Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

MountainAgenda
Target knowledge

Mountains of Our Future Earth: Defining Priorities for Mountain Research

A Synthesis From the 2015 Perth III Conference

Erin H. Gleeson[1], Susanne Wymann von Dach[2], Courtney G. Flint[3], Gregory B. Greenwood[1], Martin F. Price[4], Jörg Balsiger[5], Anne Nolin[6], and Veerle Vanacker[7]*

** Corresponding author: erin.gleeson@giub.unibe.ch*

[1] *Mountain Research Initiative, c/o Institute of Geography, Erlachstrasse 9a, Trakt 3, University of Bern, 3012 Bern, Switzerland*

[2] *Centre for Development and Environment, University of Bern, Hallerstrasse 10, 3012 Bern, Switzerland*

[3] *Department of Sociology, Social Work and Anthropology, Utah State University, 0730 Old Main Hill, Logan, UT 84322-0730, USA*

[4] *Centre for Mountain Studies, Perth College, University of the Highlands and Islands, Crieff Road, Perth, PH1 2NX, Scotland, UK*

[5] *Department of Geography and Environment and Institute for Environmental Sciences, University of Geneva, Bâtiment Uni Carl Vogt, 66 boulevard Cal Vogt, 1205 Geneva, Switzerland*

[6] *College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, 104 CEOAS Administration Building, 101 SW 26th St, Corvallis, OR 97331, USA*

[7] *Earth and Life Institute, Georges Lemaître Centre for Earth and Climate Research, Université catholique de Louvain, 3, place Louis Pasteur/L4.03.08 (Bâtiment Mercator, 3e étage), 1348 Louvain-la-Neuve, Belgium*

The Perth conferences, held every 5 years in Perth, Scotland, bring together people who identify as mountain researchers and who are interested in issues related to global change in mountain social-ecological systems. These conferences provide an opportunity to evaluate the evolution of research directions within the mountain research community, as well as to identify research priorities. The Future Earth Strategic Research Agenda provides a useful framework for evaluating the mountain research community's progress toward addressing global change and sustainability challenges. Using a process originally set up to analyze contributions to the 2010 conference, the abstracts accepted for the 2015 conference in the context of the Future Earth framework were analyzed. This revealed a continued geographic underrepresentation in mountain research of Africa, Latin America, and South and Southeast Asia but a more even treatment of biophysical and social science themes than in 2010. It also showed that the Perth conference research community strongly focused on understanding system processes (the Dynamic Planet theme of the Future Earth research agenda). Despite the continued bias of conference contributions toward traditional observation- and conservation-oriented research, survey results indicate that conference participants clearly believe that transdisciplinary, transformative research is relevant to mountains. Of the 8 Future Earth focal challenges, those related to safeguarding natural assets, promoting sustainable land use, increasing resilience and understanding the water-energy-food nexus received considerable attention. The challenges related to sustainable consumption, decarbonizing socioeconomic systems, cities, and health were considerably less well represented, despite their relevance to mountain socioeconomic systems. Based on these findings, we outline a proposal for the future directions of mountain research.

Keywords: *Global change; sustainable development; social-ecological systems; transdisciplinary research; transformative research.*

Reviewed by Editorial Board: *March 2016*
Accepted: *July 2016*

Introduction

Mountains, which according to the FAO (Romeo et al 2015) cover 22% of the Earth's surface and are home to about 915 million people, provide ecosystem services (eg freshwater, food and fiber, genetic resources, timber, energy, and protection against natural hazards) to about half of the global population, and play a decisive role in shaping a sustainable future (Körner et al 2005; Viviroli et al 2007; Price et al 2011; Ariza et al 2013). The significance of mountain environments and people and the need for sustainable development in mountain regions has increasingly been recognized in global agendas, international conventions, and action plans, from the Mountain Chapter in *Agenda 21* in 1992 (United Nations 1993) to 2 of the 17 recently agreed upon Sustainable Development Goals (United Nations 2015). These documents have been jointly developed and promoted by representatives of national governments, intergovernmental organizations, and scientists (Debarbieux and Price 2008; Messerli 2012; Debarbieux et al 2015).

With the goal of fostering sustainable development, scientists and scientific collectives have provided sound evidence for policy- and decision-making at different governance levels. They have contributed knowledge useful for addressing today's global societal challenges, enhanced justice, and the transformation toward a more desirable future (Rockström et al 2009; Raworth 2012). Accordingly, mountain researchers are constantly challenged to consider the orientation and framing of their research (Leach et al 2010). As Miller et al (2014: 240) argue, "sustainability scholars, practitioners and decision-makers [have to] critically reflect on how to best position sustainability research to ensure that knowledge creation enhances decision-making capacity and the ability of our institutions to navigate socio-technical systems along more sustainable trajectories." However, depending on individual values and conceptions of sustainable development (Leach et al 2010; Wuelser 2014), conclusions related to the orientation and priorities of future research for sustainable mountain development may differ and need to be negotiated.

The Perth Conferences, held in 2005, 2010, and 2015 in Perth, Scotland (Perth I, II, and III, respectively), aimed to address issues of global change across the world's mountains. They have offered unique opportunities to evaluate the state, progress, and orientation of mountain research with regard to global change, as well as to ascertain how research can identify "critical priorities for global change and sustainability research" (Future Earth 2014a: 3) related to mountains. Conference participants come from all over the world and from a broad range of disciplines (210 people from 41 countries in 2005, 450 people from 60 countries in 2010, and 400 people from 52 countries in 2015). Each conference brings together a new cohort of mountain researchers; for instance, only 75 participants at the 2015 conference had attended the 2010 conference. The participation in and contributions to these conferences can therefore yield insights into priorities and progress within the research community.

Before, during, and after the 2010 conference, a group of participants jointly evaluated the status of global change research in mountain areas based on conference contributions (Björnsen Gurung et al 2012). To do so, they assessed the accepted abstracts using the analytical structure of the Global Land Project (GLP 2005) and the then-current Grand Challenges in Global Sustainability Research (ICSU and ISSC 2010) as the guiding frameworks. This assessment revealed a "need for a reorientation of both mountain research and the mountain research community" (Björnsen Gurung et al 2012: S54). The authors called for more research into social systems and their interactions with ecological systems, as well as a greater emphasis on responses and innovation toward sustainability. To achieve this, they recommended a stronger integration of social and political scientists into the mountain research community, as well as an increase in the involvement of mountain societal partners in transdisciplinary research.

Since 2010, the international debate about global change in mountains has evolved, as have the global research and policy frameworks. The title of the Perth III conference was chosen to link this event to the new Future Earth program, a 10-year international research initiative that aims to develop the knowledge for responding effectively to the risks and opportunities of global environmental change and for supporting transformation toward global sustainability. The Strategic Research Agenda of Future Earth is the outcome of a worldwide consultation among scientists and societal partners (Future Earth 2014a). Like the Global Challenges framework used in 2010, this agenda provides a useful frame of reference for evaluating how the research presented at the Perth III conference contributes to addressing emerging challenges of global change in mountains, and to identifying existing gaps in knowledge.

