options for local communities.

SPATIAL DATA

Assessing human conflict is inherently difficult because those involved are rarely willing or able to provide accurate information. War zones are often isolated and dangerous, which severely limits opportunities for data collection, and estimates of numbers of casualties are subject to a high degree of inaccuracy. Figure 42 represents the intensity of conflict estimated to have occurred between 1946 and 2001.

The maps are approximate in nature because they are based on the estimated radius of conflict around a central point. These are the ellipses shown on the mountain map. The intensity relates to the estimated number of battle deaths in the entire ellipse, rather than in each map unit. Hence, conflicts with a larger radius appear comparatively more serious than those with a smaller radius, which is not necessarily reflected in the number of deaths.

The risk of serious violent conflict appears to be higher in mountain regions than in non-mountain areas. There is a significant difference between the 41 per cent of mountain and the 26 per cent of non-mountain regions that have fallen within the estimated radius of a high intensity conflict between 1946 and 2001. The proportion of mountain areas affected by conflict is substantially higher in Africa than in the other regions considered. Extensive areas have also been affected by conflict in Eurasia and Southeast Asia.

Table 14: Percent of mountain land within the radius of war*

REGION	%
North and Central America	5
South America	34
Eurasia	51
Africa	67
Australasia and Southeast Asia	54
Greenland	0
GLOBAL VALUES	
% of area within the radius of a war that occurs in mountain regions	32

* A war is defined as a conflict in which at least 1 000 battle deaths a year occurred for at least 1 year between 1946 and 2001

Afghanistan: post-conflict

Current reforestation schemes at Bamian (above) and near Kabul (opposite), bring welcome shade and greenery to a region with very little tree cover.

Cut timber being transported through Konar Province, Afghanistan.

The environment is often forgotten in post-conflict recovery plans, although it provides the foundation of human society and civilization. If the environment has degraded to the point where ecosystem processes are impaired and services are no longer available, reconstruction efforts are likely to fail no matter how much money and energy are put into the recovery effort.

Without addressing the enormous direct human cost of the past three decades of armed conflict in Afghanistan, the broader environment has also suffered heavy damage from military activity, refugee movements, overexploitation of natural resources, and lack of management and institutional capacity. The past three years of drought have added further pressure. This presents an enormous challenge to the Afghan people, over 80 per cent of whom live an agrarian lifestyle and thus depend directly on natural resources for their survival. During the December 2001 Bonn negotiations, the international community made a commitment to support the post-conflict Afghan Administration in striving for political stability, reconstruction, and the safe return of millions of Afghan refugees. These refugees will need a sustainable resource base if repatriation is to succeed.

More than 60 per cent of Afghanistan's land surface consists of mountains and hills. The core of the country is dominated by the Hindu Kush range, with the Wakhan corridor extending northeast to the Pamirs. This rugged terrain once held important wild pistachio woodlands and forests of spruce, pine, deodar, juniper and oak at higher elevations. The forests have been important refuges for threatened wildlife populations, including Asiatic black bear, Persian leopard, Caspian tiger and Bactrian deer, among larger mammals. These forests are highly important not just in harbouring biodiversity, but in restricting erosion in the steep and arid terrain, maintaining soil conditions, and sustaining the water table by slowing runoff.

Unfortunately, Afghanistan is estimated to have lost up to 30 per cent of its forests in the past two decades, and the remaining fragmented forest patches may cover less than 2 per cent of the country. Already the Caspian tiger and Bactrian deer are thought to have been lost from the country, and many other species of mammals and birds are undoubtedly threatened with extinction. The forests have been felled to provide wood for heating, cooking and housing construction. Some of the timber has also been illegally cut and exported to neighbouring countries for use as building materials. Regeneration has been hampered by soil erosion and grazing pressure. Few of Afghanistan's remaining timber stands are within existing protected areas, which only cover about 1 per cent of the country and have not had any management in a quarter century, highlighting the urgent need for protection.

The post-conflict recovery period will lead to further pressure on timber resources owing to the need for construction materials, as much of the physical infrastructure in the country has been destroyed. There will also be a critical need for heating material, especially as millions of refugees return and face the bitterly cold winters. If Afghanistan's remaining forest patches are to survive, alternatives must be immediately identified to prevent their unsustainable use. In addition, the efficient use of fuelwood for heating and cooking must be promoted.

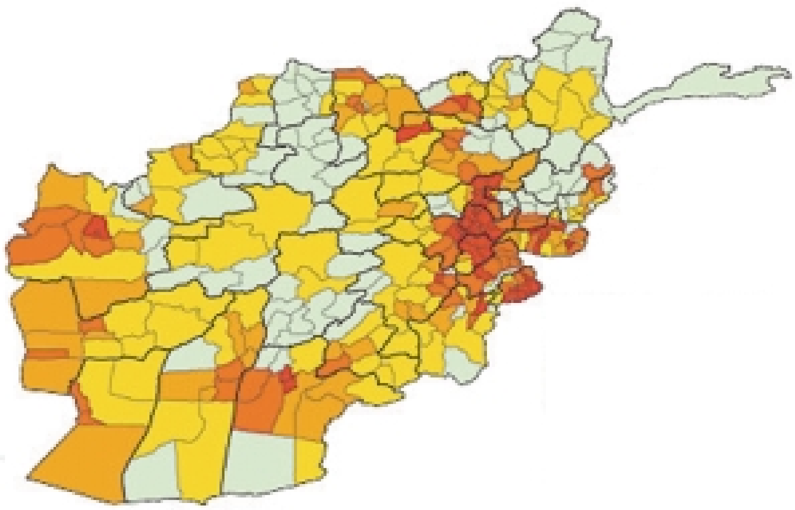
The United Nations Environment Programme (UNEP) is the United Nations body with specialized environmental expertise and with the responsibility to address environmental concerns. Since the Balkan conflicts, UNEP has developed special programmes for post-conflict environment assessment and recovery through the Post-Conflict Assessment Unit in Geneva. In Afghanistan, UNEP proposes to conduct a six-month strategic environmental mission to assess the state of the country's environment and to recommend projects to improve conditions. UNEP's assessment work is based on three components:

- remote sensing and field assessment of forests, protected areas, wetlands and pollution hotspots;
- evaluation of the administrative capacity within environmental institutions, with a view to support and development;
- identification of opportunities and potential benefits provided by international environmental conventions.

UNEP's field assessment of the environment will be conducted by six teams of international and Afghan experts. Remote sensing data for specific focal areas will be obtained from a combination of optical sources and state-of-the-art synthetic aperture radar (SAR). One aspect of the remote sensing activities will be to determine where existing mountain forest remnants can still be found, so that field mission teams can assess their condition and make recommendations for their management. The study will also identify the extent and rate of deforestation, and identify sites for potential protected areas and reforestation projects.

Source: Peter Zahler, UNEP PCAU, Geneva

Figure 43: Landmine-contaminated areas in Afghanistan, May 2002



Percent of settlements within 5 km of areas contaminated with landmines and unexploded ordnance (UXO)

