Selected Issues from the Samedan GLOCHAMORE Workshop on Altitudinal Gradient Studies

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In the context of the EU GLOCHAMORE project (Global Change in Mountain Regions, 2003–2005) a workshop was held on Altitudinal Gradient Studies from 27 to 30 July 2005 in Samedan/Switzerland. The main topic of the workshop was ecology and ecosystem processes (see "Ecological and land use studies along altitudinal gradients," Becker et al 2007, in this issue). Other issues that arose at the workshop, including general aspects and hydrological and geomorphological issues, are presented here in brief.

Elevational belts and socio-economic aspects

A characteristic feature of high mountains is their vertical zonation into climate-driven elevational belts: 1) the snow and ice covered nival belt, 2) the alpine belt (treeless, above treeline), 3) the mainly forested montane belt (below treeline), and 4) the valley floors and forelands. Figure 1 shows a typical mountain region with clearly identifiable belts.

People live and use resources in these altitudinal belts (Allan 1986). However, at higher elevations, conditions become increasingly difficult, creating societal interdependencies with lower belts and the lowlands. Traditionally, there are 3 ways to secure a livelihood at high elevations despite the harsh environmental conditions:

- Using overly large land areas, thus compensating for low annual productivity per unit of land and mitigating seasonal irregularities in resource availability through traditional storage/reserve schemes and transhumance systems;
- Capitalizing on specific mountain resources, which are valued downslope and can be traded for basic supplies (eg medicinal plants, wool, timber, minerals);
- Capitalizing on the recreational, trade, or spiritual demands of non-mountain societies, and operating within the associated mountain infrastructure (eg pass roads, pilgrimage trails). These cross-elevational linkages still exist, but modes of interaction have changed (Price and Thompson 1997).

Tourism has replaced trade, pilgrimage, and pastoralism. Resources extracted on a large scale such as water, electric energy, and minerals have become major sources of income. In most of the world's mountain systems, traditional and modern societal linkages are mixed. Common to all mountain systems is the gradual decline in formal land use rights and ownership with elevation, which is a source of conflict when new land use systems are installed in a traditional cultural landscape (Berge 2006; Körner and Ohsawa 2006). Cultural landscapes include many ecological elements rooted in traditional land use practice that are not necessarily obvious from scientific knowledge but contribute to sustainable development (Ramakrishnan et al 2005). There are new challenges in identifying and measuring the advantages of traditional (sustainable) land care systems in terms of lowland benefits such as safety of transit routes and amount and quality of drinking water (catchment value).

Mountain Biosphere Reserves (MBRs): an essential component of GLOCHAMORE

MBRs often cover a large fraction of this geographical teleconnection. Hence their management affects societal benefits outside MBR boundaries; these should be quantified in economic terms. Furthermore, a re-visitation of the potential for traditional food production in light of the growing demand for organic products is needed. These traditional land use forms preserve options for future generations which otherwise might be lost through land abandonment (Körner and Ohsawa 2006).

Mountain regions and MBRs usually have greater geological, topographical, and climatic diversity and hence greater biodiversity across altitudinal zones than the surrounding lowlands. Land use interacts with these natural drivers, creating the well-known mosaics of land cover types. The management of MBRs influences these patterns, which in turn affect biodiversity and ecosystem processes, including the delivery of goods and services to society such as freshwater, food, and slope stability. The mitigation of risks associated with slope forces (avalanches, debris flows, floods) and the provision of clean water are crucial tasks for MBR management. Knowledge-based decision-making is thus imperative.

Traditional experimental knowledge and skills, including observation and monitoring practices, are abundant in MBRs. However, owing to global environmental change, population growth, and technological pressures, MBR management requires a broader knowledge base than previously. The EU-funded GLOCHAMORE project (Global Change and Mountain Regions) addresses recent and future challenges to the world's mountain regions and aims to develop a research strategy to meet them. The strategy provides guidance to scientists, MBR managers, decision-makers, and policymakers (Björnsen Gurung 2005). A selection of key themes was made (Becker and Bugmann 2001) and dealt with in a 2-year series of 4 workshops: 1) long-term monitoring, 2) the impacts of global change, 3) tools and methodologies to be applied. The fourth and final workshop led to the current report and associated publication emphasizing altitudinal gradients.

Transects crossing altitudinal belts cover various environmental gradients over relatively short distances (Figure 1). At various scales, such gradients illustrate "experiments in nature." For example, thermal gradients over several hundred meters present us with the potential steady-state responses of biota to global warming (space for time approach).

