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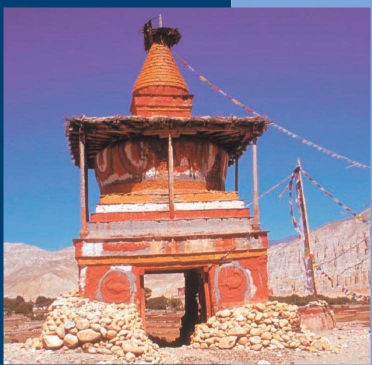
GLOCHAMORE

Global Change and Mountain Regions

Research Strategy[*]



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The Global Change and Mountain Regions (GLOCHAMORE) Research Strategy has been developed to guide managers of mountain Biosphere Reserves (MBRs) and scientists in planning and implementing global change research. The research strategy is the outcome of numerous workshops beginning with the launching workshop on "Global Change in Mountain Biosphere Reserves" in Sörenberg, Entlebuch (Switzerland) in November 2003, which for the first time brought together Global Change scientists and managers of MBRs. This was followed by four thematic workshop, the first of which on "Global Environmental and Social Monitoring" was held at the Institute of Plant Ecology (Vienna, Austria) in May 2004, the second on "Projecting Global Change Impacts in Mountain Biosphere Reserves" in Nov/Dec 2004 in Gran Sasso National Park (Aquila, Italy), the third on "Sustainable Land Use and Natural Resource Management in Mountain Biosphere Reserves" in March 2005 in Granada, Spain, and the forth on "Process Studies along Altitudinal Gradients" in July 2005 in Samedan, Switzerland. Each of these thematic workshops contributed to the development of the GLOCHAMORE Research Strategy. During a meeting of the workshops chairs and the scientific project manager of GLOCHAMORE at the Institute of Plant Ecology in Vienna in September 2005, the first draft of the GLOCHAMORE Research Strategy was elaborated. Presented at the Open Science Conference on "Global Change in Mountain Regions" in October 2005, which was organized by the UHI Centre for Mountain Studies at Perth College (Scotland, UK), the draft strategy was reviewed and discussed in the concurrent sessions. In November 2005, the inputs were compiled and, in a first round, reviewed by the GLOCHAMORE consortium, MBR representatives and those conference participants who have actively contributed to the strategy. In December 2005, the GLOCHAMORE Research Strategy was sent to all people who have been involved in the development process of the strategy and other individuals interested in the topic inviting further comments.

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Mountains are an important part of the global system. Because of their vertical extent, mountain climates differ from those in nearby lower elevations, as do the essential natural resources, such as water, associated with them. Their verticality also generates tremendous habitat and species diversity over short horizontal distances. Human societies – not only within the mountains but also beyond them – exploit the diversity of resources available in and around mountain regions, but are also exposed to the unique hazards associated with these regions. Mountains have both unified and divided human societies, and have seen the development of unique institutions for their governance.

Global change, whether generated from climate, land use change, biological invasion, global economic forces, or other sources, will reverberate through networks of relationships that are part of the land and economic systems of mountain regions. This research strategy highlights the key areas for research needed now to guide the sustainable management of mountain regions, particularly in Mountain Biosphere Reserves (MBRs), which are to be "sites of excellence to explore and demonstrate approaches to conservation and sustainable development at a regional scale" (UNESCO 1995). The GLOCHAMORE research strategy has been developed and refined by Global Change scientists and MBR representatives sponsored by the European Commission, UNESCO Man and the Biosphere and the International Hydrological Program. The strategy reflects the interests of both scientists and practitioners, whose views should mirror the concerns and priorities of local stakeholders. Details of thematic research interests expressed by various MBRs can be found on the Mountain Research Initiative's web site (see RP^2 in http://mri.scnatweb.ch). Designed to be implemented in MBRs (see "Perth Declaration," http://www.unesco.org/mab/mountains/news.htm), the research proposed in the strategy addresses concerns that are valid for the core zone, buffer zone and/or transition zone of such sites. Relevant and feasible research themes and questions from the strategy should be chosen and implemented so that they address relevant cultural and environmental concerns in each area.

The research strategy is built on the assumption that sustainable management can only be achieved with stakeholder involvement. Stakeholder involvement will not only increase the clarity of the research, but also enhance its relevance and acceptability, and thus the efficiency and impact of the research project. Consulting local people and the managers of MBRs and other sites in the project planning and implementation phase is therefore central to the implementation of future GLOCHAMORE projects. In this vein, the GLOCHAMORE consortium recommends following the 11 principles of research partnerships developed by the Swiss Commission for Research Partnerships with Developing Countries (KFPE, 1998), which will enhance the quality, acceptability, and ultimately the impact of projects following the GLOCHAMORE research strategy. For the same purpose, at the end of each project, policy-relevant information gleaned from local research activities should be delivered back to the stakeholders as well as decision-makers, and the public.

This research strategy is organized according to our current understanding of the main axes of causality. It focuses first on drivers of global change, then on the impacts of global change on ecosystems, then on the subsequent impacts on ecosystem goods and services, regional economies, and health, and finally on institutional arrangements. Placing the human dimension in the second half of the list emphasizes mountain and lowland people's dependence on mountain goods and services that are affected by both indirect and direct impacts of global environmental change. As human activities have become important drivers of global environmental change only in the recent past, the list does not represent a uni-directional flow of causalities, nor is it neatly hierarchical. It must be seen as a coupled human-environment system in mountains, with integrated crosscutting themes that include feedback loops. The subsequent implementation of the research strategy will certainly recognize this complexity. However, a strategy cannot be blinded by complexity. Instead, it must designate the main points of leverage within the system where more research will yield the highest returns in terms of understanding and prediction.

The GLOCHAMORE research strategy has been developed with the context of existing international global change research programs of the Earth System Science Partnership, and especially the new Global Land Project (GLP) of the International Geosphere-Biosphere Project and the International Human Dimensions Project. Appendix A explicitly maps the GLOCHAMORE research strategy to that of GLP.

1. Climate

Rationale: Changes in climate, including the frequency of extreme events, will alter a wide range of characteristics of mountain systems: the cryosphere, ecosystems, and mountain economies. An understanding of the likely trajectories of climate in mountain regions is thus a pre-requisite for any management or adaptation strategy.

Research goal: To develop consistent and comparable regional climate scenarios for mountain regions, with a focus on MBRs.

Actions:

• Expand the network of high-elevation observation stations worldwide as a basis for the development and validation of regional climate models.

