

## Global Environmental Change in Mountain Regions: An Overview

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Mountain regions have often been perceived in the past – and to some extent still today in certain parts of the world – as hostile and economically non-viable regions. They have in the latter part of the century attracted major economic investments for tourism, hydro-power, and communication routes. Mountains have often been perceived as obstacles to be conquered, but their importance as a major resource for mankind is generally underestimated. Mountains, in fact, provide direct life support for close to 10% of the world's population, and indirectly to over half (IVES 1992), principally because they are the source region for many of the world's major river systems. They also sustain many important economic activities, such as mining, forestry, agriculture, and energy resources.

Water resources for populated lowland regions are highly influenced by mountain climates and vegetation; snow feeds into the hydrological basins and acts as a control on the timing of water runoff in the spring and summer months. Regions such as southern and eastern Asia, where almost half the world's population resides, depend largely upon water originating in the Himalaya-Karakorum-Pamir-Tibet regions for economic activities such as agriculture, industry, and energy production. Changes to the mountain environment, such as shifts in precipitation regimes in a changing climate, reduced snow and ice resources which today feed the major rivers flowing from the Himalayan chain, or deforestation, could significantly alter the flow patterns in rivers such as the Ganges, the Irrawady, the Salween, or the Yangtze, and thereby perturb patterns of water use and water management in India, China, Bangladesh, Thailand, Laos, Vietnam, Cambodia, and Myanmar.

Biological diversity is an important issue in mountain regions. Biodiversity is high because of the fact that vegetation patterns are largely governed by climatic factors, which change rapidly with altitude. Over relatively short horizontal distances in high mountain ranges, it is possible to span a wide range of ecosystems, which would otherwise occur over widely-separated latitudinal belts. For example, in tropical regions such as the Peruvian Andes, vegetation will go from tropical species at low elevations to tundra and cold-vegetation species in the upper reaches of the Cordilleras. Because of their relative isolation, mountains often harbor unique species of endemic plants and animals, such as the cloud forests in Costa Rica or Papua-New Guinea and tropical montane rainforests in many of the equatorial mountain regions of the world. In the eastern Bor-

neo state of Sabah in Malaysia, there are an estimated 4500 species of plants on Mount Kinabalu, which represents 25% of the entire plant species of the United States (STONE 1992). In terms of fauna, there are more birds species in Costa Rica (850) than in the whole of North America (BOZA 1992), including the mythical Quetzal found in the mountains of Central America from southern Mexico to northern Panama. Some of our most common foodstuffs originated in mountains, such as potatoes (Andes), coffee (Ethiopia and Kenya), wild corn (Mexico); the genetic reserves found in these regions need to be preserved for future use.

Mountains provide recreational, research and educational opportunities; in terms of scenery, they are often recognized as being among the most spectacular features of our planet. Tourism is now one of the major income sources for many mountain economies. The attractiveness of remote mountain regions, for mountaineering, hiking, or even skiing, has increased substantially over the last decade as the costs of air travel to most parts of the world have become more accessible to a larger number of people.

Global environmental change can be defined as a series of stress factors on the physical and biological systems of the planet. The Earth's environment is continuously subjected to various stresses through natural processes and human interference. Global change is not a new concept, but with the rapid industrialization and population growth which the 20th century has witnessed worldwide, the natural environment has undergone unprecedented changes. In some instances, environmental degradation is inevitable because of the basic requirements of human populations, particularly where those are growing rapidly; in other cases, environmental damage is a direct result of mismanagement and over-exploitation of natural resources. The consequences of such degradation are sometimes not recognized or are often ignored because of the perceived higher benefits of economic gain.

Whether or not the global environment is capable of withstanding natural and anthropogenic stresses is a matter of constant debate. In some instances, the environment has – at least on local to regional scales – been able to revert to its previous levels; examples of such resilience abound; for example, the acidity of lakes in Northern Ontario, Canada, reverted to their natural levels following significant abatement of sulfur-based pollution from a major smelting plant (GUNN & KELLER 1990). In other instances, environmental damage appears to be irreversible, such as the large perimeter of

contaminated lands following the 1986 nuclear accident in Tchernobyl, Ukraine, or the deforestation of pristine jungles in many tropical regions. Examples of irreversible degradation have provided arguments to those who believe that environmental impacts are cumulative and difficult to reverse. A third paradigm is that there are certain beneficial effects of stresses on the environment, namely that ecosystems become resilient and can therefore withstand further and possibly greater stresses in the future. Forest fires, for example, are not solely a devastating phenomenon: they also return essential nutrients to the soil, allowing vigorous regeneration to occur. Indeed, some environments can maintain themselves in the long term only through fire.