0*
0 – 25
25 – 50
50 – 75
75 – 100
Province boundary

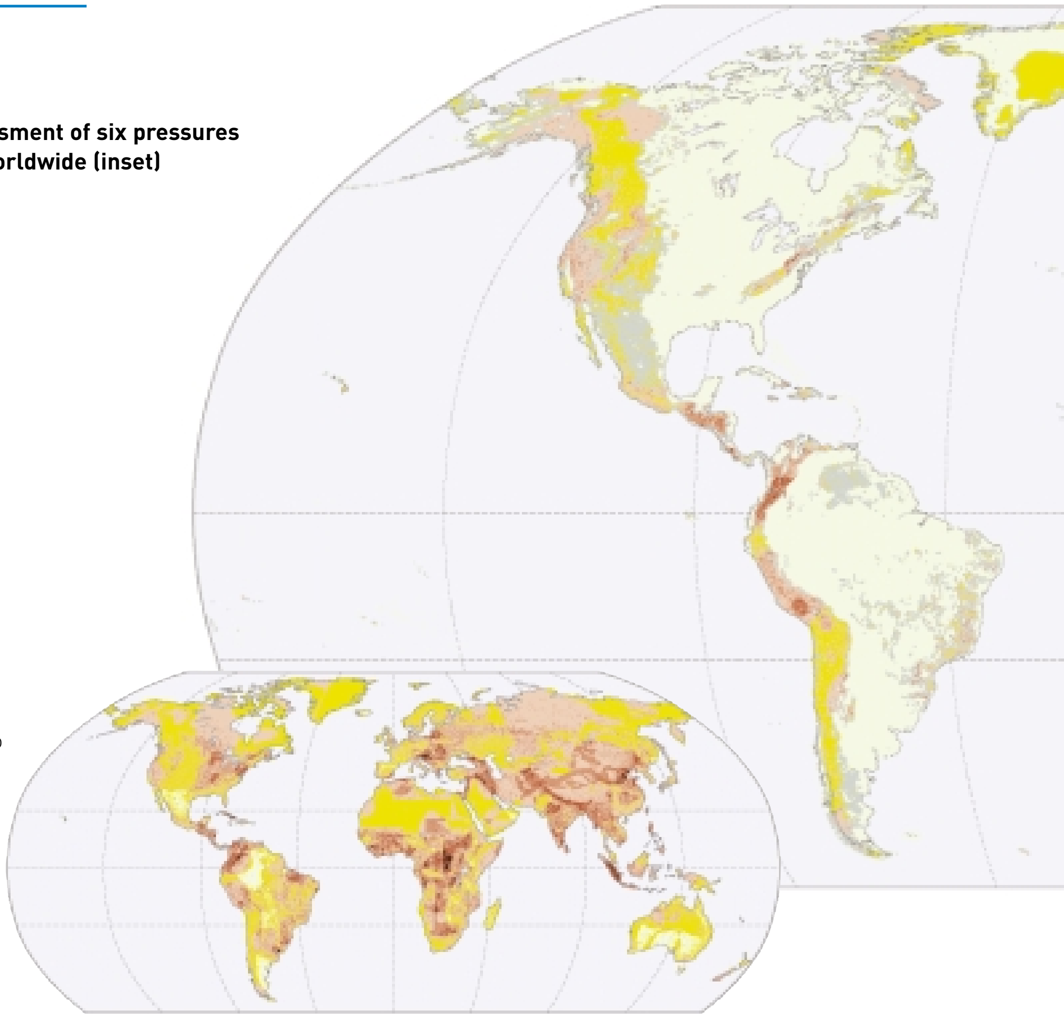
** 0 = no communities within 5 km of known/suspected contaminated areas*

Map prepared by the Afghanistan Information Management Service (AIMS) (UNAMA–UNDP at http://www.aims.org.pk/)

Figure 44: Integrated assessment of six pressures in mountain regions, and worldwide (inset)

Number of severe pressures

- 5 – 6
- 4
- 3
- 2
- 1
- Mountain region



Mountain areas most subject to the pressures considered here are widely distributed, both in the tropics – where the northern Andes, the African Rift Valley and Sumatra stand out – and in temperate regions, particularly Eurasia, including the Balkans, the Middle East, and the high mountains of Central Asia.

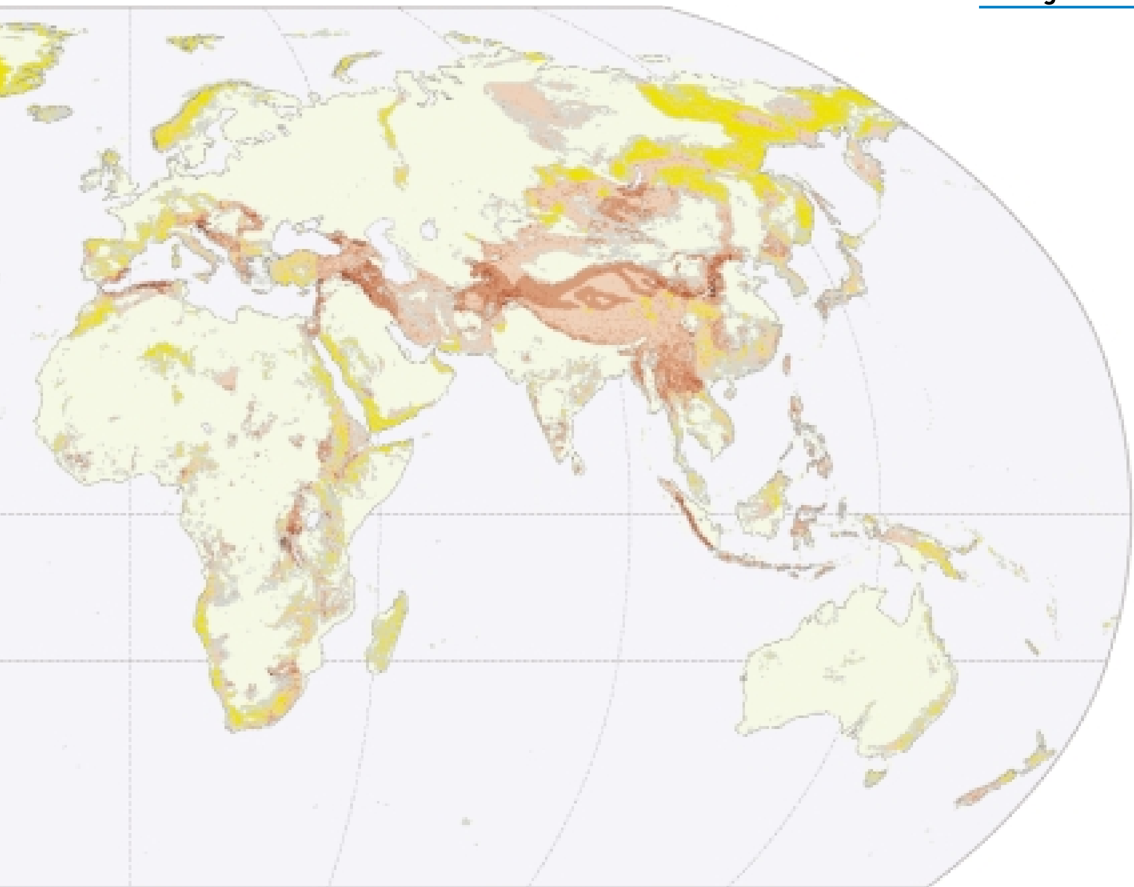
Pressures

Pressures causing environmental change in mountain areas can have a greater impact in combination than in isolation. Climate change, for example, may alter the probability of fire occurrence and its potential spread. Pressures can also interact in unexpected ways: conflicts can decrease land conversion by reducing opportunities for trade in agricultural goods or timber.

To produce this preliminary assessment of areas of high combined pressure in mountain regions, six global pressure maps presented in this report were reclassed as binary data (i.e. a 1 value where each pressure was considered to be severe, and a 0 value in all other locations; see Table 15). The maps generally had a 5' latitude-longitude resolution; those that differed from this were transformed using GIS prior to the binary classification. The values from the six binary maps were summed to give an overall score of 0-6.

One of the challenges of combining pressures is that each is assessed in a different way. The pressures illustrated include a combination of future scenarios (for climate change, infrastructural development and seismic hazard), and past or present reality (fire and conflict) (see Table 15). The agricultural suitability map defines areas that may be under pressure from conversion, but in the present preliminary analysis, does not distinguish between land already converted and land subject to future pressure. Ideally, in future analyses, the potential impacts of each pressure variable would be assessed to enable identification of those areas most vulnerable to environmental change. This requires information on the ability of a given area or ecosystem to tolerate the impact of the pressure under consideration, but information of this kind is often lacking. It may in future be possible to undertake such analyses, and to integrate data on different approaches more effectively, through the development and use of modelling approaches. Analysis and presentation of the uncertainty associated with pressure data and model outputs would also be of value to decision-makers.

Mountain areas are slightly



Source: See Figures as listed in Table 15

more likely to experience three or more severe pressures than non-mountain areas (24 and 23 per cent respectively). Results suggest that Eurasian mountains and those in Australasia and Southeast Asia experience a combination of multiple pressures over a larger percentage of land area than other mountain regions.

Table 15: Integrated pressures datasets

SOURCE MAP	DEFINITION OF SEVERE PRESSURE
Agricultural suitability for rainfed crops (Figure 30)	All map units classed as 'good' to 'very suitable' for rainfed crops
Nighttime fire: ATSR satellite observations, 1998-2000 (Figure 20)	All map units experiencing fire in the three-year period
Climate change anomalies: 2040-2069 means from five GCMs (Figure 22)	All map units with a decrease in precipitation > 50 mm/y and/or increase in temperature > 2.5° C
Conflict with 50-km radius of stated intensity (Figure 42)	All map units included in the radius of a conflict that led to at least 1 000 battle deaths per year
Global seismic hazard (Figure 16)	All map units with a 10% chance of exceedance in 50 years of a peak ground acceleration of 10% g ('destructive' quake on the Modified Mercalli scale)
GLOBIO scenario at 2035 (Figure 38)	All map units with an impact value of 1 (high impact)

Table 16: Percent of mountain land with three or more severe pressures

REGION	%
North and Central America	10
South America	21
Eurasia	31
Africa	22
Australasia and Southeast Asia	27
Greenland	0
GLOBAL VALUES	
% of area with three or more severe pressures that occurs in mountain regions	24

Figure 45: Severe pressures in mountain areas of importance for biodiversity

Pressures and values

- 3 areas, 3 – 6 pressures
- 3 areas, 1 – 2 pressures
- 2 areas, 3 – 6 pressures
- 2 areas, 1 – 2 pressures
- 1 area, 3 – 6 pressures
- 1 area, 1 – 2 pressures
- Mountain region

This map illustrates an approach to identifying areas of high biodiversity value in mountains that experience severe pressures. When the map of biodiversity value (Figure 15) was overlaid with the integrated pressure data (Figure 44), several areas in the Americas and Eurasia appeared of special concern.