• For each MBR or other site, produce spatially and temporally downscaled climate scenarios including temperature, precipitation (amount, distribution), mist and cloudiness (intensity, height), for an ensemble of general circulation models, each for several emissions[1] scenarios as prepared for the Intergovernmental Panel on Climate Change. Spatial downscaling should be either be interpolated from general circulation models or, when available, run from regional circulation models. Temporal downscaling should be at least to monthly averages in order to see potential changes in annual cycles and phenology. The scenarios should be extended at least to a 3x CO_2 future, i.e. to at least the end of the 21st Century. The scenarios should be based on an ensemble of models in order to understand the uncertainty inherent in modeling.

• Identify palaeoecological signals of key past climate parameters and construct place-specific strategies to acquire long sequences of climate and plant records.

2. Land Use Change

Land use change is a major driver of mountain ecosystems and economies and is often the principal preoccupation of land managers in such regions. Land use is also subject to external forces such as climate and global markets.

2a. Quantifying and Monitoring Land Use

Rationale: Very few sites have accurate data on the current land use, much less on its historical trends. Such baseline is as essential prerequisite for further research.

Research goal: To monitor land use change in mountain regions using methods that are consistent and comparable.

Actions:

• Ensure that the technical (e.g., GIS) and human resources are available to map land

[1] CO_2, CH_4, SO_2, NO_x, Hg, CFCs, other organochlorines, dust and other aerosols.

uses in MBRs and other participating sites at different scales.

• Document existing and historic land uses (typology and quantification of change).

• Use multi-side palaeocological studies to broadly map historic and prehistoric patterns of landuse.

2b. Understanding the Origins and Impacts of Land Use Change

Rationale: Land use is a key intermediate variable, the result of a range of forces, some of which are global in nature. Land us in turn is a key driver of local, regional and even global environment and economy. The dynamics mediated by land use are central to understanding the earth system itself.

Research goal: To detect and assess the importance of drivers of land use changes and their implications for mountain ecosystems and the livelihoods of people dependent on mountain resources.

Actions:

• Develop consistent quantitative methods to model land use change, incorporating biophysical parameters (including those deriving from climate change) and appropriate driving factors such as population growth and economic change. This includes to:

- analyze mechanisms of land use change as a prerequisite for modeling and scenario building. This includes the role of external drivers (e.g., climate, market-oriented agriculture, tourism) and internal drivers (e.g., ecosystem change, demography, economies, institutions);
- compute correlations between economic flows, land value, and household types and household incomes with observed land use change; and to
- describe and analyze the underlying rationales and processes in individual and collective decision-making related to land use.
- simulate scenarios of possible future land uses, taking into account the interactions between the various driving factors of global change;
- identify the results of land use change impact on mountain environment and define indicators of these changes;
- identify what time scales are of interest to different stakeholders (e.g. peasant farmers vs. government officials) in scenario building.environment and define indicators of these changes;
- identify what time scales are of interest to different stakeholders (e.g. peasant farmers vs. government officials) in scenario building.

3. The Cryosphere

The existence of large frozen areas outside of the polar regions strongly differentiates many mountain regions from surrounding areas. This frozen zone will change with climate, leading to a cascade of changes in adjacent lower areas. The research strategy is consistent with other overlapping international research programs such as GCOS and GTOS.

3a. Glacier Extent

Rationale: Glaciers are unique indicators of climate change and a specific type of land cover with quite different albedo. Climate change has and will have strong influence on the extent of glaciers, with implications for people dependent on glacial water resources.

Research goal: To predict the areal extent of glaciers under different climate scenarios.

Actions:
• Remeasure glacier extent periodically using glacier inventory work with regular coverage at the regional scale (Landsat, Spot, Aster). Broader cooperation with the Global Land Ice Measurements from Space (GLIMS) project and World Glacier Monitoring Service (WGMS).
• Model variation in glacier surface area using satellite imagery, digital terrain information, meteorological data, and scenarios from regional climate models.
• Develop quantitative palaeoecological indicators of glacier change (e.g., glacially derived sediment input to lake records). Apply those indicators to test and validate prediction models for climate change with long-time records.

3b. Glacier Mass Balance and Melt Water Yield

Rationale: Glaciers are significant reservoirs of water in mountain regions. The timing and amount of water release from glaciers has been and will continue to be strongly influenced by climate change.

Research goal: To observe and predict the change of glacial mass and the proportion of that loss in the form of runoff under different climate change scenarios.

Actions:
• Measure and model mass balance using direct field methodologies (stakes and pits) in combination with distributed energy and mass balance models. Mass balance calculation needs to be calibrated and validated using repeat geodetic or stereo photogrammetry analysis.
• Measure glacial snow melt to verify to model predictions.

3c. Snow Cover

Rationale: Snow cover is a key ecological and economic feature of mountains regions.

Research goal: To observe and predict the spatial and temporal extent of snow cover under different climate scenarios.

Actions:
• Optimize the network of meteorological stations dedicated to snow depth and energy balance measurements.
• Test spatially explicit models of snow cover against historic records.

3d. Snow Melt

Rationale: Melting mountain snow is an important source of water. Climate change will likely lead to important changes in the timing and amount of water release from snow packs, thereby affecting the livelihoods and economies of people living downstream.

Research goal: To predict the timing and amount of runoff generated from the snow pack under different climate scenarios.

Actions:
• Measure discharge, snow pack extent and properties in selected drainages at a fine temporal scale.
• Develop models to predict the timing and amount of snow melt under different meteorological conditions, including rain-on-snow events.
• Validate models against empirical data.

3e. Permafrost

Rationale: Frozen ground is a key long-term control on erosional processes. Climate change will likely change the extent and nature of permafrost with impacts on both the water cycle, hazards, and the stability of infrastructure built on permafrost.

Research goal: To map, monitor and predict the extent of permafrost in mountain regions

Actions:
• Map, monitor and model permafrost.
• Simulate scenarios for temperate-climate mountain sites related to ground measurements.
• Survey glacier and permafrost-related hazards.

4 Water Systems

Water storage in and flow through mountains are major features of mountain regions linking climate and its change to the hydrological cycle and human water use. This section emphasizes certain key aspects of the hydrology of mountains as well as those of downstream importance.

4a. Water Quantity

Rationale: Mountains are a key source of water for human consumption and economic use (irrigation, hydropower) both within mountain regions and in downstream lowlands. The main impact of climate change on mountains may well be on the amount and timing of water released.

Research goal: To determine and predict water balance and its components, particularly runoff and water yield of mountain catchments (including wetlands and glaciers) under different global change scenarios.

Actions:
• Establish and maintain gauging stations on representative drainages within MBRs.
• Determine the relationship between precipitation, soil moisture, evapotranspiration, runoff and land use characteristics within representative drainages.
• Develop models to predict discharge from representative drainages at several different timescales from monthly to hourly.
• Develop required input datasets for other basins and test model predictions against observed discharges at a range of time scales.

4b. Water Quality and Sediment Production

Rationale: Water quality, including sediment transport to downstream reservoirs and streams, is important for human health, water supply, energy production, and the status of aquatic and terrestrial ecosystems.