This paper continues the effort of Björnsen Gurung et al (2012) to (1) assess the geographic and thematic coverage of the 2015 presentations and the respective changes since 2010, (2) evaluate the Future Earth research priorities' relevance for mountains and current contributions toward these priorities, and (3) propose future directions for research on global change in mountain regions based on identified gaps and opportunities. This analysis of the Perth III contributions should enable the mountain research community to "explore new development paths, and to find new ways to accelerate transitions to sustainable development," as called for in the Future Earth vision statement (Future Earth 2014b: 2).

Assessment and synthesis

To address these objectives, a 3-step assessment approach was developed. A synthesis of this assessment was presented during the final plenary session of the Perth III conference, during which a roundtable of experts discussed elements of an effective framework for achieving sustainable development in mountains. (A video of the roundtable is accessible at https://cast.switch.ch/vod/clips/ux5ps72nv/streaming.html.) The authors of this article used the synthesis and the outcomes of the roundtable discussion to develop a proposal for the future direction of mountain research.

Step 1: Comparing Perth II and Perth III presentations

Following the same synthesis procedure used at the 2010 conference (Björnsen Gurung et al 2012), the same 2 experts who coded the Perth II abstracts coded the 446 Perth III abstracts according to their geographical and thematic foci and categorized them according to the components of a simplified representation of mountain

social–ecological systems, based on the analytical structure of the Global Land Project's *Science Plan and Implementation Strategy* (GLP 2015). In 2015, the experts used 7 of the 9 components used in 2010, deeming the other 2 redundant. Abstracts were coded for multiple components where appropriate. Of the 7 components used in both analyses, the average abstract addressed 2.13 in 2010 and 2.38 in 2015. Comparison of the results from 2010 and 2015 allowed evaluation of the extent to which the research community present in Perth in 2015 addressed research gaps and needs identified in 2010.

Step 2: Assessing contributions to the Future Earth Strategic Research Agenda

The experts also assessed the papers in terms of their contribution to Future Earth's 8 focal challenges and 9 research themes (Future Earth 2014a: 6, 12). Perth III participants were also asked which of the 9 Future Earth research themes and 62 research priorities were especially relevant to mountains. The conference registrants were asked to complete an online Qualtrics survey. A total of 302 surveys were completed, yielding a 72% response rate. The first part of the survey served to develop a deeper understanding of the research community present in Perth and included questions regarding participants' involvement in single-disciplinary and inter- or multidisciplinary research (see Lang et al 2012). In the second part of the survey, respondents were asked to rank the Future Earth research priorities for mountains on a scale from 1 ("not a priority") to 5 ("high priority"). The data were analyzed to assess overall priority rankings as well as differences based on respondent characteristics.

Step 3: Identifying gaps and emerging issues to inform future research directions

The goal of the third part of the analysis was to derive a synthesis of each of the 31 sessions and of the conference as a whole. To distill the outcomes of each session, the session chairs summarized their impressions and insights in the conference blog (https://perthmountains2015.wordpress.com/). The session attendees were encouraged to record their own impressions and continue the discussion on the blog.

Subsequently, members of the Mountain Research Initiative's Science Leadership Council, which is composed of leading scientists from a range of disciplines and locations, worked in 3 teams of 6 people each to distill the outcomes of the conference with regard to the 3 Future Earth themes (Dynamic Planet, Global Sustainable Development, and Transformations towards Sustainability). Using the session blogs and the insights gained throughout the conference, the 3 teams synthesized the research contributions presented at Perth III to identify major trends and gaps in our understanding of mountains. This provided crucial inputs for the identification of future work and research lines in relation to the Future Earth program.

Status of global change research in mountains

Toward more balanced geographic and thematic coverage

The assessment of abstracts revealed a geographic bias similar to that observed at Perth II, although less pronounced. Europe was over-represented and Africa, Latin America, and North America under-represented—a pattern that does not reflect the geographical distribution of mountain areas or mountain people, who live primarily in developing regions, especially Asia and Africa (Figure 1; Romeo et al 2015). The lack of geographic balance, especially regarding Africa, thus remains a challenge.

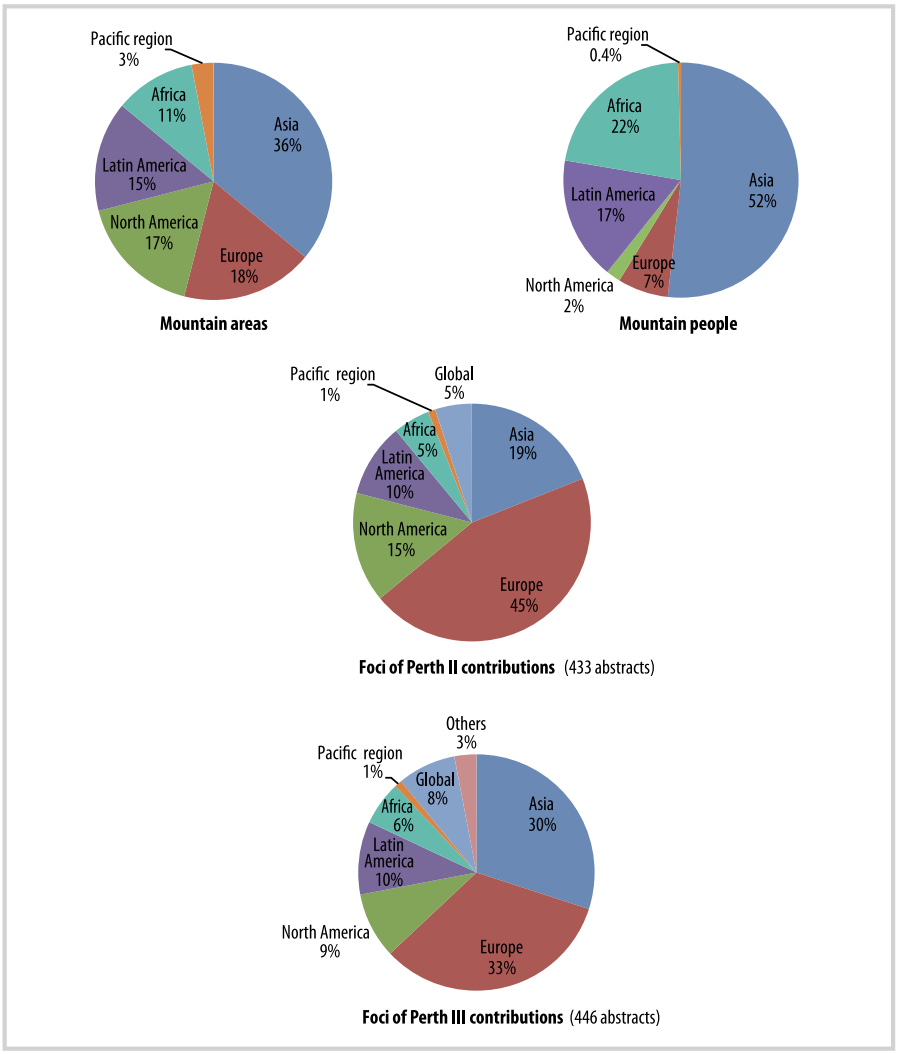
The comparison between the Perth II and III contributions also revealed a thematic shift (Figure 2). In 2015, ecological systems were still the most frequent focus of mountain research, but the distribution between the main components of the social–ecological system was more even. For instance, while attention to the impacts of global environmental change on ecological systems decreased markedly, attention to impacts on social systems remained rather low. Overall, the natural science bias identified in 2010 (Björnsen Gurung et al 2012) was less pronounced in 2015; the contributions in 2015 provided a more balanced treatment of the interactions between the social and ecological systems in mountain regions.

