Global Change Impacts in Mountain Biosphere Reserves




2nd Thematic Workshop:
Gran Sasso National Park near L'Aquila, Italy 29 Nov–2 Dec 2004
and 3rd Thematic Workshop:
Sierra Nevada Biosphere Reserve, Spain 14–17 March 2005

PROJECTING GLOBAL CHANGE IMPACTS AND SUSTAINABLE LAND USE AND NATURAL RESOURCES MANAGEMENT IN MOUNTAIN BIOSPHERE RESERVES

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Projecting Global Change Impacts and Sustainable Land Use and Natural Resources Management in Mountain Biosphere Reserves

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Second Thematic Workshop:
Projecting Global Change Impacts in
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Gran Sasso National Park (near L'Aquila), Italy
29 November–2 December 2004

Part I

Working Group Presentations

1 Climatic Change and its Possible Impacts in the Alpine Region

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ABSTRACT

This paper provides a brief overview of climatic change as observed in the twentieth century in the alpine region, and the shifts in mean and extreme climates that may occur in coming decades if so-called 'global warming' is of the amplitude and speed projected by numerous climate models. The impacts of climatic change may be significant in regard to many fragile systems in the mountain environments, notably snow and ice, hydrology, vegetation and natural hazards, and may also affect humans and their economic activities; these topics will be briefly discussed. This overview paper concludes with some remarks concerning adaptation options in the face of climatic change, notably through the application of the UN Framework Convention on Climate Change.

INTRODUCTION

The geographical location and configuration of the Alps make it a particularly interesting region for many climate and environmental studies, because the mountains are at a 'climatic crossroads' that is affected by oceanic, continental, polar, Mediterranean and, on occasion, Saharan influences.

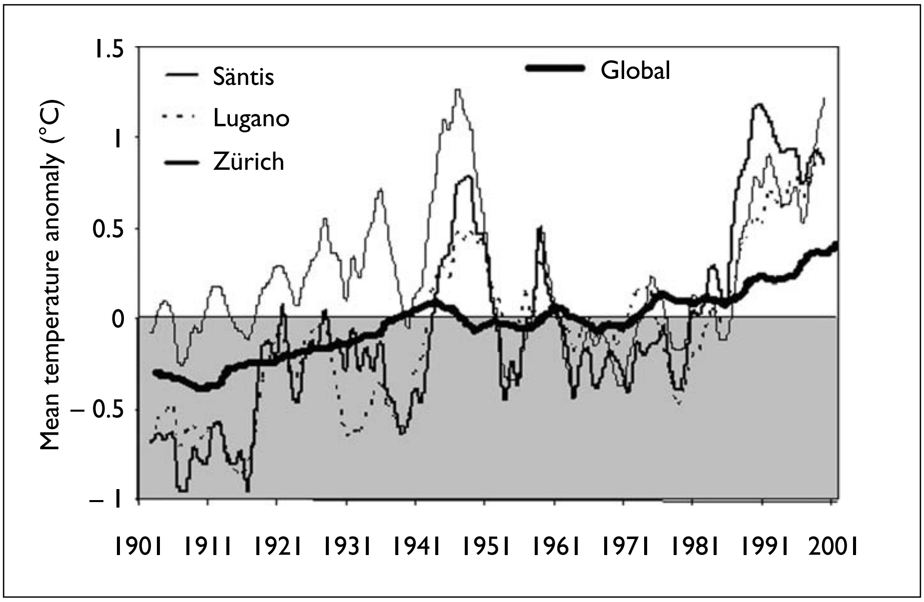
The Alps are to some extent defined by the competing influences of the Mediterranean, the Atlantic, and to a lesser extent the North Sea and the Baltic. Due to the modulating influence of the Atlantic Ocean and the heat reservoir of the Mediterranean Sea, they are one of the warmest areas of the Northern Hemisphere mid-latitudes.

The alpine arc is subject to the influence of storms that cross the Atlantic or develop in the Mediterranean, but it can also in turn influence weather patterns in several ways. For example through lee cyclogenesis (the development of low-pressure systems resulting from the interaction between large-scale atmospheric flows and topography), the Alps contribute to the formation and persistence of blocking high pressure systems, and to the triggering of turbulent mountain waves (gravity waves) whose influence can be felt far downstream of the mountains themselves.

OBSERVED CLIMATIC CHANGE IN THE ALPS IN THE TWENTIETH CENTURY

Figure 1.1 shows the changes in annual surface temperature anomalies during the twentieth century for three typical Swiss stations, as a representative example of changes that have occurred in the region at various altitudes. The anomalies are computed as the difference between daily mean temperatures and the mean daily average for the 1961–1990 period, defined by the World

Figure 1.1 Temperature departures from the 1961–1990 climatological mean for three sites in Switzerland compared to global temperature anomalies



Meteorological Organization (WMO) as the reference period for the latter part of the twentieth century. In order to remove the noisiness of year-to-year variability, the data has been smoothed with a five-point filter for clarity. The global data described in Jones and Moberg (2003) has been superimposed on this graph to illustrate the fact that the temperature change in the Alps is more conspicuous than is the case on a global or hemispheric scale. The warming experienced since the early 1980s, while synchronous with warming on the global scale, is of far greater amplitude and exceeds 1.5°C at certain sites such as Säntis or Jungfraujoch, which represents roughly a three-fold amplification of the global climate signal (Diaz and Bradley, 1997).

Beniston (2004), among others, concludes that climatic change in the alpine region has been characterized during the twentieth century by increases in minimum temperatures of over 2°C in some locations, a more modest increase in maximum temperatures (with the exception of the sudden jump in maxima resulting from the 2003 heatwave that affected much of western and central Europe), and little change in the average precipitation data. Several periods of warming were observed during the instrumental record, with the 1940s exhibiting a particularly strong warming and then a cooling into the 1950s, possibly associated with increased solar energy fluxes.

The most intense warming occurred in the 1990s, which can be explained in part by the influence of the North Atlantic Oscillation (Beniston and Jungo, 2002). During the last decade of the twentieth century, persistently positive values of the North Atlantic Oscillation (NAO) index were observed. The NAO index is based on the pressure difference between the Azores and Iceland and is an indirect measure of the intensity of the atmospheric general circulation over the North Atlantic. The behaviour of the NAO accounts for over 60 per cent of the variability of climate in both the eastern third of North America and a major part of western and central Europe (Hurrell, 1995).

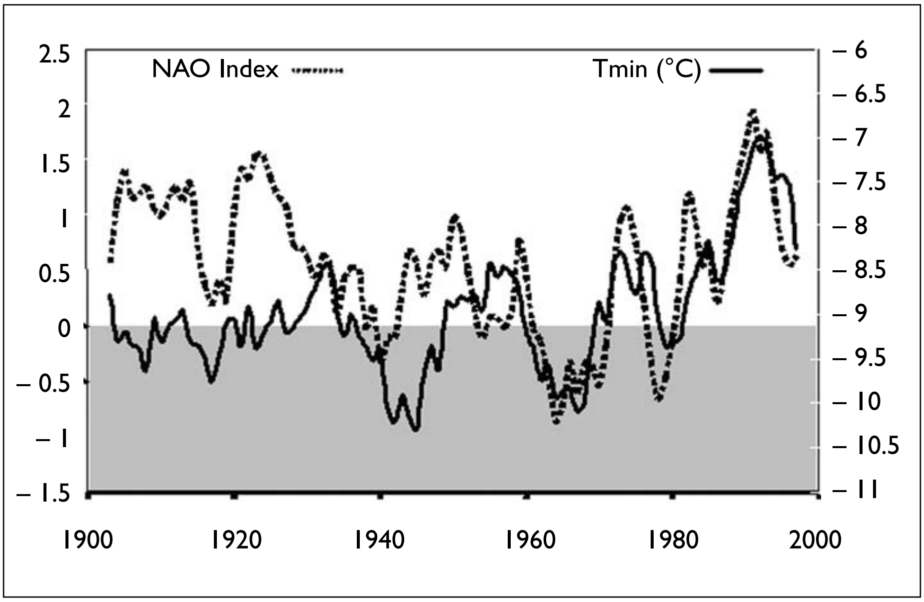


Figure 1.2 Twentieth century time series of the wintertime (DJF) NAO index and winter minimum temperature anomalies at Säntis (2,500 m above sea-level). A five-point filter is used to eliminate high-frequency oscillations in the series

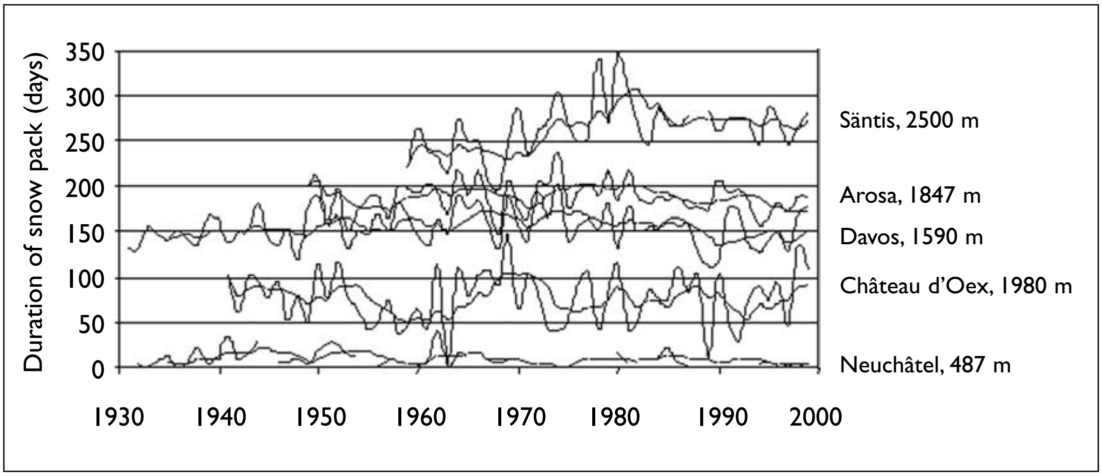
When the NAO index is high, the alpine climate tends to respond through lower-than-average precipitation and higher-than-average temperatures. Figure 1.2 shows the relationship between the NAO index and minimum temperatures at Säntis (eastern Swiss Alps, at 2,500 m above sea level), and in particular the strong synchronous behaviour since the 1970s. Beniston and Jungo (2002) have computed that the bias on minimum temperatures due to the highly positive NAO index since the early 1970s exceeds 1°C (about 0.7°C bias for maximum temperatures). In other words, if the NAO index had not exhibited such strongly and persistently positive behaviour, the observed amplitude of warming in the Alps would probably be lower than recorded.

The importance of snow in terms of environmental (e.g. hydrology, vegetation) and economic systems (e.g. tourism, water management) has been stressed in numerous studies (*inter alia*, Beniston, 2004). A quantification of the amount of snow in the mountains and the changes that occur with shifts in climate is crucial for assessing the amount of water that will ultimately runoff and be routed into the numerous river systems originating in the Alps in the spring and early summer.

The Alps in general, and Switzerland in particular, are frequently referred to as 'the water tower of Europe'. Any substantial changes in the mountain snowpack would have a significant impact on the flow of many major river basins, not only because of changes in the amount and timing of runoff, but also because of the potential for enhanced flooding, erosion, and associated natural hazards. The timing of snowmelt is also a major determinant for initiating the vegetation cycle of many alpine plant species, and therefore its quantification is necessary when assessing the response of vegetation to climatic change (e.g. Keller and Körner, 2003; Myneni et al., 1999).

Figure 1.3 illustrates the manner in which the alpine snowpack responded in past decades to the degree of climatic change experienced in the Alps (Beniston et al., 2003). The data for each of the selected sites shows that while there was much interannual variability, overall the trends in

Figure 1.3
Time series of the duration of the snow season for a number of Swiss observing sites located at different altitudes, for a threshold of snow depth of 10 cm or more. Bold lines are smoothed series where a five-year filter has been applied



snow quantity did not change substantially. The reason for this was that the rate of warming that occurred in the course of the twentieth century was still relatively modest compared with future projections – and snow still falls during the winter months at most locations. Since the mid-1980s, at elevations below about 1,200 m, there has been a reduction in both the total amount of snow and in the duration of the snow season, but these remain well within the bounds of annual variability despite the strong warming that has intervened, particularly in the winter, since about 1985.

Säntis, like other sites above 2,000 m, has experienced an increase in the amount of snow; this could be related to warmer temperatures and certainly more precipitation in the last two decades resulting in snow at high elevations (thus accumulating more snow over a longer season) and rain at low elevations (thus reducing the potential for snow accumulation).

Glacier mass balance, on the other hand, has responded very sensitively and negatively to warming since the termination of the 'Little Ice Age' in Europe in the mid-nineteenth century. The principal explanation is related to the fact that most alpine glaciers have a surface temperature close to freezing point, so that any minor increase in temperature in the mountains can have a major negative impact on the glaciers. Haeberli (1995) estimates that 40 per cent of the surface area of glaciers in the Alps and over 50 per cent of their volume have disappeared as a result of climatic change.

POSSIBLE CLIMATIC CHANGE AND IMPACTS IN THE ALPS IN THE TWENTY-FIRST CENTURY

The complexity and mutual inter-dependency of mountain environmental and socio-economic systems pose significant problems for climate impacts studies (e.g. Beniston, 1998). This is essentially because the current spatial resolution of general circulation climate models (GCM) still remains too crude to represent the topographic detail of most mountain regions adequately. Most impacts research requires information with fine spatial definition, where the regional detail of topography and land-cover are important determinants in the response of natural and managed systems to change. Since the mid-1990s, the scaling problem related to complex topography has been addressed through regional modeling techniques, pioneered by Giorgi and Mearns (1999), and through statistical-dynamic downscaling techniques.

So-called 'nested' approaches to regional climate simulations, where large-scale data or GCM outputs are used as boundary and initial conditions for regional climate model (RCM) simulations, have been applied to scenario computations for climatic change in the twenty-first century (Giorgi and Mearns, 1999). The technique is applied to specific periods in time ('time windows') for which high-resolution simulations are undertaken over a given geographical area. The nested modeling approach represents a trade-off between using decadal or century-scale, high-resolution simulations that are too computationally expensive to attempt, and relying only on coarse resolution results provided by long-term GCM integrations. Although the method has a number of drawbacks, in particular the fact that the nesting is 'one-way' (that is the climatic forcing occurs only from the larger to the finer scales and not vice versa), RCMs have shown their capacity to generally improve the regional detail of climate processes. This is an advantage in areas of complex topography, in particular where orographically-enhanced precipitation often represents a significant fraction of annual or seasonal rainfall.

Over time, the increase in spatial resolution of RCMs has resulted in an improvement in the understanding of regional climate processes and the assessment of the future evolution of regional weather patterns influenced by a changing global climate. Since the mid-1990s, RCM spatial resolution has continually increased, partially as a response to the needs of the impacts community. Currently, detailed simulations with 5 km or even 1 km grids are used to investigate the details of precipitation in relation to surface runoff, infiltration and evaporation (e.g. Arnell, 1999), extreme events such as precipitation (Frei et al., 1998) and damaging wind storms (Goyette et al., 2001). This is an interesting development for impacts studies, because extreme climatological events tend to have a greater impact on natural and socio-economic systems than changes in mean climate.

When applied to climate change scenarios, global and regional models are powerful tools that provide insight into how the possible future climate may respond to various levels of greenhouse gas emissions and concentrations (IPCC, 2001). According to the scenarios, the response of climate ranges from an increase in global mean temperatures of 1.5°C to 5.8°C. These scenarios (IPCC, 2001) are based on the levels of emissions of greenhouse gases in the atmosphere as a result of pathways of economic and population growth, hypotheses related to technological advances, the rapidity with which the energy sector may reduce its dependency on fossil fuels, and other socio-economic projections related to deforestation and land-use changes.

Within the European Union project PRUDENCE (Christensen et al., 2002), a suite of regional climate models has been applied to the investigation of climatic change over Europe for the last thirty years of the twenty-first century, enabling changes in a number of key climate variables to be assessed. A suite of regional models operating at a 50 km resolution have simulated two thirty-year periods: the 'current climate' or the 'control simulation' for the period 1961–1990, and the future 'greenhouse gas climate' for the period 2071–2100. Regional climate model simulations suggest that the alpine climate in the late twenty-first century will be characterized by warmer and more humid winter conditions, and much warmer and drier conditions in the summer. Winter minimum temperature increases at the lower elevations of Switzerland, such as Basle, Geneva and Zurich, are projected to be in the range of 4°C, while summer temperatures will increase by 5.5–6°C compared with current values based on the 1961–1990 climatological mean record.

Figure 1.4 compares the1961–1990 climate with the range of summer temperatures at Basle (Switzerland) that are projected to occur, both on average (lower curve), and in the upper 10 per cent extreme of maximum temperatures (that is, those associated with heatwaves). The respective levels recorded in Basle during the 2003 heatwave, which severely affected many parts of western and central Europe from June to August, are superimposed on these figures. The results indicate that the 2003 event may well be a precursor to the type of summers that are likely to occur with increasing frequency in a warmer climate by 2100 (for example, Schär et al., 2004, suggests that 50 per cent of future summers will resemble the 2003 event in Europe).

Precipitation change in the Swiss Alps exhibits a more heterogeneous behaviour than temperature, with one model realization that winter precipitation could increase by about 25 per cent in alpine source areas, while summer precipitation is projected to decrease by about the same amount (Figure 1.5), with relatively little significant change in the other seasons on average. According to Christensen and Christensen (2003), reductions in average summer precipitation may be simultaneously accompanied by a sharp increase in short but potentially devastating heavy precipitation events in many parts of Europe, including the Alps. First indications based on

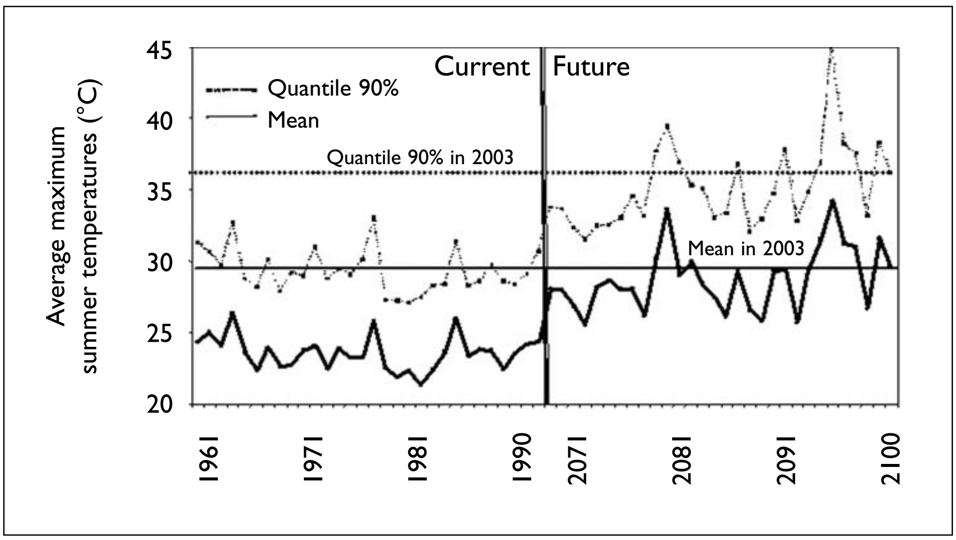


Figure 1.4
Average maximum summer temperatures in Basel, Switzerland, for the 1961–1990 reference period (left) and the 2071–2100 future simulated period (right). The solid line refers to mean summer temperatures, the dashed line refers to the upper 10 per cent extreme temperatures associated with heat waves. For comparison purposes, the horizontal lines identify the mean and upper 10 per cent extreme maximum temperatures that were recorded at this location during the 2003 heat wave in Europe.

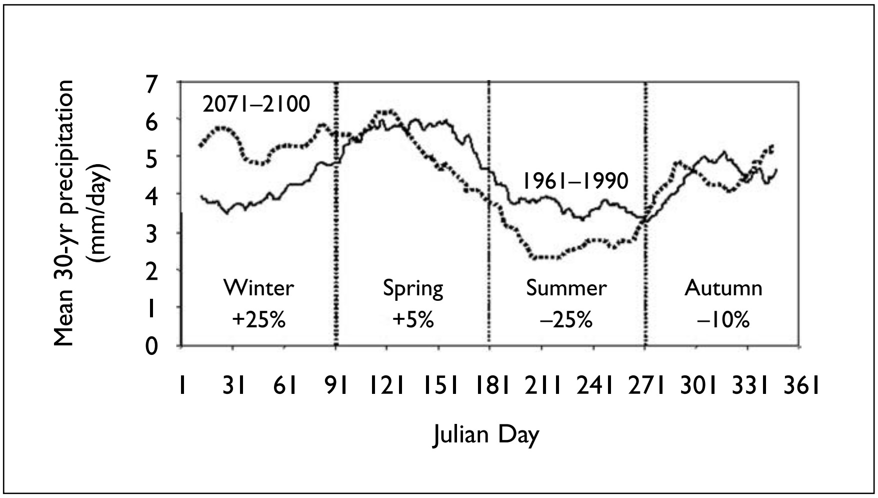


Figure 1.5 Changes in precipitation in the Alps, averaged over the 1961–1990 reference period (solid line) and the 2071–2100 future simulated period (dotted line). Figures refer to the shifts in precipitation amounts by season (in %)

model results show that while annual average precipitation will be almost unchanged in the future, drought events could increase by over 30 per cent and heavy precipitation events (of 50 mm/day or more, which have the potential to cause floods and slope instabilities in the mountains) may increase by as much as 25 per cent.

The sharp reduction in mean precipitation in summer explains why much greater warming occurs in the Alps and other parts of Europe in that season than in winter. Cloudiness is reduced in the summer months, and therefore more incoming solar energy is available to warm the surface; in addition, soil moisture diminishes, thereby exerting a positive feedback effect on the lower atmosphere. Slightly enhanced winter precipitation, on the other hand, implies a small increase in snow accumulation, although at higher altitudes than today, but more rainfall at or below 1,500–2,000 m above sea level (Beniston et al., 2003). However, it is not expected that the increase in winter accumulation will do much to compensate for the direct influence of higher temperatures on glacier mass balance. Glaciers are likely to lose between 50 per cent and 90 per cent of their remaining mass, according to the extent of warming, by the end of the twenty-first century.

The impacts of climatic change on physical systems will affect water, snow and ice, and shifts in extremes will lead to changes in the frequency and intensity of natural hazards. Water availability in some regions may decline because of a reduction in precipitation, and also because of the reduced snowpack and snow season in many mountain regions. Changes in the amount of snow will lead to significant changes in the timing and amount of runoff in various hydrological basins on average over the 1961–1990 and 2071–2100 periods, as seen in Figure 1.6 for a typical alpine catchment such as the Rhine or the Rhone (Graham et al., 2005).

Figure 1.6 clearly highlights the strong shift in seasonality in the distribution of water throughout the year, with a potential risk of more flooding in late winter than occurs today, and more frequent drought (with riverbeds running dry) in the late summer and early autumn. Such regimes, as projected by RCM simulations, are reminiscent of current conditions in the

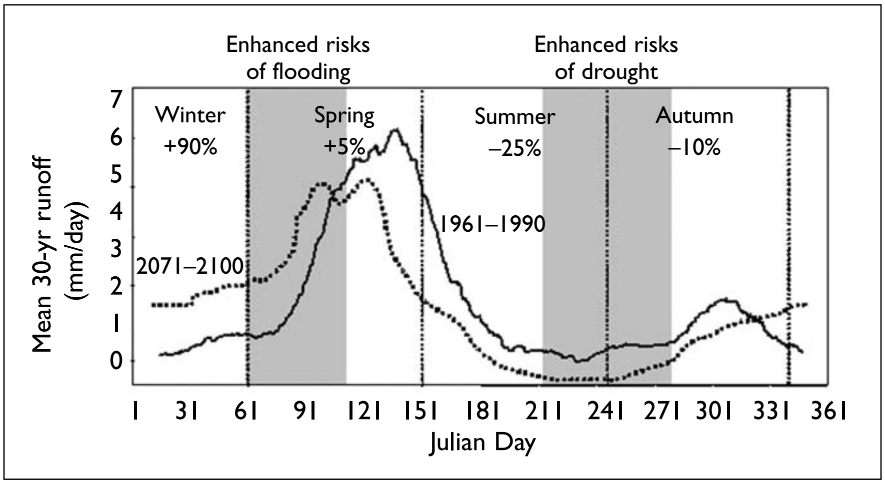


Figure 1.6 Changes in surface runoff in a typical alpine catchment area, such as the Rhone or the Rhine, averaged over the 1961–1990 reference period (solid line) and the 2071–2100 future simulated period (dotted line). Figures refer to the shifts in runoff by season (in %).

Mediterranean mountain regions. Water supplies to more populated areas outside the mountains themselves will be influenced by shifts in precipitation regimes (both rain and snow) in the source regions of many of Europe's rivers.

A key variable that controls the various components of the hydrological cycle contributing to discharge in alpine rivers is the behaviour of the winter snowpack, which determines the timing and amount of runoff that will feed into rivers during the snowmelt season. A two-dimensional representation in temperature–precipitation space, first shown by Beniston et al. (2003; see also Figure 1.7), shows that as a result of the expected winter minimum temperature rise of more than 4°C by the end of the twenty-first century, a reduction in snow duration by more than 100 days is likely to occur at the Säntis and Arosa sites represented in Figure 1.7 (Beniston et al., 2003).

The increase in winter precipitation that is expected during this period only slightly modulates the dominant effect of the +4°C warming. The 'migration' of the Arosa and Säntis statistics can be considered highly significant, because the location of snow duration in the temperature–precipitation space by the 2070s is well outside the range of natural variability of current snow duration. This variability is defined by the ellipses that are centred on the average temperature–precipitation data for the two alpine sites (see Beniston et al., 2003, for more details).

In a changed climate, meteorological extremes may also occur in regions that are today less prone to such events, and vice versa. Because of the amount of precipitation and relief, the added effect of intense rainfall in low-to-middle-altitude regions is to produce some of the highest global rates of slope erosion. Climate change could alter the magnitude and/or frequency of a wide range of geomorphologic processes (Dehn et al., 2000). Increases in extreme precipitation events, associated with snowmelt, could increase the frequency and severity of floods. Such extreme events would affect erosion, discharge and sedimentation rates, with associated damage to hydropower infrastructures. Furthermore, sediments deposited in large quantities on agricultural lands, irrigation canals and streams would lead to reductions in agricultural production.

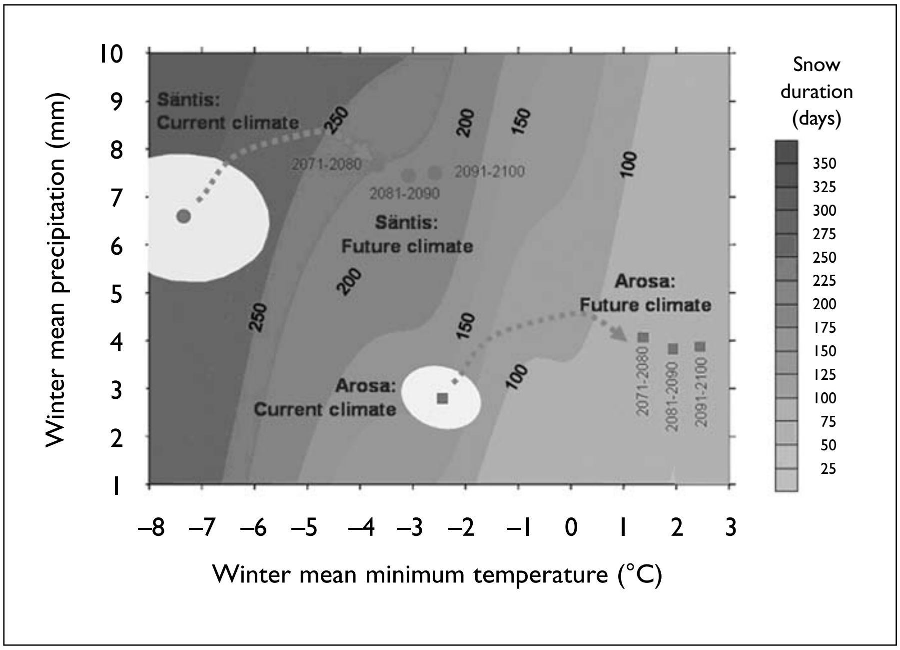


Figure 1.7
2-D contour surfaces of snow-cover duration as a function of twenty Swiss climatological sites. Superimposed on this figure is the temperature–precipitation–snow duration data for the Arosa and Säntis sites, for current climatic conditions, and for the three last decades of the twenty-first century. The ellipses show the 2σ range of DJF minimum temperature and precipitation, and corresponding spread of snow-cover duration for Arosa and Säntis. The orientation of the ellipses is related to the covariance of temperature and precipitation. The figures on the isolines identify the length of the snow season.

As a result of much longer growing seasons and higher temperatures, in the twenty-first century the European alpine areas will face an upward shift in the alpine tree-lines of 300–400 m (Holten and Carey, 1992). Depending on the magnitude of temperature increase, the response time for the invasion of mountain birch into the current low alpine zone may be fairly short, and easily observed within around two to three decades (Woodward et al., 1995). The reductions in area of the alpine zones will probably be relatively smaller in the Alps, due to the higher and very often steeper mountains. Melting of permafrost and changes in hydrology at higher altitudes will change the ecological conditions on steep mountain slopes, making them much more unstable, probably causing more frequent and maybe more serious avalanches and landslides.

CONCLUSIONS

There is a wide consensus about the very real threat that abrupt global warming poses to a wide range of environmental, social and economic systems, both globally and regionally such as in the Alps. The IPCC (2001) has been instrumental in providing state-of-the-art information on climatic change and its environmental and economic consequences, so that while science can continue to refine its predictions for the future, there is sufficient material to justify joint international action to reduce the risks related to climatic change and to define strategies for adapting to change as soon as possible, before such actions become much more costly in the future.

The United Nations Framework Convention on Climate Change (UNFCCC) has the explicit objective of protecting the climate system, through political, economic and legal measures destined to reduce the emissions of greenhouse gases into the atmosphere and ultimately to stabilize their concentrations. Indeed, in terms of ecological systems, Article 2 of the FCCC explicitly states that:

> The ultimate objective of the UNFCCC ... is the stabilization of greenhouse gas concentrations at a level which would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

In facing up to environmental change, it will be necessary to think in terms of decades and centuries, because the impacts of these profound changes may not become clearly apparent for several generations. Many of the policies and decisions related to pollution abatement, climatic change, deforestation or desertification will provide opportunities and challenges for the private and public sectors. A carefully selected portfolio 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.

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2 *Alpine Snow Processes and Modeling*

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INTRODUCTION

A recent survey (this volume) of mountain biosphere reserve (MBR) managers revealed that recreational use of the MBRs and tourism on the one hand, and water supply, floods, avalanches and earth movements on the other hand, are thought to be greatly affected by global change. In many cases, these processes are closely linked to snow cover dynamics.

A famous example is the snow-albedo feedback mechanism: a warmer earth surface leads to less snow on the ground in areas with seasonal snow cover. As a result, less shortwave radiation is reflected back from the snow into space and more radiation is converted to heat at the earth's surface (due to the higher albedo of snow when compared with surfaces that are not snow-covered). This added heat will further contribute to warming. This positive feedback interacts, however, with so vast a number of other processes that its overall effect is difficult to quantify. Models can help to quantify such complex interaction processes. Therefore, this contribution reviews important snow processes and discusses current modeling approaches, in particular the one-dimensional snow cover model SNOWPACK, and the three-dimensional model of Alpine surface processes ALPINE3D.

The numerical model SNOWPACK, originally developed for avalanche warning applications (Lehning et al., 1999), has evolved into a multi-purpose modeling tool of snow cover in general but also for vegetation–snow–soil interactions. In an effort to model the spatial variability in complex terrain, SNOWPACK has been coupled with a drift model (Lehning et al., 2000a), an energy balance model for topography (Fierz et al., 2003) and a runoff model (Zappa et al., 2003) to provide a complete description of surface processes in complex terrain. This distributed model is called ALPINE3D, and a first overview description has been given in Lehning et al. (2004).

SUMMARY OF ALPINE SNOW PROCESSES

Figure 2.1 schematically shows the complex processes in the atmosphere–snow–soil system. Precipitation can occur as snow, rain, graupel, hail or rime. With sufficient wind, snow will start to drift. In complex terrain, this results in an irregular snow deposition, with maximum snow depths up to ten times the average depth. The wind will also influence the snow crystals, which may form a hard crust at the snow surface. Vegetation (if present) will alter the surface water balance considerably through interception, unloading and evapo-transpiration. Once the snow is on the ground, it settles and water vapour fluxes cause the snow crystals to change. This change is known as 'metamorphism' and is heavily influenced by the snow energy balance. The snow cover receives a small but constant flux of energy from the ground, but the exchange of energy with the atmosphere is

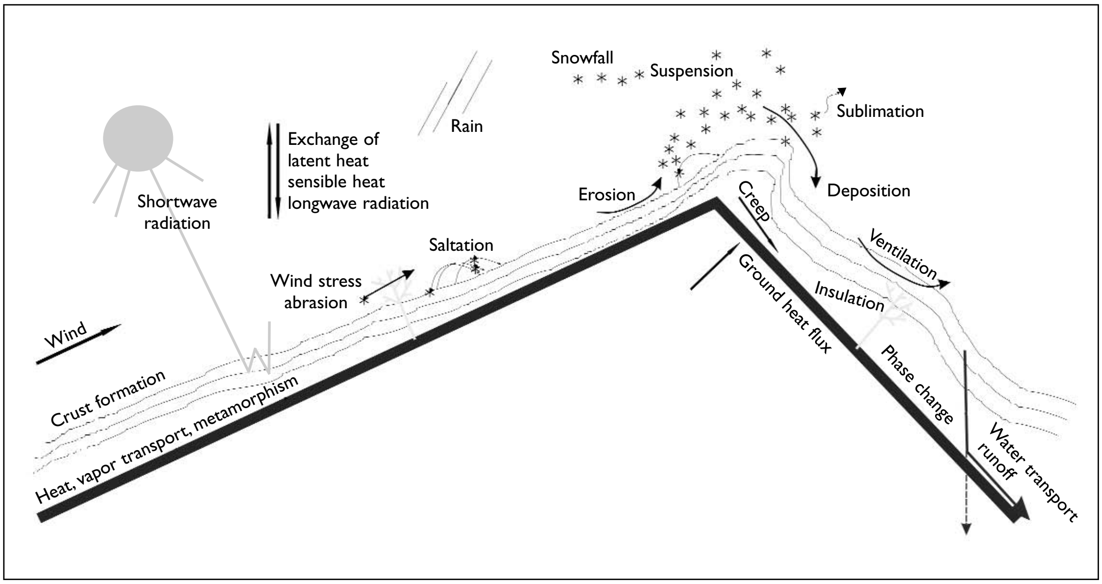


Figure 2.1 Schematic representation of Alpine surface processes as modeled in the ALPINE3D and SNOWPACK models

much more intense. During the day, the snow cover absorbs shortwave radiation. Energy is usually lost to the atmosphere by longwave radiation. The turbulent fluxes of heat and moisture can add or take away energy and mass (latent heat only) from the snow cover. On clear nights, surface hoar is often formed by moisture sublimation on the snow surface, which then creates a dangerous weak layer. All these processes change rapidly over space and time and interact with the topography. As soon as enough energy has entered the snow, it starts to melt and produce water. This will lead to a large change in the snow structure and may cause wet snow avalanches. A refreezing event will then, however, stabilize the snow cover. The melt water is first stored in the snow pores but then starts to percolate downwards, often along so-called preferential flow paths.

The complex processes continue in the soil. Depending on soil grain size and soil history, more or less water may be stored in the pores. In springtime or after heavy precipitation, the soil might already be saturated and any water entering the soil will immediately produce surface runoff. The dynamics of water transport and storage behaviour are altered by the layered structures of soil and bedrock, which may contain impermeable layers such as clay or very permeable bedrock such as limestone.

SNOWPACK FUNCTIONALITY AND APPLICATIONS

Snow description: the SNOWPACK core

SNOWPACK is a one-dimensional heat and mass balance model that describes the evolution of snow covers. It is based on finite element numerics (Bartelt and Lehning, 2002) and provides state-of-the-art descriptions of snow metamorphism (Lehning et al., 2002a) and the surface energy exchange (Lehning et al., 2002b). The model has been developed to describe as accurately as possible the snow structure as it influences the thermal and mechanical snow properties.

As an example, Figure 2.2 shows the result of a simulation of snow cover on a northerly slope in the region of Davos, showing the grain type representation. On the northerly slope, faceted crystals and layers of surface hoar dominate the profile. Close to the ground can be seen a rain crust, created during a rain-on-snow event in early winter.

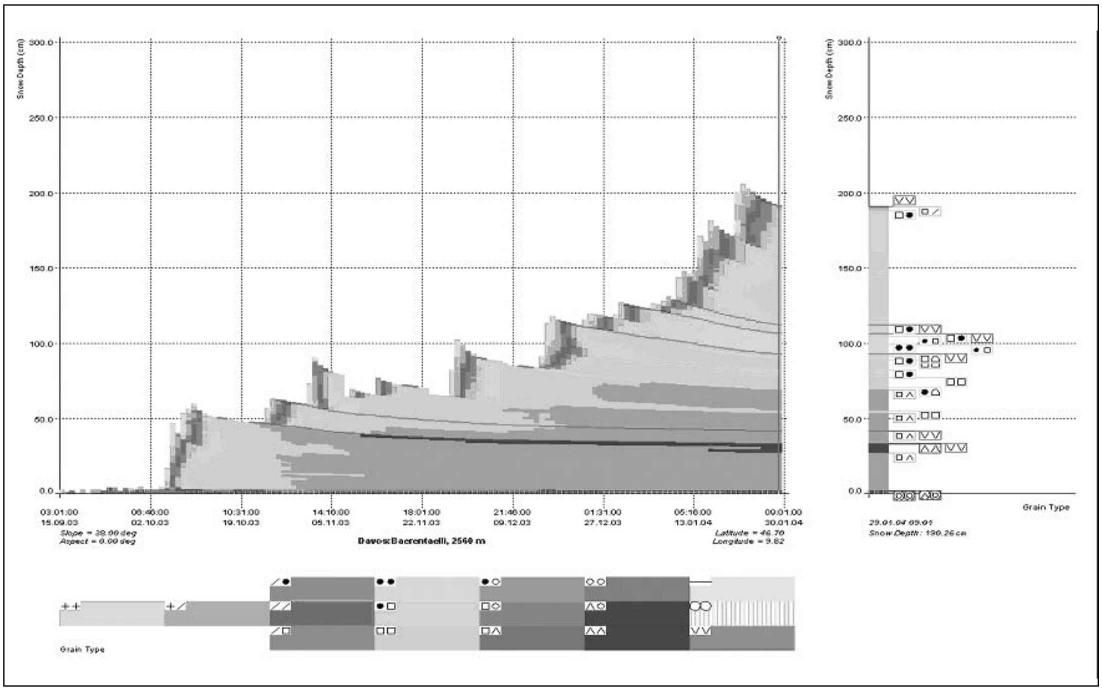


Figure 2.2 Grain type representation of a SNOWPACK simulation for a northerly slope in the Davos region. Grain types are given by colors and symbols. The profile at the right part of the figure shows the situation at the end of January.

SNOWPACK vegetation module

The forest canopy in SNOWPACK is represented by a single big model leaf, which has two state variables: temperature, and interception storage. The basic input parameters are tree stand characteristics, canopy height, leaf area index (LAI) and the direct throughfall fraction; these describe the variation between different forest stands without further tuning.

The water and heat balance of the canopy layer – and its influence on the accumulation and ablation of the snow cover below – is calculated in three steps. First, a preliminary mass balance is calculated, taking account of interception and throughfall of precipitation. Second, the canopy temperature is calculated by solving the energy balance of the canopy, whereby the radiation transfer and turbulent exchanges of sensible and latent heat are calculated. Third, the mass balance of the canopy is updated by the evaporation (or condensation) calculated in step two. Obviously, the accumulation of snow below the canopy is governed by step one, whereas the input of radiation and turbulent heat for ablation is governed by step two. The interception of precipitation in the forest canopy during a model time step is calculated by the method shown in Koivusalo and Kokkonen (2002).

As an example, Figure 2.3 shows the cumulative runoff from a sub-alpine area. The influence of the canopy is well represented by the model, and the comparison of the open land and forest situations indicates the importance of the canopy for the local mass and energy balance.

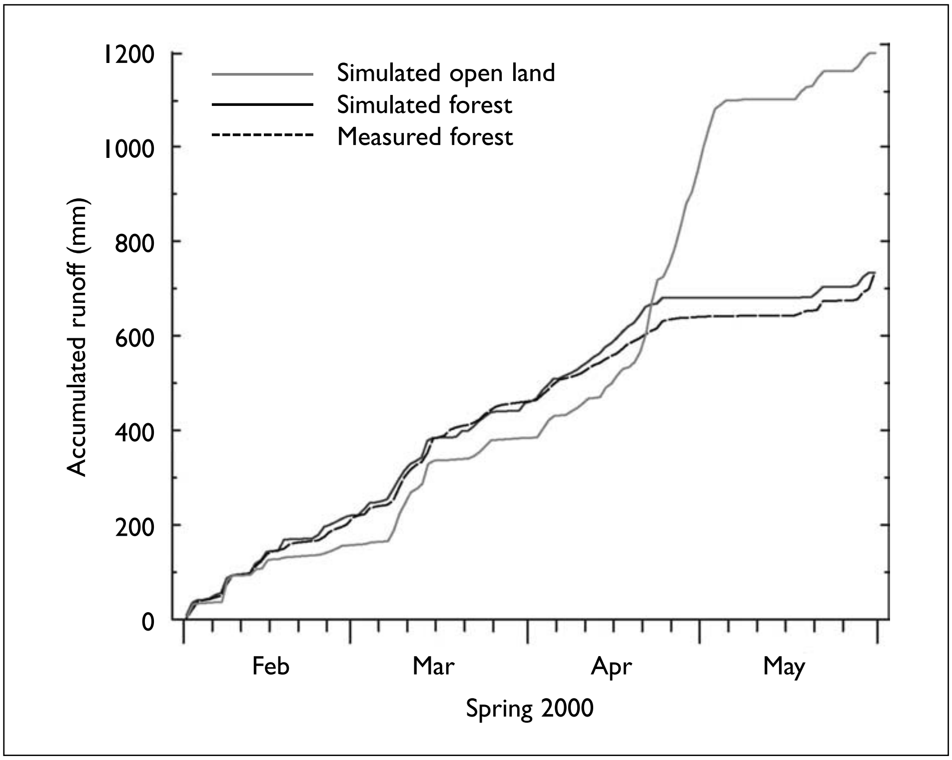


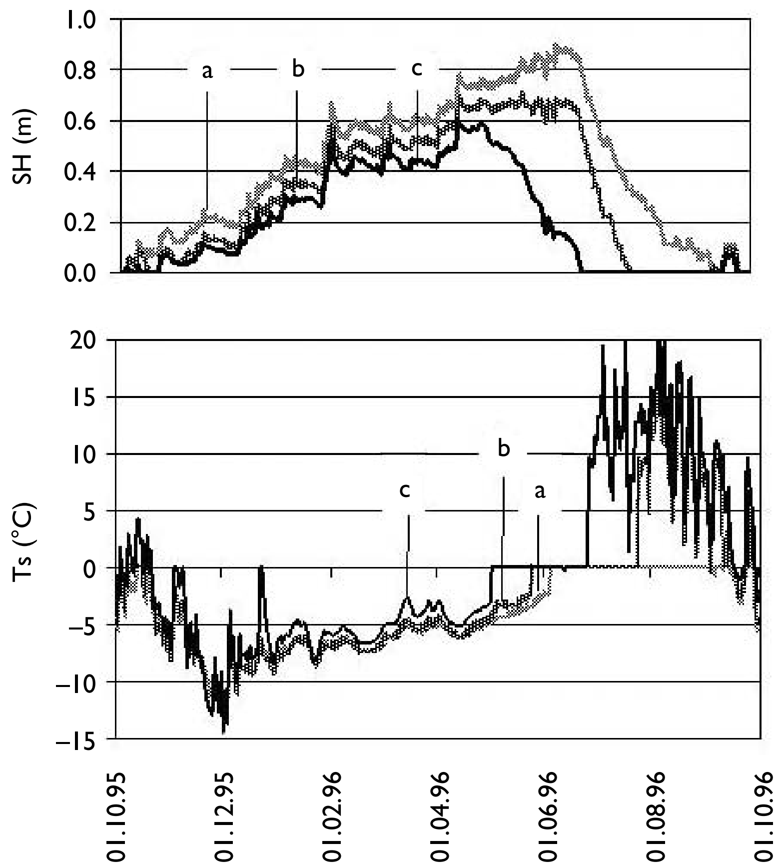
Figure 2.3 Runoff from a forested site as calculated by SNOWPACK. If the vegetation module is included, measurement and simulation agree well.

SNOWPACK soil module

The multi-component numerical SNOWPACK model can readily be extended to simulate other materials such as soil, permafrost, rock, gravel or even tarmac road surfaces. Soil (and other substrates) are also treated as a four-component material containing air, water, ice and one additional component. Heat capacity, thermal conductivity and other 'raw' material properties can be provided as input. In the soil part of the model, mass and energy transport and phase change processes are taken into account in the same way as for the snow layers.

The influence of increasing mean annual air temperatures on mean annual soil surface temperatures of different soil types can be investigated as an example (Lütschg et al., 2003). The soil/rock types 'rock ridge', 'fine grained' and 'coarse blocky' are used. Figure 2.4 shows the effect on the snow's depth of increasing the air temperatures by 1°C and 3°C (upper graph). The depth decreases asymmetrically, with a sharp decline in the last three months of the snow period. This affects the underlying soil accordingly: the lower graph shows the resulting increase in soil surface temperatures, and a rise at the start of the zero threshold of two months.

Figure 2.4 Simulations of the snow cover (SH) under increased mean annual air temperatures of (a) 0°C, (b) 1°C and (c) 3°C show an asymmetric decrease. The lower graph shows the corresponding soil surface temperatures (Ts).



SNOWPACK superimposed ice simulation

SNOWPACK has also been used to simulate superimposed ice (SI) formation on glaciers (Obleitner and Lehning, 2004). SI formation is a process that significantly influences the mass and energy balance of high latitude glaciers. Understanding the process will help in making predictions of how glaciers will react under conditions of climate change. To simulate SI formation, modeling of the the water transport routine in SNOWPACK had to be improved to allow for ponding. Ponding has been found to be important for superimposed ice formation.

Figure 2.5 shows the simulation of two consecutive years of surface ice and snow at about the equilibrium line of Kongsvegen glacier at Svalbard (Spitzbergen). The model simulations helped to identify different processes of SI formation. In addition to the common formation from below due to cold ice temperatures (region A and C in Figure 2.5), a significant portion of SI was formed by falls from above when the average surface energy balance switched to negative (region B in Figure 2.5). This behaviour was confirmed by observations (Obleitner and Lehning,

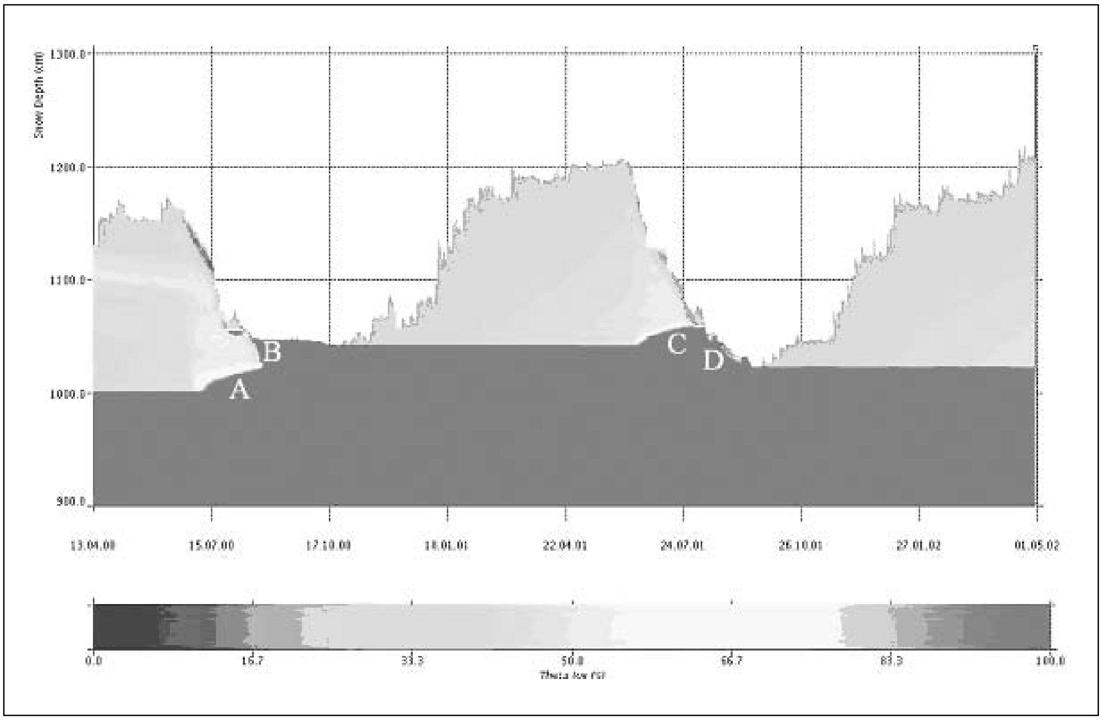


Figure 2.5 Simulation of ice (dark gray) formation for an Arctic glacier

2004). The high sensitivity of SI formation is also shown in Figure 2.5. In the warmer second year, all the SI formed earlier the same year (region C) and even some of the SI from the previous year melted away (region D).

ALPINE3D: A 3D MODEL OF SURFACE PROCESSES IN STEEP TERRAIN

Motivation

Applications suitable for a 1-D snow cover model have been summarized above. However, for the purposes of avalanche warning or predicting vegetation development, it would also be useful to know about the spatial distribution of energy and mass fluxes. In addition, the effect of drifting snow is hard to implement in a 1-D model, and the model cannot adequately deal with the effects of shade on mountain slopes or forest edges. Another problem requiring a 3-D model of surface processes is the prediction of runoff in Alpine catchments. In response to these problems, a new modular model system has been introduced, which combines the distributed application of SNOWPACK with fully 3-D modules of blowing and drifting snow, radiation balance and runoff.

ALPINE3D structure and input

The modular structure of ALPINE3D also accommodates input of a varying degree of complexity. A simple representation of the modular structure is shown in Figure 2.6. In the simplest case, ALPINE3D is driven by the measurements of a single meteorological station in or near the domain (analysis mode) or by the output from one grid point of a (coarse) meteorological model (forecast mode). The radiation energy balance component (eb@ALPINE3D) will then calculate the radiation distribution in the domain, while wind speed and direction, air temperature, humidity and pressure are simply adjusted with a given vertical gradient. Alternatively, the latter parameters can be read from 2-D surface fields, which may have been created by a meteorological model or by interpolating between a number of meteorological stations (Garen and Marks 2001). If calculations of snowdrift are to be made, full 3-D wind fields need to be available. These are also read from a meteorological model, which will then also provide surface fields of wind speed and direction, air temperature, humidity and pressure.

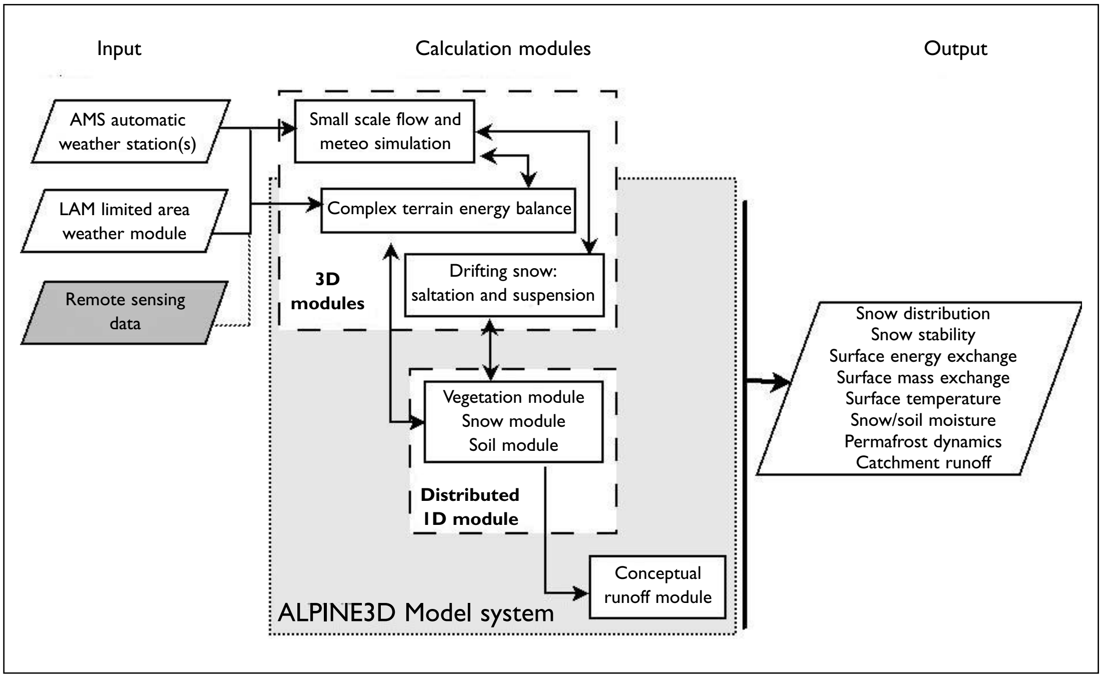


Figure 2.6 Conceptual chart of ALPINE3D model modules

Drift@ALPINE3D

The starting point of ALPINE3D was the coupling of model modules of snow saltation and suspension with SNOWPACK (Lehning et al., 2000) in order to calculate snowdrift, snow distribution and snow cover development on a steep Alpine ridge. This application has been improved to better simulate 3-D wind fields with the meteorological model ARPS. The latest version of the SLF saltation model (Doorschot et al., 2004) contributes to this improvement. Finally, using this together with the radiation module (eb@ALPINE3D) allows a more realistic simulation of the snow cover development over longer periods of time.

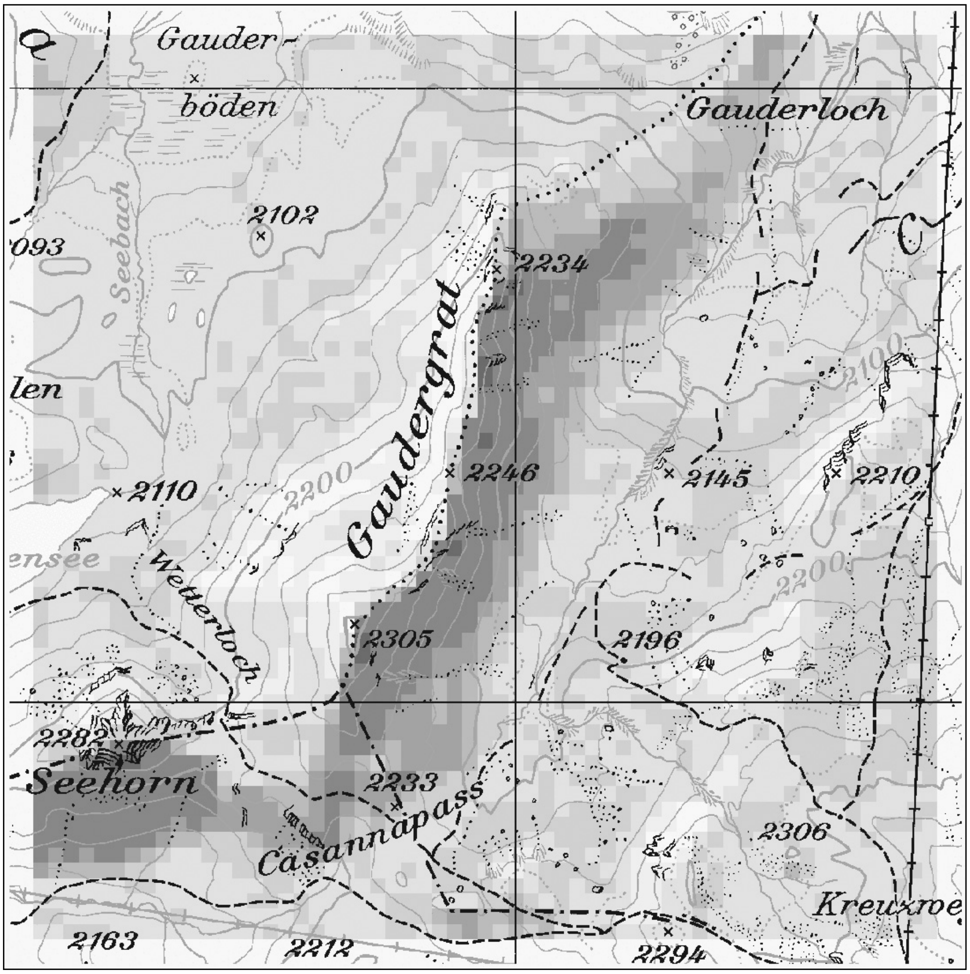


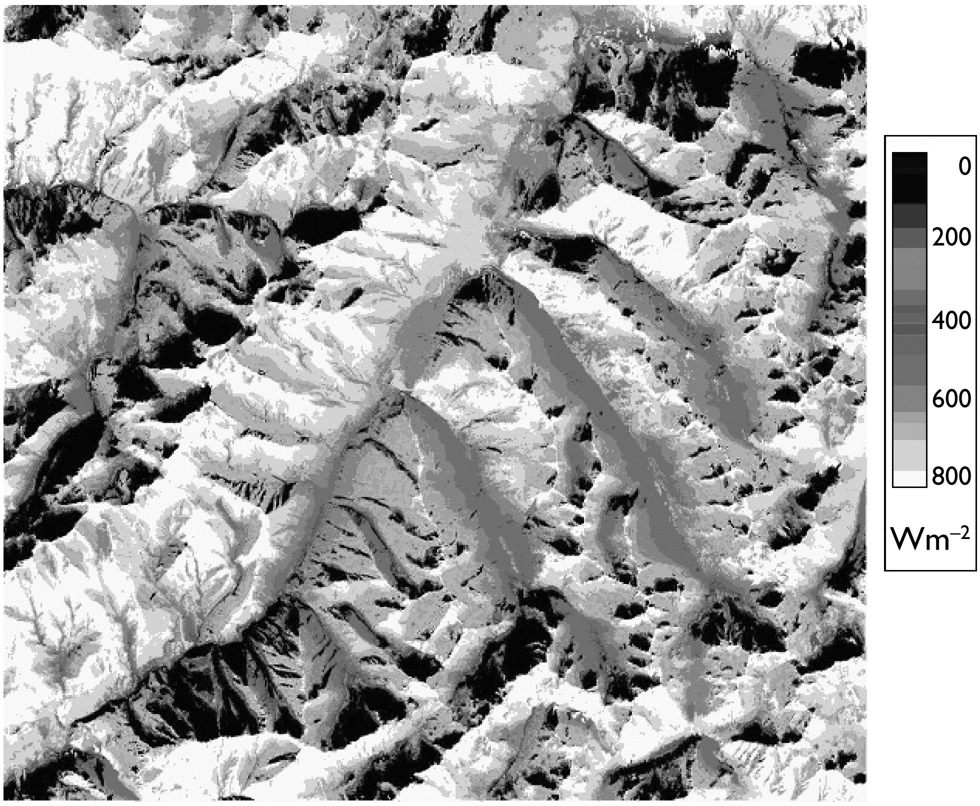
Figure 2.7
Simulated snow distribution over the Gaudergrat ridge

Figure 2.7 shows the distribution of newly deposited snow over the Gaudergrat ridge after the first snowstorm period in the avalanche winter 1999. Some of the unrealistic deposition features of the earlier version (Lehning et al., 2000) have been eliminated through the improvements discussed above.

Eb@ALPINE3D

When working with very high resolution (order of 10 m) in Alpine terrain, the surface energy balance is strongly influenced by local shade and other ways that the terrain affects the radiation balance (Fierz et al., 2003). Therefore a model module has been developed and coupled to ALPINE3D, describing these effects on the basis of a view factor approach. One simple task that such a model can perform is the calculation of potential total sunshine. Figure 2.8 shows an example of this calculation for March for the region of Davos.

Figure 2.8
Potential sunshine for March in Davos



Hydro@ALPINE3D

Since ALPINE3D allows the calculation of snow cover and soil dynamics in alpine terrain with or without vegetation, a natural add-on to the model is a runoff module that calculates discharge for whole alpine catchments. Therefore we have coupled the PREVAH runoff module (Gurtz et al., 1999) to ALPINE3D.

Previous attempts to work with distributed snowmelt models have shown that not much improvement is obtained when compared with simple but well-calibrated degree-day methods (Zappa et al., 2003). However, these attempts have not made use of high-quality, high-resolution meteorological input fields. As a hypothesis, it is expected that with the ALPINE3D approach, the surface processes will be represented with enough detail that the physical snow and soil representations will lead to an improvement of runoff calculation or to less need for calibration. Combining measured ground data from meteorological stations with meteorological model output is a first step to obtain better meteorological forcing. The assimilation of satellite information has been suggested as the next step. This information can significantly enhance the representation of such aspects as the snow cover distribution.

First verifications with ALPINE3D show the influence of a correct representation of energy balance, vegetation and soil processes on the runoff calculations. Figure 2.9 presents a comparison of calculated versus simulated runoff for the Dischma catchment in the Davos landscape for the peak runoff season in 1991, when the spring runoff generation produced the highest runoff peaks. For the critical spring melt situation, ALPINE3D already clearly represents the runoff dynamics as indicated by the coefficient of determination (r^2) of 90 per cent. That this result is really caused by including the physical processes in the model in great detail can be shown by repeating the simulation without part of the process descriptions. If we switch off the modules for vegetation, radiation balance, and interpolation of the meteorological variables in ALPINE3D and only work with a uniform soil representation, the r^2 value goes down to 46 per cent.

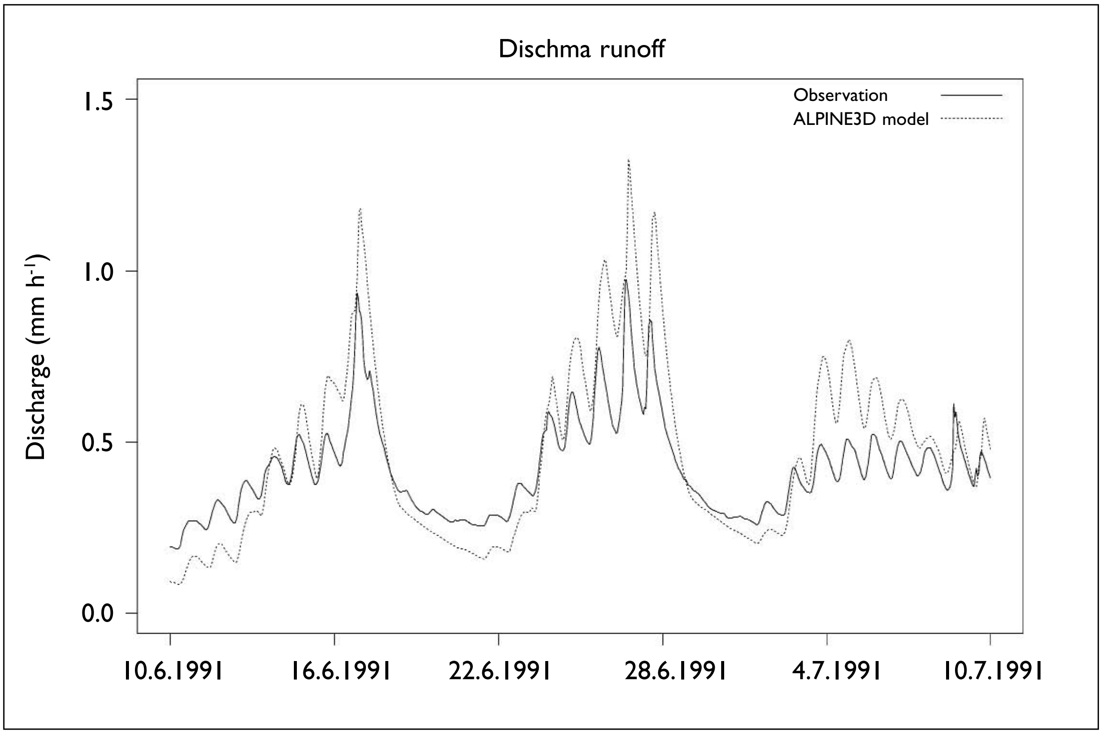


Figure 2.9 Runoff simulation with ALPINE3D for the peak runoff season in early summer 1991

CONCLUSIONS AND IMPLICATIONS

Many areas with a seasonal or perennial snow cover are severely influenced by global change. For example, the duration and maximum depth of snow cover are already significantly declining at altitudes between 800 and 1,300 m a.s.l. in the Alps. This has immediate consequences on activities such as winter sport use or water storage. How far these change processes will also affect the overall level of natural hazards such as avalanches or mud flows has not yet been determined, but we can safely assume that the incidence of such hazards will locally increase or decrease.

As a result, organizational measures will become more and more important in risk management. Organizational measures are usually cost effective (Wilhelm, 1998) when compared with more conventional measures such as building protection structures. This will become even more significant when we have to deal with changing conditions. An integral risk management system with a strong contribution from organizational measures will require good forecasts of the danger, however. Model support will be highly welcome in this context.

In addition to risk management, model support to monitor and manage global change effects in high mountain environments can be useful for a variety of specific tasks. Examples may include estimates of snow cover mass, energy balance development and snow cover mechanical structure changes. With regard to snow cover mass change, the most important consequences are its influence on vegetation and hydrology and also on tourism and recreational use. Using a model, we can answer such questions as: how long will the snow cover last under changed climate conditions? A combined mass–energy balance question is: how far will certain vegetation belts shift upwards due to local changes in microclimate? Mechanical changes in snow cover characteristics will not only influence avalanche danger but may also have consequences related to animal mobility and therefore also to habitat changes.

However, the role of models in predicting and finally managing those changes depends on the quality of those models. Only if quantitative model predictions come with an estimation of the models' accuracy will they help to support human action on the changing climate. Model validation is therefore an immensely important task, but one that is often neglected.

ACKNOWLEDGEMENTS

This work is supported by the Swiss National Science Foundation and the Board of the Swiss Federal Institutes of Technology. I thank Tuan Anh Nguyen, David Gustafsson, Manfred Stähli, Martina Lütschg, Barbara Landl, Charles Fierz, Norbert Raderschall, Jakob Rhyner and Walter Ammann for their contributions, help and support.

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3 *Glaciers and Permafrost in Mountain Areas: Different Modeling Approaches*

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INTRODUCTION

Glaciers and permafrost are common phenomena in high-elevation mountain regions all over the world. They are widespread in several of the mountain biosphere reserves (MBR) and there is an urgent need to assess the impact of global change in these areas. The documentation of existing conditions and ongoing changes in MBRs is very important and can only be achieved by a combined modeling and monitoring approach. In addition, modeling is the only tool existing today that provides forecast simulations and sensitivity studies for such areas (Haeberli and Dedieu, 2004).

Over the past thirty years a whole set of different models at various levels of sophistication and scale have been developed by the glacier and permafrost research community. Today, permafrost and glacier models combine stochastic with deterministic elements and can be divided

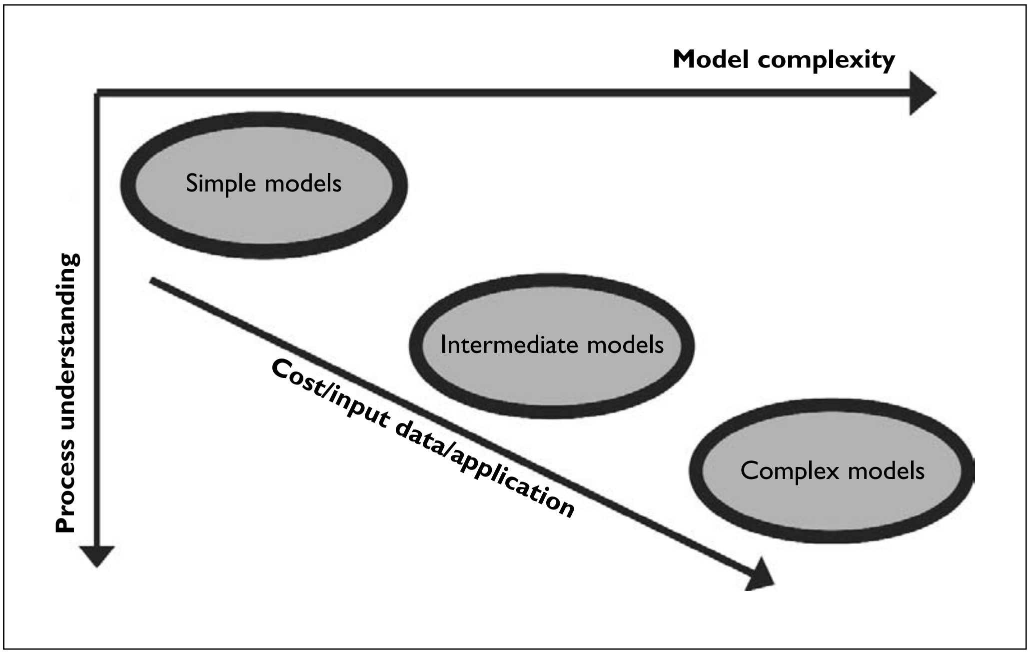


Figure 3.1
Scheme showing the relationship between model complexity and process understanding for different types of models

into two main types: regionally calibrated empirical–statistical models and process-oriented models, which are more physically based.

In most cases there is a relationship between model complexity and process understanding. Simple models have the advantages of needing, in most cases, only a small level of input data, being inexpensive and often relatively easy to apply. However, the understanding of the related processes that these so-called 'black box' models offers is not very sophisticated (Figure 3.1). In contrast, more complex models allow deeper insight into the physical processes in nature, but they usually need more input data and are more difficult to apply.