Research goal: To predict water quality and sediment delivery from mountain catchments under different scenarios and understand their effects on human health, ecosystem functioning, and economies dependent on such water resources.

Actions:
• Determine key water pollutant variables for each MBR and other research sites.
• Establish a network of water quality monitoring sites and a frequency of sampling appropriate to both base flow and high flow conditions within MBRs.
• Test hypotheses regarding the drivers of pollutant concentration, using both palaeo observations and experimental manipulations.
• Develop models to predict pollutant load and simulate pollutant load under future climate scenarios.

4c. Aquatic Community Structure

Rationale: Mountain lakes and streams, particularly small and remote ones, are very sensitive to changes in climate, weather patterns and atmospheric deposition, and thus suitable for global change research. Many of their characteristics, from physical parameters (such as water temperature and ice cover duration) to chemistry and biology, can serve as indicators for global change.

Research goal: To monitor the ecological status of mountain lakes and streams; this includes the study of biodiversity, the functioning of food chains, and water quality parameters .

Actions:
• Identify the natural variability of systems and their responses to changing external drivers by long-term monitoring and/or with palaeolimnological methods to test prediction models.
• Study the response of macro-invertebrates, aquatic insects and plankton to different threats (e.g., global warming, acidification, atmospheric deposition of pollutants and nutrients, water withdrawal, and direct pollution).
• Predict future community structure by using models
• Propose measures to avoid or mitigate impacts and developments defined by stakeholders as undesirable.

5. Ecosystem Function and Services

Ecosystems are central components in the biogeochemical cycling of elements. This research strategy focuses on specific ecosystem functions and potential alterations from global change.

5a. Role of Alpine Areas in N and Water Cycles

Rationale: The biotic part of alpine ecosystems modifies biogeochemical and hydrological processes both qualitatively and quantitatively, especially affecting nitrogen storage and cycling. Nitrogen fertilizing enhances the effects of warming in cold environments. Thus changes of process rates driven by climate or land use change, or pollution, have significant consequences for the services alpine ecosystems provide, e.g., the quality of drinking water.

Research goal: To understand how biogeochemistry changes under different climate change, land use and pollution scenarios, and how these changes affect ecosystem services (such as providing drinking water), and to investigate the relative importance of those external drivers.

Actions:
• Monitor water quality at the outflows of catchments.
• Perform process studies including fertilization experiments in alpine catchments that are known to provide ecosystem services.
• Develop spatially explicit models for quantifying climate and land use change on vegetation structure and composition of alpine habitats (i.e. dry and wet meadows, mires, dwarf shrub heath, tree line ecotone, etc.), and how these changes influence water balance and nitrogen release
• Conduct pilot interventions using adaptive management techniques to test and demonstrate active vegetation management options (e.g., fire management, medicinal plant substitution, crop and livestock substitution).
• Use non-linear models to identify thresholds for ecosystem change.

5b. Role of Forest in C Cycle and Resource Production

Rationale: Mountain forests are important sinks for carbon and important sources of natural resources, especially timber and fuel.

Research goal: To predict the amount of carbon and the potential yield of timber and fuel sequestered in forests under different climate and land use scenarios.

Actions:
• Set up experimental catchments to investigate the carbon balance of mountain catchments using a "carbonshed" approach, i.e. a combination of terrestrial (flux towers, forest inventories) and airborne (aircraft) measurements.
• Develop and validate models of biogeochemical cycling and forest growth using these data.
• Apply the models to investigate both C cycling and yields of timber and fuel under scenarios of global change.
• Conduct pilot interventions to test and demonstrate active vegetation management options (e.g., for fire management).

5c. The Role of Grazing Lands in C, N and Water Cycles, Slope Stability and Household Economy

Rationale: Grazing lands - alpine pastures and meadows - are critical to both the ecological and economic functioning of mountain regions. Climate and land use change will drive changes in the vegetative cover and the use of this land, affecting ultimately the carbon, nitrogen and water cycles, the stability of mountain slopes and household economies.

Research goal: To predict the future structure and function of mountain grazing lands along with the likely impacts on material cycles, geomorphic processes and household incomes.

Actions:
• Characterize and map existing grazing lands.
• Quantify the structure and function of such lands, with and without livestock grazing, and by species of grazing animal, if appropriate.

• Quantify the role of livestock grazing with different household economies with respect to its consumption of labor and capital and its contribution to food security and income.
• Develop models of plant community composition change, nutrient and water retention, and erosional processes that can be used to predict future conditions under various times and intensities of grazing.
• Assess the likely future characteristics of livestock grazing as driven by climate change, invasive plants, alternative uses of the land, access by households to grazing land and market demand for different livestock products.

5d. Soil Systems

Rationale: Soil is a non-renewable resource and the basis of mountain ecosystems and the economies that depend on them. Both climate change and land use change may cause significant changes in the biological, chemical and physical characteristics of the soil system.

Research goals: To assess and understand the impact of global change on soils i.e. the effects of changes in temperature and precipitation and associated land use change scenarios on evatranspiration, soil organic matter (SOM) levels and pools, carbon store, and biodiversity (in particular keystone species or species with unique functions such as symbiotic microorganisms).

Actions:
• Develop indicators of soil quality to facilitate management of soil biodiversity on local level.
• Develop evaluation system for soil quality to enhance the interpretation of indicator values.
• Study well dated chronosequences of soils (e.g. post-glacial, post-erosional, post-landslides surfaces) to collect data on soil regeneration in different conditions of mountain environment.
• Set up monitoring network of stations for soil climate dynamics.
• Investigate the impact of climate and land use change on soil condition (soil erosion rate, organic carbon content). Correlate soil data with C cycling in ecosystems.
• Conduct repeated measurements in MBRs where background information is available (maps, plots, monitoring data).
• Develop models of mountain soil formation under different climate scenarios.
• Develop tailor-made conservation and remediation strategies to preserve soil (and water) resources.

5e. Pollution

Rationale: Many organic and inorganic chemicals and products have toxic effects on both human-influenced and natural ecosystems. These compounds may often be detected far from their site of production (e.g., in high altitude lakes).

Research goal: To explore the effects of changing and increasing levels of organic chemicals on physiological, species, community and especially ecosystem-level processes.

Actions:
• Assess current levels of pollutants and compare with historical levels. Define critical thresholds of these pollutants and how they interact with climate change and variability.

• Incorporate toxic material transport and toxic effects on ecosystems in ecosystem modeling.

5f. Plant Pests and Diseases

Rationale: The incidence of pests and diseases, either endemic or exotic, is likely to change with climate or land use changes.

Research goals: To predict the future abundance, distribution and impacts of pests and diseases on natural and cultivated systems.