Conditions and drivers across altitudinal gradients

It is common knowledge that atmospheric pressure and temperature decrease with elevation. However, several other phenomena often considered "common trends" are not so common in the wide spectrum of mountain regions across the globe (Körner 2003). Common to all mountains is declining atmospheric pressure with elevation and the associated partial pressure of oxygen (affecting humans) and carbon dioxide (potentially affecting plants). Humans, wild animals, and plants have adapted to these differences through different evolutionary mechanisms. For instance, humans adapt to oxygen shortage at high altitude with physiological "tricks," which appear to differ between Andean and Central Asian populations (Beall 2002). Another example are physical "tricks" such as changes in the porosity of egg shells in birds (Rahn et al 1977). Adapted high-elevation populations commonly have superior fitness under highland conditions compared to populations at lower elevations.

Related to declining pressure is reduction in temperature (around a mean of 0.55 K/100 m), causing the above-mentioned altitudinal belts. This gradual temperature reduction influences virtually all environmental conditions, including reduction of evaporative forcing at high elevation under isothermal conditions. Finally, clear sky turbidity decreases with elevation, while clear sky solar radiation increases simultaneously.

However, contrary to widespread belief, all other climatic variables do not vary with altitude in a common manner. Actual solar radiation is influenced by cloudiness and thus often declines with elevation. Precipitation patterns vary greatly, and much confusion had been introduced by associating local peculiarities of rainfall patterns with general altitudinal phenomena. Precipitation may increase (eg European Alps, Rocky Mountains), or first increase and then decrease with elevation (eg many tropical and subtropical mountains). Except for summits or exposed ridges, mountains are also commonly less windy than the plains.

Often the same environmental changes exert different effects across altitudinal gradients. For instance, climatic warming reduces snow pack duration at lower elevations, but—due to associated greater moisture loading in the atmosphere—may actually enhance snow pack at higher elevations. By contrast, warming may cause drought at low elevations and improve the conditions of life at high elevations. Accounting for this spectrum of altitudinal gradients and the linkages between highland

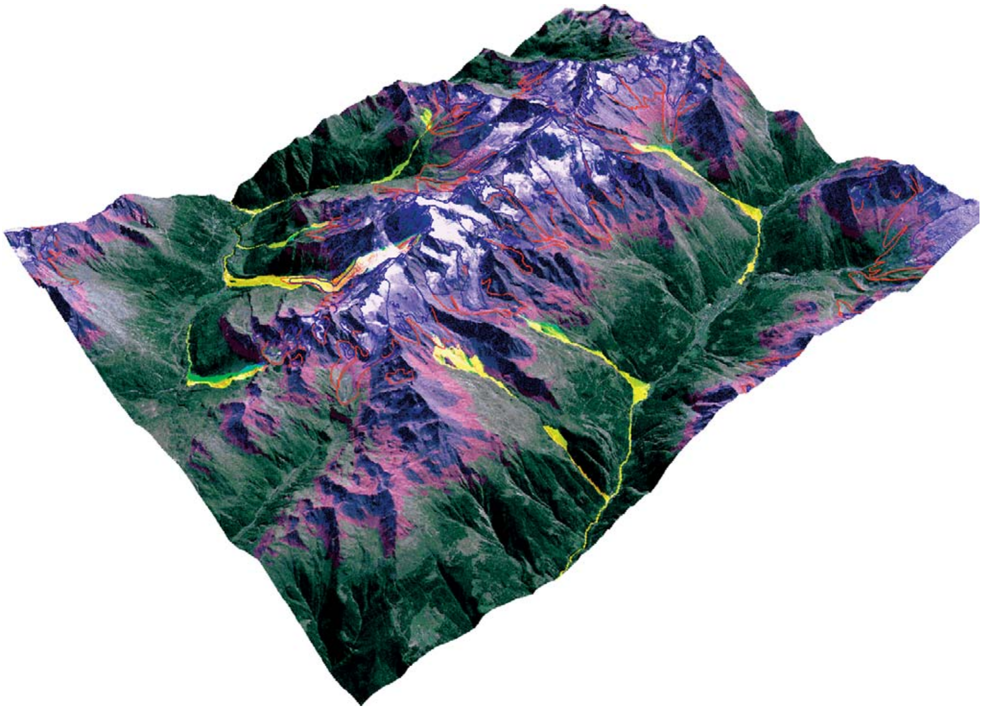

FIGURE 1 View of a typical high mountain region: the Saas Valley/Simplon region, Switzerland, as derived from a combination of information from Indian Remote Sensing satellite (IRS) and Landsat satellite images. The image shows the glacier belt (white and gray, about 3000 m; red lines define the extent of the glacier in 1850 and blue the position in 1973), the periglacial belt (blue and pink; where blue represents permafrost and pink the transition from warm/thin permafrost to seasonal soil freezing), the alpine vegetation belt (light green), and the montane forest belt (dark green) down to the valley bottoms (about 1500 m). Potential pathways of debris flows, rock avalanches and lake outbursts (GLOFs), estimated by integrative modeling, are indicated in light yellow and green. (Source: Huggel et al 2004 and 2005)

and lowland conditions and processes is a key to knowledge-based MBR management and generalization of findings along altitudinal transects.