Synthesis

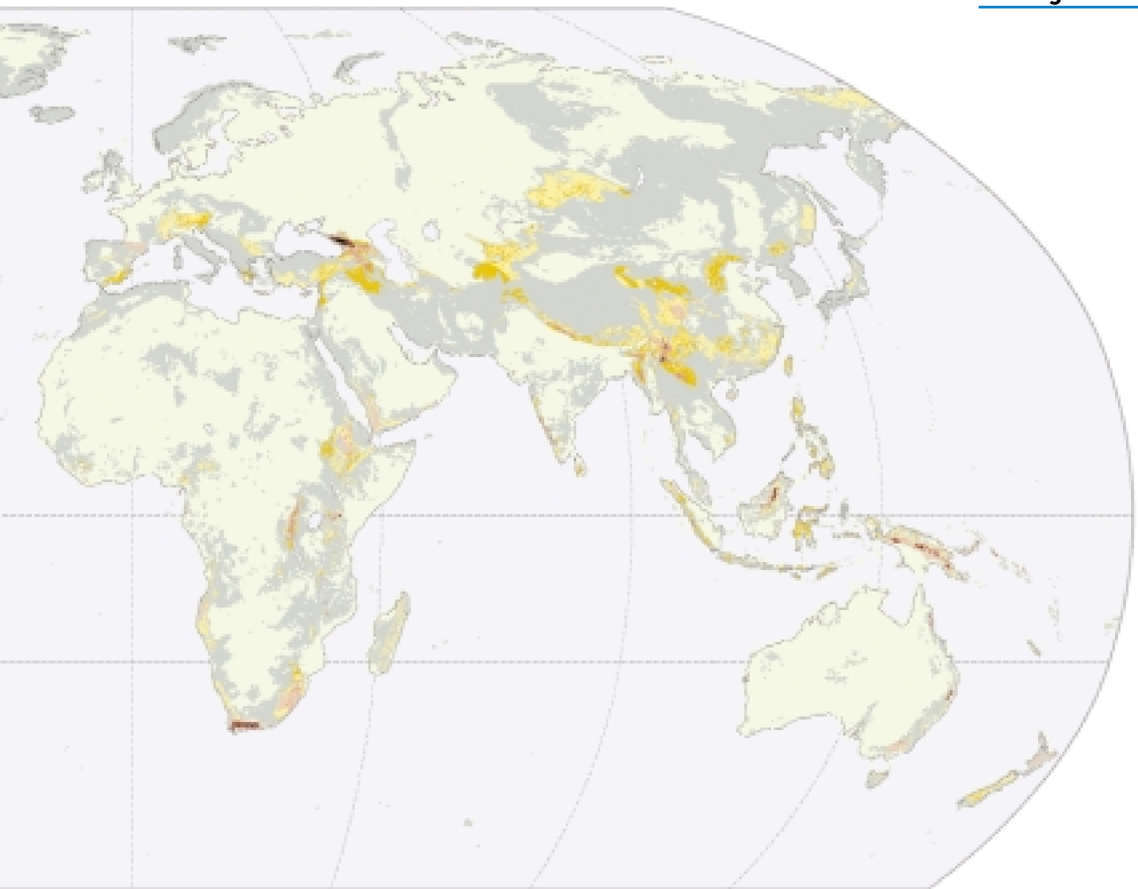
This analysis identified several areas of concern, which experience or are projected to undergo at least three severe pressures, and fall within three priority areas for biodiversity conservation. They are located primarily in South America and Eurasia, with a third group in North America, and constitute a very small proportion of total land area.

The South American area falls largely within the North-Western Andean moist forest and Magdaleña Valley dry and montane forest ecoregions, as defined by WWF (see http://www.worldwildlife.org/ecoregions). These represent dry and moist montane forest ecosystems in North-West South America. Some parts of surrounding montane ecoregions such as the Chocó-Darién moist forests are also of highest concern. Habitat loss in North-Western Andean forests is so far limited to low altitudes, but the Magdaleña Valley forests in Colombia have undergone major deforestation. Crucially, there are no protected areas in the Magdaleña Valley.

Most of the Eurasian area falls within the Caucasian mixed forests ecoregion, with some in the Crimean submediterranean forest complex, which includes montane pine forest. This Crimean mountain area has suffered from deforestation, but is still rich in endemic species.

A third area of concern includes parts of four Californian ecoregions, from chaparral to coastal redwood forests. This area has a history of logging and land conversion for agriculture. There is some protection in the form of National Parks, and intact habitats are more commonly found on the higher slopes than in the lowlands.

The analysis presented here should be considered as preliminary. Relatively few groups of organisms were included in the assessment. As Figure 15 shows, centres of diversity or endemism for one group of organisms do not necessarily correspond with those of another. Therefore an additional set of areas of high value would be expected were similar criteria applied to additional taxa. Furthermore, components of biodiversity unique to mountains, such as alpine plants, have not been explicitly



Source: See Figures 15 and 44

considered here. As improved data become available on patterns of diversity in other groups of species, they could be incorporated into this assessment. In addition, the approach here focuses on species diversity, but does not consider other elements such as genetic variation and ecosystems.

Biodiversity is a complex, multifaceted variable, which could be illustrated in many different ways. The most important information required by decision-makers is the identification of areas of high value for biodiversity, so that this information can be incorporated into environmental planning. The identification of high value areas at risk of environmental change, by combining pressure data with assessments of value, can assist in the prioritization of management action. However, it should be noted that biodiversity can be valued in many different ways. The simple scores of relative biodiversity value, as presented here, could similarly be applied to assessments of value based on cultural, amenity or economic criteria. Assessing the value accorded to biodiversity by different stakeholders is increasingly recognized as an important element of sustainable development.

Furthermore, several pressures of known significance for mountain systems have not been included in this analysis. Ideally, a measure of deforestation risk would be used, as would an assessment of suitability for other agricultural practices such as grazing. Habitat fragmentation and invasive species have not been included despite their importance for biodiversity. Future analyses should incorporate comprehensive assessments of different pressures, including those of particular importance within specific regions.

Assessments of the area affected or likely to be affected by different pressures could be used as indicators of sustainable development.

In future it would be useful to integrate data on pressures with other values and services. These analytical approaches could be applied to assess the impacts of change on the provision of water, forest resources or food.

Table 17: Percent of mountain land with three or more severe pressures and three values

REGION	%
North and Central America	0.19
South America	0.70
Eurasia	0.13
Africa	0.04
Australasia and Southeast Asia	0.13
Greenland	0.00

SUSTAINABLE DEVELOPMENT

Chapter 13 of Agenda 21 recognizes the need to strengthen knowledge about the ecology and sustainable development of mountain ecosystems, and to promote integrated watershed development and alternative livelihood opportunities in mountain areas.

Implementation has been led by the Food and Agriculture Organization of the United Nations (FAO), in collaboration with a wide range of partners. The Millennium Summit of September 2000 reaffirmed international commitment to sustainable development and the elimination of poverty, and defined the Millennium Development Goals, all of which are relevant to mountain areas. Furthermore, the World Summit on Sustainable Development, which took place in Johannesburg in 2002, developed a Plan of Implementation for sustainable development of mountain regions (see page 80). This section highlights some approaches and tools that could be used by decision-makers to work towards achieving these goals.

APPROACHES FOR SUSTAINABLE DEVELOPMENT

Development options that are particularly important in mountain areas include tourism, mining, and development of water and energy resources including dams. As with other development options, such as agricultural intensification and forest management, these approaches need to be planned and implemented appropriately to ensure that environmental impacts are minimized. Ideally, an environmental impact assessment would be carried out prior to development taking place, and impacts should be monitored to enable management approaches to be adapted appropriately. In some countries, such assessment and monitoring is required by legislation.

In areas that have experienced environmental degradation as a result of inappropriate development or overexploitation of resources, ecological restoration or rehabilitation may be required. The aim of restoration is to re-establish the key characteristics of an ecosystem, such as composition, structure and function, which were present prior to the degradation taking place. Such restoration can significantly improve the provision of ecosystem services to people. A large number of restoration projects have now been initiated in different parts of the world. In mountain areas, re-establishment of forest cover is often a priority. For example, in the European Alps, reforestation is being undertaken on a large scale to reduce avalanche risk.