Actions:
• Establish databases on recently spreading diseases as a basis for analysis and modeling efforts.
• Develop models to predict which diseases have the potential for impacting mountain ecosystems outside of their current range.
• Develop models for investigating cascading effects, such as parasitic fungi that depend on several hosts.
• Link models of pest and disease dynamics (e.g. bark beetles in forests) with models of vegetation dynamics, and test models using existing data.
• Apply the models to predict the joint development of pest/diseases and their host(s), and their ecological and economic impacts on the functioning of mountain regions.

6. Biodiversity

Mountain regions constitute a significant part of global biodiversity, particularly plant diversity, which will change with habitat conditions. This outstanding diversity is related to a high diversity of habitats, which increases with elevation up to the alpine zone. Zonal habitats such as montane or subalpine forests, low alpine dwarf shrub heath, or alpine dry or wet meadows are intermixed with rock outcrops, screes, wetlands, sites of recurrent disturbance (e.g. avalanche corridors), nutrient accumulation sites. Traditional land use practices have maintained habitat diversity in many mountain regions, particularly below tree line.

6a. Biodiversity Assessment and Monitoring

Rationale: Biotic inventories of MBRs and other key sites are often lacking, and loss or gain of species (e.g., invasives) and changes in species abundances are possible. Attention should be given to as many taxa as possible, taking advantage of new techniques of identifying species in aquatic and terrestrial (above and belowground) ecosystems.

Research goal: To assess current biodiversity and to assess biodiversity changes.

Actions:
• Regular inventory (monitoring) of key taxa (plants, insects, birds).

6b. Biodiversity Functioning

Rationale: Changes in species composition and interaction will influence ecosystem functions. Relevant functions such as providing water quantity and quality, slope stability and biological processing of matter ensure ecosystem services such as cultural/medicinal plants, forage production, water infiltration and storage, nutrient retention, and insurance of catastrophic slope failure.

Research goal: To define functions and services associated with biodiversity and predict the possible effects of global change on these interactions.

Actions:
• Quantify the effects of short- and long-term changes in biodiversity on ecosystem functions and services by means of manipulative research (see Bulte et al. 2005).

6c. Biodiversity Management

Rationale: Humans use a substantial proportion of the global biota, and those uses in turn affect biodiversity, ecosystem goods and services, and the resilience of ecological and economic systems. As mountain biota often exist as fragmented populations, careful management practices (grazing, mowing, burning) are needed to prevent local extinctions under changing environmental conditions. The role of species interactions (predation, pollination, facilitation), which are important maintaining biodiversity should be protected.

Research goal: To identify adaptive management practices that mitigate global change effects on biodiversity.

Actions:
• Assess and understand environmental thresholds that determine biodiversity, in particular for higher trophic levels.
• Conduct experiments to determine appropriate management practices to conserve biodiversity.

6d. Alpine Community Change

Rationale: Many alpine regions above the tree line ecotone are still in a natural or at least semi-natural state. Here climate change signals are most clearly to be detected because they are not overridden by direct land use effects. Furthermore, lower temperatures limit alpine ecosystems, and thus warming will have immediate and direct effects.

Research goal: To detect and understand the shifts in species abundance and distribution driven by climate change, and to understand how limiting factors for plant life may change.

Actions:
• Implement the basic approach of the Global Observation Research Initiative in Alpine environments (GLORIA), i.e. the multi-summit approach, in as many MBRs and other sites as possible to improve the existing global network (www.gloria.ac.at).
• Develop spatial explicit models for climate change effects based on climate parameters specific to the multi-summit data sources.
• Establish in different life zones, i.e. zonobioms, GLORIA master stations for monitoring complementary indicator sets, and perform experiments such as transplanting whole vegetation samples.
• Investigate the range of orographically controlled variation in meso-scale (downscaled or instrumental) meteorology, especially the effects of duration and depth of snow cover.
• Monitor the shift of subalpine meadow - forest boundary as signal of climate change.
• Estimate and model vegetation development and corresponding landscape

appearance in areas uncovered by glaciers.
• Use observation of modern relationships between ecosystem components and palaeo-indicators to improve algorithms for spatially explicit reconstructions of plant ecosystem distribution.
• Develop appropriate palaeoecological records from MBRs as a baseline for explanations of present-day biogeography and as a basis for management.

6e. Key Fauna and Flora

Rationale: Certain species are politically very important and constitute the very reason that a given biosphere reserve has been created. The fate of the site is thus tied to the fate of the species. The fate of the species is frequently influenced by land use change and could certainly be threatened by climate change.

Research goal: To predict the probability of local persistence of key species under different global change scenarios.

Actions:
• Collect presence, and if possible, abundance data on key species along with abiotic environmental data.
• Develop models that predict the likelihood of species occurrence (and if possible abundance) on the basis of abiotic environmental characteristics.
• Assess the extent to which biotic interactions (e.g., competition and facilitation) must be addressed in order to predict distribution and abundance
• Undertake experimental studies on the response of common and rare species to climate change.
• Validate models and scenarios using empirical studies of basic population and organismic processes.
• Simulate future distribution and if possible abundance under different climate and land use scenarios (local and regional), and under different assumptions of species mobility
• Identify key species at risk in participating MBRs and other sites.

6f. Forest Structure

Rationale: Individual forest species are highly valued, and mountain forests often provide protection from natural hazards, which depends on forest structure and composition.

Research goal: To predict future forest structure and composition under different climate change and land use scenarios.

Actions:
• Set up a cross-regional program for monitoring of past and recent changes in tree demography (dendrochronology, recruitment and mortality), similar to the ongoing GLORIA effort for the alpine environment.
• Develop and validate models of forest structure (succession models) using these data.
• Apply the models to quantify changes in mature forest structure and composition under scenarios of global change.

6g. Culturally Dependent Species

Rationale: Many species associated with mountain regions, and the assemblages they form (e.g. species-rich hay meadows), depend on traditional cultural practices for their persistence. Land use change especially threatens these species assemblages, and causes regional extinction of species. Maintaining these elements of mountain biodiversity is politically very relevant in mountain regions such as the Alps, as it provides the basic argument for agroenvironmental subsidies, and is also linked to food security in developing countries.

Research goal: To understand the fate of species, and species assemblages that depend on particular cultural practices as a basis for developing and demonstrating sustainable land use systems.

Actions:
• Carry out research on historical and recent land use practices and how they determine landscape and biodiversity. Detect legacies of old land use systems.
• Explore how industrial agriculture has already been influenced, or how it has been influenced agricultural practices and agrobiodiversity in mountain regions.
• Predict loss of the diversity of species, community types and landscapes under different land use scenarios, e.g., introduction of agro-industrial practices, abandonment, change of cultivated plants, introduction of exotic livestock.