In the same vein, human interactions with mountain ecosystems do not vary in a systematic way with elevation. Quite often, activities peak in the foothills with a mid-montane minimum (mainly due to the steep slopes) and an upper montane maximum of activities (eg in the Andean Altiplano or in tourist areas in the European Alps). But there are also regions with a mid-montane maximum of land use pressure (eg New Guinea highlands).

Special hydrological aspects

The main components of the water balance—precipitation, evapotranspiration, and runoff along altitudinal transects (slopes)—are not easy to assess. Even precipitation, usually measured with rain gauges (or pluviometers), requires a number of conditions on slopes (horizontal area, no shadow effect of surrounding subjects) for sufficient accuracy of measurement (Sevruk 2004).

Evapotranspiration is assessed in various ways. One is to calculate it via energy balance-related approximations using existing formulas by Penman or Turc, accepting all uncertainties caused by disregarding mountain-specific factors such as exposure, aspect, slope angle, or incoming radiation (in addition to soil and vegetation characteristics). Direct measurement using lysimeters (Körner et al 1989) is laborious and subject to spatial constraints. The best way is to solve the water balance equation, ie subtract runoff from catchment precipitation over longer periods, ideally in "microcatchments" with no uncontrolled subsurface water exchange with neighbor catchments.

At least 3 components of runoff (or stream flow) should be considered (Becker 2005):

- Base flow fed by groundwater with residence times of months to years (most stable component);
- Interflow or subsurface storm flow with residence times of weeks to several months; and
- Direct (immediate) runoff, especially overland flow, with residence times of hours or days after the generating rainfall or snowmelt.

For estimation of regional water availability, the base flow component and its behavior is most important. By contrast, direct runoff after rainfall and snowmelt is the main source of floods and related hazards. All 3 components define the flow regime in rivers.

Seasonality of runoff and its change play a crucial role in mountain regions, particularly at higher elevations. The dramatic retreat of high mountain glaciers, of reduced snowfall at lower elevations, and of higher winter and early spring rainfall and snowmelt lead to increasing flows at the beginning of the snowmelt period, followed by flow reductions as the snow masses disappear. In the long run this will result in a reduction of river flow in dry summer periods and an increase in drought. Even if total precipitation were to increase, the resulting combination would probably mean lower lake levels, dryer wetlands, and greater shortages of available water in late summer and early autumn.

Temperature is expected to increase by about 3.5 K in the coming 100 years (Houghton et al 2001). The situation is less clear for precipitation, particularly its elevational trends. Shrestha (2005), for example, found a clear decrease in annual precipitation of 35 mm per year in the middle transect in Alaknanda (India)—at the steepest of the world's altitudinal transects, the southern slope of the Himalayas, ranging from 60 m in the Nepalese Terai to 8848 m at Mount Everest. By contrast, he found an increase of 2–31 mm per year in the Kalagandaki (Nepal). Moreover, he noted an increasing trend to greater extremes (monsoonal floods and droughts), as well as increasing precipitation in areas where precipitation is already high and reduced precipitation in areas where it is currently low (in agreement with the last IPCC assessment report, Houghton et al 2001).

Altitudinal gradients as a source of natural hazards

Slopes are the basic condition for the occurrence of hazards in terms of landslides, debris flows, rockfalls, avalanches, etc. The probability of such hazards increases remarkably when slope gradient reaches or exceeds 25° to 30°. Modern technology offers sophisticated tools to describe and model landscapes and their evolution in mountain regions. Figure 1 offers an example of the assessment of landscape elements in a mountain area of the Alps, the Simplon region (Saas Valley) in Switzerland. Using satellite images from Indian Remote Sensing (IRS) and Landsat (Huggel et al 2004), the main altitudinal belts can be identified (between about 1500 and 3000 m).

Decades of worldwide research have helped to create a comprehensive basis of scientific knowledge about landscape evolution in high mountains and their forelands, as influenced by glaciers and frozen ground. Recent and ongoing atmospheric warming, however, has confronted us with new challenges of historic dimensions (Watson and Haeberli 2005). Under the influence of accelerating climate change, the disappearance of glaciers and the degradation of permafrost in the highest parts of the mountains, the conditions of life will change in most mountains and present risks different from those in the recent past (Haeberli and Burn 2002).