Contributions to Future Earth challenges and priorities

The abstracts focused principally on 4 of the 8 Future Earth focal challenges (Table 1). The challenge most frequently addressed, safeguarding natural assets, corresponds well with the predominance of ecological systems as research topics (Figure 2). The second most important challenge, identifying options, matches the more even treatment given to social, management, and ecological aspects of land systems. The third and fourth topics, increased resilience and the water-energy-food nexus, indicate a strong interest in the livelihood and governance aspects of mountain systems and how people cope with changes.

The extremely limited interest in the remaining 4 challenges—sustainable consumption, decarbonizing socioeconomic systems, cities, and health—is striking, as at least 3 of these challenges are directly relevant to mountain regions. In particular, hydropower from mountain areas has great potential for contributing to decarbonization (Ahlers et al 2015; Kohler et al 2015; Björnsen Gurung et al 2016; Hastik et al 2016). Furthermore, about 30% of mountain people today live in urban areas (Romeo et al 2015), which poses challenges with regard to city design, sustainable consumption, and health.

FIGURE 1 The worldwide distribution of mountain areas and mountain people (Romeo et al 2015), compared with the geographic foci of research presented at Perth II and III.

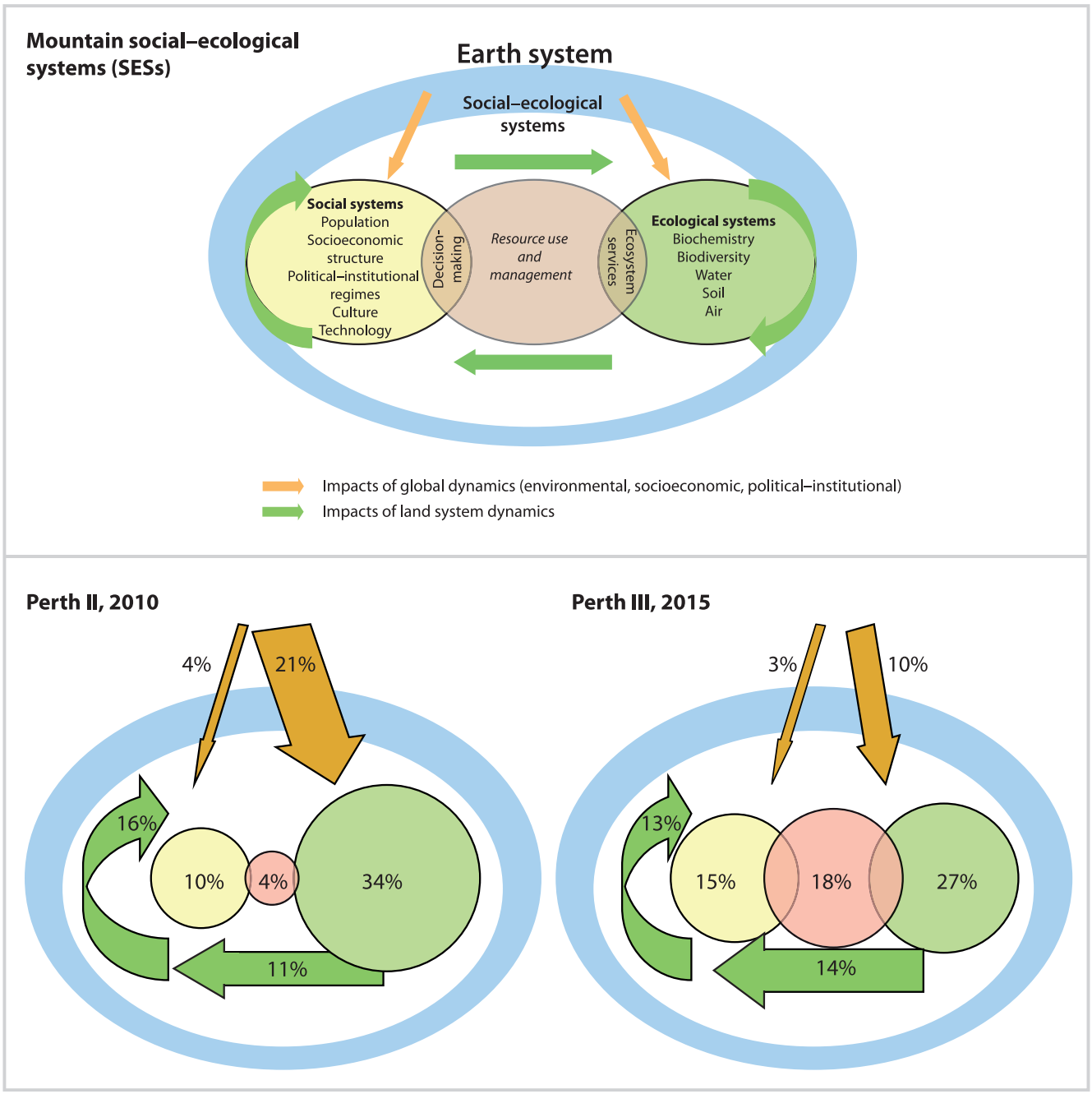


A similarly lopsided picture emerged in the distribution of abstracts' topics among the 9 themes of the Future Earth Strategic Research Agenda (Figure 3). A majority of the abstracts addressed focal areas related to the Dynamic Planet theme (A), particularly observation (A1) and understanding (A2), while noticeably fewer focused on forecasting future conditions (A3) was noticeably less in focus. A smaller but still considerable number of abstracts addressed the 2 other main themes: Global Sustainable Development (B) and Transformations towards Sustainability (C).

Conference participants' focus on Future Earth themes in their contributions differed substantially from their perceptions of the relevance of those themes for mountains. While the first theme was predominant in the contributions, all 3 themes ranked high (over 3.5 on a 5-point scale) in terms of relevance (Figure 3). This suggests that, while current mountain research is strongly focused on assessing dynamic processes, the mountain research community considers many other research areas important.

An in-depth analysis of this mismatch could be helpful in prioritizing research that can contribute effectively to sustainable development in mountains. A first step in this direction is to drill down into the averages summarized in Figure 3 to the relevance rankings of all 62 Future Earth research priorities. Table 2 lists Perth III participants' 10 highest and lowest priorities, and Table S1, *Supplemental material* (http://dx.doi.org/10.1659/MRDJOURNAL-D-16-00094.S1) explores responses to all 62 priorities in more

FIGURE 2 Occurrence of common thematic foci (Björnsen Gurung et al 2012) in the abstracts submitted to Perth II and Perth III. The top figure is the modified analytical structure of the GLP Science Plan and Implementation Strategy (GLP 2005); the bottom 2 figures show the emphasis given to the various components of the structure by the papers presented at the 2 conferences.



detail. The main trends in those responses are discussed below.