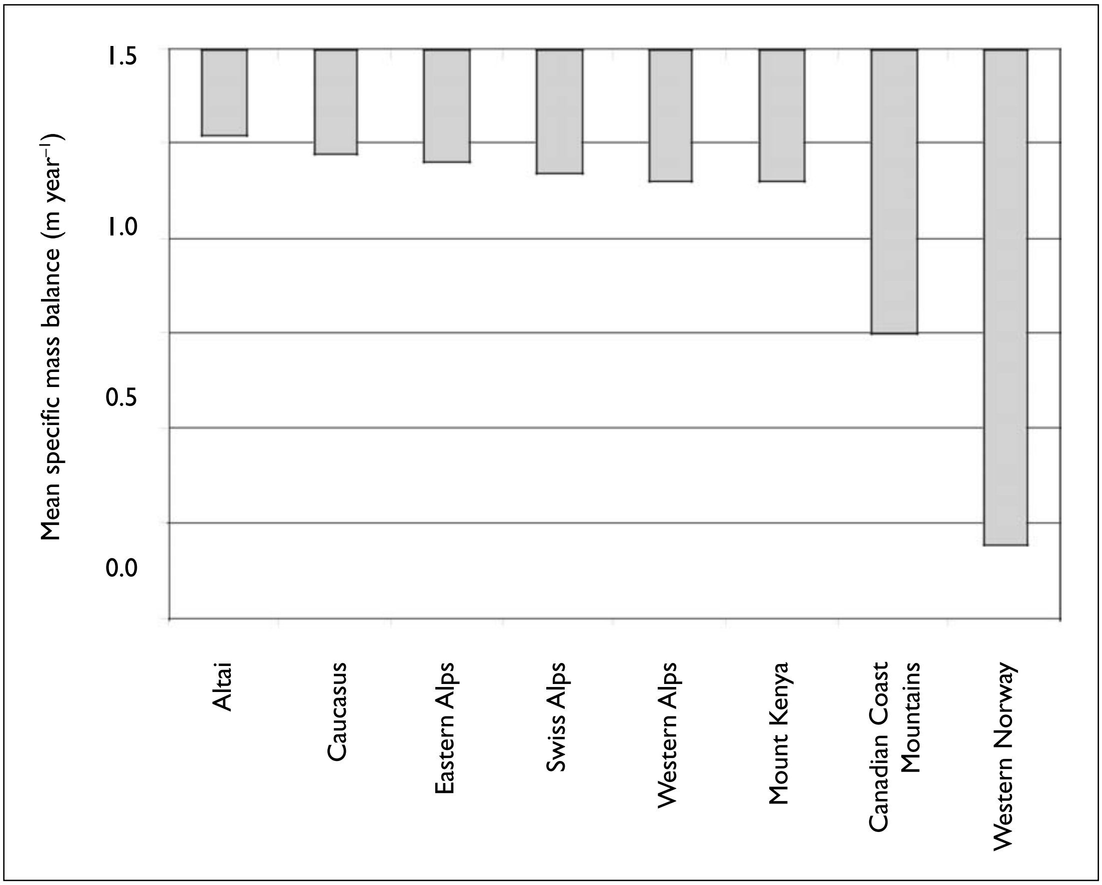
GLACIER MODELS IN MOUNTAIN AREAS

The first dynamic glacier models were developed by Nye in the early 1950s (1952, 1960). The first simple energy and mass balance models were implemented in the early 1980s by Kuhn (1979, 1980a, 1980b, 1984, 1985, 1988, 1989). Since then, a wide variety of models in glacier research has been developed. Calculations of glacier contributions to global sea-level rise from observed or predicted climate data (mainly temperature) are generally based on degree-day models (e.g. Braithwaite, 1981; Braithwaite and Zhang, 2000; Hock, 2003) which allow us to estimate glacier runoff at a global scale from sparse data sets (e.g. Gregory and Oerlemans, 1998; Van de Wal and Wild, 2001; Zuo and Oerlemans, 1997). The required global distribution of glacier properties is, however, only known from scaling paradigms (Bahr and Dyurgerov, 1999) and local calibration is difficult. On the other hand, long-term monitoring of changes in glacier length together with simple continuity considerations allow us to estimate mean specific mass balances for different mountain regions (Hoelzle et al., 2003) (see Figure 3.2) and over longer time periods (Haeberli and Holzhauser, 2003).

For small catchments, when there is accurate input data, degree-day models calculate runoff quite precisely (Hock and Noetzli, 1997). In addition, much progress has been made recently in glacier mass balance modeling based on energy balance calculations (Greuell and Oerlemans, 1987; Oerlemans, 1992a, 1992b) and combined mass balance and flow modeling (Greuell, 1992; Kääb and Funk, 1999; Oerlemans, 1988). Numerous field campaigns provided measurements (Greuell et al., 1997; Greuell and Smeets, 2001; Marty et al., 2002; Oerlemans, 2000; Wagner, 1979, 1980) and parameterizations for specific variables of the energy balance (Brutsaert, 1975; Konzelmann et al., 1994; Munro, 1989). They allow a consecutive adoption to the meteorological input data available for a specific region. Distributed mass balance modeling with digital elevation models (DEMs) has shown realistic results compared with *in situ* measurements (Arnold et al., 1996; Brock et al., 2000; Klok and Oerlemans, 2003) (see Figure 3.3).

However, these studies focus on the physical formulation of the energy fluxes and have mostly been applied to individual glaciers. Moreover, the spatial variability of precipitation and the redistribution of snow by wind or avalanches are not taken into account. Such information could be gained from new snow models that allow sophisticated modeling of snow transport by wind and avalanches (Lehning, this volume). The modeling of the dynamic behaviour of glaciers has also been further developed. Flow modeling is especially important in the context

Figure 3.2
Mean specific mass balance in m year^{-1} in different mountain regions (since ca. 1900) calculated from data on cumulative length changes of glaciers (Hoelzle et al., 2003)



of larger valley glaciers, ice caps and large ice sheets, where processes of deformation and sliding have to be taken into account. Simple flow models (Oerlemans, 1997) and complex models (Gudmundsson, 1999) exist today in a quite large variety. Recent studies by Leysinger Vieli and Gudmundsson (2004) show that comparable simple model approaches are sufficient to simulate past and future glacier flow sensitivity behaviour. However, an increase in detailed process understanding is only assured by more complex flow modeling (Oerlemans, 2001; Paterson, 1994; Van der Veen, 1999).

Especially for mountain areas, such as the Alps, the rapid disintegration and downwasting that have been observed in the past two decades (Paul et al., 2004) (see Figure 3.4) caused by atmospheric warming, indicate that the glaciers are increasingly decoupled from their dynamics (Kääb, in press). The observed decay can be best modelled with a distributed mass balance model, or a combination of a mass balance model with a flow model coupled to a global climate model forcing (Schneeberger et al., 2001; Schneeberger et al., 2003).

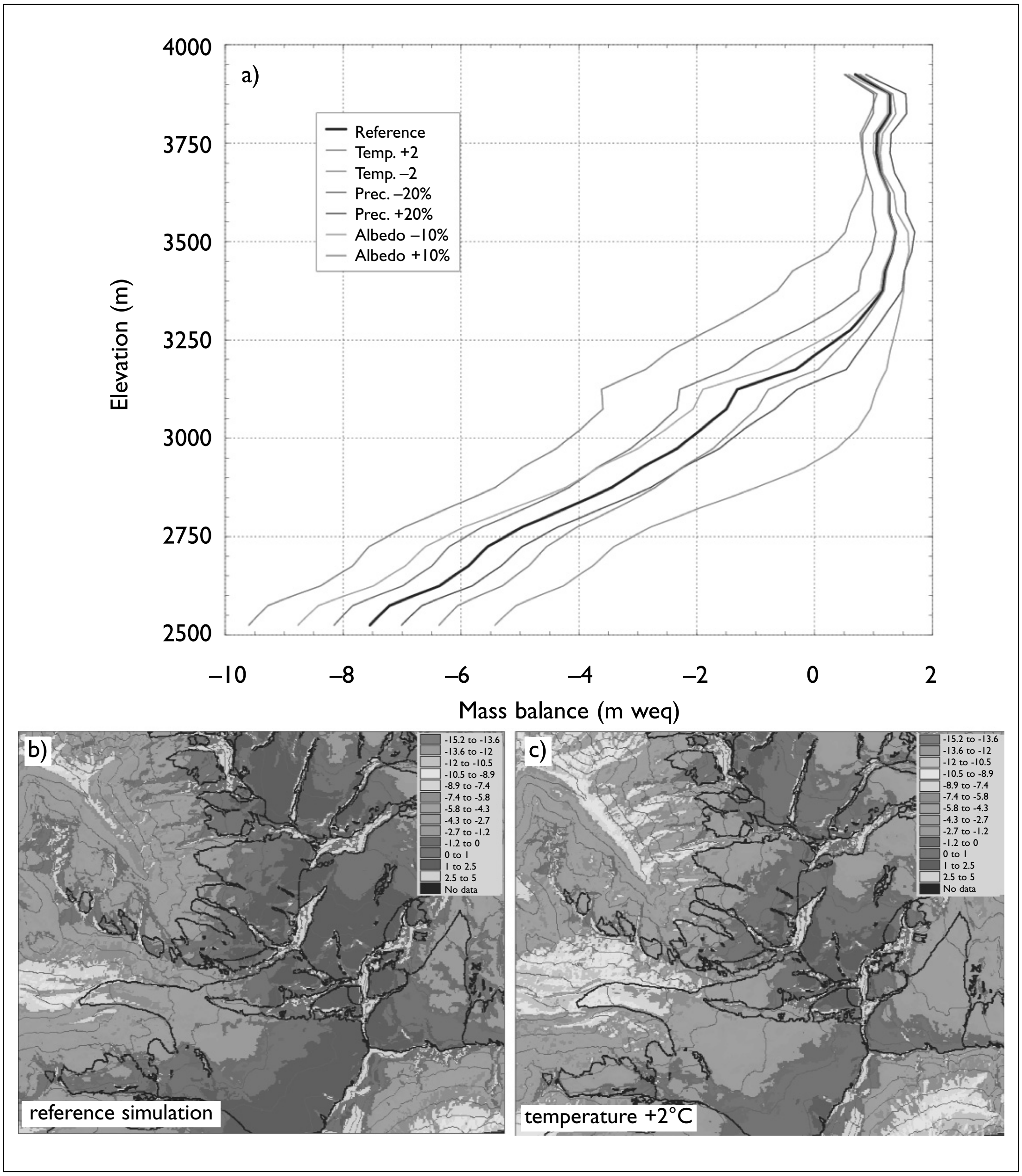


Figure 3.3
Distributed mass balance modeling, based on an energy balance approach. a) mass balance-altitude profiles for different variables and their sensitivities on the profiles. b) distributed mass balance model calculation based on a reference simulation for the area of the Findelengletscher, Valais. c) distributed mass balance model calculation based on a scenario with a change of temperature of 2°C for the same area.

Figure 3.4 Cavagnoli glacier in the year 1985 (above) and 2003 (below). The strong disintegration and downwasting of this glacier can be clearly recognized.

PERMAFROST MODELS IN MOUNTAIN AREAS

Empirical–statistical models directly relate documented permafrost occurrences to topoclimatic factors (altitude, slope and aspect, mean annual air temperature, solar radiation and so on), that can be measured or computed (Etzelmüller et al., 1998, 2001; Frauenfelder et al., 1998; Gruber and Hoelzle, 2001; Hoelzle and Haeberli, 1995; Imhof, 1996; Keller, 1992; Kneisel et al., 2000; Lieb, 1998a). The complex energy exchange processes at the surface and within the active layer are not treated explicitly, but rather as a 'grey box' with topoclimatic factors being selected according to their relative influence in the energy balance equation. This simplification results in advantages and disadvantages: empirical–statistical permafrost distribution models can be easily applied, have a limited need for input parameters and are quite reliable if well calibrated locally or regionally. They are, however, 'yes/no' functions about the presence or absence of permafrost, primarily applicable to specific areas and assuming steady-state conditions. Extrapolations in time and space are problematic and need to be interpreted with great care.

Process-oriented models focus on a more detailed understanding of the energy fluxes between the atmosphere and the permafrost (Hoelzle et al., 2001). They explicitly parameterize solar radiation, sensible heat flux, surface albedo, heat conduction and so on, and are often quite

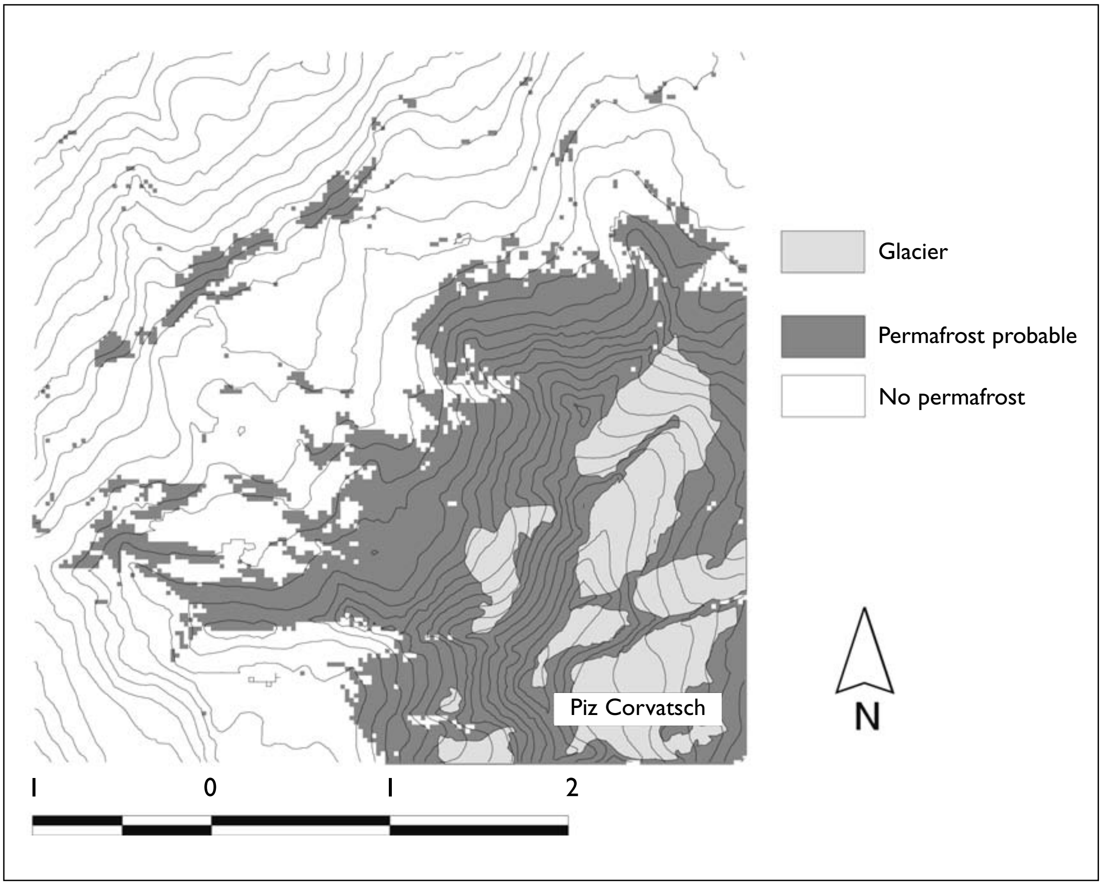


Figure 3.5 Permafrost distribution in the Corvatsch area modelled by Permamap (Hoelzle and Haeberli, 1995)

complex and need a correspondingly large amount of precisely measured or computed data (Marchenko, 2001; Mittaz et al., 2002; Stocker-Mittaz et al., 2002). Such approaches allow for spatio-temporal extrapolation and are especially well suited for sensitivity studies with respect to interactions and feedbacks involved with climate change scenarios. They enable surface temperatures to be computed, and hence thermal conditions at depth and transient effects to be estimated (Gruber et al., 2004b, 2004c).

In recent years, much progress has been made in modeling permafrost distribution in steep alpine rock walls (Gruber et al., 2003, 2004a, 2004b) (see Figure 3.6). However, major challenges remain with the modeling of alpine permafrost distribution underneath other surface types, such as coarse/fine debris or vegetation. The processes within the active layer of such high alpine ground covers comprise a very complex interaction between micro-climate, snow, ice, air, rock and water. Their composition and interaction show a high temporal and spatial variability, leading to different processes that can be simplified by the concept of the 'thermal offset' as defined by Burn and Smith (1988), Goodrich (1982) and Romanovsky and Osterkamp (1995).

A further complication of the system is that bodies of debris with a well-organized viscous appearance are evidence of cumulative creep deformation due to the long-term existence of

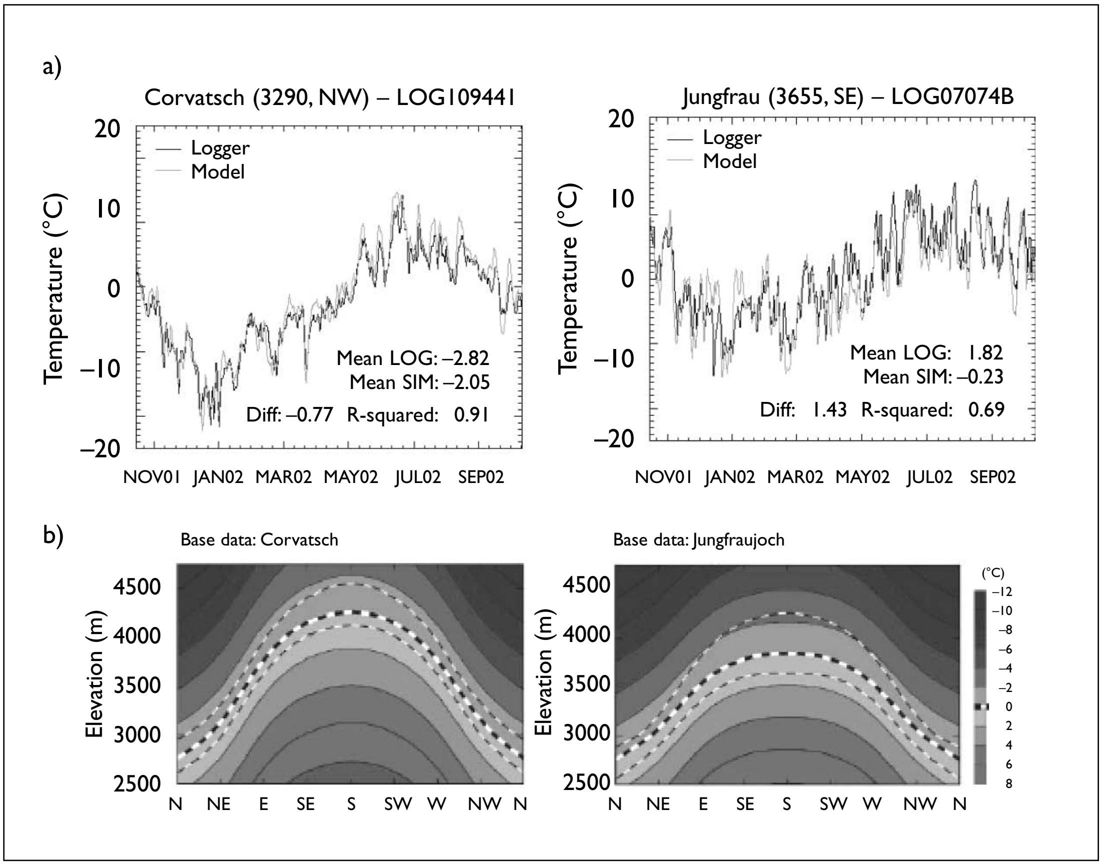


Figure 3.6
a) Measured (black) and modelled (brown) mean daily near-surface (10 cm) temperatures at two locations. b) Mean simulated annual rock-wall surface temperature for 70° slope steepness and at two locations, 1982-2002. The thick dashed line indicates the elevation of the mean 0°C isotherm during these 21 years. The thin dashed lines indicate the highest and lowest positions of the mean annual 0°C isotherm during that time (Gruber et al., 2004b).

ground ice in various forms, either now or formerly (Haeberli et al., 1998). Today, corresponding flow fields can be measured effectively over large areas using digital photogrammetry (Kääb and Vollmer, 2000). In the European Alps, rock glacier inventories exist in various countries. (For Switzerland: Delaloye and Morand, 1998; Frauenfelder, 1998; Hoelzle, 1998; Imhof, 1998; Phillips et al., 1998; Reynard et al., 1998; Schoeneich, 1998. For Austria: Lieb, 1998b. For Spain: Martinez de Pisón et al., 1998. For Italy: Guglielmin, 1998. For Norway: Sollid, 1998. For Poland: Dobinski, 1998; Kotarba, 1992. For Romania: Urdea, 1992, 1993). These inventories are most suitable for estimating the lower limit of permafrost occurrence during recent or past periods (Barsch, 1996; Frauenfelder et al., 2001; Frauenfelder and Kääb, 2000). Recently, a new modeling approach has been developed that allows estimations of the regional distribution of creeping debris (Frauenfelder, 2004; Frauenfelder et al., 2002) (see Figure 3.7).

CONCLUSIONS AND PERSPECTIVES

Today, there is a hierarchy of models for glaciers and permafrost on different levels of sophistication and scale, which are suitable to use in MBRs. All these models have their advantages and

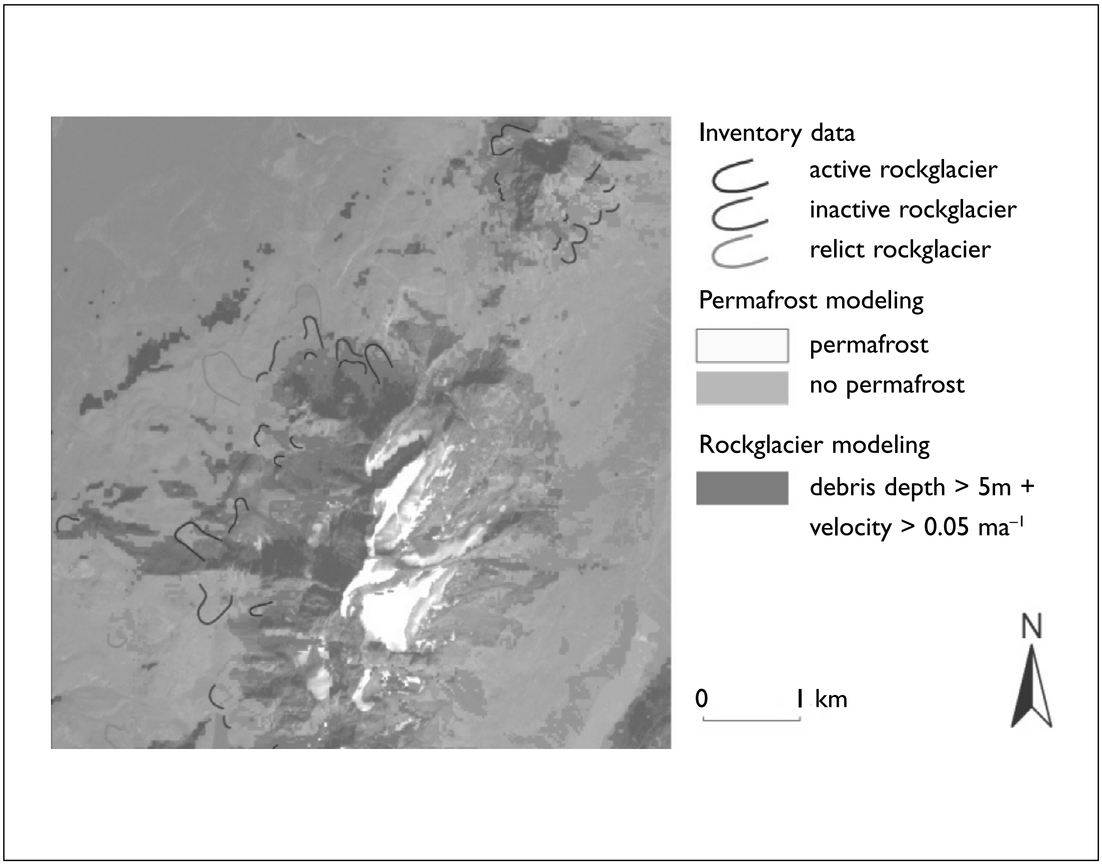


Figure 3.7
Rock glacier model. Dark zones represent areas where thickness of the debris-ice mass is greater than 5 m and velocities are greater than 0.05 ma^{-1}. Background: satellite image of the panchromatic channel of the IRS-1C, 25 September1997, ©Eurimage / NPOC (Frauenfelder, 2004).

disadvantages and should be used in an appropriate way. Modeling, mapping and monitoring should be closely linked and are directly related to the essential tasks of calibration and validation. Sophisticated models are not a priori better than simple ones; both have to be applied carefully and must be well tested. Coupling of models (e.g. output from regional climate models to local scale cryospheric models) needs careful selection and evaluation.

Future progress will come from two main directions. First, individual local scale modeling (1-D or 2-D) in combination with precise measurements will allow a better process understanding and is well suited for sensitivity and validation studies. Second, a model set for cryospheric distribution models (snow, permafrost and glaciers) has been developed that will allow an integrated view of future and past behaviour of the mountain cryosphere. In the near future, it is to be hoped that these models will serve as inputs for existing impact models, which are very helpful in the determination of potential hazards and for climate related studies.

ACKNOWLEDGEMENT

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4 *Mass Balance Modeling in the French Alps: Reconstruction and Sensitivity to Climate*

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Glacier retreat is now a familiar picture in the Alps and attests to climate change (Church and Gregory, 2001). It is important to understand this evolution in order to enhance water resources or tourism, or to prevent glacier hazard. Glacier retreat will be amplified during the twenty-first century with the warming of the climate. Thus, a precise knowledge of glacier mass balance sensitivity to various meteorological parameters is needed to form a good idea of what glaciers will look like in the future.

A new physical mass balance model has been developed to apply to glaciers. This was done here using the CROCUS snow model (Brun et al., 1992) developed by Météo-France. CROCUS was initially developed to simulate alpine seasonal snow and assist in the evaluation of avalanche risk. It is a one-dimensional model with layers taken parallel to the slope through which mass and energy are exchanged to account for physical processes such as heat diffusion, radiation transfer or liquid water percolation. Phase changes are taken into account and snow densification and metamorphism are parameterized, affecting mass and energy transfer and changing the surface albedo. At the surface, the snow–ice model is driven by prescribed hourly meteorological measurements: 2 m air temperature, 10 m wind speed, 2 m air relative moisture, precipitation quantity and phase, incoming direct and diffuse solar radiation, and incoming longwave radiation and cloudiness. As there are no meteorological observations available on or next to the glaciers, we use the synthetic SAFRAN data (Durand et al., 1993) that combine disaggregated large-scale meteorological analysis and nearby observations. SAFRAN data have been available since 1981.

To model glaciers, ice has been defined as a special kind of snow with a specific albedo or rugosity. The mass balance is calculated on a 200 m grid spacing over the glacier, taking into account the topography of the place (altitude, exposition, slope and masks). The single parameter that is checked in the model is a precipitation multiplying factor to take into account the variability of precipitation over the glacier basin. This factor is checked according to mass balance field measurements (accumulation and ablation are measured by means of drilling and stakes on several points on the glacier).

The mass balances of two French glaciers have been reconstructed with success over the 1981–2003 period: Saint Sorlin (3 km^2) in the Grandes Rousses range and Argentière (19 km^2) in the Mont Blanc range. These two glaciers are monitored by the Laboratoire de Glaciologie et de Géophysique de l'Environnement (LGGE) in Grenoble, with a long-term and dense dataset (Vincent, 2002). The model has been validated thanks to optical satellite imagery for equilibrium line position (Gerbaux et al., 2004), and to geodetic measurements on the glaciers for global volumetric changes. Thus, for modeled glaciers, mass balance is available everywhere and for every date since 1981.

Figure 4.1 shows the spatial distribution of the mass balance on Saint Sorlin glacier. We can see the effect of slope exposure on mass balance when looking to the west slope between Col de Quirlies and Pic de l'Etendard, which has a weaker balance than the north face at the same altitude.

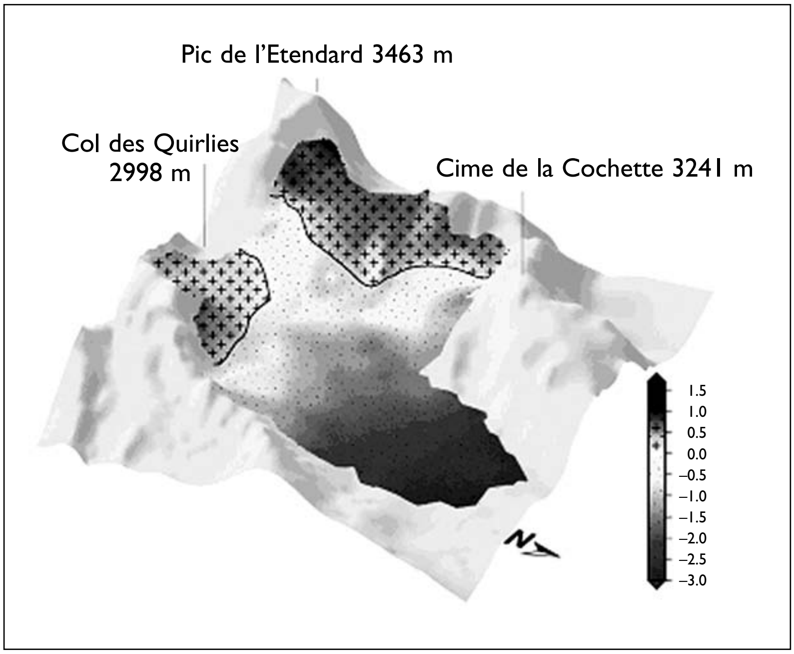
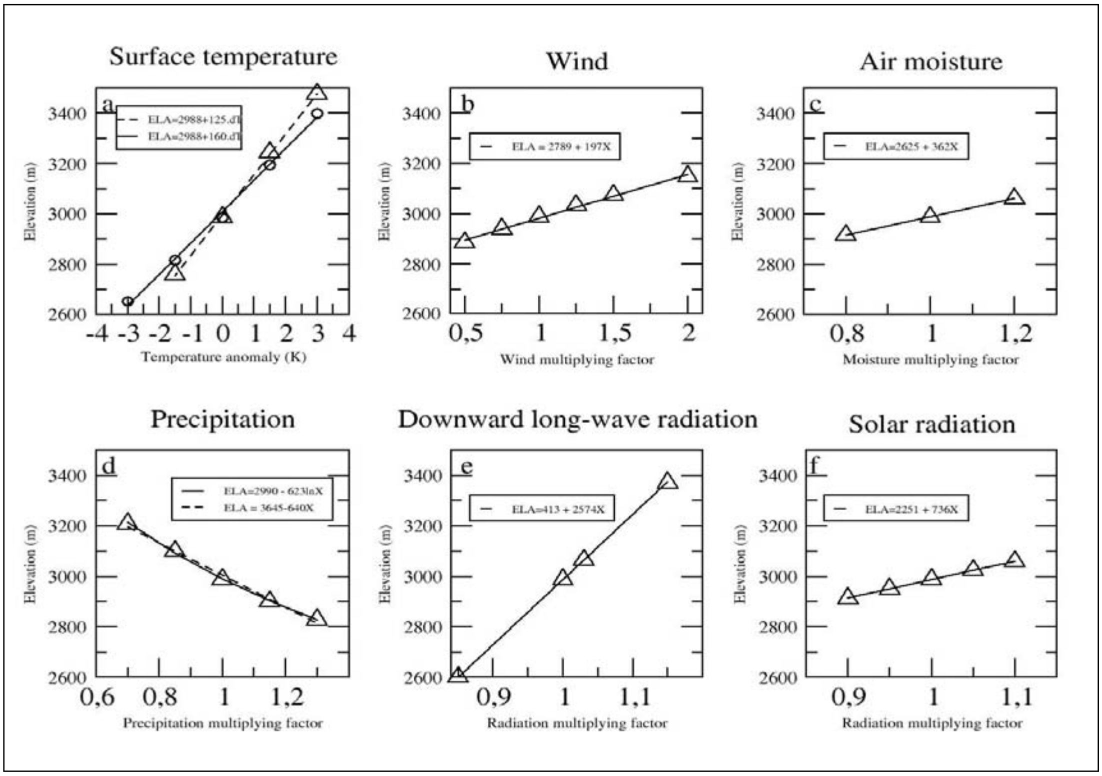


Figure 4.1 Modelled mean annual mass balance for Saint Sorlin glacier for the period 1981-2003. Mass balance is expressed in metre water equivalent. Solid line is the equilibrium line (mean altitude = 2995 m)

The results of mass balance reconstruction show that both Saint Sorlin and Argentière glaciers are losing mass and that their shrinking has accelerated in the last twenty years. During the period 1981–2003 Saint Sorlin has lost on average 1 m of water equivalent each year (m.w.e/y), while it lost only 0.31 m.w.e/y during the 1957–1997 period (Vincent et al., 2000).

When studying climate impact with the aid of past records, it is generally difficult to separate the different meteorological parameters that vary concurrently, so it is mainly the combined sensitivity which is given today. As the snow–ice model is explicitly and separately driven by the various meteorological terms that determine the mass balance, it is therefore particularly suited to evaluate the impact that climate change has on glaciers beyond periods for which the glaciers have been monitored, either in the past or in the future. We have studied changes in both mass balance and equilibrium line altitude (ELA) for an alteration of the different meteorological parameters. The order of magnitude of these alterations was derived from climate change scenarios for the twenty-first century computed by a general circulation model over the Alps. The results confirm that temperature change is the main parameter involved in future glacier shrinking. Figure 4.2 presents results for ELA change. For example, sensibility to temperature is found to be 125 m/K, and up to 160 m/K if concurrent longwave radiation change from the atmosphere is taken into account.

Figure 4.2 Modelled sensitivity of ELA (in m) to surface meteorology. The printed mean sensitivity is the equation of a linear fit. Graph (a) is sensitivity to temperature variation in °C. Graphs (b), (c), (d), (e), (f) are sensitivities to other parameters with variations expressed in fractions.



To conclude, climate simulations for the twenty-first century over the alpine region show that the rise in precipitation will probably not be able to compensate for the increase in summer temperature. Glacier retreat will thus continue and most of the glaciers, depending on their ice thickness, local exposure and average elevation, will shrink or disappear in the coming decades.

NOTE

This paper is a summary of an actual modeling study carried out at LGGE/Météo-France by Martin Gerbaux, Jean-Pierre Dedieu, Pierre Etchevers and Christian Vincent. For more information contact: Martin.Gerbaux@lgge.obs.ujf-grenoble.fr

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5 *Glaciohydroclimatology of the Altai Mountains: Condition of Study and Main Regularities*

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The natural instrumental glaciohydroclimatological study of the Altai Mountains has more than 100 years of history. In the early years these studies were related to modern glaciation research and associated orographical and climatological factors.

Glaciers in the mountains of south Siberia have been known since the first half of the nineteenth century. The position of glaciers upstream of the Katun River was first described in detail in 1835 by F.V. Gebler (Gebler, 1836), but the systematic study of glaciation in the Altai began with Vasiliy Sapozhnikov, and Boris and Mikhail Tronov. The first studies, carried out between 1895 and 1911 (Sapoznikov, 1901,1949), produced detailed descriptions of the main centres of glaciation and the fixed positions of the largest glaciers' tongues. These descriptions are supported by vast photographic archives (more than 6,000 images).

At the time of the Second International Polar Year (1932), a topographical fieldwork survey (1:5000 scale) of the Gebler Glacier was made and hydro-meteorological observations were begun at two high mountain stations, Akkem and Katun.

The Tronov brothers' expeditions began in 1912, and in 1925 Boris Tronov published the first catalogue of Altai glaciers (Tronov, 1925). The catalogue systemized all the available data: 408 glaciers with a general area of 590 km^2 (including 249 glaciers with an area of 300 km^2 located in Russian Altai). Later, Mikhail Tronov, in his well-known monographs presenting 754 glaciers with an area of 600 km^2 (Tronov, 1948, 1949, 1966), described the first stage of glaciological investigations in the Altai; this was a period of geographical study of Altai glaciation, descriptions and mapping.

At this stage (1895–1956) the research focused on the spatial analysis of glaciation: detection of the relationships between the territorial location of glaciers and the climatic and orographical conditions. It was determined that the concentration of the basic area glaciers in the main orographical centres of Altai and the comparatively weak development of glaciation in the internal regions are conditioned by the increase in climate continentality from the west to the east. The reduction of precipitation and increase in annual air temperatures accounted for the existing conditions of atmospheric circulation in the region with a stable westward transfer of air masses. The height of the snowline and other glacioclimatologic factors relate to this. This situation (Tronov, 1948, 1949, 1966) became the starting point for the second period of glaciological investigations in 1956.

Studies in the second period focused primarily on the regime, fluctuation and dynamics of glaciers in the Aktru (1957–2004), Mulita (1968–1975) and Akkem (1968–1974) high mountain stations. The observations produced useful and interesting data (*Aktru Glaciers*, 1987; Narozhniy, 1987; Revyakin et al., 1981; Revyakin and Kravtsova, 1977): they revealed zones with high and low background snow, and made it possible to determine the main regularities in the pattern of snow accumulation and melting on glaciers with different morphological types.

The most important stage of this period was the creation of the catalogue of glaciers for all mountain areas (*Katalog Lednikov*, 1969, 1974, 1977, 1978, 1980), which brought together all the available knowledge about the size and regime of glaciation. However, all of this requires wider generalization and verification in insufficiently studied areas.

With the creation of the *World Atlas of Snow and Ice Resources* (1977) it became possible to approach the concept of internal and external interrelations with the environment, not only for separate glaciers but also for the global glacial system (Krenke, 1982; Narozhniy and Nikitin, 2003; Revyakin, 1981).

Maps of the glaciers and their regime have been compiled, showing snowline heights, air summer temperatures and background precipitation, as well as long-scale maps of accumulation, melting, mass balance, drainage and similar factors. These in many respects demonstrate our state-of-the-art knowledge of the way glaciation factors interact, and have established the basic movement of the damp air masses that 'feed' the Altai glaciers. In addition, this research has defined the place of the Altai region in the common glaciosphere of the Earth.

The distinctive feature of the period since 1980 has been the production of a great deal of highly qualitative and versatile data on the nature of glaciation in the Altai. Research continued after the creation of the *World Atlas of Snow and Ice Resources* and has been greatly extended. The most important stimulus for glaciological research in the Altai is the inclusion of several glaciers in the programme of a complex of observations for the World Glacier Monitoring Service (WGMS) under the aegis of UNESCO. Observation data for the mass balance and morphological characteristics of basic glaciers (Maliy Aktru, forty-eight years; Vodopadniy and Leviy Aktru, twenty-eight years) are especially valuable. These data are valuable for demonstrating and making prognoses of the dynamic status of glaciation in the centre of Eurasia. The results of annual research are presented to the Institute of Geography, Russian Academy of Sciences, on a regular basis and are periodically published in the *Glacier Mass Balance Bulletin* (Nos. 1–7, 1991–2003, Zurich) and *Fluctuations of Glaciers* (Nos. 1–7, 1967–98, Paris, IAHS–UNESCO).

Furthermore, data have been collected for 120 glaciers located in different areas of the Altai in different years during the period from 1835–2004. These data refer to the balance status (five glaciers), accumulation and distribution of snow stocks (thirty-six glaciers), melting (eight glaciers), stocks of ice and changes of terminus (120 glaciers). For some glaciers the features and temperature status of active structural units have been investigated. This has enabled the discovery of zone features of mass changes and glacier dynamics, glacial climate, and drainage (Narozhniy, 1987, 2001; Narozhniy and Nikitin, 2003; Okishev et al., 2000). Since 1999, ecological-biological research has been carried out in the Aktru basin at experimental sites that characterize the entire basin biodiversity (Vorobiev, 2001). The basic purpose of this research is to determine the influence of climate change in terms of both the structure and evolution of high mountain landscapes.

Analyses were improved for a display rating of glacier fluctuation techniques: dendrochronological (Adamenko, 1986; Vorobiev et al., 2001; Okishev et al, 2000), lichenometrical (Solomina, 1999) and geomorphological (Okishev, 1982).

We possess a vast archive of photographs of practically all areas of the Altai, beginning with photographs by Vasiliy Sapozhnikov, which can be used to reveal environmental change over the past century. In essence, more than one and a half centuries of significant glaciological, hydrological and climatologic information has been accumulated. These data have repeatedly been used in scientific generalizations and are of great value for future research, particularly under the WGMS programme.

MOUNTAIN-GLACIAL AKTRU BASIN: THE OBJECTIVE OF THE 'GLOBAL CHANGE RESEARCH IN MOUNTAIN BIOSPHERE RESERVES' MONITORING PROGRAMME

The mountain-glacial Aktru basin is located on the northern macroslope of the northern Chuya ridge in the Altai Mountains (Altai Republic). The first data referring to the basin can be found in V.V. Sapozhnikov's field report of 1898. He marked the position of the Maliy Aktru glacier some time later (in 1911). Mikhail Tronov made repeated visits to the Aktru glaciers from 1936 onwards. Continuous glaciological, hydrological and meteorological observations in the basin began during the International Geophysical Year (1956/57); they were further stimulated during the International Hydrological Decade (IHD), 1966–76, and the International Geosphere Program (1977–80). Since 1987, the Aktru glaciers have been included in the WGMS.

Current work in the Aktru basin includes annual research and observation of the dynamics and distribution of snow cover and avalanches, glaciers' mass balance, change of volume and area, hydrothermal conditions and pollution of glaciers and water objects, as well as geomorphologic, lichenometric, dendrologic and landscape research.

The natural characteristics of the Aktru basin

Geological and geomorphologic structure

The greater part of the Aktru basin is composed of Middle Devonian rocks consisting of two units: effusive-sedimentary at the bottom and sandy-schist at the top. The bottom unit comprises quartz porphyries, black and dark-grey schist, grey and dark-grey/yellow sandstones and limestone. The top unit contains black and grey clayey slates that are stratified with malm and lime sandstones. Downstream of the valley, Silurian marine deposits of Chuya's formation (green and grey sandstones and clayey schist) can be found on the surface of Devonian deposits. Rocks are prominent and fall abruptly on the northeast (70–80°). Quaternary deposits are subjected to glacial and fluvial-glacial sediments of the Pleistocene and Holocene Ages, and to modern alluvial and colluvial sediments.

The Aktru valley is a typical trough valley. Terminal moraine complexes and sandy fields of different sizes are located at its bottom. The right-hand side of the valley is high and rocky with

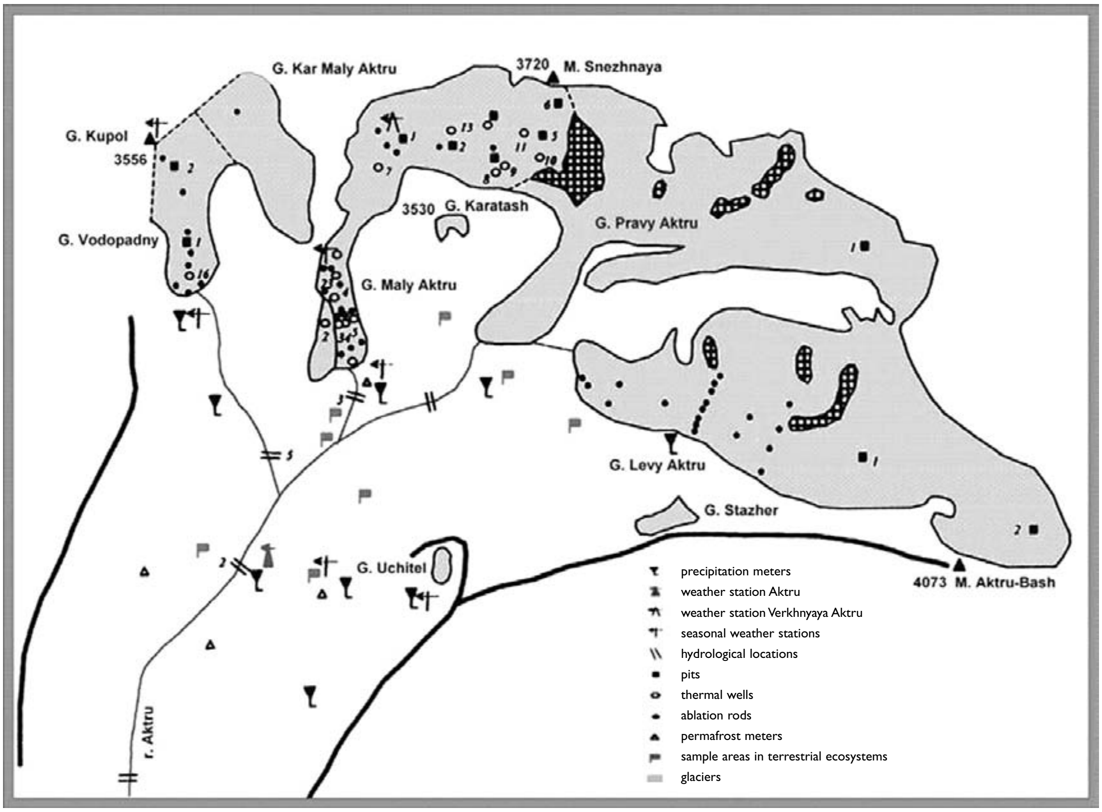

Figure 5.1 The Actru cluster: studies and observations

multiple coombs and colluvial fans; in periods of intense rains in particular, it is susceptible to mudflows. The left slope of the valley is steep and high only in the upper part, while the lower part is complex. Snow avalanches are one agent of the formation of colluvial fans and screes; they are most frequent in spring time, with an interval of one to three years.

Terminal moraine from the Little Ice Age is situated near the confluence of the Aktru and Maliy Aktru rivers. The distal slope of this moraine marks final limit of large glacier advance. Higher up on the watercourse of the main river are some younger terminal, lateral and side moraines.

Climatic characteristics

Meteorological observations are carried out throughout the year by a meteorological station at an altitude of 2,135 m, and forty-two years of continuous data have been accumulated. During the summer, three temporary observation posts are set up to carry out measurements of temperature, humidity and precipitation upstream of the basin (eleven points with intervals between 1,800–3,100 m).

The pattern of the southern Siberian mountains exerts the most important effect on climatic conditions in the basin. In winter, weather conditions are determined by a steady Asian anticyclone. In summer, circulating factors are determined by processes of transformation of air masses and the formation of local continental air. The summer is characterized by the domination of anticyclone weather. Within a background of general circulation in the basin, local circulation is largely affected by factors such as slope, valley and glacial winds. The annual course of air temperature is well defined. The average annual air temperature at the Aktru meteorological station is –5.2°C; the absolute minimum was observed in February 1974 (–39.5°C), and the absolute maximum was observed in July 1998 (25.7°C).

Analysis of the change in climatic parameters over the last fifty years show that since mid-1970 on Altai there has been steady general warming (Aktru Glaciers, 1987; Narozhniy 2001; Shantykova and Paromov, 2001). An increase of mid-annual air temperatures can be observed throughout the territory of the Altai. In the high mountains, temperature is monitored for all seasons of the year (except autumn) and an increase in average seasonal air temperature of 2.1°C has been noted. For the summer period (in Aktru), the increase (over the last forty-two years) has been 0.5°C . This warming has also influenced the mode of precipitation.

Glaciological features

Since 1956, glaciological studies in the basin have been continuously carried out on four glaciers: Maliy Aktru (the main object of the studies), Vodopadniy, Leviy Aktru and Praviy Aktru. The suite of observations includes regular snow measurements on glaciers, observations for melting (the network of ablation rods above 70), observations in pits (stratigraphy of the snowed-neve units, density, filtering of water, chemical analysis), study of the warm-up mode active glacier layer (first 10–15 m), observations of the surface velocities of moving glaciers in transverse profile, and contour mapping of terminus. The volume of ice is calculated once every five years by field methods of radar-tracking sounding. Maps of ice thickness and subglacial relief are made on the basis of the received data. A study of snow cover and avalanche is carried out annually between the end of March and the second half of May.

The modern glaciation of the Aktru basin is situated at an altitudinal interval ranging from 2,250 to 4,043 m. Some of the morphological characteristics of Aktru glaciers are presented in Table 5.1.

The database that has been compiled indicates a tendency towards a change in the mass balance of glaciers that conforms with fluctuations of climate (Narozhniy, 2001; Narozhniy and Nikitin, 2003; Narozhniy and Okishev, 1999). Analysis of the fluctuations in the annual mass budget of the Aktru glaciers over the period 1957–2004 shows a general tendency to decrease. Distinct periods of accumulation and of loss can be identified. The periods of accumulation were 1956–60, 1967–73, 1975–77 and 1983–90, and periods of loss were 1961–66, 1978–82 and 1991–2004. Thus most of these periods lasted between six and nine years. There have been abnormally positive changes in mass balance in around nine to twelve years, and abnormally negative changes between twenty and twenty-two years; thus, despite some short-term gains, over the long term the average mass balance has shown a tendency to decrease. There is a broad tendency for a change in orientation to occur after about six years, and the full cycle of fluctuations is eleven to twelve years. For the forty-eight years from 1957 to 2004, the general loss of

Table 5.1
Morphological characteristics of Aktru glaciers

Glacier	Morpho-logical type	Exposition	Altitude Min	Altitude Max	Area (km^2)	Volume (km^3)	Thickness (m) Average	Thickness (m) Max
Maliy Aktru	Valley	N	2,220	3,714	2.84	0.245	86	235
Leviy Aktru	Valley	SE	2,520	4,043	5.95	0.534	90	185
Praviy Aktru	Valley	NW	2,390	3,785	5.15	0.288	56	194
Vodopadniy	Ice cup	N	3,050	3,556	0.75	0.041	55	113
Kar M. Aktru	Ice cup	NW	2,560	3,556	0.91	0.062	69	109
Stazher	Suspended	NE	3,230	3,560	0.24	0.013	53	91
Kara-Tash	Suspended	W	3,160	3,530	0.09	0.005	–	–
For all glaciers in basin			**2,220**	**4,043**	**15.93**	**1.188**	**73**	**235**

mass is equivalent to about 7 m of water; since the middle of the nineteenth century, the loss has been about 16 m.

The area of glaciation of the basin over 150 years has decreased by 11.5 per cent (2.1 km^2), and a third of this loss has occurred over the last fifty years. The volume of glaciers has fallen more, by almost 20 per cent (0.3 km^3), varying from 18 per cent up to 34 per cent for some glaciers. The high sensitivity mass-balance and the responsiveness of the morphological characteristics of the Aktru glaciers to climatic change make possible both glaciological monitoring and repeated climatic monitoring. The tendencies that have been discovered in the fluctuations of the Aktru glaciers are representative of all modern glaciation of the Altai. It is therefore very important to continue the annual supervision of Aktru glaciers that began in 1957.

Hydrological characteristics

Hydrological observations on the Aktru River have been carried out throughout the year for forty-eight years. During the summer period (May–September) they are carried out near glaciers. All observation points are equipped with recorders that monitor the changes in the level, discharge and temperature of water. The mountain-glacial basins of the Altai are basic surfaces that act like a drain in the hydrological cycle. The Aktru is typical of mountain rivers in the Altai. The river is 40 km in length, and its dimensions at the hydro station are: width 6–8 m, depth 0.2–0.8 m, velocity of current 0.3–2 m/s (maximum 3.5 m/s).

Table 5.2
The distribution of areas (km^2) of various types of landscapes on high-altitude zones of Aktru mountain-glacial basin

High-altitude zone, km	**1***	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
4.0–3.9	0.15	0.01									**0.16**
3.9–3.8	0.17	0.01									**0.18**
3.8–3.7	0.40	0.08									**0.48**
3.7–3.6	1.01	0.12									**1.13**
3.6–3.5	1.32	0.29	0.05	0.02							**1.68**
3.5–3.4	1.80	0.78	0.11	0.07							**2.76**
3.4–3.3	2.30	1.33	0.21	0.13		0.07					**4.04**
3.3–3.2	2.16	1.36	0.23	0.14		0.08					**3.97**
3.2–3.1	1.66	1.37	0.44	0.10		0.12					**3.69**
3.1–3.0	1.38	1.25	0.37	0.15		0.58					**3.73**
3.0–2.9	1.20	1.30	0.38	0.26	0.04	0.71					**3.89**
2.9–2.8	0.87	1.16	0.39	0.28	0.17	0.22					**3.09**
2.8–2.7	0.42	1.11	0.26	0.17	0.10	0.04					**2.10**
2.7–2.6	0.23	1.07	0.26	0.15	0.09						**1.80**
2.6–2.5	0.39	0.72	0.15	0.38	0.35		0.14	0.12		0.03	**2.28**
2.5–2.4	0.33	0.42	0.06	0.65	0.33		0.23	0.19		0.03	**2.24**
2.4–2.3	0.10	0.26	0.05	0.50	0.31		0.49	0.05	0.12	0.12	**2.00**
2.3–2.2	0.10	0.11		0.58	0.32		0.46		0.31	0.06	**1.94**
2.2–2.1				0.40	0.04		0.25	0.04	1.02	0.39	**2.14**
2.1–2.0				0.08				0.09	0.54	0.71	**1.42**
Total	**15.99**	**12.75**	**2.96**	**4.06**	**1.75**	**1.82**	**1.57**	**0.49**	**1.99**	**1.34**	**44.72**

* Note:
1: Glacial surface.
2: Rocky sites and landslide slopes.
3: Erosive hollows, avalanche sites.
4: Colluvial and avalanche fans and slopes.
5: Young moraine deposits.
6: High-mountainous peneplain, breakstone tundra.
7: Alpine meadows and turf-clad slopes.
8: Slopes with bushes.
9: Coniferous wood.
10: Floodplain sites.

One of the characteristics of an intra-annual drainage is that the river experiences a sharp rise in water level during the summer (three months) and a very low mean water level during the cold season. The feed share from glaciers is about 50 per cent, of which snow makes up 25 per cent, rain 7 per cent, and groundwater 18 per cent.

The mode of drainage has a complex character. During winter the mean water discharges (0.03–0.2 m^3/s) are very low and are typical of the Altai rivers. In spring and early summer this increases to its highest rate of about 5 m^3/s in July and August, and the average discharge for warm periods (80–120 days) is 2.8 m^3/s. During this time 85–90 per cent of the annual drainage passes. The average module of drainage for the basin is 75 $l/s\ km^2$, equivalent to an 815 mm layer of water. In summertime the maximal discharges in the river are constant, and there are between fifteen to eighteen hours of sunny weather. There is a decreasing discharge and transition to groundwater feed during the autumn. The prominent feature of water in the river in winter is the formation of frazil. The largest frazil (up to 3.5 km in length, with an area of 1.6 km^2) is formed below the meteorological station.

Landscape characteristics

Within the confines of the Aktru basin and its surroundings, all varieties of high-mountainous landscapes are observed and are expressed in their vertical belts. It is possible to trace a mosaic of age and landscape changes in small areas, from open rocks and stony tundras, to the alpine meadows and belts of coniferous woods. Downstream of the valley, there are fragments of forest–steppe complexes and light forest meadows with a prevalence of cereals, sagebrush and bushes. Forest–steppe landscapes further along the valley are replaced with a dry steppe landscape. Using landscape (Narozhniy and Okishev, 2001) and topographical maps of the Aktru basin, we are able to determine areas containing various landscape types of the high-altitude zones. Some of these are shown in Table 5.2.

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6 *Hydrological Modeling for Simulating the Effects of Global Change on the Hydrological Cycle*

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INTRODUCTION

Numerical models are being used to simulate the response of hydrological basins to meteorological events so as to aid the decision-making process in cases of severe weather, as well as to manage water resources and the environment. It is becoming increasingly important to understand the possible effects of observed climate changes on the hydrological system, and in order to simulate these effects we need a complex numerical system that involves the coupling of atmospheric and hydrological models.

A complete description of the different approaches used to simulate the hydrological system and its possible response to climate change is beyond the scope of this paper. However, we will look at typical numerical applications of varying degrees of difficulty, focusing on the few available algorithms with the aim of encouraging the GLOCHAMORE community to use them for different applications.

We will briefly introduce the basic concepts of the hydrological cycle and the main physical processes affecting the groundwater balance.

It is possible to simulate flood and water supply using a numerical approach by employing practical examples of increasing complexity. Some of the algorithms used to implement the Cetemps Hydrological Model (CHyM) are also discussed, with some attention given to the potential for using these algorithms for many different purposes.

Finally, the preliminary results of a hydro-climatic simulation are discussed, showing the possible change in the average available water resources of the Po river catchments due to changes in the glacier cover and consequently in the average rain regime during the spring season.

HYDROLOGICAL MODELS

According to Penman (1961), hydrology can be defined as the science that attempts to provide an answer to the question: 'What happens to rain?'. A deterministic approach to this question requires a detailed study of the many processes involved in the hydrological cycle, usually defined at the global scale, and the continuing process linking water in the atmosphere, on the continents and in the oceans.

Precipitation (rain and snow) and evapotranspiration are the two basic mechanisms that allow exchange of water between the soil and the atmosphere. The term evapotranspiration refers to two different processes: the evaporation of water stored in the soil and transpiration from vegetation. Not all precipitation is available for surface runoff: a portion of it is stored as a solid in seasonal snowpacks or in permanent snowpacks (glaciers). When the temperature is greater than 0°C, the snowmelt that occurs also contributes to surface water balance. A quantity of surface water infiltrates the soil until saturation, while the remaining part is discharged into streams and rivers. Most infiltrated water discharges ultimately into the oceans (groundwater runoff).

All these different processes contribute to the soil–water balance on different timescales. For example, evapotranspiration represents an important contribution at the climate timescale, but can be ignored at shorter scales. For a detailed description of the hydrological cycle, see Hornberger et al. (1998). An overview of the most important hydrological models can be found in Singh et al. (2002).

A SIMPLE EMPIRICAL MODEL USING A NEURAL NETWORK APPROACH

Hydrological models are often classified into deterministic and empirical, depending on whether the physical processes involved in the hydrological cycle are simulated using a physics-based implementation or an empirical approach.

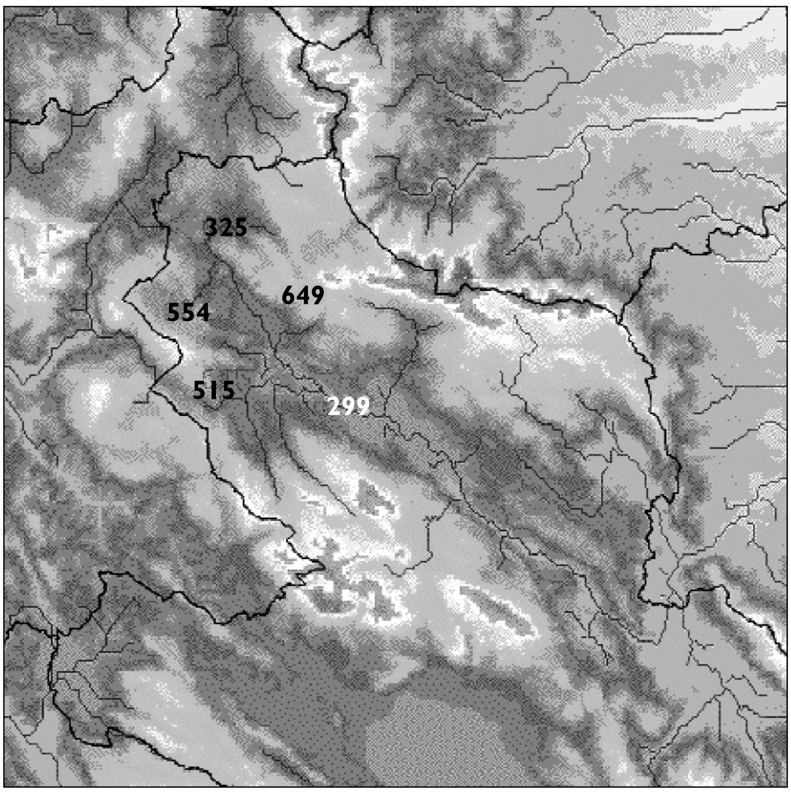

Figure 6.1 A portion of the Aterno river drainage network as rebuilt by CHyM Hydrological Model. Dark numbers indicate the position of rain gauges used for the calibration of Artificial Neural Network (see Figure 6.2 and discussion) and white numbers indicate the position of the discharge sensor. Rain gauge 325 is located exactly at Assergi INFN Lab where the L'Aquila GLOCHAMORE workshop took place.

To demonstrate a very simple model predicting the flow discharge of a river as a function of the observed rain rate, we used a short time series of flow discharge and rain gauges located in the highest portion of the Aterno river close to l'Aquila. In Figure 6.1 the position of available rain gauges (black numbers) and the discharge sensor on the Aterno river are shown. As a very trivial approximation we can think about predicting the flow discharge at the point where the discharge sensor is located, using a linear combination of rain-gauge rainfall observations during the previous six hours. The choice of this time interval is warranted by the fact that it represents an average runoff time from the location of the rain gauges to that of the discharge sensor: in other words, the average time interval it takes for a raindrop to arrive at the discharge sensor location. In practice, discharge at time t is estimated as:

$$D(t) = \alpha R_1(t-1) + \beta R_2(t-1) + \gamma R_3(t-1) + \delta R_4(t-1)$$

where $R_i(t-1)$ is the rainfall observation in the previous time step and α, β, γ and δ are the coefficients to be optimized. The comparison of the observed and predicted flow discharge time series for the first twenty days of February 2004 is shown in the first panel in Figure 6.2. The simple linear regression is able to correctly predict the occurrence of the discharge peaks, but the heights of the peaks are not realistic; for example the first maximum, occurring between 4 and 6 February, is greatly overestimated. This is probably because we did not take account of the loss of surface water due to infiltration, when in fact the first rainfall event occurred after a long dry period. To take this into account, we can refine the model by adding to the previous equation a term that implicitly contains information about the average conditions on the previous day; an empirical estimator could be the average rainfall observed by rain gauges in the last five days. If we include this term in the linear regression the performances of our simple model greatly improves (top right plot of Figure 6.2), but the highest peak, occurring around 12 February, is still underestimated. Of course, approximating the complex relationship between rainfall and discharge with a linear regression is not a realistic approach; thus we might consider refining the model using a neural-network-based empirical model.

Artificial neural networks (ANNs) have been studied since the early 1960s, but were only extensively implemented in software packages and applied to a wide range of problems in the 1990s, when the increase in available computing power made it possible to actually use this approach for non-trivial applications.

The concept of an artificial neuron is inspired by the physiology of the biological neuron. It can be thought of as a simple computing device that receives many input signals and provides an output: a sort of linear combination of different inputs with a set of characteristic weights whose values represent the *knowledge* of the neuron. We usually refer to the process of optimizing these weights as the 'training (calibration) of the network'.

In an artificial network, the output of a single neuron becomes one of the inputs to many other neurons, and two neurons are usually said to be *connected* when the output of the first neuron represents one of the inputs to the second neuron. The configuration of an ANN, namely the definition of how the neurons are connected together, is usually referred to as the 'architecture of the network'.

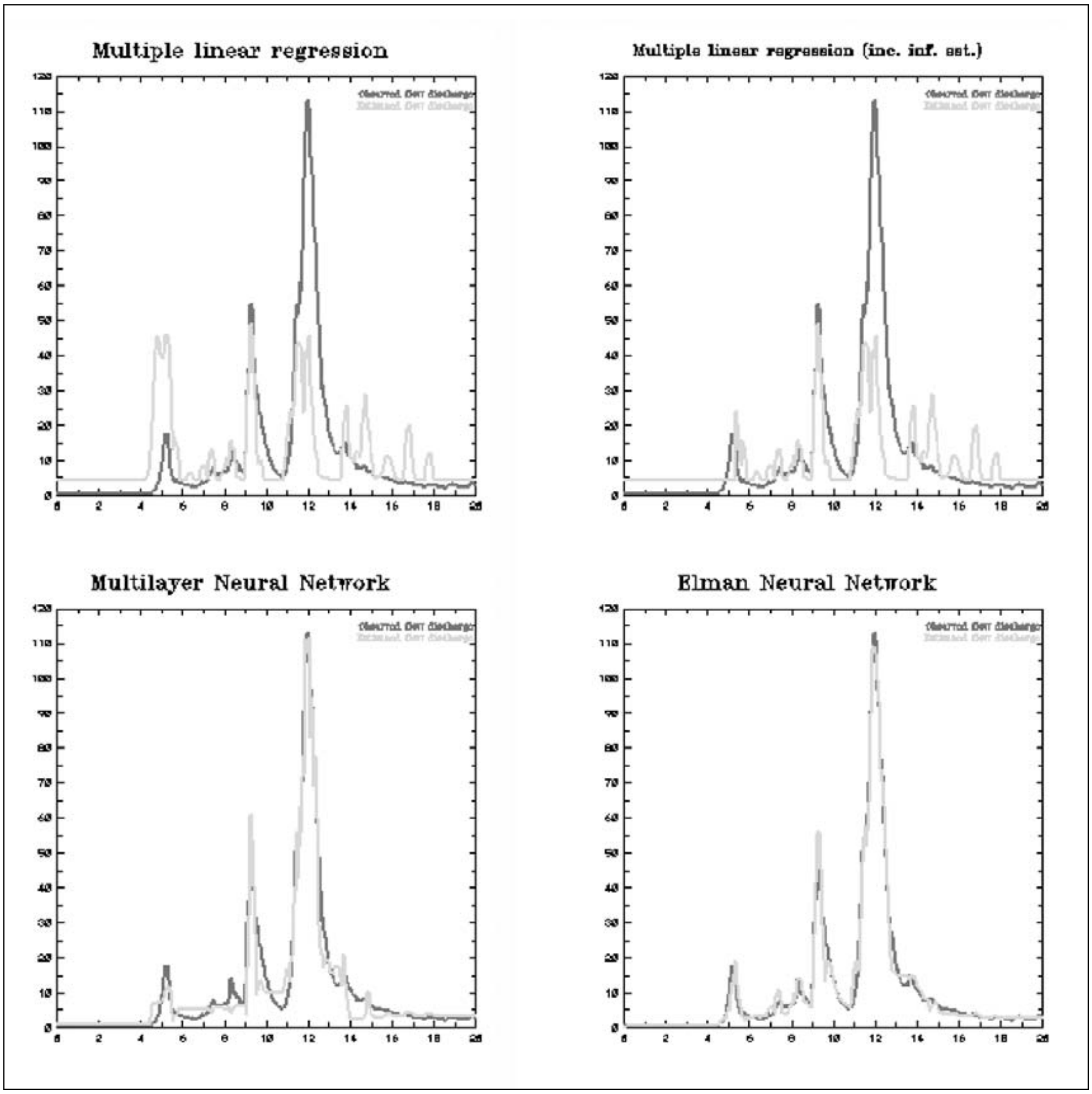

Figure 6.2 Observed (dark line) and predicted (pale line) for a monitored point along the Aterno river. The four panels refer to four different approaches: Multiple linear regression (top left), multiple linear regression including information about rainfall on previous days (top right), Multilayer Neural Network (bottom left) and Elman Neural Network (bottom right).

For many applications, one of the most widely used forms of architecture is the one known as a 'multilayer perceptron'. In this kind of neural structure, neurons are arranged in different layers with each neuron connected to all the neurons of the subsequent layer, but there are no links (connections) between neurons of the same layer. The first layer of the network, referred to as the 'input layer', receives as input the variables of the function to be mapped (in our case rain-gauge measurements); the neurons of the last layer, referred to as the 'output layer', represent the output of the whole network. Theoretical results ensure that a multilayer perceptron, with at least three layers, is able to map any non-linear and inseparable functions (see Hect-Nielsen, 1991). Though we will not go into detail here, it is important to underline that in using an ANN instead of a linear regression we are not using just a more sophisticated function but a totally different method: when we use a linear regression (or a more general statistical regression), we simply optimize the parameters of a chosen function, whereas by training an ANN the *function* is optimized, which is better adapted to our data.

Continuing our simple exercise in predicting flow discharge by using observed rainfall data, we use a multilayer network to map the same time series that we discussed earlier, the results of which are shown in panel 3 (bottom left) of Figure 6.2. Our simple model now performs well, and it is easy to see that the two curves are very alike for the entire time interval being considered. The only important bias seems to be connected to the rapid oscillations of the predicted time series after intense precipitation events.

Further improvements can now be achieved by using a more sophisticated network architecture known as 'Elman ANN'. This is still a multilayer network but the status of neurons in the intermediate layer (usually referred as the 'hidden layer') is propagated back to the input layer. In this case the input values are the rain gauges' readings at time step $t-1$, and the status of the hidden neurons depending on the observation at time step $t-2$ (for a more detailed description see Elman and Jeffrey, 1990).

In fact, Elman ANN implements a sort of dynamic memory and takes into account not only the time step at time t but also the sequence of input vectors. The results obtained with this approach are shown in the last panel of Figure 6.2. The comparison of predicted and observed time series is now very impressive and the performance obtained by the neural device appears very encouraging. Of course it must be recalled that the analysis has been carried out only on short time series, and it cannot be said that the time series used are actually representative of a complete climatology of rainfall events in the zone. In addition, the number and location of the rain gauges must be verified to ensure that they adequately represent of complex rainfall field over the upstream basin of the chosen river. (In this case they probably do.)

The above discussion outlines a simple exercise carried out over a couple of days where we demonstrated how a simple and totally empirical model could be built to predict flow discharge at selected points in a very realistic way. For practical purposes this kind of approach could be useful for short-term forecasting ('now-casting') or for a flood alert to avert the risks linked to severe meteorological events. A further development could be to predict the discharge at other points in order to monitor the different segments of a river basin.

CHyM: AN EXAMPLE OF A DISTRIBUTED HYDROLOGICAL MODEL

The Cetemps Hydrological Model (CHyM) has been developed since 2002 with the aim of integrating observations and numerical simulations so as to predict the effects of severe weather events on the hydrological system. CHyM is a grid-based distribution model designed to simulate any geographical domain at any resolution up to the digital elevation model (DEM) being used (in the current version, 300 m for Italy and 1 km for the rest of the world). In order to ensure maximum flexibility, portability and generality, it was decided not to use a commercial (GIS) product. Thus the model uses a sophisticated numerical algorithm to retrieve only the

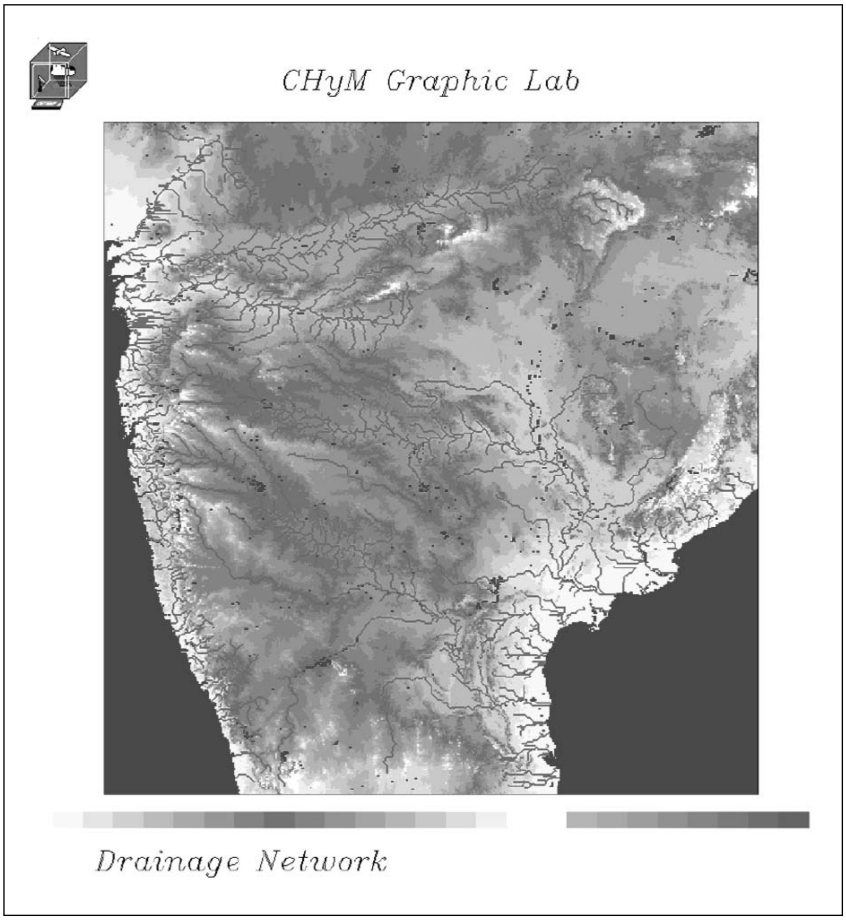

Figure 6.3 The drainage network for the Indian Peninsula as rebuilt by the CHyM Hydrological Model. The Indo river mouth is located in the northwest part of the domain. The mouth of the Krisna river, in the central eastern part the mouth of Godaveri river can be recognized in the southeast.

drainage structure of any watershed using the DEM. This report will briefly describe the main steps of these algorithms with the aim of encouraging the GLOCHAMORE community to use them for other purposes.

A distribution model is built that defines all the hydrological and geomorphologic parameters on a regular grid. For each cell of the grid, the elevation and flow direction are also defined. Starting from the DEM matrix, and following the minimum energy principle, flow direction is established whereby the downstream slope is at a maximum. For each cell we consider the eight neighbouring cells; this approach is usually referred to as a D8 scheme.