6h. Impacts of Invasive Species

Rationale: As a result of global (climate) change, alien plant invasions are increasingly becoming a major source of change in mountain regions. Recognition of the role of management practices (e.g., fire, grazing) that influence the success of the spread if invasive species is required. These invasions may involve substantial changes in mountain ecosystem structure and function, (e.g., biogeochemical cycles or increased risk of fire).

Research goal: To predict the threats by invasive alien plants to mountain ecosystems, and to develop management strategies (precautionary principle).

Actions:
• Develop a global database on the patterns, dynamics and impacts of alien plants in mountain systems.
• Monitor alien plant spread into the mountains and develop early detection mechanisms (management strategies on the landscape scale).
• Test mechanistic hypotheses of alien plant spread experimentally.
• Model patterns of alien plant spread in the wake of global change.

7. Hazards

Global change, particularly climate change, can alter the frequency of extreme or rare events that pose hazards to life and property in mountain regions. As such events often cause great loss of life and severe impacts on local economies, an understanding of changes in exposure to hazard is critical to sustainable adaptation to global change.

7a. Floods

Rationale: Floods, including glacier-related floods, are among the most destructive and frequent natural disasters encountered by human societies. The steep gradients and constriction of water courses in mountain regions makes such regions particularly susceptible to floods.

Research goal: To predict changes of lake systems and incidence of extreme flows in terms of frequencies and amounts, under different climate and land use scenarios.

Actions:
• Develop palaeo and historical records to identify the frequency of past regimes, and through comparisons to other palaeo records, to identify causal relationships leading to change in the regime.
• Identify potentially dangerous (outbursting) lakes in which the monitoring of the water level changes is feasible. Monitor water level changes together with surface and water temperature and precipitation.
• Organize a monitoring system network.
• Perform a probabilistic analysis of observed floods to estimate potential changes in the frequency and magnitude of extreme events.
• Model outburst processes and suggest management activities to minimize risk.
• Analyze the flow profile along river courses and develop methods to justify keeping flow profiles open and inundation plains free to have retention space.
• Consult with management authorities to develop tools to predict flood responses to land cover and land use changes.

7b. Wildland Fire

Rationale: Fire, while often a natural feature of mountain ecology, may change in frequency and intensity as climate changes and mountain societies develop. Thus, fire will under some circumstances be a hazard to economic, ecologic and social functioning, while in others it can promote biodiversity, reduce hazard levels, and maintain ecological function. In any wildland fire management will be incorporated into overall land use and natural resources planning and management.

Research goal: To predict the incidence, intensity and impacts of fires under different climate, land use, and management scenarios and to evaluate the impacts of different wildland fire management strategies.

Actions:
• Quantify existing and historic fire regimes over different landscape units, and if possible, the response of the existing suppression system, using both recent and long-term fire history data (i.e., dendroecological and paleoecological data).
• Develop dynamic models that link climate, fuel properties and the wildland fire regime, so as to predict the fire regime.
• Use fire history data and vegetation properties to model/ future wildland fire regimes across elevational gradients and changing land use systems in mountain regions
• Develop input data for fire weather danger rating systems from regional climate scenarios.
• Analyze feedback cycles between fire, ecosystem function and vegetation change.
• Determine how changes in the delivery of ecosystem services following unexpected fire events or changes in fire regimes can cause changes in land use that in turn will further modify fire regimes.

7c. **Mass Movements**

Rationale: Landslides, rock falls and debris flows are hazards unique to mountain regions. The geomorphic and hydrological processes underlying the incidence of such events are likely to change with climate change.

Research goal: To predict incidence of landslides and debris flows under different scenarios.

Actions:
- Prepare maps of mass movement risks.
- Monitor the most dangerous and frequent mass movements.
- Quantify the changes in mass movements associated with predicted changes in precipitation, glacier melt and other anomalies.

7d. **Avalanches**

Rationale: Avalanches constitute an important impact on mountain ecosystems and are an important factor in risk for habitation, transport and recreation.

Research goal: To understand and predict the potential change in avalanche activity on the mountain ecosystem and hazard level under different global change scenarios.

Actions:
- Map avalanche run-out distances and return periods for the current climate in MBRs and other participating sites.
- Monitor selected avalanche tracks (snow cover before and avalanche characteristics after the event).
- Investigate ecosystem response to avalanches (disturbance ecology).
- Statistically link snow cover status and distribution to avalanche activity.
- Model expected snow cover changes under climate change scenarios (e.g., with CROCUS or Alpine3D/SNOWPACK).
- Try to interpret expected changes with respect to avalanche activity and make a final link to ecological changes and hazard level.

8. Health Determinants and Outcomes Afficiting Humans and Livestock

Rationale: Global change can create new health hazards for humans and their domestic animals and worsen existing risks (e.g., malaria and other vector-borne diseases, water-borne diseases, water scarcity (quality and quantity), food insecurity, and dust storms). Populations that are particularly vulnerable in these mountain regions include the poor, children, women, elderly adults, and self-sustaining ethnic groups in remote areas.

Research goal: To understand the current and future distribution and intensity of climate-sensitive health determinants, and predict outcomes that affect human and animal health in mountain regions.

Actions:
• Identify pests and other organisms that cause diseases of humans and livestock (host populations) within and near to mountain regions.
• Define the biotic and abiotic factors and processes that determine the spread of these organisms and their impacts on host populations.
• Develop models that predict the occurrence of these species on the basis of biotic and abiotic factors.
• Simulate the future distribution and impacts of these species under different regional scenarios of climate, land use, and the demography of host populations.
• Better understand the relationships between dust storms, air pollution, non-communicable diseases and climate change.
• Better understand how climate change could interact with population growth and other drivers to affect water quantity and quality, and food security.
• Develop health and environmental indicators for monitoring and evaluating the impacts of climate variability and change on health.
• Create partnerships involving all relevant stakeholders (particularly climate/ meteorology, environment, and public health/medical specialists) to guide research needed to reduce health impacts of climate variability and change.

9. Mountain Economies

9a. Employment and Income

Rationale: Global change will change the capacity of landscapes to generate wealth and to provide livelihoods for resident populations and for distant but nonetheless dependent populations. An understanding of these changes and local peoples' ability to respond is a prerequisite for successful adaptation to such impacts.

Research goal: To predict the impacts of global change scenarios on the economies of mountain regions and economies dependent on mountain goods and services. To assess the resilience of mountain societies (especially in developing countries) to global environmental change.

Actions:
• Compile data on incomes deriving from all economic sectors.
• Develop regional economic models for both monetized and subsistence economies, taking into account environmental, demographic, economic, and political driving forces.
• Simulate possible future economies under different regional scenarios of climate, land use, human demography, and external forces.
• Identify attributes of mountain communities that make them resilient to global change.