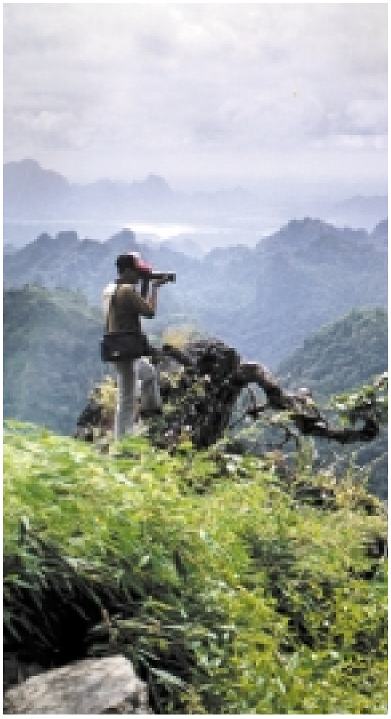
TOOLS FOR SUSTAINABLE DEVELOPMENT

Geographical information systems (GIS) are computer systems that can be used to assemble, analyse and display geographically referenced information. GIS technology is of particular value for resource management and development planning, by enabling maps to be produced incorporating a variety of different data layers. This can support an integrated approach to land use planning and development, which is a key requirement for sustainable development.

The previous sections of this report illustrate how GIS can be applied to assess environmental condition and trends, often by incorporating remote sensing data. The global maps present spatial data on different pressures affecting mountain environments. Such analyses enable areas at risk of environmental change to be identified and considered as priorities for action. For example, areas of particular importance for biodiversity conservation that are threatened by infrastructural development might be prioritized for designation as protected areas.

GIS databases can be used as decision support systems in a number of other ways. Modelling approaches such as GLOBIO can be used to develop scenarios of possible future change. These can be produced for different management options, providing an assessment of possible consequences. GIS tools can also be used to evaluate the potential of different rural livelihood options. The factors considered important for rural development, such as agricultural potential, access to markets and population pressure, can be represented spatially together with the likely environmental impacts of different land use strategies, to indicate development domains, where particular livelihood options are preferable. The definition of areas where potential environmental impacts and trade-offs are particularly high is of critical importance for ensuring that development decisions are environmentally sustainable.

Indicators summarizing complex data in relatively simple forms are now widely used to inform decision-making. Indicators can be developed for different environmental pressures, ecosystem condition, impacts and response measures, and can also be used as a tool to monitor change over time. Many initiatives focusing on sustainable development have identified the need for indicators to assist in the assessment of policy implementation, and to provide practical tools for resource managers. The methods of analysing and presenting spatial data illustrated in this report provide a basis for the development of such indicators.



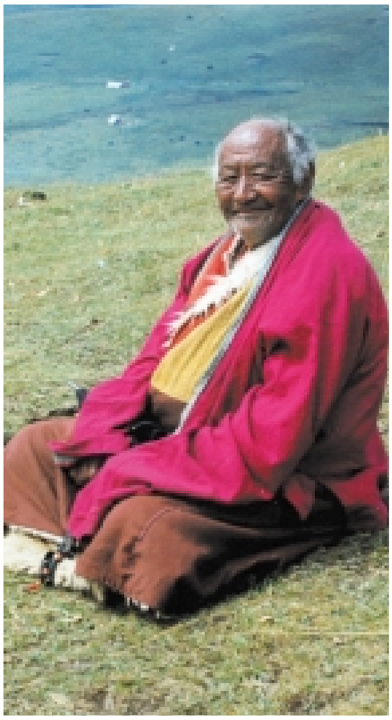
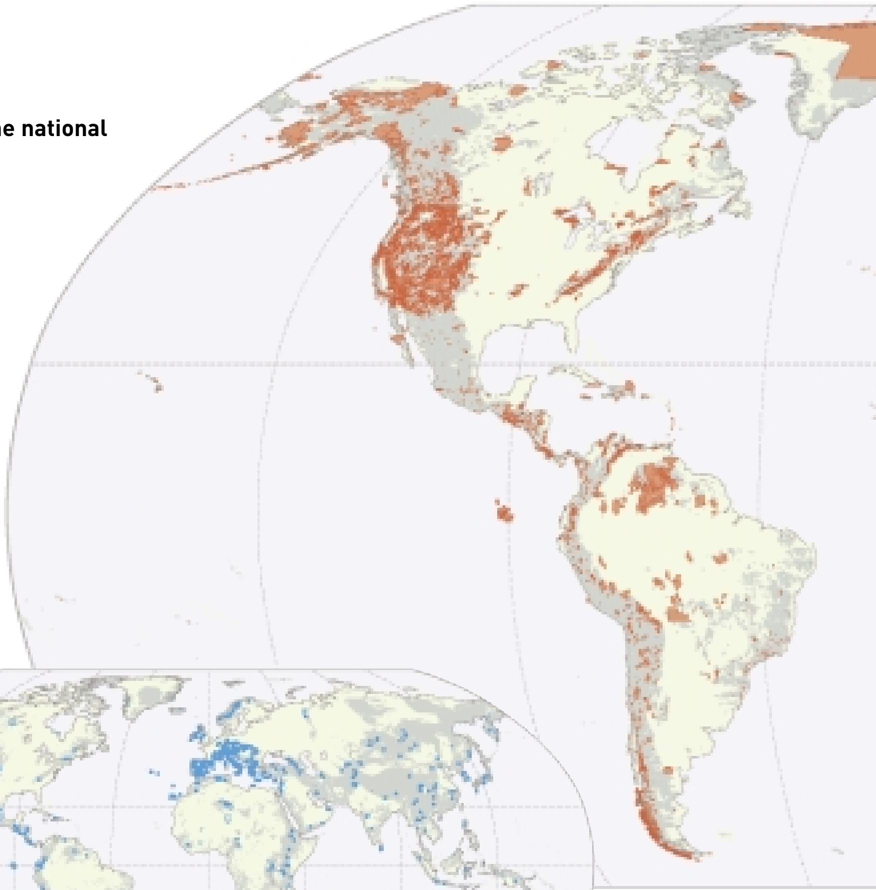
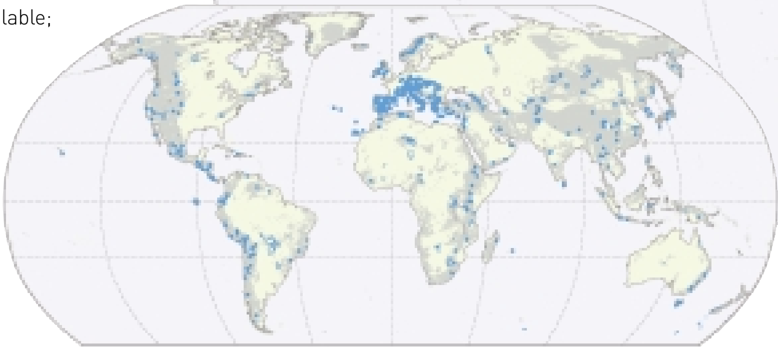


Figure 46: Protected areas in mountains at the national level and the international level (inset)

Protected areas

- Nationally designated sites
- Internationally designated sites
- Mountain region





The main map shows the position of all national protected areas thought to be entirely or in part within mountains. All management categories and sizes are included. Boundaries are shown for larger areas where data are available; the point symbols otherwise used exaggerate actual area in many cases. The inset shows international sites in mountains designated under the UNESCO Man and the Biosphere Programme, the World Heritage Convention and the Ramsar Convention. A small number of sites designated under European agreements are also included.