Unfortunately, retrieving a coherent flow scheme from the DEM presents many numerical difficulties due to the finite horizontal and vertical resolution of the DEM. The first numerical difficulty stems from the presence of a so-called 'pit': that is, cells having an elevation lower than the eight surrounding cells. To overcome this problem, the elevation of the pit is increased to the lower value of the neighbouring grid points. This procedure must in fact be repeated many times, because the application of this simple algorithm often simply 'moves' the pit to one of the adjacent grid points. Another numerical difficulty arises with the determination of the flow scheme in a flat zone: that is, a group of cells having the same elevation. Such flat zones occur mainly along the riverbed where the slope is minimal.

Many strategies have been developed to overcome these numerical singularities (see Garbrecht and Martz, 1997, for example), but most of them imply an unrealistic modification of the DEM for many cells. To prevent this, CHyM implements a cellular-automata-based algorithm. In this approach, the whole DEM matrix is slightly smoothed before flow scheme extraction and, once the flow direction has been obtained for most of the cells, the same algorithm is repeated only for the still indeterminate flow direction. Like neural networks, the concept of cellular automata (CA) takes its inspiration from biology, and especially from the observation that many biological systems made up of many separate parts seem to behave in a collective manner: in other words, they seem to have computational capabilities. According to Packard and Wolfram (1985), cellular automata are simple mathematical idealizations of natural systems. They can be described as a lattice of discrete identical sites, with the values of the sites evolving in discrete time steps according to deterministic rules that specify the value of each site in terms of the values of the neighbouring sites. In our application, a cellular automaton is a cell whose status is the elevation value. In a first phase, all the values of DEM matrix are recursively modified according to the following rule:

$$DEM(i, j) \Rightarrow DEM(i, j) + \alpha \sum_{neighb} DEM(k, l)$$

The sum is calculated for all the neighbouring cells, and α is a small coefficient. In fact this simply relates to smoothing the DEM; however, despite taking into consideration a small value for the α coefficient, most of the cells are modified by only a few centimetres. It has been established that beyond this step the D8 scheme can be calculated for the majority of the cells. In a second phase the CA algorithm is repeated again, but the evolution rule is applied only for cells where singularities still occur, and this will limit the number of cells whose elevation has significantly changed.

The next step is to verify whether the calculated flow scheme reproduces in a realistic way the drainage network of the river basin that we wish to simulate. Another algorithm has been implemented for this purpose to measure the total number of cells drained by each grid point. This can be done by carrying out the following steps:

1. From each cell of the domain a 'stone' rolls down, following the flow direction map calculated from the DEM.
2. Each time a stone passes by a cell, a counter is incremented for that cell.

The procedure is followed until all the stones reach a 'sea' point or the boundaries of the domain. The algorithm is called the Rolling Stones algorithm (RSA), as a small tribute either to the famous rock band or to Bob Dylan's song 'Like a Rolling Stone' (two of the authors, Marco Verdecchia and Guido Visconti are big Dylan fans).

The drainage networks shown in Figures 6.1 and 6.3 have been obtained using this numerical approach. The RSA can be generalized to estimate different quantities: for example, if the area of the starting cell is associated with the 'stones' we can estimate the total area drained by each cell, whereas if the rainfall in the starting cell is associated with the 'stones' we can estimate the total of drained rain. We will see in the next section that these few algorithms provide possibilities for many applications.

DIFFERENT APPLICATIONS OF THE CHyM MODEL

We shall briefly describe a few possible applications of the algorithm implemented in the CHyM model described above. Flood alert mapping has been operational in the region of central Italy for one year now. The study of changes in the hydrological cycle due to land-use change is still in progress: coupling CHyM with MM5 mesoscale meteorological model and studying the effects of the observed decrease of glaciers on the Po river basin.

The identification of areas of pollution is another possible application, though it is at moment just an idea.

Flood alert mapping

The CHyM model rebuilt the rainfall field on an hourly basis at the same DEM resolution using a different data source. In the current operational version for the Abruzzo region, rainfall data are rebuilt using radar estimation as well as observations from a rain-gauge network that acquires data in real time of the preceding hours. (Daily simulation results are available at http://cetemps.aquila.infn.it/chymop.) For future time steps, the precipitation field is rebuilt at a hydrological model spatial scale using an MM5 mesoscale model forecast (Dudhia, 1993; Grell et al., 1994) running over central Italy with a horizontal resolution of 3 km (Paolucci et al., 1999).

Using the RSA algorithm discussed in the previous section, the CHyM model is able to calculate a flood alert index that can be used to identify the segments of drainage network where flood events may occur. The alarm index is calculated, at each grid point, as the ratio of total drained rain in an assigned time interval and total drained area. The time interval is chosen according to the typical runoff time for the selected river, as explained above.

Analysis of different case studies demonstrated that the proposed index is in fact able to highlight segments of the drainage network where flash floods actually occurred (Tomassetti et al., 2005).

Identifying pollution source areas

The RSA algorithm briefly described earlier has been implemented in a CHyM module to 'paint' the drainage area of an arbitrary catchment; in order words, this module calculates all the cells belonging to a basin (Figure 6.4 shows an example for the Pescara-Aterno river in the Abruzzo region). This feature is very important for many practical reasons; for instance, it enables us to verify whether the whole catchment we wish to simulate is contained in the selected domain. In addition, this tool means that we only run the model for the grid points belonging to a river basin, which may greatly reduce the required computing time.

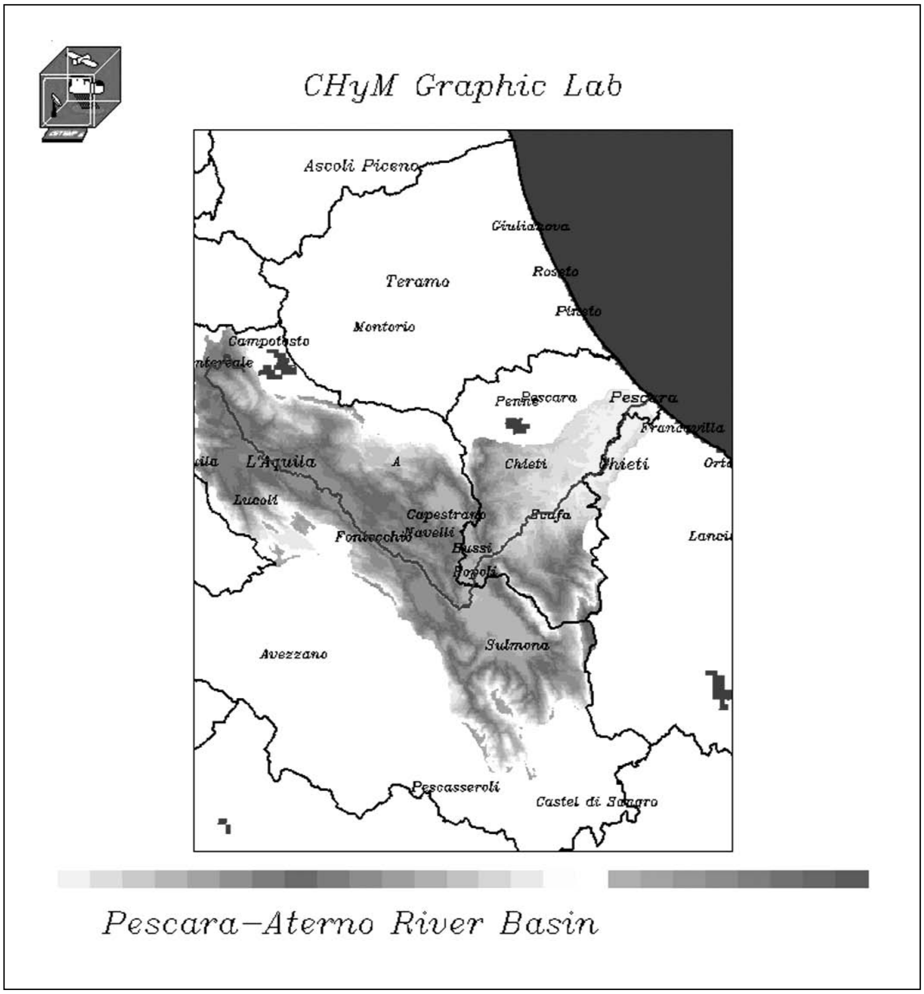

Figure 6.4
The Pescara-Aterno river catchments as rebuilt by CHyM hydrological model. The CHyM module selecting an arbitrary river catchments could be used to localize pollution source areas.

The module has been implemented in the most general way, and could in fact be used to locate the drainage area for an arbitrary segment of a river. For example, suppose that, following an intense precipitation event, a strong gradient in the concentration of pollutants (say pesticides or nitrates) is observed between two points of the river, say A and B. Now it is realistic to assume that the pollutants have been carried by surface runoff. The CHyM module is able to identify the area that could be the source of pollution, which will quite simply correspond to the entire area that is drained by point B, but not by point A (A is in the upstream basin of point B).

Changes in the hydrological system due to land-use modification

Change in land use due to human activities may cause a significant change in typical meteorological and climatic conditions at the regional scale (see, for example, Tomassetti et al., 2003). However, there are also many observations on the change in glacier cover in mountain regions due to climate change. In this context, it appears to be a strategic challenge to couple the different numerical models in order to investigate the possible effects of these changes in the hydrological cycle. This kind of study presents at least two different and interesting aspects: the first is the possibility of simulating future changes in water resource availability, and the second relates to the prediction of possible stresses in the whole drainage network, or only a few segments, due to changes in the typical precipitation regime.

A specific experiment has been designed to investigate the hydro-meteorological effects on the Po river basin associated with the melting of glaciers in the alpine region. A climate simulation was carried out in March 2004 using two different scenarios for glacier cover. The first depicts the current situation, while the second represents an extreme scenario whereby all the glaciers located below 3,000 m disappear. Changes in the water resources upstream of the Po river drainage network are then computed using the CHyM model.

Figure 6.5 illustrates the preliminary results. It seems likely that an increase in the total amount of precipitation drained by the Po river (the light grey segments of drainage network) is due to glacier melt, as the average precipitation increases throughout the entire basin close to the mountains, while the coastal section of basin seems to drain a lower quantity of precipitation (black segments of drainage network).

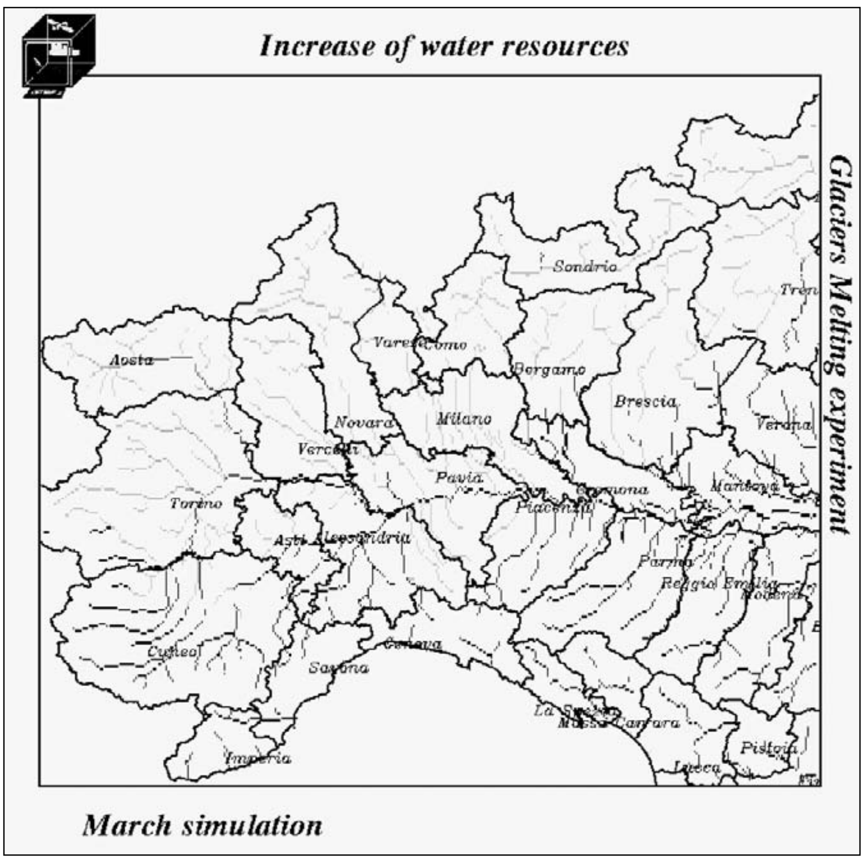

Figure 6.5
Predicted change in monthly average drained precipitation in the upstream sector of the Po river basin. The pale segment of the drainage network corresponds to an increase in total drained water while the black segments correspond to a decrease of the same quantity.

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7 *Modeling future vegetation cover, forest dynamics and fire occurrence in mountain biosphere reserves*

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INTRODUCTION

Over the past thirty-five years, a wide variety of approaches have been developed to simulate the possible impacts of changes in climate and land use on the vegetation cover in terrestrial ecosystems. Some of these approaches were targeted specifically towards mountain regions, while others were generally applicable to terrestrial ecosystems. In the context of the research project GLOCHAMORE (funded by the European Union 2003–2005), the managers of selected mountain biosphere reserves (MBRs) worldwide have compiled lists of their major concerns regarding the possible impacts of climate and land-use changes in their reserves. Among the key topics listed by the managers were vegetation cover (particularly forests), water resources, fire, biodiversity and charismatic species.

Therefore, this contribution focuses on reviewing, by example, a number of approaches that are at least potentially useful and amenable for application in mountain biosphere reserves to study the impacts of climate and land-use changes on vegetation cover, carbon storage, water resources, and fire. In a companion contribution in this volume, Guisan (2005) reviews approaches for projecting the impacts on biodiversity and charismatic species.

In the first part of this paper, models of vegetation cover and vegetation dynamics are reviewed, starting from simple approaches and moving towards more sophisticated models, and moving from consideration of 'point models', which do not consider spatial processes (though it should be noted that their output can be mapped, so as to provide a quasi-landscape picture), to 'landscape models' that explicitly consider the interactions between the processes occurring at each point of a landscape.

In the second part of this paper, models for projecting properties of the wildfire regime are reviewed, again starting with simple approaches and ending with fairly sophisticated tools that provide a lot of information, but require a large amount of background information and input data.

MODELING VEGETATION COVER AND ITS DYNAMICS

The Holdridge Life Zone model

Among the simplest means to project changes in the equilibrium between climate and vegetation structure are the so-called 'climate classification schemes', among which the scheme by

Holdridge (1967) has become quite widespread and was applied on a routine basis until the early 1990s to project the impacts of climate change on the broad-scale distribution of vegetation complexes. Originally, these schemes were not developed with this objective in mind, but were rather intended as classifications of climate. However, the close association of climate with vegetation distribution soon led to their application in climate impact research.

The Holdridge scheme is particularly suitable in areas where high-resolution meteorological data and detailed information on soils and other geographical features are scarce or lacking entirely (see Figure 7.1). This static model requires the following input variables: (1) the annual precipitation sum of a site; (2) the 'biotemperature', which is the annual sum of the positive differences between each monthly average temperature and 5°C; and (3) the ratio of potential evapotranspiration (which can be calculated from monthly temperature alone according to the scheme by Thornthwaite and Mather 1957) and the annual precipitation sum. As long as standard meteorological data are available from a site, the corresponding vegetation complex according to the Holdridge scheme can be derived for this site after a few calculations that only require a pocket calculator. The model can then be used to investigate the degree of vegetation shifts under the assumption of a future equilibrium between climate and vegetation distribution by

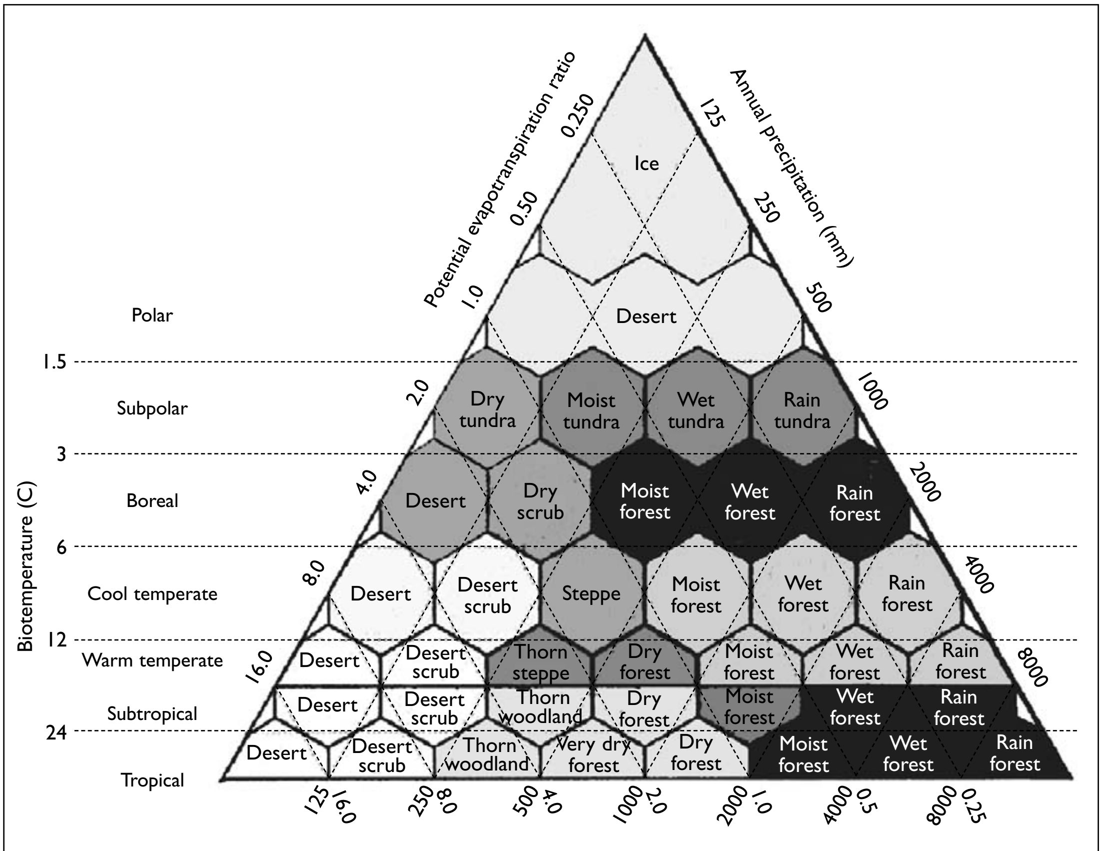


Figure 7.1
The Holdridge (1967) Life Zone Scheme as an example of a static model that can be applied easily to project possible climate-induced changes in vegetation complexes in mountain biosphere reserves and other areas

using scenario data on climatic change from other sources, such as the IPCC (Intergovernmental Panel on Climate change – http:/www.ipcc.ch), regional climate model simulations, or simple scenario assumptions (for example 'year-round temperature increase by 3 K, and year-round increase of precipitation by 10 per cent'), imposing these changes on the measured climatic data from the study site, and again determining the corresponding vegetation complex according to the Holdridge model (Figure 7.1).

Key advantages of the Holdridge scheme are:

- The simple input variables that are needed by this model make it applicable in almost all MBRs and other mountain regions, at least for selected points within a landscape.
- Its predictor (input) variables are relatively mechanistic in the sense that they encapsulate features such as growing-season length and temperature during the growing season (as contained in biotemperature), or the water balance of a site (evapotranspiration ratio).
- The model can be applied to provide full spatial coverage, provided that sufficient climatic information and GIS capabilities are available (see Smith et al., 1992, for a global application).

Thus, it would be possible to derive current and future vegetation maps for the larger MBRs based on the Holdridge model, and in many cases such information would provide important insights, such as for anticipating 'hot spots' of vegetation change in the future. For example, an analysis of the displacement of modified Holdridge life zones was performed for the Cinturón Andino Biosphere Reserve (as presented by M. Cañón at the kick-off GLOCHAMORE Workshop in November 2003), showing that many vegetation types in this reserve would be affected quite heavily by climatic change.

However, the simplicity of the approach comes with a number of disadvantages:

- More recent developments (as reviewed further below) provide a more mechanistic basis for predicting the occurrence of vegetation, so that their results under a future climate scenario are likely to be more robust than those from the Holdridge scheme; this is actually the major reason why the Holdridge scheme is no longer used as a research tool.
- The taxonomic resolution of the model is very coarse, and in many cases no shift to another vegetation complex would occur under a given climate scenario at a given site. It is likely, however, that in many cases there would still be drastic changes of vegetation composition within that vegetation complex, which might go unnoticed by the Holdridge scheme but could still be quite relevant for guiding management decisions, particularly regarding individual species.
- The model does not take into account other factors such as CO_2 fertilization of the atmosphere, nitrogen deposition, or – perhaps most importantly – land use, as it is a pure climate classification scheme.
- The Holdridge life zone scheme is a static model: that is, it is based on the assumption that there is an equilibrium between climate and vegetation distribution. Therefore, the scheme cannot be used to make inferences about the temporal development of vegetation cover.

The BIOME model family

To rectify two key deficiencies of the Holdridge approach, Prentice et al. (1992) developed the BIOME1 model. Their first measure was to base this on plant functional types (PFTs, such as 'tropical raingreen tree', 'temperate summergreen tree', 'warm grass' and so on; see Table 7.1) rather than on biome-like vegetation types; they then used rules to determine the 'biomes' from the combination of PFTs that were predicted to be potentially present at a given site. Second, they used bioclimatic variables that have a more direct, more 'mechanistic', meaning for the plants than the predictors used in the Holdridge model. Most notably, the assumption was developed that every modeled entity has to be limited simultaneously by all predictor variables (as was done in the Holdridge scheme and several other, similar classifications). Thus, a key feature of Table 7.1 showing the bioclimatic limits of the BIOME1 model is that this table is about half empty. That is, numbers are used only in those places where there is a known mechanism determining the presence of a PFT with respect to a certain predictor variable.

By comparison with the Holdridge model, the BIOME1 model requires, in addition to monthly temperature and precipitation averages, data on percentage cloud cover on a monthly basis. This variable is an important driver of the soil moisture balance routine that is used to

Table 7.1
The parameters of the BIOME1 model (Prentice et al., 1992)

	T_c		GDD	GDD_0	T_w	α		
	min	max	min	min	min	min	max	D
Trees								
tropical evergree	15.5					0.80		1
tropical raingreen	15.5					0.45	0.95	1
warm-temperate evergreen	5					0.65		2
temperate summer green	–15	15.5	1200			0.65		3
cool-temperate conifer	–19	5	900			0.65		3
boreal evergreen conifer	–35	–2	350			0.75		3
boreal summergreen		5	350			0.65		3
Non-trees								
sclerophyll/succulent	5					0.28		4
warm grass/shrub					22	0.18		5
cool grass/shrub						0.33		6
cold grass/shrub				100		0.33		6
hot desert shrub					22			7
cold desert shrub				100				8

Environmental constraints: mean temperature of the coldest month, T_c; growing degree-days on 5°C base, GDD; growing degree-days on 0°C base, GDD_0; mean temperature of the warmest month, T_w; Priestley–Taylor coefficient of annual moisture availability, (α) and dominance class (D) for each plant type in the model.

derive the drought index α from climatic information and the water-holding capacity of the soil, which also has to be estimated. The determination of the drought index cannot be done on a pocket calculator (as in the Holdridge scheme), but it uses very little computer time. As with the Holdridge scheme, the BIOME1 model can be used to map vegetation properties across large areas, provided that sufficient climatic and soil information is available, and that there are GIS capabilities.

The key advantages of the BIOME1 model compared with the Holdridge scheme are that it is much more mechanistic, because it uses other bioclimatic variables, and it provides a higher taxonomic resolution because it is based on PFTs. As a matter of fact, the bioclimatic variables developed for BIOME1 continue to be used in state-of-the art models of vegetation distribution at regional to global scales (for example Sykes et al., 1996), and even in the latest generation of dynamic global vegetation models (for example Sitch et al., 2003).

Some disadvantages of the Holdridge approach remain with BIOME1, such as its static nature, the lack of a representation of individual species and the focus on climate.

More recently, the BIOME3 (Haxeltine and Prentice, 1996) and BIOME4 (Kaplan, 2001) models were developed from BIOME1. The major differences from BIOME1 are as follows: (1) modeling of net primary productivity (NPP) and water exchange between vegetation and the atmosphere in a fully mechanistic and highly detailed manner; (2) the modeling of competition as a function of NPP. Since the BIOME models were targeted for global application, the input data requirements of the more recent members of this model family are no higher than those of BIOME1, which may render them quite attractive for application in some MBRs. For example, Ni (2000) presented an assessment of the anticipated changes in vegetation complexes for the Tibetan Plateau based on BIOME3 (Figure 7.2). Although this is still a fairly large-scale picture from the point of view of an individual MBR, such an assessment at the regional to subcontinental scale also provides quite a lot of detail at the regional level.

Forest succession models

A widespread family of models are the so-called 'forest gap models', originally developed by Botkin et al. (1972) to portray the long-term development of species composition and other forest properties in New England, USA. In contrast to the models reviewed above, gap models are dynamic: that is they can be applied to study the changes of forest properties over time. They simulate the establishment, growth and mortality of individual trees on small patches of land (often 1/12 ha) as a function of the species' autecological requirements and the extrinsic and intrinsic conditions of the stand. To obtain forest development at larger spatial scales, the successional patterns of patches from many simulation runs are averaged.

In contrast to the models reviewed above, gap models require as input data a long time (>30 yr) series of monthly temperature and precipitation data, not just the long-term means, because a weather generator is used to derive synthetic weather series as driving variables for the model. In addition, because the models are based on tree species (and not PFTs or biome types), a significant amount of information on the autecological properties of the species is required to parameterize the model, and first simulation results for a given site or a series of sites often

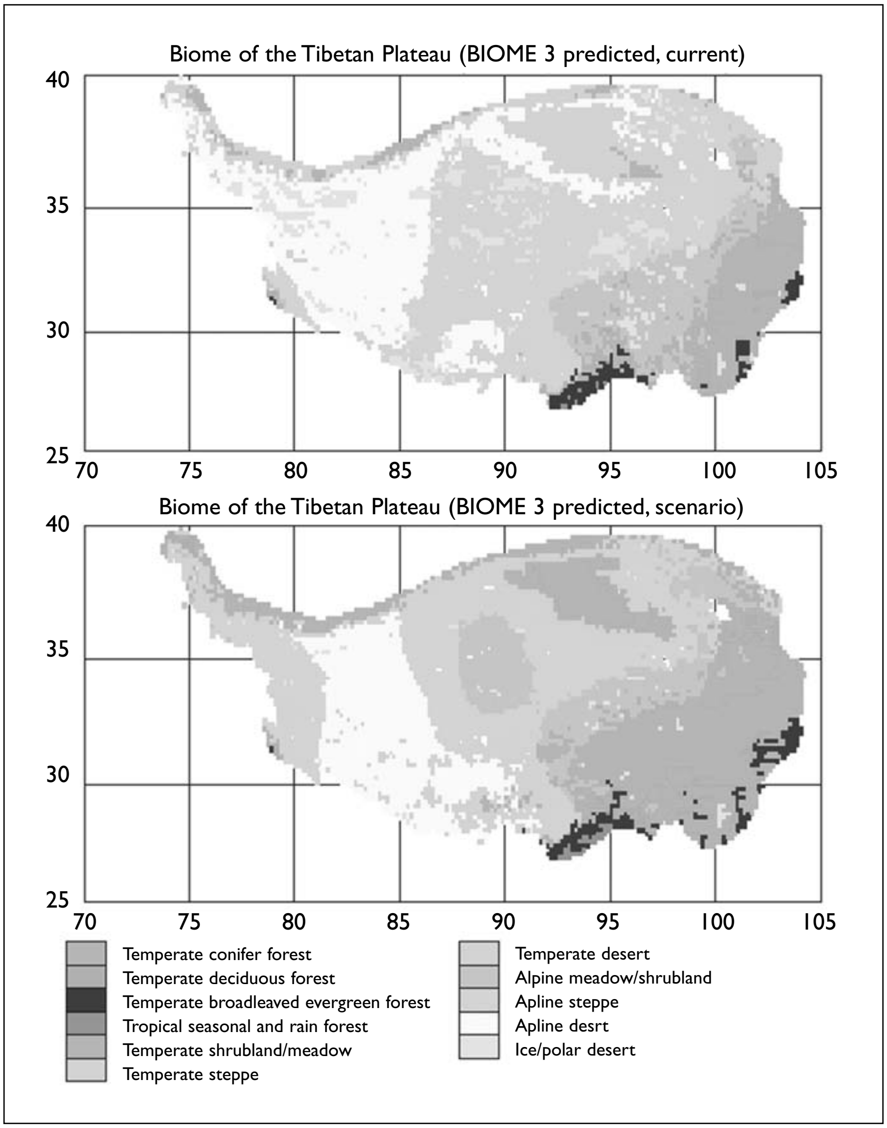


Figure 7.2 Application of the BIOME3 model for the Tibet region. From Ni (2000)

provide unsatisfactory results, thus leading to further model development efforts before the model can be applied to study the impacts of climatic changes on forest succession.

Three forest gap models have been applied to study future vegetation dynamics in the Changbaishan Mountain Biosphere Reserve in northeastern China (for an example of results from the FORCLIM model, see Figure 7.3). While the behaviour of the models agreed reasonably well regarding forest composition under the current climatic conditions along a gradient from the low-elevation mixed deciduous forests up to treeline forests, the results from the models under the same scenarios of anthropogenic climatic change disagreed sharply, suggesting that further research efforts are required to identify those formulations of tree establishment, growth,

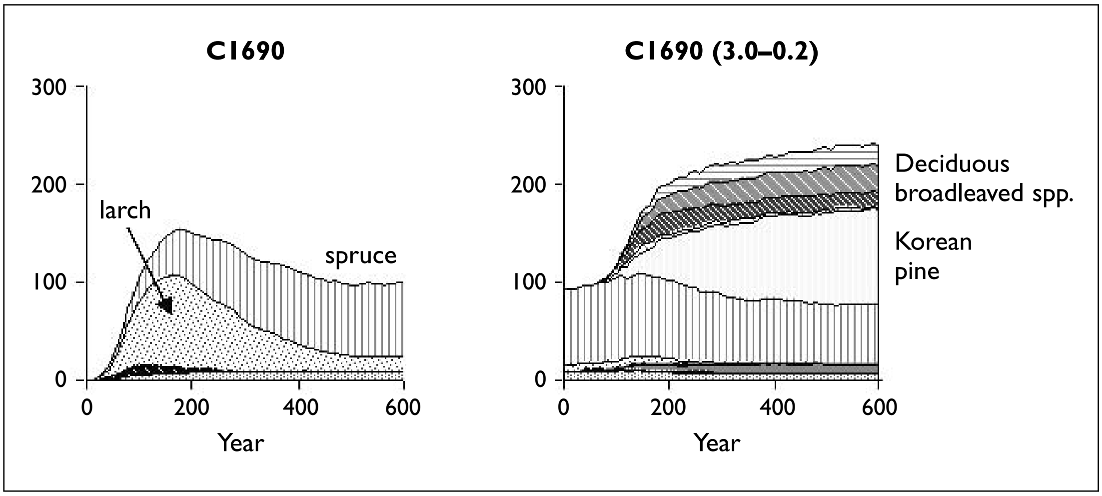


Figure 7.3
Application of the FORCLIM succession model (Bugmann 1996) to study the impacts of climatic change on the composition and biomass of high-elevation conifer forests of the Changbaishan Biosphere Reserve. Left: Model behavior at an elevation of 1,690 m a.s.l. under current climatic conditions. Right: Continuation of the simulation with 100 years (simulation years 600-700) of a linear change of climatic conditions (here, a 3 K temperature increase and a 20 per cent decrease of precipitation throughout the year relative to current conditions), followed by the new, constant climate in the simulation years 700-1200. After Shao et al. (2001).

competition and mortality that are adequate for the systems under study. This model comparison exercise suggested strongly that it may be advisable to apply several models in an impact assessment rather than to rely on the results from one single model (see Bugmann 1997).

Key advantages of the application of forest gap models or other models of the dynamics of vegetation structure are as follows:

- The taxonomic resolution is at the species level, which is highly desirable from the point of view of resource management.
- The models provide information not only on species composition and biomass, but also on ecosystem structure, such as diameter distributions, which are of immediate interest for managers.
- Since the models are dynamic, they provide an assessment of the development over time of these ecosystem properties, whereas the approaches reviewed above assumed an equilibrium between a future climate and vegetation properties.
- The models can easily be extended to include land use (that is, harvesting regimes), although it is more difficult to incorporate other drivers such as nitrogen deposition and CO_2 fertilization.

These advantages are associated with some disadvantages from a resource management perspective:

- The information required about each individual species may often not be available for a target region of model application, thus adding considerable uncertainties if parameter estimation is based on 'educated guesses' (and may even be impossible).
- As mentioned above, the models are not easily transferable from one region to the other, so that before applying them in a 'new' region, a phase of model development must be undertaken, which requires intensive collaboration with a research institution (university or research station) that must have modeling and simulation experience.
- The models have relatively low local precision because they try to capture forest dynamics with fairly simple formulations; however, recent experience suggests that it is possible to track measured forest dynamics across several decades fairly well with this model type (Risch et al., 2005 for the Swiss National Park MBR).

Catchment-scale models of biogeochemistry

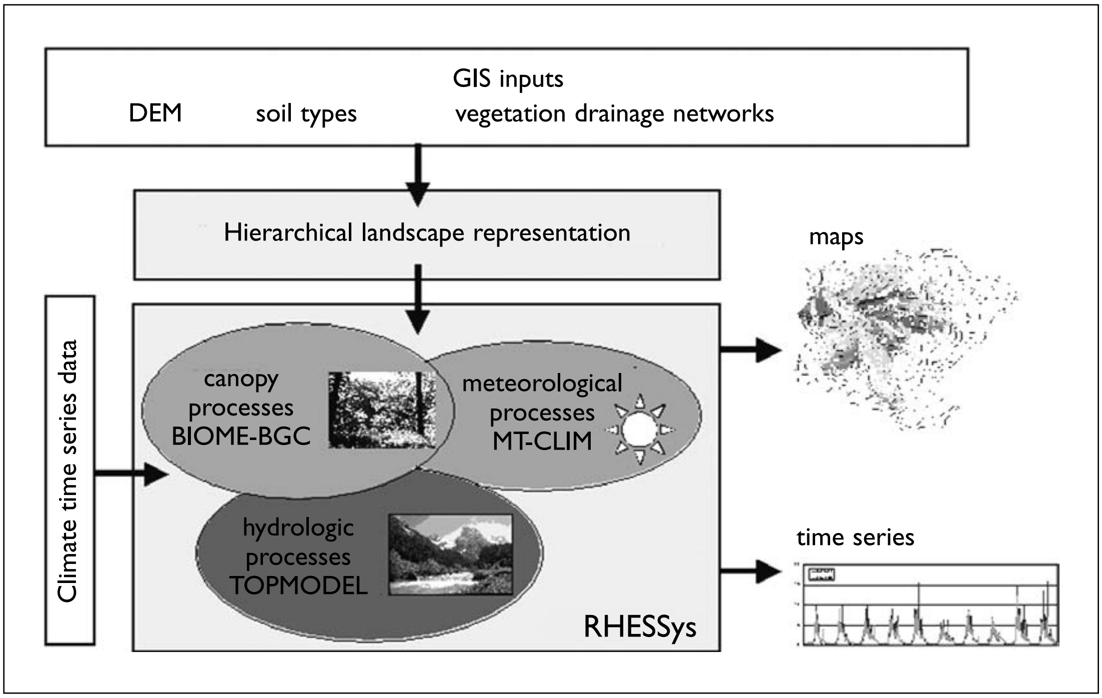
In mountain ecosystems, several factors are of crucial importance that may be virtually negligible elsewhere. Examples include:

- the role of slope angle and aspect in determining energy balance
- the significance of lateral (downhill) water flows because of the steep slopes
- the role of diverse root systems for slope stabilization
- high topographic heterogeneity, which induces strong biotic heterogeneity
- the importance of vegetation, particularly forests, on steep slopes for protecting ecosystems and human infrastructure from natural hazards such as avalanches and rockfall.

In addition, the tight coupling of the various processes in mountain regions makes it necessary to consider a range of ecological and hydrological processes simultaneously if we are to be able to project the impacts of climate change on these systems. The integration of vegetation dynamics and catchment hydrology in mountain regions requires simulation of both the vertical fluxes between soil, vegetation and atmosphere, and the lateral fluxes between adjacent vegetation patches. Band et al. (1993) and White and Running (1994) combined distributed flow modeling based on TOPMODEL with an ecophysiological canopy model based on BIOME-BGC and a climate interpolation scheme based on MTCLIM to build the Regional HydroEcological Simulation System, RHESSys (Figure 7.4). We built upon this tool in a research project that focused on global change effects on mountain ecosystem goods and services, which was part of the 'Advanced Terrestrial Ecosystem Analysis and Modeling' project funded by the European Union (ATEAM, see http://www.pik-potsdam.de/ateam).

RHESSys is an example of a spatially distributed daily time step model designed to solve the coupled cycles of water, carbon and nitrogen in mountain catchments. It has been widely used to simulate hydroecological processes in various mountain catchments in North America (Hartmann et al., 1999; Baron et al., 2000; Tague and Band 2001), and also in the Glacier National Park MBR (Fagre et al., 1997), among others.

Figure 7.4 Schematic diagram of the RHESSys model, which can be used to project the cycling of carbon, nitrogen and water in mountain catchments under scenarios of global change (including both climate and land-use changes). From B. Zierl (unpublished, ETH Zurich).



We used RHESSys to analyse the impact of climate and land-use change on river discharge and carbon storage in mountain catchments in Europe. We used the model to perform sensitivity studies of hydrology and carbon storage under a range of state-of-the-art scenarios of climate change, with a particular emphasis on disentangling the impacts of future land use and direct climatic effects (including CO_2 fertilization) for future ecosystem dynamics in a spatially explicit manner (for an example, see Figure 7.5). For most of the case study areas, we found that land-use effects (as imposed by large-scale scenarios of land use in Europe developed within the ATEAM project) are quite likely to be far more important than direct climatic effects (Figure 7.5). This result, however, cannot be generalized readily to other areas, because it depends on the nature and direction of land-use changes as well as on the exact magnitude of the climatic change scenario that is employed. Hence, it is important to conduct case studies specific to individual MBRs across the world to determine the actual local to regional effects.

The advantages of highly mechanistic models such as RHESSys are as follows:

- They include some key processes that will determine the fate of future ecosystem properties at a higher level of resolution than the approaches reviewed above.
- They provide a spatially explicit, landscape-scale picture of ecosystem dynamics, which is of great interest in a management context.
- They integrate both ecological and hydrological processes, whose interaction is important in mountain regions and thus in MBRs.

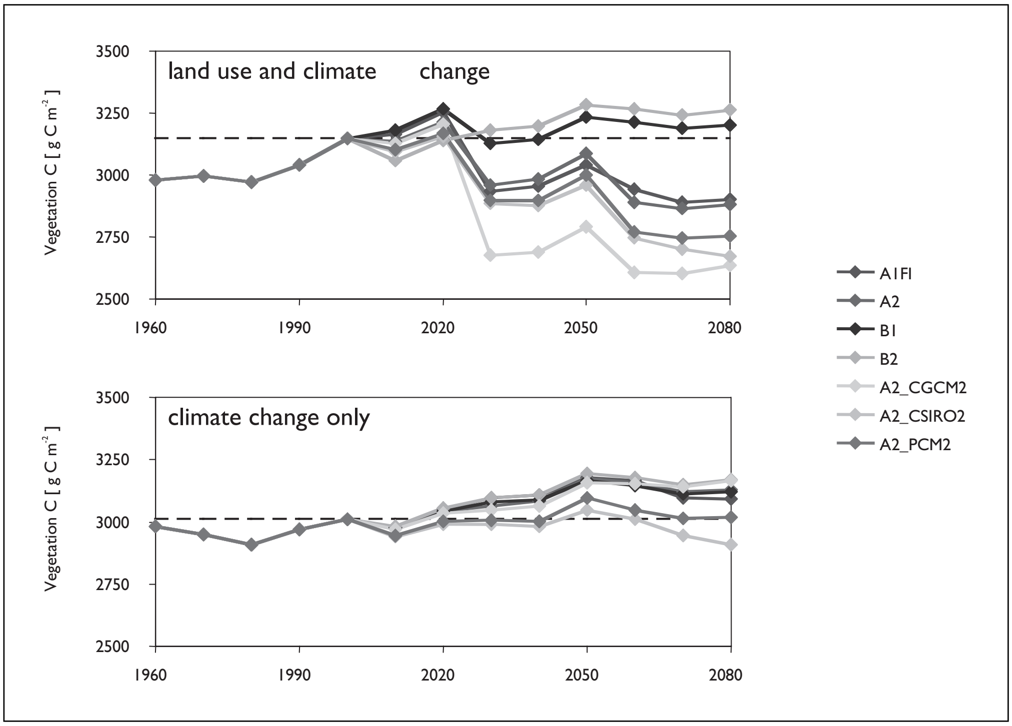


Figure 7.5
Example results from the application of RHESSys (cf. Figure 7.4) to the Saltina catchment in southwestern Switzerland. Shown are the simulated catchment averages of carbon storage in vegetation from 1960 to 2080 under four different IPCC SRES scenarios of climatic and land-use change, plus three variants of one of these scenarios (A2) where climate is taken from different General Circulation Models. The figure shows that land use is the more important driving force of future changes (top) compared with climate change (bottom). From Zierl and Bugmann (2005).

There are some disadvantages to RHESSys-type models that may render their use in MBRs difficult. Among others:

- They require highly detailed input data with regard to climate, soil properties and vegetation in a spatially explicit manner based on GIS layers; daily climatic data are needed to feed such models because they simulate photosynthesis and respiration at high temporal and process resolution.
- They incorporate less detail regarding vegetation structure than forest gap models, although there are exciting new developments of hybrids between forest gap models and dynamic global vegetation models (for example LPJ-GUESS, Smith et al., 2001) that promise to provide the 'best of both worlds'.
- In most circumstances, the application of such models in a resource management context implies a very close collaboration with an academic institution.

MODELING FIRE OCCURRENCE AND FIRE DYNAMICS

In many parts of the world, mountain landscapes are strongly shaped by natural (for example windstorms, wildfires, avalanches) and anthropogenic (e.g. management) disturbances. Such large-scale spatial phenomena cannot be modeled easily at the patch scale, and therefore this is the realm of so-called 'landscape models'. Changes of disturbance regimes are expected for the twenty-first century as a consequence of global change, particularly changes of climate and land use; therefore we cannot ignore possible changes of the disturbance regime in MBRs when making assessments of their future ecosystem properties. However, almost all of the models reviewed above either ignore these spatially explicit processes altogether, or they contain only highly simplified formulations that are likely to provide insufficient detail when the models are applied at the local to regional scale in MBRs. Thus, additional and complementary approaches are needed to look into disturbance regimes.

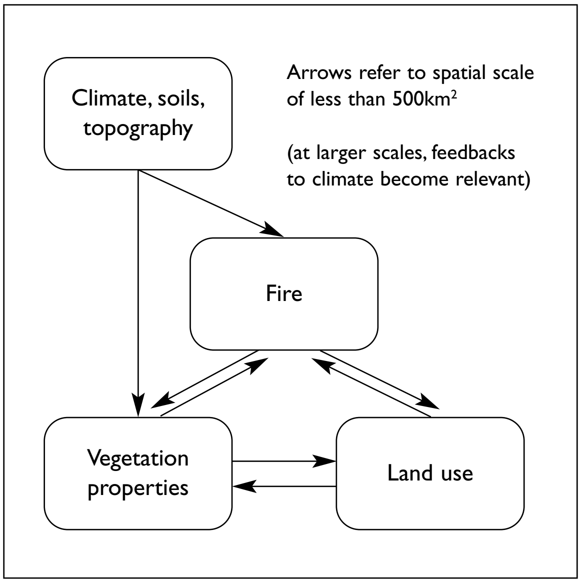
I will focus below on fire, because this has been identified as being of particular importance for many MBR managers, and wildfires may actually become more prominent even in areas that are not currently subject to this disturbance agent (see Schumacher, 2004).

Ideally, a modeling approach would encompass all the major relationships between climate, soils, topography, vegetation properties, climate and fire activity (Figure 7.6). However, since this is a fairly complex issue, it is useful first to review a range of simpler approaches that are available to assess fire hazard.

Predicting fire hazard from climatic information alone

There are quite a few fire indices that were derived to predict aspects of the fire regime from climatic information alone, thus ignoring most of the interactions and feedbacks depicted in Figure 7.6. A simple forest fire index (FFI) that was developed by Gerstengarbe and Werner (1999) seems to work fairly well for predicting the probability of fire occurrence:

Figure 7.6 Relationships between physical variables (climate, soils, topography), vegetation properties, land use, and fire. Adapted from Schumacher (2004).



$$FFI = \sum_{i=v_b}^{v_e} sd_i / \sum_{i=v_b}^{v_e} p_i$$

where sd = 1 for days with T > 25°C;
sd = 0 otherwise
p = daily precipitation sum
v_b, v_e = beginning and end of vegetation period

Other indices such as the fire weather index (FWI), which is used widely in North America, are available to assess the likely fire severity (that is, assuming that ignition sources are not limiting), but it is beyond the scope of this contribution to review these numerous approaches in more detail.

A combination of indices can be used to determine fire risk for both the current climate as well as for the conditions projected by climate change scenarios if we adopt the definition of fire risk (FR) as the product of fire probability and fire severity, for example R = FFI · FWI (or another combination of indices).

The key advantage of these indices is the simplicity of their calculation; key uncertainties relate to the fact that many other processes (Figure 7.6) operating in reality are ignored, and that the applicability of these indices under changed climatic conditions may be doubtful because using them would mean extrapolating empirical relationships derived under current conditions without much consideration of the actual mechanisms.

Models of fire dynamics under a constant climate

There is a wide range of software tools that are quite useful for assessing fire dynamics under current climatic conditions (see http://www.fire.org), and many of these tools are used for operational forecasting of forest fires in a management context. They thus also have a high potential for applicability in MBRs that so far have not focused on these issues. Again, it is beyond the scope of this contribution to provide a more detailed review, but a host of information can be found on the Internet, and many natural resource managers have already used these tools, particularly in North America and Australia.

Key uncertainties over the use of these tools are that they have not been developed for application in a changed climate, and in most of them the properties of the wildfire regime (such as fire frequency and fire size distributions) need to be prescribed by model parameters. Thus they cannot actually predict the future wildfire regime, but rather this needs to be imposed on the models via separate scenario calculations. Below, a new approach is reviewed that appears to be capable of integrating the major processes given in Figure 7.6 so that the fire regime results as an emergent property of these processes. It is thus easier to make projections of the wildfire regime under a changed climate than with traditional fire models, let alone with simple fire indices.

Modeling the interactions between fires, vegetation properties and climate

Landscape-level ecological simulation models are important tools for improving our understanding of the ecological consequences of changes in climate in concert with changes in large-scale disturbance regimes and human land use. However, the interactions between climate, disturbance dynamics and vegetation properties are still an active research field, and the associated tools are not normally applied in a management context yet. At ETH, we have started looking into these issues, using temperate mountain catchments in the European Alps as case studies. First, the sensitivity of the fire regime to altered environmental conditions and to the spatial heterogeneity of fuel availability was addressed. Second, the sensitivity of forest landscape patterns to the direct impacts of climatic change as well as the indirect impacts of changes in fire regimes was investigated. Other drivers of landscape dynamics, such as windthrows and avalanches, were also considered via simple parameterizations, but they are not highlighted here.

For the study shown here, we used LANDCLIM, a modeling framework of landscape dynamics (Schumacher, 2004). LANDCLIM is a spatially explicit, raster-based, and stochastic model that includes a new competition and succession submodel as well as a representation of wildfire dynamics that depends on weather properties as well as vegetation patterns in the landscape.

Among others, we applied the LANDCLIM model to study future vegetation patterns in the Gantertal in southwestern Switzerland, a central alpine catchment that ranges from 1,100 to 2,500 m a.s.l. (Figure 7.7). For the climate scenario, we used output from a recent regional climate model simulation for the years 2070–2100 (Schär et al., 2004) that was downscaled to this catchment by means of a simple protocol. The climate change scenario was driving both vegetation dynamics and the wildfire regime, and the latter in turn had impacts on vegetation patterns. The key objective of the study was to quantify the relative importance of the direct effects of climatic change on tree population dynamics (that is, individual-tree establishment, growth, competition and mortality processes) versus the indirect effects via the wildfire regime in this catchment, which under current climatic conditions is not subject to a noticeable wildfire activity (note its elevation above 1,100 m a.s.l.; at lower elevations in the southwestern Swiss Alps, wildfires are an important driver of landscape dynamics already today).

The simulation results (Figure 7.7) clearly suggest that both climate and wildfires have an important role under the scenario conditions, with climate driving the upward shift of the treeline (the current treeline is located at 2,100–2,200 m a.s.l) and the wildfire regime driving the transition of today's dense Norway spruce (*Picea abies*) forests at elevations below 1,900 m a.s.l. into pine-dominated savannah-like stands, particularly at the lowest elevations of the catchment. Compared with direct climatic effects and those that are mediated by the wildfire regime, changes in land use and in the windthrow regime turned out to be practically negligible (results not shown). If we take into account that the current forests below 2,000 m a.s.l. in the Gantertal often protect human settlements and other infrastructure (roads, power stations and so on) from gravitative natural hazards such as snow avalanches, rockfall and landslides, it becomes clear that the simulated changes could have strong implications for the future management of this region, including the question of whether such a valley could still be inhabited by humans.

Besides the fact that approaches such as LANDCLIM provide a host of spatial and temporal detail on ecosystem dynamics that are relevant in a management context, their advantages include the following:

- The models are typically not very data intensive (that is, monthly climatic data and a simple characterization of soil properties are often sufficient), although these data must be available in a spatially explicit manner, or there must be the possibility and capability to extrapolate them in space.
- Many of these models operate on the species level but still do not require a high level of knowledge about the autecology of the species (for example as compared with forest gap models).
- Although computation time may be an issue compared with point models, models like LANDCLIM try to balance the level of detail with efficiency in the simulation, so that areas up to a size of 100 km^2 can be simulated relatively easily.

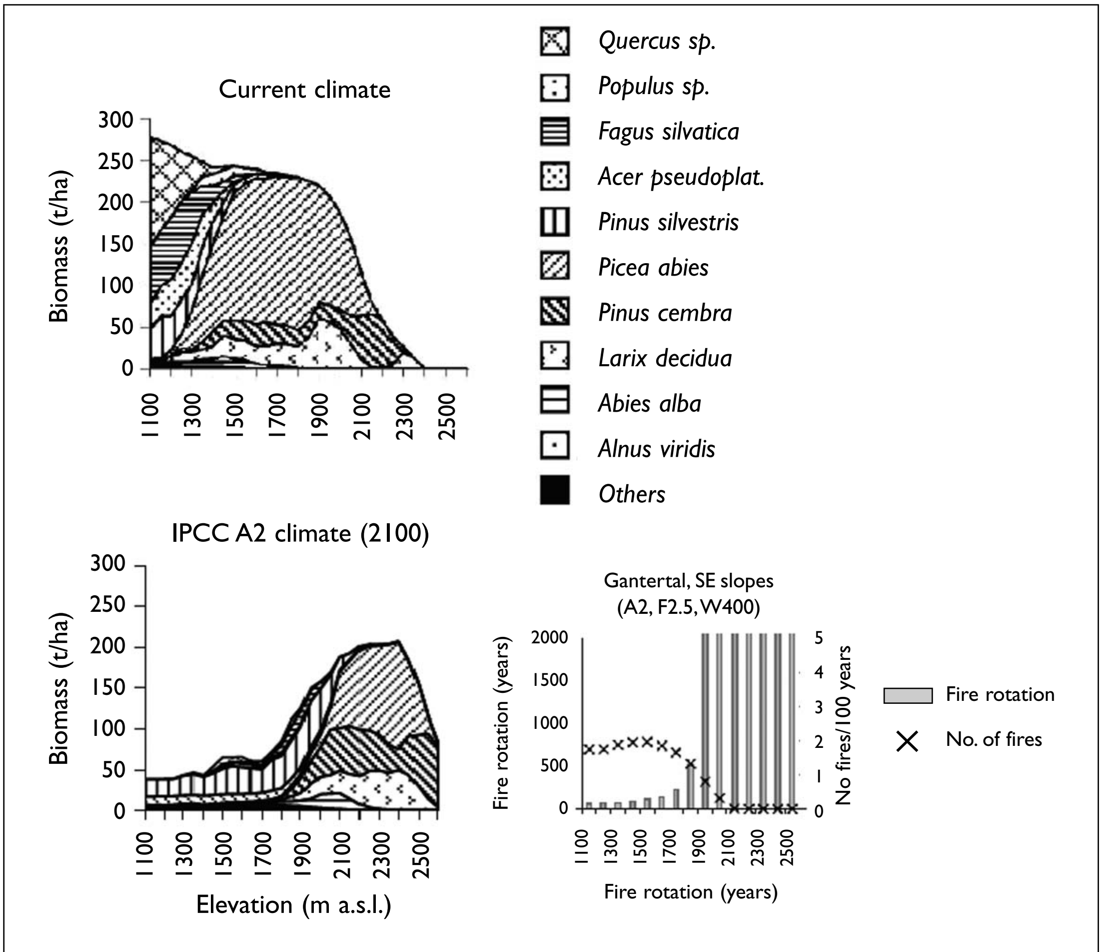


Figure 7.7
Averaged vegetation properties in the Gantertal (southwestern Switzerland) under the downscaled climate from a Regional Climate Model (for details, see Schumacher 2004) as simulated by the LANDCLIM vegetation model (Schumacher, 2004). Forests in the current landscape above 1,200 m a.s.l. are dominated by Norway spruce (*Picea abies*); the simulations thus suggest a drastic change of vegetation at lower elevations towards pine (*Pinus sylvestris*) savannahs, and an increase of the elevation of upper treeline (under the assumption that there are no land use constraints to this increase). The fire rotation shown in the small panel on the right is the time that is required to burn an entire elevational band (of 100 m witdth), and the number of fires [per century] refers to fires larger than 1 ha in the same elevational bands. Adapted from Schumacher (2004).

The major disadvantages of landscape-scale models are that:

- They require relatively sophisticated GIS support, as the model must be interfaced with GIS data layers, both for the input (see above) and also for the processing and analysis of the simulation results.

- There is quite a lot of uncertainty about how to formulate ecological processes in these models. Thus confidence in the accuracy and precision of the results may not always be adequate to support resource management decisions.
- In all likelihood close cooperation between managers and an academic institution is required if such models are to be applied in MBRs, even in 'developed' countries.

CONCLUSIONS

First of all, I hope to have shown in this contribution that there are a large number of approaches for assessing the impacts of global change on the distribution, structure, function and dynamics of vegetation properties in mountain regions. Some of these tools have been used for several decades and represent widely respected standards for certain purposes (for example the BIOME1 model), whereas the more 'sophisticated' tools in particular are often subject to ongoing research efforts, making close collaboration between resource managers and research scientists necessary if the latter tools are to be used for predicting the future of vegetation cover in MBRs.

Second, the available approaches vary tremendously in terms of their requirements with respect to modeling skills and the input data that must be available to successfully apply them in a management-oriented context. I would assert, however, that even with modest resources (for example by using the BIOME1 model, or a version of the BIOME3 model that has more plant functional types than those normally included in global applications of that model, see Ni, 2000), it would be possible to perform robust impact assessments for individual mountain regions or MBRs that would yield highly relevant insights into likely shifts of vegetation cover under scenarios of climate change. As a matter of fact, it could be a highly rewarding exercise to apply one single vegetation model across a wide range of MBRs, so as to evaluate the relative sensitivity to climatic change of the individual reserves within the global network of MBRs; this would lead to the identification of 'hot spots' among the MBRs that may deserve particular attention in the future.

Finally, the modeling studies that have been performed in the past, some of which were reviewed in this contribution, typically suggest that mountain regions and MBRs are likely to be subject to major changes (some beneficial, some detrimental) with respect to vegetation and disturbance dynamics. This clearly suggests that additional studies are required to evaluate these impacts in areas that have not been investigated to date. The available evidence suggests that the vegetation of mountain regions could serve as 'canaries in the coal mine' to signal the impacts of global change on ecosystems (see Huber et al., 2005).

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8 *Niche-based Models as Tools to Assess Climate Change Impact on the Distribution and Diversity of Plants in Mountain Reserves*

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INTRODUCTION

There is now considerable evidence of ongoing climatic change (Luterbacher et al., 2004), and observed trends (e.g. an increase of 0.6–1K on average since the Industrial Revolution) are predicted to increase drastically by the middle of this century, with extreme warming projections reaching average values as high as +5.8K by 2100 (IPCC, 1996). Together with habitat destruction and biological invasions (due to global change), climate change now represents one of the major threats to species, ecosystems and biodiversity (Thomas et al., 2004).

Further evidence is published each year on various observed impacts, such as geographic range shifts (Grabherr et al., 1994; Parmesan 1996; Parmesan and Yohe, 2003). These observed changes are often referred to as 'biological fingerprints' of climate change (see, for example, Root et al., 2003; Walther et al., 2002). They can be expressed at various levels of biological responses (physiological, phenological and distributional, for example; see Figure 8.1).

Mountain areas and alpine ecosystems are often considered as potentially very sensitive to climate changes (Beniston et al., 1996; Guisan et al., 1995; Nagy et al., 2003; Theurillat et al., 1998; Theurillat and Guisan 2001). Many isolated endemic and orophytic plants now living in refugias, such as the peaks of low mountains in the Alps, are threatened because it will be almost impossible for them to migrate to higher elevations. This will occur either because they are unable to move there rapidly enough, or because the nival zone is absent (Grabherr et al., 1995). For instance, Theurillat et al. (1998) expect most alpine and nival species to be able to tolerate direct and indirect (e.g. competitive exclusion) effects of an increase of 1–2K, but not a much greater change (such as 3–4K). Such upslope migrations of plant species along elevation gradients have already been already reported (e.g. Bahn and Körner 2003; Grabherr et al., 1994), and more than 80 per cent of the species that exhibit such changes are shifting in the direction expected on the basis of known physiological constraints on the species (Root et al., 2003).

Because anticipation of changes improves our capacity to properly manage landscapes and ecosystems, it is becoming increasingly urgent to improve our understanding of species'

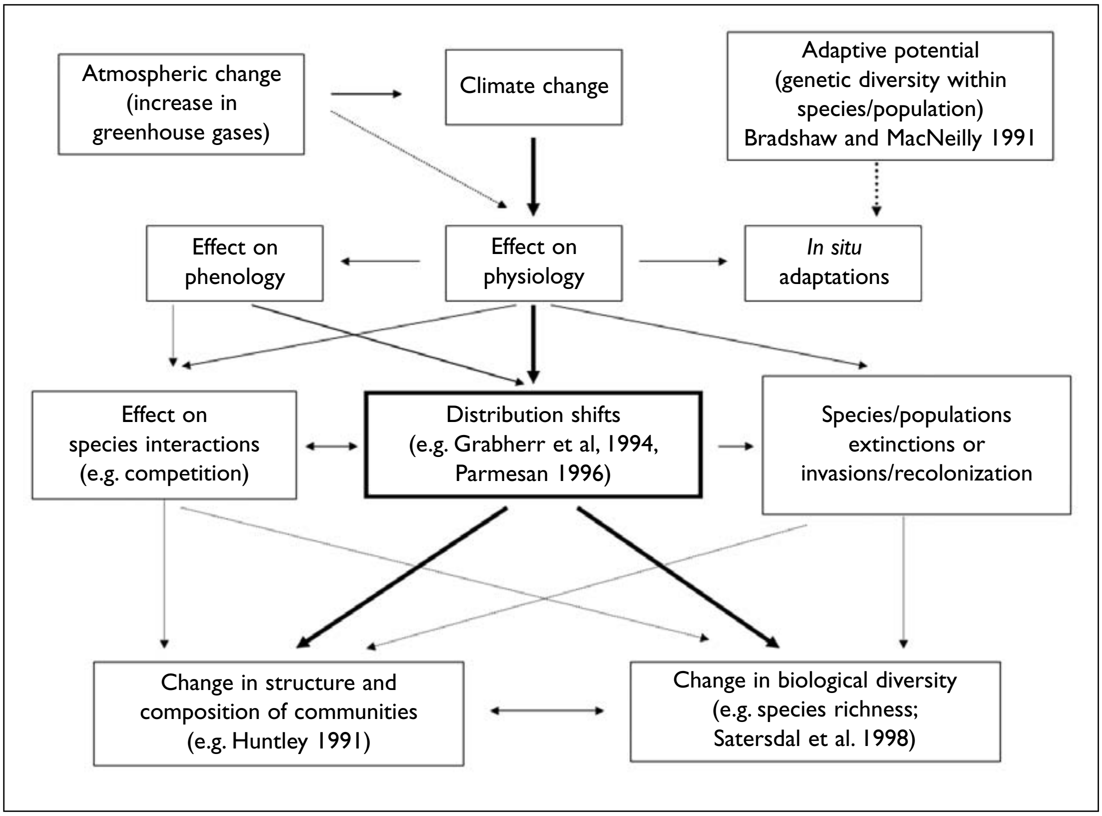

Figure 8.1 The different pathways of plant responses to climate change. Inspired from Theurillat and Guisan 2001

responses to a changing climate (Root et al., 2003), such as assessing possible changes in their geographic distribution (Parmesan, 1996).

One possible approach is to use niche-based predictive models of species distribution. In this paper, I review and discuss how projections from these models can be used to assess the likely impact of climate change on the flora of mountain reserves.

NICHE-BASED DISTRIBUTION MODELS AS FORECASTING TOOLS

Predictive species' distribution models are empirical models relating field observations to environmental predictor variables based on statistically or theoretically derived response surfaces that best fit the realized niche of species (Franklin, 1995; Guisan and Zimmermann, 2000). Species data can be simple presence, presence–absence, or abundance observations based on random or stratified field sampling. Environmental predictors (such as topography or climate) are preferably factors that are expected to have a causal effect on species physiology and fitness (Austin, 2002). These models result in spatial predictions that indicate the locations of the most suitable/ unsuitable habitats for the target species or community. However, their robustness relies heavily on a proper fitting of the realized niche, and thus their success is largely dependent on having sufficient ecological knowledge of the important descriptors of the niche in a spatially explicit form (Austin, 2002). Therefore, they also play an important role from a more fundamental ecological perspective, as they allow for the identification of the most important factors.

By changing the input climatic maps in the models, various climate change impact scenarios can be derived. The projections show not only the future location of suitable habitats (local colonization) but also the location of habitats that may become unsuitable after climate change (local extinctions). Hence, they constitute valuable tools to study the most likely impact of climate change on the distribution of plant species (Bakkenes et al., 2002; Iverson and Prasad, 1998; Thomas et al., 2004; Thuiller, 2003), communities (Brzeziecki et al., 1995; Kienast et al., 1998) or diversity (Bakkenes et al., 2002; Saetersdal et al., 1998).

Recent projections using such models suggest that in some areas, under the most severe climate change scenarios, up to 35 per cent of endemic species may be doomed to extinction by 2050 (Thomas et al., 2004; but see Thuiller et al., 2004a and other replies). Species turnover may also be very high in some regions, possibly leading to ecosystem disruption (Thuiller, 2004).

In Europe, most published examples are based on numerical data from the *Atlas Flora Europaea* database (Lahti and Lampinen, 1999), resulting in predictions at the coarse resolution of 50×50 km^2 (e.g. Bakkenes et al., 2002; Thomas et al., 2004; Thuiller, 2003) where the whole European Alps only represent a few pixels. The same applies to most other regions in the world. Hence, in such coarse scenarios, predictions for alpine and subalpine plant species that only occur on small areas at high elevation cannot be depicted appropriately. Modeling their distribution at a finer resolution is likely to provide quite distinct projections (e.g. persistence in micro-sites at high elevation; see Theurillat et al., 1998). The fine distribution of mountain plant species results from complex interactions among factors such as snow cover duration, soil water availability during the growing season, soil properties, soil temperature and wind (Humphries et al., 1996). Hence, attempts to include these – and their possible interactions – as predictors in climate change impact assessments have shown that they generate improved predictions (Dirnbock et al., 2003; Dullinger et al., 2004). However, no formal comparison between climate change projections obtained from coarse-resolution models fitted at the European-scale and those from fine-resolution models fitted at the local scale has been made for alpine species.

MODELING THE IMPACT OF CLIMATE CHANGE IN ALPINE AREAS

In an early study, maps were drawn for sixty-two higher plant species found at alpine/subalpine elevations, from which three separate climate change impact scenarios (+1.5K, +3K, +4.5K) were derived (Guisan and Theurillat, 2000; Guisan and Theurillat 2001, 2005; Lischke et al., 1998). We expected strict alpine species to be at higher risk of local extinction than species that are also distributed at lower elevations, as the latter were thought to have a wider tolerance of those ecological factors that vary with elevation (e.g. climatic ones), and thus to run a lower risk of local extinction (Theurillat and Guisan, 2001). Subalpine species would also be at lower risk globally, since the total area of the subalpine belt would be only slightly reduced by moderate warming, as shown by a GIS-based analysis of the Swiss Alps (Theurillat and Guisan, 2001). The resulting scenarios supported these hypotheses, by showing a great range of responses (positive or negative), depending on the species and the degree of warming. They showed that alpine plant species consistently remained at greatest risk of local extinction, whereas species with a larger elevation range were predicted to be at lower risk. It was however concluded that further studies were needed (Guisan and Theurillat, 2001), especially to:

- consider a larger elevation range, as a way to include the effect of possible invaders from lower elevations
- use an improved set of predictors and related climate change scenarios, including the effect of temperature change on all related predictors (e.g. potential evapotranspiration, site water balance, snow cover, permafrost)
- consider the effect of inter-specific competition
- take species' dispersal into account.

Guisan and Theurillat (2005) discuss more specifically some different scenarios for a dominant species – the alpine sedge *Carex curvula* – and how other issues, like competition, migration and ecological inertia, might modulate the responses predicted by these models. Combinations of predictions about individual species to assess the possible impact of climate change on the diversity, structure and composition of communities were also explored in a bottom-up approach (Guisan and Theurillat, 2000), and guidelines were given on setting-up appropriate field monitoring schemes to test our projections in the future (Guisan and Theurillat, 2005).

Another study was conducted by Dirnböck et al. (2003) and Dullinger et al. (2004). Although additionally considering the abundance of species and a combination of climate with land-use change scenarios, it yielded very similar results when land use was assumed to be constant. In particular, the up-slope shift of subalpine forest was shown to represent one important mechanism by which loss of alpine species might occur (Dullinger et al., 2004). The authors further showed that summer pasture may facilitate the persistence of alpine species by providing refuges, but that their overall coverage might prove insufficient to prevent large extinctions on a regional scale (Dirnbock et al., 2003).

These scenarios for alpine species are tenable. Indeed, when considering a large territory like Switzerland, some physiographic predictors, such as slope angle, are unequally distributed among different elevations (Theurillat et al., 1998; Theurillat and Guisan, 2001; Körner, 2003). As height increases, fewer gentle slopes are available, causing a decrease in the variety of habitats. If climate warming affects these high areas, some species from lower elevations would become able to extend their range upwards and competitively displace some native alpine and nival species. As no escape routes to higher elevations are available to these species, (these areas are already at the tops of mountains), they would probably suffer most from any warming, even if only slight. As a result, they might be confined to small vegetation patches at the periphery of habitats colonizable by plants, or become locally extinct (Guisan and Theurillat, 2005).

These earlier studies also highlighted several weaknesses of current modeling exercises, a selection of which are discussed in the next sections.

SAFE PROJECTIONS REQUIRE PROPER MODEL VALIDATION

Useful projections require robust models, but many published projections of shifted climate-envelopes are derived from models that have been insufficiently tested (see Araújo et al., 2005). Model validation is usually performed internally on a pseudo-independent data set sampled from the same study area, or by re-sampling the training data set (e.g. by cross-validation or bootstrap, as for the studies previously cited). All these approaches are bound to the same training area, and thus suffer from the same problem of spatial and temporal autocorrelation in the calibration and validation sets. Their robustness when applied to new situations, like future climate change, cannot be appropriately tested by internal validation. Building the models in one area and projecting them into another, comparable area, where a truly independent data set exists, constitutes a more independent validation, and is thus expected to provide a more objective evaluation of model robustness (Pearson et al., 2002; Randin et al., in review).

Another, more novel approach to independent validation is to test the behaviour of models by projecting them into the past, using paleoclimatic maps (see e.g. Hugall et al., 2002; Martinez-Meyer et al., 2004). The rationale here is that a model that predicts the past extinction of a species that is known to exist now cannot be expected to predict the future adequately, and conversely. This could be either because the model is wrong or because the assumption of niche conservation over time (Peterson et al., 1999) does not hold for the species. Although often advocated, this approach has surprisingly rarely been tested in practice. For instance, a recent phylogeographic study of skinks (*Saproscincus basliscus*) demonstrated the failure of back projecting a niche-based model fitted under current conditions to predict the retention of multiple populations in the south of the species range known from independent phylogeographic studies (A. Moussalli and C. Moritz, unpublished data). Very few examples of this approach exist and none was found for plant species.

Such an approach is demanding as it requires paleoclimatic data in a spatially-explicit form throughout the study area, and this largely explains why little has been attempted so far. As paleoclimatic maps obtained from multiproxy reconstructions have just become available for Europe (Luterbacher et al., 2004), it will be fascinating to test the robustness of models by projecting them to past periods and to compare their predictions with independent paleodata on species distribution, such as that obtained from palynological record databanks (e.g. ALPADABA; van der Knaap and Ammann, 1997). As such paleoclimatic maps have a crude resolution of 0.5° × 0.5° (about 55 km × 55 km), such an approach will only be possible at the European scale, where it matches the resolution of most species' range shift models (50 km × 50 km; e.g. Bakkenes et al., 2002; Thuiller, 2003). This should prove to be very useful as a way to get a first evaluation of this new approach, and to test the robustness of models to such a 'validation in the past'.

TAKING PLANT DISPERSAL INTO ACCOUNT

Most climate change impact scenarios are limited to a comparison of the present and future distributions of species, without any consideration for their dynamics of migration and colonization (Davis et al., 1998; Pearson and Dawson, 2003; Pitelka et al., 1997; Ronce, 2001). Although many modeling studies have predicted the way species habitat may be shifted (e.g. Bakkenes et al., 2002; Gottfried et al., 1999; Guisan and Theurillat, 2001; Iverson and Prasad, 1998), few of them assessed the real possibility for species of actually migrating to new habitats (e.g. Carey, 1996). Instead, scenarios usually rely on considering (in the best case) the two extremes: namely, 'no dispersal' (that is, considering the intersection between current and future predicted ranges) and 'universal dispersal' (that is, the full future range is immediately occupied; e.g. Araújo et al., 2004; Thomas et al., 2004; Thuiller, 2004). The resulting projections often differ strikingly, with large related uncertainty between the two extremes, which limits their usefulness for properly assessing climate change impact. This is despite several spatial autocorrelation studies indicating that dispersal and colonization processes influence the distribution of many plants in a much more refined way, as shown for instance for alpine plants (Dirnbock and Dullinger, 2004). Since most habitat distribution models commonly ignore such spatial processes, they miss an important driver of plant distribution at the local and landscape scales.