Differences in personal values and conceptions of sustainable development may lead researchers to assess priorities differently. We therefore investigated whether or not subgroups of mountain researchers varied in their ratings of research priorities. The first comparison made was between biophysical scientists (63% of respondents) and social or sustainable-development scientists (37% of respondents). For just over half of the priorities (33 out of 62), there were no statistically significant differences (at $p < 0.05$ level) between these 2 groups. For the remaining priorities, the 2 groups differed as expected. Biophysical scientists gave higher ratings to biodiversity and ecosystem trends as well as climate variability; social and sustainable-development scientists' higher ratings fell mainly under the Future Earth themes Global Sustainable Development (B) and Transformation towards

TABLE 1 Number of Perth III abstracts ($N = 446$) addressing specific Future Earth focal challenges.

Focal challenge[a]		Total	Percentage
3	Safeguard the terrestrial, freshwater and marine natural assets underpinning human well-being. . . .	222	49.8
5	Promote sustainable rural futures to feed rising and more affluent populations . . . by analysing alternative land uses, food systems and ecosystem options. . . .	182	40.8
8	Increase social resilience to future threats by building adaptive governance systems, . . . [and] testing effective, accountable and transparent institutions that promote transformations to sustainability.	117	26.2
1	Deliver water, energy, and food for all, and manage the synergies and trade-offs among them. . . .	110	25.7
7	Encourage sustainable consumption and production patterns that are equitable by understanding . . . options for sustainable development pathways and related changes in human behavior.	14	3.1
2	Decarbonise socio-economic systems to stabilise the climate by promoting the technological, economic, social, political and behavioural changes enabling transformations. . . .	12	2.5
4	Build healthy, resilient and productive cities by identifying and shaping innovations. . . .	6	1.4
6	Improve human health by elucidating, and finding responses to, the complex interactions amongst environmental change, . . . ecosystem services, and people's livelihoods, nutrition and well-being.	7	1.5
Not clear		41	9.2

[a]Challenges are quoted from Future Earth 2014a: 6.

Sustainability (C). This is not surprising, given that many of these priorities referred to elements within social systems, including human wellbeing, demographic change, urban systems, governance, markets, and technology.

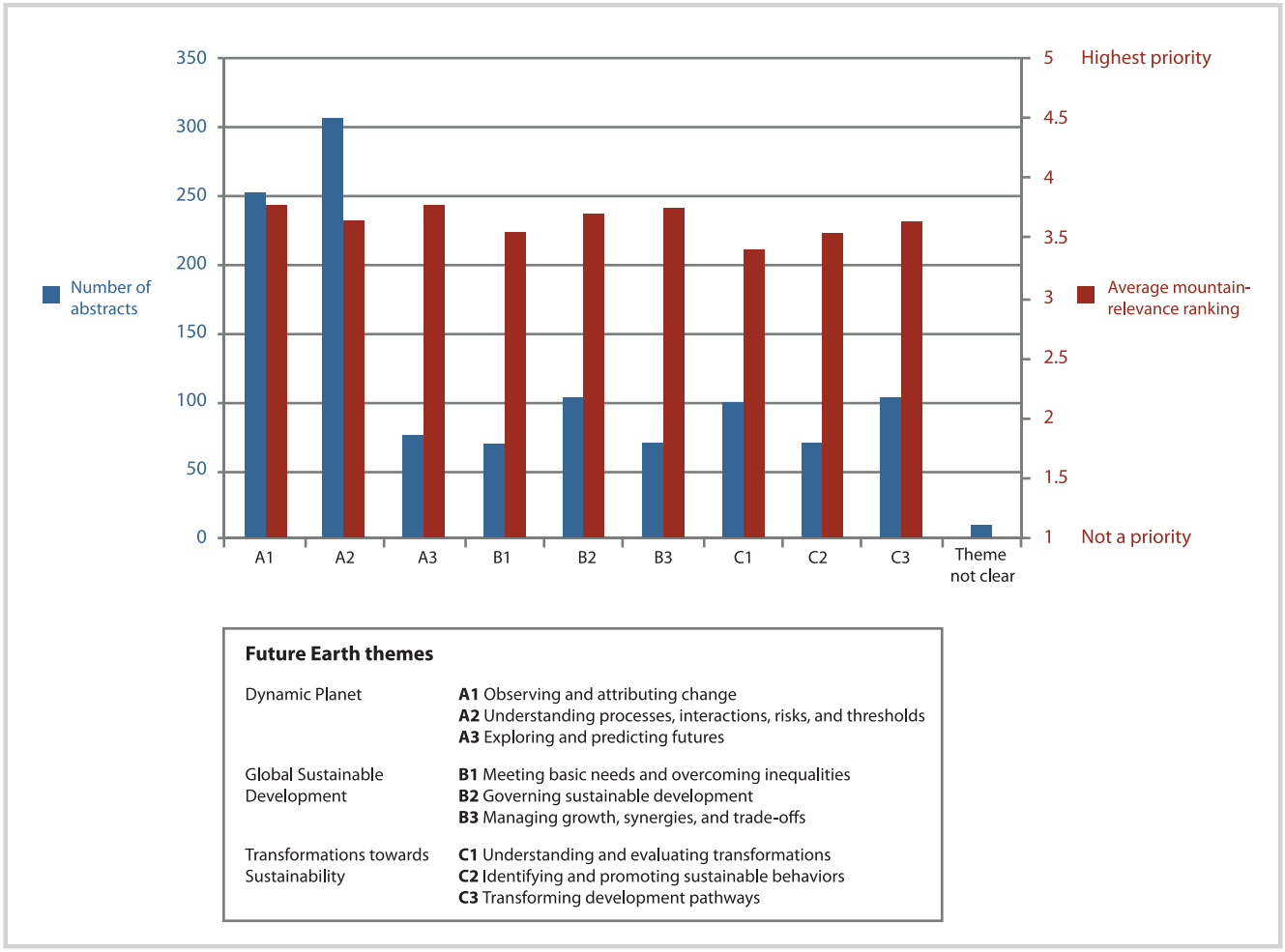
Similar findings emerged with regard to the influence of interaction with societal partners. The more respondents reported such interactions, the more likely they were to rate highly priorities that referred to human wellbeing or vulnerability. The extent of reported interdisciplinary focus influenced ratings as well, with positive and significant relationships for priorities emphasizing topics relating to social–ecological systems or comparisons across varying contexts.

A new kind of knowledge

The *Future Earth 2025 Vision* calls for a "new type of science that links disciplines, knowledge systems and societal partners" to shape pathways toward a more sustainable and equitable world (Future Earth 2014b: 2). The analysis of the Perth III sessions by the Science Leadership Council revealed that numerous sessions reflected this plea for collaborative research formulation, implementation, and diffusion of results. It was recognized that transdisciplinary research can be a powerful means to involve various actors in the generation of shared knowledge, as well as to ensure their ownership of research results, including scenarios, models, and future trajectories. This finding is supported by the survey: close to 70% of respondents assessed their work as moderately or even highly inter- and multidisciplinary, and close to 50% work closely with societal partners in the context of their research projects in mountain regions (Figure 4).