Protected areas

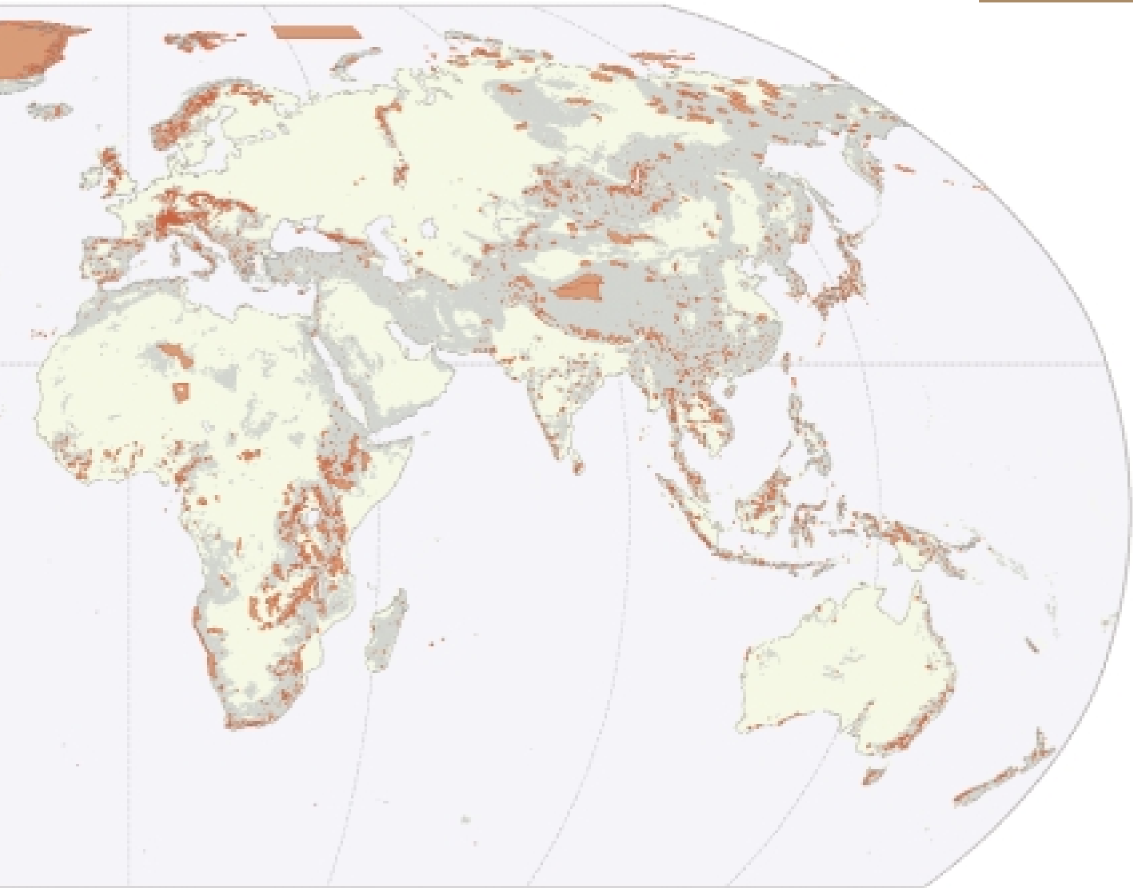
The initial purpose of many protected areas was to protect spectacular scenery and provide recreational facilities. As a result, many mountain areas were among the first to be accorded protected area status. With time, the concept has evolved to include areas of particular importance for biodiversity, such as locations that harbour threatened species or high species diversity. Increasingly, management of protected areas has also sought to meet the needs of people living within and near to designated sites. Because international boundaries were often drawn in mountains, these areas provide valuable opportunities for international cooperation in protected area management.

INTERNATIONAL SYSTEMS

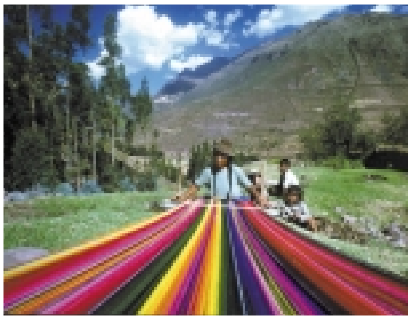
At global level two international conventions and one international programme provide for designation of internationally important sites. These are the World Heritage Convention, the Ramsar (Wetlands) Convention, and the UNESCO Man and the Biosphere (MAB) Programme.

The World Heritage Convention (Convention Concerning the Protection of the World Cultural and Natural Heritage) was adopted in Paris in 1972, and provides for the designation of areas of 'outstanding universal value' as World Heritage Sites, with the principal aim of fostering international cooperation in safeguarding these important areas. There are some 227 World Heritage Sites (123 cultural, 88 natural, 16 mixed). Ramsar sites are designated for conservation of wetland habitats; few are in mountain regions.

The establishment of Biosphere Reserves is not covered by a specific convention, but is part of the UNESCO Man and the Biosphere (MAB) Programme. Biosphere Reserves differ from the preceding types of site in that they are not designated only to protect unique or important areas, but to achieve a range of objectives including research, monitoring, training and demonstration as well as conservation. In most cases, meeting the needs of people is a central component to their management of Biosphere Reserves. Some 190 Biosphere Reserves are within mountains.



Source: UNEP-WCMC database, IUCN World Commission on Protected Areas



NATIONAL PROTECTED AREAS

Many other types of protected area have been designated within countries, including nature reserves, wilderness areas, national parks, natural monuments, habitat/species management areas, protected landscapes, managed resource protected areas, etc. In many cases, these coincide entirely or in part with international sites.

Many protected areas are effective in conserving species, habitats and landscapes of value. However, a large number are inadequately supported because of a lack of financial resources or capacity, and this can greatly reduce their effectiveness. Many protected areas are also under pressure from environmental change. For example, pressures such as fire, human conflict, natural hazards, land cover change and infrastructural development all have significant impacts on protected areas in many parts of the world, and present a major challenge to their effective management. In addition, climate change may in future have significant implications for the design and management of protected area networks.

Spatial information on the pressures responsible for environmental change, as presented in this report, can be of value for identifying those areas most at risk and therefore help to focus resources on those sites most in need of protection. In addition, spatial analyses can identify the extent to which priority areas for conservation coincide with areas of value for economic development, such as mineral exploitation, timber harvesting or agricultural production. Wise management of land outside the protected area network can also play an important role in the maintenance of biodiversity.

Table 18: Percent of mountain area within protected areas

REGION	%
North and Central America	30
South America	23
Eurasia	10
Africa	15
Australasia and Southeast Asia	25
Greenland	32
GLOBAL VALUES	
% of protected area that occurs in mountain regions	32

** These figures include IUCN categories I-IV plus other national sites with spatial coordinates in the UNEP-WCMC dataset. Sites designated under the Antarctic Treaty are not included.*

Note: the % of protected area that occurs in mountain regions is slightly larger than the % of the total global area defined as mountainous (27%).

GEF and mountains

In 2002, as we observe the United Nations International Year of Mountains, the Global Environment Facility (GEF) continues to champion initiatives that enable mountain communities to improve their quality of life while protecting globally important ecosystems. GEF supports projects in the areas of biodiversity, climate change, ozone layer depletion, international waters, land degradation (desertification) and persistent organic pollutants. Through these multiple areas of activity, GEF is helping mountain people face a full range of environmental problems.

BIODIVERSITY

The GEF biodiversity portfolio coverage in mountains is quite extensive, ranging from the Andes in South America, the Carpathians in Europe and the Drakensberg in Africa, to the Himalayas in Asia. The total GEF biodiversity portfolio contains more than 100 projects in globally significant mountain ecosystems. As of 2002, the GEF allocations for projects with mountain components total more than $601 million. Most of the projects have focused largely on protected areas and surrounding sites. In addition, at least 84 projects are in globally significant sites including World Natural and Cultural Heritage Sites, the Global 200 list, and UNESCO-MAB Biosphere Reserves, among others. In terms of geographic coverage, about 38 per cent of projects in mountain ecosystems are in Latin America, with 31 per cent in Asia.

Activities in GEF's mountains projects include *in-situ* conservation and sustainable forest management, water catchment and integrated watershed management, erosion control and other conservation programmes. Using community-based approaches, many projects identify sustainable use activities, such as ecotourism and the harvesting of non-timber forest products.

CLIMATE CHANGE

GEF is playing a catalytic role in promoting sustainable energy development, which will help mitigate the impacts of global warming on mountain environments. GEF aims to: remove barriers to energy conservation and energy efficiency; promote the adoption of renewable energy by removing barriers and reducing implementation costs; reduce the long-term costs of low greenhouse gas emitting energy technologies; foster more environmentally sustainable transportation systems; identify and implement measures to adapt to the impacts of climate change.

GEF renewable energy projects also directly support mountain communities situated far from existing power grids to have access to cost-effective and sustainable energy. Examples include renewable energy projects in Argentina and Lao PDR.