For each species, considering more dynamic dispersal scenarios requires consideration of (1) dispersal abilities (e.g. wind- versus animal-dispersed seeds), and (2) landscape permeability, for instance through the existence of barriers to seed dispersal, whether these be physical (e.g. topography) or ecological (such as unsuitable soils) (see, for example, Rupp et al., 2001). Whereas multiple descriptions of the mechanisms and ecology of migrations and seed dispersal can be found in the literature (Greene and Calogeropoulos, 2002; Harper, 1977; Howe and Smallwood, 1982; Körner, 2003; Pitelka et al., 1997; Watkinson and Gill, 2002), there are only a few examples of spatially explicit models that integrate seed dispersal in a dynamic way (e.g. Carey, 1996; Dullinger et al., 2004), and these examples usually only consider a single species. The reason why no such assessment has been made on multiple species is certainly the lack of data on dispersal traits, although such databases are now becoming increasingly available.

Integrating dispersal mechanisms in predictive models of species range shift will help to identify species capable of tracking climate change that is occurring at a predicted rate (Ronce 2001; Watkinson and Gill, 2002). It will also make it possible to check the capacity of species to cross linear obstacles in the landscape in order to reach suitable habitats (e.g. at higher elevation).

One method already explored is the use of cellular automata to simulate the spread of species in the landscape as the climate changes (Carey, 1996). The approach combines the use of a correlative habitat model with the population dynamics and dispersal features of the focus species. For instance, the DISPERSE model (Carey, 1996) uses simple dynamic parameters and a bivariate normal distribution to simulate the dispersion curve of seeds that travel long distances, but it was applied on a large spatial scale using a rather coarse resolution (several square kilometres). Few examples exist of application at finer resolution in alpine landscapes.

One example is Dullinger et al. (2004), although their model was developed for a single tree species (*Pinus mugo*). Another example is the MIGRATOR model (Engler and Guisan, in preparation), which simulates the dispersion of plant species at fine scale in a mountain environment according to a transient climate change scenario. In this model, stochastic long distance seed events, barriers to dispersal and various seed dispersal parameters can be implemented. Varying the dispersal distance in these models additionally allows the assessment of uncertainty in projections. Early results show that some species would need to migrate as much as 100 m each year to reach the unlimited dispersal scenarios required to keep pace with climate change, a rate much greater than the actual migration rate of 4 m per decade observed for alpine plants (Grabherr et al., 1994). Although such analysis demands a great deal of data, it is very promising in a context of global climate change (see also Collingham and Huntley, 2000; Collingham et al., 2000).

COMMUNITY RESPONSE AND IMPLICATIONS FOR RESERVES

As species are unlikely to exhibit similar responses, an important consideration is to know if some species traits might explain the sensitivities of particular species to climate change. More specifically, it would be informative to identify which traits are likely to favour species expansion and which are likely to cause shrinkage of the species range. Species traits related to niches have already been shown to influence the distribution of species (e.g. Segurado and Araújo, 2004; Thuiller et al., 2004b), and thus differential responses of these species to climate change can be realistically expected due to these and other traits. However, I have found no published example in the literature of such an assessment in the context of climate change.

Due to the individualistic responses of species to environmental change (e.g. different speed of dispersal), future communities and ecosystems are unlikely to be the same as those observed today (Huntley, 1991), at least for communities under climatic determinism. Hence, modeling communities as fixed entities or diversity as fixed numbers (that is, species counts) has little meaning. For this reason, bottom-up approaches that attempt to build these collective properties from individual species predictions are gaining support (Figure 8.2; see also Austin 2002; Ferrier et al., 2002; Guisan and Theurillat, 2000; Peppler-Lisbach and Schröder, 2004).

This approach of assembling communities was first used in dynamic models, providing greater realism for testing important ecological hypotheses (e.g. community stability) than previous approaches that considered communities to be created spontaneously (e.g. Wilmers et al., 2002). Assembly rules based on experimental and observational findings have been proposed and developed (e.g. Weiher et al., 1998; Weiher and Keddy, 2001). The next step now is to try using such rules – and possibly other ecological laws (e.g. partitioning of resources among species) and species-sorting processes – to constrain assemblages based on individual species predictions or alternatively on predictions of functional groups of species.

A final, but most intriguing question that easily comes to mind when discussing impacts of climate change is: how will current nature reserves behave in order to maintain biodiversity in a climatically changed future? The question is particularly important in the case of mountain reserves that might face extinctions at their highest elevations. Earlier modeling studies have shown that several reserves might not fulfil their role of nature sanctuary (see Araújo et al., 2004; Williams and Araújo, 2000). Indeed, in mountain areas, few reserves include the full elevation gradient from lowland to the highest peaks (Kienast et al., 1998), although such a large amplitude is expected to facilitate species migration. In the past, without human fragmentation of the landscape, mountains seemed to have acted as refuge areas for many species due to their high altitudinal variation over short distances, which allowed species to track climate change by having to move only over short distances ('yo-yo' behaviour; Theurillat et al., 1998). More investigations are clearly needed to test this hypothesis and a powerful approach is necessary to precisely

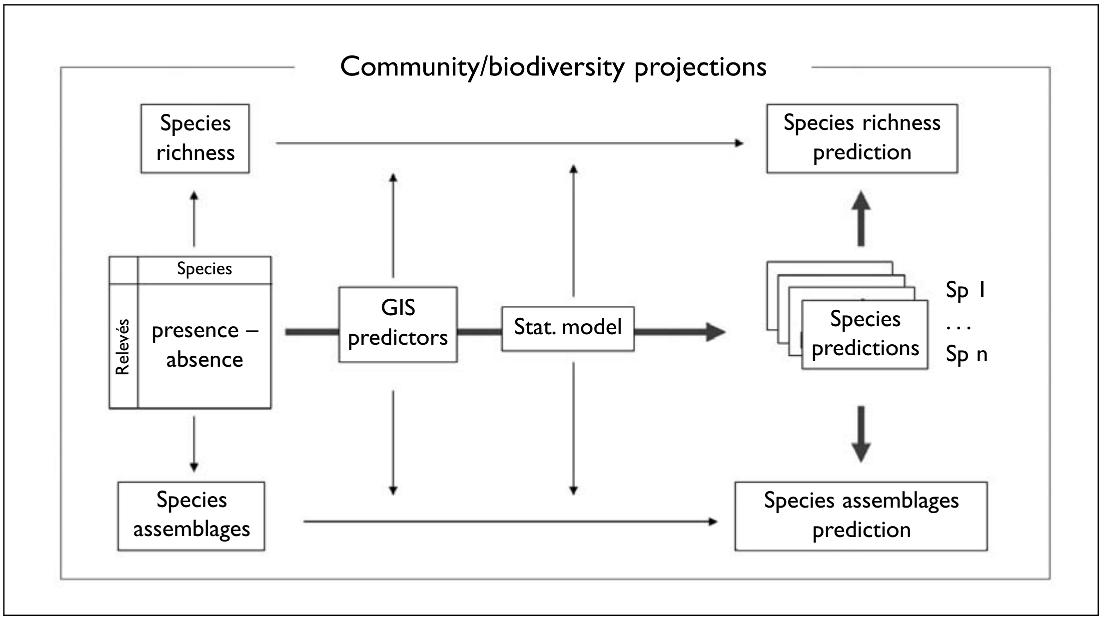

Figure 8.2 The different pathways of plant responses to climate change. Inspired from Theurillat and Guisan 2001

use projections from predictive species distribution models and reconstructed ecological assemblages within a reserve with wide elevation under different scenarios of climate change.

THE MODIPLANT PROJECT IN THE SWISS ALPS

The MODIPLANT project is an initiative of the ECOSPAT laboratory at the Department of Ecology and Evolution, University of Lausanne, Switzerland (http://ecospat.unil.ch). It was started as a medium- to long-term project aimed at providing improved climate change scenarios and a network of permanent plots to observe and test, in the future, the veracity of current projections.

The study area encompasses all alpine areas of the Canton de Vaud, a canton of western Switzerland (ca. 700 km^2). Two large floristic databases are available for open and forest vegetation, covering more than 3,500 plots. These biological observations can be related to a large series of environmental maps stored in a GIS database and providing information on topography, climate, geology and land-use. The study area also encompasses one large reserve ('natural park') and several smaller ones, thus providing opportunities to test their value in maintaining future diversity.

Various aspects of climate change impacts are studied in the area, such as impacts on invasive species (that is, whether they are favoured) and on rare and alpine plant species. The modeling approach is mostly used but complementary aspects are investigated by, for instance, using experimental (e.g. common gardens along an elevation transect) and monitoring approaches (setting permanent plots at successive elevations). Models for species and diversity are thereby improved in many aspects, such as:

- improving the whole modeling approach, using published 'best practice' insights
- taking dispersal into account (Migrator model; Engler and Guisan, in preparation)
- testing their transposability in space (Randin et al., in review) and time
- testing the effect of plot size on their robustness
- testing the combined effect of changes in land use and climate
- assessing the role of inter-specific competition in determining the lower altitudinal limit of species
- testing various approaches to assembling individual species' predictions in communities and functional groups, using for instance information on species traits (e.g. assembly rules)
- testing various hypotheses recently proposed or renewed in biodiversity and alpine biogeography (e.g. neutral versus niche theories, causal determinants of biodiversity).

CONCLUSIONS

By providing a visual prognosis of the contraction or expansion of species habitats, these models and related climate change impact scenarios can help to identify the most dramatic trends that can be expected in mountain regions, and particularly in reserves, such as the disappearance of all suitable habitats for a species at the highest elevations, or the invasion by exotic species at the lower elevations. In the first case, a species might well be able to persist in certain locations that are least affected by climate change. However, its survival in the long-term would be seriously jeopardized, especially in the case of small, fragmented populations, as reproduction might for instance be affected (Guisan and Theurillat 2001, 2005). In the second case, studying the impact of alien species can only be done by considering a larger geographic extent than just the strict boundaries of the reserve, to allow us to include the niche of species located outside the margins of the reserve that may possibly invade the protected area.

Hence, mountain reserves – and particularly UNESCO's mountain biosphere reserves (MBRs) – represent interesting situations in such climate change impact assessment, because their borders are usually defined by natural features (e.g. including a whole mountain range) and impact assessments can thus be more easily derived for their entire flora. Furthermore, due to their particular status, a concentration of good GIS and field data is usually available, or on the way to becoming available. Last but not least, MBRs have a very important role to play in this regard by promoting interdisciplinary and transdisciplinary research within a single study area.

Predictions from spatially explicit niche-based distribution models can prove very useful to assess the risks of climate change impact. However, earlier studies showed the importance of improving existing models by incorporating species dispersal and population dynamics, for instance using parameters obtained from emerging plant trait databases. Going one step further, predictions from these models can be used as input data in reserve selection algorithms as a way to properly assess the role of reserves as natural sanctuaries. As yet no such assessment has been made for mountain areas, but early attempts elsewhere showed the importance of quantifying the level of uncertainty in predictions (arising from using distinct modeling techniques, different climate change scenarios or different sets of predictors) and using it as additional information to be provided to managers.

In all these regards, the MODIPLANT project being currently conducted by my group in the western Swiss Alps should provide useful additional insights.

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9 *Remote Sensing of Mountain Environments*

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INTRODUCTION

Remote sensing technologies provide powerful tools for observing mountain environments such as UNESCO's mountain biosphere reserves (MBRs). Due to the difficulty of access to most mountain regions for physical and/or political reasons, remote sensing is often the only method for investigating large sections of the Earth's surface. The purpose of this contribution is to give a brief overview on how remote sensing can contribute to the mapping, monitoring and modeling of mountain environments.

In general, remote sensing methods can be classified according to the platform location (space, air or ground) and according to the section of the electromagnetic spectrum covered by the sensor (visible and near infrared light, shortwave infrared, thermal infrared and microwaves) (Figure 9.1). Together with the basic sensor types 'active' (sending and receiving signals) and 'passive' (receiving signals from a natural source), a combination of the above characteristics determines to a large extent the applicability of the data and the costs, expertise and analysis equipment required.

The typical data characteristics for the three platform types are:

- *Spaceborne platforms*: high acquisition frequency of up to a few days; coverage of up to 10,000 km^2 in one view; potential coverage of the whole surface of Earth; spatial resolution from metres to hundreds of metres; decade-long time series already available; data costs in the order of 1€/km^2 or much less.
- *Airborne platforms*: low acquisition frequency of (usually) years; coverage of a few or a few tens of km^2 by one survey; study areas have to be accessible by plane or helicopter; spatial resolution from centimetres to metres; decade-long time series partially available (mapping authorities); data costs from a few euros/km^2 (data reproduction) to hundreds of euros/km^2 (original acquisition).
- *Terrestrial platforms*: very high acquisition frequency possible (hours and less for automatic systems); coverage of single points or a few hundred metres; study areas have to be directly accessible; spatial resolution from millimetres to metres; data costs from a few euros to hundreds of euros/km^2.

Depending on the sections of the electromagnetic spectrum exploited, remote sensing data are characterized as follows:

Platform:	Space		Air			Ground			
Sensor:	Optical	SAR	Optical	SAR	LIDAR	Polar survey	Terrestrial photography	Laser-scanning	SAR
Resolution:	100-1 m	100-10 m	1-0.01 m	1-0.1 m	0.1 m	0.01 m	10-0.01 m	0.01 m	0.1 m
Data:									
Digital elevation model	** Stereo photogrammtry	* SRTM **/*** Inter-ferometry	**/*** Stereo photogrammetry	*** Inter-ferometry *** Multi-frequency tomography	**/*** Laser-scanning **-*** tomo-graphy from multi-pulse	** 3D point positions	*** Stereo photo-grammetry	*** 3D point cloud	-
Vertical and horizontal terrain movement	** Repeat DEM **/*** Image matching, (image algebra)	**/*** Repeat DEM *** Differential InSAR	**/*** Repeat DEM *** Image matching	*** Repeat DEM (Differential InSAR)	**/*** Repeat DEM *** DEM matching	** Repeat measurement	*** Repeat DEM *** Image matching	*** Repeat DEM *** DEM matching	- *** Diff. InSAR
Surface cover and change	*/**/*** Multispectral segmentation and analysis *** Hyper-spectral analysis *** Thermal IR */**/*** change detection techniques	**-*** Backscatter, polarimetry, multifrequency	*/** (Multi-) spectral segmentation and analysis *** Hyper-spectral analysis *** Thermal IR */**/*** change detection techniques	*** Backscatter, polarimetry, multifrequency	*** Laser intensity, surface roughness	-	*/** Segmentation	*** Laser intensity, surface roughness	-
Atmosphere (selection)	*/**/*** cloud cover, water vapor, aerosols, etc.	**/*** rain cells, etc.	*/**/*** cloud cover, water vapor, aerosols, etc.	*** rain cells, etc.	*** water vapor, aerosols, etc.	-	*/**/*** cloud cover, etc.		-

Legend:

* *basic knowledge; simple (free) GIS and remote sensing software; cheap or free data*
** *expert knowledge; advanced GIS and remote sensing software*
*** *research institute level; sophisticated GIS and remote sensing software; expensive data / campaigns*

Figure 9.1
Overview of selected remote sensing methods suitable for mapping, monitoring and modeling of MBRs. The methods are sorted according to the platform/sensor-type used (horizontal) and the data-type needed (vertical). A rough estimation on the applicability of the methods to MBRs is also given, in terms of expertise required, costs, equipment, etc.

- *Visible light and near infrared (VNIR)*: sensors collect the reflected sunlight (passive sensing); data content similar to what is visible to the human eye; multi- and hyper-spectral sensors split the light into separate sections of the spectrum, which facilitates automatic analysis; laser sensors (light detection and ranging, LIDAR; active sensing) are used, often near infrared.
- *Shortwave infrared (SWIR)*: some surfaces show significantly different reflectivity in the SWIR compared with VNIR (for example ice and vegetation), or a high variability in reflectivity with wavelength (for instance according to the mineral composition). These properties enable automatic multi or hyper-spectral classification.
- *Thermal infrared (TIR)*: the longwave emitted radiation is indicative of the surface temperature (and thus, for example, is helpful for energy balance studies or surface characterization).
- *Microwaves*: the surface reflection of microwaves (wavelength in the order of millimetres to metres) depends on the dielectric (near-)surface properties, which are among others sensitive to roughness and humidity. Synthetic aperture radar (SAR) combines multiple radar returns to images. In contrast to optical sensors, which do not work through clouds, microwave sensors have all-weather (and day-and-night) capabilities.

(For further discussion of the above, see Figure 9.1; Schowengerdt, 1997; Lillesand and Kieffer, 2000; Campbell, 2002; Bishop and Shroder Jr, 2004).

DIGITAL ELEVATION MODELS

From a topographical point of view, large relief essentially defines mountains. Thus, digital elevation models (DEM) usually form the base data for any mountain geoinformation system and any spatial model.

If not readily available (that is, digitized from topographic maps), satellite-derived DEMs can be computed from optical satellite stereo and interferometric SAR (InSAR). Satellite stereo, using sensors such as ASTER or SPOT5, provides DEMs with a spatial resolution in the order of some tens of metres, and with a vertical accuracy ranging from some metres to a few tens of metres (Kääb, 2005). InSAR-derived DEMs have similar resolutions and accuracy, but are not limited by cloud-cover at the time of data acquisition (Toutin and Gray, 2000).

A unique DEM, which is available at no cost for the continents between 60°N and 54°S, was computed from the Shuttle radar topography mission (SRTM). The SRTM DEM has a spatial resolution of about 90 m and a vertical accuracy varying from metres to a few tens of metres (Kääb, 2005) (Figure 9.2).

Another group of DEMs with better spatial resolution and vertical accuracy is derived from aero-photogrammetry (based on analogue or digital imagery), airborne InSAR and laser scanning. Stereo-photogrammetry of air photographs is one of the best-established methods for DEM generation. DEMs produced in this way have spatial resolutions ranging from some metres to some tens of metres, and a vertical accuracy in the centimetre to metre range. Similar DEM characteristics are obtained from airborne InSAR. Airborne laser scanning offers slightly better vertical accuracy and

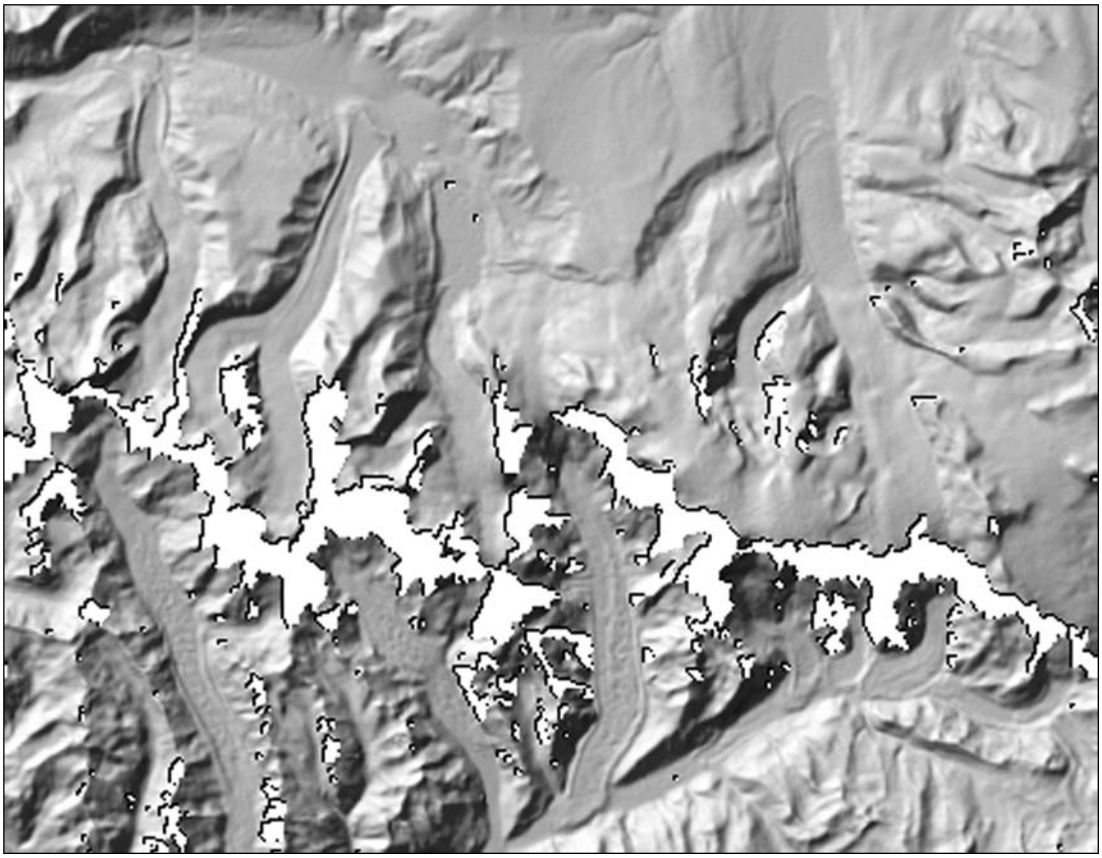

Figure 9.2 Hillshade of an approximately 40 × 30 km section of the SRTM digital elevation model in the Bhutanese Himalayas. White areas indicate data gaps. This data set has a spatial resolution of 90 m and is freely available for large parts of the continents.

a significantly higher DEM point density (around a metre) than aero-photogrammetric DEMs and airborne InSAR. If high resolution and accuracy are required, this technique offers as-yet unexplored possibilities. (For discussion of these methods, see Kääb, 2004).

InSAR and laser scanning not only provide terrain elevations, but can also be used to derive forest tomography, a valuable tool for forest and fire management. The vertical structure of the forest can be resolved if several return pulses from different heights of the vertical vegetation column are recorded, and if the signal amplitude (which varies with leaf size and density) is also analysed (Lefsky et al., 1999). Similarly, different radar wavelengths penetrate the canopy in different ways. Thus, multifrequency SAR systems are also able to resolve the vertical forest structure (Figure 9.3).

In addition terrestrial methods can be used to generate DEMs for detailed local studies. Global navigation satellite systems (GNSS, for instance the GPS) and optical levelling require direct access to the DEM points, but provide centimetre to millimetre accuracy. Remote-controlled close-range techniques are available to conduct polar surveys with laser rangers. Terrestrial laser scanning is an upcoming technology providing nearly continuous descriptions of object surface geometries.

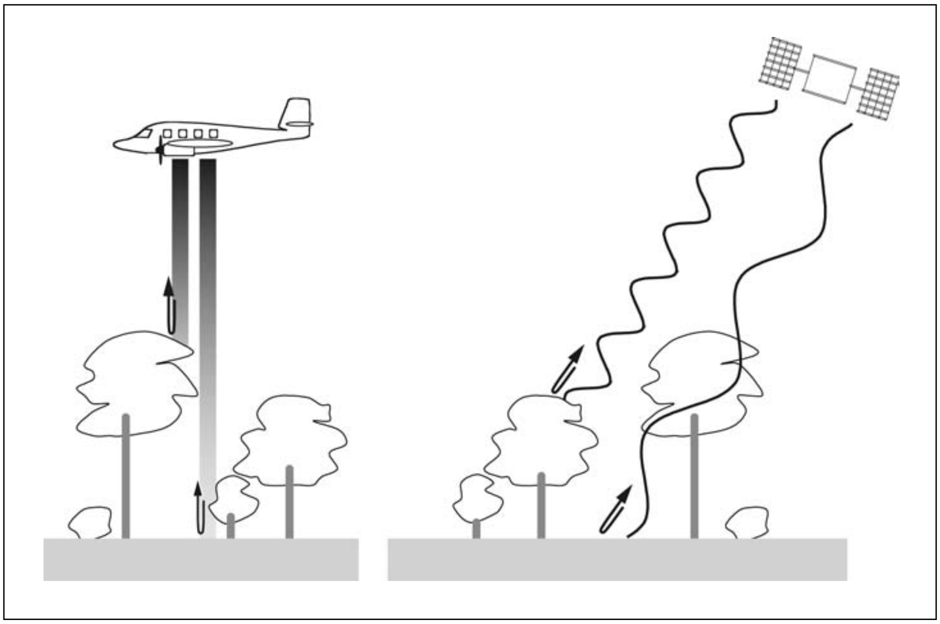

Figure 9.3 Laserscanning combined with laser intensity measurements (left) and multi-frequency synthetic aperture radar (SAR; right) allow the resolution of the vertical structure of forest (so-called tomography), a valuable prerequisite for forest and fire management.

TERRAIN MOVEMENT

Mass movement systems have particularly strong impacts in mountains and thus form important drivers of mountain landscape evolution and related processes.

Vertical changes, such as glacier thickness changes or different types of accumulation/erosion, can often be derived as differences between repeat DEMs (Kääb, 2004) (Figure 9.4). Horizontal glacier movement can under certain circumstances be measured by matching repeat satellite images, with a horizontal accuracy in the order of ten metres (Kääb, 2002). Similar techniques are applied to air and terrestrial photographs, showing horizontal terrain displacements on landslides, glaciers and rock glaciers with an accuracy of centimetres to decimetres. Surface movements on dry and open terrain can be determined with millimetre accuracy through spaceborne repeat application of InSAR (differential InSAR, DInSAR) (Strozzi et al., 2004). This technique is, for the most part, used for landslide monitoring. Classic terrestrial methods for observing the movement of single terrain points are GNSS and polar survey.

SURFACE COVER

One of the most common applications of remote sensing is for mapping and characterizing the surface cover. Manual and semi-automatic segmentation of optical images for vegetation, open water, snow, ice, rock, human interventions and so on can be based on panchromatic or colour images. Multi-spectral remote sensing makes possible the automatic classification of surface cover by analysing the variation in reflectivity with wavelength, which differs for most surface types. Besides such purely spectral classification methods, there are particularly promising spectral–

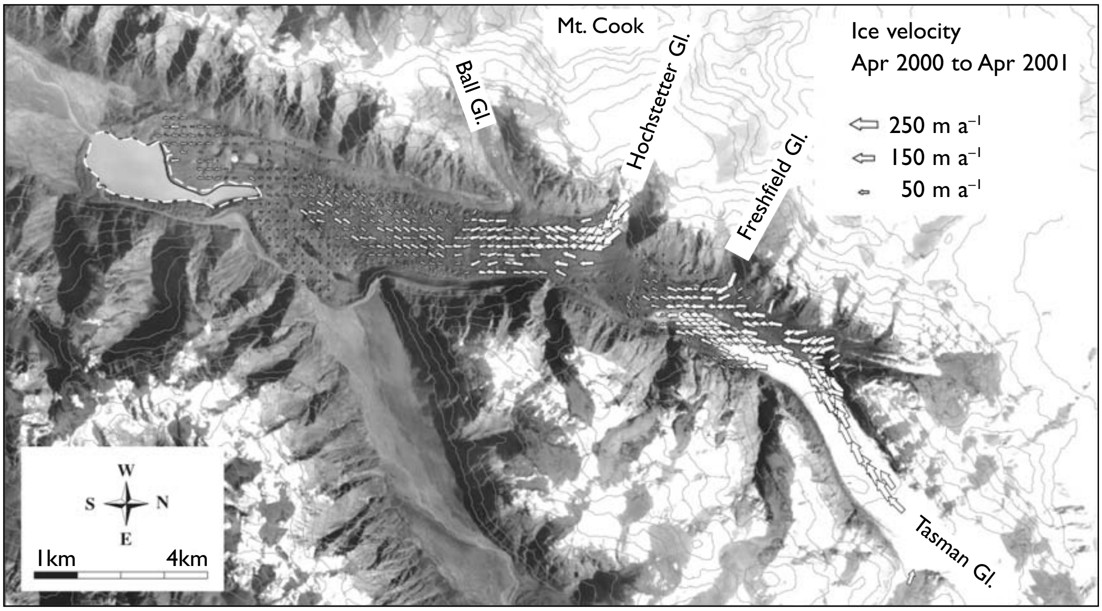

Figure 9.4 Glacier flow field of Tasman Glacier, New Zealand as derived from repeat images from the ASTER satellite sensor. Similarly, many types of high-mountain terrain movement can be investigated through optical and microwave techniques.

spatial methods, also involving for example DEMs or neighbourhood relations. Inclusion of not only VNIR data, but also SWIR and TIR in the spectral analysis allows us to distinguish and describe surface types in a way that cannot be accomplished by the human eye. Multi-spectral analysis techniques are particularly powerful (and of special interest for MBRs) if used on a series of repeated images (change detection). In this way, land-cover/use change can be detected very efficiently (Figure 9.5). (For these techniques, see Schowengerdt, 1997; Lillesand and Kieffer, 2000; Campbell, 2002; Kääb, 2004).

Another class of surface characterizations, which is very different from the optical methods described above, stems from the analysis of SAR backscatter, possibly even polarimetric or multi-frequency. These techniques are presently at the research stage and are thus much less established than multi-spectral ones (Curlander and McDonough, 1991). Similarly, using hundreds of different, very narrow spectral bands (hyper-spectral remote sensing) instead of some broad bands in multi-spectral imaging allows for much more detailed – though more complicated – surface characterization (such as vegetation, lithology and open water composition) (Schowengerdt, 1997).

In general, the accuracy of spectral or SAR-derived classifications and mappings is in the order of the applied image pixel size, ranging from metres to tens or hundreds of metres for spaceborne sensors, and centimetres to metres for airborne sensors.

REMOTE SENSING OF MOUNTAIN BIOSPHERE RESERVES: A PROPOSAL

The possible applications of remote sensing to mountain environments, and UNESCO's MBRs in particular, are too manifold to be listed here. They depend largely on the human, technical and

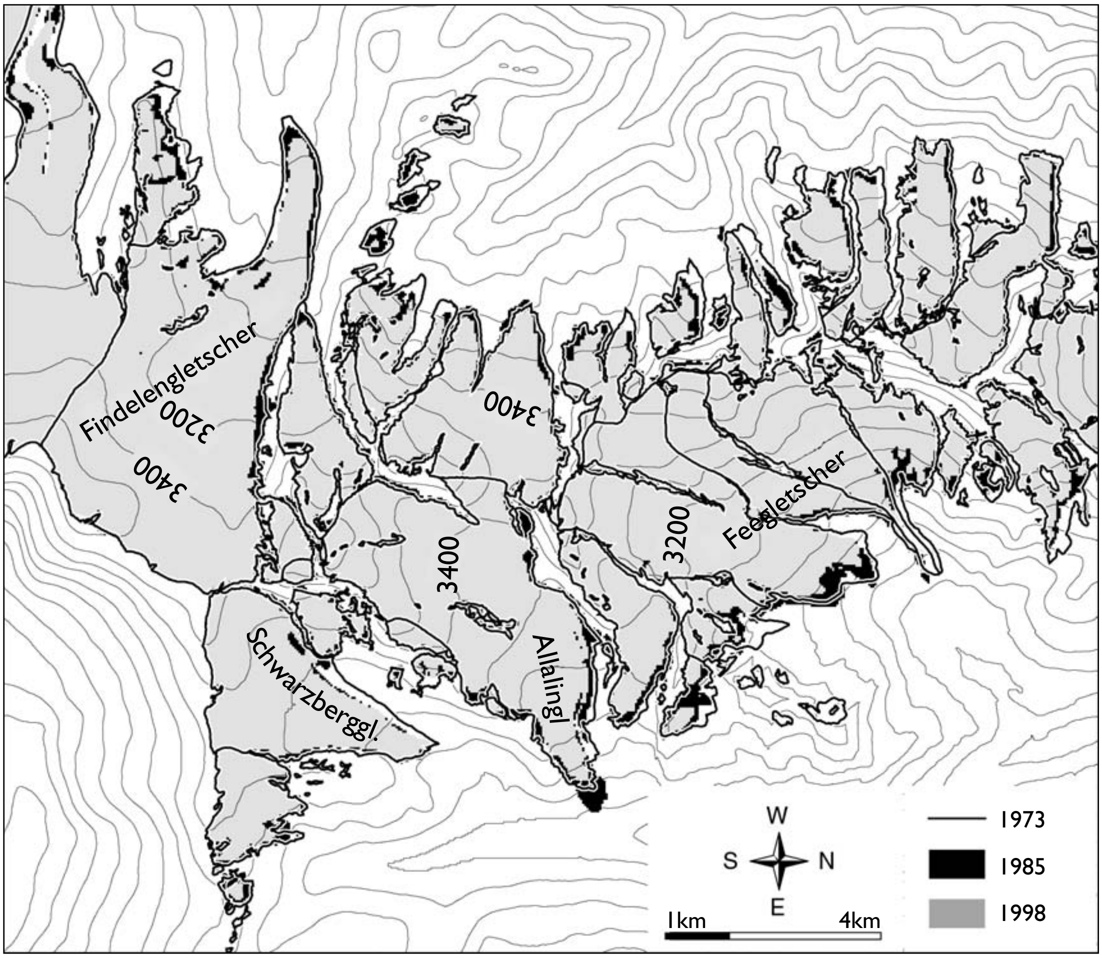

Figure 9.5 Glacier change in the Mischabel range, Swiss Alps, derived from a 1973 inventory based on maps and air photos, and satellite imagery of 1985 and 1998. Repeat satellite imagery offers a simple and effective method for detecting many kinds of land-cover change.

financial resources provided, as well as the knowledge level available to the individual MBRs. Focus should therefore be on establishing a minimum but global set of data, methods and expertise with respect to remote sensing application in/to MBRs. The potential aim of such a strategy is, to some extent, to obtain a standardized and thus compatible set of data, methods and results, thus facilitating inter-MBR knowledge-sharing and support. The latter can help to make remote sensing a sustainable part of MBR mapping, monitoring and modeling. First steps towards the proposed strategy are (1) a representative set of pilot studies, (2) a survey of needs, and actual GIS and remote sensing resources existing in the MBRs, (3) selection of sophistication levels (*, **, ***, etc.; see Figure 9.1), and (4) selection of related sets of data and methods.

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Part II

Biosphere Reserves

10 *Recent Changes in Species Composition and Species Richness of Alpine Grasslands in Berchtesgaden Biosphere Reserve and National Park*

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ABSTRACT

To determine whether the composition of alpine calcareous grasslands (*Carex sempervirens*, *Carex firma* communities) has changed during the last twenty years, historical plant *relevés* (from Herrmann et al., 1988) in the Berchtesgaden National Park were revisited in 2003. The aim of the study was to identify and interpret floristic changes during this time period. The question as to whether the rise in temperature during the last twenty years was the main cause for the changes observed was particularly emphasized.

Since 1988 the average number of species per *relevé* has increased significantly by eleven species in both plant communities. This rise is not caused by the immigration of new species but by an increase in the frequency of the species that already existed in 1988. A trait analysis showed that species which have clearly increased in their frequency tend to be of small growth, have chiefly generative reproduction and have light seeds. In the *Carex firma* community the species are also characterized by a late start in flowering. Altogether, they are typical alpine plant species.

As possible reasons for the changes observed, different exogenous and endogenous factors were discussed. The floristic changes can best be explained by global warming. Natural succession and nitrogen deposition, as well as changed land use practices, obviously play a less important role.

KEY WORDS

Alpine vegetation, site re-visitation, semi-permanent plots, monitoring, species composition, species richness, *Carex firma* community, *Carex sempervirens* community, global warming, Berchtesgaden National Park.

INTRODUCTION

By repeated documentation of vegetation stands (site revisitation), temporal changes of vegetation can be shown and a hypothesis of their causes can be made. Therefore, well-documented, historical vegetation surveys are of very high value for actual global change research (Körner, 1999).

Alpine vegetation stands are – like almost all vegetation types in the world – undergoing temporal changes. These changes can be induced by exogenous factors (that is, changes in climate, nitrogen deposition or land use) as well as by endogenous factors (that is, within the plants themselves).

Since alpine vegetation is limited by low temperatures, the actual research focuses on global warming as the main cause for proven floristic changes (that is, increases in species richness and the immigration of species from lower altitudes (Hofer, 1992; Grabherr et al., 1994; Klanderud and Birks, 2003; Burga et al., 2004).

In the past, numerous plant *relevés* have been carried out in the area of the Berchtesgaden National Park, which are suitable for repeated surveys (Herrmann et al., 1988). Out of this data pool, twenty-five *relevés* of the *Carex sempervirens* community and twenty-three of the *Carex firma* community were chosen as a reference. These *relevés* were revisited in 2003, using the same methods as in 1988.

The data for the two years were compared in order to study the following questions:

- Are there changes in species composition between the two years?
- Can a rise in the number of species be ascertained?
- Can the changes in vegetation be explained by exogenous and/or endogenous factors?
- Is the rise in temperature during the last two decades the main cause for the changes?

STUDY SITE

The study was carried out in the alpine zone of Berchtesgaden National Park. The National Park (also a UNESCO biosphere reserve) is situated in Bavaria, southeast Germany. The park is located in the Northern Calcareous Alps and the bedrock in the study area consists of limestone and dolomite (Langenscheidt, 1994). Corresponding to the geological conditions, calcareous raw soils and different types of rendzina are found.

The studied plots are located in the northeast of the Park, between the Hohem Brett (2,331 m a.s.l.) and the Kahlersberg (2,350 m a.s.l.), ranging from about 1,800 to 2,350 m above sea level. The mean annual temperature in this area ranges between 0°C and 4°C. The adiabatic lapse rate of atmospheric temperature is about 0.4 K per 100 m of altitude.

As a result of the decrease in temperature as altitude increases, the length of the growing season (number of days per year with a mean temperature of more than 5°C) declines from almost five and a half months at 1,800 m to two and a half months at 2,400 m above sea level. The mean annual precipitation in the area is between 1,925 and 2,100 mm. Maximum precipitation occurs in July and the minimum in January (Konnert, 2001).

Vegetation

The study was carried out in stands of the *Carex sempervirens* and the *Carex firma* communities. These represent the most frequent vegetation types of alpine calcareous grasslands.

The stands of the species-rich *Carex sempervirens* community are found in the more favourable locations of the alpine zone (deep soils, high sun radiation, higher temperatures) whereas the species-poor *Carex firma* community colonizes more extreme sites (initial soils, low sun radiation and temperature, strong winds; Reisigl and Keller, 1994; Rösler, 1997).

Methods

For the site revisitation, plant *relevés* of the *Carex sempervirens* and *Carex firma* community (from Herrmann et al., 1988) were chosen. These *relevés* were conducted in the context of the MAB-6 project 'Ökosystemforschung Berchtesgaden' between 1984 and 1988. The positions of the plots were marked on a topographic map and could therefore be re-identified in the countryside. For the selection of the plots, the site descriptions (altitude, exposition, inclination, coverage of vegetation) and additionally the species composition of the historical vegetation samples were taken into account (semi-permanent plot approach; Schwabe et al., 1989; Hagen, 1996).

The actual and the historical *relevés* were carried out using the Braun-Blanquet approach (Braun-Blanquet, 1964). The plot sizes of the historical study have been retained unchanged. All vascular plants were recorded; as in Herrmann et al.'s study (1988), cryptogams were not considered. Species and subspecies which were difficult to identify were pooled to superordinate species groups.

To enable their future use as real permanent plots, the corners were marked with magnets and mapped by means of GPS. In the future, the exact coordinates of each plot can be recalled via the vegetation database of Berchtesgaden National Park.

The statistical evaluation of the data is based on a comparison of the historical and present *relevés*; the t-test was used to compare the samples (given normal distribution). For deviation from the normal distribution the U-test was carried out. The statistical evaluation was supported by SPSS 12.0 for Windows.

A trait analysis was conducted using data from Rothmaler (1995) and Klotz et al. (2002).

RESULTS

Species turnover and dynamics

In both communities, changes in the species pools occurred (Figure 10.1). Due to species turnover the community-species pool of the *Carex sempervirens* community decreased from 157 to 149 species, whereas the community-species pool of the *Carex firma* community increased from 100 to 113 species. Twenty-one new species (not recorded by Herrmann) were found in the *Carex sempervirens* and twenty-seven in the *Carex firma* community. In contrast, twenty-nine species (*Carex sempervirens* community) and fourteen species (*Carex firma* community) could not be found in 2003. It must therefore be assumed that most of these species are of only scarce frequency in the *relevés* of 1988 and 2003.

Figure 10.1 Changes in the community-species pools since 1988

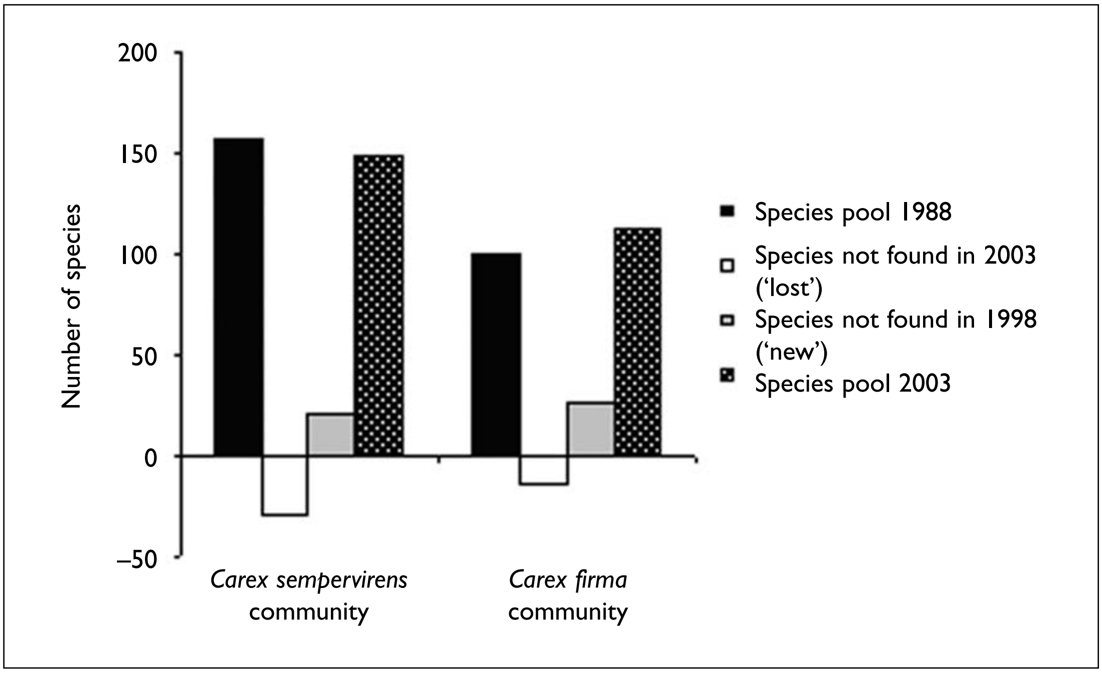
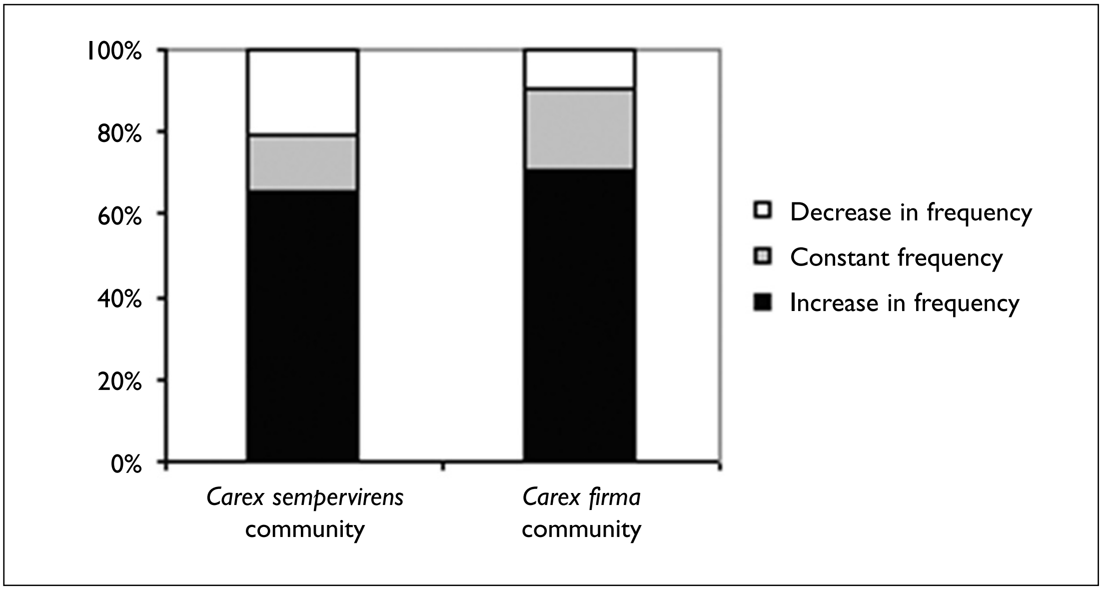


Figure 10.2 Changes in the frequency of 'continuous species' (species that occur in 1988 as well as in 2003) in the *Carex sempervirens* and the *Carex firma* community



Of the 128 (*Carex sempervirens* community) and the 86 (*Carex firma* community) species that occurred in both 1988 and 2003 ('continuous species'), over 60 per cent have increased in their frequency (Figure 10.2). The remainder of the species show either a constant frequency or a decrease in frequency. Overall, in both communities increases in frequency are clearly more pronounced than decreases.

Table 10.1 shows the species that show significant changes in frequency since 1988. In the *Carex sempervirens* community more species show a significant change in frequency than in the *Carex firma* one. Overall more species show a significant positive change in frequency than show a negative one. Comparing both communities, it can be seen that some species increased their frequency in the *Carex sempervirens* community as well as in the *Carex firma* community (*Agrostis alpina, Campanula scheuchzeri, Euphrasia officinalis agg, Phyteuma orbiculare*). Apparently these species were able to increase their frequency within the alpine grasslands regardless of the vegetation type in which they occur.

Tests were carried out to determine whether species with a clear increase in frequency (by 20 per cent or more) – the so-called 'winners' – differed from species which did not change their frequency so much (a difference of 20 per cent or less) in terms of their generative or reproductive traits. Species with a clear decrease in frequency were not taken into account, because of their scarce number.

In the *Carex sempervirens* as well as in the *Carex firma* community the 'winners' are characterized by a small plant height, a tendency to generative reproduction and a light seed mass (Figure 10.3). Obviously the 'winners' are mobile species without a pronounced place-holder strategy. In the *Carex firma* community the species with a clear increase in frequency are also characterized by a late onset of flowering.

To test if the 'winners' are species of lower altitudes or typical alpine species, the upper limit of the altitudinal distribution in the Berchtesgaden National Park was also taken into consideration (Hecht and Huber, 2002). The comparison shows that the 'winners', on average, have a higher upper limit than the 'neutral' species (*Carex sempervirens* community: 2,378 versus 2,245 m a.s.l.; *Carex firma* community: 2,379 versus 2,321 m a.s.l.). Therefore the hypothesis that the 'winners' are species of lower altitudes cannot be confirmed.

Species richness

Since 1988 the mean number of species per *relevé* has increased significantly, by eleven species in each community (Table 10.2). This is an increase of 27 per cent in the *Carex sempervirens* community and 42 per cent in the *Carex firma* community.

A change in mean species richness can be caused by:

1. An enrichment/reduction of the community-species pools (appearance of new species/disappearance of former species).
2. An increase/decrease in the frequency of 'continuous species' (those recorded in both 1988 and 2003).

By determining the extent of the two effects (1: species pool effect; 2: frequency effect), it can be seen that in both communities the influence of the frequency effect is clearly greater than that of the species pool effect (Figure 10.4). In both communities increases in frequency affected the mean number of species in a positive way, whereas changes in the community-species pools led to either a decrease (in the *Carex sempervirens* community) or an increase (*Carex firma* community) in mean species richness. Overall, the observed increase in mean species richness is mainly caused by increases in the frequency of 'continuous species' and not by an enrichment of the community-species pools.

Table 10.1
Species with significant changes in the *Carex sempervirens*-community (left) and the *Carex firma*-community (right)

***Carex sempervirens* community (N = 25)**					***Carex firma* community (N = 23)**					
Species	**Frequency** (number of plots)				**Species**	**Frequency** (number of plots)				
	1988	**2003**	**U**	**Sign.**		**1988**	**2003**	**U**	**Sign.**	
					Asplenium viride	0	4	218.5	*	Species not found
					Minuartia sedoides	0	18	57.5	***	in 1988 ('new')
Ligusticum mutellinoides	5	0	250.0	*	*Euphrasia officinalis*	4	0	218.5	*	Species not found
Veronica aphylla	4	0	262.5	*						in 2003 ('lost')
Aconitum napellus	3	13	187.5	**	*Agrostis alpina*	4	17	115.0	***	Continuous species with
Agrostis alpina	16	25	200.0	**	*Arabis bellidifolia*	4	11	184.0	*	increased frequency
Alchemilla species	7	14	225.0	*	*Campanula cochleariifolia*	1	6	207.0	*	
Aster alpinus	1	6	250.0	*	*Campanula scheuchzeri*	1	14	115.0	***	
Biscutella laevigata	12	21	200.0	*	*Euphrasia salisburgensis*	1	20	46.0	***	
Campanula scheuchzeri	14	25	175.0	***	*Phyteuma orbiculare*	2	9	184.0	*	
Carex firma	12	21	200.0	*	*Saxifraga aizoides*	2	8	195.5	*	
Chamorchis alpina	1	7	237.5	*						
Euphrasia officinalis	7	20	150.0	***						
Festuca quadriflora	15	23	212.5	*						
Gentiana vema	12	19	225.0	*						
Gentianella aspera	10	17	225.0	*						
Helianthemum nummularium	13	22	200.0	*						
Hutchinsia alpina	3	9	237.5	*						
Ligusticum mutellina	10	19	200.0	*						
Lotus comiculatus	6	15	200.0	*						
Myosotis alpestris	8	16	212.5	*						
Nigritella nigra	11	18	225.0	*						
Phyteuma orbiculare	18	25	225.0	*						
Soklanella alpina	8	19	175.0	**						
Thesium alpinum	2	10	212.5	*						
Viola biflora	2	10	212.5	*						
Carex atrata	9	2	225.0	*						Continuous species with
Helianthemum alpestre	19	5	137.5	***						decreased frequency

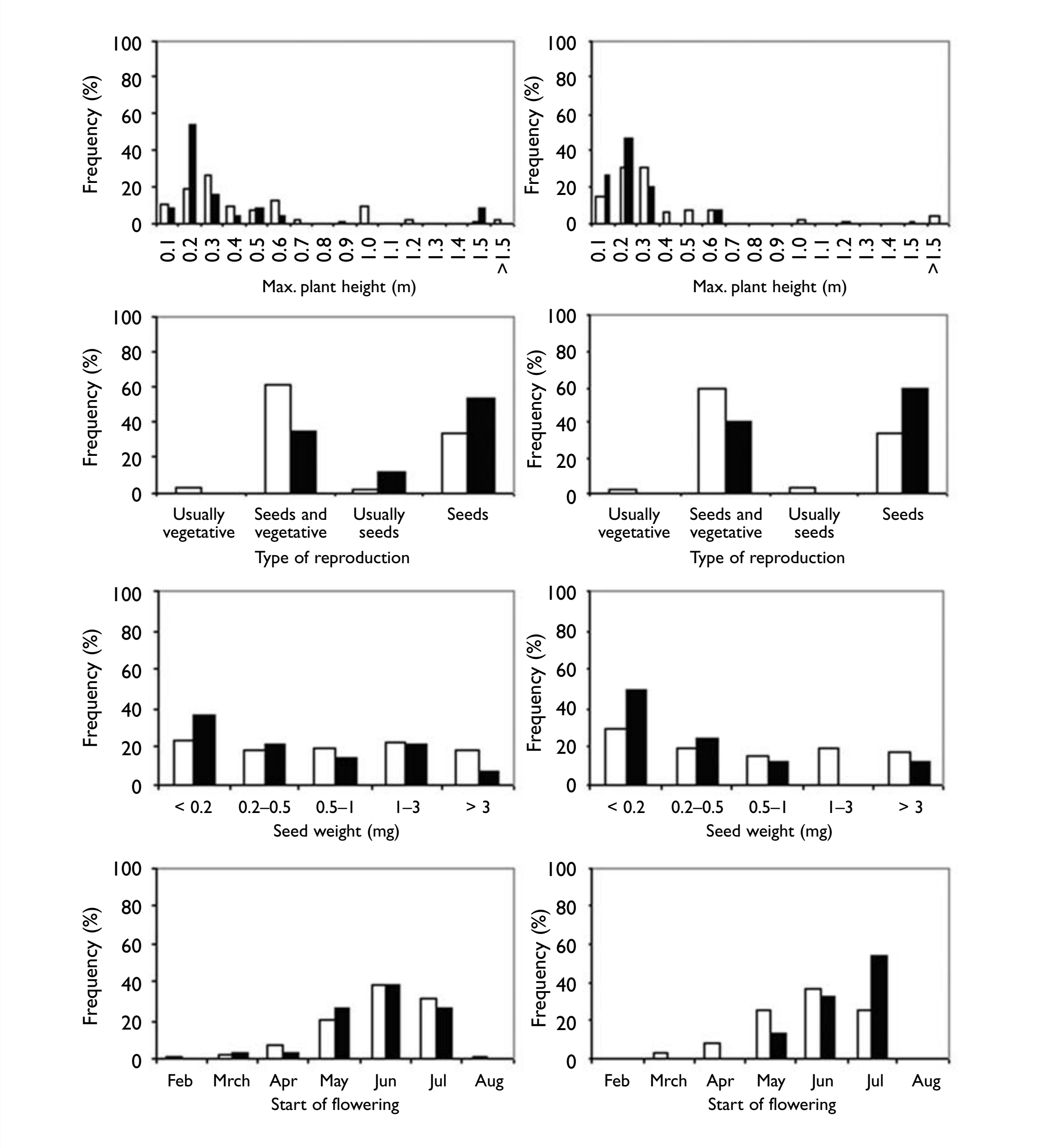
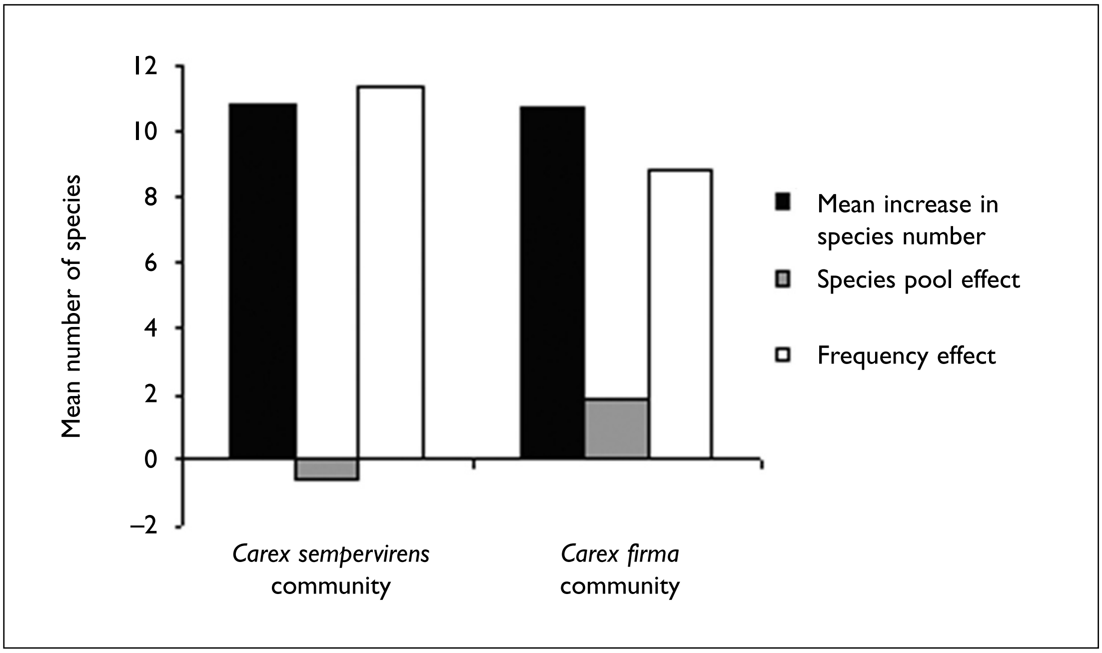


Figure 10.3 Comparison of the selective vegatitive and reproductive traits of species with a clear increase in frequency (≥ 20 per cent; black bars) and such without a pronounced change in frequency (< ±20 per cent; white bars). the illustrations on the left side describe the *Carex semper-virens* community and the ones on the right side the *Carex firma* community. Data from Rothmaler (1995) and Klotz et al. (2002).

Table 10.2 Comparison of the mean number of species from 1988 and 2003

Community	Year	N	Mean	Standard deviation	Difference	T	Significance
Carex sempervirens community	1988	25	39.6	8.1	10.8	–4.758	***
	2003	25	50.4	8.0			
Carex firma community	1988	23	25.7	6.4	10.7	–4.710	***
	2003	23	36.4	8.9			

Figure 10.4 Influence of the species pool effect and the frequency effect on the mean increase in species number



DISCUSSION

Each vegetation stand is an expression of a dynamic balance between different endogenous and exogenous factors (Dierschke, 1994). If these factors change over the course of time, the consequence is a change in the composition of species. In the following sections, possible reasons for the observed changes are discussed. Therefore several endogenous as well as exogenous factors are taken into account.

Global climate change

In the last twenty years, distinct changes of climate can be proved to have taken place in the alpine zone of the Northern Calcareous Alps. Since 1980 the mean annual temperature at the Zugspitze (2,964 m a.s.l.) increased by 1.9°C, and the length of the growing season extended by almost three weeks. Accordingly, the duration of snow cover decreased. Precipitation showed strong fluctuations between the years, but on the whole it stayed constant (Data: Deutscher Wetterdienst). Thus direct and indirect temperature factors in particular have shown major changes during the last two decades.

Since alpine ecosystems are limited by low temperatures, changes due to global warming are expected to be particularly marked in these regions (Theurillat and Guisan, 2001). That alpine vegetation responds to temperature enhancement has already been proved in several warming experiments (Stenström et al., 1997; Arft et al., 1999; Gugerli and Bauert, 2001; Kudo and Suzuki, 2003). These studies show that the growth and reproduction of different alpine species is stimulated by warming, and their development (phenology) is accelerated.

Herbaceous species react more strongly than woody ones (Arft et al., 1999). Changes in vegetation structure and therefore in competition are proven (Kudo and Suzuki, 2003). Species that benefit from global warming by growth stimulation, higher reproduction and accelerated development should, in the long run, increase in their frequency (Wagner and Reichegger, 1997). The proven increases in frequency and thus species richness are in line with the above-mentioned observations. Also, consistent with the results of the temperature enhancement experiments, herbaceous species react more strongly than woody species: among all species with a significant increase in frequency, only one woody species could be found (*Helianthemum nummularium*).

An extension of the growing season is also directly linked to warming (Menzel and Fabian, 1999; Theurillat and Guisan, 2001). It is assumed that late-flowering species, so-called 'seed riskers' (Molau, 1993), benefit from a lengthening of the growing season whereas early flowering species, so-called 'pollen riskers' do not (Theurillat and Guisan, 2001).

In the context of a warming experiment, Totland (1997) has shown that there is earlier flowering as well as a higher reproduction and growth under warmer conditions for the late-flowering species *Leontodon autumnalis var. taraxaci*. In fact in the *Carex firma* community the 'winners' are characterized by late flowering; for the *Carex sempervirens* community this correlation cannot be shown. Since the duration of the growing season is longer in the *Carex sempervirens* than in the *Carex firma* community, a lengthening of the growing season is especially important for late-flowering species in the latter community.

The species response to warming can be due to direct temperature effects (that is, higher photosynthesis) or indirect ones (that is, better availability of nutrients through increased litter decomposition and nitrogen mineralization; Rustad et al., 2001). In fact, an increase in nitrogen mineralization has been demonstrated in several warming experiments (for an overview see Rustad et al., 2001). Under low nutrient conditions the mineralized nitrogen is indeed incorporated in the plants; there is no fixation of the nitrogen by micro-organisms (Jonasson et al., 1999). Since alpine calcareous grasslands are a comparatively nutrient-poor ecosystem, indirect temperature effects could play a major role.

Changes in the species composition of alpine and nival vegetation have for a long time been attributed to global warming. Braun-Blanquet (1957) observed an increase in species richness on the summit area of Piz Linard (3,414 m a.s.l.) between 1835 and 1947 and explained its association to climatic warming. Also Hofer (1992); Grabherr et al., (1994); Klanderud and Birks, (2003); and Burga et al., (2004) have found an increase in species richness in alpine and nival ecosystems, and mention global warming as the main reason for this.

In these studies the rise in species richness is explained by an upward movement of species from lower altitudes, whereas the present study indicates that the increase in mean species richness is mainly caused by an increase in frequency of species already found in 1988.

To test if the observed floristic changes can indeed be explained by warming, a temperature enhancement experiment is being carried out in addition to the revisitation of historical *relevés*. The experiment is also located in the alpine zone of the Berchtesgaden National Park within the *Carex sempervirens* and the *Carex firma* communities.

Nitrogen deposition

Nitrogen deposition is another possible reason for floristic changes in alpine vegetation stands. In different nitrogen fertilizer experiments, increases in biomass production and growth were found (Hegg et al., 1992; Körner et al., 1997; Theodose and Bowman, 1997). These studies showed that grasses in particular respond to fertilization. Changes in vegetation structure and species composition due to nitrogen fertilization were also shown.

In the alpine zone of the Rocky Mountains, Theodose and Bowman (1997) conducted a fertilizer experiment in a nutrient-poor, dry grassland and proved that nitrogen fertilization leads to an increase in species diversity. But considering that the Berchtesgaden area, with 5 kg N/ha/y, actually has the lowest amount of nitrogen deposition in Bavaria (and this has even been falling since the early 1990s; Bayerische Landesanstalt für Wald und Forstwirtschaft, LWF, 2004), it seems unlikely that nitrogen deposition is the main cause for the changes observed.

Land-use changes

Changes in land use also can cause floristic changes in alpine vegetation (see Körner, 1999; Tasser and Tappeiner, 2002). In Berchtesgaden National Park, pasture grazing, hunting and tourism are of importance in this regard. The mountain pastures in the study area were abandoned a long time ago: the Kahlersberg and the Seelein-Alm in 1915 and the Reinersberg-Alm in 1925 (Springer, 1997). According to Spatz (1980), alpine grasslands are in general only slightly influenced by pasture grazing and the vegetation stands show a rapid regeneration after the cattle have gone. Thus ongoing redevelopment cannot be the cause for the observed changes in species composition, particularly because only a few plots are located in the area of former mountain pastures.

For about eight years, hunting has been stopped in the core zone of the Berchtesgaden National Park. It is possible that the populations of chamois and ibex have increased during this period, giving them an increased influence on vegetation. But so far no clear changes in the population densities are apparent (Franz, personal communication). Furthermore it is known that grazing in poorly productive ecosystems decreases species richness (Proulx and Mazumder, 1998; Austrheim and Eriksson, 2001), and thus an increased grazing pressure cannot explain the increased numbers of species found.

Any influence of tourism on vegetation can be discounted, since all the survey plots are situated away from footpaths.

Endogenous factors

Medium to long-term changes in vegetation can be accounted for not only by exogenous factors but also by the vegetation stands themselves (endogenous factors). The typical progressive succession from scree-vegetation to initial and later mature grasslands in mountain regions is an example of a predominantly endogenous process (Thiele, 1978). Several studies have revealed that a progressive succession leads to an increase in species diversity (Begon et al., 1991). Therefore the observed increase in species richness could also be the result of natural vegetation development (endogenous succession). The fact that the majority of the species with a significant increase in frequency are typical late-successional species (Beck, 2004; Krenzer, 2004) confirms this assumption. However, the period of time in which such changes usually occur has to be considered.

Braun-Blanquet (1964) analysed the vegetation development on limestone and dolomite scree at the Ofenpass (1,800–2,000 m a.s.l.). He calculated an average time period of about 200 years for the succession from initial to mature grasslands. Kudernatsch (2001) provides information about the rate of vegetation development in the Wimbachtal in the area of Berchtesgaden National Park (1,000–1,500 m a.s.l.). There the succession from initial to mature *Carex firma* grasslands takes about 100 years. In this time the mean number of species increases by five. Grabherr (2003) also estimates periods of more than 100 years for the regeneration of alpine grasslands once they have been disturbed.

The period of about twenty years therefore seems too short a timespan to explain the observed changes by endogenous processes alone, particularly at altitudes of over 2,000 m a.s.l., where the development of vegetation is probably even slower than in the cited examples. On the other hand, it seems possible that global warming and nitrogen deposition are accelerating natural succession at the present time (Klanderud and Birks, 2003).

CONCLUSIONS

Considering all exogenous factors, land-use changes are of least importance in terms of noticeable change. Tourism, the abandonment of mountain pastures and recently changed hunting practices cannot explain the floristic changes since 1988.

Nitrogen deposition can change alpine vegetation stands in different ways, but because of the low deposition rates in the Berchtesgaden area it seems unlikely that nitrogen is the main reason for the changes observed.

Considering all exogenous factors, global warming is considered to be the most likely driving factor for the observed changes in species composition and richness. Since 1988, air temperature is the factor that has changed most. It is most probably the effects of global warming on alpine and nival vegetation, as described in the literature, that are responsible for the noticeable floristic changes, particularly as low temperatures are the limiting factor in alpine ecosystems.

Endogenous processes (progressive succession) could explain some of the changes, but given the historical rates of succession, the timespan of the present study seems to be too short to explain the observed changes by these processes alone. On the other hand it is possible that global warming and nitrogen deposition are now accelerating natural succession.

ACKNOWLEDGEMENTS

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11 Global Change Impacts and Management Challenges in Changbaishan MBR

Li Yang, Mingcai Liu, Changbaishan MBR

Changbaishan Mountain Biosphere Reserve (MBR) is a typical forestry and mountainous ecosystem with alpine lakes and different zones of vegetation extending from the temperate to the polar zone, and is therefore a good area for monitoring.

The changing climate and the negative influence exerted by human beings are having both visible and invisible impacts on mountainous areas and their delicate ecosystems, and scientists, researchers and MBR managers need to collaborate in order to both project and implement more effective methodologies to monitor these impacts and predicted scenarios.

The visible impacts and hazards in Changbaishan MBR that have occurred in the last twenty years include wild forest fires, landslides, typhoons and increasing land use by local people near the reserve. There are also some in-depth changes in the four vegetation zones within the complex ecosystem of Changbaishan MBR, with some vegetation and wildlife dynamics being affected by changes in climate and habitat. More research needs to be carried out on these developments.

The incidence of forest fires is growing, largely because of climatic changes. The dry season is getting longer and warmer than before; in spring, the snow melts earlier and the autumn comes later than in the 1970s and 1980s. There are also other reasons, such as the increasing influence of human activities.

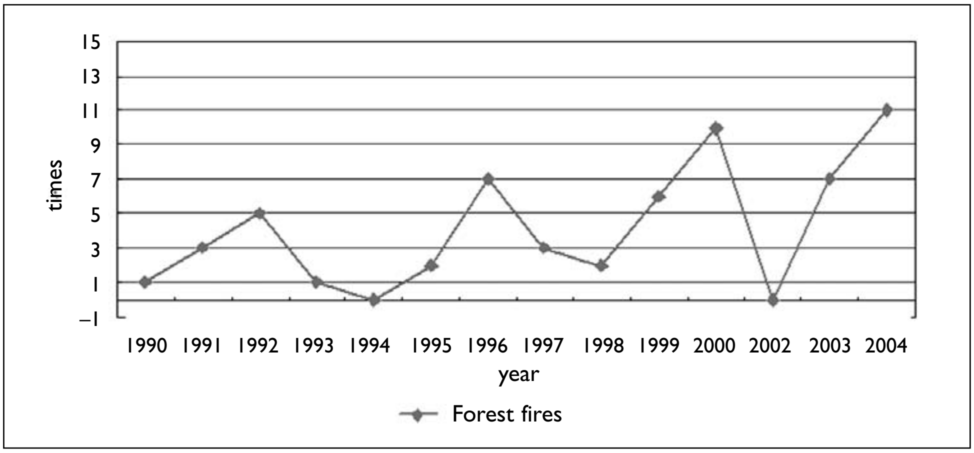

Figure 11.1 Number of forest fires in Changbaishan BR, 1990–2004

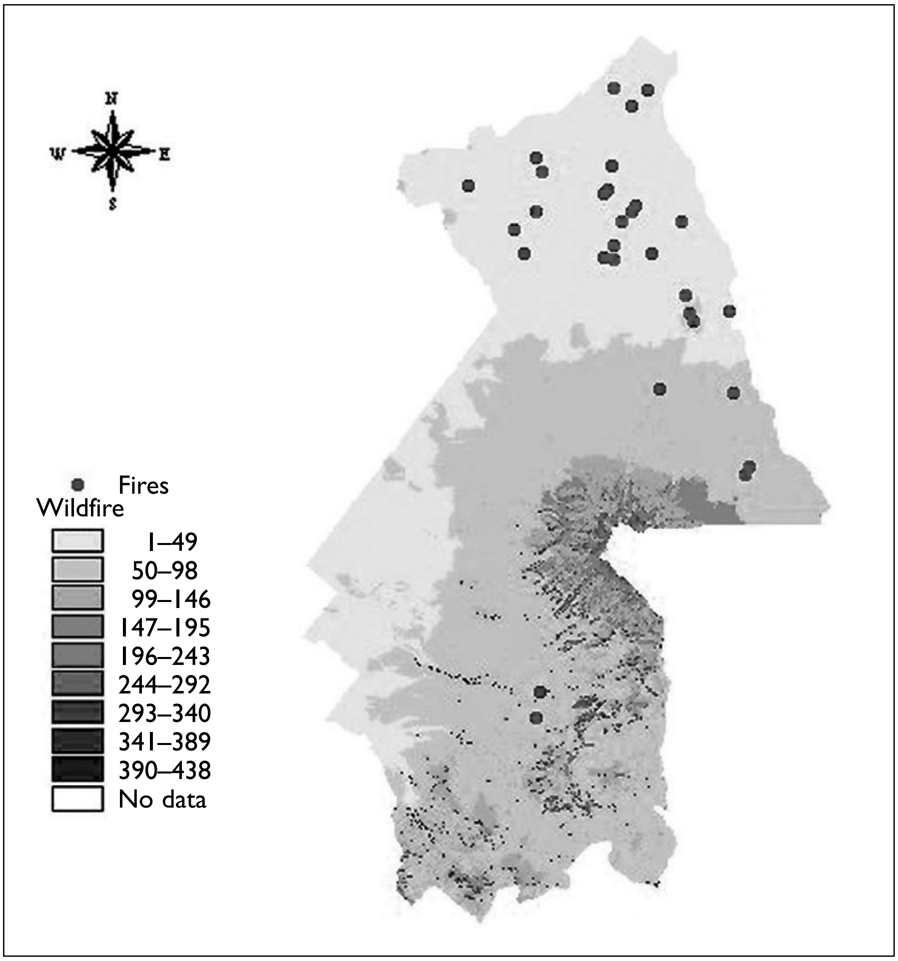

Figure 11.2 Locations of forest fires

Landslides occur almost every year during the rainy season (July–August). These have always resulted in the destruction of roads and tourist facilities, but no historical records are available. Figures 11.3 and 11.4 are photographs of landslides that have occurred in the last five years. In the past, tourists were injured almost every year by rocks dislodged by wind erosion or by running water during the rainy season.

Increasing land use is also an important focus in Changbaishan MBR, which was delimited in 1961 and designated a BR in 1979. Human activities and construction are strictly prohibited, except for a few tourist hotels and administrative buildings, which are located outside the reserve. However, logging, farming and construction are continuing, while the residential area is growing year after year as the population increases, posing a potential threat to the future of the reserve. We can see the land-use changes by comparing the satellite images from 1986 and 2000 shown in Figures 11.5 and 11.6. The white areas indicate the extent of human land use in and outside the reserve. When Figure 11.6 (2000) is compared with Figure 11.5 (1975), the increase in land use is obvious. This land-use trend is continuing.