However, discussions during sessions and roundtables showed that, in many cases, researchers still view stakeholders mainly as sources of information, not as full partners in the co-design of projects and the co-production of knowledge, as put forward by transdisciplinary research approaches (Pohl et al 2010; Renner et al 2013; Schneider and Rist 2014). Understanding of the true nature of transdisciplinarity and associated research methods still needs more refinement to avoid labeling as transdisciplinary any research involving stakeholders as information sources. Until this is achieved, scientific projects are less likely to have positive transformative impacts (Lang et al 2012). Nevertheless, many of the Science Leadership Council observers felt that the Perth III conference was the first they had attended in which the key role of stakeholders was repeatedly addressed in so many different contexts. It is important to acknowledge the challenge associated with questions about transferability of findings in transdisciplinary research, especially in the face of the

FIGURE 3 Future Earth themes (Future Earth 2014a: 12) addressed by Perth III abstracts and their ranking by conference participants as a priority for mountain areas.



highly contextual nature of most such research (Lang et al 2012).

Future directions for mountain research

Together, the Perth conferences and the Future Earth framework provide a unique opportunity to evaluate progress toward sustainability-oriented mountain research and to identify priorities. Over the past 15 years, a number of proposals for mountain research have been published (Becker and Bugmann 2001; Björnsen Gurung et al 2006; Björnsen Gurung et al 2012). All of these have emphasized that sustainable mountain development in the context of global change requires holistic approaches, a conclusion reinforced by our analysis of the Perth III conference. Although the mountain research community is becoming increasingly interdisciplinary, it does not yet fully address all aspects of social–ecological systems in the many mountain ranges around the world, nor fully exploit the potential for knowledge co-production that actively advances transformation processes (WBGU 2011: 22; Future Earth 2014a). We therefore make the following propositions for the future directions of mountain research.

Filling geographical gaps in mountain research

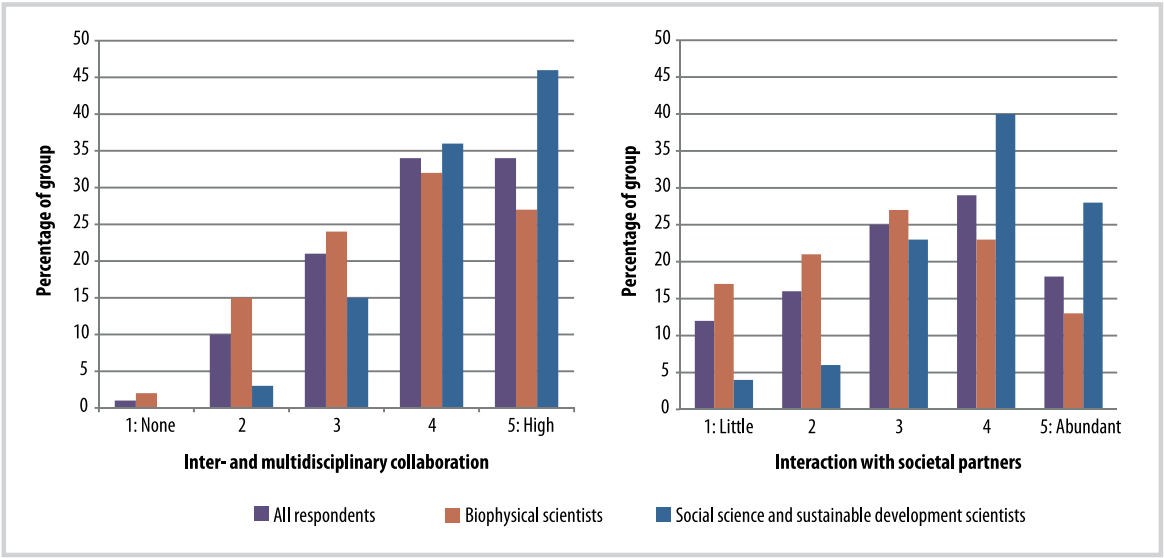
Although one would expect more research on mountains in which more people live, the number of research presentations pertaining to mountainous areas in Africa, Latin America, South Asia (apart from the Hindu Kush–Himalaya), and Southeast Asia was not commensurate with these regions' share of mountain areas and mountain populations. As priority funding for all 3 Perth conferences was available to registrants from developing countries and underutilized, we suggest that this under-representation may be due more to a lack of research output, penetration (networking), and perhaps capacity than a lack of travel funding per se.

To overcome the geographic under-representation of African, Latin American, and South and Southeast Asian mountain research, we suggest the following:

TABLE 2 Perth III participants' highest and lowest research priorities in terms of relevance for mountains.

Top 10 priorities	Mean
Water access and security; livelihood implications (B1.1)	4.21
Trends of biodiversity, ecosystems and ecosystem services (A1.4)	4.17
Implications of different land-use changes on biodiversity, ecosystems and their services (B3.6)	4.16
Community involvement in environmental change activities (B2.6)	4.12
Future scenarios of changes in biodiversity and ecosystems and their potential social implications (A3.3)	4.11
Future changes in climate variability and their impacts on vulnerability (A3.2)	4.11
Spatial and temporal interactions and cascading effects (A2.1)	4.04
Past changes and main patterns in regional and global environmental and social systems (A1.1)	4.04
Prioritizing the management of natural resources (C1.5)	4.03
Identifying, mapping, predicting, managing resource use conflicts (B3.2)	4.03
Bottom 10 priorities	
Predictive models of human threats and diseases related to environmental change (A3.4)	3.23
Mechanisms for addressing market and policy failures (B2.5)	3.18
Measures and metrics for human wellbeing and progress per the UN post-2015 agenda (B1.7)	3.18
Different pathways to decarbonization for different contexts (B3.3)	3.17
Influence of environmental changes on health (A2.9)	3.15
Possible "withdrawal" strategies when limits of adaptation are reached (and their implications) (C1.4)	3.13
Opportunities and risks of new technology (C1.2)	3.12
Patterns and drivers of urbanization; sustainability of urban systems (A2.8)	3.11
Development pathways of cities (B1.3)	3.00
Main drivers of human vulnerability in wetland and coastal areas; factors for improving resilience (A2.7)	2.92

FIGURE 4 Perth III participants' approaches to conducting research in mountain regions.



