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Source: Mountain Research and Development, 32(S1)

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-11-00084.S1

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Author(s): Astrid Björnsen Gurung, Susanne Wymann von Dach, Martin F. Price, Richard Aspinall, Jörg Balsiger, Jill S. Baron, Eklabya Sharma, Greg Greenwood, and Thomas Kohler
Source: Mountain Research and Development, 32(S1):S47-S54.
Published By: International Mountain Society
DOI: http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00084.S1
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Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

Supplement Issue
Synthesis, Perth 2010

Global Change and the World's Mountains—Research Needs and Emerging Themes for Sustainable Development

A Synthesis From the 2010 Perth II Conference

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The conference on Global Change and the World's Mountains held in Perth, Scotland, in 2010 offered a unique opportunity to analyze the state and progress of mountain research and its contribution to sustainable mountain development, as well as to reflect on required reorientations of research agendas. In this paper we provide the results of a three-step assessment of the research presented by 450 researchers from around the world. First, we determined the state of the art of mountain research and categorized it based on the analytical structure of the Global Land Project (GLP 2005). Second, we identified emerging themes for future research. Finally, we assessed the contribution of mountain research to sustainable development along the lines of the Grand Challenges in Global Sustainability Research (International Council for Science 2010). Analysis revealed that despite the growing recognition of the importance of more integrative research (inter- and transdisciplinary), the research community gathered in Perth still focuses on environmental drivers of change and on interactions within ecological systems. Only a small percentage of current research seeks to enhance understanding of social systems and of interactions between social and ecological systems. From the ecological systems perspective, a greater effort is needed to disentangle and assess different drivers of change and to investigate impacts on the rendering of ecosystem services. From the social systems perspective, significant shortcomings remain in understanding the characteristics, trends, and impacts of human movements to, within, and out of mountain areas as a form of global change. Likewise, sociocultural drivers affecting collective behavior as well as incentive systems devised by policy and decision makers are little understood and require more in-depth investigation. Both the complexity of coupled social–ecological systems and incomplete data sets hinder integrated systems research. Increased understanding of linkages and feedbacks between social and ecological systems will help to identify nonlinearities and thresholds (tipping points) in both system types. This presupposes effective collaboration between ecological and social sciences. Reflections on the Grand Challenges in Sustainability Research put forth by the International Council for Science (2010) reveal the need to intensify research on effective responses and innovations. This will help to achieve sustainable development in mountain regions while maintaining the core competence of mountain research in forecasting and observation.

Keywords: *Mountains; global change; state of the art in research; emerging themes; social–ecological systems; Global Land Project (GLP); Grand Challenges (ICSU); sustainable development.*