9b. Forest Products

Rationale: Mountain forests provide a variety of goods such as timber, fuel, fiber, food, etc. In many mountain regions, non-timber forest products are even more valuable than timber and fuelwood. Climate and land use change will alter yield rates of these products, leading to important economic and social impacts.

Research goal: To predict changes in the availability of economically important forest products in mountain regions.

Actions:
• Prepare quantitative inventories of forest products in MBRs and other participating sites to define the relative economic importance of these products at the regional scale.
• Determine the biophysical factors that control the occurrence, abundance and availability of economically important forest products in mountain regions.
• Develop quantitative models to predict the availability of economically valuable species.
• Simulate their future distribution and, if possible, abundance under different regional climate and land use scenarios.

9c. Mountain Pastures

Rationale: Mountain pastures play a key role in economic life of high mountain population (cattle husbandry, apiculture, medicinal herbs, and esthetic resources). Climate change and rapid land use changes, both overgrazing and undergrazing, impact biodiversity and productivity of meadows, especially in subalpine belts.

Research goal: To understand and predict changes in the mountain pasture conditions and availability of economically important mountain meadow products.

Actions:
• Monitor mountain meadows biodiversity and productivity.
• Prepare quantitative inventories of mountain meadows products in MBRs and surrounding areas to define the relative economic importance at the regional scale.
• Determine the responses of meadow ecosystems and their components on climate and land use changes, focusing on economically important meadow products and properties.
• Simulate the future distribution of meadow products and, if possible, abundance under different regional climate and land use scenarios.

9d. Valuation of Ecosystem Services

Rationale: Mountain ecosystems provide a wide variety of useful services that enhance human welfare. These ecosystems are under enormous pressure from the growing demands placed on them by human economies for inputs (e.g., fresh water, fiber, soil fertility) as well as pressure on the capacity of these systems to assimilate waste. Future sustainable development and forward-looking policy will depend upon accurate assessment of ecosystem services so that well informed choices for mitigation and adaptation to climate change can be made.

Research goal: To assess the value of mountain ecosystem services and how that value is affected by different forms of management.

Actions:
• Identify ecosystem services providing economic value to mountain people and those in adjacent lowlands depending on mountain services (e.g., regulation of rainwater run-off, climate stabilization, hazard prevention).
• Identify the beneficiaries of those services.
• Determine the value of each of those services and the total value of the current flow of benefits from a mountain ecosystem.
• Estimate the changes in benefit flows (how much, how rapid, how long-lasting) that will result from changes in ecosystem management or climate.

9e. **Tourism and Recreation Economies**

Rationale: Tourism and recreation are major industries in many mountain regions. Tourism and recreation are both affected by global change and constitute a form of global change themselves.

Research goal: To characterize the tourism and recreation sectors and to project their future nature and extent.

Actions:
• Analyze the current nature of tourism and recreation in terms of activities offered, sources of clients and economic impact.
• Assess the impacts of global change on the different types of tourism and recreation.
• Assess the tourism and recreation sectors as source of global change themselves.
• Project the future nature and extent of tourism and recreation as a function of global change scenarios.

10. Society and Global Change

10a. **Governance Institutions**

Rationale: Institutions are the means by which human societies, respond to environmental change. Successful adaptation to global change will occur both through existing institutions and through the development of new institutional arrangements.

Research goal: To understand the origins and functioning of existing governance institutions, their effectiveness in terms of range of potential stakeholders goals, and options for improved effectiveness with respect to different goal sets.

Actions:
• Develop case studies of participation in decision-making and management in MBRs and other participating sites.
• Analyze factors that have led to both ineffective and successful participation in individual sites.
• Develop a 'toolbox' of good practices to foster participatory decision-making mechanisms and management structures that are effective in specific types of settings.
• Identify power structures and decision-makers within and outside the system and build scenarios.
• Describe and understand institutional settings in which decisions are made.
• Quantify the role of international trade agreements on economic activities.
• Identify the role of communication in shaping governance.
• Assess to what degree various social groups can express their expectations (gender, generations, land property, innovation, legitimacy, authority) and which social, economic and political drivers interfere with individual expectations, local social structures and local economies (types and modes of production).
• Draw lessons for response strategies for mountain regions based on examples of sustainable mountain livelihoods and adaptive management (for different time scales, governmental and regional).

• Identify environmental, economic, and social processes behind exploitation and distribution of mountain resources, especially water, and management approaches to better balance resource use.

10b. Rights and Access to Water Resources

Rationale: Institutions mediate among water users and determine access to, and availability, quantity and quality of water. As such, they play a central role when environmental change, trade, and globalization alter the quality, availability and distribution of water.

Research goal: To understand the role of water resource institutions in the functioning of mountain economies and environments.

Actions:
• Assess the role of water rights and governance institutions in organizing economic activity at community, national and international levels.
• Undertake joint studies to identify good practice in the management of transboundary water resources.
• Develop consistent water scenarios for science support to policy making.

10c. Conflict and Peace

Rationale: With few exceptions, the most numerous and obdurate conflicts in the world occur in mountain zones, which are rooted in a social and economic breakdown in mountain societies almost everywhere. Conflicts in remote mountain areas readily become sources of tension in the larger community of nations (Starr 2004).

Research goal: To systematically monitor economic and social conditions leading to and maintaining conflicts in mountains.

Actions:
• Generate liable data on the actual conditions in mountain regions, i.e. the economy, ecological conditions, state of human welfare, and public health and disaggregate these data from the national whole.
• Identify successful "best practices," i.e. the basic elements of long-term successes in averting or resolving conflicts in mountain regions.

10d. Traditional Knowledge and Belief Systems

Rationale: Local knowledge, cognition, perceptions and beliefs differ from scientific concepts of the modernized world. Incorporating local concerns, intentions, needs and knowledge into applied research projects can enhance the efficiency and thus the impact of the project. Warming climate affects local religious belief systems in areas near sacred mountains with glaciers that have receded or disappeared. Worship of mountains offers conservation opportunities for protected area managers to link intangible values with tangible conservation values.

Research goal: To identify the kinds of knowledge (traditional and modern) associated with the research activity and the relationship between those knowledge systems.

Actions:
• Document knowledge systems (ethnography, quantitative and qualitative approaches

in anthropology).
• Document cognitive systems and perceptions of scientists, MBR managers and local stakeholders.
• Document the human time dimension (oral history) to interpret present culture, attitudes, and adaptive capacities of local stakeholders.
• Establish an inventory of sacred natural sites within the MBR in direct collaboration with local people.
• Study the effect of global change on intangible values placed on mountains by local and non-local societies.