1. Engage existing contacts in these regions in a rapid review of the literature, in all languages, to obtain a more complete overview of the research output and capacity in these regions.
2. Encourage participation in long-term capacity-building programs for researchers, especially for those early in their careers. These long-term programs should involve both South–South and North–South exchange. Examples include the 14-year "Uplands program" in the mountains of Southeast Asia (Fröhlich et al 2013), the Marie Skłodowska-Curie fellowships (http://ec.europa.eu/research/mariecurieactions/), and the 12-year Swiss-based National Centre of Competence in Research North-South (http://www.north-south.unibe.ch; see also Heim et al 2012). The Global Change System for Analysis, Research and Training (http://start.org/) is another important means for such capacity-building and an existing initiative with which the mountain research community could become more strongly engaged. In addition, regional initiatives such as the University of Central Asia's Mountain Societies Research Institute (www.ucentralasia.org/Research/MSRI) and the International Center for Integrated Mountain Development's Himalayan University Consortium (www.icimod.org/huc) are key to strengthening research capacities.
3. Commit to clearly defined, long-term projects that become axes around which research communities can coalesce. Pathfinders in this regard include the Global Observation Research Initiative in Alpine Environments (GLORIA: http://www.gloria.ac.at/), the Global Network of Mountain Observatories (GNOMO: http://gnomo.ucnrs.org/), the Global Mountain Biodiversity Assessment (GMBA: http://www.gmba.unibe.ch/), and the Mountain Invasion Research Network (MIREN: www.mountaininvasions.org/).

Filling thematic gaps in mountain research

Research that focuses on mountain areas is place-based and benefits from a social–ecological approach (Ostrom 2009). Compared to the 2 previous conferences, the focus of abstracts accepted for Perth III was more evenly spread over social and ecological systems and the links between them. This is not to say that research in every mountain region benefited from a social-ecological approach, but rather that the research community covers the breadth of interests and competences requisite for interdisciplinary science.

If one accepts the Future Earth focal challenges as a useful description of the scope of research needed, the mountain research community has to significantly expand its scope. Currently, it addresses 4 of the 8 focal challenges well (see Table 1). It shows its origins in conservation through its interest in ecosystem health and the wise use of natural resources, particularly with regard to the water-food-energy nexus and adaptive governance. However, it almost entirely fails to address the remaining 4 focal challenges—health, energy, urbanization, and sustainable economies—although these were all ranked as moderately relevant for mountains. In order to address these shortcomings, we recommend the following:

1. Strengthen the mountain research community's ability to apply an integrated systems approach, using the concept and frameworks of social-ecological systems (Binder et al 2013; Greenwood 2013; McGinnis and Ostrom 2014). While there is general agreement within the community regarding the appropriateness of the social–ecological-systems approach, the development of methodologies for applying this approach still requires a concerted effort. In this context, the Mountain Sentinels Initiative (http://mountainsentinels.org) is particularly welcome.
2. Identify and engage with social and policy scientists to expand from biophysical foci into the social and policy realms. One means for doing this may be to support social and policy scientists who are already working in mountains to convene special sessions and discussion panels at their disciplinary conferences.
3. Identify researchers who work on the 4 currently under-represented focal challenges and bring them into the community. This effort should include conferring with the few authors at Perth who did address these themes, reviewing the literature to identify other active scientists, and creating new venues for future exchange.

Embracing transformative research

Although the mountain research community clearly believes that all 9 sub-themes of Future Earth are relevant to mountains (Figure 3), this community is still strongly anchored in disciplinary scientific endeavor, as the majority of scientists continue to focus their research on understanding system processes. Fully embracing transformative research that supports sustainable development will require a systemic perspective (WBGU 2011) and will thus challenge the mountain research community to become more diverse, as recommended above. We also recommend the following:

1. Devote more research to understanding how transformation occurs, how it can best be accomplished, and how unintended consequences can be avoided. This focus implies a better understanding of not only the outcomes of scientific research activities, but also their effective communication and utilization. Two relevant examples are the Hindu Kush–Karakorum–Himalaya (HKKH) Partnership project (Amatya et al 2010) and the C3-Alps project, funded by the EU Alpine Space program (http://www.c3alps.eu/

index.php/en/), which brought together the outcomes of a number of previous projects funded by the program.
2. Increase the focus on transformative research. This implies a new emphasis on transformative research as an alternative for standard ecosystem-services approaches that are typically based on valuing ecosystem goods and services and their trade-offs (Gorddard et al 2016). Again, this implies a need for more effective learning, using examples of both failure and success, to foster the necessary inter- and transdisciplinary research.
3. Develop the community's capacity to promote co-production, which replaces the trope of producer and consumer with a vision of a shared quest in which knowledge production is achieved through the active collaboration of scientists and diverse stakeholders. Future Earth's Knowledge-Action Networks (www.futureearth.org/knowledge-action-networks), for example, provide valuable opportunities for mountain researchers to engage in and promote solution-driven knowledge co-production.
4. Call for funding opportunities that support the inclusion of inter- and transdisciplinary components in funding proposals. For example, this need has been an explicit emphasis in Belmont Forum's recent collaborative research awards on Mountains as Sentinels of Change (Belmont Forum 2016). Drexler et al (2016) and others have also campaigned for more specific calls for proposals for research in mountain areas within the EU's Horizon 2020 program.

Setting up new science frameworks

Around the world, a number of collectives of mountain scientists already exist, both globally (eg the Mountain Research Initiative—http://mri.scnatweb.ch/en/) and at regional scales (eg the Consortium for Integrated Climate Research in Western Mountains—www.fs.fed.us/psw/cirmount/; see also Debarbieux et al 2015). These are important structures within which the recommendations presented above can be taken forward, but other elements of science frameworks also need to be developed or strengthened:

1. *Geographies*—A conscious awareness on the part of researchers as to the meaning, not just the accuracy, of their work in territorial contexts would improve effectiveness. A key set of issues to be considered and addressed relates to the most effective ways to study mountains and inform action when phenomena do not map to jurisdictional boundaries. This is a particular problem in mountain areas, where mountain ridges often define such boundaries (Price 2015). Research that increases the awareness and recognition of upland–lowland interrelations may be particularly effective in conveying the need for mountain research to funding agencies, policy-makers and other relevant decision makers, as these are predominantly based in lowland areas.
2. *Time frames and funding*—These elements link to the previous point as well as the need for capacity-building and transformative research. Research funding is typically awarded in 3- to 5-year cycles and may not mesh well with relevant timescales in governance. As funding agencies are unlikely to change their time frames, it might be more productive to convince universities and other research organizations to create institutions with a long-term commitment to a mountain region—as suggested in the call for "centres of excellence" in *The Future We Want* (United Nations 2012)—and thus create a framework for shorter-term, more focused projects.
3. *Partnerships within the scientific community*—Since Perth III, Future Earth has begun to develop Knowledge-Action Networks (www.futureearth.org/knowledge-action-networks), which present particular opportunities for developing mountain research agendas in partnership. Some networks relate to Future Earth's societal challenges, whereas others are cross-cutting. Of the first group, launched this year, those that present the greatest opportunities in relation to mountain research are probably Water-Energy-Food Nexus, Transformations, Natural Assets, and Sustainable Development Goals. The last of these, in particular, shows a clear link between research and policy agendas. As has been done recently in Europe (Drexler et al 2016), emphasizing this link may be crucial to ensuring that mountain researchers contribute not only to increased knowledge, but also to the achievement of the SDGs Sustainable Development Goals in and beyond mountains.
4. *Partnerships with other mountain constituencies*—In the policy arena, depositing knowledge in the form of reports has been marginally effective in inducing knowledge uptake by policy- or decision-makers. As suggested above, establishing clear links between upland and lowland issues may be particularly effective for communicating the value of sustainable mountain development to policy-makers, as well as for establishing stronger partnerships with other mountain constituencies. As noted at the beginning of this article, the principal documents advocating for sustainable mountain development have emerged from long-term initiatives in which scientists and other mountain stakeholders have worked collaboratively. It is imperative for the mountain research community to strengthen such collaborations with both global structures—such as the Mountain Partnership, Mountain Forum, and World Mountain Forum—and regional institutions, which exist in many parts of the world (Price 2015).