Reviewed by the Editors: *October 2011*

Accepted: *November 2011*

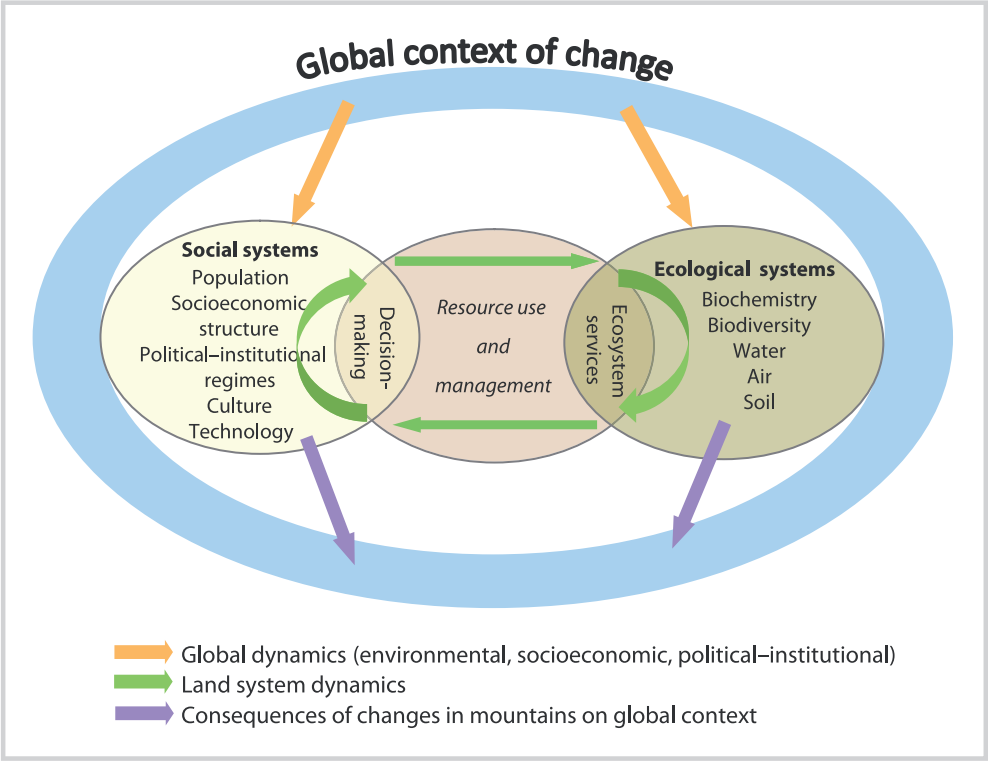
A unique opportunity

The Perth II Conference on Global Change and the World's Mountains (26–30 September 2010, Perth, Scotland) brought together 450 scientists from 60 countries to pursue three objectives: first, to discuss progress on the understanding of global change in mountain regions; second, to reflect on this progress with regard to the implementation of the Global Change in Mountain Regions (GLOCHAMORE) research strategy (Björnsen Gurung 2006); and third, to work towards a global agenda for research and action in mountain regions.

The manifold presentations covering 28 global and 4 regional themes and the gathering of such a

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FIGURE 1 Modified analytical structure of the GLP Science Plan and Implementation Strategy (GLP 2005).



large number of researchers with their broad and multidisciplinary expertise in both social and ecological sciences offered a unique opportunity to determine the state of the art of mountain knowledge, to identify the way forward for mountain research, and to give the global mountain research community a voice. An assessment and synthesis process was designed to identify the direction to be taken by future research with a view to furthering sustainable development in mountains.

Assessment and synthesis approach

A three-step approach was followed to capture and analyze mountain research findings presented at the conference. Internationally acknowledged concepts were used as frames of reference in order to structure the research findings and to link mountain research with ongoing scientific debates on sustainable development and global change.

Step 1

The first step aimed at determining the state of the art of global change research in mountains. The extended abstracts of presentations were evaluated against a slightly modified version of the analytical structure of the Global Land Project (GLP 2005) (Figure 1). This structure aimed to facilitate analysis of the transition undergone by Land Systems, recognizing that resource use and management are shaped by ecosystem services, on the one hand, and by social systems through decision-making processes, on the other hand. As mountains are an important Land Subsystem, such an analytical structure offers a meaningful paradigm to organize global change research in mountain areas. Whereas the original GLP structure focuses on the transition of Land Systems, we embedded mountain systems in the context of global change.