All these paradigms are based on the assumption that the time scales associated with environmental change are long and that, in many situations, the environment may find a new equilibrium, if not its original state. Environmental upheavals have occurred in the past, along with species extinctions, and yet the planet has «survived» and evolution has continued. However, it is possible that anthropogenic pressures are accelerating change and that many systems may not adapt to rapid rates of change, even if they could adapt to the amplitude of change over longer time periods.

Mountain regions are particularly sensitive to a wide range of environmental stresses acting at various spatio-temporal scales. Erosion is a constant feature of mountain environments, from the long-term effects of glaciological, hydrological and chemical weathering (which act on time scales from centuries to millennia or more), to the sudden manifestation of major natural catastrophes such as rock falls and mud slides (which may occur over a time-span of but a few minutes). The extent to which a region will be sensitive to the agents of erosion depends largely upon the climatic, geological and biological features of the region considered.

Whatever the source of the disturbance, mountains are composed of a number of inherently fragile systems which may have difficulty in adapting to changing environmental conditions. It may appear paradoxical that mountain plants, for example, which are capable of resisting extreme climatic conditions, may be threatened by extinction following a seemingly minor environmental stress. This can be explained by the particular characteristics of the mountain environments themselves, which all contribute to, and interact with, vegetation processes. Plants have adapted to climatic extremes, short growing seasons, lack of soil nutrients, steepness of slopes, competition between species, etc. These conditions allow plants to survive within a very narrow «environmental bandwidth», and any disturbance to their basic living conditions can lead to severe stresses to particular types of vegetation. Perhaps the most sensitive element to environmental change in the mountains are

snow and ice; if climatic conditions become warmer, then the only possible response of snow fields and glaciers is to melt. In this respect, the mountain cryosphere is a valuable indicator of climatic change.

Mankind is adding a new dimension to the global environment in general, and mountain regions are no exception. «Human interference» is generally perceived as being detrimental to mountain environments; while this may often be the case, there are examples where man has augmented the safety or the esthetics of mountains. Terraced agriculture as practiced in many parts of the world (Nepal, Indonesia, the Philippines) are considered by many to enhance the beauty of a region; in addition, this form of land-use acts to stabilize mountain slopes.

In other regions, however, direct or indirect environmental mismanagement has led to irreversible damage: notable examples include the denudation of mountain slopes following forest fires, as in parts of the Mediterranean basin or in California, the die back of mountain forests as a result of industrial pollution (mountain regions of Poland, the Czech Republic, and Germany), open-pit mining such as that practiced in Chile or the United States. Environmental considerations are often opposed to economic interests; an example typical of such potential sources of conflict is the construction of hydro-power facilities which would destroy unique ecosystems or lead to the displacement of indigenous people; a notable example is the mega-project of the «Three Rivers» in China, in which a 600-km artificial lake will lead to the displacement of an estimated two million persons. In partially taming the mountain world, mankind has often generated as many problems as he has resolved.

There are two principal causal mechanisms which can account for human interference on the natural environment: economic growth and demography. The economic level of a country determines to a large extent its resource requirements, in particular energy, industrial commodities, agricultural products and fresh water supply. Demography, on the other hand, is a critical factor in the sharing of the resources available to a particular country or set of countries (BENISTON, in press).

High economic levels are resource-intensive, and this frequently leads to environmental degradation because of the resources required to maintain a high standard of living. As an extreme example, WRI (1996) statistics show that the energy use per capita in the United States is 350 times greater than in Ethiopia or Rwanda. Technology is today still energy-intensive, particularly in the transportation sector where fuel demand for road and air transportation continues to grow rapidly. Technology as used in the industrialized countries, along with the image of «western lifestyles» is often replacing traditional consumption and resource-use patterns in the develop-

ing world, even though traditional methods are often better adapted to local conditions. As a consequence, environmental concerns become a very low priority as economic survival becomes the dominant objective.

High population growth, on the other hand, can also lead to environmental damage as the inhabitants of poor countries attempt to maintain or improve their current economic level through the exploitation of their resources often without any long-term planning or management. While in most of the industrialized world, population growth is low (often less than 1%), in some developing countries, demography is such that economic levels are dwindling. Kenya, for example, has a rate of population growth of around 4.3% per annum, which implies that if this is sustained, its population will double within 17 years. In order just to maintain present economic levels, Kenya would need to double its existing infrastructure (energy supply, housing, schools, hospitals) and food and water supply. Such pressing demands on an already depressed economy represent a challenge which even the most affluent countries would not be able to meet. The general lowering of a population's standard of living implies that economic survival takes place at the expense of environmental protection, management and planning.