INTERNATIONAL WATERS

Many mountain ranges have been used as national boundaries. Rivers that originate in mountain ranges often provide freshwater to more than one country. GEF is contributing as a

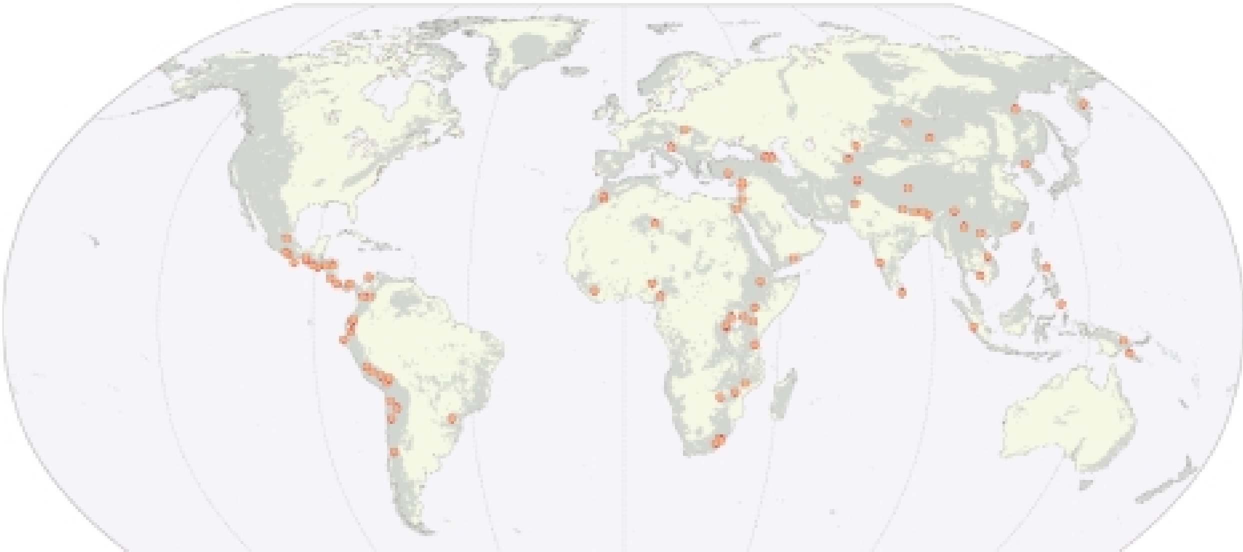
About the Global Environment Facility (GEF)

The Global Environment Facility (GEF) is a major catalyst for improving the global environment. Following a three-year pilot phase, GEF was formally launched in 1994 to forge cooperation and finance actions addressing four critical threats: biodiversity loss, climate change, degradation of international waters, and ozone depletion.

During its first decade, GEF allocated $4.0 billion, supplemented by $12.4 billion in co-financing, to more than 1 000 projects in 160 developing countries and countries with transitional economies. GEF is the only new funding source to emerge from the 1992 Earth Summit and today counts 173 countries as members. GEF is the designated financial mechanism for international agreements on biodiversity, climate change, and persistent organic pollutants; GEF also supports the work of the global agreements to combat desertification and protect international waters and the ozone layer.

GEF projects are carried out by a wide range of public and private partners. The United Nations Development Programme, the United Nations Environment Programme and the World Bank have managed GEF projects in their capacity as implementing agencies since 1991. In 1999, the GEF Council expanded the opportunities for seven other agencies to work on GEF projects. Today, the Food and Agriculture Organization of the United Nations, the United Nations Industrial Development Organization, the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, the Inter-American Development Bank, and the International Fund for Agricultural Development execute GEF projects.

Figure 47: GEF projects in mountain regions



GEF project   Mountain region

catalyst to the implementation of a more comprehensive, ecosystem-based approach in managing international waters, which includes restoring and maintaining mountain ecosystems associated with international waters. The Bermejo River Binational Basin projects in Argentina and Bolivia offer an example of GEF International Waters activities in mountains.

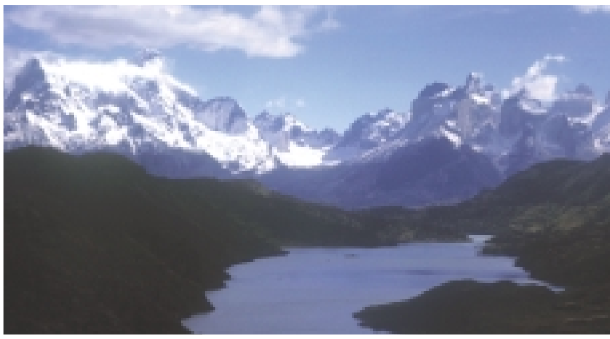
INTEGRATED ECOSYSTEM MANAGEMENT

GEF has started to catalyse widespread adoption of comprehensive ecosystem management interventions that integrate ecological, economic and social goals to achieve multiple and cross-cutting benefits. Typical GEF activities may include: improved management of a forested watershed to achieve multiple benefits, including improvements in soil and water conservation; aquatic biodiversity conservation; flood control, minimization of sedimentation of globally important water bodies; and reduction of net emissions or improved storage of greenhouse gases. This integrated ecosystem management approach is especially important when people in lowland and highland work together to protect their watershed environment and achieve sustainable development.

PERSISTENT ORGANIC POLLUTANTS (POPS) AND LAND DEGRADATION

Research has demonstrated a high concentration of POPs in some remote mountain lakes. GEF has been designated as the interim financial mechanism for the Stockholm Convention on Persistent Organic Pollutants, and supports governments in preparing national implementation plans. GEF has also been financing activities to prevent and control land degradation, cutting across the focal areas described above. In late 2002, the addition of POPs and land degradation as GEF focal areas was expected to enhance GEF's holistic support of mountain regions.

Note: The map above only includes:
(a) GEF's large and medium-sized projects categorized under GEF mountain ecosystem operational programme OP N°4
(b) GEF large and medium-sized projects whose area includes mountains, but which are categorized under other operational programmes in the biodiversity focal area.
Global projects, and other projects for which it is difficult to indicate the project area are not included. Locations are approximate.



Annapurna, Nepal

Nepal is centrally located in the Himalaya chain, and mountain ecosystems cover about 77 per cent of the country, supporting 52 per cent of the human population. Nine of the world's 14 recognized peaks rising above 8 000 m are within or border Nepal, and many rare species occur, such as the snow leopard and Himalayan thar. Nepal is a low-income country, ranked by the United Nations as among the 49 'least developed countries', and has among the lowest scores in the United Nations Development Programme's Human Development Index.

Most people in the mountains depend on forests for fuel, fodder, timber and medicine. Traditional energy sources, notably firewood and agricultural residues, respectively supply about 75 per cent and 20 per cent of the total energy demand in the country. Poverty and high dependence on firewood as the source of energy for cooking and heating have caused deterioration in the quality and quantity of forest cover and often contributed to soil degradation, erosion, landslides and flooding. The rate of population growth and lack of livelihood options in villages are two of the factors underlying pressure on forest resources. The mountain ecosystem is also affected by improper development interventions, high out-migration and, at present, insecurity caused by insurgence and political instability.

Various past initiatives have tried to address these issues, especially poverty, population growth and the environment in mountain ecosystems, but there remains a need to learn from these experiences and modify current initiatives accordingly. The Annapurna Conservation Area Project (ACAP) in Nepal attempts to build on past experience in a way that emphasizes the needs and aspirations of the local community. Although the creation and management of protected areas have traditionally been government responsibilities, the Annapurna Conservation Area is, for the first time in Nepal, managed by a national non-governmental organization – the King Mahendra Trust for Nature Conservation. The Annapurna Conservation Area extends over 7 629 km^2.

The rationale behind the project is to link conservation directly with quality-of-life issues and the basic human needs of the people living in an environmentally sensitive mountain region. ACAP promotes environmentally sound multiple land use, incorporating traditional methods of resource utilization and animal husbandry.

This integrated bottom-up approach to resource management distinguishes the Annapurna Conservation Area from many other environmental protection programmes. A fundamental element in ACAP is that instead of relying on legislation and force to exclude people, as in many protected areas elsewhere, the local communities are actively involved in conservation and development work toward long-term biodiversity conservation goals. Community needs, such as drinking water, health, schools and trail maintenance, are carefully integrated into the development programme.

At present, ACAP is one of the most frequently cited models in protected area management. The success of this approach was formally recognized by the Nepal Government, which took a bold step in amending the existing 1973 National Park and Wildlife Conservation Act N° 2029 with development of a new conservation area regulation 1996 (KMTNC 1996) and supporting guidelines 1999 (KMTNC 1999). The establishment of two new conservation areas suggests that this community-based conser-

Figure 48: Projects of the King Mahendra Trust for Nature Conservation, Nepal

Environmental research and monitoring in the Annapurna Conservation Area is supported by the Darwin Initiative

vation concept can be replicated elsewhere in Nepal.

The new approach of matching protection priorities more closely with human needs and aspirations is widely accepted as an important element in protected area management strategies. However, the question about whether this new approach provides a new paradigm for protected area management or whether it is just another fashionable trend is still to be answered. Current research aims to analyse the impacts of these conservation initiatives on biodiversity and on the livelihood of local people in the Annapurna region. Some of this work will use geographic information system (GIS) technology to integrate and analyse spatial data to expand the knowledge base on changes in the mountain ecosystem.