10e. Development Trajectory and Vulnerability

Rationale: Different social groups in and around MBRs and other mountain areas are vulnerable to potential future global change. While poverty in general increases vulnerability, so might physical location, dependence of certain economic activities and other non-poverty related characteristics. Successful adaptation to global change, particularly in advance of perfect knowledge of future conditions, will require an understanding of the relatively vulnerability of different social groups.

Research goal: To characterize the vulnerability of different social groups associated with MBRs to future global change.

Actions:
• Establish transdisciplinary teams in each MBR and an overall vulnerability assessment framework.
• Specify the principal sources of insecurity as perceived by different social groups.
• Translate potential future scenarios into terms relevant to those sources of insecurity and assess likely outcomes for different social groups.
• Determine the costs and benefits of different potential mitigation strategies.

10f. Urbanization in Mountain Regions

Rationale: Urban areas are growing rapidly in many mountain areas. In less developed countries, capitals or major towns develop as regional metropolises with all global socio-cultural phenomena and economic and social problems. In tropical mountains, favorable highland climates stimulate the growth of urban areas. In dense settled regions, especially in Europe, the piedmont of the mountains serves as leisure and residential area for the adjacent metropolitan areas. Resort towns develop as tourist or residential areas. In other developed countries as in North America, amenity migration to mountain areas is common. Cities can strengthen the rural mountain areas as sinks for mountain products from agriculture, for waters, minerals, wood, and energy. They can also weaken the adjacent mountain areas by workforce drain, and can radically transform land use both within and around urban boundaries.

Research goal: To understand the environmental, economic, and demographic processes linking rural and urban areas in mountain regions, as well as those leading to urbanization, peri-urbanization and metropolization.

Actions:
• Develop scenarios of future urban development in mountain regions and assess the impacts of such development on land use, climate, demography, economy and culture.
• Predict the future trajectory of rural areas and the consequences of their

transformation.

• Understand stakeholder constellations and their decisions in forcing or inhibiting development, preservation, and structural changes.

• Analyze the development history of individual urban areas in mountain regions in terms of nature, extent, demographic and socio-economic processes.

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Appendix A

Relation of GLOCHAMORE Research Strategy Topics to Global Land Projects Themes and Issues

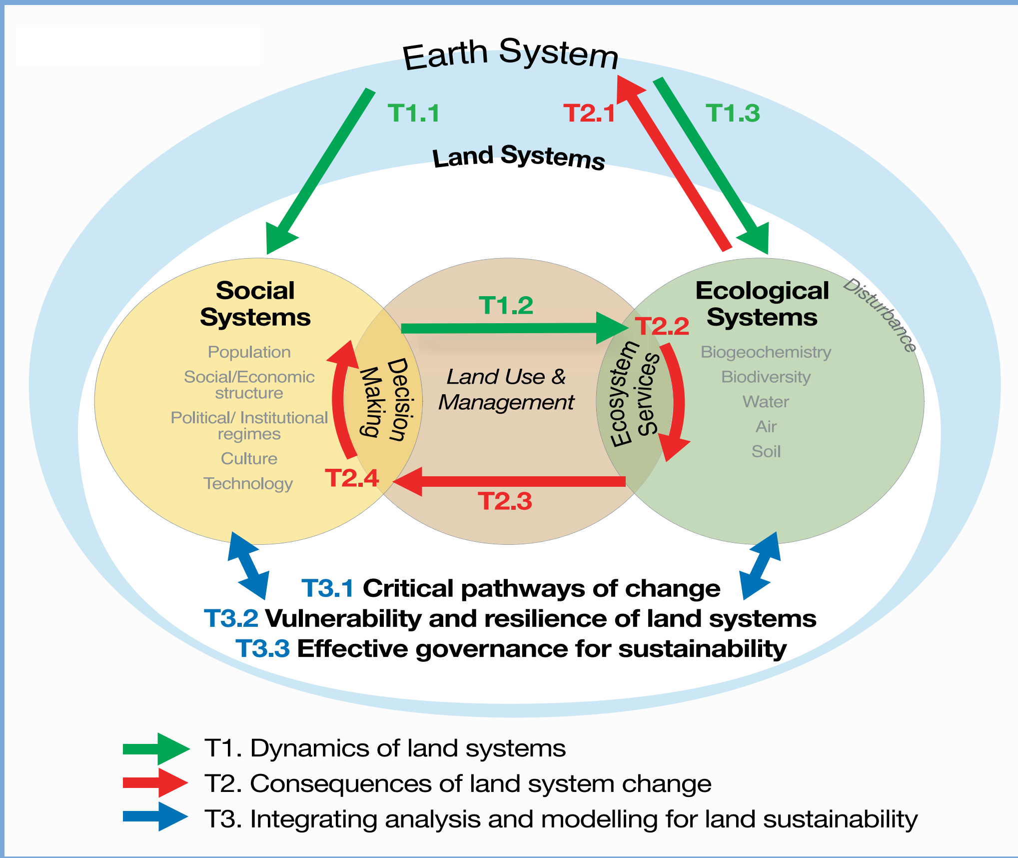

Figure 4 from GLP Science Plan and Implementation Strategy (GLP 2005:8).

The following table relates the specific topics in the GLOCHAMORE Research Strategy to the Research Themes and Issues list in the Global Land Project Science Plan and Implementation Strategy (GLP 2005). In many instances, GLOCHAMORE topics followed a causal chain in Figure 4, and therefore involved several different GLP Issues. To the extent possible, GLOCHAMORE topics were mapped to the GLP Issue most closely related. However in a few cases such a mapping would have considerably truncated the conception of a GLOCHAMORE topic, and in those cases, the topic was mapped to several GLP Issues.

Global Land Project Themes	**Global Change in Mountain Regions Research Topics and Goals**
Theme 1: Dynamics of Land Systems	
Issue 1.1: How do globalisation and population change affect regional and local land use decisions and practices?	2b. Understanding the Origins and Impacts of Land Use Change: To detect and assess the importance of drivers of land use changes and their implications for mountain ecosystems and the livelihoods of people dependent on mountain resources 11f. Urbanization in Mountain Regions: To understand the environmental, economic, and demographic processes linking rural and urban areas in mountain regions, as well as those leading to urbanization, peri-urbanization and metropolization.
Issue 1.2: How do changes in land management decisions and practices affect biogeochemistry, biodiversity, biophysical properties and disturbance regimes of terrestrial and freshwater ecosystems?	2a. Quantifying and Monitoring Land Use: To monitor land use change in mountain regions using methods that are consistent and comparable. 2b. Understanding the Origins and Impacts of Land Use Change: To detect and assess the importance of drivers of land use changes and their implications for mountain ecosystems and the livelihoods of people dependent on mountain resources. 4b. Water quality and sediment production: To predict water quality and sediment delivery from mountain catchments under different scenarios and understand their effects on human health, ecosystem functioning, and economies dependent on such water resources. 4c. Aquatic Community Structure: To monitor the ecological status of mountain lakes and streams; this includes the study of biodiversity, the functioning of food chains, and water quality parameters. 6a. Biodiversity Assessment and Monitoring: To assess current biodiversity and to assess biodiversity changes. 6g. Culturally Dependent Species: To understand the fate of species, and species assemblages that depend on particular cultural practices as a basis for developing and demonstrating sustainable land use systems. 9e. Tourism and Recreation Economies: To characterize the tourism and recreation sectors and to project their future nature and extent.