The current trends of globalization of economic markets and highly liberalized economies are not always compatible with environmental concerns. Present-day economic policies are often on the short-term (from a few days to a few months), whereas environmental management is by essence on the long-term (several years to several decades). Environmental protection is sometimes perceived to be contrary to free trade; indeed, attempts to slow down and possibly reverse tropical deforestation are considered in some circles to be contravening the WTO (World Trade Organization) accords on free trade. In the context of economic recession as experienced in many industrialized countries in the 1990s, environmental protection is sometimes seen as a menace to job security.

Because many actors in the economic and industrial arena tend to believe that the natural environment has no intrinsic value, there is often little incentive towards environmental protection or management, since the environment is perceived as an unlimited resource to be utilized in order to sustain economic growth. Exploitation of raw materials by major manufacturing firms is a direct threat to indigenous people in different parts of the world; it is estimated that about 300 million people live in regions which account for about 60% of the world's natural resources.

Globalization is leading to a real or perceived trend of weakening of policy-making at the national level. Because major economic and financial decisions are taken outside a purely national framework, the ability of politicians to respond to such decisions is reduced. Politics,

which up till recently was the driving force behind the nation-state, is today increasingly involved in economic management. So powerful is the wave of globalization that many policymakers are more concerned with economic affairs than environmental issues. They also are sensitive to shifts in the priorities of the general public, which is today more preoccupied by economic conditions than by the environment. In the industrialized countries, unemployment, crime, health insurance are all considered more pressing issues than those pertaining to environmental matters. In the developing world, food security and access to basic commodities and health are perceived as being far more urgent issues than a healthy environment. Conflicts between environmental issues and economic development have been described and understood for a long time. Awareness of these issues have progressively resulted in the concept of sustainable development.

Whatever the perception, it is highly likely that global environmental change will lead to lasting degradation and damage. This will in turn reduce the capacity of human societies to maintain their lifestyles at current levels, in particular because the driving forces of global economy may no longer be able to use the resources which the environment provides in a sustained manner. Regional disparities between rich and poor, which have always existed, will be exacerbated in a degraded environment. Issues related to global change highlight the general problem that Society has difficulty in using the limited resources of the planet in a rational manner, and of sharing equitably the essential commodities which the environment provides.

In facing up to environmental change, human beings are going to have to think in terms of decades and centuries. Many of the impacts of these profound changes may not become unambiguously apparent for several generations. Perhaps the key to success is through long-term economic thinking, based on concepts of sustainable development. Although sustainability is a much-flaunted term today, the common-sense basis for sustainability (i.e., environmental conservation and careful resource use to improve living standards worldwide today, and to provide these resources for future generations) should be seen as the only long-term alternative to current economic trends. The search for sustainability in any form of development presumes that the thresholds of the environmental carrying capacity for a given region are known or can be established on the basis of existing information. For the present time, sustainable economic development can be observed after the fact; in addition, sustainability is a notion which is not necessarily valid for an infinite time, but may change over time as population, technology, or the environment shift in response to sustainable policies. The establishment of the goals of sustainable development are essentially social decisions related to the desirability of establishing a



dual environmental-economic system which can survive as long as possible. The real problem here is not to define the goals of sustainability per se, but rather to determine the policy implications of what will lead to the establishment of a sustainable system. These considerations, and the large uncertainties associated with them, can only be alleviated to some extent by a consistent application of the precautionary principle mentioned earlier in this chapter.

Many of the policies and decisions related to pollution abatement, climatic change, deforestation or desertification would provide opportunities and challenges for the private and public sectors. A carefully selected set of national and international responses aimed at mitigation, adaptation and improvement of knowledge can reduce the risks posed by environmental change to ecosystems, food security, water resources, human health and other natural and socio-economic systems.

There are large differences in the cost of attempting to address crucial global environmental problems among countries due to their state of economic development, infrastructure choices and natural resource base. International cooperation in a framework of bilateral, regional or international agreements could significantly reduce the global costs severe environmental stress. If carried out with care, these responses would help to meet the challenge of climate change and enhance the prospects for sustainable economic development for all peoples and nations.

When progress has been made towards attaining some of these global objectives, and the positive effects of implemented policies begin to be perceived, mountain and upland environments will also benefit from these measures. Mountains are unique features of the Earth system in terms of their scenery, their climates, their ecosystems; they provide key resources for human activities well beyond their natural boundaries; and they harbor extremely diverse cultures in both the developing and the industrialized world. The protection of mountain environments against the adverse effects of economic development should be a priority for both today's generation and the generations to come.