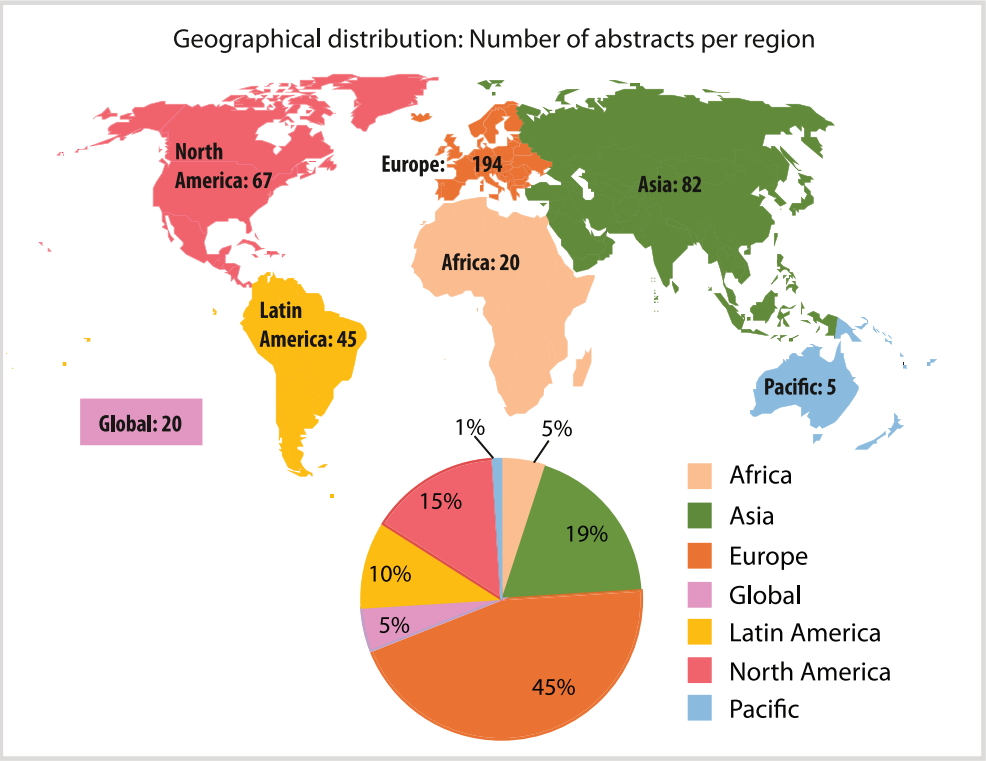
To determine the state of the art and to identify gaps in global change research on mountains, each abstract submitted for the Perth II conference was attributed to one or several components and linkages of the GLP structure. In addition, each paper was coded according to the geographical focus of the research.

Step 2

The second step aimed at identifying emerging themes for future research and sustainable mountain development and thus required closer investigation of the data and findings presented. The chairs of the 42 sessions screened the abstracts of the papers in their sessions and took stock of the presentations during the conference in order to pinpoint 3 emerging topics for both research and development. These topics were subsequently validated in consultation with other leading

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FIGURE 2 Geographical focus of the 433 accepted abstracts.



scientists. Based on this procedure, 3 experts summarized and synthesized the emerging research themes from different perspectives, focusing on ecological and social systems as well as interactions between these systems.

Step 3

The third step in the assessment and synthesis process aimed at understanding how the research presented at the conference contributes towards coping with emerging challenges of global change in mountains. This step also provided indications of necessary adjustments and reorientations of future global change research in mountains.

The Grand Challenges in Global Sustainability Research brought forward by the International Council for Science in collaboration with the International Social Science Council (ICSU 2010a, 2010b) offered a suitable frame of reference for this third step. The Grand Challenges—identified by scientists from around the world—are categorized broadly into 5 thematic fields:

1) Forecasting,
2) Observations,
3) Thresholds,
4) Responses, and
5) Innovation.

The ICSU Report calls for research "that examines how the coupled social–environmental system is changing […] and what actions and interventions may alter the environmental and social outcomes" (ICSU 2010a: 9). In doing so, research related to the Grand Challenges—in contrast to the analytical structure of the GLP—goes beyond enhancing understanding of social–environmental systems by placing emphasis on informing action towards coping with global change. Against this background, session chairs assessed the degree to which the papers in their sessions addressed the 5 Grand Challenges.