Source: Siddhartha B. Bajracharya, King Mahendra Trust for Nature Conservation

Women carrying fuelwood in the Annapurna region, with Machapuchare rising to 6 850 m in the background.

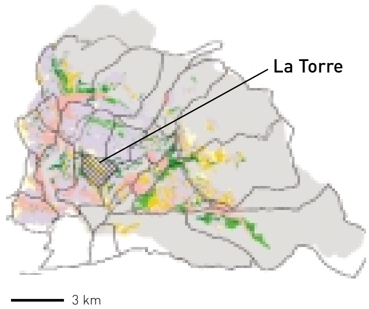
The Peruvian Andes

Since the early 1990s three trends have stimulated new approaches to natural resource management planning in the Andes. First, national governments in Latin America are decentralizing and allocating part of the national budget to be managed by local mayors. Second, the information revolution is making data and images on the Internet available to researchers and project officials at a low cost. Third, there is increasing opportunity to access land and weather data that had been exclusive to the military.

In a project initiated by CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion) and CIP (International Potato Center), secondary data were digitized and used to develop a database for two districts in the Cajamarca region of Peru. These districts comprise two small catchments and the database was designed to support planning at the local watershed level. Using a simple information flow diagram, data layers were compiled in a geographic information system (GIS) to build a slope classification map, a vegetation map and a soil depth map. Data sources included national and local thematic maps, aerial photos and information gathered during participatory planning processes. When combined and classified with constraints criteria, these data layers generated a map indicating where measures to reduce soil erosion were recommended. Interventions included terracing or infiltration ditches, and vegetation restoration and reforestation. By adding the boundaries of the local school districts (*caseríos*), the information could be targeted at decision-makers within local community groups. Table 19 summarizes the data in two typical *caseríos* in La Encañada (La Torre) and Asunción (Shirac).

Since this first exercise was completed in 1999, local NGOs have collaborated with municipal officials to expand the original databases and have developed maps focusing on grazing quality, irrigation canals and zones suitable for new crops, in accordance with community needs.

Figure 49: Soil conservation intervention for La Encañada watershed



Land use	Area (ha)
Annual cropping	
No intervention	417
Infiltration ditches	542
Sloping terraces	3 288
Permanent cover/restricted use	450
Permanent cover/protection	438
Degraded area	
Rehabilitation	1 092
Permanent ground cover	
No intervention	9 510

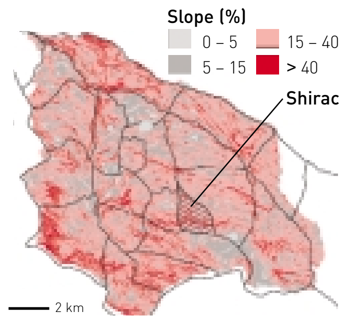
Top left: Farmers identify their land on an enlarged aerial photograph.

Source: Hector Cisneros, CONDESAN
For further information contact: Coen Bussink, c.bussink@cgiar.org, Pablo Arturo Sánchez, aspader@terra.com.pe, Carlos Cerdán, ccerdan@cedepas.org.pe, Jorge Reinoso, cirnma@terra.com.pe

Table 19: Interventions in cropland in the *caseríos* of La Torre and Shirac

CASERÍO	ANNUAL CROPPING AREA (HA)				
	Intervention not recommended	Infiltration ditches	Sloping terraces	Create permanent ground cover with restricted use	Create permanent ground cover for protection
La Torre (La Encañada)	41	35	127	0	17
Shirac (Asunción)	6	39	8	0	106

Figure 50: Classified slope map for Asunción watershed



The Colombian Andes

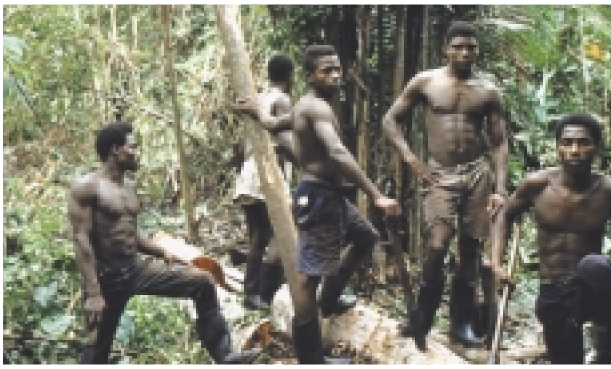
In part because of its location in northern South America, Colombia is exceptionally rich in biodiversity (one of the world's five 'megadiversity' countries), and the Andes is the richest region. Some 21 distinct ecosystem types differ markedly in altitude, climate and geology, tending to isolate populations in valleys and mountain tops, resulting in very high rates of endemism.

Although the biological diversity of the region remains incompletely documented, about two-thirds of the area is highly affected by human activities; some ecosystem types are now greatly reduced in extent, and many species are at risk.

The Global Environment Facility (GEF) is supporting an ambitious project, focusing on the conservation and sustainable use of biodiversity in the Andean Region of Colombia, with implementation over a six-year period led by the Alexander von Humboldt Research Institute (Instituto de Investigación de Recursos Biológicos Alexander von Humboldt). The project launches Colombia's National Biodiversity Policy and Proposed Action Plan, prepared within the framework of the Convention on Biological Diversity, and aims to:

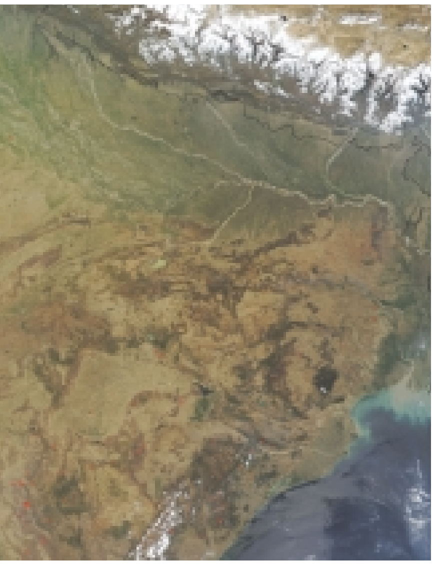
- support the development of a more representative, effective and viable Andean protected area system;
- identify conservation opportunities in rural landscapes;
- develop and promote management tools for biodiversity conservation;
- expand, organize and disseminate the knowledge base on biodiversity in the Andes to a wide audience of stakeholders and policy-makers and implement monitoring tools;
- promote intersectoral strategies to address some root causes of biodiversity loss in the Andes.

One project component will promote consolidation of Colombia's national protected areas system in the Andean region, and support planning for conservation zones and management in priority protected areas. A second will address the conservation and sustainable use of biodiversity in rural landscapes, a crucial component for an integrated strategy for the Andean region. Some ecosystem types and threatened species are found only in landscapes already modified by agricultural practices near and around the protected areas. The third component will support and expand existing efforts to improve knowledge and monitoring of different aspects of the region's biodiversity, emphasizing information for decision-making.



Source: Juan Pablo Ruiz Soto, Natural Resources Management Specialist, LCSES-Colombia LO, GEF

Defining mountain regions



Geographers have produced numerous definitions aiming to distinguish mountain environments from non-mountains; many build on common perceptions of what constitutes a mountain, and none is fully quantitative. With the support of the Swiss Development Corporation, UNEP-WCMC used criteria based on altitude and slope in combination in order to represent the environmental gradients that are key components of mountain environments (Kapos *et al.* 2000).

Topographical data from the GTOPO30 global digital elevation model (USGS EROS Data Centre 1996) were used to generate slope and local elevation range on a 30 arc-second grid of the world. These parameters were combined with elevation to arrive at the empirically derived definitions of six mountain classes. To reduce projection distortion in the original dataset, analysis was based on continental subsets in equidistant conic projection.

Class

1 elevation > 4 500 m
2 elevation 3 500 – 4 500 m
3 elevation 2 500 – 3 500 m
4 elevation 1 500 – 2 500 m and slope ‡ 2°
5 elevation 1 000 – 1 500 m and slope ‡ 5° or local elevation range (7 km radius) > 300 m
6 elevation 300 – 1 000 m and local elevation range (7 km radius) > 300 m
7 isolated inner basins and plateaus less than 25 km^2 in extent that are surrounded by mountains but do not themselves meet criteria 1-6

The seventh class was introduced in the 2002 revision of the original 2000 system. The global mountain area thus defined is almost 40 million km^2, or some 27 per cent of the Earth's surface. If all Class 7 areas are excluded, the total area classified as mountainous falls to 39.3 million km^2, and the area of non-mountain land increases to 107.6 million km^2.

Antarctica has been excluded from the statistics presented in this report; this reduces the proportion of land area classified as mountainous to around 24 per cent. Future work will try to incorporate bioclimatic data into this formal topographic definition in order to model regional and latitudinal variations in the transition to mountain conditions.