Figure 11.3
Landslide (1)

Figure 11.4
Landslide (2)

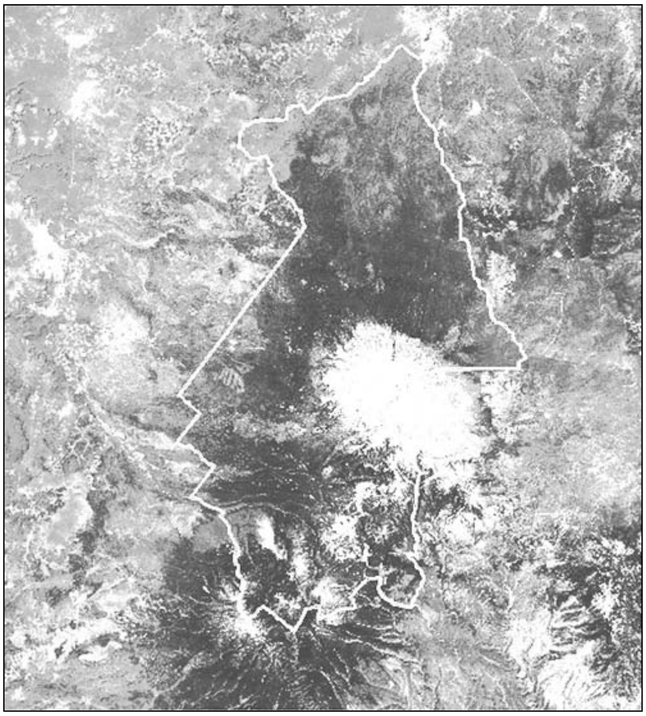

Figure 11.5
Satellite view of land use, 1975

Figure 11.6
Satellite view showing changes in land use by 2000

Typhoons sometime strike Changbaishan MBR. The most serious event happened in 1986 when an area of over 10,000 hectares was devastated, inflicting huge damage on the most primeval forest areas. In the two decades since then, through natural succession, more than half of the ruined area has been covered by new growth with trees such as poplar and willow. However, the succession of other areas is slow and difficult, with land and grassland still exposed. In 1999, a project to regenerate the forest in these areas artificially was launched and achieved some success.

Figure 11.7 Effects of typhoon damage on a once-wooded area

To protect and manage the MBR more effectively, it is very important to monitor changes in climate, hydrology, the ecosystem and human activities. Climate modeling, ecosystem modeling and remote sensing would thus be particularly useful to the managers in Changbaishan.

12 *Global Changes in Katunskiy Biosphere Reserve: Drivers and Responses*

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ABSTRACT

Katunskiy Biosphere Reserve (BR) is located in the highlands of the Altai mountains near the borders of four countries: the Russian Federation, Kazakhstan, Mongolia and China (see Figure 12.1). However, it occupies a 'transboundary' position in a more than merely political sense, for the southern part of the Altai is a global watershed for Asia. Different tectonic structures and geological history have led to the formation of a wide diversity of geological complexes and relief types from flat intermountain valleys (800–1,000 m above sea level) to high mountain ridges (up to 4,500 m). By virtue of its geographic position and the particular way its natural landscape has evolved, this territory is situated at the junction of different floristic subkingdoms: Boreal and Tethyan (Ancient-Mediterranean) and Holarctis (Takhtajan). This results in a great diversity of highly contrasting species and plant communities (Kamelin, 1998). These combined conditions produce the uniqueness and landscape diversity of the Altai. This region is one of 200 WWF ecoregions and is being designated as a UNESCO World Heritage Site.

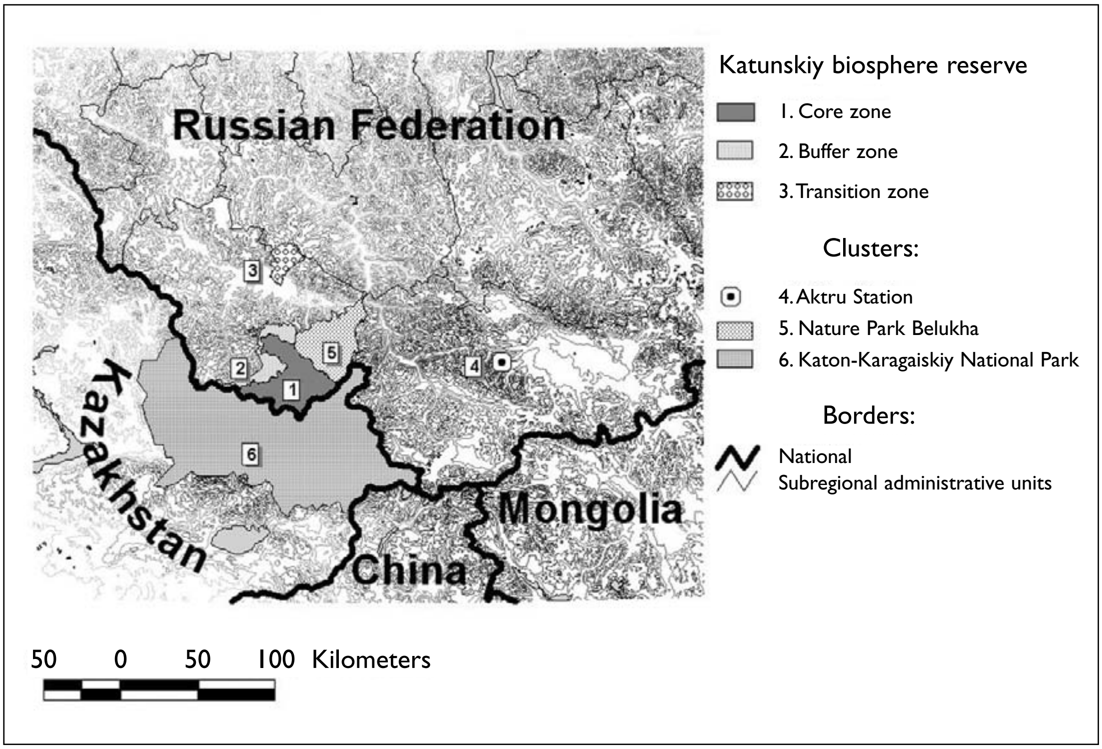
The cultural and historical dimensions of this territory are also diverse. For example, there are several ethnic communities within the Altai Republic: more than ten groups of native Altaians, as well as Russians, Kazakhs and so on. Its lengthy cultural history is displayed in many historical monuments of different eras: stone sculptures, tombs, petroglyphs and so on. Among the most interesting archaeological artefacts are the frozen tombs, which include unique remnants of Pazyryk culture dating from the fourth to second centuries BC. In the light of global changes it is extremely important to undertake a special investigation of these unique archaeological complexes so as to ensure their conservation.

All these characteristics allow us to suppose that for global change research we should consider Katunskiy BR in a wider context, taking into consideration the possibility of including other important aspects for research purposes.

STRUCTURE OF KATUNSKIY BR

Katunskiy BR was founded in 1991, primarily for the conservation of the snow leopard (*Uncia Uncia*) population and habitats, and was designated as a UNESCO Biosphere Reserve in 2000.

Figure 12.1 Altai transborder region



The core and buffer zones are located at the middle and high levels of the Katunskiy ridge, covering its northern and southern slope expositions (see Figure 12.2). They vary in altitude from 1,850 up to 3,280 m above sea level.

There are a number of popular tourist itineraries within the buffer zone. Tourism here is organized: various paths have been constructed for tourists and the routes are equipped with services and utilities. BR staff regularly monitor the condition of these paths.

Some parts of the buffer zone are used by local dwellers, who collect medicinal plants and other non-timber products. There are also several private apiaries.

Within the buffer zone there is a geographic station, 'Multa', where various monitoring and research activities are carried out. The main areas of study include lake investigations, vegetation and bird population dynamics, and geomorphic processes. Glaciological monitoring and investigations will be recommenced in 2005.

The landscapes of the Terecta transition zone contrast with the core and buffer zone. The Terecta transition zone is situated within the southern macro slope of Terectinskiy ridge covering all altitudinal zones from the steppes of the Ujmonslaya intermountain hollow (1,100 m) to subalpine and alpine meadows (up to 2,500 m).

Within the Terecta transition zone the following types of land use occur:

- maral (red deer) farms
- apiaries

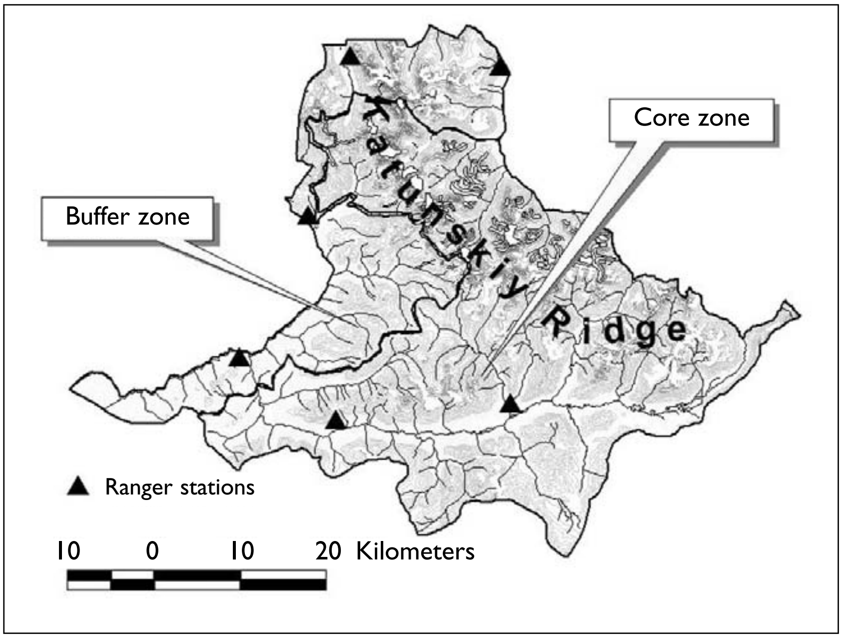


Figure 12.2 Katunskiy BR (core and buffer zones)

- agricultural lands (in flat intermountain valleys)
- forestry, including non-timber products
- grazing lands
- hunting lands
- settlements with private kitchen-gardens.

Ecotourism in this area is being developed in cooperation with Katunskiy BR.

The natural and socio-economic characteristics of Katunskiy BR are described in Badenkov et al. (2004).

To implement the GLOCHAMORE programme, it is useful to extend the research area by including additional clusters: Aktru, the geographic station of Tomsk State University, Belukha Nature Park and Katon-Karagaiskiy National Park (Kazakhstan). The last two clusters adjoin the core area of Katunskiy BR. Incorporating these protected areas will allow us to take account of wider landscape diversity, and so improve studies of global change. It is also very important to mention previous and current investigations of global change within these territories. This research includes long-term glaciological studies at Aktru station, Belukha Nature Park, and retrospective studies of swamps and lakes within Katunskiy BR, Katon-Karagaiskiy National Park and Belukha Nature Park.

Another important element for global change research is the presence of weather stations within the investigation area. There are two stations in Belukha Nature Park: one at Aktru station and one in Katon-Karagaiskiy National Park.

A brief outline of the characteristics of these clusters are given below. For a general description of landscapes and current research into the Aktru cluster, see the paper by Narozhniy and Borodavko in this volume.

Belukha Nature Park

Belukha Nature Park is situated within the most elevated part of Katunskiy ridge. The highest peak of Siberia (Mt Belukha, 4,506 m) is located in the park. The majority of this territory is covered by highlands containing glaciers, snowfields and mountain tundra. Belukha is one of the significant centres of glaciation within the Altai mountains. The total area of glaciation in Belukha massif is 98.3 km^2 (in 1985); in the middle of the nineteenth century it was 113.2 km^2 (Arefjev and Mukhametov, 1996). The dynamics of large glaciers in this area are given in Table 12.1.

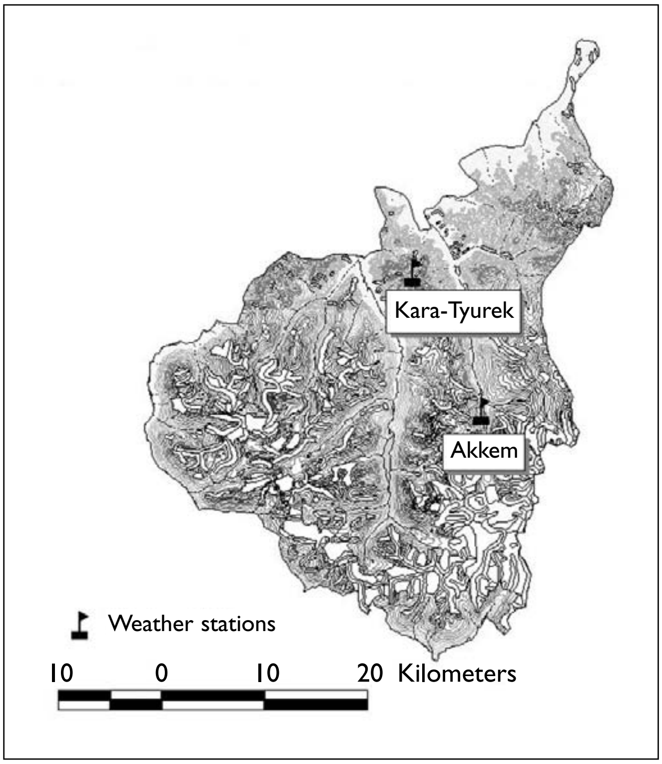


Figure 12.3
Belukha Nature Park

Within this cluster there are two weather stations: Akkem (2,200 m) and Kara-Tyurek (2,600 m). Meteorological information is available from 1932 and 1939 respectively.

The Belukha Nature Park is one of the main tourist regions of the whole Altai Republic. Mt Belukha attracts different types of people, from climbers and hikers to religious pilgrims. There are several tourist centres here, but generally speaking tourism is not organized.

Other types of land use within this cluster are forestry (including non-timber products), grazing and hunting.

Table 12.1
Alteration of the area of large glaciers in Belukha massif (after Arefjev et. al, 1996)

Glacier	Area, km^2 Mid 19th century	1952	1970	1980	Area reduction from mid 19th century to 1980, %
Sapozhnikov	25.6	23.1	22.0	21.9	14.4
Rodzevich	19.6	17.2	–	16.9	12.0
Br. Tronovy	15.9	–	13.4	13.3	16.4
Chernyje	8.3	7.0	–	6.8	18.1
Gebler	15.7	13.7	13.6	13.5	14.0
B. Berel'skiy	15.0	–	–	12.6	16.0
M. Berel'skiy	13.4	11.1	10.6	10.5	21.6

Katon-Karagaiskiy National Park (Kazakhstan)

This protected area participates in GLOCHAMORE activities within the framework of transboundary collaboration with Katunskiy BR. These protected areas have a common border of more than 100 km.

Katon-Karagaiskiy National Park straddles two regions – central and southern Altai. Katunskiy (Belukha massif), Southern Altai and Tarbagatai ridges are within the National Park boundaries. The altitude of its northern part is between 2,000 and 4,506 m (on the southern slope of Belukha), and the southern part is between 850 m (the Bukhtarma river valley) and 3,487 m. The alpine relief type with high peaks and deep river valleys lies within the northern and eastern parts of the park; the remaining territory has a smoother mountain relief. Present glaciation is located in the Belukha massif. The climate of the national park is assessed by data from two weather stations: Akkem (Russia) and Katon-Karagai (1,087 m above sea level, data available since the beginning of the twentieth century).

The park's nature is described in detail in Krykbaeva (2004).

Socio-economic characteristics

There are thirty-one settlements within the national park (see Figure 12.4). The principal economic activity in this area is agriculture. The structure of land use within the park includes:

- maral farms
- grazing lands
- hayfields
- apiaries
- forestry (including non-timber products such as medicinal plants)
- settlements.

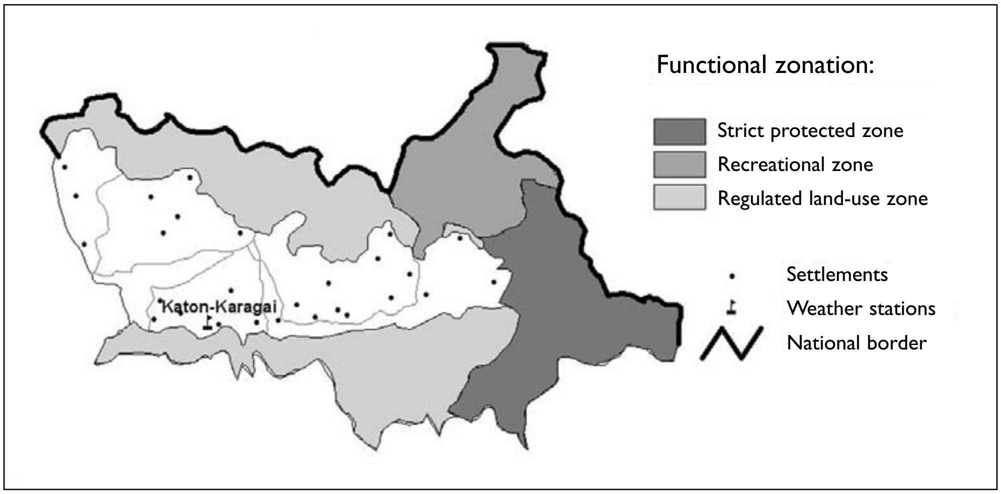
Hunting and fishing also play a significant role in the use of natural resources, and tourism has been developed on a large scale.

DRIVERS OF AND POSSIBLE RESPONSES TO GLOBAL CHANGE IN KATUNSKIY BR

Climate change in the Altai-Sayan region

First of all, we should mention that before the 1990s there were few weather stations within this transboundary region. Most of the stations are located in the centres of administrative units (such as Slavgorod, Kulunda, Mikhailovka, Gornyak, Zmeinogorsk and Charyshskoye – within Ataiyskiy Kray; Ust-Kan, Ust-Koksa, Ust-Ulagan, Kosh-Agach and Ulandryk – within the Altai Republic; and Mugur-Aksy, Khondagaity and Samagaltay – within the Tyva Republic). Weather stations were rarely developed for research purposes (Aktru, Akkem, Kara-Tyurek, Katun and Bertek are located high up in the highlands far from settlements), and most have rather short data series; several of them were closed in the 1990s.

Figure 12.4
Katon-Karagaiskiy National Park



The most valuable source of meteorological data comes from the oldest weather station, 'Barnaul'. It was set up in 1835 and there is continuous temporal data for the period 1838–1964 for the area around Barnaul city. In 1946 the 'Barnaul-Agro' weather station was established away from the city area. Thus the two parallel time series of these stations make it possible to correlate the data of Barnaul station to that of the Barnaul-Agro station and to eliminate the thermal effect of the city (Kharlamova, 2000). These data are not only representative for the steppe regions of the Asian part of Russia but, by using a significant correlation coefficient of mid-annual temperature at Barnaul and Tomsk weather stations (0.76), we can extend the results to include a wider intracontinental area. Present climatic trends show significant warming. To improve our understanding of climate changes in the Altai-Sayan region, however, it is necessary to analyse the data retrospectively.

The time series of mid-annual temperatures (Barnaul weather station) is characterized by differently scaled cycles (see Figure 12.5). The detailed analysis showed that the coldest time during this 160-year period was the end of the 1830s. The lowest mid-annual temperature was registered in 1839, followed by a rapid increase of temperature until 1847. Between 1848 and 1865 there was a second period of cooling followed by a constant alternation of short periods with mid-annual temperature deviations of different extents. A warm period between 1894 and 1904 was followed by a cold one, which ended in 1912. Then in the twentieth century we can distinguish periods of warming (1913–1928, 1939–1949, 1961–1968, 1977–1983, 1988 until now) and relatively cold ones (1929–1938, 1950–1960, 1969–1976, 1984–1987). The trend towards ever-shorter periods is marked, demonstrating the instability of the thermal regime.

Normalization of mid-annual temperatures over the medium to long term for the 1970–1999 period under criteria $t = (X_i - X_{m.})/ D$ (D is dispersion) showed that in the 162 years of observations there were no extraordinarily warm years, eight warm years (4.9 per cent), forty-four normal years (27.7 per cent), fifty-six cold years (34.6 per cent), forty-nine unusually cold years (30.2 per cent), three abnormally cold years (1838, 1841 and 1853) and two extremely

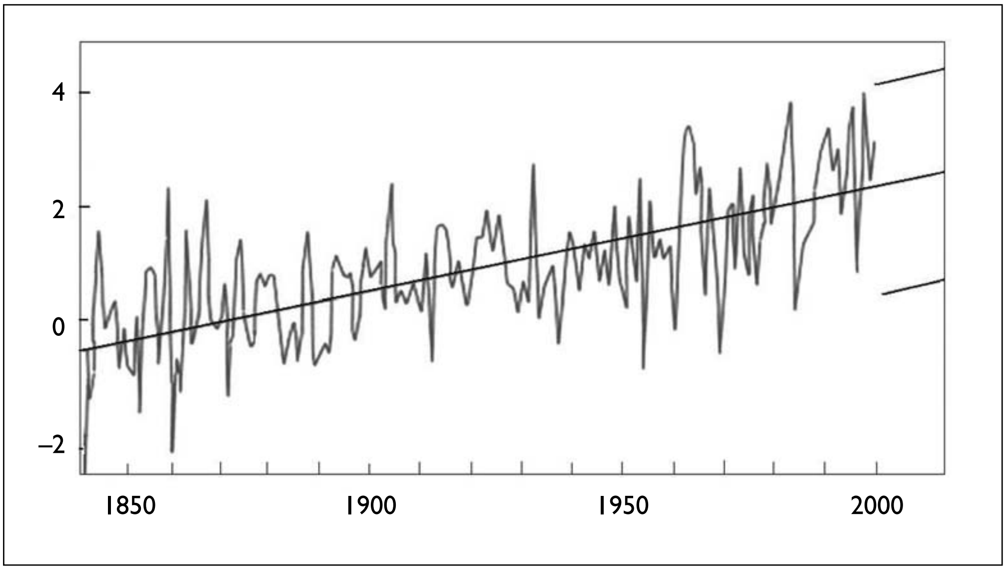


Figure 12.5
Trend of mid-annual temperature (°C) at Barnaul weather station (Kharlamova, 2000)

cold years (1839 and 1860). Normalization of mid-month temperature for every month showed that in most cases cold years were characterized by cold winters. Moreover, there has been a marked increase of interannual and interdecadal variability, not only for annual temperatures but also particularly for the temperatures of warm seasons.

The trend of mid-annual temperature is characterized by an increase of temperature from –0.5°C to 2.3°C. This rise of 2.8°C is much higher than the average for continents of the Northern hemisphere (0.7°C over the last 100 years (Price and Barry, 1997)) or the increase in global mid-annual temperatures (0.35°C over 140 years (Kondratjev, 1996)). Since the 1950s, rates of temperature increase have changed considerably. Before 1950, mid-annual temperatures increased by 0.008°C per year, but rose by 0.01°C annually between 1950 and 1980, and by 2000 were increasing by 0.02°C per year. Extrapolation from the trend of mid-annual temperature suggests that in 2010 it may reach 2.5°C. Calculations of the Box–Jenkins model testify to more significant possible change: up to 3.1°C (the rate of increase is about 0.06°C per year) with small-scale fluctuations between 2.4°C in 2000 and 3.12°C in 2004 (Figure 12.6). It is expected that the rate of warming will then decrease, so that in 2025 mid-annual temperature will be 3.5°C higher.

Changes in monthly temperatures are not of the same ratio as annual temperatures. The trend has been towards higher temperatures in the cold period (from November to March); the average has increased by 3.4°C (from –15°C to –11.6°C), and this trend may continue with a further 0.2°C rise until 2010. The most significant temperature increase is indicated for January, with a rise of 4.8°C, although this rate has since decreased. March temperatures have increased by 4.4°C. For warmer periods (from April to October) the temperature has increased by 2.3°C (from 9.9°C to 12.2°C) and by 2010 it is expected to rise by a further 0.2°C. The highest rates of temperature increase are observed in April, and the lowest in July, August and September. The increase in mid-annual temperatures is thus the result of more significant warming during winters.

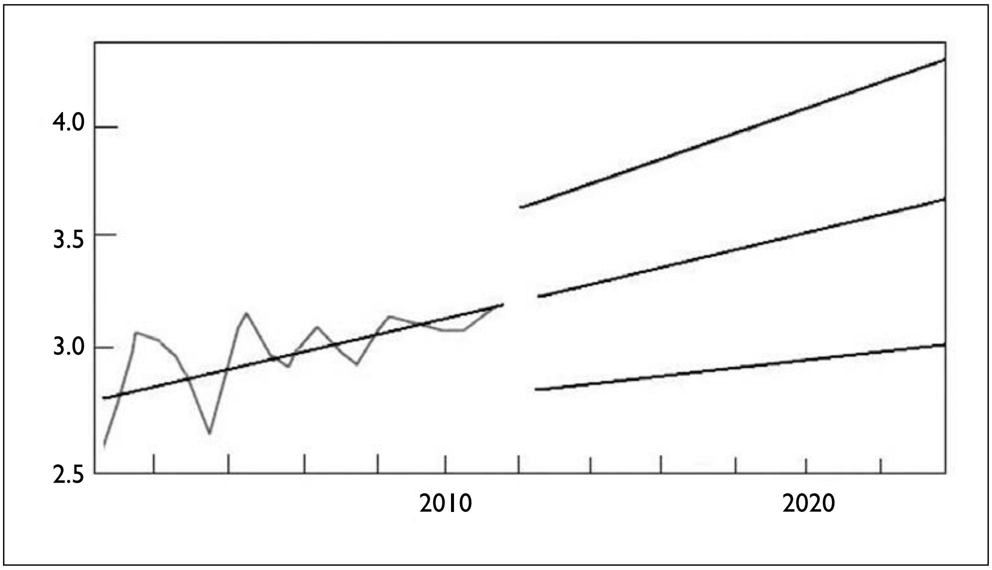


Figure 12.6 Forecast of mid-annual temperature (°C) at Barnaul weather station under Box-Jenkins model (Kharlamova, 2000)

Calculations based on the model mentioned above indicate a trend towards winter warming from –11.6°C to –11.4°C in 2011, with cold winters in 2000 and 2004 and a warm winter in 2003. There have been fluctuations in warm season temperatures, with a minimum of 12.5°C in 2000 and maximum of 13.1°C in 2001.

Generally, the changes of the thermal regime at Barnaul weather station show the presence of long-term cycles lasting up to eighty years, with a modern warming trend that is more significant for cold seasons. Decadal fluctuations are based on long-term changes. The timescale of the fluctuations is constantly decreasing, demonstrating the increasing instability of the thermal regime. This instability increases the probability of natural risks and disasters and makes it difficult to forecast events.

However, estimates for precipitation and moisture regime diverge. Despite an increase in total precipitation in the European part of Russia, only an insignificant increase of precipitation is expected in the Altai region, with a decrease in precipitation during warm seasons and an increase during cold ones.

The structure and function of mountain landscapes, and therefore land-use structure and economies, are affected by both biophysical and economic drivers.

The main responses to global changes in the biophysical environment in this region are:

- glacier degradation and consequent changes in the hydrological regime of the surface water
- changes in plant distribution and vegetation patterns, and the invasion of exotic species
- changes in ecosystem functioning.

In the light of global change study, all responses will be considered in detail as 'key issues'. For Katunskiy BR and clusters, key issues were defined as glaciers, vegetation, land use, recreation/tourism, maral farming and apiculture.

Glaciers variability and evolution trends

Modern glaciation is an important component of mountain landscapes of the Altai-Sayan ecoregion. Glaciation is highly dependent on climate and thus is a good indicator of climate change. Glaciological observations are extremely important for areas with a poor environmental monitoring network, such as the majority of the Altai-Sayan region.

Modern glaciation is widespread in the Altai mountains (Katunskiy, the northern and southern Chuyskiy ridges, southern Altai, Tabyn-Bogdo-Ola). In all, there are about 1,500 glaciers with a total area 910 km^2. There are also small glaciers in the Mongun-Taiga massif, Kuznetskiy Alatau and eastern Sayan. Glaciers are a regular habitat for several high-mountain animals (snow leopard, argali and so on), and changes in glacier coverage may as a consequence cause changes in biodiversity.

Observations of glaciers in the Altai mountains indicate glacier retreat: a simultaneous decrease of their area and depth (Mukhametov, 1988). Since the middle of the nineteenth century there has been a constant tendency of glacier retreat within this region. This results in a rise of the firn line, changes in glaciation pattern, and a decrease in the area, depth and formation of the modern moraine relief. Consequently, there is a migration of the upper treeline.

During the observation period (from the middle of the nineteenth century), small glaciers have retreated by 20–40 per cent (and some have disappeared altogether), and the larger glaciers have seen a decrease of 8–20 per cent in their area (Galakhov and Mukhametov, 1999). The tongues of several glaciers are now situated in the former accumulation zones. Generally, glacier lengths have decreased by between 1,000–1,500 m, while the tongue zone has been elevated by 150–170 m at Katunskiy and the southern Altai ridges, and by 50–100 m at Northern Chuyskiy and Mongolian Altai. The average rates of retreat are 8–10 m per year for the large glaciers and up to 12 m per year for the smaller glaciers. However, during the twentieth century these rates differed (Galakhov and Mukhametov, 1999; Mikhailov and Ostanin 2001, 2002). The zones most affected by climate change have been the tongues and to a lesser degree accumulation zones.

The lowering of glacier surface is greatest in places where there has been total degradation of glaciers, where it reaches 50–100 m. The surfaces of modern glaciers have declined by 50–70 m, which is marked by the level of lateral morains. Towards the firn line, the degradation of glaciers gradually decreases by 5–10 m.

All young moraine complexes are well-conserved. They are represented by lateral moraines with an elevation of 50–100 m above the valley bed. Low depth of glacial sediments is a specific characteristic of several glaciers (such as the Kozlov and Russian Kanas glaciers). The last moraine is rather insignificant (its elevation is about 1–1.5 m above the valley bed). The modern moraine covers ancient glacial sediments (see Figure 12.7) 1) watersheds, 2) peaks, 3) rivers, 4) moraines of the mid-nineteenth century, 5) glacier contours by the end of 1970s, and 6) glacier contours by the end of 1990s.

Lower and upper treelines

Lower and upper treelines are good indicators of environmental change. An estimate of changes in these parameters for Katunskiy ridge is given in Mikhailov and Chistyakov (1999).

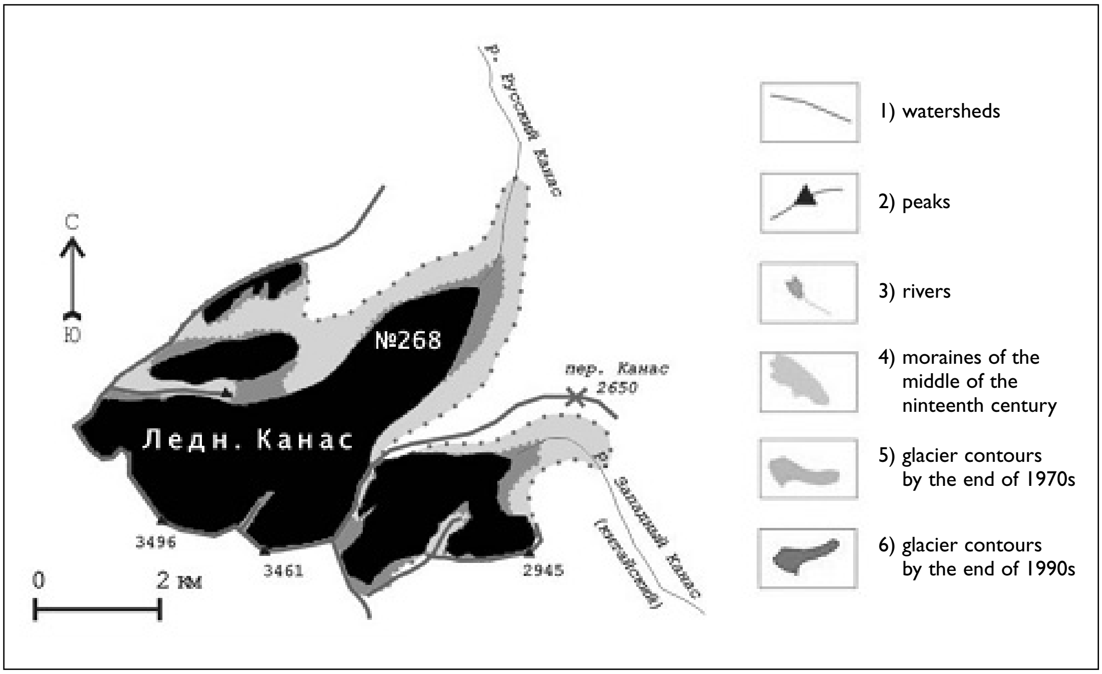


Figure 12.7 Dynamics of glaciers within upstreams of Russian Kanas and Western Kanas from the end of the ninteenth century to the end of the twentieth century

The results show that at the height of the last glaciation (about 18,000 years ago) the upper treeline was 620 m higher than at present. At the end of the most recent cooling period (from the end of the eighteenth century to the mid-nineteenth century), the upper treeline had shifted upward by 70 m, and the lower treeline (the ecotone between forests and steppes) had shifted by 100 m.

The modern trend of treeline dynamics in mountains is characterized by a continuous shift upward. Within mountain regions with modern glaciation this shift reaches 60–100 m. For the Altai this altitudinal diapason is characterized by the occurrence of three generations of trees, which form the upper treeline. The lowest generation is 250 years old, the middle one is 120–150 years old, and the youngest is 50–70 years old. This specific structure of the upper treeline within glaciation areas shows the climate variability and concrete periods of changes. The dendrochronological data correspond very well to glacier dynamics. The upper treeline in the Altai is hardly affected by human activity and therefore its dynamics are a good indicator of environmental change.

The upper treeline shifts upward; however this process has a specific rhythm. Above the border of old forest, a new generation of trees forms the new treeline. However, a severe climate with long cooling periods, characterized by a shift downward of the snowline in the summer over several years and glacier activation, leads to mass degradation of trees on the upper treeline (Ovchinnikov, 2002). The lower treeline also shifts upward. Unfortunately, there are no exact observation data on this natural process. A clear trend towards an upward shift is linked to human activity.

Maral (red deer) farming

This is a traditional type of land use in Central and Southern Altai within the intermountain valleys of the Altai-Sayan region. The end product of this economic activity is maral antlers, which are used in the pharmaceutical industry. Marals are reared within fenced pastures.

Nearly all antler production is exported to South Korea, which is why the development of maral farming depends heavily on economic and market changes. However, because of the almost natural conditions of maral rearing this activity is also vulnerable to natural global changes. Natural conditions determine the animals' forage base, which may be affected by global warming that causes an upward migration of plants and plant communities with subsequent changes in pasture productivity.

A current problem in maral farming in the Ust-Koksa district is its intensification. Until recently it was developed extensively through the addition of new lands. Today more than 70 per cent of suitable lands are now maral farms, meaning that there is no scope for further extension of the farms.

Today Katunskiy BR, together with the maral farm administration, carries out special interdisciplinary research on the intensification of the maral economy within the 'Terecta' transition zone. One of the main objectives of this case study is to achieve a balance between economic progress and environmental issues. This is extremely important in the case of maral farming because animal productivity is directly dependent on the condition of the ecosystem.

Since 2000, BR research staff have been monitoring the pastures of model maral farms in the transition zone. This monitoring activity includes observation of vegetation (species composition and abundance) and the dynamics of erosion processes. These data, combined with a landscape map, will be the baseline for working out the model of pasture rotation and sustainable land use.

Apiculture

Apiculture is the other traditional type of land use found within this region. Honey from the Altai mountains is very valuable because it is produced at high altitudes with unique melliferous vegetation. The other important factor is the unpolluted environment of the Altai highlands.

Apiculture is environmentally friendly and is highly influenced by global change. Global warming may cause changes in plant phenology (the duration of vegetation and flowering periods) and precipitation in summer. Moreover, global change affects the melliferous base. In this case, exotic plant invasions are extremely important because the species composition determines the quality of the honey. Bee-keeping can also be affected by invasions of exotic insects.

In the development of apiculture, global economic changes are also significant. At the present time, the Katunskiy ridge environment is relatively unpolluted as there are no industrial complexes to be found there. However, there is a risk of transboundary air pollution due to the development of metallurgy in eastern Kazakhstan. Katunskiy ridge is high enough to act as a barrier to the transport of air masses, so its environment may be affected by air pollution. This has been proved by the presence of heavy metals in the glaciers of Katunskiy ridge (Bondarovich, 1997). We assume that this pollution results from the industry of eastern Kazakhstan. To achieve a more accurate definition will require the creation of a regional atmospheric circulation model.

For global change study in the Katunskiy BR and clusters, the establishment of apimonitoring is suggested. Bees are among the universal bioindicators of environmental conditions. At the same time, apimonitoring (that is the study of ecological parameters of the environment by studying bees) is one of the least costly or labour-consuming types of monitoring activity. Today apimonitoring is not widespread either in Russia or abroad, but there are enough scientific recommendations to justify the establishment of a new site (Makarov and Mishin, 1999). This activity is especially effective in mountain regions with difficult and inaccessible territories because it requires less transport and time than other types of monitoring.

Apimonitoring may reveal the following characteristic aspects:

- Concentration of heavy metals, radioactive substances and waste rocket fuel in plants and soils. Correlations have already been established between products of the bee tissue system and the presence of such elements in precipitation, soil and plants (Makarov and Mishin, 1999).
- By analysing the bee family phenology we may observe local trends of global warming.

Research has determined that bees are very sensitive to the geophysical state of the environment. Thus, specific changes in bee behaviour and physiology may predict possible earthquakes (Mironov, 1993).

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Part III

Workshop Report and Appendices

Workshop Report

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BACKGROUND

Mountains and mountain societies are particularly sensitive to the effects of global environmental change. Many of the world's mountain ecosystems are moving along trajectories that couple high rates of environmental change with strong economic changes, whose collective effect may alter the ability of mountain regions to provide critical goods and services, to both mountain inhabitants and lowland communities. In order to address the environmental challenges facing the world's mountain regions in the twenty-first century, the EU-funded GLOCHAMORE ('Global Change in Mountain Regions') project aims at:

- developing an integrative research strategy for detecting signals of global environmental change in mountain environments
- defining the impacts of these changes on mountain regions as well as lowland areas dependent on mountain resources
- facilitating the development of sustainable resource management regimes for mountain regions.

Following the kick-off meeting of the project (held in Entlebuch, Switzerland, in November 2003), the details of the research strategy are being formulated through a series of product-oriented workshops dedicated to:

1. Long-term monitoring (Vienna, Austria, May 2004).
2. Projections of global change impacts through modeling (the workshop this report is focusing on)(L'Aquila, Italy, Nov/Dec 2004).
3. Sustainable resource management (Sierra Nevada, Spain, March 2005).
4. Process studies (Samedan, Switzerland, July 2005).

The concepts developed in these thematic workshops will be revisited, refined and synthesized during a final Open Science Conference on Global Change in Mountain Regions, which will be held in autumn 2005 in Perth, Scotland.

In GLOCHAMORE, activities from both the natural and social science research communities are integrated to establish a framework for long-term research efforts. The project takes advantage of the infrastructure and ongoing research activities in a selection of UNESCO MAB's mountain biosphere reserves around the globe, with the explicit goal of implementing the research strategy in these reserves in both developed and developing countries. This is achieved through the active participation of biosphere reserve managers ('stakeholders') in the development of the research strategy, and thus in the thematic workshops as well as in the final Open Science Conference.

WORKSHOP OBJECTIVES

The objectives of this workshop were as follows (cf. Figure WR.1):

- to evaluate the state of the art of projections of global change impacts in mountain regions that are relevant for MBR managers
- to identify the modeling approaches that (1) are required for deriving such projections, and (2) can be implemented in MBRs
- to identify the needs (capacity building, funding, infrastructure development) for successfully implementing further approaches that are currently infeasible in the MBRs.

WORKSHOP OVERVIEW

The workshop consisted of seven thematic sessions with keynote presentations and short discussions, followed by breakout sessions that were devoted to in-depth discussions of the seven themes and the associated writing tasks. The five topics were:

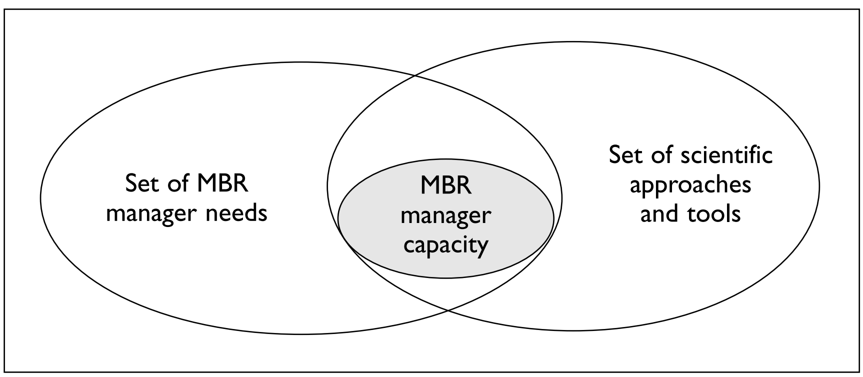


Figure WR.1
Scheme of the set of scientific approaches and tools that are available for predicting the impacts of global change on mountain regions (right), the set of needs of the managers of mountain biosphere reserves (left), and the set of the capacities of MBR managers (or 'local' scientists) to implement such research activities in a given MBR (centre). The shaded area is what should be identified in this workshop, and it is evident that this will vary from one continent to the other, or even from one MBR to the other.

a) Regional climate change.
b) Snow and ice development.
c) Ecological changes:
   – ecosystem structure and biodiversity
   – ecosystem function (biogeochemistry and hydrology).
d) Land-use changes.
e) The role of remote sensing for developing and validating impact models.

Prior to the workshop, a questionnaire had been sent to nearly 30 MBR managers so they were able to express their needs for the modeling of future biosphere reserve dynamics. The MRI Director, Greg Greenwood, processed the returned questionnaires and provided the results to the workshop participants prior to the workshop (see Appendix).

The keynote speakers were asked to address to the largest extent possible in their presentations the issues raised by the MBR managers in the questionnaires. Thus, the keynote presentations at the workshop were targeted towards the implementation of scientific research on global change in the specific set of MBRs, rather than towards general, technical overview presentations. MBR managers in turn were asked to prepare posters expressing the key aspects (resources, services, goods) of their reserves that should be protected, maintained or improved in the future, and the key drivers of change that may threaten them.

The workshop agenda can be found on pages 167–8.

REPORTS FROM WORKING GROUP SESSIONS

Regional climatic change

Compiled by Harald Bugmann and Gregory B. Greenwood

Providing scenarios of climate change that are specific for mountain regions is of high importance for the sustainable management of natural resources in these areas, including MBRs. However, it is currently impossible to deliver precise, state-of-the-art scenarios of regional climate change at high resolution for each mountain region where the impacts of global change are being studied. Therefore, it is advisable to develop a strategy where with minimal effort some statements can already be made about the likely impacts of climate change on ecosystems, cryospheric systems and human societies in mountain regions at a regional scale. Such a strategy was proposed, discussed and agreed upon in plenary at the GLOCHAMORE workshop, starting from a minimum approach and increasing in sophistication, as follows:

- At the *minimum level*, the global climate projections of the IPCC (2001) can be used to guide simple analyses with impact models. In such an approach, the IPCC data would be used to define a number of scenarios for setting up simulation studies. For a number of reasons, most evidently because these scenario data would be global in nature, such analyses could not qualify as 'predictions' of the future trajectories of ecosystems or cryospheric systems in MBRs. However, they can still be quite useful for elucidating the *sensitivity* to climatic changes of certain ecosystem goods and services provided by mountain regions, and this can provide useful insights for management. It is noteworthy that if a small set of common, simple scenarios of climate change were applied in all MBRs that are participating in this research initiative, it would become possible to evaluate which MBRs are most sensitive to a given amount of climate change with respect to certain goods and services (e.g. biodiversity loss, changes in water yield). Together with considerations regarding the adaptive capacity of MBRs to the projected changes, this could lead to the identification of those MBRs that are particularly vulnerable to climatic change.

- At a *more sophisticated level*, the output of general circulation models (GCMs), some of which are available free of charge on the Internet, can be used in a 'brute-force' downscaling effort; that is, by using the climate anomalies of the nearest grid cell(s) of the climate model for driving impact models in a given MBR. While it is clear that such an approach ignores any fine-scale details, which are quite important for weather and climate in mountain regions, it has the advantage of providing some regional (or at least continental) details that are absent from the minimum level, where only global average data are being used.
- The *third level of sophistication* would include a more sophisticated downscaling technique, such as statistical downscaling or the application of high-resolution regional climate models (RCMs), which can provide climatic information at a spatial grain of a few km and at a spatial extent of several hundred km^2. To apply such techniques, however, the collaboration of impact researchers in MBRs with climate scientists would typically be required.

While the discussion at the workshop focused on climatic change alone, it is important to keep in mind that climatic parameters are changing in concert with other drivers of global change, such as human populations, land use, atmospheric CO_2 concentrations and nitrogen deposition, to name just a few. Thus, wherever possible the joint effect of these various drivers should be considered through a set of systematic simulation studies with impact models, where scenarios for each driver are applied in isolation (e.g. change of CO_2 alone, change of climate alone) as well as in combinations, up to scenarios that include the full set of all drivers. Such an approach is highly valuable because it allows us to determine the relative importance of the various drivers for a given system/service in a given MBR, and it is quite likely that this importance would vary strongly from one MBR to the other.

Finally, it should be kept in mind that projections of future climate, CO_2, human population sizes, nitrogen deposition and so on cannot predict the future state of the earth system. They represent scenarios and thus should be viewed as 'what-if' questions. Attaching probabilities to certain scenarios is an active research field at the moment, which would make it possible to move from projections to forecasts (cf. Bugmann, 2003; Clark et al., 2003). For the time being, it is thus important to keep in mind that, for example, the average of +3.6 K of the IPCC (2001) projections for global temperature rise (the range is +1.4 to +5.8 K) is by no means a value that is more likely to occur in reality than the upper or lower bound of that range. This underlines the importance of sensitivity studies that explore the full range of possible conditions rather than focusing on a hypothetical and unwarranted scenario that is viewed as being 'most likely'.

A reality check with the MBRs represented at the workshop suggested that these MBRs differ vastly in their experience with scenarios of climatic change. While in some reserves, full-fledged regional climate model simulations are available to the MBR managers and associated researchers, in many parts of the world there were good reasons to focus on other drivers (such as land-use changes) to date, rather than on climatic changes. However, the need to also address climatic change for longer-term assessments was recognized, and it was concluded that the approach proposed above should be tested and applied in the near future through a follow-up project to GLOCHAMORE.

Modeling snow and ice conditions in MBRs

Compiled by Wilfried Haeberli, Jean-Pierre Dedieu, Martin Hoelzle and Michael Lehning

Fast climate changes affecting snow and ice constitute an extraordinary challenge for integrative monitoring and modeling strategies in mountain areas. In particular, the differing response characteristics of snow, glaciers and permafrost, as well as the numerous interactions and feedbacks involved, cause disequilibria within these highly complex and very dynamic systems. Numerical modeling must, therefore, primarily address transient properties of the systems, and anticipate the possible occurrence of new processes.

Snow

Depending on the level of sophistication in representing snow processes, a distinction can be made between (i) simple (single-layer) energy models and (ii) mass balance models. The latter are mostly used as a part of snow–vegetation–atmosphere transfer (SVAT) schemes in large-scale models (Slater et al., 2001; Schlosser et al., 2000). Only a few models incorporate the complex processes within the snow cover, and hence provide information on structural and mechanical snow properties (Etchevers et al., 2005). For applications in mountain regions, the structure and spatial distribution of the snow cover are important, for example for determining the likelihood of snow movements and thus the occurrence of natural hazards such as snow avalanches. Currently, models are being developed that include this spatial distribution (e.g. ALPINE3D, Lehning et al. 2004); it is likely that this type of model will find widespread application for scientific questions in the near future. In the meantime, 1-D models provide important quantitative information such as the temporal development of the water equivalent in the snow cover. Similarly, data on snow structure and stability support avalanche warning models and estimates of the conditions for animal mobility. Representative snowmelt curves help to determine mass and energy fluxes between snow and vegetation or the underlying substrate (i.e. soil, permafrost). Large MBRs, such as some in North America, span several zones/belts of different snow characteristics and extend from maritime to more continental climatic conditions. Even in these MBRs, a representative ensemble of snow covers can be simulated on the basis of data from a few meteorological stations.

At the *minimum level*, simple global change experiments, which could be conducted among MBR sites, should simulate the hydrological response of the snow cover (snow melt curve) for the sites on the basis of a few global change scenarios. In this way, representative but relatively general information can be produced for simple applications (for instance, estimates of water supply from snowmelt). More sophisticated snow studies can be done at the intermediate and optimal levels, but they will typically require collaboration with scientists from universities or research stations.

Glaciers

Glacier fluctuations are linked to climate change by a process chain, which first includes the surface mass balance (SMB) via the surface energy balance. Therefore, the SMB is a direct and immediate signal of climate change. After a certain lag time following an assumed step change in climatic conditions, glaciers start to change their geometry (and temperature in the case of non-temperate glaciers), and their tongues adjust within the dynamic response time until a new equilibrium is reached (Jòhannesson et al., 1989). A number of successful numerical models at different levels of sophistication have been developed for both the glacier mass/energy balance and the dynamic response of glacier tongues. Such modeling varies from (1) relatively simple degree-day approaches for mass balance (Braithwaite, 1998; Greuell and Genthon, 2003), (2) continuity considerations relating length and mass change over extended time periods (Jòhannesson et al., 1989; Haeberli and Hoelzle, 1995; Hoelzle et al., 2003; cf. also Leysinger and Gudmundsson, 2004) to (3) sophisticated models of the distributed energy balance (Klok and Oerlemans, 2002) and glacier flow (Oerlemans, 2001). A specific problem occurring with distributed energy balance approaches concerns the inclusion of the effects of snow redistribution by wind and avalanches (Brun et al., 1989; Gerbaux et al., submitted). Numerical glacier modeling constitutes an essential component of modern glacier monitoring strategies and is crucial for extrapolating observed developments in space and time (Haeberli, 2004). Observation and modeling efforts within mountain biosphere reserves should therefore fit into already existing networks and monitoring strategies, such as the Global Hierarchical Observing Strategy (GHOST) within the Global Terrestrial Observing System (GTOS; cf. Haeberli and Dedieu 2004).

At the *minimum level*, all MBRs containing glaciers should observe and model their evolution as a key indication of climate change. Basic requirements are (1) a digital elevation model, (2) basic climatic information from one or a few stations, and (3) satellite images for delineating glacier extent. Models at the minimum level can then be applied immediately and with a minimum of input data. Degree-day models are a simple and easy parametric approach that calculates ablation primarily from temperatures, derived from valley meteorological stations using an altitudinal gradient calibration. In fact, the degree-day approach is a simplification of an energy balance model. However, the energy input is parameterized only roughly in these approaches; in reality, some of the excess energy may be used for sublimating surface ice rather than being used for melt. Using estimates of mass balance change versus altitude over time periods of a few decades, average mass balances can be inferred from calculated shifts in equilibrium line altitude (ELA) and from continuity considerations applied to the easily documented cumulative length changes for different glaciers within their characteristics response time.

Permafrost

Permafrost stabilizes soils on many mountain slopes above a certain elevation, and thus is essential for protection of ecosystems and human infrastructure at lower elevations. Today, permafrost distribution models combine stochastic with deterministic elements and can be divided into two main types: regionally calibrated empirical–statistical models (simple models) and more physically based process-oriented models (complex models). Empirical–statistical models directly relate documented permafrost occurrences to topographically controlled microclimatic factors (altitude, slope and aspect, mean air temperature, solar radiation), which can be measured or computed easily (e.g. Keller, 1992). Detailed energy-exchange processes at the surface and within the active layer are not treated explicitly but rather as a grey box, with topographic/microclimatic factors being selected according to their relative influence in the energy balance. Process-oriented models focus on more detailed understanding of the energy fluxes between the atmosphere and the permafrost. They explicitly parameterize solar radiation, sensible heat, surface albedo, heat conduction and other factors, are often complex, and need a large amount of precisely measured or computed data. Such approaches allow for spatio-temporal extrapolation and are well suited for sensitivity studies with respect to interactions and feedbacks involved with climate-change scenarios. They make it possible to compute surface temperatures and, hence, to estimate thermal conditions at depth and transient effects (Hoelzle et al., 2001; Stocker-Mittaz et al., 2002; Gruber et al., 2004). Processes within the active layer (between the surface and the permafrost table) remain a primary challenge for every modeling exercise in mountain permafrost.

At the *minimum level*, empirical–statistical steady-state models calibrated with field measurements should be applied in each of the MBRs. These models provide a spatial overview of the potential permafrost distribution patterns under present-day climatic conditions but are less suited for climate projections. Basic prerequisites for permafrost modeling are digital elevation models, satellite imagery for surface characterisation (forest, meadows, debris, bedrock) and GIS software. MBRs should start collecting information about the occurrence of mountain permafrost for calibrating and validating numerical models. Corresponding cheap and simple-to-use tools consist of measurements of the bottom temperature of winter snow cover (BTS) combined with miniature temperature loggers within the active layer of the permafrost at sites with different surface characteristics. For in-depth studies, sophisticated validation tools (geophysical soundings, drilling, borehole observations) are available.

At the *intermediate level*, time-dependent 1-D models based on snow/ground-coupled energy balance approaches can be applied (Lütschg et al., 2003). These models can also be used as spatially distributed models if they are well calibrated with measurements at several places in the field.

At the *optimum level*, complex, time-dependent 3-D models based on energy balance approaches including meteorological information, digital elevation data and documentation by remote sensing can be applied. As snow determines the ground temperature, snow redistribution by wind and avalanches should be included.

Remote sensing and integrated assessments

Optical and microwave remote sensing data, in particular satellite-based data, are especially important for defining 2-D and 3-D glacier extent and surface characteristics (albedo), surface conditions in permafrost areas and snow melt-out patterns (see the section on remote sensing, p149). The interconnection of models for integrated assessments, including interactions and feedbacks between the components (snow, glaciers, permafrost) constitutes a major challenge (Mittaz et al., 2002). Coupling local and regional GIS-based impact models with high-resolution climate models is a high priority and is being addressed by various groups worldwide. Existing models at different levels of sophistication can be used to improve integrative studies and assessments. Avalanche models, for instance, can be applied with variable input for management purposes (extreme events in connection with safety aspects or road conditions), and also for ecosystem understanding (annual redistribution of snow). They can help in exploring the connection between snow and permafrost microclimate in complex topography (snow deposition at the foot of slopes), spatial patterns of glacier mass balance and the occurrence of specific habitats with high biodiversity. The optical satellite imagery necessary for calibrating and validating the corresponding models is now available. As an example, the drastic snow and firn meltout and strong albedo reduction of Alpine glacier surfaces after the extreme heat/drought during summer 2003 is clearly detectable in remote sensing data.

Changes of ecosystem structure and biodiversity

Compiled by Antoine Guisan

The work of this breakout group was dedicated to discussing possible approaches for modeling and predicting the structure, composition and diversity of terrestrial ecosystems, be it by assembling predictions for individual species (e.g. bioclimatic envelope approaches) or by using models that incorporate processes at the community level (e.g. forest gap models). Here, ecosystems are considered in a broad sense, including for instance landscape units (as defined in the Katunskiy MBR, Russia), or smaller spatial and organizational units down to small patches of land that may have particular conservation status in a given MBR.

The discussion of this working group aimed at identifying:

- existing modeling studies in MBRs
- scientific issues that are of concern for sustainable resource management in MBRs for which modeling approaches are useful or even indispensable, including their priorization
- which data are required to make this feasible
- what financial and human resources would be required to put this into practice
- which modeling tools should be applied in this context.

Below, the term ‘modeling’ refers specifically to the mathematical prediction of ecosystem structure, composition or diversity.

Existing modeling studies in MBRs

From the previous GLOCHAMORE workshops and the discussions at this workshop, it has become clear that the various MBRs differ strongly in the degree to which modeling activities for terrestrial ecosystems have been conducted and/or integrated into the development of resource management strategies. For example, several MBRs, particularly in Europe and North America (such as Glacier NP, Yellowstone NP or Berchtesgaden NP) have a long tradition of modeling studies as a complement to monitoring efforts, or at least modeling studies are underway in these MBRs, often in close collaboration with neighbouring universities. However, in MBRs in other parts of the world such studies have also been completed or are underway (e.g. Cinturion Andino or Changbaishan MBR). Still other MBRs, such as Katunskiy, are highly interested in implementing such approaches although modeling efforts have not yet been made.

Key issues identified as relevant for modeling

The discussions at the workshop and the results of the survey conducted prior to it suggested the following scientific issues as being of particular relevance for the management of MBRs and requiring modeling support. Here, they are listed roughly by order of importance, although their actual importance may vary depending on the situation in a particular MBR.

1. *The future of charismatic species.* All MBR representatives present at the session expressed their interest in developing projections of the impacts of changes of climate or land use on the distribution of charismatic species, not least as a way to raise public and policy-maker awareness on these matters. It is noteworthy that several MBRs have been founded mainly for the protection of single species or species groups, which now may be threatened by global changes.
2. *Integration of monitoring networks with modeling efforts.* A common denominator of all MBRs is to collect and make available data from monitoring networks, so as to support resource management. The interpretation of the resulting data often becomes easier if the monitoring is accompanied by modeling studies, because the latter can provide an enhanced understanding of the underlying processes. In combination with other kinds of surveys in MBRs, monitoring data can also provide a basis for fitting predictive models, for example for the distribution of single species, communities or other biological entities of interest. In turn, these models can be used to improve the design of monitoring strategies (e.g. more efficient sampling).
3. *Multiple species and biodiversity assessment.* An assessment of the expected gains, losses and turnover of species in all the MBRs included in GLOCHAMORE would make it possible to develop a comparative view of the sensitivity of the various reserves to drivers of global change (see the section on climate scenarios, above). Although this would require sampling of additional data in many MBRs, it was welcomed as an effort that would be of interest to science and resource management as well as policymaking.
4. *Invasive species.* Invasive species, be they from lower elevations surrounding the MBRs or from far away (‘exotic species’), were identified by many MBR managers as being likely to take on more and more importance in the future. However, to date little attention has been

paid to invasive species in many MBRs, and the working group members agreed that this is an area that should be strengthened in the future.

Overall, it was concluded that initiating a cross-comparison study of all selected MBRs based on model projections for many species would be a highly useful effort. Among other advantages, this would promote the development of standardized modeling procedures applicable to all MBRs. The resulting predictions would also provide the necessary basis for designing model-based sampling and monitoring strategies, and in this way it would be possible to obtain valuable additional data to calibrate improved models.

Data for cross-comparison modeling

Due to time constraints at the workshop, cross-comparison modeling was not addressed in detail but needs to be elaborated further as a follow-up activity. However, evidently, many MBRs have monitoring data on plant species in permanent plots, and several MBRs have vegetation maps, at least for parts of their reserves. Occurrence data for emblematic species are often available. Hence, simple modeling analyses appear feasible, and they could focus on plant species, plant communities (e.g. by taking the centroid of vegetation polygons as observation data), and finally charismatic plant and animal species.

It has become clear from other workshop sessions (cf. land use, remote sensing) that basic GIS data are now available worldwide at no or reduced cost (e.g. DEM 90 m for the whole Earth; high-resolution satellite images). Thus, basic spatial modeling efforts can at least use topographic and remote-sensing-derived data to predict the distribution of species and communities. As many MBRs are currently initiating their own GIS database, more refined GIS predictors (e.g. climatic layers) are likely to become available soon, or can be derived by capitalizing on other planned GLOCHAMORE projects (cf. section on cryosphere).

Resources required to perform the modeling

The predictive, static modeling of the distribution of species and communities is made much easier today by the availability of fairly user-friendly packages, often accessible via the Internet (e.g. the BIOMAPPER package). Hence, a lot of these modeling activities can be performed by managers and scientists in the MBRs themselves, even though it would probably require some early training by partners who are doing scientific research on the further development of the methods, be they within or beyond the GLOCHAMORE project. One way to promote this technology transfer and capacity building could be to have MSc or PhD students from universities close to the MBRs visit other, more highly trained MBRs or specialized scientific laboratories.

For other issues, such as dynamic modeling of communities in time and space, where the modeling approaches are still research tools rather than packages that are amenable to the non-researcher (e.g. forest gap models, or landscape models for predicting future disturbance dynamics), joint research projects or at least short-term collaborations between universities or other research facilities on the one hand and MBR managers on the other hand will be required.

Tools and approaches

A large spectrum of approaches for modeling the distribution of species and other biological entities (e.g. communities, biomes, functional or structural types) has been developed in recent years and implemented in many modeling packages that are now available online or from their authors (see Guisan and Thuiller, in press). Most of these are statistical approaches relating the observed distribution of the modeled entity to a set of environmental descriptors extracted from a GIS database, and using the fitted relationship to derive predictions for the whole geographical area of concern. As both the species and the GIS data usually correspond to specific periods in time (e.g. years of sampling or time interval for maps of climatic data interpolated from weather records), these models are called 'static'; in other words, they represent snapshot views that are valid for the considered period only, without including changes in time. More sophisticated approaches, implemented in cellular automata (a dynamic counterpart of the raster data format in GIS), tend to additionally consider population dynamics and species dispersal to more realistically simulate distributional changes. The implementation of these models is still ongoing in many academic laboratories, and their application to MBRs would thus require much higher levels of technical support.

There is a close relationship between the modeling tool and the size of the area to consider. Is it sufficient if GIS data are available for the area of the MBR only? Or should they be collected from a larger spatial extent, including those neighbouring areas where key processes may take place that can have a distinct influence on processes of interest within the MBR boundaries (see the discussion in the land-use group)? It is clearly desirable, if not indispensable, to broaden the view beyond the boundaries of the MBR, otherwise it is likely that erroneous assessments will occur. Considering a larger spatial extent than the MBR itself also avoids undesirable edge effects when deriving new environmental predictors, such as slope angle or slope aspect, which are based on neighbour analyses in the digital elevation model.

When considering much larger spatial extents, possibly encompassing several conservation areas, a second level could be considered when migration corridors and landscape connectivity have to be assessed. However, this was beyond the focus of the discussions, which very much focused on single MBRs rather than on MBR networks. The latter will need to be addressed at a later point.

Changes of ecosystem function (biogeochemistry and hydrology)

Compiled by Dan Fagre

This work group examined the needs of MBR managers for information on changing ecosystem functions during climatic change. The focus was primarily on net primary productivity, carbon sequestration and hydrology. Because ecosystem models require monitoring data for parameterization and validation of outputs, two representative MBRs were reviewed for available data and the specific needs of their managers.

MBR managers' information needs and available data

The Changbaishan MBR (represented by Li Yang) needs improved vegetation cover maps and change-detection maps, to assess rates of past change. A large typhoon destroyed a considerable forested area, so there is interest in understanding the impacts of large-scale disturbances on ecosystem function. Specific ecosystem function information is needed for the four vegetation zones in the MBR (that cover vegetation from the temperate to the polar) to assess impacts of climate change. Carbon storage, particularly fuel maps, would be a valuable adjunct to understanding the role of fire in this ecosystem. Fire management and firefighting operations would benefit from a fire-spread model such as FARSITE (Finney et al. 1995).

Two weather stations are operated in the MBR (one was established in 1950). There is one river gauging station (established in 1980). Neither is operated by the MBR, which has to buy the data. The MBR has a GIS with several layers at present. These include a soils map, vegetation cover, DEM and jurisdictional boundaries.

The Huascarán MBR (represented by Jorge Recharte) has three major features that are of concern regarding climate change, ecosystem function and MBR management. These are their glaciers, grasslands and high-altitude relict forests dominated by *Polylepis* spp. Potential future changes in hydrology are a concern because of current glacial recession rates that already have caused problems in the adjoining grassland communities and further downstream. The MBR would like to understand glacier recession impacts on vegetation, including plant colonization of areas vacated by glaciers. There has been discussion regarding whether vegetation can be managed to slow down glacier melting with attempts at reforestation and microclimate management. Similarly, the MBR would like to know if there are grassland/forest management approaches that would reduce the amplitude of fluxes in basin runoff. The current discharge variability is causing erosion and increasing natural hazards. In general, the MBR would like to link natural hazards to ecosystem process models; for example, what will future hydrology do to geomorphological hazards? A focus of this MBR is on carbon sinks and the possibility of obtaining carbon funds via carbon sequestration in the Polylepis forests. An estimate of the annual grassland carbon stored would be useful for establishing carrying capacity under both present and future climates.

This MBR has a unique need to understand groundwater hydrology in the context of climate change. The largest copper/zinc mining operation in the world is just outside the MBR and there also are high concentrations of natural contaminants in the groundwater. A large reservoir has been built in a high-elevation valley to hold mining contaminants underwater. Potential leakage into the groundwater is a concern but so is the availability of surface water to keep the contaminants underwater. This reservoir is in an active earthquake zone and climatic change was not considered when engineering the reservoir. Mapping groundwater pathways, modeling groundwater flows and linking the annual basin water balance to groundwater are fairly urgent actions to aid MBR management in assessing water supply and contaminant issues. Continual baseflow recession analysis was suggested for understanding potential groundwater issues. Water quality analyses could help in estimating ground water flows/pathways (essentially tracer studies) that could be useful for remediation of groundwater pollution.

There have been glacier mass balance measurements since about 1940. Three Pacific watershed climate stations are available with data extending back to 1940. Twelve river gauging stations exist and a hydropower company calculates the annual water balances. However, the MBR management faces difficulties in accessing the data collected. Some remote sensing data already are available from the two science teams associated with the glacier research.

Tools for understanding ecosystem function

Remote sensing

A useful starting point for obtaining ecosystem-scale perspectives on potential function, or determining relevant MBR physical characteristics, can be derived from remote sensing techniques. The foremost need is for multitemporal Landsat coverages at 30 m resolution to derive basic vegetation cover. This should be standardized across all MBRs so that similar estimates of vegetation diversity and comparable levels of change can be detected. Historic rates of change for all MBRs can be detected using 1982 and 2002 Landsat scenes. These ecosystem change rates can also act as a gauge against which projected future change in MBRs can be compared. The historical changes also can be used to validate ecosystem function models at broad scales. The Normalized Difference Vegetation Index (NDVI), also derived from Landsat, can provide a standardized proxy for ecosystem productivity across MBRs that have different vegetation covers. Change detection for MBRs could be automated by acquiring Landsat scenes at preset intervals and processing them with the classifications determined for each MBR.

Remote sensing data are widely available, relatively cheap, and extend back to approximately 1980. Many ecosystem function analysis techniques have been developed, and people can play with Landsat data on their own with readily available software. One possibility for GLOCHAMORE to consider is to use students at a Swiss university who are paired with an MBR to do more sophisticated analyses or validations of models. Many students would be eager to do this on a volunteer basis or may base a thesis on a particular problem. The human component costs could be managed if each MBR had a basic GIS capability and web-based instructions were provided to do basic ecosystem comparisons. This first stage would need centralization to establish comparable approaches and algorithm choices across MBRs to facilitate a network-wide analysis, but the system could then be decentralized so MBRs are asking and answering very specific questions with remote sensing data. It will be particularly important to have analyses extend beyond the MBR boundaries to capture change in surrounding landscapes of critical importance to the MBR function. This may require the purchase of full Landsat scenes for most MBRs.

Ecosystem modeling

Ecosystem models offer useful perspectives on ecosystem function that cannot be directly derived from remote sensing. Further, the models can be used to assess MBR responses to different management and climate change scenarios. Their results allow relative comparisons between MBRs or over time under different scenarios. The Regional HydroEcological Simulation System (RHESSys) model running on a desktop personal computer (PC) at each MBR is a useful starting point. This approach has been used at Glacier National Park MBR (Fagre et al. 2005).

Initially, a centralized approach similar to that proposed for remote sensing could guide users with either hands-on training or web-based instruction. A small team could establish the capability at each MBR and help prepare the input datasets. Establishing this capability could be a GLOCHAMORE proposal for the near future. Implementing the RHESSys PC model would provide a first, general assessment of ecosystem function at each MBR using a common tool that facilitates MBR network comparisons. Interpretations would be customized to each MBR and additional models employed for specific MBR needs.

A major drawback of ecosystem models is input data problems. Good soils maps, for instance, are relatively rare but important for most ecosystem models. The challenge for a GLOCHAMORE ecosystem modeling initiative will be to find minimum datasets common to all MBRs. This data-gathering phase would act as a data inventory for the MBR network and may help target funding to bring specific MBRs up to the minimum datasets needed for modeling.

Once RHESSys PC can be implemented, common outputs from all MBR model runs can be compared. These potentially include hydrologic discharge, net primary productivity, and carbon storage (a proxy for fuel build-up relevant to wildfire potential). Common climate change scenarios can then be applied. An ensemble of IPCC climate change scenarios will capture the range of forcings for use in assessing MBR responses. The relative sensitivities of biospheres to this range of forcings will be of key importance for each manager and, globally, will identify MBRs of highest vulnerability. As interesting as these model results may be, this common ecosystem modeling approach will help to prioritize ecosystem monitoring activities by identifying common validation datasets. This should be linked to the GLOCHAMORE monitoring workshop results and proposed monitoring initiative.

The Ecosystem Function Working Group considered the minimum data from field monitoring for effectively utilizing modeling to assess climate change impacts to MBRs. At least one strategically located stream gauging station in a relatively undisturbed watershed, a climate station and a vegetation cover map with some level of Leaf Area Index validation would be needed for parameterizing models. Estimating annual water balance for key watersheds within the MBR using a nested watershed design would provide the most comprehensive understanding of MBR hydrology and may help identify spatially explicit ecosystem changes (e.g. mid-elevation vegetation changes that affect evapotranspiration).

The working group also felt common science questions should be asked across the MBR network, such as the relative effects of elevation on key ecosystem functions. MBR managers should examine modeling results from applying future potential scenarios to look for possible thresholds in ecosystem function changes. Climatic and ecosystem function variability will become issues long before permanent changes in average values, and should be tested by the model applications. As previously described, establishing the relative sensitivity of different biospheres to climatic change should be an objective of applying models.

Future research

Eventually, the ecosystem function modeling and monitoring must include managed ecosystems and incorporated management policies and guidelines to provide relevant results for key decisions. These future applications will have many of the same information requirements as those applied to the core areas of the MBRs. Future GLOCHAMORE proposals need to address the difficult task of coupling ecosystem models to socio-economic models. Coupling ecosystem models with farming system models could be a first attempt, since decision making about management of land (e.g. grassland) in MBRs will mainly be done at the farm level. In a second step these models may be linked to, for example, marked models to account for the impacts of the socio-economic conditions on the decision-making process at the farm level (see preliminary web site: http://www.seamless-ip.org/).

Changes of land use

Compiled by Frank Ewert, Andrew Hansen and Greg Greenwood

The occurrence and importance of changes in land use and land cover

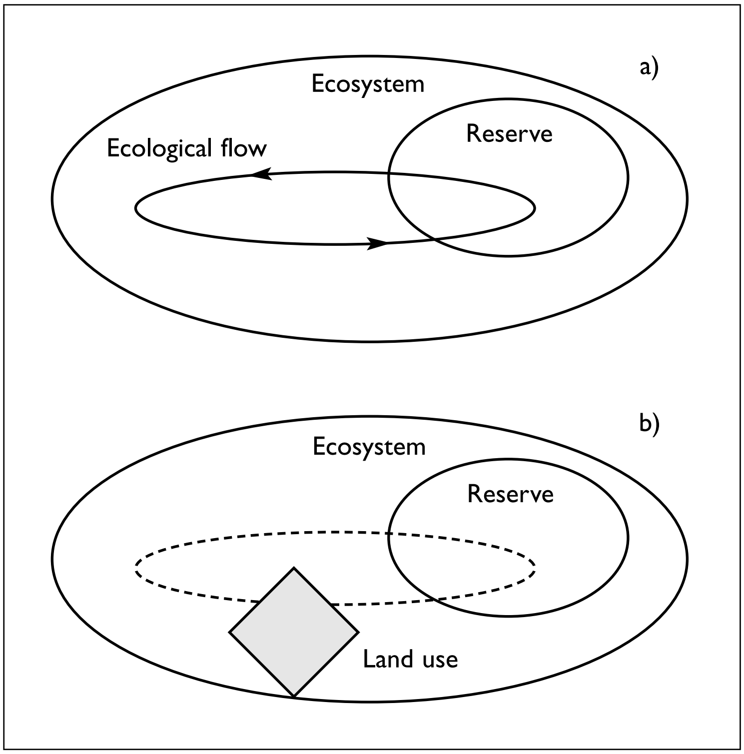
Land-use and land-cover change (LUCC) is increasingly recognized as a key component of global change. Land use may influence ecological systems by altering ecological processes and biodiversity, and it may also interact with climate to drive ecosystems.