Conclusion

The Perth III conference, like its predecessors, was important not only for exchanging information and strengthening connections within the mountain research community, but also for providing opportunities to assess the state of the art and to propose future directions. The imperatives for transformative research—contributing both to scientific knowledge and to sustainable development in mountain areas and beyond—are clear. This is a challenging process that requires not only an expansion of the mountain research community, but also a shift in science funding and science policy frameworks. Such concerns are currently being tackled at scales beyond the mountains within institutions, such as Future Earth and the Global Change System for Analysis, Research and Training, giving mountain scientists opportunities to create new synergies and play key roles.

ACKNOWLEDGMENT

We would like to thank the members of the Mountain Research Initiative Science Leadership Council for their synthesis work at the conference, all the conference session chairs for their input to the session synthesis blogs, and all the conference participants who responded to our survey. Moreover, we would like to thank Hans Hurni (University of Bern Institute of Geography and Centre for Development and Environment) for organizing the final conference roundtable, which contributed elements to the propositions for "new science frameworks." We also acknowledge thoughtful and constructive feedback on the manuscript from Davnah Payne (Global Mountain Biodiversity Assessment). Financial support by the Swiss Agency for Development and Cooperation enabled the synthesis work of the Perth III conference and Swiss National Science Foundation funding from project number 137989 enabled co-author collaboration.

REFERENCES

Ahlers R, Budds J, Joshi D, Merme V, Zwarteveen M. 2015. Framing hydropower as green energy: Assessing drivers, risks and tensions in the Eastern Himalayas. *Earth System Dynamics* 6:195–204. www.earth-syst-dynam.net/6/195/2015/; accessed on 18 April 2016.

Amatya LK, Cuccillato E, Haack B, Shadie P, Sattar N, Bajracharya B, Shrestha B, Caroli P, Panzeri D, Basani M, Schommer B, Flury B, Manfredi EC, Salerno F. 2010. Improving communication for management of social–ecological systems in high mountain areas. *Mountain Research and Development* 30:69–79. www.bioone.org/doi/abs/10.1659/MRD-JOURNAL-D-09-00084.1; accessed on 7 July 2016.

Ariza C, Maselli D, Kohler T. 2013. *Mountains: Our Life, Our Future: Progress and Perspectives on Sustainable Mountain Development from Rio 1992 to Rio 2012 and Beyond: A Global Synthesis Based on 10 Regional Reports*. Bern, Switzerland: Swiss Agency for Development and Cooperation (SDC) and Centre for Development and Environment.

Becker A, Bugmann H. 2001. *Global Change and Mountain Regions: The Mountain Research Initiative*. International Geosphere-Biosphere Programme (IGBP) Report 49, Global Terrestrial Observing (GTO) System Report 28, International Human Dimensions Programme (IHDP) on Global Environmental Change Report 13. Stockholm, Sweden: IGBP, GTO, IHDP.

Belmont Forum. 2016. *Belmont Forum Announces Collaborative Research Awards for the Recent Call on Mountains as Sentinels of Change*. www.belmontforum.org/announcements/2016/belmont-forum-announces-collaborative-research-awards-recent-call-mountains; accessed on 7 July 2016.

Binder CR, Hinkel J, Bots PWG, Pahl-Wostl C. 2013. Comparison of frameworks for analyzing social–ecological systems. *Ecology and Society* 18: [no page numbers].

Björnsen Gurung A, Becker A, Brun J-J, Bugmann H, Dedieu J-P, Grabherr G, Haeberli W, Hohenwallner D, Körner C, Lotter A, Price M, Raftoyannis Y, Ramakrishnan PS, Schaaf T, Visconti G. 2006. *GLOCHAMORE [Global Change and Mountain Regions: Research Strategy]*. Bern, Switzerland: Mountain Research Initiative, United Nations Educational, Scientific and Cultural Organization—Man and the Biosphere Programme and International Hydrological Programme, and the European Union Framework Programme 6.

Björnsen Gurung A, Borsdorf A, Füreder L, Kienast F, Matt P, Scheidegger C, Schmocker L, Zappa M, Volkart K. 2016. Rethinking pumped storage hydropower in the European Alps. *Mountain Research and Development* 36:222–232. http://www.bioone.org/doi/full/10.1659/MRD-JOURNAL-D-15-00069.1; accessed on 22 August 2016.

Björnsen Gurung A, Wymann von Dach S, Price MF, Aspinell R, Balsiger J, Baron JS, Sharma E, Greenwood G, Kohler T. 2012. Global change and the world's mountains—Research needs and emerging themes for sustainable development. *Mountain Research and Development* 32:47–54.

Debarbieux B, Balsiger J, Djordjevic D, Gaberell S, Rudaz G. 2015. Scientific collectives in region-building processes (reprint). *Environmental Science & Policy* 49:21–31. www.sciencedirect.com/science/article/pii/S146290111500026X; accessed on 6 December 2015.

Debarbieux B, Price MF. 2008. Representing mountains: From local and national to global common good. *Geopolitics* 13:148–168.

Drexler C, Braun V, Christie D, Claramunt B, Dax T, Jelen I, Kanka R, Katsoulakos N, Le Roux G, Price MF, Scheurer T, Weingartner R. 2016. *Mountains for Europe's Future—A Strategic Research Agenda*. Bern, Switzerland: Mountain Research Initiative, Institute of Interdisciplinary Mountain Research.

Fröhlich HL, Schreinemachers P, Stahr K, Clemens G, editors. 2013. *Sustainable Land Use and Rural Development in Southeast Asia: Innovations and Policies for Mountainous Areas*. Heidelberg, Germany: Springer.

Future Earth. 2014a. *Future Earth Strategic Research Agenda 2014*. Paris, France: International Council for Science.

Future Earth. 2014b. *Future Earth 2025 Vision*. Paris, France: Future Earth Interim Secretariat.

GLP [Global Land Project]. 2005. *Science Plan and Implementation Strategy*. International Geosphere—Biosphere Programme Report No 53/International Human Dimensions Programme on Global Environmental Change Report No 19. Stockholm, Sweden: International Geosphere-Biosphere Programme Secretariat.

Gorddard R, Colloff MJ, Wise RM, Ware D, Dunlop M. 2016. Values, rules and knowledge: Adaptation as change in the decision context. *Environmental Science & Policy* 57:60–69. www.sciencedirect.com/science/article/pii/S1462901115301210; accessed on 18 April 2016.