Another study (Meybeck *et al.*, 2001) used the same digital elevation model and a combination of 'relief roughness' and elevation to partition the entire land surface into 15 classes of relief typology. In this system, Tibet and the Altiplano are classed as 'very high plateau' rather than mountains, and the global mountain area is calculated as 33.5 million km^2.

Networks and resources

Mountain Networks

Mountain Forum
http://www.mtnforum.org/index.html

Asia Pacific Mountain Network
http://www.mtnforum.org/apmn/index.html

CONDESAN: Consorcio para el Desarrollo Sostenible de la Ecorregión Andina
http://www.condesan.org/

Mountain Livelihoods

Sustainable Livelihoods and Poverty Alleviation. Background paper and discussion for the Bishkek Global Mountain Summit
http://www.mtnforum.org/bgms/paperb2.htm

International Conference on Sustainable Agriculture and Rural Development in Mountain Regions (SARD) 16-20 June 2002, Adelboden, Switzerland
http://www.iisd.ca/linkages/sd/mountains/sard/

Hunger and food insecurity. An introduction for the International Year of Mountains
http://www.mountains2002.org/i-hunger.html

High stakes: The future of mountain societies. Panos report
http://www.panos.org.uk/environment/high_stakes_mountain_societies.htm

Sustainable rural development and food security: the role of mountain development in Africa.
Twenty-second FAO regional conference for Africa, Cairo, Egypt, 4-8 February 2002
http://www.fao.org/DOCREP/MEETING/004/Y6056E.HTM

Sustainable Development In Mountain Areas in Latin America and the Caribbean.
Twenty-sixth FAO regional conference for Latin America and the Caribbean, Merida, Mexico, 10-14 April 2000
http://www.fao.org/docrep/meeting/x4442e.htm

Energy, transport and water

Mountains of the World: Mountains, Energy, and Transport
http://www.mtnforum.org/resources/orders/energy.htm

Mountain Waters. An introduction for the International Year of Mountains
http://www.mountains2002.org/i-water.html

Biodiversity

Mountain biodiversity.
An introduction for the International Year of Mountains
http://www.mountains2002.org/i-bio.html

Mountains and Mountain Forests. UNEP-WCMC maps of mountains and mountain forests of the world
http://www.unep-wcmc.org/habitats/mountains/index.html

Mountain forests. An introduction for the International Year of Mountains
http://www.mountains2002.org/i-forests.html

Mountain People, Forests, and Trees: Strategies for Balancing Local Management and Outside Interests. Synthesis of an electronic conference, 1999
http://www.mtnforum.org/resources/library/mpft_01.htm

Cloud Forests
http://www.unep-wcmc.org/forest/cloudforest/english/homepage.htm

Mountain biodiversity at risk. Review of mountain biodiversity and agrobiodiversity
http://www.idrc.ca/Media/MountainBio_e.html

Biodiversity in the Hindu Kush, Himalayas. ICIMOD articles and information resources
http://www.icimod.org.sg/focus/biodiversity/biodiv_toc.htm

First global conference on mountain biodiversity, Rigi, Switzerland, Sept. 2000
http://www.unibas.ch/gmba/rigi.html#Anchor-Conference-35326

GRASP - Conservation of Mountain Gorillas and their Afromontane Forest Habitat
http://www.unep.org/grasp/supportmountaingorillas.asp

Tourism

Mountain tourism. An introduction for the International Year of Mountains
http://www.mountains2002.org/i-tourism.html

Community-Based Mountain Tourism: Practices for Linking Conservation with Enterprise
http://www.mtnforum.org/resources/library/cbmt_01.htm

Mountains of the World: tourism and sustainable mountain development. Report produced by Mountain Agenda
http://www.mtnforum.org/resources/library/magen99a.htm

Conflict

Conflict in mountain regions. An introduction for the International Year of Mountains
http://www.mountains2002.org/i-conflict.html

Climate Change

Climate change and mountains. An introduction for the International Year of Mountains
http://www.mountains2002.org/i-climate.html

Glacial Lakes and Glacial Lake Outburst Floods
http://www.icimod.org.sg/publications/profiles/glacial.htm

Kilimanjaro's melting cap
http://www.peopleandplanet.net/doc.php?id=972

Australia's declining alpine regions
http://www.peopleandplanet.net/doc.php?id=1055

Case studies, best practices

Mountain People, Forests, and Trees: Strategies for Balancing Local Management and Outside Interests. Synthesis of an electronic conference, 1999
http://www.mtnforum.org/resources/library/mpft_01.htm

Mountain Laws and Peoples: Moving Towards Sustainable Development and Recognition of Community-Based Property Rights. Synthesis of an electronic conference, 1998
http://www.mtnforum.org/resources/library/mlp_01.htm

Community-Based Mountain Tourism: Practices for Linking Conservation with Enterprise. Synthesis of an electronic conference,1998
http://www.mtnforum.org/resources/library/cbmt_01.htm

Mountains of the World: tourism and sustainable mountain development. A review and case studies of the issues involved in sustainable mountain tourism
http://www.mtnforum.org/resources/library/magen99a.htm

Moving Mountains. A special edition of the UNASYLVA forestry magazine of FAO
http://www.fao.org/docrep/w9300e/w9300e00.htm#Contents

People & the Planet. A special issue of the magazine on mountains
http://www.peopleandplanet.net/doc.php?id=966&section=11

State of the Environment

GMBA: Global Mountain Biodiversity Assessment
http://www.unibas.ch/gmba/index.html

Global Change and Mountain Regions. The Mountain Research Initiative of IGBP, IHDP, GTOS and UNESCO MAB
http://www.mri.unibe.ch/

Our Planet. UNEP's magazine for environmentally sustainable development, special issue on mountains and ecotourism
http://www.ourplanet.com

Policies and Conventions

UN Division of Sustainable Development
The text of Chapter 13, Agenda 21 – managing fragile ecosystems: sustainable mountain development
http://www.un.org/esa/sustdev/agenda21chapter13.htm

Sustainable mountain development. The state of implementation of Chapter 23 of Agenda 21, on sustainable mountain development
http://www.un.org/documents/ecosoc/cn17/2000/ecn172000-6add3.htm

European Mountain Initiative
http://www.unep.ch/roe/emi.htm#top

The Alpine Convention
http://gridk1ach.grid.unep.ch/preAC/en/convalp.htm

Institutions, programmes

FAO Mountain Programme
http://www.fao.org/forestry/foda/infonote/en/t-smd-e.stm

The Mountain Institute
http://www.mountain.org/index.html

GEF: Global Environment Facility Operational Programme No 4 (Mountains)
http://gefweb.org/Operational_Policies/Operational_Programs/OP_4_English.pdf

UNU Project on Sustainable Mountain Development
http://www.unu.edu/env/mountains/index.htm

International Centre for Integrated Mountain Development (ICIMOD)
http://www.icimod.org.sg/

Mountain Research and Development. The primary journal for mountain research
http://www.mrd-journal.org/

UNESCO in the Mountains of the World. An overview of the principal UNESCO programmes operating in mountain regions
http://valhalla.unep-wcmc.org/unesco/index.htm

Banff Centre for Mountain Culture
http://www.banffcentre.ab.ca/cmc/

CIPRA: Commission Internationale pour la Protection des Alpes
http://www.cipra.org/

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http://mountains.unep.net

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Paragraph 40

«Mountain ecosystems support particular livelihoods, and include significant watershed resources, biological diversity and unique flora and fauna. Many are particularly fragile and vulnerable to the adverse effects of climate change and need specific protection. Actions at all levels are required to:

a develop and promote programmes, policies and approaches that integrate environmental, economic and social components of sustainable mountain development and strengthen international cooperation for its positive impacts on poverty eradication programmes, especially in developing countries;

b implement programmes to address, where appropriate, deforestation, erosion, land degradation, loss of biodiversity, disruption of water flows and retreat of glaciers;

c develop and implement, where appropriate, gender-sensitive policies and programmes, including public and private investments that help eliminate inequities facing mountain communities;

d implement programmes to promote diversification and traditional mountain economies, sustainable livelihoods and small-scale production systems, including specific training programmes and better access to national and international markets, communications and transport planning, taking into account the particular sensitivity of mountains;

e promote full participation and involvement of mountain communities in decisions that affect them and integrate indigenous knowledge, heritage and values in all development initiatives;

f mobilize national and international support for applied research and capacity-building, provide financial and technical assistance for the effective implementation of sustainable development of mountain ecosystems in developing countries and countries with economies in transition, and address the poverty among people living in mountains through concrete plans, projects and programmes, with sufficient support from all stakeholders, taking into account the spirit of the International Year of Mountains 2002.»

Full text available at: www.johannesburgsummit.org