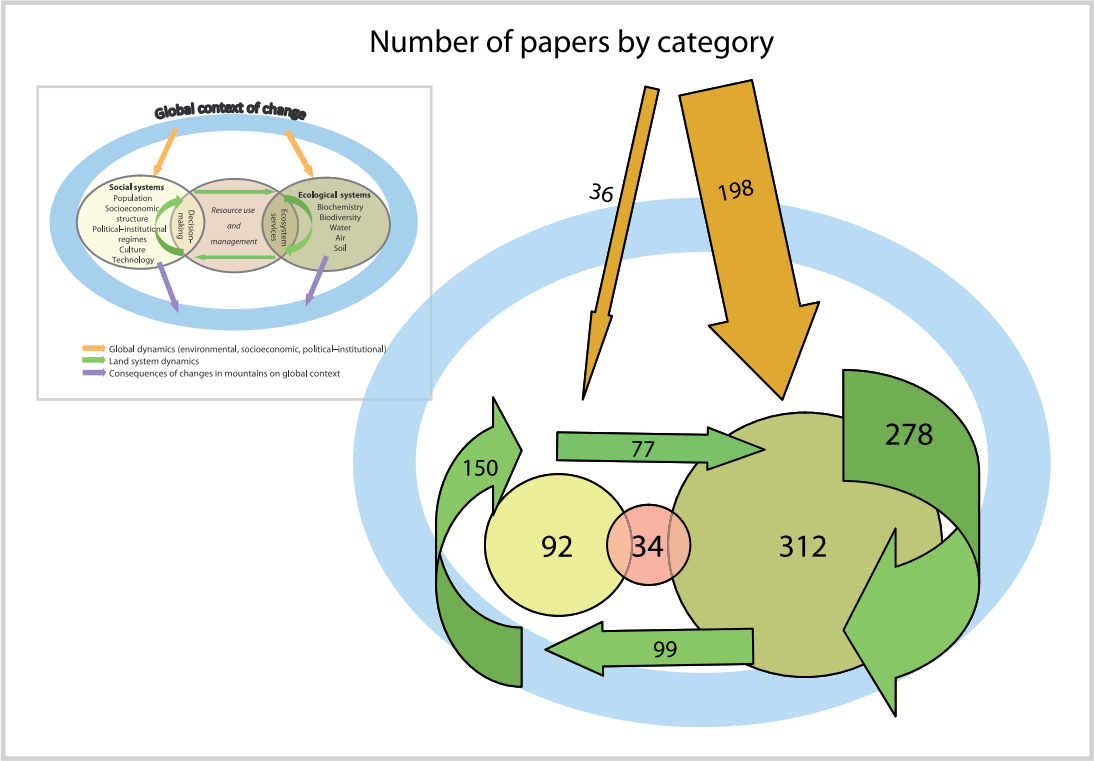
The insights gained from the assessment and synthesis process form the basis for working towards a global agenda for mountain research that advances both scientific knowledge and sustainable development.

State of the art of global change research on mountains

From the 610 abstracts submitted, 433 were accepted for oral or poster presentation (CMS 2010). They represent the state of the art in global change research in the world's mountains in 2010, giving a broader perspective than the commissioned overview compiled in 2004 (Huber et al 2005) or the Perth I Conference held in 2005 (Price 2006). Nearly one half of the abstracts referred to research in Europe, one fifth concerned Asia, and one sixth North America (Figure 2). To some extent, this distribution doubtless reflects the fact that the conference took place in Europe; nevertheless, all authors from developing countries who had an abstract accepted for oral presentation were given travel

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FIGURE 3 Number of papers assigned to the different components of the modified GLP analytical structure.



funding and free registration, so that financial issues should not have been too significant a barrier to participation.

A majority of the abstracts (312 or 72%) dealt with ecological systems, 92 (21%) with social systems, and 34 (8%) with resource use and management (Figure 3). With regard to interactions, 278 abstracts (64%) referred to interactions within ecological systems, 198 (46%) to influences of global environmental drivers on ecological systems, 150 (35%) to decision making and institutions, and 99 (23%) to influences of ecological systems on social systems. Some initial conclusions can be drawn as follows:

- In terms of global change drivers, the main research focus was on global drivers directly impacting ecological systems; only 36 abstracts (8%) considered social and/or economic global forces such as globalization or demographic change.
- The emphasis was clearly on the natural sciences, that is, on ecological systems and interactions within them.
- A significant proportion of papers considered decision making and institutions.
- While rather few papers (34 or 8%) focused on resource use and management, over twice as many (77 or 18%) investigated how changes in resource use and management impact the ecological system.
- Only 6% of papers were interdisciplinary in the sense of addressing interactions of coupled social–environmental systems or processes driven by global environmental change.
- No papers dealt with the consequences that changes in mountain systems may have on the global context (Figure 3).