Managers of MBRs often see LUCC as a more immediate concern than climate change. LUCC often correlates with economic development as well as changes in ecosystem services. It can frequently affect other key resources, for instance through impacts on downstream water supply and quality. In addition, and unlike climate change, LUCC appears to be under more immediate policy control. In any event, LUCC establishes a framework that controls the expression of climate change impacts across landscapes. Thus, LUCC is a key issue for many MBR managers and therefore a key entry point for global change scientists.

LUCC is manifest through agriculture, resource extraction and urbanization, and it is increasing rapidly around many nature reserves in the world (DeFries et al., in press). Many unprotected wild lands around nature reserves have been converted to human uses over the past decades at an accelerating rate. In some developing areas, road construction and demand for resources is leading to the harvesting of primary forest (Curran et al., 1999). In older settled areas, increases in wealth, technology and population density are leading to more rural settlement. In the US since 1950, for example, rural residential development has been the fastest growing land-use type and now covers 25 per cent of the lower 48 states (Brown et al., in review). Rates of land-use intensification around reserves may be even faster than on private lands in general. Particularly, nature reserves often contain natural amenities (e.g. scenery, wildlife, outdoor recreation) that attract higher rates of land-use activity near park borders (Rasker and Hansen, 2000).

LUCC in and around reserves affects reserve function through ecological linkages (Figure WR.2). Reserves are often connected to surrounding areas by flows of energy, materials, and organisms (Hansen and DeFries in preparation). The larger, effective ecosystem encompassing a park includes those areas where ecological interactions are strongly tied to park processes. Hence, the functional integrity of ecological processes within parks reflects their inclusion in a larger system. Recognizing parks as parts of larger ecosystems thus facilitates understanding of how land-use

Figure WR.2
a) Nature reserves as part of a larger ecosystem with energy, materials and/or organisms flowing through the ecosystem.
b) Human activity in the unprotected portion of the ecosystem disrupts ecological flows and alters properties of the nature reserve.



change in unprotected areas outside parks can disrupt ecological processes within parks. This is especially true for land use, as intense land-use change frequently occurs just outside of park boundaries but can exert strong impacts within park boundaries.

Projecting LUCC through models and scenarios

A range of models has been developed to better understand, assess and project changes in land use and land cover (Veldkamp and Lambin, 2001; Parker et al., 2003; Veldkamp and Verburg, 2004). More recently, models have become available that combine knowledge and tools from biophysical and socio-economic sciences (Veldkamp and Verburg, 2004). This has resulted in spatially explicit models focused on patterns of change as well as agent-based models focused on the underlying decision processes (Veldkamp and Verburg, 2004). However, in spite of these advances the multiscale analysis of complex systems in a biophysical and socio-economic context remains quite difficult.

Processes of land-use and land-cover modification, particularly urbanization and the associated agricultural land intensification, require particular attention. Important factors that should be considered when developing future LUCC models are the geographic and socio-economic context of a particular study, the spatial scale and its influence on the modeling approach, temporal issues such as dynamic versus equilibrium models, thresholds and surprises associated with rapid changes, and system feedbacks (Lambin et al., 2000). Factors at multiple scales are frequently important. The factors that explain LUCC in a region arise from both the specific socio-economic and environmental characteristics of that region and processes operating at larger scales. For instance, agricultural land-use change within a region cannot be assessed independently of the socio-economic conditions in the country or even larger administrative units (Table WR.1). The identification and quantification of drivers of LUCC often requires consultation with experts in the specific field and involvement of stakeholders.

The quantification of the factors driving future LUCC is often impossible. In that case, scenarios may be used to explore alternative options of LUCC, considering specific assumptions about changes in environmental and socio-economic conditions. Scenarios are coherent, credible

Table WR.1
Key drivers of agricultural land-use change in Europe (Ewert et al., 2005a; Rounsevell et al., 2005). Drivers were identified in cooperation with stakeholders and can be organized in three main groups: supply and demand for food; feed and fibre; and policy. Changes in land use will depend on changes of these drivers. For instance, increases in crop productivity will result in oversupply if demand remains constant. Without market intervention, oversupply is only avoidable through reduction in land use.

Suppy	Demand	Policy
Land use competition (e.g. urban)	Population (Europe, world)	Market intervention (subsidies, quotas)
Suitable areas	Consumer diet and preferences (meat, organic)	Rural development
Productivity (climate change, CO_2, research and technology)	Import/export regulations (World Trade Organization)	Environment protection (e.g. nutrient vulnerable zones)

stories about alternative futures. The scenario approach is widely used in many sciences (physical, economic and social) in varied circumstances and for different purposes (Alcamo, 2001; Carter et al., 2001). Importantly, scenarios are not predictions or preferences of the future. Rather, the main idea of the scenario approach is to use multiple perspectives to explore a specific problem. The development and application of environmental change scenarios has been reported widely (e.g. Alcamo et al., 1996; Leemans, 1999; Nakícenovíc et al.; 2000, Rotmans et al.; 2000, Mearns et al. 2001).

Early attempts at developing scenarios of socio-economic change have tended to focus on qualitative descriptions (e.g. the Acacia project, Parry, 2000; the Visions project, Rotmans et al., 2000), short time spans and a 'best-guess' approach (e.g. the SeEOR project, Alexandratos, 1995) or the global scale (Arnell et al., 2004), or have been constructed for small, well-characterized regions (e.g. the RegIS project, Holman et al., in press) or individual countries (Kaivo-oja et al., 2004). A suitable and widely accepted concept for the development of spatially explicit scenarios for land-use change is the IPCC Special Report on Emissions Scenarios (SRES, see Nakícenovíc et al., 2000). In the SRES scenarios, principal drivers of land-use change (both biophysical and socio-economic) are integrated using an internally consistent framework.

A recent research effort in the context of the EU project ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling) provides an example of the integrated estimation of land-use change (Ewert et al., 2005a,b; Rounsevell et al., 2005). The project considered important environmental and socio-economic drivers for Europe (Table WR.1) and developed scenarios of land-use change suitable for ecosystem analysis. The scenarios were based on SRES storylines, from which the key drivers of land-use change were identified and scaled down from the global to the regional and sub-regional levels (Rounsevell et al., 2003). Drivers were then quantified to estimate land-use changes for the entire study area, which were allocated to individual grid cells across Europe according to scenario-specific rules (see Figure WR.3). Stakeholders were involved

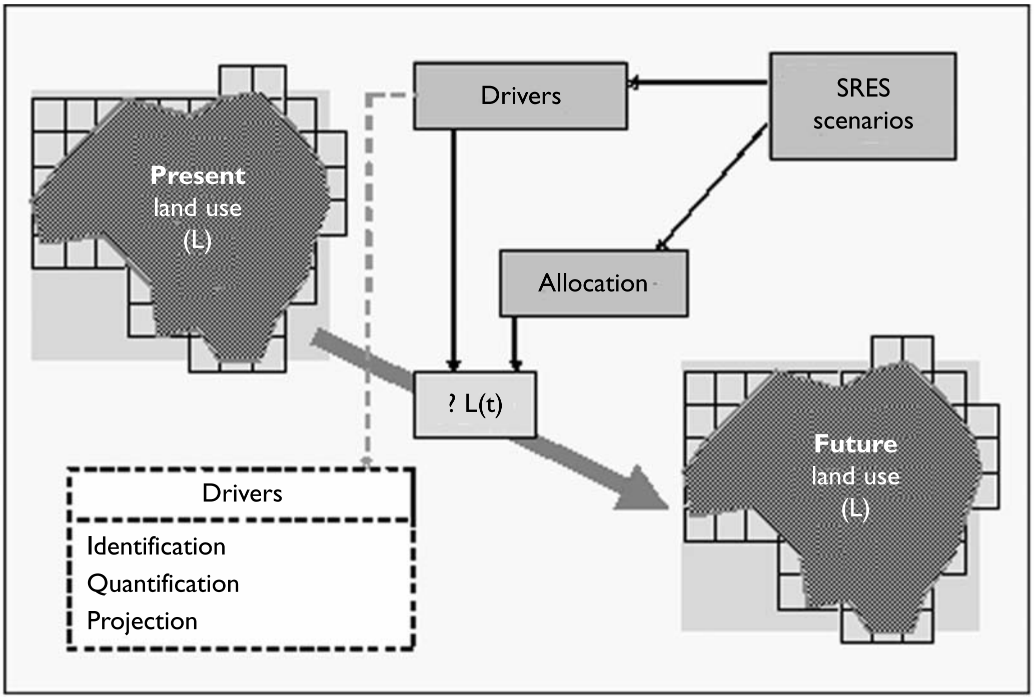


Figure WR.3 Schematic representation of the general methodology for the development of quantitative, spatially explicit and alternative scenarios of future land use in Europe. The methodology was developed in the EU-funded ATEAM project (Rounsevell et al., 2003; Ewert et al., 2004a).

in all activities, including the identification and quantification of drivers and the formulation of allocation rules. To ensure proper communication with stakeholders and the subsequent use of the results in regional development discussions, simplicity and transparency were important modeling criteria. This approach might serve as a template for the derivation of LUCC scenarios for MBRs.

Assessing LUCC impacts on reserves

The conceptual model of the relationship between reserves and regions (Figure WR.1) leads to hypotheses on the ways in which land use outside reserves may influence ecosystem services such as biodiversity within them. Hansen and DeFries (in preparation) outline four general mechanisms through which land use may impact park processes (Table WR.2):

- *Effective ecosystem size.* Conversion of a park's surrounding landscape reduces the size of its effective ecosystem. Reduction in functional size can simplify trophic structure, degrade the reserve's ability to recover from natural and anthropogenic disturbances, and increase species extinction rates.
- *Ecological flows.* Land use may inhibit flows of nutrients, energy and organisms through a park's surrounding ecosystem.
- *Unique habitats.* Conversion of surrounding lands may eliminate or isolate unique habitats outside parks, such as dispersal and migration habitats or important source populations.

Table WR.2 General mechanisms by which land use around nature reserves may alter ecological processes and biodiversity within reserves (Hansen and DeFries, in preparation).

Mechanism	Type	Description
Change in effective size of reserve	Minimum dynamic area	Temporal stability of seral stages is a function of the area of the reserve relative to the size of natural disturbance.
	Species area effect	As natural habitats in surrounding lands are destroyed, the functional size of the reserve is decreased and risk of extinction in the reserve is increased.
	Trophic structure	Characteristic spatial scales of organisms differ with trophic level such that organisms in higher levels are lost as ecosystems shrink.
Changes in ecological flows into and out of reserve	Initiation and runout zones	Key ecological processes move across landscapes. 'Initiation' and 'run-out' zones for disturbance may lie outside reserves.
	Location in air- or watershed	Land use in upper watersheds or airsheds may alter flows into reserves lower in the water- or airshed.
Loss of crucial habitat outside reserve	Seasonal and migration habitats	Lands outside reserves may contain unique habitats that are necessary for organisms within reserves. Organisms require corridors to disperse among reserves or to migrate from reserves to ephemeral habitats.
	Dispersal/migration habitats	
	Population source sink habitats	Unique habitats outside of reserves are 'population' source areas required to maintain 'sink' populations in reserves.
Increased exposure to humans at park edge	Hunting/poaching; exotics/disease	Negative human influences from the reserve periphery extend some distance into nature reserves.

- *Edge effects.* Edge effects from adjacent land use may introduce invasive species, and alter community structure within parks (e.g. invasive species, predator communities).

Management designs thus need to consider nature reserves and the effective surrounding ecosystem. Considerable attention has focused on regional designs for maintaining connectivity among nature reserves (Miller et al., 2001). However, comprehensive approaches to regional management are only now being developed (Prendergast, 1999; Margules and Pressey, 2000). The ecological mechanisms presented above provide design criteria for regional landscapes (Table WR.3). Knowledge about land use, about the spatial dynamics of these ecological mechanisms, and about the responses of ecological processes and biodiversity provides a context identifying the places in the unprotected parts of the ecosystem that are most critical for maintaining ecosystem function and biodiversity within nature reserves. Several incentive and regulatory tools could be used to maintain ecological function in these keystone locations (Theobald et al., in review). Once management designs are implemented, monitoring can be used to assess management effectiveness, update natural resources objectives, and improve models.

Table WR.3
Criteria for managing regional landscapes to reduce the impacts of land-use change outside nature reserves on ecological processes and biodiversity within reserves

Mechanism	Type	Design criteria
Change in effective size of reserve	Species area effect; minimum dynamic area; trophic structure	Maximize area of functional habitats
Changes in ecological flows into and out of reserve	Disturbance initiation, runout zones; placement in water- or airshed	Identify and maintain ecological process zones
Loss of crucial habitat outside reserve	Ephemeral habitats; dispersal or migration habitats; population source; sink habitats	Maintain key migration and source habitats
Increased exposure to human activity at reserve edge	Poaching; displacement; exotics/disease	Manage human proximity and edge effects

A LUCC strategy for MBRs

As noted above, the very first step in assessing LUCC impacts on MBRs is an examination of the nature of LUCC surrounding each MBR. While LUCC is clearly important, the exact nature of meaningful change depends on the context of each MBR. In some areas, a shift from grazing to subsistence cropping is the main manifestation of change, while in others changes in seral stage due to fire are most important. In yet other areas, abandonment of grazing lands and conversion to forests is key, while in still others, settlement of those grazing lands is most meaningful. Thus it is not obvious at the outset that a single global classification system of LUCC can capture all the meaningful shifts. However, it is reasonable to categorize MBRs and surrounding areas by their biophysical and socio-economic conditions, from which key drivers and relationships of LUCC may be derived.

While all the managers present at the workshop desired plausible LUCC scenarios for their MBRs and adjacent areas, only a few of the MBRs appear ready to embark immediately on such modeling or scenario development. Many more find themselves at an early stage of inquiry focused on quantifying the current state of land use and land cover, characterizing the current trajectories of change, and understanding better the underlying processes of change. Clearly, these are important prerequisites for developing scenarios of future LUCC.

The most *basic level* of a strategy addressing land-use/land-cover change consists of developing the capacity at MBRs to view and manipulate spatial data and imagery. Not all of the MBRs represented at the workshop possessed GIS. It is hard to imagine that GLOCHAMORE will successfully address most ecological issues, and much less LUCC, without all participating MBRs achieving some minimum competence with GIS as part of their standard operating procedure. Success here involves both equipment and training. Of course, increased GIS capacity is of little use without access to spatial data pertinent to both the current state of land use and land cover, and to its rate of change. This constitutes the *second requirement* for LUCC research in MBRs.

Fortunately, the most basic data (including digital elevation models and repeated satellite imagery) are available virtually for free, and are being used in many MBRs already. The *third component* of the basic strategy involves classification and analysis of the data to achieve a comprehensive view of land-use/land-cover condition and trend. Change detection through comparison of repeated imagery holds particular promise for quickly locating and quantifying the nature of land-use/land-cover change. Thus, an essential next step for GLOCHAMORE will be to assess the current GIS resources (equipment, personnel and data) at each MBR.

The *next level of the strategy* involves process studies to understand the origins and causes of the observed changes. This research will require a clear definition of the nature of the expected change (e.g. change in range condition) and the development of specific hypotheses (e.g. changes in production practices of red deer as a function of market prices). It includes the identification of key drivers and relationships determining LUCC. Progress in quantitative understanding of relationships between changes in drivers and LUCC will eventually allow for the most advanced strategy.

This *most advanced strategy* involves the development of informed future land-use scenarios based on spatial data portraying the current conditions and spatial modeling of potential future change considering all important processes determining LUCC. It may be possible to find a shortcut through this work by simply specifying future LUCC scenarios through a stakeholder process (i.e. the land-use/land-cover equivalent of identifying a warmer and wetter climate change scenario without using GCM or RCM runs), but the power of such scenarios will depend almost entirely on the credence and plausibility accorded them by decision makers and stakeholders. However, the combination of simulation modeling and stakeholder involvement has been shown to be most effective in developing scenarios of LUCC.

Remote sensing of mountain environments

Compiled by Andreas Kääb

Introduction

Remote sensing technologies provide powerful tools today for observing mountain environments such as mountain biosphere reserves (MBRs). Due to the difficulties of access to most mountain regions (be it for physical and/or political reasons), remote sensing is often the only way for investigating large sections of Earth's surface. The purpose of this contribution is to give a brief overview of how remote sensing can contribute to the mapping, monitoring and modeling of mountain environments.

In general, remote sensing methods can be classified according to the platform location (space, air or ground) and according to the section of the electromagnetic spectrum covered by the sensor (visible and near-infrared light, short-wave infrared, thermal infrared, and microwaves). Together with the basic sensor types – 'active' (sending and receiving signals) and 'passive' (receiving signals from a natural source) – the combination of the above characteristics determines to a large extent the applicability of the data and the cost, expertise and analysis equipment required.

The typical data characteristics for the three platform types are as follows:

- *Spaceborne platforms*: high acquisition frequency of up to some days; coverage of up to tens of thousands of km^2 by one scene; potential coverage of the complete surface of Earth; spatial resolution from metres to hundreds of metres; decade-long time series already available; data costs in the order of €1/km^2 or much less.
- *Airborne platforms*: low acquisition frequency of (usually) years; one scene covers a few or a few tens of km^2; study areas have to be accessible by plane or helicopter; spatial resolution from centimetres to metres; decade-long time series partially available (mapping authorities); data costs from of a few euros per km^2 (data reproduction) to hundreds of euros per km^2 (original acquisition).
- *Terrestrial platforms*: very high acquisition frequency possible (hours and less for automatic systems); coverage of single points or a few hundred metres; study areas have to be directly accessible; spatial resolution from millimetres to metres; data costs from of a few euros to hundreds of euros per km^2.

According to the sections of the electromagnetic spectrum exploited, remote sensing data are characterized as follows:

- *Visible light and near-infrared (VNIR)*: sensors collect the reflected sunlight (passive sensors); data content similar to what the human eye sees; multi- and hyper-spectral sensors split the light in separate sections of the spectrum, which facilitates automatic analysis; laser sensors (light detection and ranging, LIDAR; active sensors) often use near-infrared.
- *Short-wave infrared (SWIR)*: some surfaces show significantly different reflectivity in the SWIR compared to VNIR (e.g. ice, vegetation), or a high variability in reflectivity with wavelength (e.g. according to the mineral composition). These properties enable (automatic) multi- or hyper-spectral classification.
- *Thermal infrared (TIR)*: the long-wave emitted radiation is indicative for the surface temperature (e.g. helpful for energy balance studies or surface characterization).
- *Microwaves*: the surface reflection of microwaves (wavelength in the order of millimetres to metres) depends on the dielectric (near-)surface properties, which are sensitive to roughness and humidity among other factors. Synthetic aperture radar (SAR) combines multiple radar returns to images. In contrast to optical sensors, which do not work through clouds, microwave sensors have all-weather (and day-and-night) capabilities.

Digital elevation models

From a topographic point of view, large relief essentially defines mountains. Thus, digital elevation models (DEMs) usually form the base data for any mountain geo-information system and any spatial model.

If not readily available (e.g. digitized from topographic maps), satellite-derived DEMs can be computed from optical satellite stereo and interferometric SAR (InSAR). Satellite stereo using sensors such as ASTER or SPOT5 provides DEMs with a spatial resolution in the order of some tens of metres, and with a vertical accuracy in the order of some metres to a few tens of metres. InSAR-derived DEMs have similar resolution and accuracy, but are not limited by cloud cover at the time of data acquisition.

A unique DEM that is available at no cost for the land area between 60°N and 54°S was computed from the Shuttle radar topography mission (SRTM). The SRTM DEM has a spatial resolution of about 90 m and a vertical accuracy in the order of metres to a few tens of metres.

Another group of DEMs with better spatial resolution and vertical accuracy is derived from aero-photogrammetry (based on analogue or digital imagery), airborne InSAR and laser scanning. Stereo-photogrammetry of air photos is one of the best-established methods for DEM generation. DEMs produced with this method have a spatial resolution of some metres to some tens of metres, and a vertical accuracy in the centimetre to metre range. Similar DEM characteristics are obtained from airborne InSAR. A slightly better vertical accuracy and a significantly higher DEM point density (metre-order) compared with aero-photogrammetric DEMs and airborne InSAR can be achieved by airborne laser scanning. This technique offers possibilities if high resolution and accuracy are required.

Apart from providing terrain elevations, InSAR and laser scanning can be used to derive forest tomography, a valuable tool for forest and fire management. The vertical structure of the forest can be resolved if several return pulses from different heights of the vertical vegetation column are recorded, and if the signal amplitude (varying with the leaf size and density) is also analysed. Similarly, different radar wavelengths penetrate differently into the canopy. Thus, multifrequency SAR systems are also able to resolve the vertical forest structure.

For detailed and local studies, terrestrial methods can also be used for DEM generation. Global navigation satellite systems (GNSS, e.g. the GPS) and optical levelling require direct access to the DEM points but provide centimetre to millimetre accuracy. Remote-controlled close-range techniques are available for polar survey with laser rangers. Terrestrial laserscanning is an upcoming technology providing nearly continuous descriptions of object surface geometries.

Terrain movement

Mass movement systems are particularly effective in mountains and are therefore important drivers of mountain landscape evolution and related processes. Vertical changes, such as glacier thickness changes or different types of accumulation/erosion, can often be derived as differences between repeat DEMs. Horizontal glacier movement can under certain circumstances be measured from matching of repeat satellite imagery, at a horizontal accuracy in the order of ten metres. Similar techniques are applied to air and terrestrial photos, providing horizontal terrain displacements on landslides, glaciers and rockglaciers with some centimetres to decimetres accuracy. The surface movement of dry and open terrain can be determined with millimetre accuracy through spaceborne repeat application of InSAR (differential InSAR, DInSAR). This technique is for the most part used for landslide monitoring. Classical terrestrial methods for observing the movement of single terrain points are GNSS and polar survey.

Surface cover

One of the most common applications of remote sensing is mapping and characterising the surface cover. Manual and semi-automatic segmentation of optical images for vegetation, open water, snow, ice, rock, human artefacts and so on can be based on panchromatic or colour images. Multispectral remote sensing offers the opportunity for automatic classification of surface cover utilising the variation in reflectivity with wavelength, which differs for most surface types. Besides such purely spectral classification methods, spectral-spatial methods are in particular promising also involving, for example, DEMs or neighbourhood relations. Complementing VNIR data with SWIR and TIR in the spectral analysis allows the discrimination and description of surface types, which cannot be accomplished by the human eye. Multispectral analysis techniques are particularly powerful (and of special interest for MBRs) if applied on repeat imagery (change detection). Thus, land-cover/use change can be detected very efficiently.

Another class of surface characterization, very different from the above optical methods, stems from the analysis of SAR backscatter, possibly even polarimetric or multi-frequency. These techniques are presently at the research level and thus much less established than multispectral ones. Similarly, utilizing hundreds of different, very narrow spectral bands (hyperspectral remote sensing) instead of some broad bands in multispectral imaging allows for much more detailed but more complicated surface characterization (e.g. vegetation, lithology, open water composition).

In general, the accuracy of spectral or SAR derived classifications and mappings is in the order of the applied image pixel size: ranging from metres to tens or hundred of metres for spaceborne sensors, and centimetres to metres for airborne sensors.

Remote sensing of MBRs: a proposal

The possible applications of remote sensing to mountain environments, and UNESCO MBRs in particular, are too manifold to be listed here. They largely depend on the human, technical and financial resources, and the knowledge level available at the specific MBR. Focus should therefore be on establishing a minimum but global set of data, methods and expertise with respect to remote sensing application in/to MBRs. A standardized and compatible set of data, methods and results facilitating inter-MBR knowledge sharing and support is the potential outcome of such strategy. The first steps towards the proposed strategy are:

1. A representative set of pilot studies.
2. A survey of needs, and GIS and remote sensing resources existing in the MBRs.
3. Selection of sophistication levels.
4. Selection of related sets of data and methods.

CONCLUSIONS AND RECOMMENDATIONS

The presentations and discussions at this GLOCHAMORE workshop provided several important insights that should be incorporated or addressed in the GLOCHAMORE research strategy.

First, modeling, process studies and observations should be conducted as an integrated effort. The development of models needed to study future trajectories of ecosystems, land use and societies in MBRs (and elsewhere) relies on a sound understanding of the key processes driving past and present dynamics, which in turn depends on observations. Models can be used to guide future observational and process studies, so that these three components of scientific inquiry provide a sound basis for natural resource management.

Second, MBRs (and mountain regions in general) need sound modeling tools to support management in the face of rapid environmental change. The workshop showed that even with modest means (i.e. at the 'minimum level'), models provide preliminary insights into the future trajectories of cryospheric, hydrological, ecological and land-use systems in mountain regions.

Remote sensing, in particular satellite-based, is able to support a number of MBR modeling issues, such as base data, land-cover data, detection of changes, or trans-boundary issues. A basic and globally applicable remote sensing component should become part of the MBR scientific strategy.

Third, MBRs will require specific, place-based projects to achieve the promise noted above. This requirement arises not just from the biogeophysical uniqueness of each MBR but also from the variation among MBRs in the technical and infrastructural capabilities to support modeling.

Fourth, modelers should render their models – their inputs, their outputs and the transformations that convert one to the other – as transparent as possible to the many user groups, especially to politicians and decision makers. Models do not merely generate numbers but in fact provide insight into how the world works, and as such as are particularly powerful in providing insights for politicians and decision makers. An attention to transparency will improve if not actual comprehension by these groups, at least confidence in the model and modelers. Ideally, stakeholders are involved in the process of model development. Suitable participatory methods for stakeholder involvement may depend on the specific conditions of each MBR.

Fifth, trans-national collaborations on scenarios for the future of MBRs that span or abut national boundaries are essential. Environmental change does not recognize national boundaries; neither then should our analyses and tools. Finally, regional climate scenarios and land-use change scenarios stood out as key products applicable to nearly all MBRs. The climate scenarios should emphasize changes in the frequency and magnitude of extreme events (rather than changes of averages), as extremes have strong impacts on, for example, energy production, water quality and surface runoff (erosion). Impact models in other sectors should assess the impacts of changes in the seasonality of climate parameters and the distribution of extreme events. Land-use change scenarios will allow the MBRs to assess the impacts of this other important global change driver. In addition, their use will drive the deployment of geographic information systems at MBRs, a prerequisite for the use of any remotely sensed data or detailed projection of future conditions.

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Appendix 1
Results of MBR questionnaires

	Vertical range m	Area (ha)	Climate observations	Elev. range for meteo. stations	Forests restoration timber fuel wood carbonsink	Glaciers	Hunting fishing	Endangered spp.	Charismatic spp/wildlife/migratory waterfowl	Other vegetation	Active recreation	Tourism and associated infrastructure; pilgrimages	Snow cover	Hydro power	Water supply, water quality, transboundary water	Spiritual site	Medicinal non-timber forest products bees	Grazing lands meadows	Agriculture	Research site	Resource conflict/governance/population movements/sustainable harvest	Lakes, wetlands	Avalanches	Pests, disease	Fire	Desertification, soil erosion	Floods/lake outbursts	Earth movements	Invasives	Coastal	Permafrost	Mining	Severe winters
Sikhote-Alin	1,900	340,000	5	50–350	1		1				1	1			1		1	1		1					1					1			
Kruger to Canyons	1,900	2,500,000	4	700–1900	1			1			1	1			1		1	1		1								1					
Berchtesgaden	2,200	47,000	6	700–2500	1					1	1	1	1		1			1		1			1	1				1			1		
Sierra Nevada	3,100	172,000	39	400–1700			1	1			1	1	1		1			1	1		1			1	1	1	1						
Huascarán	4,300	400,000	15	1400–5100	1	1					1	1			1			1	1			1	1					1					
Niwot Ridge	700	1,200	6	2000–3800							1				1					1			1		1			1					
Mount Arrowsmith	1,800	119,000	2		1			1	1		1	1			1	1								1	1		1		1	1			
Kosciuszko	2,000	626,000	6	1300–2000			1				1	1	1	1	1									1	1				1				
Glacier	2,200	410,000	5	980–2100	1	1		1	1	1	1	1			1	1				1		1	1		1				1				
Gossenkollesse	400	100	1	2400							1		1					1		1	1	1						1					
Lake Torne	1,300	97,000	1	400			1				1		1					1		1	1		1				1	1			1		
Gurgler Kamm	1,500	1,500	2	1930	1	1		1		1	1	1	1					1		1	1		1				1	1			1		
Katunskiy	3,700	695,000	4	900–2600	1	1			1	1	1	1	1		1		1	1			1	1	1		1		1	1					
Chanbaishan	2,000	196,000	2	780–2600	1		1					1	1	1	1		1							1	1			1					
Tassilil N'Ajjer	1,000	7,200,000																															
Swiss National Park	1,700	172,000	7	1300–2300	1		1	1	1		1	1		1	1			1			1		1		1		1	1	1		1		
Entlebuch	1,800	40,000																															
Araucarias	2,300	94,000																															
Olympic	2,400	370,000																															
Kavkazkiy	3,000	276,000																															
Torres del Paine	3,000	184,000	3	40–270		1			1		1	1						1		1	1						1						
Oasis du Sud	3,400	7,200,000																															
Mt. Kenya	3,600	72,000	14	600–2300	1	1	1	1				1	1	1	1			1	1		1			1	1		1						
Cinturon Andion	4,000	175,000	41	2200–3500	1	1				1				1	1	1		1	1		1		1	1			1		1				
Nandi Devi	4,100	200,000																															
Denali	6,100	780,000																															
Issyk-Kul	6,400	4,300,000	1		1	1	1					1			1		1						1				1	1	1			1	
TOTALs					14	9	9	8	6	5	15	16	9	5	16	3	6	14	4	10	9	5	10	8	11	2	11	12	6	2	4	2	1

Appendix 2
Workshop agenda

MONDAY 29 NOVEMBER

9.00	Workshop opening: Welcome, objectives, and products *Harald Bugmann (Switzerland) and Thomas Schaaf (France)*
9.15	Presentation of biosphere managers' 'hit list of urgent needs' regarding projections of the impacts of global changes[1] *Greg Greenwood (MRI)*
9.45	Comments on and discussion of hit list
10:15	*Poster session[2] including coffee break*
11.00	**Session A: Climate modeling** Regional climate modeling in mountain regions *Guido Visconti (Italy)* Perspectives of climate change in the Alps *Martin Beniston (Switzerland – in absentia, presented by Harald Bugmann)*
12.15	*Lunch*
13.45	**Session B: Snow and ice modeling** Mass balance modeling in the French Alps: reconstruction and sensitivity to climate *Jean-Pierre Dedieu (France)* What is global change doing to Alpine surface processes (in particular snow processes) and vice versa? *Michael Lehning (Switzerland)* Glaciers and permafrost in mountain areas: different model approaches *Martin Hoelzle (Switzerland)*
15.00	*Coffee break*
15.30	**Session C: Hydrological modeling** Hydrological modeling for simulating the effects of global change in the hydrological cycle *M. Verdecchia (Italy)*
16.15	**Session D: Ecosystem modeling** Vegetation cover, forest dynamics and fire *Harald Bugmann (Switzerland)* Biodiversity *Antoine Guisan (Switzerland)*
17.30	*Adjourn*

TUESDAY 30 NOVEMBER

8.30	**Session E: Land-use modeling**
	Scenarios of future land-use change in Europe[3]
	Frank Ewert (the Netherlands)
	Ecological mechanisms linking nature reserves to surrounding lands: implications for regional sustainability
	Andrew J. Hansen (USA)
9.45	*Coffee break*
10.15	**Session F: The role of remote sensing**
	The role of remote sensing for developing and validating impact models
	Andreas Kääb (Switzerland)
11.00	**Session G: Integrated modeling of global change impact in mountain regions**
	Integrated projections of climate change impacts to the Glacier National Park Biosphere Reserve
	Dan Fagre (USA)
11.45	*Lunch*
13.30	Introduction of working groups
14:00	Working group session I
15.15	*Coffee break*
15.45	Working group session I (cont'd.)
17.00	*Adjourn*

WEDNESDAY 1 DECEMBER

8.00	Working group session II
10.00	*Coffee break*
10.30	Report from working groups to plenary
11.45	Working group session III. Groups as needed
13.00	*Lunch*
14.30	Working group session IV. Writing assignments for all topics
15:45	*Coffee break*
16.00	Report from working groups to plenary
16:30	Synthesis. Next steps
17.30	*End of workshop*

1. This 'hit list' was compiled via a questionnaire and other survey activities prior to the workshop.
2. Ad-hoc posters from each MBR presenting the 'hit list' of concerns (with examples) about global changes. The posters were on display throughout the workshop.
3. By F. Ewert, M.D.A. Rounsevell, I. Reginster, M.J. Metzger and R. Leemans

Appendix 3
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Third Thematic Workshop:

Sustainable Land Use and Natural Resources Management

Sierra Nevada Biosphere Reserve, Spain

14–17 March 2005

Part IV

Introduction to the Workshop

13 *What are the Important Global Change Themes and Issues in Mountain Biosphere Reserves?*

Gregory B. Greenwood, Mountain Research Initiative, Bern, Switzerland

INTRODUCTION

GLOCHAMORE's main product will be a global change research strategy that mountain biosphere reserves (MBRs) could implement. The research strategy is not only simply to create more knowledge in the minds of researchers, but also to make that knowledge useful for managers, decision-makers and policy makers (Research Strategy Report, 2005).

Achieving impact on management and policy requires, at the very minimum, consultation with the would-be clients of the research strategy (Maselli et al., 2004). GLOCHAMORE strove to involve MBR managers in its strategy-formulating workshops. While laudable and effective to a certain point, including managers in the first scientific workshops did not in itself lead to a rich, mutually beneficial dialogue between scientists and managers. The minimal nature of the dialogue perpetuated the project's relative ignorance of the specific issues and context of each MBR, and therefore threatened to limit the eventual impact of the research strategy.

As a complement to traditional scientist-driven workshops, the MRI and UNESCO MAB jointly decided in mid-2004 to undertake a survey of MBRs to better understand each MBR. The two organizations expected that responses to the survey would help orient future workshops and would focus discussions leading to the development of projects congruent with the emerging research strategy.

METHODS

The MRI and UNESCO MAB decided on an open-ended questionnaire or survey as the appropriate instrument (attached as Appendix). The questionnaire did not use a checklist or other multiple choice format but rather asked for essay responses to a set of questions.

The questionnaire led respondents through an analytical process. It first asked who cared about the reserves and why, that is to say, to identify the Reserve's stakeholders and their stakes. Having thus established a range of interests, the survey next asked how climate change would affect these stakes and consequently stakeholders. The survey made no attempt to specify what direction climate change might take in these reserves but rather asked managers to use whatever scenarios appeared plausible for their reserves. The survey then asked more specific questions regarding hazards in order to focus attention of aspects of global change other than average cumulative trends. Finally the survey asked managers to identify key contentious scientific issues, independent of any consideration of climate or global change. The survey's intent here was to elucidate the issues that structured discourse related to MBR management as these issues would be the most likely points by which global change could enter that discourse. The survey also requested information of meteorological infrastructure, the results of which will not be summarized here.

At time of writing, MRI has received twenty completed surveys from the twenty-eight MBRs nominated by UNESCO. The author undertook a first reading of all the returned surveys in order to develop a master list of values likely to be affected by global change, and hazards and disturbances likely to be exacerbated by global change. These lists of values and hazards became the headings in the spreadsheet included in the Appendix. The set of values and hazards taken together are for this paper termed 'themes'. In addition, the first reading established a list of contentious issues. As these issues tended to be more idiosyncratic, the author tended less to lump these issues together.

It is important to note that these themes have no set epistemological relationship to each other. They are not hierarchical, nor do they represent a set of orthogonal axes. The themes are heuristic shorthand for the expectations of MBR managers regarding global change impacts to their sites. Some themes are internally homogenous: earth movements are generally perceived in a common manner by all who note them as important. Other themes however are relatively heterogeneous (for example, forests). The use of these single umbrella themes in lieu of a set of more finely drawn themes reflects the author's balance of parsimony and accuracy in summary.

The author then re-read the surveys several times in order to determine which themes were associated with each MBR. Generally speaking, the author erred on the side of commission, that is, if a survey mentioned, even without explanation, a theme, that theme was coded into the spreadsheet. The author made no attempt to weight the themes present within a given MBR, but coded strictly their presence or absence.

At time of writing, MRI has asked each MBR manager to review and revise the author's interpretation of the manager's survey. Certain MBRs have completed this revision while others have not. The results reported below reflect the current state of knowledge as of 10 May 2005.

RESULTS

Themes

As of 10 May 2005 the attribution of themes to MBRs, ranked in descending order by the number of MBRs that cited them, are shown in Table 13.1. The responses themselves are available on the Internet at http://mri.scnatweb.ch/component/option,com_docman/task,view_category/Itemid,25/subcat,16/catid,19/limitstart,0/limit,10/ for anyone who wishes to replicate this summary.

Certain themes were quite heterogeneous.

Table 13.1 Themes cited by MBR by frequency of citation

Theme	No. of MBRs citing theme (out of 20 total)
Tourism and associated infrastructure	16
Water supply, water quality, transboundary water issues	16
Active recreation	16
Forests, forest restoration, timber, fuel wood	15
Grazing lands, meadows	13
Fire	12
Earth movements	12
Research site	12
Resource conflict, governance, population movements, sustainable harvest	11
Endangered species	11
Floods, lake outbursts	11
Snow cover	11
Avalanches	10
Glaciers	10
Hunting and fishing	10
Invasive species	8
Lakes, wetlands	8
Charismatic species, wildlife, migratory waterfowl	8
Pests and diseases	7
Medicinal plants, non-timber forest products, bees and honey	6
Vegetation (other than forests or meadows)	6
Hydroelectric power	5
Agriculture	5
Permafrost	6
Spiritual site	4
Mining	2
Desertification, soil erosion	2
Coastal resources	2
Severe winters	1

Tourism and associated infrastructure

The central question was clear enough: how will climate change affect this economically critical sector? However, this deceptively simple question regarding climate change impacts on tourism took a variety of forms in different MBRs. In several cases there was an expectation that warmer average temperatures will simply shift the balance of activities within resort areas. A longer summer season could generate new levels of impacts on infrastructure and resources. And while tourism manifests itself in some isolated MBRs as ecotourism, in other MBRs the expansion of tourism is driven by more generalized economic development. In several cases it takes the form of the expansion of developed ski areas. Finally, tourism is not simply a sink for impacts but is itself a form of global change (see 'Contentious issues' below).

Responses related to *active recreation* showed the diversity of activities that are potential sinks for impacts: not only the standard mountain sports of hiking, climbing and so on, but also guided high elevation mountaineering, biking, four-wheeling, swimming and white water rafting, as well as Army manoeuvres!

The diversity of perspectives related to *forests* may require further clustering in order to allow a coherent and focused research strategy. In certain MBRs forests were viewed clearly as a resource, be it for subsistence (for example, fuel wood) or commercial (for instance, sawlogs), or both. In some of these MBRs the existing forests were plantations, and of these, some were to be maintained while others were to be restored to their pre-plantation condition. In yet other MBRs forests were viewed as plant communities and habitats, the growth, composition and value of which may be driven by climate change. Natural disturbances and human conversion of forests frequently appeared as other drivers, proximate or ultimate, of forest conditions. Whatever approach is developed for estimating global change impacts on mountain forests, it will need to express impacts in these multiple vocabularies.

The diversity of perspectives related to *water* was only slightly smaller than that related to forests. Water was similarly viewed as a resource: for local municipal supply, for irrigation of subsistence and commercial agriculture. A discussion of how climate change will affect that resource must encompass the potential for the new water development, the expedient use of groundwater as a hedge against drought and attempts to modify rainfall. Water pollution, caused by other activities but perhaps exacerbated by low or variable precipitation, was also important. Water was an ecological feature as well, with running water a particularly important habitat itself, the quality of which affects lakes and coastal areas. A research programme that focuses on climate change impacts on water must therefore incorporate other drivers and express impacts on these many values.

While the variety of species *grazing in mountain pastures and meadows* was surprising, grazing lands and meadows carried three values: local subsistence (often using idiosyncratic species – reindeer, llamas), commercial export (for example, red deer) and iconic (for instance, Swiss cow and alpine landscapes). Climate can certainly influence grazing resources but agricultural policy and markets can similarly drive the enterprise.

Conflict and governance issues arose in a dizzying number. In some cases the conflicts were foundational: the need for reserves at all, the accommodation of food security with conservation, the maintenance of cultural identity. Other conflicts are more project or sector specific: timber harvest, large predator management, ski area expansion, snowmaking, reservoir construction, managing tourist numbers. Whatever the research strategy may be, if it is to provide advice, it must learn how to provide that advice, if not directed at resolving, at least within the context of, these kinds of conflicts.

Snow cover had multiple aspects. Snow was iconic and a major tourist draw. Its absence in ski areas encouraged snow making, which was both a water resource issue and a conflict. Snow cover had ecological and environmental impacts on watersheds. And it had economic meaning as a water resource and a limiting factor in the use of mountain areas. Prediction of snow cover will allow assessment of impacts in multiple other sectors.

Most of the remaining themes had two or at most three aspects:

Earth movements:	How will the hazards change, and for whom?
Fire:	How will the hazards change, and for whom?
Floods and lake outbursts:	How will the hazards change, and for whom?
Avalanches:	How will the hazards change, and for whom?
Glaciers:	How will climate change affect their value as icons? How will they generate hazards and for whom? How will they act as water resources?
Hunting and fishing:	How does poaching and illegal introductions interact with climate change to affect game species? How will climate change affect trophy hunting?
Endangered species:	How will illegal poaching and harvest add to climate change to affect persistence?
Invasive species:	How will climate change influence invasions?
Pests and diseases:	How will climate change affect abundance of pests and diseases?
Lakes, wetlands:	How will climate change affect their tourist value? How will it interact with pollution to affect their ecological function? How will their transboundary location influence perception and response?
Charismatic species, wildlife/ migratory waterfowl:	How will climate change affect the many taxa of interest? How will it affect core habitat and habitat linkages?

Contentious issues

Phenomena other than climate change set the context within which climate change is perceived. Appendix Table 2 shows the issues important in different reserves. Table 13.2 lists the issues that MBR managers cited as governing the discourse surrounding their reserves in order of frequency.

Many MBR managers saw their very success as sites for tourism as generating impacts and contention among stakeholders. Tourism, along with active recreation, had impacts on habitat and on water resources. It both drove the natural system itself and, as a receptor of climate changes, modulated that change and created new impacts (for example, snow making).

Disturbances such as fire and pests concerned many stakeholders. While they themselves may be a manifestation of climate change, such disturbances often generated their own dynamics.

Grazing as a driver of ecosystem conditions was a contentious issue in a surprising number of MBRs. Resource degradation, caused by either subsistence or commercial grazing, may be far more important in the immediate future in many MBRs than climate change.

Rare species management was as contentious as grazing. Managing these species created winners and losers. Interestingly, neither grazing nor rare species management were associated with either industrialized or developing countries. These issues cut across development status.

Table 13.2 Contentious issues cited by MBR by frequency of citation

Contentious issues	No. of MBRs citing theme (out of 20 total)
Tourism and active recreation: impacts on habitat, water quality	10
Impacts on and of fire, pests	8
Impacts of grazing of land resources and domestic/wild ungulate relations	7
Rare species management and protection	7
Forest restoration following disturbance	6
Land management impacts on hydrology, flow regimes, groundwater, water scarcity, competing uses for water	5
BR definition and management, desired future condition	5
Land use conversion, impacts of management of surrounding area, infrastructure needs, land use suitability	4
Extent of forest harvest, forest vegetation change	3
Impacts of habitat fragmentation	2
Status of medicinal, non-timber forest products, apiculture	2
Geological or other risks	2
Access to private land as fire risks increase	1
Communication of environmental issues	1
Pollution impacts	1
Impacts of feral animals	1
Effectiveness of cloud seeding	1
Marine ecosystem recovery	1
Impacts of values on management	1
Maintenance of traditional food crops	1

Land management impacts on hydrology and water resources, and the scope and definition of reserves themselves were seen as contentious issues in at least one quarter of the reserves that responded.

IMPLICATIONS FOR THE GLOCHAMORE RESEARCH STRATEGY

A global change research strategy for MBRs is likely to be more widely supported to the extent that it brings information to bear on the values and hazards associated with each MBR. It will be more sustainable institutionally to the extent that such a strategy, if not addressing the full suite of global changes associated with contentious issues, then at least conducts discussions of climate change within the context established by these issues.

Thus from this perspective a research strategy will likely find support from at least half of the MBRs if it addresses global change impacts on tourism, active recreation, water, forests, grazing, earth movements, resource conflicts, fire, floods, research sites, snow cover and avalanches.

Similarly a research strategy will find support if includes tourism, recreation, fire, pests and disease, grazing, land management and land conversion as either independent drivers of global change or as manifestations of climate change sufficiently distinct as to merit specific attention.

These results do not however indicate that these topics are the only ones that will find support, or that they are the only ones that merit scientific attention. In the first instance, certain 'minority' topics (such as glaciers, noted by nine out of twenty MBRs) are extremely important where they exist and therefore will have strong support in those sites. In the second instance, a lack of political support for certain topics (such as impacts on vegetation types other than forests or range lands) in no way indicates a lack of scientific merit. For instance, the monitoring of plant compositional change in alpine areas is at the heart of GLORIA, one of the most successful global change impact detection projects.

Thus it is instructive to compare the themes and contentious issues noted by MBR managers with the scientific strategy being developed through GLOCHAMORE's workshops. The strategy should not be constrained to addressing only the themes and issues cited frequently by MBR managers for reasons given previously. On the other hand, the strategy should probably address the most important of these themes and issues if it wishes to make good on its commitment to providing advice to management and policy making.

For example the two most frequently mentioned values (highly correlated as might be expected) are active recreation and tourism. One could ask:

1 Does the GLOCHAMORE monitoring strategy recognize and propose methods for tracking active recreation and tourism, as it may change with climate or other global drivers?
2 Does the GLOCHAMORE modeling strategy address modeling of demand for, and supply of, active recreation and tourism in MBRs?
3 Does the GLOCHAMORE process study strategy attempt to discern the cause and effect relationships driving active recreation and tourism?
4 Does the GLOCHAMORE sustainability strategy focus on the provision of advice to the institutions that govern active recreation and tourism in MBRs?

This quartet of questions can of course be reframed for all of the themes and issues noted in the Tables 13.1 and 13.2 above.

A provisional answer at least with respect to the first two questions can be ascertained by comparing the GLOCHAMORE Monitoring and Modeling Workshop Reports with the themes shown in Table 13.1. (The workshop reports for the process study and sustainability workshops have not yet been drafted.)

Table 13.3 makes this comparison, which, because it depends on a reading of documents, is entirely subjective. The author invites others to make their own comparisons.

Gaps or only peripheral consideration of themes near the top of Table 13.3 can be considered as opportunities that could be lost without more emphasis. These include tourism, active recreation, forests, grazing, fires, research sites and conflicts. Gaps further down the list could similarly be considered opportunities at risk, especially if these themes are extremely important in the sites where they do occur. Given what we know about these issues, endangered species, floods, invasive species and non-timber forest products may well of that order.

Table 13.3 Themes cited by MBR by decreasing frequency of citation

Theme	Addressed in Monitoring workshop report (** = centrally; * = peripherally)	Addressed in Modeling workshop report (** = centrally; * = peripherally)
Tourism and associated infrastructure		
Water supply, water quality, transboundary water issues	*	**
Active recreation		
Forests, forest restoration, timber, fuel wood	*	*
Grazing lands, meadows	*	
Fire		
Earth movements		**
Research site		
Resource conflict, governance, population movements, sustainable harvest		
Endangered species		
Floods, lake outbursts		
Snow cover	**	**
Avalanches		*
Glaciers	**	**
Hunting and fishing		
Invasive species		
Lakes, wetlands	**	
Charismatic species, wildlife, migratory waterfowl		**
Pests and diseases		**
Medicinal plants, non-timber forest products, bees and honey		
Vegetation (other than forests or meadows)	**	
Hydroelectric power		
Agriculture	*	**
Permafrost	**	**
Spiritual site		
Mining		
Desertification, soil erosion		
Coastal resources		
Severe winters		

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APPENDIX: SURVEYS AND RESPONSES

Global change in mountain biosphere reserves

Key questions for mountain biosphere reserve managers

1. Which different groups care about your biosphere reserve and why?

Background: Biosphere reserves are very diverse. In some, the emphasis of the protected core area is the protection of a particular plant or animal species or a unique ecosystem, such as an alpine lake or a watershed. Others cover enormous areas, encompassing the diversity of landscapes within a region.

In addition to the conservation/protection function of a biosphere reserve, other groups of people find important resources within it, usually but not always through legal means. Distant as well as local residents may use a biosphere reserve for recreation. City dwellers that never visit the biosphere Reserve may still have a strong interest in it if their municipal water supply depends on land cover within the biosphere reserve. Local merchants may find that the biosphere reserve promotes commerce, while other local people may find that it provides them, legally or illegally, with the opportunity to gather fuel wood, hunt wildlife, or gather non-timber forest products.

Task: Please list, in any order, the groups who have an interest or a stake in the biosphere reserve for which you are responsible, regardless of their proximity to the reserve, and the nature of that stake. Please try to be as specific as possible about both the groups and the resources they use.

Group (identity, location, objectives)	Resource(s) of interest

2. Which resources and which interest groups are likely to be affected by global change, especially climate change, as it affects your reserve?

Background: Global change manifests itself in a variety of ways. Global economic change could increase or decrease the pressures which different groups put on the resources from your biosphere reserve. Invasions by exotic plants and animals can change the biological composition of the site and therefore its value to a variety of groups. Climate change, with its changing temperature and precipitation regimes, its impacts on glaciers, snow pack and sea level, and possible changes in the nature and frequency of extreme weather could also affect a wide range of interests, from upward migration of plants to changes in forest composition and the extinction of individual species.

Task: Please give us your best estimates about what aspects of global change might be important in your biosphere reserve, and how they could affect (hurt but also perhaps benefit) the stakeholder groups listed under 1).

Groups and resources	Possible global change	Possible outcome

3. Will climate change exacerbate any existing or create any new hazards?

Background: The environment, while usually the basis of local and national economies, often presents challenges and hazards to society. Mountain biosphere reserves may present particular hazards, as mountains in general pose hazards related to avalanches, mudslides, floods, etc. The vegetation cover of many mountain ranges often presents additional challenges, e.g. in the form of wildfire danger, or habitat for wild animals that occasionally pose a threat to humans.

Global change will change the incidence of many recognized hazards and may create new ones as well. For example, global change and particularly climate change has already been implicated in extensive forest fires and insect outbreaks in the mountains of Western North America, and in the floods in central Europe in 2002.

Task: From what you know about what climate change will do in your region, what hazards may become more severe and who might be most affected in your biosphere reserve? What new hazards might appear in the future?

Nature of the hazard and relationship to global change	Groups most likely to be affected

4. What are the contentious scientific issues associated with your biosphere reserve?

Background: Biosphere reserves occasionally provoke contention between stakeholders. In many cases the contentions involve questions of value (for example each stakeholder group thinks its particular interest is more important than that of another group) or simply around power (for example, who has access to the management and policy structure in ways that maximize achievement of their goals to the detriment often of others).

Stakeholders may also disagree over matters of facts (such as does species A, the conservation of which is the reason for the reserve, actually require a specific kind of habitat called for in the management plan? Does the suppression of forest fires inevitably lead to more damaging fires later? Will a certain engineering approach increase or decrease flooding hazard?). These disagreements over facts often drive stakeholder groups to quite different conceptions of how a Reserve should be managed and can generate considerable political turmoil. Yet such disagreements, unlike those associated with values or power, are fundamentally amenable to resolution through more research.

Task: Please list any specific issues related to the management of your biosphere reserve that might be more easily settled with more research on the nature of the problem and the likely outcomes of different management or policy actions.

Issue	Description

5. What is the existing scientific infrastructure for assessing the impact of global climate change in your biosphere reserve?

Background: Climate data are key to an assessment of climate trends in mountain regions over the past thirty years or more. In addition, remote sensing imagery and satellite data portray changes in vegetation and land-use, and when used in conjunction with climate data, can quantify the impacts of climate change on land cover and use. UNESCO is currently exploring with NASA and ESA the possibility of obtaining low-cost satellite data for mountain biosphere reserves.

Task: In the first table below, please identity climate/meteorological stations within or near your biosphere reserve and note the length of time over which data have been recorded (in particular temperature and precipitation).

In the second table below, please note with a check mark

- *if the use of satellite imagery could or would not pose a problem in your biosphere reserve (for example because of classified military considerations), and*
- *if image interpretation could be carried out by a research institution in or near your biosphere reserve.*

Name, location and altitude of climate station	Data available since (please indicate year when recordings started)

Use of satellite imagery will pose no problem	Use of satellite imagery will or may pose a problem	Interpretation of satellite imagery can be carried out by a scientific institution in or near your biosphere reserve

	Forests : restoration timber fuel wood carbonsink	Glaciers	Hunting fishing	Endangered spp.	Charismatic spp/wildlife/migratory waterfowl	Other vegetation	Active recreation	Tourism and associated infrastructure; pilgrimages	Snow cover	Hydro power	Water supply, water quality, transboundary water	Spiritual site	Medicinal non-timber forest products bees	Grazing lands meadows	Agriculture	Research site	Resource conflict/governance/ population movements/sustainable harvest	Lakes, wetlands	Avalanches	Pests, disease	Fire	Desertification, soil erosion	Floods/lake outbursts	Earth movements	Invasives	Coastal	Permafrost	Mining	Severe winters
Sikhote-Alin	1		1				1	1			1		1	1		1					1					1			
Kruger to Canyons	1			1			1	1			1		1	1		1								1					
Berchtesgaden	1					1	1	1	1		1			1		1			1	1				1			1		
Sierra Nevada			1	1			1	1	1		1			1	1		1			1	1	1	1						
Huascarán	1	1					1	1			1			1	1			1	1					1					
Niwot Ridge	1	1	1	1	1	1	1		1		1					1		1	1		1			1	1		1		
Mount Arrowsmith	1			1	1		1	1			1	1								1	1		1		1	1			
Kosciuszko			1				1	1	1	1	1									1	1				1				
Glacier	1	1		1	1	1	1	1			1	1				1		1	1		1				1				
Gossenkollesse							1		1					1		1	1	1						1					
Lake Torne			1				1		1					1		1	1		1				1	1			1		
Gurgler Kamm	1	1		1		1	1	1	1					1		1	1		1				1	1			1		
Katunskiy	1	1			1	1	1	1	1		1		1	1			1	1	1		1		1	1					
Chanbaishan	1		1	1			1	1	1	1	1		1			1	1	1			1			1					
Tassilil N'Ajjer																													
Swiss National Park	1		1	1	1		1	1		1	1			1			1		1		1		1	1	1		1		
Entlebuch																													
Araucarias																													
Olympic																													
Kavkazkiy																													
Torres del Paine		1			1		1	1								1	1				1		1						
Uvs Nuur	1	1	1	1	1			1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1		1	1	1
Oasis du Sud																													
Mt. Kenya	1	1	1	1				1	1	1	1			1	1		1			1	1		1						
Cinturon Andion	1	1		1	1	1				1	1	1		1	1	1	1	1	1	1			1		1				
Nandi Devi																													
Denali																													
Issyk-Kul	1	1	1					1			1		1						1				1	1	1			1	
Total	15	10	10	11	8	6	16	16	11	5	16	4	6	13	5	12	11	8	10	7	12	2	11	12	8	2	6	2	1

Table A.1
MBR Responses to UNESCO/MRI Survey (10.05.05)

Table A.2
Contentious Scientific Issues (as of 10.05.05)

	CC and land management impacts on hydrology, flow regimes, groundwater, water scarcity, competing uses for water	Access to private land as fire risks increase	Communicating environmental issues	Impacts of grazing, domestic/wild ungulate relations	CC impacts on tourism; impacts of recreation and tourism on habitat, water quality	Rare species management and protection	Impacts on and of fire, pests	Forest restoration following disturbance	Pollution impacts	BR definition and management, desired future condition	Impacts of feral animals	Effectiveness of cloud seeding	Impacts of habitat fragmentation	Status of medicinal, non-timber forest products, apiculture	Extent of forestr harvest, forest vegetation change	Marine ecosystem recovery	Conversion, impacts of management of surrounding area, infrastructure needs, land use suitability	Impacts of values on management	Geological or other risks	Maintenance of traditional food crops
Araucarias																				
Berchtesgaden	1				1		1								1					
Chanbaishan					1	1	1	1												
Cinturon Andion	1							1		1							1			1
Denali																				
Entlebuch																				
Glacier					1	1	1	1									1	1		
Gossenkollesse					1															
Gurgler Kamm				1	1					1										
Huascarán				1	1		1			1				1						
Issyk-Kul																				
Katunskiy				1	1									1						
Kavkazkiy																				
Kosciuszko					1		1				1	1	1							
Kruger to Canyons						1				1										
Lake Torne			1	1																
Mount Arrowsmith	1	1																		
Mt. Kenya				1				1							1		1			
Nandi Devi																				
Niwot Ridge					1				1											
Oasis du Sud																				
Olympic																				
Sierra Nevada				1		1		1												
Sikhote-Alin	1					1	1								1	1	1			
Swiss National Park	1			1	1		1												1	
Tassilil N'Ajjer																				
Torres del Paine						1				1									1	
Uvs Nuur						1	1	1					1							
TOTAL	5	1	1	7	10	7	8	6	1	5	1	1	2	2	3	1	4	1	2	1

14 *Institutional and Policy Contexts of Biosphere Reserves: Potential Roles for Social Science in Sustainable Development Strategies*

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OVERVIEW OF PRESENTATION

This presentation was prepared for the GLOCHAMORE workshop in Granada, Spain. My preparation for this workshop included communication with Dr Greg Greenwood of MRI and Dr Martin Price of the Millennium Institute, as well as several background documents from former GLOCHAMORE workshops and other website information. My background as a social scientist does not specifically include work with biosphere reserves. However, my extensive background in both international development in Latin America, as well as substantial practical and research involvement with local conservation partnerships, provides me with a fundamental understanding of the management and research problems addressed by MRI, GLOCHAMORE and the Mountain Research Partnership.

In this presentation, I began by defining key terms from the policy sciences that are potentially useful for conservation management systems. This facilitated a better understanding of the framework I then presented for thinking about the use of social sciences in conservation. The framework includes categories such as tools for assessment and analysis, as well as institutional arrangements to support adaptation and adaptive management. I conclude with some general thoughts on sustainability in the mountain biosphere context.

KEY DEFINITIONS IN A CONSERVATION CONTEXT

Given the interdisciplinary nature of the audience, and the predominance of physical sciences and management among conference participants, it was important to provide some fundamental definitions of terms used in the presentation. These definitions may be slightly idiosyncratic, drawn from my own practical research experience. A more formal dictionary of the social sciences might differ in nuance, but not in fundamentals. Naturally, many of these terms have entire bodies of literature dedicated to their understanding, such as 'institutions' or 'policy'. I present them here to clarify terms I use throughout the presentation, and are to be understood in this narrow context only.

- *Social science*: The processes by which qualitative and quantitative information is developed, leading to a disciplined and accurate understanding of individual and collective human behaviour.
- *Politics*: The negotiation among stakeholders of differences in values and priorities. This term is particularly germane, because very often the failure of a programme or policy can be traced back to a failure to understand unshared values and the roles they play in collective choices.
- *Policy*: Generally speaking, policy refers to the rules by which a management agency or implementing organization performs its mandates and carries out its authorities.
- *Stakeholders*: Individuals or organizations clearly engaged in affecting policy and management outcomes. In the conservation management context, this should be construed fairly narrowly, since too broad a definition often dilutes the focus of the project or programme. On the other hand, when the definition of a stakeholder is construed too narrowly (which is too often the case), one fails to account for often unrecognized competitors for resources and agendas.
- *Coalitions*: Clusters of political and scientific interests affecting policy and management outcomes. One might also think of this as groups of stakeholders who find sufficient commonality of interest to commit jointly to agendas or shared resources.
- *Policy elites*: Individuals who directly shape a decision or outcome (often with no official position). This term is too often misunderstood, and misconstrued as meaning 'elitist'. We use this term to refer fairly objectively to those who actually participate and actively seek information in a given decision process.
- *Management*: The operational level of any given programme or policy in which the relationships between rules and reality, or policy and application, are continuously negotiated.
- *Adaptive management*: Management shaped by a systematic and structured engagement of public members and scientists, addressing explicit risks and uncertainties. We place the emphasis on 'systematic', in order to call out the explicit need for institutionalization of the tensions between management, science and public preferences.
- *Institutions*: Institutions are *not just organizations*. They embody and constitute sets of rules and constraints. In this context, institutions are more than formal agencies with formal mandates. Informal institutions often structure agendas and determine outcomes as well.

SOCIAL SCIENCE MONITORING AND RESEARCH: WHAT IS IT FOR?

There is little doubt that the social sciences can help to link scientific information to policy making in the pursuit of sustainability in mountain biosphere reserves (MBRs). Obviously, the more one knows about the social context of a management strategy, the greater the likelihood the strategy will be designed for success. Social science can also help in implementing agencies to better understand the audience and constituency for a conservation strategy, therefore making one better able to communicate that strategy and attract appropriate resources.

In order to realize the potentials of the social sciences to contribute, it is important to be as precise as possible about the purposes information derived from social science methods are to serve. Too often social statistics are gathered and presented without an adequate framework within which information can be focused on a particular problem. There is a plethora of social indicators to choose from, as is evidenced in the Vienna Conference report. But it is not well understood that many social indicators are developed to monitor social phenomena in a specific context. This is one reason that programmes that encounter the need for social indicators often are frustrated with the apparent 'cafeteria' phenomenon, in which a long menu of indicators appears disconnected from the problems we are trying to solve.

Further, in many cases social scientists working with interdisciplinary teams on management issues find that the 'clients' for their information do not fully understand what they are asking for. In many cases, the management side of the program needs better communication tools and strategies, not necessarily more or better social science data and information. In other words, managers often need a public relations specialist, not a social scientist.

I leave aside for the moment the range of work in the social sciences devoted to basic research and discovery. Important discoveries or interpretations often arise from basic research that can help to influence policy or change a society's thinking about a particular problem. But in the context of the development of sustainable conservation strategies, which is part of the focus of GLOCHAMORE and MRI, social sciences serve a different function. To be specific, sustainable conservation strategies in MBRs will depend importantly on an understanding of the cultural, social, political and institutional context in which they are expected to participate. In evidence at this conference, there is already a great deal of wisdom and experience accumulated among reserve managers and programme officers associated with the MBRs. But systematic knowledge on which funders and policy makers can rely for macro level decisions is lacking. The social sciences may be able to help move beyond the accumulation of anecdotes and case studies, and to identify patterns of social, political and institutional behaviour and preferences that tend to contribute to programmatic success or compromise.

Below I will discuss three broad methodologies or approaches by which social sciences can help discover useful patterns of behaviour and preference. To set the stage for that discussion, I will present five key principles that, in my experience, should be kept in mind when developing a social science research agenda to support sustainable conservation. Most of my comments are offered from a policy and institutional perspective (that is, they do not address issues one might find specifically presented by sociology, anthropology or psychology), and are meant to illuminate issues that make social science relevant or irrelevant for conservation strategies.

First, it is well to keep in mind that science *never* speaks for itself. Too often, scientists believe that, were people to know the facts, the policy choices would be far more obvious. This misperception is exacerbated by ignorance of the policy world, in which facts and values are inextricably intertwined. Scientific information tends to become more relevant in the policy world when the risks of ignorance (or perhaps embarrassment) outweigh the ability to pursue interests primarily by negotiation. If policy elites judge risk and uncertainty to be relatively low, the marginal value of additional scientifically sound information also remains low. Simply having more information does not lead managers and policy makers to make changes *sui generis.* Changes always involve trade-offs, and many factors go into the calculus of change that are not put on the table as 'facts'.

Second, and related to the above, policy is primarily reactive. Policy changes are usually responses to perceived failure. This is not to suggest that policy is always retrospective; it is simply that policy makers are often reluctant to try to solve problems that are not fully manifest. Each attempt to solve a problem by policy change requires the expenditure of political capital. Many policy makers are conservative about how they invest political capital, often creating the impression that the policy world is hidebound and unable to change out of sheer inertia.

The third principle is especially important for the social sciences in the context of sustainable conservation strategy development. The relevance of social science information is critically dependent upon the legal and policy frameworks within which the information actually makes a difference. Put most simply, without the requirement to gather social indicator data for a particular purpose, it is rarely very useful in guiding policy and decision-making. That is, one should consider very carefully the risks and consequences of not gathering that information. In many cases, the risks are relatively low. One might end up being ignorant and ineffective, but not legally or statutorily liable. Therefore, some key questions to ask are:

- Is there an actual need for the information?
- What policy agendas are served by knowing more about a particular suite of social indicators?
- Do these social indicators actually make a difference when it comes time to make programmatic or budgetary decisions?

Fourth, in the policy world, most issues are negotiable. This is not to imply that policy makers generally act without principle or conviction. It is simply to observe that policy making, like politics, is an attempt to find accommodations among competing, and often incommensurable, goals and interests. One often hears about 'balance' and 'fairness' in policy development circles. These are reflections of the policy world's need to find what is possible within a vast range of potential solutions.

This fourth principle impacts on the social sciences in important ways. Since policy making is negotiation, social science information that would support policy making is part of that negotiation. The questions or hypotheses that social sciences would attempt to address must also be negotiated. There is a delicate balance between political control of the scientific research agenda and the development of research agendas that are socially and politically relevant. While this tension is often felt in the conservation-oriented physical sciences, the social sciences are even more pressed to find the correct balance between relevance and capture. Many of us in the social sciences have found that many times, when working in a conservation and management context, social scientists will either negotiate the nature of the questions or they will end up negotiating the meaning of the answers. Social science must be very specifically targeted toward the policy-relevant problem or risk having answers that have no analytical power.

Finally, all social science has, by definition, an underlying theory of individual and collective human action. But beyond this truism, social science in a policy context must also have a theory of social and political structure, policy formation and political change. Put more simply, in order to be effective, a social scientific approach to a management problem must make certain assumptions about how and why humans organize themselves to pursue their interests, how policy responses to those interests are developed, and how the political process relates to policy outcomes.

To summarize the five principles above in the context of policy change, it is useful to divide social science indicators into broad categories. In the Granada conference, I showed a diagram based on the work of Richard Hofferbert to explain the general path of political change. This 'funnel' model helps to understand the increasing pressures and constraints that lead to changes in policy, illustrated by the arrow at the bottom of the funnel. At each level of the funnel, social science methods may prove useful in gathering information to help one understand at which point a given issue or programme may be.

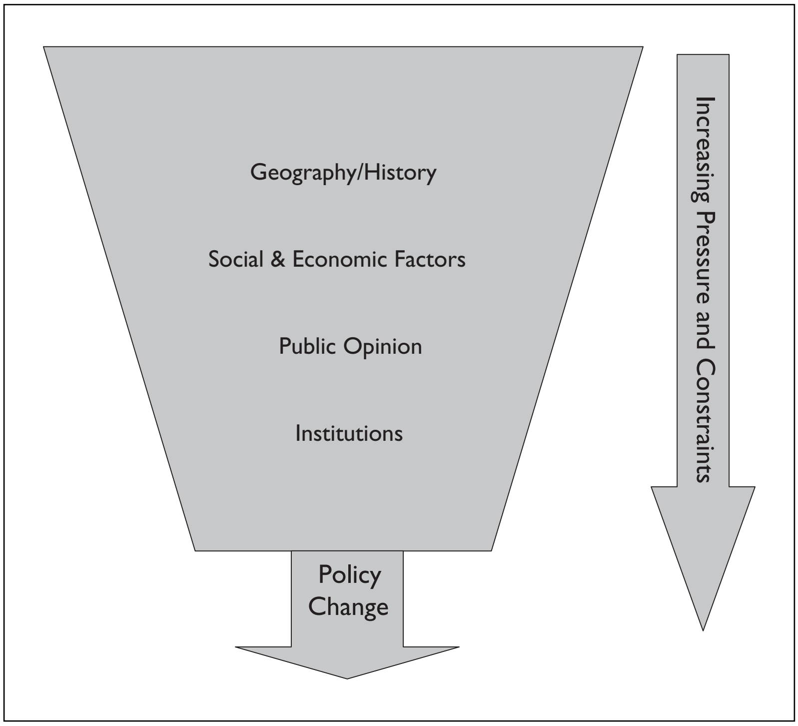


Figure 14.1 Funnel model diagram

At the top of the funnel one finds the most general kinds of information. As mentioned above, knowledge of geography, history and socio-economic factors should be considered basic in any sustainable development strategy. And as I stated in the Granada Conference, the GLOCHAMORE process of identifying social indicators, based on the Vienna Conference report, appeared to be somewhere just below the 'social & economic factors' level in the funnel.

As one descends through the funnel, one finds greater pressure and constraint. Options for policy change become narrower, although by no means inevitable. Public opinion may become stronger around key issues (which of course must be carefully assessed and analysed), and institutional rules and constraints may further narrow the options. Finally, one finds the constraints of elite opinion, understood as the perceptions, attitudes and beliefs of those who are both knowledgeable about, and regularly attempt to influence, policy.

By using this model as an assessment tool, one can begin to see the factors that contribute to actual changes in policy. In the MBR context, it is clear that development and establishment of sustainable development strategies will require a thorough assessment of all five levels. Social science methods may be useful in gathering information about each of the levels. The use of that information will depend critically on how managers and funders agree to interpret each stage of constraint.

With the five principles outlined above, I will turn to the roles social sciences may play in the development of sustainability strategies and suggest three approaches that can make substantial contributions toward that end.

THE ROLE OF SOCIAL SCIENCES IN SUSTAINABLE DEVELOPMENT STRATEGIES

At the risk of simplifying too much, I suggest that social sciences can make their most solid contributions to sustainable development strategies in three categories: Assessment, Analysis and Adaptation. In each case, social science plays a supporting role, helping decision-makers and policy makers to think through options with a broader base of information. The methods often vary widely, and of course there is disagreement about which methods are appropriate to which situations. But broadly speaking, the social sciences contribute most powerfully in decision support. I will address each briefly below.

Assessment

Assessment is critical to any scientific endeavour. Most fundamentally, one is looking for key information leading to a better understanding of the resources and interests at play in a given management or policy context. Social indicators, as discussed above, can aggregate a rich understanding of the situation, and the standard lists of social indicators are probably basic to any complex strategic development plan (that is, population, nutrition, land ownership, natality, mortality and so on).

It is important to keep in mind that, historically, the most relevant social indicators are related to legal mandates. Most democratic constitutions, for example, mandate a periodic census of the population in order to maintain adequate political representation. However, these are often the most simple (not easy) data to collect, and have very specific applications. Unfortunately, many social science efforts linked to development programmes gather indicators that are disconnected from actual problems. In many cases, when examined with a critical eye, one finds that indicator data has been gathered largely for ‘moral’ reasons. That is, one feels compelled to gather the data because of underlying ethical considerations, despite the fact that there is no legal or policy framework in which the data are relevant.