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#### Summary: Global Environmental Change in Mountain Regions: An Overview

Mountain regions cover 20% of terrestrial land surfaces and represent one of the principle source regions for the world's hydrological systems. Mountain regions are today under pressure as a result of human interference; climatic change could lead to an additional stress on natural and socio-economic systems.

Paleo-climatic evidence has shown that past climatic change has led to substantial shifts in the distribution of vegetation. If the present warming trend were to continue into the 21<sup>st</sup> century, there would be significant impacts on ecosystems. In particular, certain species may become extinct because of their limited capacity for migration to regions with favorable climatic and soil conditions.

In most mountain regions, a warmer climate will lead to a reduction in the mass of glaciers, as well as snow-pack and permafrost. Changes in precipitation regimes may have far-reaching consequences for fresh-water supply to agriculture, tourism and hydro-power. These shifts would affect not only mountain populations, but also those living downstream from the mountains and who depend on mountain-fed water resources.

The social structure of populations in the mountains of the developing world may be disrupted by environmental change, because of the impacts this change is likely to have on the natural resources essential to traditional lifestyles of mountain communities.

#### Zusammenfassung: Globale Umweltveränderungen in Gebirgsregionen: Ein Überblick

Gebirgsregionen bedecken 20% der Landoberflächen und stellen eine der Ursprungsregionen für die hydrologischen Systeme der Welt dar. Durch die menschliche Einflussnahme geraten Gebirgsregionen heute unter Druck. Klimatische Veränderungen könnten zu einer zusätzlichen Belastung der natürlichen und sozioökonomischen Systeme führen.

Paläo-klimatische Zeugen zeigen, dass klimatischer Wandel in der Vergangenheit zu erheblichen Veränderungen in der Verteilung der Vegetation geführt hat. Wenn sich der gegenwärtige Trend zur Erwärmung bis in das 21. Jahrhundert fortsetzen würde, resultierten bedeutende Auswirkungen auf Ökosysteme. Insbesondere könnten bestimmte Arten verschwinden aufgrund ihres begrenzten Vermögens zur Migration in die Regionen mit vorteilhaften klimatischen und Bodenbedingungen.

In den meisten Gebirgsregionen wird ein wärmeres Klima zu einer Verringerung der Gletschermasse, der Schneedecke sowie der Verbreitung des Dauerfrostbodens führen. Änderungen in den Niederschlagsregimen können weitreichende Konsequenzen für die Wasserversorgung der Landwirtschaft, des Tourismus und für die Gewinnung von Hydroelektrizität haben. Diese Veränderungen würden nicht nur die Gebirgsbevölkerungen betreffen, sondern auch die von der Gebirgswasserversorgung abhängige Bevölkerung in den Niederungen.

Die Sozialstruktur der Bevölkerung in den Gebirgsregionen der sich entwickelnden Welt könnte durch *Global Change* beeinträchtigt werden, da dieser Umweltveränderungen Einfluss nehmen auf die für die traditionellen Lebensformen der Gebirgsbevölkerung notwendigen natürlichen Ressourcen.

**Résumé : Le changement environnemental global dans les régions de montagne : Une synthèse**

Les régions de montagne recouvrent environ 20% des surfaces continentales et constituent les sources principales de la plupart des grandes rivières du monde. Les régions de montagne sont aujourd'hui sous pression à cause des activités de l'Homme; les changements climatiques pourraient ajouter une contrainte supplémentaire aux systèmes naturels et socio-économiques.

Les indices paléo-environnementaux nous ont montré que des changements climatiques dans un passé plus ou moins lointain ont provoqué des modifications sensibles

dans la distribution de la végétation. Le réchauffement actuel, s'il devait se poursuivre au 21<sup>e</sup> siècle, aurait des conséquences importantes pour les écosystèmes, avec la menace d'extinction pour de nombreuses espèces peu capables de s'adapter à ces changements ou de migrer vers d'autres régions plus favorables au niveau climatique et pédologique.

Dans la plupart des régions de montagne, un climat plus chaud réduira le volume des glaciers, ainsi que la quantité de permafrost et du manteau neigeux. Des modifications du régime des précipitations pourraient avoir des répercussions sur l'agriculture de montagne, le tourisme, ou encore l'hydroélectricité. Les conséquences pour les populations situées dans des régions de plaine, qui dépendent de l'eau en provenance des montagnes, seront certainement considérables.

Le tissu social de populations dans de nombreux pays en voie de développement pourrait se désagréger, car les changements environnementaux et climatiques vont certainement perturber la vie traditionnelle et les ressources naturelles à la base de la subsistance des populations autochtones.

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