Research needs and emerging themes for sustainable development

The following section specifies the research needs and emerging themes for sustainable development that were identified when analyzing the abstracts and presentations (see step 2 above). In line with the GLP, the results are structured using the components of ecological systems, social systems, and the various interactions that occur across the components and systems.

Ecological systems perspective

Analysis of the presentations focusing on ecological systems substantiated that important progress had been made since the first conference in Perth in 2005. However, major knowledge gaps remain and new challenges are emerging with regard to sustainable mountain development. They can be summarized in the following two points:

1. Global change research in mountains currently focuses mainly on studying climate change and its impact on mountain ecosystems. However, climate change is just one of many global drivers of

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change in mountain areas. To understand the different drivers, as well as to disentangle their cascading impacts on, and disturbances of, mountain ecosystems, remains a major research challenge. For example, changes in downstream systems have to be recognized as the result not only of glacier retreat but also of socioeconomic changes in the watershed. A shift of timberlines can be due to climate as well as land use changes. To detect such impacts and attribute them to specific drivers of change, suitable indicators need to be identified and long-term and cost-effective monitoring schemes established. Such monitoring has to be coordinated and based on integrative approaches to gain an improved understanding of global change impacts. In addition, monitoring provides significant data for improving models and for downscaling results to regional and local levels, thus making them relevant to policy and decision making.

2. Obtaining a differentiated understanding of the impact of global change on mountain ecosystems and landscapes is crucial but not sufficient. It is equally important to enhance knowledge on how changes in mountain ecosystems influence human well-being in and beyond mountain regions through changes in ecosystem services. Although research on ecosystem functioning and services in mountain regions has gained momentum, appropriate indicators are often lacking and concepts for valuating such services are not yet able to address the complexity of the issue at stake. More research is needed to design meaningful compensation mechanisms that will eventually contribute to more sustainable management of mountain ecosystems. Changes in mountain ecosystems are clearly detectable and may exceed certain limits (eg pest outbreaks, fires, and invasive species). Research into how ecosystems adapt to changes (eg shifts of species and habitat ranges) as well as into ways of mitigating risks and threats is therefore urgently needed in order to develop innovative pathways towards sustainable mountain development. One illustrative example is the ongoing discussion on how the United Nation's Collaborative Initiative on Reducing Emissions from Deforestation and Degradation (REDD+ and REDD++) can provide meaningful opportunities for mountain regions. Hence, more attention needs to be given in future to how scientific knowledge about mountain ecosystems can be translated into a dialogue with decision and policy makers, landowners, practitioners, and other stakeholders to jointly develop adaptation and mitigation measures.

Hence, an important goal for ecological research in mountain regions will be to build networks: It is crucial to expand and improve monitoring networks and observation sites where common research protocols and methodologies are applied, so as to generate comparative data that allow research results to be placed into a larger context. Networks of experts from research, policy, and practice are required to facilitate coordination and information exchange and to catalyze tangible benefits. Networking at the three levels—of data, sites, and people—is a cost-effective means for addressing the complex problems of mountain environments impacted by global change.

Social systems perspective

Global change affects the different elements of social systems in mountain areas (eg culture, population, and economics) in manifold and complex ways. At the Perth II Conference only a limited number of such interactions could be discussed as there were few presentations focusing on the social system. Nevertheless, it was possible to identify important realms for future research and emerging issues for sustainable development.

The presentations of research on social systems showed that the number and forms of human movements to, within, and out of mountain areas are perceived as an important expression of global change. However, the characteristics, trends, and impacts of the diverse forms of movements—such as tourism, amenity migration, and multilocal dwelling—are still little understood and need further investigation.