Analysis and synthesis

In this section, I am assuming that, in the course of developing a sustainable conservation strategy, one is interested in the following basic question: Who is doing what, with and for whom, and why? For at least three decades, several social scientists have developed a series of analytical techniques broadly referred to as social network analysis (SNA). As a bridge between assessment and synthesis, SNA looks for patterns of knowledge, information and other resource sharing among various actors clustered around a particular problem or policy issue. Successful issue or problem based resource sharing may even lead to more permanent strategic alliances as confidence between partners grows and provides a more efficient forum for vetting of information. Institutions and their individual members tend to communicate in strategic and tactical patterns that, when mapped, can reveal what I have called elsewhere 'the geography of power'. This geography is not necessarily spatially explicit (there are some researchers examining this aspect of SNA with interesting results). Once one has analysed the strategic communication patterns among stakeholders, certain topographies of those patterns begin to emerge.

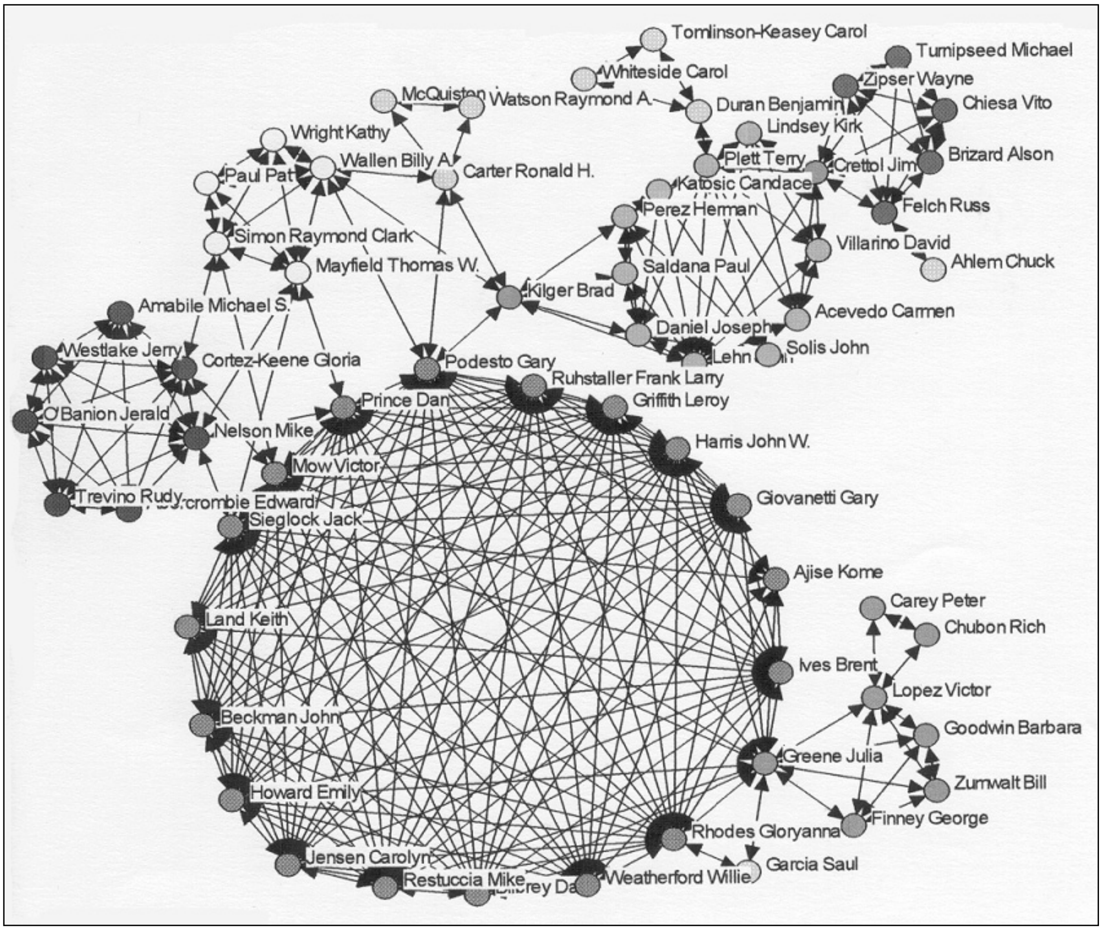
This geography of power can help to illuminate how key actors influence each other, their institutions, and therefore the policy formation process. One practical application for programme development is to better understand the 'local language' and more importantly to accurately grasp what the 'real issues' are and how local actors actually frame the problem one is trying to address. In many cases, programmes have been developed and substantial investments made long before understanding that local actors who wield substantial veto power have framed the issues in an entirely different way. The point is not to determine who is correct, so much as to comprehend where inefficiencies have been unnecessarily created.

In our Granada conference, I shared an experience with SNA that is proving effective in regional transportation planning in the Central Valley of California. The programme in question was focused on the state transportation agency's (CALTRANS) need to assess the environmental impacts of new transportation infrastructure development. Some of the planners involved, working with local interests, discovered they needed a far more sophisticated analysis than just enumerating the federal and state environmental mandates and rules impacted by CALTRANS projects. In the process of gathering information through interviews and other sources, the researchers working for CALTRANS began to recognize that those who controlled local resources (such as local land use decisions) and influenced public opinion in many cases had an entirely different set of priorities than those embedded in the environmental laws and policies that were of concern to CALTRANS.

The researchers involved began to map out the issues they encountered, and relate them to the communication patterns among the several key actors involved in the regional transportation planning effort as measured by assessment of the public record of overlapping inter-organizational officers and elites found in Internet based organizational literature. They found that 'people clusters' were strongly correlated to 'issue clusters'. Current analysis is showing a likely strong geographic clustering pattern as well. One result was to help CALTRANS' local government planning partners to re-engage a number of influential actors who otherwise would not have emerged in a traditional pattern of public hearings or a simpler analysis of stakeholders and issues. Below is a graphic that illustrates the key linkages among actors.

There are some important features to note on this mapping of the social network. First, three people appear to be the connectors between the major clusters on the map (their names are, from top to bottom, Jim Crettol, Brad Kilger and Julia Greene [note that the actual names on the map

Figure 14.2
Social network analysis graphic



are reversed due to database interaction with the mapping programme]). These people can be seen as 'brokers' between subnets, a linkage that serves an important role in helping one subnet understand the issues and problems of another.

Second, there are another three people who are called 'neutral brokers', represented by Carol Tomlinson-Keasey, Carol Whiteside and Ronald H. Carter. While these roles are not clear by their mapped locations, the underlying data about their official and unofficial roles show each of these people in positions to convene neutral venues within which other interested parties can negotiate conflicts. We know from public records that they hold executive positions in local non-profit organizations and a university. And we know from interviews that they are reputed to serve as credible neutral facilitators in local planning processes.

Although this CALTRANS planning process is still underway, the researchers that developed this SNA have confirmed a substantially lower level of conflict in a planning process that is almost always fraught with public and private battles for influence. The level of direct investment subject to this planning process amounts to hundreds of millions of US dollars, and multiplier effects are enormous and long lasting (for example, economic development is often quite strong around freeway ramp locations and many private firms find the public investment to have quite lucrative results for themselves). Conflict and lawsuits have their own costs, and often stall transportation projects for years. In this case, CALTRANS officials report much greater efficiencies because of their investment in assessment, analysis and the early engagement of broader than usual interests including both the local community and state and federal officials in the earliest phases planning. Not only has the identification of issues, interests and most importantly key actors led to a more efficient conceptual plan, it has also paid dividends in reduced conflict as individual projects are implemented based on the core general plan. In a clear recent example, a freeway overpass siting decision was concluded in one month, where the normal public and legal processes are expected to take up to 18 months.

This brief example of SNA helps to show how macro patterns of interaction and information sharing can be useful in development contexts. One should see strategic planning as one aspect of strategic investment (for why would one put substantial resources into planning if one did not intend to invest?). In complex development situations, SNA can support the necessary due diligence required before substantial investments are made.

INSTITUTIONAL AND ELITE COALITION ANALYSIS

In addition to analysing the patterns of communication and resource sharing among actors, two other major methodological approaches are useful in assessing and analysing conditions for sustainable conservation strategy development. Each of these approaches occupies fairly substantial literatures in the social and policy sciences, so I cannot hope to do them justice here. I only identify them here in order to discuss an overall framework for social science engagement. Both approaches focus on mechanisms of policy change in conservation management; the first places the emphasis on how individual beliefs affect the development of coalitions, the second focuses on how institutional rules and constraints shape policy options and outcomes.

The first of these approaches is called the advocacy coalition framework (ACF), developed by Paul Sabatier and others, and applied to such cases as California's water planning process and regional planning in the Lake Tahoe basin (California and Nevada, USA). The ACF helps to explain and predict changes in policy based on an analysis of how policy elites form coalitions, and how those coalitions function over time, typically through what Sabatier et al., call a 'policy cycle'. The ACF tends to focus on what Sabatier calls 'policy elites'. As above, this term is used with caution, since here we do not imply hierarchy or importance; the term only refers to informed and influential actors who participate in policy development and decision-making. The purpose of focusing on policy elites is to understand the relationship between core beliefs and policy preferences, and to predict the likely patterns of coalition formation among actors. One key contribution of ACF to the MBR context is a method to understand how scientific information is acquired, communicated and used to influence policy and decision-making.

The second approach, called institutional analysis and design (IAD), has been developed by Elinor Ostrom and applied throughout the developing world. Most of the early IAD cases focused on water management and irrigation conflicts, or related common-property resource management issues. Recently, IAD has been applied to a number of ecosystem management strategies, including the Great Lakes and fisheries in the North Sea. IAD tends to focus on institutional capacities, resources, rules and mandates. It can be helpful in eliciting information about what rules (formal and informal) constrain institutions in framing and responding to problems, as well as facilitating a better understanding of how institutions compete with each other for resources and opportunities.

Drawing on these two approaches, I suggested in our Granada conference a list of questions that one might ask in order to ground the use of social science in strategy development. While I will not include those questions here, it is important to note that both ACF and IAD approaches may contribute powerfully to a collective understanding of constraints and opportunities in a given situation. Emphasizing either individuals or institutions is often likely to lead one to incorrect conclusions about the strategic opportunities for development presented in a particular MBR.

ADAPTATION AND ADAPTIVE MANAGEMENT

In the final section of my presentation, I reviewed a range of options under the rubric of 'adaptive management'. While this term has been much abused, and heavily overused to indicate some vague sense of learning from experience, I find a highly constrained meaning more useful. Adaptive management, in our context, is a systematic and structured engagement of public members and scientists by conservation managers in order to address explicit risks and uncertainties.

Adaptive management is particularly important to MBR strategy development because of the nature of their charters, and the focus of the GLOCHAMORE effort. Global climate change is a key driver in the development of sustainable management practices in MBRs. Many agree that MBRs are likely to be important early indicators of climate change, as are arctic regions. Insofar as MBRs can serve as experimental adaptation regions, they may be able to show a range of opportunities for adaptation to climate change.

However, this adaptation could be haphazard and undisciplined (as policy and decision-making often is), or it can be systematic and disciplined in seeking knowledge to reduce risk. Adaptive management, narrowly defined, is one pathway to systematic risk reduction through dynamic experimentation and adaptation. While there is no agreed-upon formula for adaptive management, there are more and less effective ways of institutionalizing the adaptive management process.

It is important to acknowledge that the scientific underpinnings of adaptive management are extremely important (it is science that puts the 'adaptive' into adaptive management). However, here I am concerned with the institutional context within which adaptive management is to be applied. Space constrains the use of the diagrams I presented in Granada. Therefore, I will offer brief descriptions of the four options for institutional relationships presented.

The overall premise of the institutional framework for adaptive management is that it must deal with three primary components: management institutions; science and research activities; and public representatives. Each of these components may be composed of very different elements, depending on the conservation management situation. For example, public representatives may be a body of legislators and local elected officials, or they may be a citizen's advisory board. Similarly, the science and research element might consist of a dedicated research organization, such as a particular unit of the US Geological Survey, or it might be an officially designated science advisory panel. The point is that all conservation decision-making situations have all three components at play.

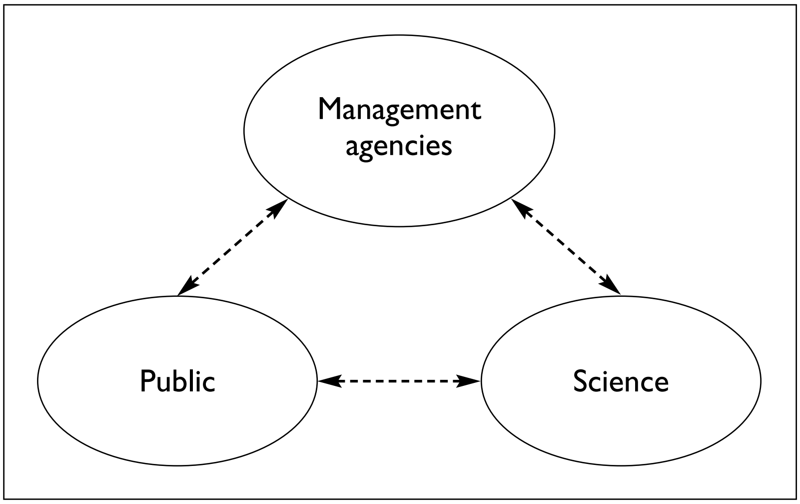


Figure 14.3 Adaptive management institutions

There are four basic 'archetypes' of institutional relationships for adaptive management. In our work in the Sierra Nevada region in California, we classified them in a range from the weakest, most ad hoc, to the strongest, most formally designed. These archetypes are drawn from a review of several US-based programmes or large-scale projects in which adaptive management has been identified as key to the implementation of that programme or project.[1] Figure 14.3 shows the three primary elements of the institutional arrangements described in greater detail below.

Management agency focus

The first archetype of institutional arrangements focuses fundamentally on the management agencies directly involved in solving a discrete suite of problems. Typically, this rarely involves more than one management agency, and the pressure to share resources or 'decision space' is minimal. Public involvement is primarily bound by disclosure and public participation requirements, and generally constrained to comments by members of the public at large. Science has no formal involvement, and scientific information used in the decision process is on a case-by-case basis. Adaptive management strategies and applications are determined by the responsible management agency with no formalized advisory or review bodies.

Ad hoc interagency focus

In this second type of institutional arrangements, there are often several management agencies involved in the decision process. In most cases, one agency has more at risk than do the others, but the other agencies have some jurisdictional relationship to the problem. Scientific information is often included informally, particularly those scientific resources available within the management agencies involved in the decision process. Interaction with the public is generally through required public involvement processes, for example the National Environmental Policy

Act in the United States, which require disclosure and analysis of direct impacts of the decision. Normally, these processes are only institutionalized through statute, and the precise institutional form of involvement varies according to management agency policies.

Formal advisory focus

The third archetype of institutional arrangements involves much more direct and formalized relationships between the management agencies, public representatives and scientific organizations or individual scientists. The management agencies (there are usually more than one) are held accountable for transparent communication with both science and the public, and this is generally institutionalized by formal advisory committees. In the United States, for example, federal agencies must use a Federal Advisory Committee, with formalized procedures for disclosure, decision-making and broader public input. What are often known as FACA Committees (after the Federal Advisory Committee Act of 1972) have a direct relationship to management decisions and outcomes, although they are technically advisory only in nature. Similarly, science advisory boards are officially designated, and usually paid for, by the management agencies or their Departments or Secretariats. This science advisory capacity is normally subject to peer review and conflict of interest provisions in order to protect the objectivity and credibility of its role in the decision process. The more formalized focus has the advantage (and sometimes disadvantage) of being able to have each component of the system hold other components formally accountable. The mechanisms of accountability include budget allocations, firm deadlines with requirements for actions or decisions to be taken, and public and peer review. While this direct accountability can foster strong working relationships, it is not necessarily tied to actual management outcomes. That is, should the management agencies fail to decide upon and implement programmatic solutions, the public and scientific bodies are not affected substantially.

Legislatively mandated focus

This fourth archetype is the most stringent and formalized. The relationships between science, public and management are formally designated in legislation and legally binding statute, with roles, responsibilities and forms of accountability written into law. These rare forms of institutional relationships generally have ‘sunset’ provisions, in which the institutional arrangements are dissolved by a certain date unless legislatively reauthorized. Where these arrangements have been instituted, the legislation also specifies a fairly narrow set of problems or issues to be addressed by the adaptive management programme. Often, the end of the process must be accompanied by a formal science review involving panels of scientists other than the ones who have been designated as members of the adaptive management science advisory processes. Representation on the public bodies is usually narrowly specified in legislation, and the composition of the range of representation is almost always broadly spread across key stakeholder groups or interests. Science representation is typically specified in legislation as ‘disciplinarily appropriate’, and occasionally a specific institution is named (such as a University) to convene and administer the science review process.

CONCLUDING REMARKS: SUSTAINABILITY AND POLICY

My presentation at the conference was broad in scope, perhaps even a bit disjointed. I sought to address the problem of the use of social science methods applied to conservation strategies. I proposed that social sciences are most useful in a framework of assessment, analysis/synthesis and adaptation for conservation strategy development. And I described all too briefly the three approaches that may prove most useful to the MBR project focused on sustainable development strategies that include the social sciences. Finally, I suggest a framework for adaptive management in which scientific information and expertise can productively interact with managers and their public constituencies, although I leave open the question of the appropriate form of institutional arrangement. These questions can only be resolved at the project or programme scale.

The GLOCHAMORE effort, tied to the MBRs, is about adaptation and sustainability in the face of global climate change. As was discussed extensively at the conference in Granada, the MBRs may be both early indicators of global change, but they may also be the best places for experiments in adaptation at a meaningful scale. UNESCO, MAB, FAO and other international and national institutional investments may benefit substantially by using the kinds of analysis I've adumbrated here, although more complete development of a social science research agenda and strategy is highly recommended.

There are two final elements to sustainability I believe are worth noting. First, 'sustainability' is a term that is part of a constitutional language. Attempts to define sustainability remain necessarily general (if not vague) because the term is being used to capture a broad range of beliefs and preferences about how humans interact with their environment. The term is often used in concert with other constitutional terms such as well-being, development and capacity. While there are operational definitions for these terms, they are always specific to the context in which they are applied.

Second, sustainable conservation is by definition long-term, likely multi-generational, and therefore is always subject to the vicissitudes of the policy world. A long-term commitment to funding, combined with disciplined monitoring of outcomes, is the bedrock of successful sustainable development. In the MBR context, sustainable development is unimaginable without robust involvement and interaction with management agencies. Without institutional commitment and a substantial engagement of scientific knowledge, there is little chance that MBRs will serve the purposes proposed by the GLOCHAMORE effort.

Given the increasing focus on global climate change worldwide, and the concrete manifestations of climate change in arctic and mountain systems, the GLOCHAMORE effort may find itself in the right place at the right time. Whether the social sciences are able to contribute to successful management strategy development will depend in large part on the degree to which scientists and managers assess their risks in terms of what they know about the human populations and institutions that surround them.

NOTE

1 The larger-scale projects that provided the most information for this review included: the Northwest Forest Plan in the Pacific Northwest United States; the Interior Columbia Basin Ecosystem Management Plan (ICEBMP), also in

the Pacific Northwest United States; the Southern Appalachian Ecosystem Assessment (which includes the Southern Appalachian Man in Biosphere program); the CALFED state-federal collaboration to 'fix the Delta' in California; the Plum Creek Habitat Conservation Plan (negotiated under Section 10 of the Endangered Species Act); the Lake Tahoe Basin regional planning process; and the Sierra Nevada Framework.

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Part V

Keynote Presentations

15 *Allocating Mountain Water: Uncertainties and Impacts*

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INTRODUCTION

Water is a critical factor influencing rural, agriculturally dependent communities throughout the world, and its availability and use must be known to effectively manage and allocate water resources. Mountain communities serve as the 'water towers' for many downstream activities, but encroachment by land use, increasing demand and poor management threaten these water sources. Quantifying the availability and temporal variability of water resources will permit improved water management, but needs to be put within the social context of water use, allocation and rights. This paper will explore how we allocate water, the factors impacting water availability and potential options for improvement in the Latin American context. While the factors and options are generic, I shall draw from case study examples in Colombia, Ecuador, Bolivia and Honduras.

HOW WE ASSIGN WATER

In the Andean mountains, water is typically assigned with little or no reference to data, if water is over distributed, little or no water is left for environmental use. The water is allocated unequally both in terms of use and users.

Lack of data

How do we manage water resources if we do not know how much we have? A transect of the current Global Climate Change Observing System along the western Cordillera of the Americas shows that there is an observational gap in the mountains, particularly above 2,000 m where the number of climate stations is limited (Büchler et al., 2004).

Consequently data for precipitation in headwater catchments is limited, and the situation for hydrometric monitoring is typically worse. There is very poor data availability on the temporal variability (spatial and annual) of stream flow. An example from the Barbas watershed in Colombia illustrates this issue. The Barbas watershed is 10,300 ha in area and is located in the central Cordillera of the Colombian Andes. Cattle ranching, coffee and flower production are important economic activities. The demand for water from the headwaters is high, with one headwater municipality (Filandia) containing 29 aqueducts and supplying water to eight municipalities downstream. Flow data is available on a sub-watershed basis, above and below each water intact for one measurement date in the dry season and one date in the wet season (CRQ, 2004). This 'data' is problematic with cases of flow measured below the water intact being greater than directly below, recorded flow levels one order of magnitude below concession rates, and zero flow being measured during the dry season in three streams.

Over-allocation

In the Andes, it is not uncommon to allocate 100 per cent or more of dry season flow. The El Angel watershed in Ecuador exemplifies this issue. The El Angel watershed in Carchi (northern Ecuador) is 30,000 ha in area. The upper zone of the watershed (>3,600 m) is páramo, which supplies water to downstream to agricultural producers. There are over 280 km of irrigation canals managed by private water user associations. The majority of water concessions (>2,500) are for flows <10 litres per second, and only eight concessions for flows >100 l/s, five of which are held by individuals. Due to concerns about over-allocation of water, the water user associations initiated simple flow monitoring in the canals to document actual flow relative to concession rates. Data derived from a semi-submersible float measurements collected over an annual cycle indicated that allocated irrigation concessions in many canals were three to five times greater than dry season flow levels. With this information, the water users were able to approach regulators with concrete arguments to revise the concessions (Proaño and Poats, 2000; Evans, 2001).

Allocation by use

Water is often allocated disproportionately between uses. Of the water that we manage, in the Andes typically 70 per cent goes to irrigation. In El Angel (Ecuador) for example, 186 of the 236 concessions are for irrigation accounting for 85 per cent of water use. In contrast there are only thirty-five concessions for domestic and drinking water comprising only 2 per cent of water use.

FACTORS IMPACTING WATER AVAILABILITY

Climate change, land use in headwater areas, increasing human demand for water, impaired water quality and water regulation are important factors impacting the availability of water in the Andean mountains.

Climate change

Anticipated impacts of climate change within the Andes include higher temperatures and consequently greater evapotranspiration, an upward shift in the zero temperature gradient resulting in less snow and more rainfall, glacial recession and a vertical displacement of vegetation. The greatest anticipated temperature changes along the Cordillera of the Americas are at high latitude near the surface and in low latitudes at higher elevations, that is, in the Andean mountains (Büchler et al., 2004). Glacial recession is as problematic in the Andes as it is in the African mountains.

Work by Thompson (Krajick, 2002) at the Ohio State Byrd Polar Research Center on the Quelccaya ice cap in Peru highlights the recent acceleration of glacial retreat; the Qori Kalis glacier is currently retreating at a rate thirty times greater than in 1963–78. In the Peruvian context, glacial recession is threatening hydroelectric power production, irrigation and municipal water supplies. Historic vertical displacement of vegetation in the Andes associated with past climate change suggests páramo and wetland ecosystems may be displaced upward.

Hooghiemstra and van der Hammen (2004) used pollen records from the Colombian Andes to determine the shift in the páramo from the last glacial maximum to the present day. At the last glacial maximum páramo at Purace occupied the 2,000–3,000 m elevation range; today the same páramo is located at 3,000–4,000 m. The hydrologic implications of climate change for the Andes potentially include a flashier runoff regime, less water storage capacity in wetlands, páramo and glaciers, and less water availability in the dry season.

Land use in headwaters

Land use and management in the headwater zones of watersheds may influence water holding capacity and the upland runoff regime. In the Andes, negative impacts are related to burning, potato production, cattle grazing and wetland drainage. Páramo vegetation is burned to stimulate grasslands for cattle grazing. The expansion of potato production is encroaching into the páramo. For example, burning and the advance of the agricultural frontier have resulted in encroachment into the El Angel páramo of an average of 1.9 per cent per year (Arellano et al., 2000). Forests and riparian vegetation are cleared for cattle grazing. In Colombia, for example, from 1960 to 1965 the area under cattle ranching increased from 14.6 to 36.5 million hectares, largely at the expense of forests (Fandiño and Ferreira, 1998), and wetlands are drained to create pasture or severely modified for use as cattle watering ponds. Research by Diaz et al. (2002) illustrates the hydrological implications as we move from natural páramo to cattle grazing to potato crops. In the páramos Las Animas and Piedra de Leon (Colombia), bulk density and cone penetrometer readings increase from natural páramo to potato production, while organic matter content and soil water content decrease. This reduction in soil water holding capacity in headwater regions will negatively impact dry season base flow.

High-elevation population centres

South America is unique globally in the number of urban population centres located at high elevation. Within the Andean countries there are 29 cities with a population over 250,000, including Bogota at 2,620 m with 6.2 million, Quito at 2,740 m with 1.4 million and La Paz at 2,925 m with 0.8 million (CIAT, 2005). The level of urbanization within Andean countries is high; 37 per cent in Bolivia, 38 per cent in Ecuador, and the percentage of urban population remains high with elevation up to 4,500 m. In comparison, in Western Europe the highest percentage of urbanization occurs at less than 1,000 m (FAOSTAT, 2004). Large urban centres place demand on water resources and mountain headwaters are disproportionately important in relation to the number of beneficiaries. Large urban centres often result in downstream water pollution (for example, Rio Bogota). Surface runoff also increases as we move from forest and pasture to urbanization, commercialization and increased impervious surfaces (Schuler, 1994).

Multiple use of water sources

Often, individual water sources in the Andes are used for multiple purposes: drinking water, domestic use, irrigation, and animal watering. This raises concerns about water quality versus its actual use. Direct users are farmers who have been granted legal rights and concessions to use water for a specific use. In El Angel (Ecuador), for example, the direct users of the irrigation canals are the field owners who form the water use associations and are responsible for the construction, maintenance and management of the irrigation systems. However, there are a number of indirect users: legal users and people living along the canals that use the irrigation water for other purposes. The Municipal authority is responsible for supplying communities with clean water, but often there are no taps or the systems do not function. People use the canal water for home consumption, bathing, and washing clothes. The canals are also used as sewers, for animal watering and waste disposal (Bastidas, 2000).

Water quality

Poor water quality may be associated with human and animal waste, agro-chemicals such as fertilizers and pesticides, sediment (natural or anthropogenic), urbanization and/or point sources such as mines. Water quality often deteriorates from upstream to downstream in association with land use practices and intensities. In the Barbas watershed (Colombia), for example, fecal coliforms which are a bacterial indicator increase from fewer than 50 in the headwaters to more than 250 counts/100 ml in the lower reaches (WHO drinking water standard = 10). Conductivity, a relative measure on contamination, doubles in the same stream system from fewer than 20 to 40 us/cm. The implications of poor water quality are in terms of both quantity and human health. Poor water quality reduces the amount of water available for human consumption.

Water regulation

Water law influences the role of civil society in management and administration of water resources, and the relation between governance and governability. Water regulation may be either centralized or decentralized, and water rights may be tied to land ownership or separate from land. In Ecuador, prior to 1972 land and water rights were acquired independently. In the El Angel watershed, farmers in the upper zone (rainfed agriculture) bought land without acquiring water concessions, while farmers in the lowland valleys bought water rights without acquiring additional land. The 1972 law granted water rights to the landowner, and concessions for the use of water were tied to the amount of land owned. Post 1972, conflicts arose as a result of population pressure and water shortages. Farmers in the upper zone want the water rights and concessions redistributed. Farmers in the lower zone indicate that there is insufficient water during the dry season, and water 'stealing' is now common (Bastidas, 2000).

In Colombia, the principal regulations for water rights, concessions, use and conservation were set out in decree 2811 of 1974. In 1993 Law 99 maintained the 1974 norms but decentralized the administration of water to the regional level. Numerous different laws and decrees govern components, such as water quality, and in 2004 a draft water law was proposed which unifies the existing laws and decrees. This draft is currently open to public discussion, and includes the creation of water councils and watershed management at the basin level (Ministerio de Ambiente, 2004). With more than twelve laws and decrees related to water, water user committees, particularly small groups, are often not fully aware of rights and responsibilities.

OPTIONS FOR IMPACT

There are a number of options potentially available to managers and administrators related to governance, structural options, environmental management, education, information, payment for environmental services and water use efficiency.

Governance

The challenge for governance is the range in capacity from small to larger water user associations, including technical and human capacity. Smaller groups may lack knowledge of water law, biological water quality and/or engineering solutions. The consortium concept implemented in the El Angel watershed in Ecuador (Proano and Poats, 2000) is one option that establishes an open forum for discussion between individuals groups and institutions. The Carchi consortium has regular monthly meetings lead by a rotating facilitator, and has been successful in identifying issues, fund raising and implementing small projects.

Structural problems

Structural or engineering problems may result in significant inefficiencies in water distribution. Estimated leakages in domestic water systems of 30–50 per cent are not uncommon, and irrigation canals are often unlined resulting in significant seepage. The Carchi consortium undertook a reservoir construction and canal reunification project in a section of the El Angel watershed where five unlined canals had previously run parallel (Proano and Poats, 2000). The project helped to alleviate conflict between upstream and downstream communities related to water over allocation. This structural option, however, was only possible due to the role of the consortium that facilitated collaboration between the three municipalities.

Figure 15.1 Monitoring macro-invertebrates together with young people, Yorito, Honduras

Environmental management

The best management practices that retain water will facilitate dry season baseflow. Protection measures include

Figure 15.2
Constructed wetland to filter grey water, Yorito, Honduras

fencing wetlands to reduce grazing pressures and soil compaction. Ecological restoration such as the planting of appropriate trees at the margins of wetlands provides shade and reduces evapo-transpiration. Constructed wetlands and detention ponds can be used to encourage infiltration. Conservation till-age and mulching in agricultural systems enhance soil organic matter and conserve soil moisture. (Barling and Moore, 1994; Kadlec and Knight, 1995; Taccogna and Munro, 1995; Cairns, 1995; FAO, 2005).

Monitoring, metering and pricing

The price of water typically varies between water allocated to different uses, and price may be used as a conservation tool. Often a combination of flat rate and volumetric pricing is employed. In Rio Barbas (Colombia), for example, concession rates are based on volume and use with agricultural paying US\$1.3/m^3, domestic US\$3.4/m^3 and industrial/energy US\$6.7/m^3. Domestic water users in 80 per cent of the system pay on an incremental block system with poorer households paying less for water (Lanza, 2005). However, consideration of human water demand, the distribution system and pricing/cost recovery mechanisms are insufficient for sustainable water management. Monitoring is required to collect data on the spatial and temporal variability in water quantity, and the factors that influence flow, in order to make better decisions on water allocation.

Figure 15.3
Water intake, Rio Barbas, Colombia

Payment for environmental services

The concept of downstream users 'paying' for upstream source protection is not new, but its implementation is often problematic. The city of Quito (Ecuador) is an example where an endowment fund has been established specifically for watershed protection activities. Quito is a city with more than 1.5 million people and has over 1,400 water concessions. More than 80 per cent of the drinking water comes from two ecological reserves, but dairy production, timber sales, hydroelectric and irrigation diversions occur within the source area. In 1997 the idea of an endowment fund (FONAG) was initiated with assistance from The Nature Conservancy. The fund is based on voluntary contributions from government and/or NGO's. EMAAP-Q the water agency contributes 1 per cent of drinking water sales; EEQ the electricity supplier contributes 1 per cent of energy sales; and other groups such as Cerveceria Andina the local beer company contribute on a flat rate basis. The financial returns from the fund are used to support projects such as soil use and conservation, sanitation, water balance and water supply-demand research (Echavarria, 2002). The fund currently holds US$1.9 million and an additional US$0.5 million funds are estimated for 2005.

Figure 15.4
Monitoring wetland outflow, Rio Barbas, Colombia

Water use efficiency

Efficiency gains in water use can be made through engineering or educational approaches. Communities and Watersheds of the International Center for Tropical Agriculture is involved in a number of youth and water science projects in Latin America where youth are integral in the collection, analysis and application of scientific information. In Yorito (Honduras), for example, both education and technical solutions are implemented through projects such as combining drip irrigation, bio-intensive gardens and rooftop water harvesting. Rural youth have demonstrated the capacity to address local issues and offer viable solutions. (Goedkoop et al., 2004).

INTEGRATION

Despite promising options for improved management and use of water, challenges in water quality, use, and administration, persist. A multi-barrier approach to integrate protection and conservation measures with infrastructure, storage and delivery systems is proposed. In headwater areas, water source protection measures such as restricting land use around source areas and accessing sources from below to minimize disturbance need to be implemented. Within the watershed, protection is required between source and supply. Options include maintaining buffer strips around streams, limiting animal stocking and limiting septic system densities. Supply protection requires multiple treatment methods, regular maintenance and monitoring. Through source, watershed and supply actions a multi-barrier approach for efficient water use will allow us to rethink water governance. However, partnering science, government and NGO efforts is essential. Science needs to generate information on water availability, climate change and variability, and to work with decision-makers to provide relevant information. Government needs to work with local stakeholders so that the regulation leads to equitable allocation, enforcement and enhanced governability. This, however, requires transparency and participation. NGOs play a large role in implementing best management practices but they need to consider upstream-downstream interactions. NGOs provide a vital link between science, decision-makers and stakeholders. If we work in partnership, taking a multi-barrier approach to water use, we can improve water quality, use and management.

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16 *Sustainable Development and Global Change: How They are Put into Effect in the Andalusian Network of Natural Protected Areas*

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Our beautiful 'Starship Earth' remains on course, and for the first time ever is facing human-made global threats: the warming of the planet, pollution, the destruction of natural ecosystems, the disequilibrium of biological, geological and chemical cycles; the modification in the composition of biotic communities and so on. Global change, which is the name given to the phenomenon as a whole, would be far more aptly named were it to be called 'global changes'. The most important of such changes is climatic , a result of the rise in greenhouse gas concentrations in the atmosphere, giving rise to the so-called greenhouse effect.

The United Nations Framework Convention on Climate Change, approved in Rio de Janeiro in 1992, defines this change as a 'change in the climate, directly or indirectly due to human activities which alter the composition of the atmosphere throughout the World, and which is adding to and compounding the natural variability of climate as recorded during comparable time periods'.

Climate change is, at this moment in time, one of the focal points of environmental concern both within the sphere of pure science and as regards society at large. The reason behind its prominent role, which the population perceives as being a recent phenomenon, may be the increased volume of information available at every level, as well as the increasing extent of public disquiet about the repercussion of our actions on the natural environment.

Over the past decade, the relevance of this problem has intensified as a result of the growing number of extreme climatic events that have been observed, and the eventual awareness that anthropogenic intervention is significantly contributing to the process. Nowadays, the Intergovernmental Panel on Climate Change (IPCC) believes human influence on the climate to be a proven fact.

The deep global transformations we are witnessing are bringing about alterations to the conditions under which life on earth takes place, which also have important repercussions on the structure of ecosystems and on the way they function. The impact on organisms making up the biosphere is known as 'biodiversity crisis', and is therefore closely linked with global change.

This crisis is not just a natural disaster. It is obvious that the loss of species is already bringing about a certain deterioration affecting the efficiency of the 'biosphere machine', with alarming repercussions on the services it renders to the planet, which make it inhabitable for the human population. Ecosystem services such as weather regulation, equilibrium of atmospheric gases, recycling of fresh water, purification of waste and production of foodstuffs simply cannot occur without biodiversity. Interest in mitigating global changes while maintaining biodiversity has healthy, albeit selfish, roots. This cannot only be attributed to sentimentalism or ethics: we are dealing with our own survival. Under these circumstances we must inevitably place the relationship between humanity and nature back on course.

Within this context, we are going to look at some interesting issues with reference to the territory of Andalusia, the southernmost region of Spain and Europe.

ANDALUSIAN STRATEGY AGAINST CLIMATE CHANGE

The Andalusian regional government, in its capacity as member of the Plenum of the National Climate Council and of the Standing Committee in charge of the preparation of the Spanish Strategy against Climate Change, for the purpose of clearly stating the will of the Andalusian government in its contribution to honour the commitments made by Spain, deems it necessary to establish a set of actions as explicitly stated in the Resolution of 3 September 2002 passed by the Regional Cabinet, whereby the adoption of an Andalusian Strategy against Climate Change was approved.

The Department of the Environment has been designated to oversee the coordination of the work and act as the elected delegate of the regional government before the competent national authorities. It is also entrusted with planning and implementing the following measures of the Andalusian strategy against climate change:

- to coordinate and promote the strategy
- to create a scientific panel for the monitoring of the strategy
- to draft a new Environmental Quality Act adapting IPPC recommendations
- to establish an inventory of gas emissions and sinks
- forest and biodiversity policy
- soil protection and erosion control policies
- to chart maps on the capacity of sinks using the Environmental Information Network
- to establish a warning system and to implement the Andalusian Environmental Meteorology Information Subsystem.

Among the measures included in the Andalusian Strategy to be developed in the 2004–2008 period, the following are envisaged:

- Citizen awareness campaigns to promote responsible consumption, and strategies to combat climate change in conjunction with local government through the CIUDAD 21 Urban Environmental Sustainability Programme. (111 Andalusian municipalities have joined the programme so far.)
- Measures associated with a new water culture based on public control, and resorting to such

financial and regulatory instruments as may be brought about by the comprehensive management and exploitation of water resources while encouraging savings. Demand-side management policies will also be used.

All these measures highlight the importance of the principle of human responsibility for natural resources, the need to become aware of the current situation and the acquisition of standards of environmental behaviour.

ANDALUSIAN SUSTAINABLE DEVELOPMENT STRATEGY AGENDA 21 ANDALUSIA

The Andalusian Sustainable Development Strategy was approved by a large majority of members of the Sustainable Development Forum on 5 June 2003, and was ratified by the Plenary Session of the Andalusian Environment Council in the course of an extraordinary meeting held on the same day. It was endorsed by the Andalusian Cabinet on 27 January 2004.

This document defines the road map towards sustainable development, and lays down the key guidelines according to which actions must be taken. It identifies the main challenges resulting from sustainability over the next ten years in order that this concept becomes operative and acts as a catalyst for the different actions.

The strategy's inspirational principles are summarized in three premises. First, sustainable development is a collective goal and is therefore both a right as well as a duty of citizens. Second, it is indispensable that the environment, its protection and the effects on it be included in the decision-making processes and related to the sectoral policies of the respective governments. Third, unsustainable production and consumption systems must be eliminated and replaced by clean-production alternatives.

The strategy intends to involve the entire Andalusian society in the design of the sustainable development system for the 21st century through twenty-four thematic areas, ranging from the conservation and sustainable use of biodiversity, the relationship between employment and the environment, institutional coordination, the fight against inequality and poverty, and international cooperation to consideration of energy, water and other resources, sustainable tourism, industrial development and citizen participation.

Among the 259 guidelines included in the text, the following stand out: the enhancement of the Andalusian Network of Natural Protected Areas within the Natura 2000 Network in such a way that the conservation of its landscape, ecological and cultural values is guaranteed through appropriate management, and the creation of a Mediterranean Forest Forum, a debating body able to channel proposals to the European Union and other international bodies.

THE NATURAL PROTECTED AREAS NETWORK OF ANDALUCÍA (RENPA)

RENPA has 148 protected areas under national or regional concepts, and covers an area of 1,703,700.13 ha, amounting to 19.45 per cent of the Andalusian region and involving 307 municipalities (39.87 per cent of Andalusian municipalities).

In addition, it has internationally recognized areas: four ZEPIMs (Specially Protected Areas of Significance to the Mediterranean), one Geological Park, nine Ramsar areas (plus thirteen applications still to be approved) and eight Biosphere Reserves.

Concept	Number
National parks	2
Natural parks	24
Natural reserves	28
Natural spots	32
Protected landscapes	2
Peri-urban parks	21
Joint natural reserves	4
Natural monuments	35

Table 16.1 Comparison of the mean number of species from 1988 and 2003

As regards the Natura 2000 Network, Andalusia has 192 areas proposed to be registered as Sites of Interest to the Community (LIC), with an overall extension of 2,579,697.93 hectares, and 62 Special Zones for the Protection of Birds (ZEPAs) covering an area of 1,572,368.57 ha. (The latter are already included in Andalusia's natural protected areas.)

SUSTAINABLE DEVELOPMENT PLANS (PDS)

Sustainable development plans (PDS) are development tools for the municipalities included in the natural parks and its social and economic area of influence. They are aimed at coordinating territorial development by maintaining or improving the natural heritage. These social and economic revitalization plans are part of a wider development policy, and are being integrated into Andalusian regional planning.

The final goal of the PDS is to improve the standard of living and the quality of life of the population residing within the vicinity of the natural parks, in a manner compatible with the conservation of the environment, by conceiving the natural protected area as an important asset to be used for local economic development. Nowadays, ten out the twenty-four natural parks have already approved PDS and the relevant document concerning eight more parks is at the draft stage.

Fifteen years after the Declaration of Natural Protected Areas received its initial impetus in Andalusia (Act 2/1989, enacted on 18 July 1989), a simple analysis of social and economic indicators show that the experience has been worthwhile. By using the natural parks as a reference, as they are the most important and most widely used concept in the Inventory of Natural Protected Areas, we can conclude that work-related income is increasing in the parks, above the Andalusian average, and that a reduction in unemployment is greater in municipalities located within the natural parks.

By way of example of a measure taken in these areas within the sustainable development framework, the introduction of the 'Natural Park Label' deserves mention. The purposes of the Natural Park Label are sharing the benefits of the increase in value of the territory by enhancing its identity and by supporting entrepreneurial initiatives, and offering to the visitor differentiated products and services associated with the environmental values, or natural, traditional and authentic products.

The Natural Park Label encompasses three fields: natural products, traditional products and ecotourism. Today there are more than 109 companies and 448 products (20 natural products, 229 traditional products and 194 ecotourism services).

17 The Mountain Partnership: New Opportunities for Networking on Mountain Research

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THE MOUNTAIN PARTNERSHIP: SOME KEY FEATURES

The Mountain Partnership, promoted jointly by the Government of Switzerland, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP), was launched at the World Summit on Sustainable Development in Johannesburg in 2002. The overall goal of the Mountain Partnership is to improve the lives of mountain people and to protect mountain environments around the world. The Partnership is a voluntary alliance of interested parties committed to working together, with the common goal of achieving sustainable mountain development around the world. The Partnership addresses the challenges of mountain regions by tapping the wealth and diversity of resources, knowledge, information and expertise, from and through its members, in order to stimulate concrete initiatives at all levels that will ensure improved quality of life and environments in the world's mountain regions. The Mountain Partnership brings members together, promotes exchange and dialogue, bridges gaps as well as identifies innovative mechanisms for collaboration among members.

The Global Bishkek Mountain Summit in 2002, the culminating event of the International Year of Mountains (IYM), was the first opportunity to initiate the discussion on the steps towards building the Mountain Partnership. During 2003 and 2004 the organizational structure, the governance and the membership criteria of the Mountain Partnership were defined. Two global meetings of partnership members, one in Merano (Italy) in 2003 and one in Cusco (Peru) in 2004, were milestone events in this building and collaborative process. By March 2005 a total of 117 members had subscribed to the Mountain Partnership: forty-five countries, fourteen intergovernmental organizations and fifty-eight major group organizations.

The dynamic core of the Mountain Partnership is action on the ground through specific thematic and regional initiatives. As of March 2005, members have identified and are actively engaged in developing seven thematic initiatives (education, gender, policy and law, research, sustainable agriculture and rural development or SARD-M, sustainable livelihoods, watershed management) as well as six regional initiatives (Andes, Central America and the Caribbean, Central Asia, East Africa, Europe, Hindu Kush Himalaya). As the Mountain Partnership evolves and its members exchange further information, experiences and best practices, other initiatives will develop. Many of these partnership initiatives build on events, processes and concrete activities that took place or were initiated in the framework of the IYM: for instance, the SARD-M

Initiative builds on the global conference held in Adelboden, Switzerland, from 16–20 June 2002 and the Gender Initiative on the Global Meeting 'Celebrating Mountain Women,' held in Thimpu, Bhutan, from 1–4 October 2002. The Partnership Initiative on Watershed Management emerges from an extended watershed management review process that was carried out between 2002 and 2003 by FAO in collaboration with various partners worldwide.

FAO is hosting the Mountain Partnership Secretariat. FAO is also a founding member of the Mountain Partnership and provides input and technical expertise to the Partnership as a United Nations specialized agency. The Mountain Partnership Secretariat is jointly funded by the governments of Switzerland and Italy. UNEP is part of the Secretariat, and the Mountain Forum is a key partner in implementing the secretariat functions. The Mountain Partnership Secretariat provides services to its members. It facilitates collaborative action, provides brokerage, information, knowledge and communication services, and finally promotes networking and liaison. The organization of e-consultations, the facilitation of workshops, the moderation of bulletin boards or discussion platforms on the website, assistance in the drafting of project proposals as well as the maintenance and updating of a database on funding sources are some of the concrete services the secretariat of the Mountain Partnership is offering to its members.

THE RESEARCH INITIATIVE OF THE MOUNTAIN PARTNERSHIP

As highlighted above, research is one of the seven thematic initiatives of the Mountain Partnership. The Research Initiative was launched in late 2003. Based on a questionnaire which was disseminated to members in January 2004 and which presented the different thematic and regional initiatives, altogether forty members had signed up for the Research Initiative by March 2005. The leading members of this initiative are the Mountain Research Initiative (MRI) and the Centre for Development and Environment (CDE). In the framework of the global meeting of the Mountain Partnership in Cusco in 2004 the members of the Research Initiative held both a workshop as well as a breakout session during which the initiative and its priority activities were discussed and recommendations for the next steps were formulated. This partnership initiative is of particular importance: it recognizes that projects, policies and laws, and other activities which support sustainable development in mountain areas have to be based on sound information and knowledge and that this is typically achieved by cooperation and information sharing among partners.

There are a significant number of institutions that are implementing global research programmes related to sustainable mountain development focusing on a variety of thematic areas (see box on pages 227–8). Of particular interest in this regard is the MRI, which is endorsed by and brings together three major global research programmes: the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the Global Terrestrial Observing System (GTOS). Many of the ongoing global mountain research programmes listed in the box were initiated in or strengthened during the IYM and the implementing Institutions are already members of the Mountain Partnership. A number of them have participated in the Third Thematic Workshop of GLOCHAMORE. Each of these mountain research programmes links together many researchers from all over the world and the potential for collaboration is enormous. However, often there is not enough awareness about the other ongoing programmes or contacts among these programmes. This is where the Research Initiative of the Mountain Partnership chips in and creates new opportunities through better coordination. Accordingly, this Research Initiative is not a new research programme and does not interfere with ongoing global mountain research projects. It is a new opportunity and institutional framework which provides a platform for communication among all these ongoing global mountain research programmes and the individuals involved, for sharing of information and experiences, for networking and communication, for the identification of gaps and needs, for creating more coherence among different research programmes, for connecting and adding value. Since research is a crosscutting issue, the Research Initiative of the Mountain Partnership should not be developed in isolation, but should be mainstreamed throughout and guided by the thematic and regional initiatives of the Mountain Partnership currently being developed (see above).

THE WAY FORWARD

By spring 2005, the establishment and consolidation phase of the Mountain Partnership and its secretariat has been completed: the governance mechanism has been defined, the partnership initiatives have been laid out and for each initiative the way forward has been at least preliminarily defined by members. The Mountain Partnership Secretariat is evolving from an interim to a long-term status. The Partnership is entering the implementation phase and is faced with two main challenges: first, there is a need to increase collaboration and to strengthen commitment of members, and second, there is a strong need to operationalize the partnership and to promote more concrete action on the ground. In terms of the Research Initiative of the Mountain Partnership the way forward is to identify more clearly who is who in mountain research and to distil needs and gaps in mountain research as expressed by members (of all thematic and regional initiatives). The stronger involvement of national research institutions into global mountain research programmes should be another focus of this partnership in the immediate future. Finally, the Research Initiative of the Mountain Partnership could play an important role in the development of a GLOCHAMORE Phase-II project.

The International Year of Mountains in 2002 was a 'window of opportunities'. It created awareness, political interest, attention and further commitment to mountains, providing unique opportunities to launch and realize joint initiatives for mountain regions, their communities, and their resources. Co-operation is one of the distinguishing characteristics of mountain societies; it has long been recognized that sharing and pooling resources and working together is essential for long-term survival in these environments.

In retrospect, the Mountain Partnership is possibly the most visible global outcome of the IYM in 2002. It created a tool and framework to enhance long-term commitment to sustainable mountain development and to implement the recommendations from the IYM in a collaborative and action oriented way.

For more information about the Mountain Partnership see www.mountainpartnership.org.

EXAMPLES OF INSTITUTIONS THAT ARE IMPLEMENTING GLOBAL MOUNTAIN RESEARCH PROGRAMMES

Members of the Mountain Partnership and participants in the Third Thematic Workshop of GLOCHAMORE

Mountain Research Initiative (MRI)
MRI is a multidisciplinary scientific organization that addresses global change issues in mountain regions around the world through publications and events. Jointly with UNESCO and a consortium of partners, MRI is implementing the GLOCHAMORE project. MRI has just published a report entitled 'Global change and mountain regions: An overview of current knowledge' (for further reading see http://mri.scnatweb.ch/)

United Nations Educational, Scientific and Cultural Organization (UNESCO)
UNESCO promotes collaboration among nations through education, science, culture and communication. UNESCO is implementing a number of mountain-specific programmes, particularly related to water, the linkages between man and the biosphere, and biosphere reserves (for further reading see http://www.unesco.org/mab/mountains/home.htm)

Food and Agriculture Organization of the United Nations (FAO)
FAO is implementing a number of mountain research related activities on themes such as vulnerability of mountain people, watershed management, forests and water, nutrition, fisheries, pastures, policy and law, etc. (for further reading see http://www.fao.org/)

International Centre for Integrated Mountain Development (ICIMOD)
ICIMOD is a focal point for research, institutional strengthening, cooperation, and information sharing among the mountain areas of Asia, especially in the Hindu Kush Himalayas. It operates through a partnership with member countries and partner institutions (for further reading see http://www.icimod.org.np/index.htm)

Centre for Development and Environment (CDE)
CDE is part of the University of Berne in Switzerland and is concerned with development and environmental problems of the South and East with special emphasis on the sustainable management of natural resources. CDE manages and edits the quarterly *Journal Mountain Research and Development*. Jointly with the United Nations University, CDE is implementing a Global Mountain Partnership Programme (for further reading see http://www.cde.unibe.ch/)

International Scientific Committee on Research in the Alps (ISCAR)
ISCAR represents the scientific community as the official observer of the Alpine Convention, promotes information exchange and facilitates networking and cooperation between alpine organizations and institutions (for further reading see http://www.alpinestudies.ch/iscar/)

Other members of the Mountain Partnership

United Nations University (UNU)
UNU is an international community of scholars, acting as a bridge between the United Nations and the international academic community, a think-tank for the United Nations' system and a builder of capacities, particularly in developing countries. Over many years UNU has supported research in mountain areas. Jointly with the Centre for Environment and Development, UNU is currently implementing a Global Mountain Partnership Programme (for further reading see http://www.unu.edu/).

World Conservation Union (IUCN)
IUCN'S mission is to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable. IUCN has many projects that are implemented in mountain areas and has established a Mountain Task Force to assist the Union in streamlining the mountain-related activities throughout the organization (for further reading see http://www.iucn.org/)

International Potato Center (CIP)
CIP promotes scientific research and related activities on potato, sweet potato, other root and tuber crops, and on the improved management of natural resources in the Andes and other mountain areas. CIP is coordinating the Global Mountain Programme of the CGIAR centres (for further reading see http://www.cipotato.org/index2.asp)

Other organizations and programmes

Global Mountain Biodiversity Assessment (GMBA)
GMBA is a global network on mountain biodiversity research of DIVERSITAS, an international global change research programme on biodiversity sciences (for further reading see http://gmba.unibas.ch/index/index.htm).

International Union of Forestry Research Organizations (IUFRO)
IUFRO has a task force on 'Forests in Sustainable Mountain Development'. The objectives of this task force are to advise the Executive Board on current issues, initiatives and research needs as well as to provide a framework for developing and strengthening linkages (for further reading see http://iufro-down.boku.ac.at/iufro/taskforce/hptffmd.htm).

18 *Innovative Approaches for Generating Knowledge to Support Sustainable Mountain Development: Example of a Strategy for the High Pamirs in Tajikistan*

Daniel Maselli with support from Thomas Breu, National Centre of Competence in Research (NCCR) North–South, former coordinator of the Pamir Strategy Project (PSP) and Hans Hurni, Director, NCCR North–South, Centre for Development and Environment (CDE), University of Berne, Switzerland

SETTING THE STAGE/INTENTION

According to the key questions posed by the organizers of the workshop, this succinct paper attempts mainly through methodological inputs exemplified in a concrete case study to respond to the following three guiding questions:

1 How can we ensure that scientists and other knowledge-holders provide policy-relevant information to the managers of mountain systems in general?
2 How can we ensure or promote community participation in decision-making, monitoring and knowledge generation?
3 How can we make 'scientific' and 'traditional' knowledge and knowledge generation systems (more) complementary?

BACKGROUND

The example presented as a case study for generalization largely draws upon the Pamir Strategy Project (PSP) summarized by Thomas Breu and Professor Hans Hurni in 2003 (Breu and Hurni, 2003). The PSP was a project funded by the Swiss Agency for Development and Cooperation (SDC) implemented by CDE from 2000–03. It was followed by an NCCR North–South PhD study (ongoing) by Thomas Breu. The PhD study particularly focuses on the role of knowledge for development, and addresses the following questions:

1 What are the current status and the dynamics of the social, economic and natural dimensions of the Tajik Pamirs?

2 How can hot spots of unsustainable land management be modeled in a spatially explicit way?
3 What role can knowledge play to further sustainable land management?

GENERAL SETTING

The region can be characterized as follows (selected main features; see Figure 18.1):

- It is a very remote mountain area.
- It is a politically autonomous region (Gorno Badakhshan Autonomous Oblast/GBAO).
- Its natural carrying capacity has been exceeded by an artificially high population concentration in a few major localities, resulting from Soviet times.
- It was a highly supported and externally supplied region during Soviet times.
- It is a mountain desert region populated by an ethnic minority (Ismailis).
- It is an economically marginal region, highly dependent on external support/aid;.
- It has a problematic/strategic border region/position.

Figure 18.1 Overview map of Central Asia with topography and political boundaries (Breu and Hurni 2003)

This general setting has to be understood in the light of the recent history of this highly contested area (see Figure 18.2).

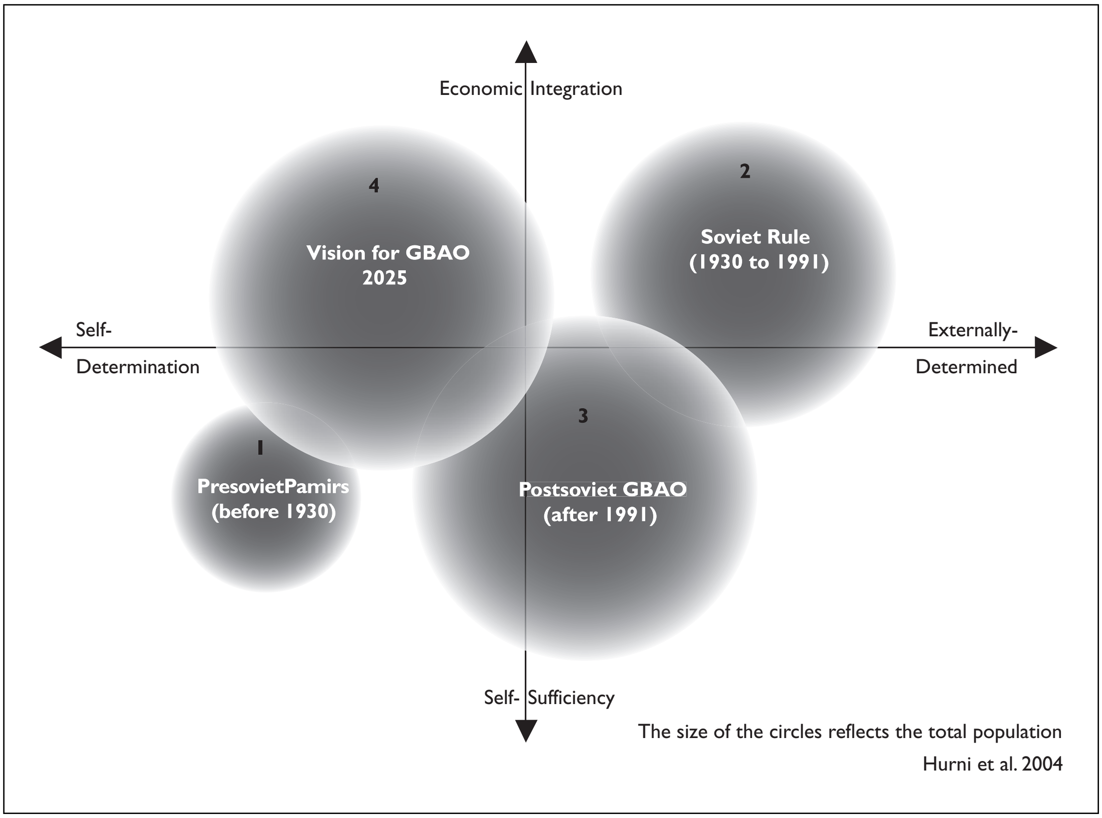

Figure 18.2 Development of the Gorno Badachshan region in the stress field of self determination versus external determination and self sufficience versus economic integration; the size of the circles reflects the relative number of inhabitants (Hurni et al. 2004)

CHALLENGES TO OVERCOME

When addressing the issue of sustainable development of this region through scientific and research activities, a range of challenges have to be taken into account:

- lack of (specific, updated) data
- access to official data
- lack of (mutual) understanding
- mutually contradictory requirements of different stakeholders (for example, local authorities versus NGOs)
- contradictory 'realities'/perceptions by different societal and political stakeholders
- multiplicity of actors at different levels
- reluctance and mistrust of other stakeholders (especially, the local population mistrusts central government representatives)
- desperate living conditions (for example, highly degraded pastures/Teresken-problematic)
- hazard-prone area (which experiences landslides, mud flows, avalanches, glacier lake outbursts, earthquakes)

- missing tradition and experience of self-responsibility as a heritage of several decades of Soviet centralistic ruling
- wide spread practices of 'bad governance' (bribing, nepotism and so on).

PRINCIPLES OR PATHWAYS FOR THE MOST PROMISING APPROACH

The following principles or pathways appear(ed) to be helpful when addressing the issues related to the participatory elaboration of a development strategy for the Pamirs:

- *Scientific approach*: This has to be understood in two ways – first, as true aspiration to be genuinely scientific, and second, as an intention to play the crucial researcher/scientist role of neutrality, objectivity and facilitation.
- *Multi-disciplinary approach*: This is to recognize the variety and interconnectivity of issues and their relationship to various scientific specialities encompassing the whole spectrum of sciences (natural sciences, social sciences, political sciences, law and so on).
- *Participative approach*: This is to recognize the need for ownership in view of implementing the findings in the future and its power to modify mind-sets and perceptions along the process of participative research and interactions of various interest groups.
- *Multi-stakeholder approach*: This is to recognize the variety of interest groups and their different eventually contradictory stakes right from the outset (see also above).
- *Multi-level approach*: This is to recognize the various levels to which the stakeholders or actors – including external ones – belong and their frequently very unequal power situation.
- *Communicative approach*: This is to recognize that ultimately openness and transparency has a strong stake in the long run when addressing all kinds of obstacles to overcome, and that research has a responsibility in this respect.
- *Dialogue approach*: This is to recognize that only joint discussions will eventually modify contradictory viewpoints, visions, expectations, commitment and so on, and help in reaching a common understanding of a jointly acceptable compromise for the problems to solve or overcome.
- *Negotiation approach*: This is to recognize that through the combination of all the proposed pathways societal learning takes place which empowers all involved stakeholders to defend and voice their stake in a joint negotiation approach leading to the jointly acceptable compromise mentioned above.

When considering all these requirements, a transdisciplinary approach appears to be one of the most comprehensive and promising ways to address the complex set of issues when developing strategies for the future evolution of mountain regions including in particular mountain biosphere reserves (MBRs). To operationalize this, the CDE has developed the *Sustainable Development Appraisal* (Hurni and Ludi, 2000).

SUSTAINABLE DEVELOPMENT APPRAISAL (SDA)

The SDA is a multi-type data collection, generation and analysis tool based upon a range of elements and steps (Breu and Hurni, 2003):

- *Preparation*: Background and initial steps.
- *Component 1*: Participatory assessments and appraisal of the current situation.
- *Component 2*: Participatory assessments and appraisal of the dynamics.
- *Component 3*: Participatory assessments and appraisal of the development.
- *Component 4*: Preparation of development profiles and synthesis.
- *Integration*: Multi-level multi-stakeholder negotiations for development actions (see Figure 18.3).

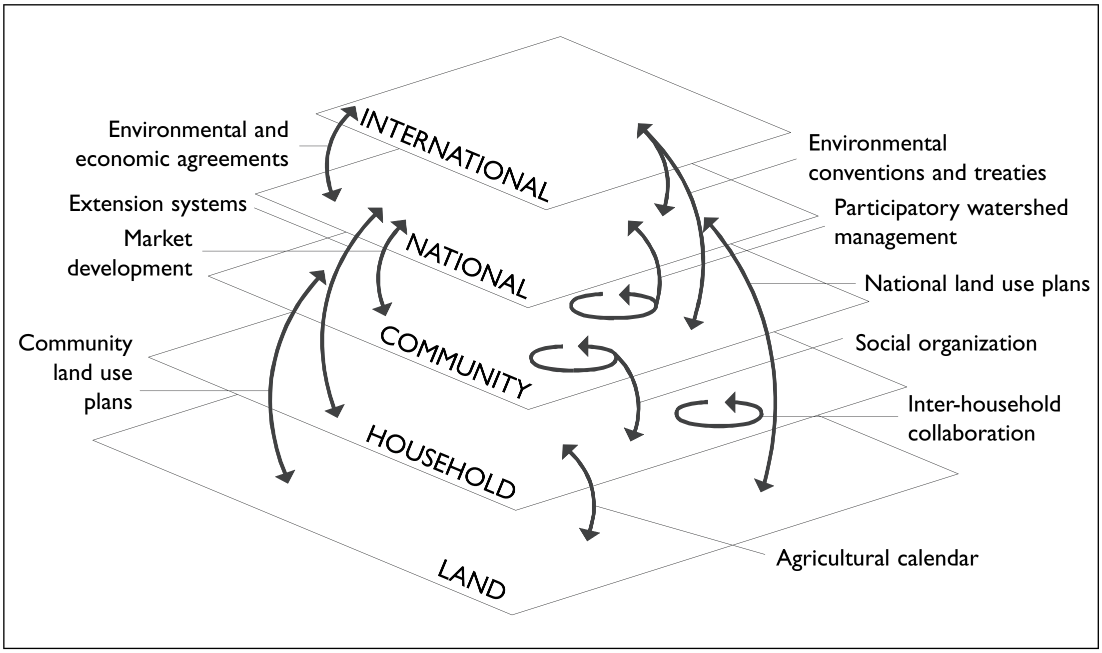

Figure 18.3
Set-up of the multi level–multi stakeholder approach for sustainable land management (Hurni 1998)

COMPONENTS OF THE BASELINE STUDY

The PSP case study presented started by collecting information and analysing the current situation in six strategic sectors (see Figure 18.4):

- agriculture, high pastures and irrigation
- biodiversity, wildlife and conservation
- energy and infrastructure
- institutional development
- industry, trade and tourism
- research development and knowledge management.

The different sectors were studied by joint Tajik–Swiss teams, and presented and enhanced in a four-day strategy development workshop. In this integrative strategy workshop five major stakeholder levels were represented:

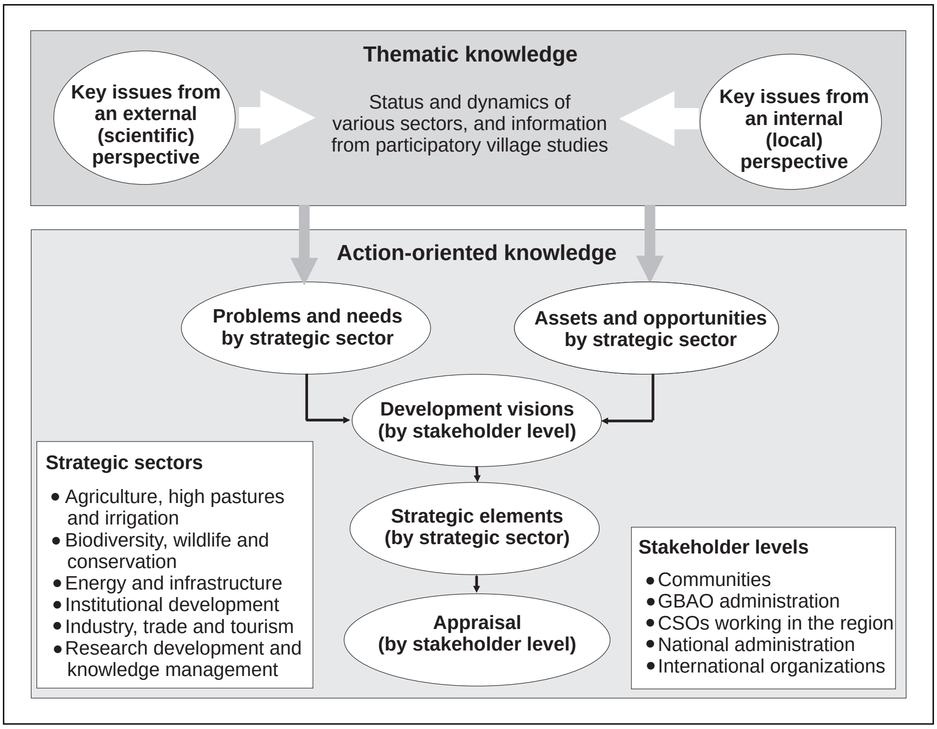

Figure 18.4 Sequence of elements dealt with in the Strategy Workshop of the Pamir Strategy Project involving various stakeholder levels and addressing different strategic sectors (Breu and Hurni 2003)

- communities
- GBAO administration
- civil society organizations (CSOs) in the region
- national administration
- international organizations.

Steps of the participatory workshop

- *Session 1*: Identify current problems, list ways of overcoming them, and identify actors affected and actors who should take action.
- *Session 2*: Compile assets and opportunities for sustainable development, identify possible beneficiaries, and discuss reasons why this has not happened so far.
- *Session 3*: Design an idealistic vision of GBAO for the year 2025 by stakeholder groups.
- *Session 4*: Name the three most important strategic objectives by sector groups and anticipate the possible outcomes.
- *Session 5*: Final plenary to rank importance and urgency by stakeholder groups in order to prioritize actions and measures to take.

Note: the importance and urgency were ranked using the following categories:

1 High importance and urgency.
2 Medium importance and urgency.
3 Low importance and urgency.

FINAL RESULTS IN A NUTSHELL

The workshop helped in identifying the objectives that received both highest importance and urgency ratings from all stakeholder groups (see Figure 18.5):

1 *Energy and infrastructure*: maintain energy facilities, use new power capacities, and increase production.
2 *Institutional development*: upgrade legislation, create favourable conditions for sustainable development in GBAO.
3 *Industry, trade and tourism*: reanimate existing enterprises; create new ones on the basis of natural resources of GBAO.

These three objectives can be considered as entry points with the potentially highest acceptance and support from which concrete actions and measures can be derived and jointly developed.

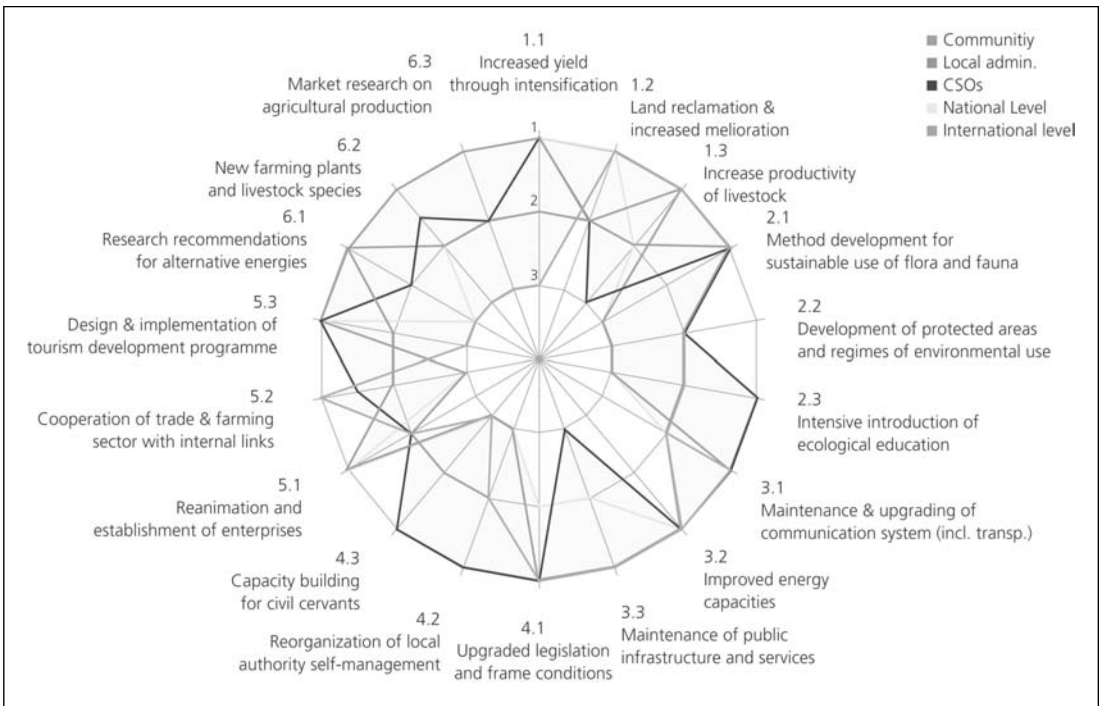

Figure 18.5 Appraisal by five different stakeholder groups of three main objectives in each of the six strategic sectors:
1 high importance,
2 medium importance,
3 low importance
(Breu and Hurni 2003)

CONCLUSIONS – MAJOR CHALLENGES FOR FUTURE

The PSP and the adopted combination of sound scientific baseline studies, knowledge database and participatory multi-level multi-stakeholders discussion and negotiation workshop has shown how important it is to venture for societally relevant research that contributes in increasing both the ownership and the commitment of the actors that are directly involved. This calls for an inter- and transdisciplinary collaboration as well as for 'new ways of thinking and working in a strategic approach to sustainable development' (OECD, 2001).

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19 *Indicators and Evaluation of Sustainable Natural Resource Management and Governance in Biosphere Reserves*

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INTRODUCTION

An innovative approach to sustainable natural resource management is the concept of biosphere reserves (BRs), which comprise a strategy to conserve biodiversity within the scope for regional sustainable development. This contribution aims to explain why and how far the evaluation of sustainable natural resources management and governance in biosphere reserves and mountain biosphere reserves (MBRs) is useful to address the challenges of increasing global change. It proposes a set of indicators for such evaluations and presents experiences and research results from applying these indicators in the field. The overall aim of the research project on which this contribution is based on (GoBi = Governance of Biodiversity) is to assess success and failure factors of current governance and management approaches used in BRs.