Slope stability is very low on recently deglaciated terrain steeper than about 25° to 30°. Thawing permafrost on steep rock walls and non-consolidated sediments induce fragile conditions. Debris flows and rock avalanches may develop under such conditions, especially during snowmelt and heavy precipitation events. Marked changes in glacier extent are commonly associated with the formation of ice- and moraine-dammed lakes, the outburst and flood potential of which constitute extensive hazards for downstream areas. Steep hanging glaciers that are partly or completely frozen to their beds could become unstable in the event of warming. There is an urgent need to extend observation-derived knowledge about these glacial and periglacial processes through improved understanding of processes, especially for runoff formation and slope stability. Robust computer models are needed to simulate such changes in space and time and to assist in the planning of hazard mitigation measures at high altitudes.

High-resolution satellite imagery combined with geoinformatics (as in Figure 1) is now available even for very remote mountain areas (Kääb et al 2003; Huggel et al 2005). Such data are being increasingly used for assessment of high-mountain environmental conditions, including permafrost distribution and formation of dangerous ice- and moraine-dammed lakes with the risk of outbursts. Calibrated numerical spatial gray-box models help to develop scenarios and identify risks. Integrated observation and information systems, including information from modeling and visualization, are needed for planning, mitigation, and adaptation.

Conclusions and recommendations

Elevational gradients and specific transects should be a primary subject of mountain research for the following reasons:

- Altitudinal gradients, especially those crossing the various elevational belts on mountain slopes, offer greater biological richness and biodiversity than other places.
- Altitudinal species or life-form boundaries associated with temperature can serve as indicators of climatic change (eg the GLORIA initiative, treeline monitoring).
- Along elevational gradients, teleconnections influence widely separated areas and biota. Through the provision of goods and services, but also through risks, the foothills, valleys, and lower slopes are functionally linked to the highlands.
- The linkage between land use, vegetation, and soil stability—influencing slope integrity, function and stability, and thus catchment value—constitutes a specific research need.
- Slopes extending to the treeless alpine belt are prime sources of avalanches, landslides, and other hazards. The protection function of the treeline and the forests in the montane zone below requires special care and development.

The presentations and discussions at this GLOCHAMORE workshop led to a list of research activities recommended as a “core research agenda for MBRs” (see Table 1 in Becker et al 2007, in this issue). The list highlights a few central themes relevant and practicable for MBRs, often even at little extra cost. Basic environmental, biological and hydrological activities are highlighted, in particular monitoring, and also a few integrative activities such as catchment monitoring (hydrological as well as surface processes). Due to their regional nature, assessments of human activities beyond land use and economic, social, and ethnological backgrounds have not been specified.

Monitoring activities have been emphasized here, as monitoring data are a prerequisite for understanding processes, which in turn is essential for modeling and, thus, the validation of current concepts of natural and socioeconomic developments. Both monitoring and modeling and cross-disciplinary syntheses will assist knowledge-based land use planning and management of MBRs.

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International Year of Mountains +5 and the Mountain Partnership

Mountain Partnership

The Mountain Partnership—an evolving voluntary alliance of countries, intergovernmental organizations and major groups (civil society, NGOs, and the private sector) on 5 continents—was set up to provide a cohesive framework in which to enhance collaboration in the implementation of both Chapter 13 in Agenda 21 and the negotiated outcome of the World Summit on Sustainable Development (WSSD), the Johannesburg Plan of Implementation, which called for on-ground action at the policy, program, and project levels.

Research

Work is underway within the context of the Mountain Partnership to develop a simple "research community information grid." The analysis of surveys among members on "Who is who" in mountain research and "What future for mountain research?"—coordinated by the Centre for Development and Environment (CDE), a Mountain Partnership member—will help to identify potential collaborative activities within the Mountain Partnership and to set up a consultative process linking donors, stakeholders, and researchers around key research issues to increase the likelihood of funding.

Biodiversity

During the International Year of Mountains (IYM2002), the Convention on Biological Diversity (CBD) pledged to achieve a significant reduction in the current rate of biodiversity loss by the year 2010. An increasing number of collaborative activities on biodiversity relevant to the CBD have taken place within the framework of the Mountain Partnership, in relation to the Andes, Carpathians, Balkans, Caucasus, European Alps, and the Hindu Kush–Himalaya. The Cogne Declaration for International Mountain Parks Twinning Program is a landmark regional agreement between significant mountain parks in Europe and Asia: it promises to serve as a model instrument for biodiversity management in these regions and beyond. Although the Programme involves the Gran Paradiso National Park and the Sagarmatha National Park as initial partners, the involvement of additional actors and international organizations will be welcomed so as to further strengthen cooperation, partnerships and impact at the regional and inter-regional levels. Importantly, the Cogne Declaration acknowledges that the Twinning Program will be further developed within the framework of the Mountain Partnership and will contribute to the development of its new Biodiversity Initiative.

Microfinance

Mountain people are among the poorest and most marginalized in the world. Microfinance can improve the livelihoods of poor