Issue 1.3: How do the atmospheric, biogeochemical and biophysical dimensions of global change affect ecosystem structure and function?	1. Climate: To develop consistent and comparable regional climate scenarios for mountain regions, with a focus on MBRs. 3a. Glacier Extent: To predict the areal extent of glaciers under different climate scenarios. 3b. Glacier Mass Balance and Melt Water Yield: To observe and predict the change of glacial mass and the proportion of that loss in the form of runoff under different climate change scenarios. 3c. Snow Cover: To observe and predict the spatial and temporal extent of snow cover under different climate scenarios. 3d. Snow Melt: To predict the timing and amount of runoff generated from the snow pack under different climate scenarios. 3e. Permafrost: To map, monitor and predict the extent of permafrost in mountain regions 4a. Water quantity: Determine and predict water balance and its components, particularly runoff and water yield of mountain catchments (including wetlands and glaciers) under different global change scenarios. 4c. Aquatic Community Structure: To monitor the ecological status of mountain lakes and streams; this includes the study of biodiversity, the functioning of food chains, and water quality parameters. 5d. Soil Systems: To assess and understand the impact of global change on soils i.e. the effects of changes in temperature and precipitation and associated land use change scenarios on evatranspiration, soil organic matter (SOM) levels and pools, carbon store, and biodiversity (in particular keystone species or species with unique functions such as symbiotic microorganisms) . 5e. Pollution: To explore the effects of changing and increasing levels of organic chemicals on physiological, species, community and especially ecosystem-level processes. 6d. Alpine Community Change: To detect and understand the shifts in species abundance and distribution driven by climate change, and to understand how limiting factors for plant life may change. 6f. Forest Structure: To predict future forest structure and composition under different climate change and land use scenarios.

Global Land Project Themes	**Global Change in Mountain Regions Research Topics and Goals**
Theme 2: Consequences of Land System Change	
Issue 2.1: What are the critical feedbacks to the coupled Earth System from ecosystem changes?	
Issue 2.2: How do changes in ecosystem structure and functioning affect the delivery of ecosystem services?	4b. Water quality and sediment production: To predict water quality and sediment delivery from mountain catchments under different scenarios and understand their effects on human health, ecosystem functioning, and economies dependent on such water resources. 5a. Role in Alpine Areas in N and Water Cycles: To understand how biogeochemistry changes under different climate change, land use and pollution scenarios, and how these changes affect ecosystem services (such as providing drinking water), and to investigate the relative importance of those external drivers. 5b. Role of Forest in C Cycle and Resource: To predict the amount of carbon and the potential yield of timber and fuel sequestered in forests under different climate and land use scenarios. 5c. The Role of Grazing Lands in C, N and Water Cycles, Slope Stability and Household Economy: To predict the future structure and function of mountain grazing lands along with the likely impacts on material cycles, geomorphic processes and household incomes. 5f. Plant Pests and Diseases: To predict the future abundance, distribution and impacts of pests and diseases on natural and cultivated systems. 6b. Biodiversity Functioning: To define functions and services associated with biodiversity and predict the possible effects of global change on these interactions 6e. Key Fauna and Flora: To predict the probability of local persistence of key species under different global change scenarios. 6h. Impacts of Invasive Species: To predict the threats by invasive alien plants to mountain ecosystems, and to develop management strategies.

Issue 2.3: How are ecosystem services linked to human well-being?	8. Health Determinants and Outcomes Afflicting Humans and Livestock: To understand the current and future distribution and intensity of climate-sensitive health determinants, and predict outcomes that affect human and animal health in mountain regions. 9a. Employment and Income: To predict the impacts of global change scenarios on the economies of mountain regions and economies dependent on mountain goods and services. To assess the resilience of mountain societies (especially in developing countries) to global environmental change. 9b. Forest Products: To predict changes in the availability of economically important forest products in mountain regions. 9c. Mountain Pastures: To understand and predict changes in the mountain pasture conditions and availability of economically important mountain meadow products. 9d. Valuation of Ecosystem Services: To assess the value of mountain ecosystem services and how that value is affected by different forms of management. 9e. Tourism and Recreation Economies: To characterize the tourism and recreation sectors and to project their future nature and extent.
Issue 2.4: How do people respond at various scales and in different contexts to changes in ecosystem service provision?	6c. Biodiversity Management: To identify adaptive management practices that mitigate global change effects on biodiversity. 10a. Governance Institutions: To understand the origins and functioning of existing governance institutions, their effectiveness in terms of range of potential stakeholders goals, and options for improved effectiveness with respect to different goal sets. 10b. Rights and Access to Water Resources: To understand the role of water resource institutions in the functioning of mountain economies and environments 10d. Traditional Knowledge and Belief Systems: To identify the kinds of knowledge (traditional and modern) associated with the research activity and the relationship between those knowledge systems.

Global Land Project Themes	Global Change in Mountain Regions Research Topics and Goals
Theme 3: Integrating Analysis and Modelling for Land Sustainability	
Issue 3.1: What are the critical pathways of change in land systems?	10c. Conflict and Peace: To systematically monitor economic and social conditions leading to and maintaining conflicts in mountains.
Issue 3.2: How do the vulnerability and resilience of land systems to hazards and disturbances vary in response to changes in human-environment interactions?	7a. Floods :To predict changes of lake systems and incidence of extreme flows in terms of frequencies and amounts, under different climate and land use scenarios. 7b. Wildland Fire: To predict the incidence,intensity and impacts of fires under different climate, land use, and management scenarios and to evaluate the impacts of different wildland fire management strategies. 7c. Mass Movements: To predict incidence of landslides and debris flows under different scenarios. 7d. Avalanches: To understand and predict the potential change in avalanche activity on the mountain ecosystem and hazard level under different global change scenarios. 10e. Development Trajectory and Vulnerability: To characterize the vulnerability of different social groups associated with MBRs to future global change.
Issue 3.3:Which institutions enhance decision making and governance for the sustainability of land systems?	10a. Governance Institutions: To understand the origins and functioning of existing governance institutions, their effectiveness in terms of range of potential stakeholders goals, and options for improved effectiveness with respect to different goal sets. 10b. Rights and Access to Water Resources: To understand the role of water resource institutions in the functioning of mountain economies and environments.