Greenwood GB. 2013. Mountain Research Initiative seeks to break new ground in second decade. *Mountain Research and Development* 33:473–476. www.bioone.org/doi/abs/10.1659/MRD-JOURNAL-D-13-00094.1; accessed on 7 July 2016.

Hastik R, Walzer C, Haida C, Garegnani G, Pezzutto S, Abegg B, Geitner C. 2016. Using the "footprint" approach to examine the potentials and impacts of renewable energy sources in the European Alps. *Mountain Research and Development* 36:130–140. www.bioone.org/doi/full/10.1659/MRD-JOURNAL-D-15-00071.1; accessed on 22 August 2016.

Heim EM, Engelage S, Zimmermann AB, Michel C, Breu T. 2012. *Tracking Alumni Career Paths: Third NCCR North-South Report on Effectiveness*. Dialogue Report No. 42. Bern, Switzerland: National Centre of Competence in Research North-South Dialogue.

ICSU [International Council for Science], ISSC [International Social Science Council]. 2010. *Grand Challenges in Global Sustainability Research: A Systems Approach to Research Priorities for the Decade*. Paris, France: International Council for Science.

Kohler T, Balsiger J, Rudaz G, Debarbieux B, Pratt J, Maselli D. 2015. *Green Economy and Institutions for Sustainable Mountain Development: From Rio 1992 to Rio 2012 and Beyond*. Bern, Switzerland: Centre for Development and Environment, Swiss Agency for Development and Cooperation, University of Geneva, and Geographica Bernensia.

Körner C, Ohsawa M, Spehn E, Berge E, Bugmann H, Groombridge B, Hamilton L, Hofer T, Ives J, Jodha N, Messerli B, Pratt J, Price M, Reasoner M, Rodgers A, Thonell J, Yoshino M. 2005. Mountain systems. *In:* Hassan R, Scholes R, Ash N, editors. *Ecosystems and Human Well-Being: Current State and Trends, Vol.*

1: Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment. Washington, DC: Island Press, pp 681–716.
Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ. 2012. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science* 7:25–43. http://link.springer.com/article/10.1007/s11625-011-0149-x; accessed on 6 July 2016.
Leach M, Scoones I, Stirling A. 2010. *Dynamic Sustainabilities: Technology, Environment, Social Justice*. London, England, and Washington, DC: Earthscan.
McGinnis MD, Ostrom E. 2014. Social–ecological system framework: Initial changes and continuing challenges. *Ecology and Society* 19(2): article 30. www.ecologyandsociety.org/vol19/iss2/art30/; accessed on 7 July 2016.
Messerli B. 2012. Global change and the world's mountains. *Mountain Research and Development* 32:S55–S63. www.bioone.org/doi/full/10.1659/MRD-JOURNAL-D-11-00118.S1; accessed on 8 April 2016.
Miller TR, Wiek A, Sarewitz D, Robinson J, Olsson L, Kriebel D, Loorbach D. 2014. The future of sustainability science: A solutions-oriented research agenda. *Sustainability Science* 9:239–246. http://link.springer.com/article/10.1007/s11625-013-0224-6; accessed on 8 September 2014.
Ostrom E. 2009. A general framework for analyzing sustainability of social–ecological systems. *Science* 325:419–422. http://science.sciencemag.org/content/325/5939/419; accessed on 7 July 2016.
Pohl C, Rist S, Zimmermann A, Fry P, Gurung GS, Schneider F, Speranza CI, Kiteme B, Boillat S, Serrano E, Hirsch Hadorn G, Wiesmann U. 2010. Researchers' roles in knowledge co-production: Experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. *Science and Public Policy* 37:267–281.
Price MF. 2015. Transnational governance in mountain regions: Progress and prospects. *Environmental Science & Policy* 49:95–105. www.sciencedirect.com/science/article/pii/S1462901114001920; accessed on 29 August 2016.
Price MF, Gratzer G, Duguma LA, Kohler T, Maselli D, Romeo R, editors. 2011. *Mountain Forests in a Changing World: Realizing Values, Addressing Challenges*. Rome, Italy: Mountain Partnership Secretariat at the Food and Agriculture Organization of the United Nations (FAO) and the Swiss Agency for Development and Cooperation (SDC).
Raworth K. 2012. Can we live inside the doughnut? Why we need planetary and social boundaries. *Oxfam GB Policy & Practice Blog*. http://policy-practice.oxfam.org.uk/blog/2012/02/can-we-live-inside-the-doughnut-planetary-and-social-boundaries; accessed on 28 September 2012.
Renner R, Schneider F, Hohenwallner D, Kopeinig C, Kruse S, Lienert J, Link S, Muhar S. 2013. Meeting the challenges of transdisciplinary knowledge production for sustainable water governance. *Mountain Research and Development* 33:234–247. www.bioone.org/doi/abs/10.1659/MRD-JOURNAL-D-13-00002.1; accessed on 22 August 2016.
Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Peter K. Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA. 2009. A safe operating space for humanity. *Nature* 461:472–475. www.nature.com/nature/journal/v461/n7263/full/461472a.html; accessed on 11 September 2012.
Romeo R, Vita A, Testolin R, Hofer T, editors. 2015. *Mapping the Vulnerability of Mountain Peoples to Food Insecurity*. Rome, Italy: Food and Agriculture Organization.
Schneider F, Rist S. 2014. Envisioning sustainable water futures in a transdisciplinary learning process: Combining normative, explorative, and participatory scenario approaches. *Sustainability Science* 9:463–481. http://link.springer.com/article/10.1007/s11625-013-0232-6; accessed on 18 February 2014.
United Nations. 1993. *Earth Summit Agenda 21, the United Nations Programme of Action from Rio*. New York, NY: United Nations.
United Nations. 2012. *The Future We Want: Resolution Adopted by the General Assembly on 27 July 2012 (A/RES/66/288)*. http://www.un.org/en/ga/search/view_doc.asp?symbol=%20A/RES/66/288; accessed on 3 October 2016.
United Nations. 2015. *Transforming Our World—The 2030 Agenda for Sustainable Development: Finalised Text for Adoption*. New York, NY: United Nations.
Viviroli D, Dürr HH, Messerli B, Meybeck M, Weingartner R. 2007. Mountains of the world, water towers for humanity: Typology, mapping, and global significance. *Water Resources Research* 43:W07447. http://onlinelibrary.wiley.com/doi/10.1029/2006WR005653/abstract; accessed on 15 April 2016.
WBGU [Wissenschaftlicher Beirat Globale Umweltveränderungen]. 2011. *World in Transition: A Social Contract for Sustainability*. Berlin, Germany: WBGU.
Wuelser G. 2014. Towards adequately framing sustainability goals in research projects: The case of land use studies. *Sustainability Science* 9:263–276. http://link.springer.com/10.1007/s11625-013-0236-2; accessed on 18 April 2016.

Supplemental material

TABLE S1 Detailed ranking of Future Earth research priorities by Perth III participants.

Found at DOI: 10.1659/MRD-JOURNAL-D-16-00094.S1 (175 KB PDF).