The major shortcoming of many disciplines continues to be poor understanding and therefore inadequate problematization of sociocultural drivers. Accordingly, the sociocultural system is often treated as a black box. There are uncertainties and disagreements as to how individuals are guided by interests and values and how individual motivations translate into collective behavior. The reasons for this knowledge gap are manifold: failure on the part of the mountain research community to involve the appropriate bodies of knowledge, mountain researchers' own normative agenda, or the lack of suitable tools to unravel the complexity of the social system.

Regarding climate change, the lack of policy-relevant information about its impacts at the regional level was identified as an important gap. Related mechanisms of policy and decision making as well as incentive schemes are not adequately comprehended. It remains a major challenge how to mobilize decision makers, whose time horizons typically extend to the next elections and whose concerns are directed towards coping with economic change and financial turbulence rather than towards climate change.

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The above research gaps are closely related to the emerging issues for sustainable mountain development. The recognition and integration of stakeholders in knowledge production processes are essential for illuminating the black box mentioned above. This calls for a shift in the perception of stakeholders: from a social identity imposed on them from outside to a collective identity asserted by stakeholders themselves, acknowledging the legitimacy of their voice and their capacity to participate in scientific and decision-making processes. Links between diverse stakeholder groups may be established on the basis of policy-oriented research. However, there must be critical reflection as to the extent to which terms such as resilience, thresholds/tipping points, or vulnerability can be imported from the natural sciences to foster a better understanding of the social system.

Overall, it seems that the economic dimension of sustainability generates much more heated scholarly debate than the environmental and social dimensions. The Perth II participants urgently called for clarification and reconciliation of the diverse needs and ambitions of researchers and mountain stakeholders in order to contextualize economic development within the broader notion of sustainable development in mountain areas.

Social–ecological systems perspective

The relatively small proportion of research dealing with intra- and intersystem interactions, for example, establishing drivers of change in systems or investigating impacts of ecosystem changes on social systems and vice versa, does not come as much of a surprise. Although problem orientation and an integrative systems approach have been promoted for more than 4 decades (eg UNESCO's MAB Programme [UNESCO 2011]; Brundtland 1987), both the complexity of coupled social–ecological systems and incomplete data sets across temporal and spatial scales remain major challenges for mountain research.

In mountain environments, the interdependency of physical and biological processes is starkly apparent. However, as is generally known, human–environment interactions are the most determinant drivers of major changes across nearly all mountain regions on Earth. Nevertheless, analysis of the conference papers revealed that research into the decisive interactions and feedbacks of such coupled social–ecological systems is still limited, while legal and political issues such as land tenure and land and water grabbing were not adequately represented. Future research needs to adopt a systems approach to understand the dynamics and processes within (as outlined above) but also between ecological and social systems. Beyond characterization and monitoring of causes and effects, increased understanding of linkages and feedbacks will help to identify nonlinearities and thresholds (tipping points) in both ecological and social systems. Improved understanding of such nonlinearities may help to avoid crossing thresholds, thereby preventing loss of ecosystems and their services, for example.

A systems approach calls for collaborative research conducted by social and natural scientists in inter- and transdisciplinary projects to avoid narrow interpretations of phenomena observed. This is still difficult to accomplish, as academic traditions, for instance, reward disciplinary rather than interdisciplinary scholarship. Therefore, a new paradigm of interdisciplinary training for students of mountain systems is required.

The sessions adopting a more integrative perspective brought to light the importance of adequate decision making. Mountain regions, already highly vulnerable to various kinds of degradation, are shaped not only by local uses, but increasingly by national, regional, and international policies and markets for resources. Integrated research into how decisions are made at the different levels of society and how they affect coupled social–environmental systems in the mountains is urgently needed.

Going beyond interdisciplinarity and pondering over the sustainability of complex social–ecological systems, we encounter further questions: How can sustainability or trends and causal factors contributing to unsustainable practices in complex systems with many uncertainties be measured? How can sustainable development be defined over the long term? What is the baseline for defining sustainability? More consistent long-term monitoring can help to answer these questions.