THE BIOSPHERE RESERVE CONCEPT

BRs – currently about 459 sites in ninety-seven countries (November 2004) – are areas of terrestrial and coastal/marine ecosystems that are internationally recognized under UNESCO's Man and Biosphere (MAB) Programme. BRs are nominated by national governments and remain under the sovereign jurisdiction of the states where they are situated. BRs are one approach to link nature conservation with a sustainable management of natural resources (Batisse, 1997). Another objective of BRs is to give logistic support such as the establishment of a research and monitoring network. They constitute a unique set of trans-sectional natural landscapes and ecosystems, many closely intertwined with human settlements and forms of use. BRs have multiple functions – conservation, sustainable development, research and monitoring, training and education – and, as a member of the World Network Biosphere Reserves (WNBR), have a responsibility for international cooperation.

In a BR, people are entitled to use biological resources according to defined spatial zones. A core zone is designated as a strict protection area where people's consumptive use of resources is prohibited. The core zone is surrounded by one or more buffer zones that allow use within limits that ensure the protection of the core zone. The original buffer zones were designed as rings of a more or less arbitrary width. Recently, a more sophisticated understanding of conservation biology has led to designs with more complex spatial arrangements that include enclaves for local communities and corridors for wildlife. It thus made a lot of sense to declare BRs as experimental places and vanguards for sustainable development, as MAB has declared in the Seville Strategy (1995) and reinforced in the Seville +5 declaration (2000). At the same time, it is clear that this ambitious claim is extremely difficult to realize. Many BR authorities, especially those in developing and transition countries, and/or those designated well before the adoption of the Seville Strategy, neither have the capacity nor the resources to enable them to meet this global mandate. The implementation of the strategy therefore still leaves room for improvement. Thus, it makes sense to investigate what success and failure factors of BR management and governance are.

EVALUATION OF BIOSPHERE RESERVE MANAGEMENT AND GOVERNANCE

There are three main reasons for evaluating governance and management aspects of BRs in the face of global change: first, to find solutions to management challenges, second, to determine whether a change to governance structure and process is due, and third, to identify the most appropriate governance system in the face of global change (Abrams et al., 2003; Hockings et al., 2000):

1 BRs face many types of threats to their ecological integrity and social and cultural significance. Harmful practices originate from the failure of policies, laws and decision-making processes to provide effective guidance and conservation incentives to managers and others involved. Responsive, coordinated and efficient governance processes can establish policies and provide incentives (for example, social recognition, financial support, consistency in agency mandates) that ensure a variety of stakeholder[1] perspectives, including expert opinions, are brought to the table to discuss and ultimately solve complex socio-ecological dilemmas.
2 Adaptive management and enhanced stakeholder participation in BRs are on the increase in many areas. This is due to several factors, including an increased appreciation of the ecological role of humans and their relationship with landscapes; a desire to improve risk management by incorporating a broader-based representation and assessments of the issues at stake; and public demands for more direct representation of their interests in decision-making. In each situation, a combination of political, institutional and economic factors may signal that the time is ripe for more (or less) collaborative approaches to management.
3 Global biophysical, socio-economic and institutional change is sweeping the world and profoundly affecting BRs. In the face of such powerful challenges, the advantages and disadvantages of different governance systems need to be evaluated in terms of their capacity to cope.

Despite the mounting interest in establishing BRs, the comprehensive understanding of the concept and its implementation is still insufficient. So too are methods to evaluate[2] management and governance arrangements (for definition of governance see box) within BRs from both a process perspective (responsiveness, equity, cost-effectiveness), and an outcome perspective (effective-

Definition of governance

Governance implies the interactions among institutions, processes and traditions that determine how power is exercised, how decisions are taken on issues of public and often private concern, and how citizens or other stakeholders have their say. Fundamentally, governance is about power, relationships and accountability: who has influence, who decides, and how decision-makers are held accountable. Governance may be used in different contexts: global, national and local, social and institutional. Governance occurs wherever people organize themselves – formally and informally – to develop rules and relationships with each other in pursuing their objectives and goals (Institute on Governance, 2002).

ness, reaching the desired goals). Though there have been several calls for comprehensive evaluation systems in BRs, few of them have implemented such systems. Those few concentrate more on biological conditions than on social monitoring and evaluation and cannot be regarded as comprehensive assessments of management (for this issue in the context of protected areas see for example, Hockings et al., 2000; Jenkins and Williamson, 2003).

The interdisciplinary GoBi research group addresses these gaps through integrating ecological and socio-economic data to identify important variables influencing management and governance success in BRs. By developing and testing a comprehensive set of indicators GoBi investigates which particular factors correlate with the management and governance success or failure of BRs. The research concept combines theoretical and empirical findings from different disciplines (such as geography, political sciences, rural sociology and environmental psychology), bringing together ecological and socio-economic conservation success criteria. In this contribution the focus is exclusively on socio-economic criteria, more on the ecological component of the GoBi research project can be found in Stoll-Kleemann and Bertzky (2005).

The selection of research methods is critical for the results of the evaluation because it determines the outcomes. Studies based on more quantitative and statistical oriented methodological approaches (for example, Bruner et al., 2001; Gibson et al., 2004) demonstrate that a strict law enforcement approach is the way to achieve conservation success. In contrast, studies based on a research design following qualitative approaches (such as in-depth case studies) have shown that participatory and inclusive (co-) management and governance approaches are more promising (for example, Wells and Brandon, 1992; West and Brechin, 1991). The conclusion to be drawn from these contradictory results is that using a multi-method research design is appropriate. Thus, the GoBi research project combines the following methods to achieve reliable and valid results:

- a comprehensive literature review
- a statistical meta-analysis of case study literature
- a global survey

- a series of detailed case studies in BRs in South Africa, Thailand, and Cuba
- expert interviews
- database analyses and supporting fieldwork.

Of particular importance are those methods that put an emphasis on comparability such as the meta-analysis because research in this area suffers from a dominance of individual case studies and a lack of meta-studies (Agrawal, 2001). 'Meta-analysis' refers to the statistical analysis of a large collection of analysis results from individual studies for the purpose of integrating the findings. Unlike traditional research methods, meta-analysis uses the summary statistics from individual studies as the data points. By accumulating results across studies, one can gain a more accurate representation than is provided by individual studies. This methodological approach seeks to crosscheck results and to rigorously discuss the findings in the light of various perspectives (for a similar application of the meta-analysis method in the context of tropical deforestation see Geist and Lambin, 2001).

INDICATORS OF SUSTAINABLE NATURAL RESOURCE MANAGEMENT AND GOVERNANCE IN BIOSPHERE RESERVES

For the evaluation of BR governance and management, criteria and indicators have to be developed. Criteria are standard conditions or key characteristics to be met or judged for sustainable use or conservation.

Indicators are measurable entities that are used to assess the status and trend of a key factor for sustainable use or conservation. A given goal, objective, or additional information can have multiple indicators. A good indicator meets the criteria of being: measurable, precise, consistent and, sensitive. A general distinction between governance and management seems to be useful (see Table 19.1).

The theoretical background of the indicators and criteria we have developed in the GoBi Research Group is based on:

- Management effectiveness research in protected areas, mainly conducted by Marc Hockings and his colleagues (see for example, Hockings et al., 2000) within the World Commission on Protected Areas (WCPA) of the World Conservation Union (IUCN) and the Enhancing our Heritage Project (funded by UNESCO); joint indicator development with Hockings and his colleagues in the social and socio-economic area takes place.
- Research on social monitoring and the BRIM process (biosphere reserve integrated monitoring), for example, the Rome Workshop and beyond (Lass and Reusswig, 2002) including the Biosphere Reserve Implementation Indicators within the Seville Strategy.
- A similar but less detailed list of indicators – only referring to internal management and not to broader governance issues – can be found in Borrini-Feyerabend, 1997.
- Abrams et al. (2003), which deliver long governance indicator lists (for a summary see Table 19.1). Parts of these indicators have been tested during a workshop on the World Parks Congress in Durban, South Africa in 2003 by the author and other participants.

Table 19.1 Selection of possible socio-economic criteria and indicators indicating success for management and governance in biosphere reserves

Dimension of evaluation	Criteria	Indicators
Management	Economic and income opportunities	• Stakeholders receive resource and/or land benefits to compensate for their biosphere reserve-related costs (e.g. guiding concessions, access and land use agreements) • Amount of funding provided by the BR to support stakeholders' conservation and development initiatives
	Responsiveness to power sharing/ participation and representation of stakeholder interests	• Existence and use of power sharing mechanisms: degree of participation of local people and other stakeholders in BR planning and management such as the attendance by elected/selected members at BR meetings meetings (percentage of meetings attended over the total) and percentage of BR meetings in locations that favour local constituencies (for instance in remote, rural environments versus meetings in BR headquarters) • Existence of joint initiatives between the BR and other bodies at regional and national level (e.g. cross-border initiatives, projects with private businesses and community organizations, inter-sectoral dialogues with forestry, tourism, fisheries agencies) • Length of time stakeholder groups have maintained relationships with BR management staff • Trend of stakeholder capacity to influence BR decision-making
	Implementation	• Degree of implementation of the planned activities, e.g. for capacity building and training, innovative policies, revenue generation, relevant partnerships, social communication
Governance	Accountability	• Existence of independent public institutions of accountability • Existence or absence of corruption • Appropriateness and clarity of roles and responsibilities
	Rules, rewards and sanctions	• Existence and accessibility of written rules and regulations for the biosphere reserve • Existence of concrete and appropriate rewards and sanctions to compensate good or negligent action
	Enforcement	• Percentage of budgetary expenditures dedicated to enforcement costs • Clear and undisputed boundary demarcation • Statistical analyses of biosphere reserve rule offenders and related sanctions

Source: summary of Abrams *et al.* (2003), modified.

- Research on common property institutions and sustainable governance of resources, which covers four main areas:
  1. Characteristics of the resource.
  2. Characteristics of the group.
  3. Institutional arrangements (including norms and duties).
  4. The external environment (mainly Agrawal, 2001, but strongly linked to Ostrom's IAD framework: see Ostrom, 1990 and 1994).
- Own *previous* research (for example, on participatory approaches, importance of leadership and on social psychological aspects/group processes, Stoll-Kleemann, 2001a, b, c; Stoll-Kleemann and O'Riordan, 2002a, b).

In the context of the authors' research group, GoBi, a criteria and indicator model (CIM), has been worked out. Within this model, governance criteria cover the institutional profile including sub-criteria such as legal foundation, governing bodies, rules and procedures and internal corruption. Further sub-criteria are participation (degree of participation, acceptance of process, strong civil society and institutional collaboration), accountability (such as transparency or existence of statutory documents), and finally political setting (rule of law, funding policy, existence/ absence of corruption and distribution of government responsibilities). Management criteria cover sub-criteria such as the management history, capacity (for example, competence, existence of a 'capable leader' and resources), the management activities themselves (such as planning, conflict management, enforcement and distributing information) and the organizational structure of the BR including its general management approach and its efficiency. The final criterion which covers a set of sub-criteria and indicators are the BR characteristics including their economic, socio-cultural and natural attributes. Sub-criteria of economic characteristics are the degree of market integration, resource use, costs and benefits and possibly the economic value of ecosystem functions (the latter one is still one of the most difficult aspects to assess). Examples for socio-cultural characteristics are socio-demographic characteristics, values and attitudes towards the BR and environmental behaviour in general. Natural characteristics include sub-criteria such as the distribution of natural resources, ecosystem integrity, topography and infrastructure and human settlement structure. Sometimes several indicators are assigned to each sub-criterion in order to have a concrete idea how an evaluation of BR reserve management and governance can take place.

On the basis of this CIM a questionnaire was constructed including forty-one critical factors from three thematic areas for evaluating governance and management success in BRs. The first thematic area is 'Governance context and social aspects', the second is 'Management activities and management system', and the third refers to 'External threats'.

Selected items are shown in Table 19.2. For these and the other items which are not mentioned in this contribution the following scale was used: (relevance for BR success) 'very high', 'high', 'somewhat', 'not at all', 'don't know' and a comments column was offered. It was also asked how each respondent defines 'Biosphere reserve success'. Finally, it was requested that the three most important aspects (out of the forty-one critical factors) be highlighted.

Governance context and social aspects	Management activities and management system	External threats
Adequate national conservation policies and programmes	Practical conservation measures like reforestation, protection against erosion	Pressures on resources: commercial exploitation of raw materials
Avoidance of counterproductive competing governmental programmes	Outreach: rural development activities	Pressures on resources: tourism
Political support at regional level	Outreach: environmental education/awareness activities	Pressures on resources:population increase
Local communities supporting the biosphere reserve	Research, monitoring and evaluation systems	Pressures on resources: proximity to cities
Adequate funding	Adequate leadership	Pressures on resources: general poverty
Adequate institutional design: distribution of responsibilities between authorities	Existence of BR-specific rules and enforcement of these rules	Pressures on resources:change of lifestyles and consumption patterns
Clear boundary demarcation	Locally adapted involvement of residents	Resource conflicts between residents
Absence of corruption	Effective mechanisms for conflict resolution	Conflict between political actors
	Compensation for use restrictions	Climate change
	Infrastructure and equipment	Invasive species

Table 19.2
Selected Items based on the Criteria and Indicator Model of the GoBi Research Group used for a study conducted during the World Conservation Congress 2004 in Bangkok, Thailand (n=163)

Results

The study based on this questionnaire was carried out in Bangkok, Thailand in November 2004 during the World Conservation Congress. In this particular study not only BR managers but also other experts related to sustainable natural resource or protected area management were asked to fill out the questionnaire to get a higher response rate. Finally 163 experts filled out the questionnaire. The results show that the two most important issues are 'local involvement of residents' and 'local communities supporting the BR'. Other aspects also regarded as highly important are 'outreach: environmental education/awareness activities', 'leadership', 'funding', 'enforcement', 'maintenance of working relations with local authorities', and 'absence of corruption'.

Respondents from Latin America also ranked 'local communities supporting the BR' as of utmost importance and 'locally adapted involvement of residents' also very high, in third position. 'Pressures on resources: poverty' was ranked second. If one compares Latin American respondents with African ones some further and very obvious differences arise, for example, the relevance of 'adequate leadership' is ranked relatively highly by African respondents but not by those from Latin America. Conversely, Latin American respondents ranked 'local communities supporting the BR (or protected area) twice as highly as African respondents did.

Results from case studies in Cuba and Thailand reinforce and extend these findings. Guiding questions in the case studies were 'Is the biosphere reserve concept successfully implemented in the case study sites?' and 'Which historical, socio-economic and management factors may influence successful implementation?' The Cuban Reserva de la Biosfera Sierra del Rosario is located in the lower mountain region of West Cuba and has been designated since 1984. It covers an area of 26,686 ha with a population of 5,500 people (2002). This BR can be regarded as quite successful. Concrete success factors in this regional context are the existence of strong and positive leadership with a long continuity, and a successful reforestation project that started in 1972. Further success factors in the BR are sophisticated ecotourism projects and large and long-lasting environmental education and awareness programmes.

In the second Cuban BR, Reserva de la Biosfera Ciénaga de Zapata, which we intended to look at, the time was not ripe to conduct a detailed study as since its designation in 2000 there has been slow progress in implementing the BR concept. Fortunately, a similar success story to the first Cuban BR can be found in the Thai Mangrove BR Ranong in the South West of Thailand: the existence of strong and positive leadership with long continuity, and a reforestation project (this time of mangroves) which started a long time ago, as well as large and long-lasting environmental education and awareness programmes are the three dominant features of success (for more details on the natural setting of the BRs please look at the *UNESCO-MAB Biosphere Reserves Directory*).

CONCLUSIONS

Up to now, little work has been done on evaluating sustainable natural resources management in BRs from a systematic perspective. The same applies for indicator development in this context. Moreover, much of the research does not take an integrated view. The GoBi research group aims to deliver a model to understand and improve the implementation of the BR concept. The research work is based on a critical and systematic examination of governance and management aspects such as the existing BR management governance situations, the BR management and governance goals, and the resulting desirable changes. The outcomes should generate support for collaborative problem solving and improve the BR planning and implementation process. Hopefully, positive experiences made in some BRs can be (at least partially) transferred to other cases, and it is expected to find relevant suggestions for future sustainable management frameworks.

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NOTES

1 Here and in the following, by ‘stakeholders’ or ‘relevant social actors’ is meant those individuals, groups and organizations bearing major and distinct interests and concerns about the biosphere reserve in question.

2 Evaluation is defined as the judgement of achievement against some predetermined criteria.

Part VI

Regional Working Group Reports

20 *Report of the Western Europe Working Group*

Rapporteur: Thomas Hofer

WORKING SESSION ON GOVERNANCE, SCIENCE AND KNOWLEDGE

The working group included thirteen participants from across Europe. Six mountain biosphere reserves (MBRs) were represented: Gurgler Kamm, Austria; Lake Torne, Sweden; Swiss National Park, Switzerland; Mount Olympus, Greece; Berchtesgaden, Germany; Kruger to Canyons, South Africa. In addition, experience from Menorca Biosphere Reserve, Spain was presented by the biosphere reserve's (BR's) former coordinator.

These MBRs represent a great diversity of situations; it is therefore difficult to translate experiences from one country to another. For instance, some are natural/national parks only; both centralized and decentralized administrations exist; patterns of land ownership vary; and each of the three 'generations' of BR was represented (see below).

GOVERNANCE STRUCTURES AND INSTITUTIONS

Key challenges recognized at the beginning of the session were that the designation of a BR often creates a new territoriality, and that conflicts can emerge between this new territoriality and the existing situation. These challenges and conflicts depend to some extent on which 'generation' a particular BR belongs to. Within the BRs represented in the session:

- Four came from the first generation (conservation/research focus): Gurgler Kamm, Austria (designated 1997); Swiss National Park (1979), Mount Olympus, Greece (1981), Lake Torne, Sweden (1986).
- One came from the second generation (conservation/development focus): Berchtesgaden, Germany (1990).
- Two came from the third generation (sustainable development, local/regional identity focus): Menorca, Spain (1993), Kruger to Canyons, South Africa (2001).

The first-generation BRs typically have only a core area; where the core area, buffer zone and transition zones have different ownership patterns and/or fall under the jurisdiction of different institutions/authorities, the challenges of governance tend to increase.

INSTITUTIONAL FRAMEWORKS AND STAKEHOLDERS

This section provides some key points regarding the institutional frameworks and stakeholders in the seven BRs represented in the working group.

1 *Gurgler Kamm, Austria*: is part of a protected area (Natura 2000 – European network of protected natural sites). The BR is not recognized by local people; there is neither a manager, nor a management plan. While local government officials and researchers are interested in the BR, the local tourist industry is not. In the region, there is also a nature park (integrating the BR, but without distinct boundaries) established by the municipality, with a recently-appointed manager.
2 *Lake Torne, Sweden*: only fourteen people live in the BR, and there is no management plan. The focus of activities is on research and monitoring. People in the local tourism industry are interested, but the local authorities are wary of the concept. There are plans to extend the BR to include the local town.
3 *Swiss National Park, Switzerland*: there are no inhabitants in the BR itself. Protection and development issues are the responsibility of different departments of the federal administration.
4 *Mount Olympus, Greece*: comprises state land managed by the national Forest Service; there are almost no inhabitants.
5 *Berchtesgaden, Germany*: has a complicated legal status, as it includes a national park (with a conservation emphasis) under German law; while the BR is a planning category under Bavarian law (development area).
6 *Kruger to Canyons, South Africa*: Limpopo Tourism and Parks manages the core areas (provincial nature reserves), the Department of Economic Development, Environment and Tourism regulates the area, and the BR is managed in consultation with local communities. There is strong interest from local stakeholders.
7 *Menorca, Spain*: has a unified system under the local government. Everyone knows who makes decisions; citizens can ask the government and vice versa. The BR coordinator is a political appointment responsible to the President of the island's government.

Mention was also made of Entlebuch BR, Switzerland (designated in 2001). In an economically weak area, designation has provided a chance for recognition of the area's economic potential, linked to the reorganization of social/economic/cultural life and a move from old structures/competencies to effective new ones.

As BRs are encouraged to conform to the Seville criteria, support for change tends to depend on whether people and institutions see the potential benefits. One key issue relates to the socio-economic context. For instance, if a BR is in a 'marginal' area, (for example, Lake Torne, Entlebuch), conflicts of interests can be small or non-existent, and the BR may be viewed as creating new opportunities. Conversely, for BRs in 'high potential' areas (for example, Berchtesgaden, Gurgler Kamm and the wider Obergurgl region), conflicts of interests tend to arise, with a need to create incentives (mainly financial) and to show benefits. In particular, BRs can be seen as opportunities for economic development; the BR 'label' (that is, membership in the World Network of Biosphere Reserves, a UNESCO 'club' of 450) can bring targeted funds. At the same time, it must be recognized that the word 'reserve' (or its translated equivalents) can create challenges to implementation. This relates to negative perceptions both of 'reserves' for people (cf. Indian reserves) and of conservationists (as external forces driving their own agenda with little regard for local people). In South Africa, there has been a shift in the perceptions of local people with regard to conservation, as they see it as a source of benefits for social improvement and so on.

PARTNERSHIPS ON THE SCIENCE–GOVERNANCE INTERFACE

Maintaining linkages between the various stakeholders concerned with BRs requires both financial and human resources. A number of examples were presented:

- *Berchtesgaden:* monitoring is done by the national park: results are provided to the public and politicians without interpretation. Scenarios of possible change have been developed and used for management planning. There is an advisory council for the national park (core area). It is valuable to persuade opinion leaders (for example, a locally-born Olympic champion) of the value of the BR.
- *Gurgler Kamm*: a major interdisciplinary study with the MAB programme was conducted in the larger (Obergurgl) region in the 1970s, during which scientists and local stakeholders worked together. The Obergurgl model integrated natural science, human science, socio-economic science and local stakeholders. However, communication broke down, and there is a need to start again. Local stakeholders are interested to repeat the 'model Obergurgl project'.
- *Swiss National Park*: there is a scientific committee which acts as an efficient means for transferring information (often face-to-face; no formal reports).
- *Menorca*: both the sustainable development plan and land planning require inputs from diverse stakeholders. There is an observatory for environmental and socio-economic monitoring which provides data that is also used for revising plans.

THE SCIENCE–GOVERNANCE INTERFACE: WHAT IS NEEDED FROM SCIENCE/ SCIENTISTS

Most research done in MBRs seems to be natural science. While it is recognized that basic science is essential in BRs – especially in core areas, but also in other zones – there is a very strong need for (more) social science, for example, on social issues and networks, participation, and management strategies. Specifically, a meeting of ten Austrian/German MBR managers in 2004 proposed that:

- *More social science is needed*: for example, on users' and local people's needs.
- *Scientists should not just produce reports*: managers (most of whom are natural scientists) need

training in [the values of] participatory methods, stakeholder analysis, stakeholder engagement and so on.
- *More proactive research is needed*: rather than waiting until conflicts appear.

A key concept is for BRs to be 'learning regions' combining scientific knowledge, education, and management. BR managers/coordinators need to provide a framework for scientists to present results from their research to visitors and other stakeholders. It was noted that the personality and the profile of the BR manager/coordinator significantly affects his/her 'receptiveness' towards research and research needs. The other side of this is that scientists must be willing and able to 'translate' their research results into easily-understood knowledge. Berchtesgaden provides a number of examples:

- Scientists propose research topics, from which the MBR manager chooses appropriate topics. Research can also be commissioned if funds permit.
- Stakeholder consultation: modeling has been used to translate scenarios of change to local people (this is expensive). Outcomes include:
  - Results used in negotiations over new agricultural subsidies.
  - These activities give scientists new standing (though some other scientists don't understand why scientists spend so much time working in BRs).
- A programme of hikes with scientists is very popular, and a way of directly communicating knowledge 'in the field'.

A critical need was identified for scientists to work in teams, rather than as individuals (and not only in research, but also in monitoring). This requires the integration of natural and social science. A key element of effective teamwork is for people from different disciplines to interact closely; one means can be for them to be in the field at the same time. Teams of scientists can jointly develop research questions and projects. Apart from basic and social science research, a key need is for empirical research on which management strategies are effective in achieving conservation success. This is essential as an input to management plans. Finally, there was general recognition of a need for increased effort in training and capacity building, based on solid and site-specific research.

WORKING SESSIONS ON INDICATORS

At the beginning of the discussion, it was agreed that different domains of global change can be defined; for example, climate change; globalization of economies; globalization of communications. All of these relate to the broad concepts of global environmental change (GEC) and sustainability. As discussed in the Vienna workshop, indicators may be used to evaluate, first, vulnerability to GEC; second, adaptive capacity to GEC; or third, both. It is important to separate criteria from indicators. Equally, the results from monitoring indicators need to be interpreted.

Following this general discussion, the emphasis shifted to the suitability of the indicators proposed in the Vienna workshop for the western European situation. It was agreed (as noted in the proceedings of the Vienna workshop) that three of the indicators in the 'maximum set' – literacy, food security, health – were not very relevant in this context. After some discussion of the need to give higher priority to certain indicators (for example, tourism, values and attitudes, ecological/sustainability knowledge), the working group decided that it would be desirable to group the indicators into the following categories:

- land
- water
- population
- livelihoods
- economic dimensions
- tourism
- policy support
- problem-solving
- adaptive management
- BR human resources
- sustainability.

Once these categories had been decided, existing indicators were considered. Some were retained, and some new ones were introduced. It was suggested that the new categories and many of the new indicators would also be appropriate in other regions of the world. The final set of indicators is shown below in Table 20.1.

The working group broke into subgroups for more detailed discussion on specific indicators. Unfortunately, insufficient time was available to consider all indicators at the same level of detail. The results are presented below.

Land

Land cover and *land use* are integrative indicators; it is possible to use remote sensing data to obtain the former and, in some cases, the latter. A number of variables for monitoring were identified, at different levels of priority, as follows:

- Minimum set
  - *land cover:* potential vegetation map, actual vegetation map (remote sensing data), land use map
  - *land ownership*: ownership identification, land-register maps.
- Medium set
  - *land use change*: changes in the past (old records, old photos, historical development) and monitoring (dimension of the changes in ha, km^2 and so on)
  - *hazards*: extension of the impact (fire, avalanche, floods, erosion, and so on).
- Maximum set
  - *productivity*: biomass (t/ha).

Table 20.1 The final set of indicators

Category	Minimum set	Medium set	Maximum set
Land	Land cover Land ownership/tenure	Land use change Hazards	Productivity
Water	Water quantity	Water quality	
Population	Census (number, gender) Permanent residents Migration	Numbers of medical centres and doctors	Mortality, diseases
Livelihoods	Sectoral employment	Farming (including livestock numbers)	
Economic dimensions	Income (total tax income)	Compensation for restrictions Value of property	
Tourism	Tourist beds Visitors to BR facilities	Number of tourists at specific locations	Frequencies, seasonality, types of tourists
Policy support	Amount/source of public funds		Infrastructure
Problem-solving	Functioning BR-society mechanisms		Chronology of interactions
Adaptive management		Hazard management	Incorporation of new knowledge in BR management
BR human resources	Number of staff Training		Visions, goals
Sustainability	Environmental actions (BR+public)		Values, attitudes Public knowledge

For flood *hazards*, the variable to be measured is flood discharge of a certain amount to occur (or be exceeded) in the long-term average once in T years (for example, 2, 10, 100 years and so on). Measurement of return periods would also apply to other types of hazards.

Water

The necessary condition for water quantity is long-term continuous records of discharge, which always belong to a gauge and its catchment area. Criteria for measurement are:

- runoff (from the catchment area) in mm per time unit (for example, year, month);
- gauge-related criteria: discharge/flow (instantaneous, average daily, monthly, yearly flow), for example, long-term average monthly flow/discharge

- specific criteria, defining water availability (quantity) in dry periods (droughts): $Q_{7,T}$ - 7 day (average) T year minimum flow/discharge (through an analysis).

Measurement of *water quality* would consider variables such as:

- chemistry, for example, nutrient content (N, P, ...g/cm^3)
- biology, for example, biomass (g/cm3 or individuals/cm^3)
- organic pollution (as before).

Population

Census data are part of official statistics, collected at regular intervals and estimated between these intervals. These data should be spatially disaggregated into population in the buffer zone, transition area, and wider region directly interacting with the BR.

Migration

The emphasis should be on permanent residents, and population changes. Specific indicators would be:

- number of *permanent residents* (as opposed to overall number of people including tourists, and seasonal workers, for example, during tourist seasons)
- *migration* (again relating to permanent residents): outmigration, immigration, and net migration balance, to indicate whether an area is losing people on a permanent basis.

Livelihoods

Data on *sectoral employment* are available from official annual statistics, and should be collected for the BR as a whole.

Economic dimensions

Data on the total tax *income* for communities within the BR are available from official annual statistics, and should be collected for the BR as a whole.

Tourism

Data on the number of *tourist beds* should be collected every five years, and also compared with the population of the area to give a measure of tourist intensity. Data on the number of *visitors to facilities within the BR* should be compiled monthly, and disaggregated between the various zones of the BR.

Policy support

Data on the *amount and sources of public funds* have to be reported annually by BR administrations. Both the total amount (investment in the area) and diversity of sources (greater diversity suggests greater sustainability) are important. Indicators of infrastructure relate to:

- roads and footpaths (trails) and may include measures such as length (total and per area e.g., km/km^2), quality, and annual expenditure for maintenance
- infrastructure for dissemination of information, for example, environmental information centres, signposts.

Such information is usually collected annually.

Problem-solving

Functioning BR-society mechanisms may include a BR advisory committee and/or a scientific advisory committee. Their activity and importance may be measured in terms of numbers of formal meetings per year, numbers of ad hoc consultations per year, and diversity of membership. Conversely, information of numbers and types of illegal activities will suggest problems in the effectiveness of such mechanisms. A *chronology of interactions* represents a retrospective indicator, which can be obtained through the analysis of documents and the regional media to identify key stakeholders (and changes in these) and their interactions.

Adaptive management

It was noted that *hazard management* would usually not be undertaken in the core area of BRs. In the buffer zone and transition area, relevant infrastructure (for example, for avalanche, fire, flood protection) could be evaluated in terms of numbers and areal coverage of structures, and budgets for installation and maintenance. Data on the existence and budgets of emergency services would also be relevant. Such data are typically available on an annual basis. Information on the *incorporation of new knowledge in BR management* would have to be collected through case studies.

BR human resources

Data on the *number of staff* are available on an annual basis. Similarly, annual data are usually available on training, with respect to budgets and the number of hours and topics of training. Information on the *visions and goals* of BR staff needs to be collected through in-depth interviews, and so on.

Sustainability

Environmental actions include activities for both local people and visitors. They may include publications (newspapers, newsletters, and so on) and guided walks. Both total numbers of people reached and more detailed breakdowns (age, local/visitor, and so on) are relevant. Means of measuring sustainable environmental actions may relate to energy efficiency and waste recycling (numbers and types of facilities, investment, and so on). Information on *values and attitudes* needs to be collected through surveys of different groups (locals, visitors, and so on).

21 *Report of the Himalayas and Central Asia Working Group*

Rapporteur: Daniel Maselli

The working group included participants both from the region and representing international and intergovernmental organizations (Centre for Development and Environment (CDE), Switzerland; International Human Dimensions Programme, UNESCO. Mountain Biosphere Reserves (MBRs) in five countries – China (Changbaishan), India (Nanda Devi), Kyrgyzstan (Issyk-Kul), Mongolia (Uvs Nuur Basin), Russia (Katunskiy) – as well as Sagarmatha World Heritage Site (Nepal) were represented.

This report should be regarded as a joint effort of the working group, which was chaired by Daniel Maselli, CDE.

INVOLVEMENT OF INSTITUTIONS IN MBR OR PA MANAGEMENT

To be able to improve the management of MBRs, a thorough understanding of the institutional actors implicated in decision-making and implementation is fundamental. Since the political, administrative, legal, and societal settings differ considerably from country to country, a rapid comparative assessment of the major actors was undertaken. With respect to the various categories of actors, the following hierarchy was adopted to analyse the various cases represented:

- inter-governmental organizations
- international organizations
- state institutions
  - federal/national government
  - state/province/oblast
  - local/district/rayon/sub-province
  - village
- population
  - community (e.g. loosely organized groups)
  - individuals
- non-governmental organizations
  - external (from abroad)
  - internal (from within the state/nation, region etc.).

In order to indicate the degree of influence, importance or involvement regarding the management of MBRs or PAs, three categories have been distinguished: high, medium, and low.

INSTITUTIONAL ARRANGEMENTS

The following section provides an analysis of the decision-making related to the management of MBRs, using two leading questions drawn from responses from MBR managers to a questionnaire from the organizers of the workshop.

1. Who makes or influences decisions about the daily management of the MBR?

Core area

In Kyrgyzstan, India, Russia, Nepal and China, the approved management plan guides the Director of the MBR in achieving the conservation goals, specifically those set for the core area. In Mongolia, the Protected Areas Management Department, belonging to the Ministry of Nature and Environment, also intervenes in daily management matters.

Buffer zone

Generally, the director of the MBR holds an authoritative position, but he/she is required to respect the customary rights of the local inhabitants and appropriately involve them in designing and executing the management tasks specified in the approved plan.

Transition area

A transition zone can have private, community and/or government land; the proportion of these categories of land may vary greatly from one reserve to the other. With regard to privately owned land, individual landowners generally decide on their own what they want to do. However, this does not apply to China and Mongolia where the law does not provide for any private ownership of land.

The MBR director, by and large, has no legal authority within the transition area. He or she therefore has to engage in informal discussions and consultations with the private landowners in order to address management issues or with regard to an intended or desired action from his or her side. In India, incentives can be given which support desired conservation goals, for example, incentives may be given to local people to cultivate medicinal plants so as to reduce the threats to the diversity of this resource in the wild.

In Russia (Katunskiy MBR) for example, a special scientific advisory board including participation from the MBR administration, landowners and land users, and scientists from different universities has been established to achieve the sustainable use of natural resources in the buffer zone and transition area. If special events occur (for example, fires, dominance of invasive species), additional actors may intervene.

2. What conflicts at present or likely to arise in future need to be addressed in order to avoid or minimize the undesirable negative changes in MBRs?

The answers to this question varied considerably from one country to another.

China

- Tourism: conflicts between the administration and travel agencies, local residents (hotels, restaurants).
- Natural resources utilization: water resources, more hydro power plants: conflicts between the administration and private companies; collection of wild plants, harvesting pine seeds, mushrooms etc.; hunting and so on (non-timber forest products): conflicts between the administration and the local population.

India

- Regulating traditional access leads to conflicts, for example, collection of medicinal plants; local people are dissatisfied with the direct economic benefits (money); who profits? fair (re-)distribution.

Kyrgyzstan

- Economic activities with negative impacts in the buffer zone, which might negatively impact the core area, include the mining industry, collection of medicinal plants, hunting, deforestation. There are therefore conflicting interests and 'bad governance' (including bribes for illegal activities).

Mongolia

- Short-term fluctuation (for example, limited to four to five years) of land utilization by private persons due to a lack of a mechanism that regulates land tenure, eventually causing harm to natural resources (exploitative behaviour) and/or is problematic for the 'land owner'.
- Consumptive resource uses are not allowed in the 'strictly protected area' (for example, the collection of medicinal plants is forbidden).
- Need for better coordination of land uses within the MBR.

Nepal

- Tourism: the high commitment of the government to conservation and simultaneously to livelihood should be increased.
- Conflict of interest results in pollution, pressure/stress on natural resources (impact on cultural and NR goals).

Russia

- Tourism: conflicts between the MBR administration and travel agencies and other tour organizers with regard to ecological regulations, especially within the core area. Also, some use the MBR for tourism illegally without any negotiations with the MBR administration.
- Collection of medicinal plants within the buffer zone results in conflict between the MBR administration and the local population. This is also with regard to ecological regulations (places, quantities, and so on).

Conclusions and recommendations

The most frequent problems relate to conflicting interests between the needs or requirements of the MBR managers responsible for conservation and those of the local inhabitants. The following recommendations result:

1 Decision-making mechanisms, obstacles and opportunities to improve the state of the buffer and the transition zone should be studied, taking into consideration the specificities of each MBR.

2 Research should be trans-disciplinary, allowing all stakeholder groups to be actively involved. Such participatory research will also help, first, to better understand and incorporate traditional knowledge systems, second, to consider community participation in decision-making, and third, give neglected groups (for example, women or minorities) a voice, thus leading to more effective management decisions.

3 When designing any research programme (strategy, project, activity), particular attention must be paid to possible non-intended negative impacts and to monitoring of the state of MBRs by neutral/independent entities.

4 Global change has to be given greater importance in the management of MBRs, with regard to both research and management.

5 New research programmes need to be developed after careful examination of existing knowledge as well as the limitations in using this knowledge in drawing up management plans. The research programmes must address the needs of the MBR managers jointly with those of the local people.

6 Meaningful management plans should consider comprehensive development strategies – including both the protection of rare species or species threatened by extinction and the needs of the local population – eventually contributing to the preservation of plant communities and pertaining to the conservation of rare species through old ('traditional') land use practices.

PROBLEMS AFFECTING THE MANAGEMENT OF MBRs OR PAs

The following list of problems encountered by MBR managers gives an insight into the high variety of obstacles to overcome while managing such protected areas. Some tentative comments and suggestions have been formulated regarding possible ways to overcome these difficulties:

- Lack of, or inadequate institutional arrangements in decision making (Kyrgyzstan, Russia).
- » Undertake research to identify the existing institutional deficiencies and opportunities to overcome them; gather information regarding the lack of appropriate institutional arrangements. This should lead to the launching of a negotiation process leading to a proposed design of new required institutions.

- Legislative gap: while nature reserves, national parks, nature parks and so on have their legislation at federal and regional level, MBRs lack such legislation (Russia, India).
- » Development of a legislation for BRs, political lobbying.

- Low priority of nature conservation given by government (Kyrgyzstan, Russia).
- » General awareness-raising efforts supported also by external (international, intergovernmental) actors.

- Inadequate or lack of coordination between different stakeholder groups or entities involved in BR management (India, Kyrgyzstan, Nepal, Russia, Mongolia).
- » Special efforts to improve or establish coordination (for example, new institutional arrangements, regular round tables); an organization such as UNESCO could contribute towards the establishment of model MBRs to disseminate strategies enabling proper coordination.

- Missing or limited capacities in conflict resolution skills suitable to address tensions and conflicts related to MBR management (India, Russia, Kyrgyzstan, Nepal, Mongolia).
- » Provision/development of special training.

- Lack of qualified staff or sufficient human resources for management in general (Russia, Kyrgyzstan, China, Mongolia, Nepal).
- » Additional specific training and possibly more staff needed.

- Lack of funds for managing MBR (Russia, Kyrgyzstan).
- » Awareness-raising campaigns among political representatives (members of parliament), donors in nature conservation and sustainable development as well as society at large.

- High fluctuation of personnel (discontinuity); this appears to be especially important in India at the level of MBR director, and particularly critical during the establishment phase of MBRs.
- » Rewards to MBR directors and their staff depending upon their performance can be a way to reduce this problem; maybe a separate cadre of directors with fixed tenurial contracts and accountable to a management committee of stakeholders could be helpful.

- Inequitable distribution of benefits stemming from the buffer zones and transition areas (Nepal, China, Mongolia).
- » Development of rules and negotiations with concerned stakeholders of benefit sharing.

- Complicated bureaucracy; a whole cascade of different jurisdictional institutions starting from the state government downwards complicates decision-making and implementation.

» A MBR-specific management committee, which meets from time to time with the involvement of all stakeholders may be a solution.

ASSESSING GLOBAL ENVIRONMENTAL CHANGE IN MBRs: CHOOSING THE APPROPRIATE INDICATORS

General thoughts

While static data are frequently collected, the group proposed to focus on time series that will better allow assessment of processes and trends of changes. Comprehensive efforts have to be undertaken to secure the active participation of local communities in MBR-related research and management activities.

Relevant fields to be observed

Basically, two fields or domains have to be taken into consideration. The first relates to the natural resources or environment where indicators related to biomass, biodiversity, soil fertility, agricultural productivity including forest productivity, or water (availability, quality, distribution) have to be assessed. Appropriate attention has to be paid to traditional knowledge with regard to better understanding and the monitoring of adaptive changes over time and space.

The second domain relates to the socio-cultural and economic systems on which the next paragraphs focus. The group strongly proposes working with a 'livelihood-centred approach', beginning with an assessment of the current livelihood conditions (according to DFID, 1999) and strategies in order to have a clear reference base for future changes. Key elements such as the role of livestock and its linkages with the other elements of the productive system will thus become more evident. Such an understanding is crucial to eventually anticipate possible reactions or actions by local actors relevant for the management of the BR.

Proposed fields and indicators

Given this perspective, the following aspects are considered key elements for a socio-economic, cultural and political assessment.

Food security

This is an issue in many MBRs where the rural population does not produce enough from private land for its livelihood. In China, this appears to be less a constraint because of government subsidies.

Land use and land cover changes

This is one of the most important indicators, since it reveals rapid adaptations of livelihood strategies and is likely to have immediate and direct positive or negative impacts on the management of the MBR. Particular attention has eventually to be paid to lowland areas which are likely to affect the uplands through direct linkages in terms of resource benefit (such as, water).

Some examples of possible changes and their implications are as follows. If rain-fed land is converted to irrigated plots, the changing cropping pattern will require more water. The same will happen if tourist infrastructure is developed and a tourist influx takes place. In addition, other resources might also be affected, for example, firewood, forage or pastures. Changes could also reduce stress on natural resources, for instance when remittances lead to a reduction of the direct daily dependency on local natural resources (such as, pasture land).

Land tenure

Ownership of land is a very sensitive indicator for rapid changes or adaptations from a livelihood strategy perspective.

The various proposed indicators or criteria related to the participation of local stakeholders in MBR management were left aside since this should be considered as a general rule to improve management and not simply considered as being a separate indicator. Pilot studies are needed to evaluate to what extent the indicators considered so far in GLOCHAMORE workshops can be measured from the existing data.

Dependence on local resources

The monitoring of the degree and the type of dependence on local resources can help to assess changes and eventually anticipate possible negative or positive impacts.

POSSIBLE OR EXPECTED CHANGES AND POSSIBLE STRESSES: IMPLICATIONS FOR PEOPLE'S LIVELIHOODS

A preliminary remark is that the details presented here emerged from a very casual discussion. A thorough analysis is needed to predict future changes and their implications. MBR managers appear to be increasingly concerned with unforeseen stresses happening over shorter time frames for which communities are not able to make the needed adaptations in time, and their traditional knowledge might therefore lose its value.

It can be expected that there will be forced changes to adapt livelihood strategies as a result of either stresses and pressures or new opportunities. Consequently, tensions and/or conflicts due to conflicting interests can appear or intensify. The following description serves as a stimulation to identify appropriate indicators under specific local conditions in the various MBRs.

List of expectable changes and some possible indicators:

- *Land use changes*
  - Shift from rain-fed to irrigated land or to cultivation of non-timber forest products on community or private land (such changes can easily result in tensions or conflicts, for example, over access to land resources or about land tenure in general); possible reduc-

tion of pressure on pasture land (for example, in Kyrgyzstan through dissolution of kolkhozes and sovkhozes).
  - Decrease of water availability/quality or increase of water use (for example, due to climate change, changes of land-use practices including tourism) leading to increased water stress.
  - Introduction or expansion of tourist activities: type, intensity (for example, construction of new tourist infrastructure, number of tourists, duration of stay, seasonal distribution, kind of activities, relationship to lowlands).
  - Changes in land tenure (these can result both in positive or negative impacts on the MBR).
- *Insufficient or decreasing economic income*
  - Migration of populations to and/or out of the region/role of remittances: type (who, for what, when, for how long etc.); contribution to livelihood, utilization of remittances, gender aspects, use of the remittances (for example, to cover food security or for investments such as cash crops such as fruit trees or new types of activities like small restaurants, pensions and so on).
  - Changes in age pyramid/composition indicating, for example, out-migration of younger people, male or female portions of population, and so on.
  - Special cultural and religious aspect in Russia (sectism).
- *Changes in various state services*
  - Availability and/or kind of health services.
  - Availability of education services (levels, quality of skills provided and so on).

In a next step, the expected impacts from these anticipated or potential changes should be described or assessed in order to develop mitigation strategies or measures where necessary. This should also include the assessment of the values of ecosystem goods and services to have a reference base.

SPECIFIC NATURAL HAZARDS IN VARIOUS MBRs: A RAPID ASSESSMENT BY COUNTRY

Given the likelihood of increasing number of extreme events as a result of global environmental change, and the resulting links to natural hazards, a rapid assessment of the situation in each country resulted in the following:

- China: predominantly fire.
- India: no specific hazards to be mentioned; however, rainy season landslides, dry season fire hazards, and earthquakes may occur (the latter did not affect the Nanda Devi Biosphere Reserve over the past 100 years).
- Kyrgyzstan: floods, avalanches, glacier lake outbursts, landslides, rockfalls.
- Mongolia: severe winter with very cold temperatures, drought.
- Nepal: fire, landslides, glacier lake outbursts, heavy rainfalls and flash floods.
- Russia: floods, lake outbursts, avalanches (mostly outside the MBR), rockfalls, earthquakes.

MAIN CONCLUSIONS

There is an obvious need for designing and developing new institutional arrangements or forms of social organization to respond to the needs and to adapt accordingly. This should be done in a participatory way.

REFERENCES

DFID. *Sustainable Development Guidance Sheet*. Department for International Development, 1999. http://www.livelihoods.org/info/info_guidancesheets.html

22 *Report of the Latin America Working Group*

Rapporteur: Christoph Stadel

The working group included eight participants: Pedro Araya, MAB, Chile; Sandra Brown, CIAT, Colombia; Marcela Cañon, National Parks, Colombia; Marco Cortes, University of Temuco, Chile; Pablo Dourojeanni, The Mountain Institute, Peru, Huascarán BR (group secretary); Javier Sánchez Gutierrez, Sierra Nevada Biosphere Reserve, Andalucia, Spain; Mark Nechodom, US Forest Service, USA; Christoph Stadel, University of Salzburg, Austria (group coordinator). While participants had experience in a number of MBRs, especially Araucarias (Chile), Cinturon Andino (Colombia), and Huascarán (Peru), the participants do not represent the whole spectrum of Latin American experience in MBRs.

THE RANGE OF ACTORS, STRUCTURES/INSTITUTIONS (FORMAL AND INFORMAL) INVOLVED IN THE GOVERNANCE OF MBRs

The mapping of all actors and their functions involves the public sector in many of its instances, such as at the:

- national level: all ministries and their dependent institutions: agriculture (institutes of natural resources, water authorities etc), mining, tourism, fisheries, environment, etc.
- provincial and district levels
- indigenous authorities.

Private sector actors include landowners, non-governmental organizations (NGOs), peasant communities (*comunidades campesinas*), and the productive sector (mining companies, power companies, large farming enterprises, and so on).

The functions of these actors are basically restricted to their institutional or community objectives, and often there are weaknesses in cooperation and coordination towards a common long-term goal.

There are many different types of land tenure in Latin America; people may have communal ancestral rights and/or private land, and sometimes these overlap, as with public land. Biosphere reserves (BRs) have public recognition but there is no legislation for BRs in the region. There is therefore a legal weakness for BR management in Latin America. There are different forms of legislation and institutions for all types of resources (water, forest, environment in general), but none specifically for BRs although they are directly related to national park authorities.

In Latin America, there is no formal administration for the BR region, but there is an administration for the core area. The BR administrators are more focused on managing the core areas because these are public lands with legal directives and also because they are usually the managers of national parks. Actions in the buffer zone are prioritized in the action plan (management plan) but, since the administrators do not have any legal competences in the buffer zones and transition areas, the responsibility is shared with too many stakeholders and becomes more difficult.

THE CAPACITY OF THE VARIOUS ACTORS, STRUCTURES, AND INSTITUTIONS TO RESPOND TO GLOBAL CHANGES

The capacity to respond to change is summarized in Table 22.1.

Table 22.1 Comparison of the mean number of species from 1988 and 2003

Changes	Reaction capacity
Ecosystem	Scarce or non-existent. There is very little information and also there is little awareness of the impacts of global change on ecosystems. If the participation of local stakeholders in management increases, the capacity to take ecosystem adaptive measures is strengthened.
Political /economic	The state does not have clarity on environmental issues, so they are not taken much into account. Political power is very permissive and the major impacts are produced by the productive sector and indirectly by the public sector. Latin American countries, due to their poverty levels, are dependent on the private sector for investments and jobs, so the economic condition of the different regions determines the level and nature of impacts from productive activities. Thus, the poorer the region, the more permissive the stakeholders will be with respect to environmental impacts.

The incorporation of new information to enhance the capacity of different actors, structures, and institutions would not be a problem, especially in NGOs, but to change the attitudes in peasant communities or the public sector would take some time.

The generation of adaptive strategies, such as ecological or community-based tourism, is a real option that could easily create new opportunities for people living in BRs. In Latin America, these strategies have to be preceded by a strong education and formation campaign at all levels.

PERCEPTIONS OF SCIENTISTS WORKING IN MBRs

In all BRs in Latin America, work is being done by scientists from a great variety of disciplines, such as biology, ecology, forestry, rangeland management, archaeology, geology, geography, climatology, glaciology, agriculture, law, sociology, anthropology, social communication, economics as well as traditional knowledge systems (medicinal plants, fauna, land use planning, and so on). Basically, scientists work independently.

All investigators require official permission from the park or BR manager to carry out their work yet they are often granted the freedom to freely pursue their research as they deem necessary. In some cases, permission may not be granted. However permission must be granted for investigations in the core areas of the BRs. This is often required for the other zones, but scientists must seek permission from the local people.

Research is sometimes directed towards management issues, but only recently has this begun to happen. The administration of the core area promotes investigation aimed at better management, for example by providing a list of potential research themes or interesting topics.

WORKING SESSION ON INDICATORS

The starting point for the discussion was the set of indicators developed at the Vienna workshop.

Minimum set of indicators (high priority)

1 *Population:* all these indicators are quite important and seen as basic information.
2 *Literacy*: rates of literacy and education levels (especially the proportion with formal education) are very important and also are seen as basic information. Skills are also important but are not measured directly by the census directly; this can only be done indirectly.
3 *Food security* or malnutrition: this is basic information for all BRs.
4 *Health*: basic information.
5 *Land use*: very useful; all countries have the capability to measure land use patterns using satellite imagery and GIS. However, the resources to acquire the imagery are usually not available.
6 *Vegetation cover*: very useful; all countries have the capability to measure the extent of vegetation cover using satellite imagery and GIS. However, the resources to acquire the imagery are usually not available.
7 *Quality of water*: very important, but not possible to measure constantly in time and space. Consequently, only the most important water basins should be chosen for measurement.
8 *Quantity of water*: very important, but not possible to measure constantly in time and space. Consequently, only the most important water basins should be chosen for measurement.
9 *Participation of different actors in BR management*: this is a very complex aspect to be measured, but there are some possibilities (sub-indicators) that could approximate to reality. An analysis of actors, their roles and their relations was considered by all to be an important indicator.

Medium set of indicators

10 *Source of livelihood*: sources of livelihood (activities) that directly affect/put pressure on the biodiversity of the BR; for example, grazing, cultivation.
11 *Employment*: permanent and seasonal measured sectorally (high priority).

12 *Investments in the BR*: from public, private or from cooperation agencies; how they invest the money and in what.
13 *Net assets*: more useful than assessing net assets is measuring the level of poverty.
14 *Agricultural productivity*: this is very important: especially for the most representative crops of the specific region (high priority).
15 *Forest productivity*: the measurement of forest resources, specifically of natural forests (high priority).
16 *Livestock*: types and numbers of native and non-native animals (high priority).
17 *Hazards*: instead of hazards, vulnerability should be assessed. Hazards are already identified.
18 *Human pressures and possible impacts:* high priority.

Maximum set of indicators (low priority)

19 *Tourism*: high priority.
20 *Value of ecosystem goods and services*: low priority.
21 *Land tenure*: high priority.
22 *Number of community-based organizations (CBOs)*: this is a good indicator but must be complemented with other information such as: the state of this CBO, whether it is formal or informal (recognized); number of members and their relation to resource conservation (does it exist or not?).
23 *Reasons for migration*: optional, may be important in some cases.
24 *Ecological sustainability knowledge*: optional.
25 *Dependence on local resources*: optional.
26 The remaining indicators suggested in Vienna would provide very important information, but are not easily measurable; they are not truly 'social' information.

RECOMMENDATIONS

- High priority to be given local stakeholder involvement, particularly in buffer zones and transition areas.
- Maintain 'distinctness' of individual BRs, no single solutions.
- Regional/global networks or subnetworks for scientific and management cooperation.
- Minimum set of indicators for global and regional comparison.
- Multi-scale approach within and between BRs to deal with scale differences and to avoid overgeneralization (particularly of indicators).
- Economic/poverty drivers and land use change are particularly relevant for Latin America.
- BR planning and management tools are to be developed to assist individual countries in regional or local planning (for countries with no legal status for BRs)
- Training and involvement of local researchers (capacity building).
- Encouragement/incentives for community based research on global issues.
- Investigation of aspects of cooperation/complementarity and possible conflicts between stakeholders to develop integrated solutions.

- Distinction between indigenous and non-indigenous priorities, strategies and potential solutions.
- Documentation of successful experiences (methods, approaches, activities, participation, and so on) and facilitation of diffusion/exchanges with the participation of major stakeholders.
- Identification of local channels of communication for the dissemination of planning, implementation and results.
- Working through local 'instances' for permission, involvement and socialization of all research activities.
- BRs should be incorporated in the national, regional or local legal framework and planning processes.

Part VII

Workshop Report and Appendices

Workshop Report

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WORKSHOP GOALS AND OBJECTIVES

The GLOCHAMORE project is predicated on the notion that scientists can contribute to the capacity of mountain communities, managers/coordinators of mountain biosphere reserves (MBRs), and the larger societies that surround them to anticipate the impacts of climate change and respond in ways that maintain or enhance economic, ecological and social capital (Reasoner et al., 2004). This interface between scientific – and more broadly, environmental – knowledge and environmental governance is an important topic for study, particularly as the exchange between knowledge and governance is often not transparent or effective.

The goals of the workshop are to better understand this interface through addressing two main issues:

- How can it be ensured that scientists and other stakeholders provide policy-relevant information to the managers of mountain systems in general, and the managers/coordinators of MBRs in particular?
- Are mountain systems, and in particular MBRs, equipped with appropriate mechanisms and institutions for governance which can address the challenges of global environmental change?

From analysis of these issues, the workshop was intended to propose a programme for applied and participatory research to improve and monitor the exchange between knowledge and governance in the specific context of moving towards sustainability in mountain regions, in the context of global environmental change.

Within the two goals, six objectives were defined for the workshop (more detailed suggested content for the working groups addressing each theme is indicated in italics):

1. Review drivers of global environmental change in mountain regions and the pressures on mountain socio-economic systems deriving from these drivers.
2. Present current theory and data regarding the nature and function of the knowledge-governance interface in mountain regions in both industrialized and developing countries: *mechanisms and institutions for governance in mountain regions, and specifically MBRs; variations in mechanisms and institutions across the ecological/social/economic/political systems in mountain regions; and the ways in which knowledge is incorporated into their function; strengths and weaknesses of science as currently practiced within this context.*

3 Describe the current practices at this interface as experienced by MBR managers/ coordinators and other participants: *the range of structures that govern MBRs and their current capacity to strategically monitor changes, incorporate new information, and generate adaptive responses and policies; the perceptions of scientists working at this interface;*
4 Identify promising institutional arrangements that can be implemented now in MBRs and in science programs: *for example, community participation in decision-making, monitoring and knowledge generation, adaptive management; enfranchisement of women and minorities.*
5 Assess the nature of additional research needed to improve prescriptions for institutional improvement: *the relative importance of 'scientific' and 'traditional' knowledge and the extent to which they can be complementary, the relative importance of economics (for example, subsidies), political processes (for example, enfranchisement and participation), cultural norms (for example, common goals) as prerequisites to systemic change; the potential for impartial evaluation of policy proposals; needs for more research versus better integration of existing knowledge.*
6 Refine or develop indicators by which to measure the success of these experiments at the interface between knowledge and governance, in the context of moving towards sustainability.

The workshop built on previous meetings within the GLOCHAMORE project – particularly the Vienna workshop on global environmental and social monitoring and the work of its working group on social monitoring in MBRs (Price, 2004) – and other meetings and projects on relevant themes. To introduce themes 1 through 4, plenary presentations were given by individuals working in MBRs and/or on relevant themes in other biosphere reserves or relevant locations.

Much of the workshop was devoted to parallel working sessions with regard to objectives 2–6 (see below). The sessions specifically addressed three sets of mountain regions:

- the mountains of western Europe
- the Himalaya and the mountains of Central Asia
- the mountains of Latin America.

This structure derived from the organizers' previous experience of organizing and participating in meetings on related themes (Price et al., 1999; Ramakrishnan et al., 2003), which led to the recognition that working sessions are far more effective when they focus on a specific region than when they attempt to address a range of regions (or the world as a whole) and/or to address issues at a global scale.

WORKING SESSIONS

During the working sessions, it was anticipated that the participants in each of the three working groups would:

- deepen their common understanding of the issues addressed in the meeting
- refine and develop appropriate criteria and indicators
- identify issues to be addressed through future collaborative research.

First series

The first series of working sessions addressed issues related to governance; how knowledge/science is used in MBRs, that is, objectives 2 and 3 of the workshop programme. MBR managers/coordinators participating in the workshop had received a questionnaire to encourage their consideration of these issues. It was proposed that the discussion should centre around two main themes, with the following questions:

1 What is the range of structures/institutions (formal and informal) involved in the governance of MBRs?
   - who is involved and how (check questionnaires)?
   - how do they work in partnership (or not)?

   What is the capacity of the various structures/institutions to:
   - strategically monitor change?
   - incorporate new information?
   - jointly identify/develop issues or questions to be addressed?
   - generate adaptive responses?

2 Perceptions of scientists working in MBRs
   - what types of scientists (which disciplines) work in the MBRs?
   - independent or employed by MBR etc. administration?
   - how do they decide what research to do/what to monitor?
   - do they direct their research towards management issues? If so, how?
   - what kind of research is being carried out by scientists related to MBRs?
   - which issues are being addressed and why? (Who sets the agenda? Who funds etc.)
   - what kind of approaches, which methods and so on, are being used, eventually developed or adapted?

If time permitted, the appropriateness of the relevant indicators developed at the Vienna workshop (Price, 2004) should be critically examined, for example:

- number of community-based organizations
- participation in BR management
- structure and function of BR management
- external influence of BR manager/coordinator.

Second series

The main aims of the second, and much longer, series of working sessions were to:

- assess indicators for social monitoring, starting with those developed at the Vienna workshop (Price, 2004)
- evaluate their applicability in the respective regional contexts

- refine and further develop these indicators in the light of sustainability in the respective geographical region.

It was proposed that the discussion should centre around the following themes:

1 Which indicators would MBR managers/coordinators find useful (to monitor and adapt to global change) and why (relevance, feasibility, and so on)?
2 Which indicators would be useful generally to improve understanding of global change and its impacts?
   - What are the overlaps between 1 and 2?
   - Are new indicators needed? If so, which ones and why?
   - Which indicators seem most important (definition of priorities)? Which are the critical indicators (triggers)?
   - Is it possible to collect these indicators? What are possible difficulties to be expected when monitoring these indicators? What can be done to overcome these difficulties?
   - What is the (most) appropriate temporal scale?
   - What is the (most) appropriate spatial scale?
   - Do priorities vary between the BR zones (core, buffer, transition)?

OUTCOMES

As the workshop progressed, the great diversity of situations both within and between the three regions addressed by the working groups became apparent. Nevertheless, common themes appeared during both series of working sessions, and provide important bases for a strategy for applied and participatory research.

With regard to the composition of scientific teams, the importance of ensuring that scientists from a wide range of natural and social science disciplines work together in interdisciplinary teams was emphasised. In fact, such research should go beyond being interdisciplinary: it should be transdisciplinary, including other stakeholders (including MBR managers and their equivalents and, critically, also members of local communities). For scientists, this requires a commitment to present their research ideas and results in ways that can be easily understood by the various stakeholders – and to be willing to listen to them and to incorporate their ideas and perspectives into research and monitoring. Thus, research and monitoring should be based on not only 'western' science, but also traditional knowledge. This is a conclusion of relevance not only in the context of this workshop, but for the development of the post-GLOCHAMORE research strategy as a whole, which should include an element of reflexivity to evaluate the success of effectiveness of such transdisciplinary activities.

One particular area on which research (and monitoring) is needed concerns the most effective participatory decision-making mechanisms and/or management structures for achieving the goals of MBRs, so that these can be implemented – an existing need which is made more urgent by global environmental change (GEC). In general, neither the signals nor the (actual and potential) impacts of GEC are well recognised by either MBR managers or local populations. This implies a significant need for appropriate communication regarding these signals and impacts by those in the scientific community who are aware of them. This links further to needs for training and capacity building. In regions where data and information are sufficient, scenario construction may be one element of these processes. Again, the relevance of this conclusion goes well beyond the themes addressed in this workshop.

Significant refinements were made to the indicators developed in the Vienna workshop, and it was recognised that very few are probably applicable at the global level; the regional – and even local – context must always be taken into account if indicators are to be meaningful for informing the development and implementation of both management actions and policy. In particular, even though the western European working group suggested that the indicators they proposed would be appropriate in other regions, this may not necessarily be true, depending on both different economic/social/political/environmental contexts and the existing and likely availability of relevant data and information. One important point to be made is that, in western Europe, agriculture and/or forestry are no longer the primary sources of livelihoods, and populations are rarely growing significantly; the converse is generally true in MBRs in developing countries. However, certain themes – of which the first two are contextual and largely natural science-based, and link to other parts of the developing post-GLOCHAMORE strategy – do appear to be of general relevance:

- water quality and quantity
- land cover and land use change
- land tenure/ownership
- population and age structure, and migration (and reasons for this)
- tourism facilities and numbers of tourists
- livelihoods and income – though what should be monitored depends on the region; tourism is increasingly important; remittances are important in MBRs in many developing countries
- food security in MBRs in developing countries; however, knowledge of livestock numbers appears to be of general relevance for both livelihood and conservation reasons.

These themes (though not all the detailed indicators proposed within them) echo the first six categories proposed by the western European working group; most of the other issues identified for possible indicators by this group were not identified as such in the other two working groups.

In summary, considerable work yet needs to be done to identify and then implement effective indicators for social monitoring in MBRs. In contrast to many of the indicators proposed in previous GLOCHAMORE workshops, there may be a greater need to distinguish between the situations and needs in different parts of the world; participatory research, management, and monitoring are likely to underline such differences. At the same time, attention should also be given to existing structures and themes for monitoring, both within individual countries and internationally (e.g., BRIM and GTOS).

REFERENCES

PRICE, M.F. Social monitoring in mountain biosphere reserves: The context. In: C. Lee and T. Schaaf (eds.) *Global environmental and social monitoring*, pp. 127–37, Paris, UNESCO, 2004.

PRICE, M.F.; MATHER, H.; ROBERTSON, E.C. (eds.) *Global change in the mountains.* London and New York, Parthenon,1999.

RAMAKRISHNAN, P.S.; SAXENA, K.G.; PATNAIK, S.; SINGH, S. (eds.) *Methodological issues in mountain research: A socio-ecological systems approach.* New Delhi, Oxford and IBH, 2003.

REASONER, M.; BUGMANN, H.; SCHAAF, T. Background and concepts for collaborative work: Global change research in mountain biosphere reserves. In: C. Lee and T. Schaaf (eds.) *Global change research in mountain biosphere reserves*, pp. xi–xviii, Paris, UNESCO, 2004.

Appendix 1
Workshop Agenda

SUNDAY, MARCH 13

Arrival of participants (for MRI Board Members: MRI Scientific Advisory Board Meeting)

MONDAY, MARCH 14

9.00 Workshop opening
Welcome
Javier Sánchez Gutierrez (Sierra Nevada Biosphere Reserve)
General Advisor (Junta de Andalucia Environmental Council)

9.45 **Session 1**
Chair: P. S. Ramakrishnan (Jawaharlal Nehru University, India)
Introductory and keynote presentations on objectives 1 and 2:

- Global environmental change in mountain regions as a challenge to management
- Social theory and constructs from economics, political theory, cultural anthropology, complex systems studies
- Knowledge systems.

Global Change impacts as perceived by MBR managers
Greg Greenwood (MRI, Switzerland)
Objectives and outcomes of the workshop
Martin Price (UHI Millennium Institute, Scotland)
The Institutional and Political Context of Biosphere Reserve Management
Mark Nechodom (US Forest Service, USA)

10.45 Discussion

11.00 Coffee break

11.30 Keynote presentations on objectives 1 and 2 (cont'd)
Allocating mountain water: uncertainty and impacts
Sandra Brown (University of British Columbia, Canada)
The science world and the biosphere reserve managers and decision-makers: the case of the BR of Minorca (Spain)
Juan Rita Larrucea (University of the Balearic Islands, Spain)
Sustainable development and global change in the mountains of Southwestern Europe (Andalucia)
Rosario Pintos Martín (Director, Natural Protected Areas Net In Andalucia)

13.30 Lunch (Botánico Café)

15.00 **Session 2**
Martin Price (UHI Millennium Institute, Scotland)
Introduction to working groups (see below)
15.15 Regional working sessions under objectives 2 and 3:
- Western Europe (Chair: Thomas Hofer)
- Himalayas and Central Asia (Chair: Daniel Maselli)
- Latin America (Chair: Christoph Stadel)

The sessions will be structured in a common way to facilitate comparison across regions and with the theory presented in theme 2.
Coffee break individual
18.30 Adjourn
20.00 Dinner

TUESDAY, MARCH 15

9.00 Working group chairs of Session 2 report to plenary
Discussion and synthesis
10.30 Coffee break
11.00 **Session 3**
Martin Price (UHI Millennium Institute, Scotland)
Introduction and keynote presentations on objectives 4 and 5: New approaches
- Networks for research for sustainable development in mountain areas
- Participatory research and monitoring

The Mountain Partnership: new opportunities for networking on mountain research
Thomas Hofer (UN Food and Agriculture Organization)
Innovative approaches for generating knowledge to support sustainable mountain development: example of a strategy for the High Pamirs in Tajikistan
Daniel Maselli (University of Bern, Switzerland)
Session 4
Martin Price (UHI Millennium Institute, Scotland)
Introduction and Keynote presentation on objective 6:
- Indicators and evaluation of sustainability

Indicators and evaluation of Sustainable Natural Resource Management and Governance
Susanne Stoll-Kleemann (Humboldt University of Berlin)
12.45 Discussion
13.00 Field trip to the Sierra Nevada BR (including lunch)
18.00 **Session 4** (cont'd)
Regional working sessions under objective 6:
- Western Europe (Chair: Thomas Hofer)
- Himalayas and Central Asia (Chair: Daniel Maselli)
- Latin America (Chair: Christoph Stadel)

The principal aim of the discussions is to consider the draft list of indicators developed during the first GLOCHAMORE workshop and evaluate their applicability in the respective regional contexts. If time allows, consideration will also be given to Objective 4 and 5.

20.00 *Adjourn*

21.00 *Dinner (individual)*

WEDNESDAY, MARCH 16

9.00 **Session 4** (cont'd)
Working groups as on previous evening

11.00 *Coffee break*

11.30 Group chairs of Session 4 report to plenary
Discussion and synthesis

12.00 **Session 5**
Chair: Thomas Schaaf (UNESCO MAB, Paris)
Discussion on next steps:

- Workshop synthesis
- Workshop products
- Workshop Proceedings
- Workshop Report
- Peer-reviewed synthesis article
- Research/implementation strategy pre-proposals as input for the Open Science Conference in fall 2005

14.00 *Lunch (Botánico Café)*

15.45 Excursion to La Alhambra

20.00 *Dinner*

THURSDAY, MARCH 17

8.30 **Session 6**
Chair: Greg Greenwood (MRI, Switzerland)
Working groups work on workshop products

10.00 Working group chairs of Session 6 report status to plenary
Next steps, deadlines and responsibilities

11.30 End of workshop

ORGANIZATION

For registration and general questions, please contact:

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For questions regarding the scientific content of the workshop, please contact:

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MEETING VENUE

The meeting will be held in Granada at the
Fundación Euroárabe
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Tel: 00 34 958 20 65 08
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http://www.fundea.org

TRAVEL ARRANGEMENTS

GLOCHAMORE consortium members will arrange and purchase their own travel tickets using their own GLOCHAMORE funds.

For all other participants, the workshop organizers strongly encourage participants to make their own travel arrangements (the most economical fare) from their country of origin to Granada (Spain). For those participants who are not in a position to advance funds for airline tickets, the Institute of Ecology and Conservation Biology at the University of Vienna will assist with the procurement of air tickets. However, it is important that in these cases travel itineraries and fares be communicated to the organizers before purchase. The workshop organizers will reimburse eligible participants in cash (€) while in Spain upon presentation of original tickets and receipts. Please note that GLOCHAMORE does not refund Business or First Class tickets. We strongly advise participants to plan their arrivals Granada for Sunday, 13 March 2005.

May we please ask participants (especially those from overseas) to book their flight as early as possible to obtain the most economical fares.

Please communicate your travel details (schedule and fares) to Natividad Jiménez and Francisca Sánchez no later than 31 January 2005.

All travel details and logistical details with Internet links can also be found at
http://www.mma.es/parques/lared/s_nevada/index.htm
> link “3rd GLOCHAMORE workshop”

ACCOMMODATION AND BOARD

The organizers will book hotel rooms for all the participants and will cover all accommodation costs. Breakfast is included at the hotels, lunch and dinner will be provided by the organizers or will be reimbursed upon receipt (developing country participants only).
Participants will stay at:
Hotel Vincci Granada
Avda. Constitución, 18
18012 Granada
Tel.: 34 958 20 40 61
Fax: 34 958 29 10 37
http://www.vinccihoteles.com

Addresses of the restaurants (dinners)

Botánico Café: C/ Málaga, 3, 18001 Granada. Tel.: 34 958 27 15 98.
La Ermita en la Plaza de Toros. Doctor Olóriz, 25, 18012 Granada. Tel.: 34 958 29 02 57.

Please also find the list of participants, city maps and the hotel at
http://www.mma.es/parques/lared/s_nevada/index.htm
> link "3rd GLOCHAMORE workshop"

VISA REQUIREMENTS

All workshop participants are requested to enquire about visa regulations for Spain and to obtain a visa in case this is a requirement in the country of origin of the workshop participants. Visa costs will be reimbursed by the workshop organizers upon presentation of the original visa cost receipt. Please inform organizers well in advance if additional documents such as invitation letters from Switzerland and/or Spain are required.

WORKSHOP LANGUAGES

The main workshop language will be English. English–Spanish simultaneous translation (and vice versa) will be available.

EQUIPMENT FOR PRESENTATIONS

The workshop facilities will comprise an overhead projector, a slide projector, a computer and a beamer for PowerPoint presentations. In order to avoid any technical problems during the workshop, participants are requested to send their PowerPoint presentations by e-mail to sierra.nevada@oapn.mma.es by 10 March 2005.

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Note

1 For example, 1) the European Conference on Environmental and Societal Change in Mountain Regions, held in Oxford, UK in December 1998, with primary funding through the European Commission's European Network for Research in Global Change (ENRICH) (Price et al., 1999); 2) University Education on 'Integrated Approaches to Mountain Natural Resource Management' in Shillong, India in November 2002, sponsored by UNESCO and co-sponsored by the MRI and ICIMOD (Ramakrishnan *et al.*, 2003).

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