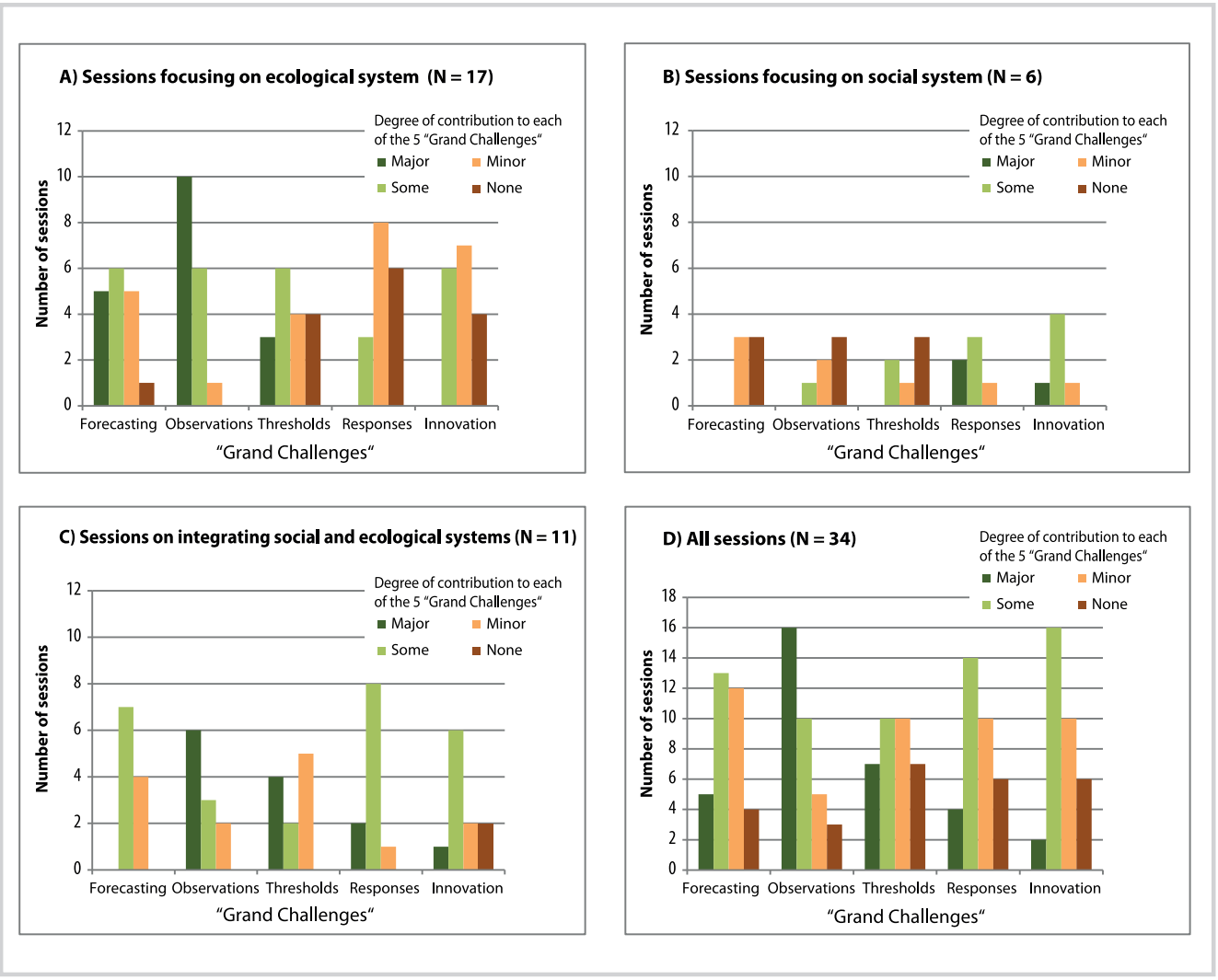
Mountain research addressing challenges of sustainable development

The third step in the Perth II Conference analysis aimed at clarifying the scope of the contribution made by current mountain research to sustainable development. According to ICSU (2010a, 2010b), global sustainability research needs to focus on 5 Grand Challenges in the coming decade in order to enable society to cope with, and manage, global change and its impact in the near future:

1. *Forecasting:* Improve the usefulness of forecasts of future environmental conditions and their consequences for people.
2. *Observations:* Develop the observation systems needed to manage global and regional environmental change.
3. *Thresholds:* Determine how to anticipate, recognize, avoid, and adapt to abrupt global environmental change.
4. *Responses:* Determine what institutional, economic, and behavioral changes constitute effective steps towards global sustainability.

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FIGURE 4 (A–D) Contributions made by the papers in the conference sessions, categorized by their main focus, to tackling the 5 "Grand Challenges" in global sustainability research (ICSU 2010a).



5. *Innovation:* Encourage innovation (along with sound mechanisms for evaluation) in developing technological, policy, and social responses to achieve global sustainability.

The session chairs' assessments regarding the degree to which the papers address these Grand Challenges are promising but equally point out major shortcomings (Figure 4A–D). Overall, current mountain research is mainly geared towards observing and thus enhancing understanding of the biophysical conditions prevailing in coupled social–environmental systems in mountains. It faces substantial difficulties, however, in determining thresholds within the systems and thus in providing reliable information on future scenarios (forecasting). Moreover, research is not yet in a position to offer major insights that would inform and empower mountain societies to adequately respond to global change, nor does it trigger sufficient innovation in this regard. This view is certainly influenced by the predominance of environmental research presented at the Perth II Conference (Figures 3, 4A). In contrast, research focusing on social systems or following an integrative approach (Figure 4B, C) tends to attach more importance to advancing responses and enabling innovation.

Towards a sustainability-oriented research agenda

The endeavor to assess and synthesize the research presented at the Perth II Conference, and to reflect on it against the background of ongoing debates of global change research, is a vibrant sign of the mountain research community's will to help develop, in partnership with stakeholders, sound response strategies for the challenges of global change and sustainable mountain development. Analysis also

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shows that mountain systems provide an exceptional opportunity for developing and advancing global change research agendas, particularly such that are directed at holistic understanding of the dynamics of coupled social–ecological systems. Mountain systems allow the key issues on these agendas to be investigated at spatial and temporal scales of direct relevance to the sustainable management of social–ecological systems. In this respect the mountain research community has already made considerable progress, not least due to the manifold international and regional as well as national initiatives promoting sustainable mountain development (Debarbieux and Price 2012; Messerli 2012; both in this issue).

However, this assessment reveals the need for a reorientation of both mountain research and the mountain research community. As emphasized by ICSU, the Grand Challenges have to be considered as an "indivisible package," implying that progress in one area depends on progress in others (ICSU 2010b: 9). Accordingly, the mountain research community should place greater emphasis on "responses" and "innovation" without neglecting its core competence in "forecasting" and "observation." Together with the clearly identified need for more research into social systems and interactions between social and ecological systems, this calls for changes in the composition of the mountain research community and a new research paradigm. Although the mountain research community possesses a great deal of social capital, it should urgently be complemented with more social and political scientists, as well as mountain stakeholders, who should be involved at all stages of research.

Networks of coordinated observatories and of mountain stakeholders with backgrounds in research, policy, and practice are promising but insufficient tools to address global change challenges in mountains. A paradigm shift towards a systems approach is called for, requiring more inter- and transdisciplinary research. This in turn implies changes in the academic education system as well as improvement of the social and communication skills of all stakeholders. Such empowered mountain networks could bring forward their arguments based on evidence and would be able to advocate mountain people and mountains not only at the local and regional levels, but also internationally. In this sense, key results of the assessment performed on the occasion of the mountain research community gathering in Perth can critically inform preparatory work for the Rio+20 Meeting in 2012.

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