The International Mountain Conference, Innsbruck, Austria, September 2019 (IMC2019): A Synthesis with Recommendations for Research

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Source: Mountain Research and Development, 42(1)

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-21-00027.1

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

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The International Mountain Conference, Innsbruck, Austria, September 2019 (IMC2019): A Synthesis with Recommendations for Research

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This paper presents a synthesis of the outcomes of sessions and recommendations for future research in mountain areas from the International Mountain Conference (IMC), held in Innsbruck, Austria, in September 2019. The thematic sections of the paper consider: first, the paleosciences, particularly archaeology; second, (bio)physical systems—the climate system, the cryo- and hydrosphere, and the biosphere—and their relationships with human systems; third, natural hazards and risks; and fourth, demographic and sociocultural trends, globalization (energy and transport networks, tourism, food supplies), policymaking, development, and research. Each section includes key literature relating to its theme, together with recommendations from the respective sessions. The paper concludes with a discussion and conclusions on the process of producing the synthesis, and its value for preparation and synthesis strategies for future conferences.

Keywords: *International Mountain Conference; research; mountain areas.*

Received: *25 March 2021* ***Accepted:*** *7 December 2021*

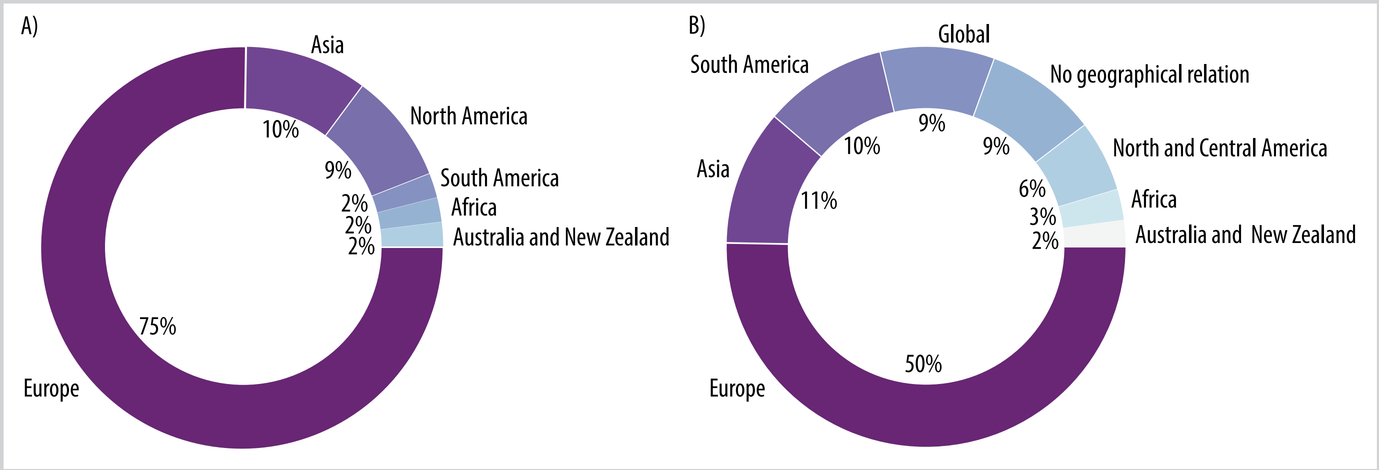
Introduction

This paper presents a synthesis of the sessions of the 2019 International Mountain Conference (IMC), supported by key literature, and recommendations for future research and related activities in mountain areas. The IMC was held in Innsbruck, Austria, on 8–12 September 2019, attracting 526 participants from 52 countries. Its aim was to encourage in-depth cross-disciplinary discussions among natural, spatial, social, and applied scientists toward improved understanding of mountain systems, their responses to stressors, and resilience to change. In this regard, it was intended to build upon the 3 mountain conferences that took place in Perth, Scotland, in 2005, 2010, and 2015, which resulted in the publication of proceedings, with conclusions and recommendations for research (Price 2006), 2 special issues of *Mountain Research and Development* (Price et al 2012; Price, Greenwood, et al 2016), and analyses of contributions with syntheses and recommendations for research (Björnsen Gurung 2006; Björnsen Gurung et al 2012; Gleeson et al 2016).

Conference design and content

IMC2019 had 3 immediate goals: (1) stimulating cross-disciplinary exchange on mountain research questions; (2) initiating or fostering collaboration between different academic disciplines; and (3) publishing summaries of all sessions (workshops and think-tanks). Referring to the conference aim and these goals, the conference organizers issued a call for sessions. After reviewing the submitted abstracts, the Scientific Steering Committee selected 47 sessions. A call for presentations resulted in the submission of more than 700 abstracts, of which 519 were presented at the conference, as oral presentations or posters, by 526 participants from 52 countries, predominantly from Europe (Figure 1A). The presentations provided an overview of research in mountain ranges from around the world; half considered mountains in Europe (Figure 1B). The geographical distribution of both participants and presentations reflects both the location of the conference and financial and bureaucratic constraints (eg obtaining travel permission and visas) for scientists from outside Europe, even though the conference organizers had made considerable efforts to address these for scientists from the global South. The 41 sessions that eventually took place covered a very wide range of topics (see the conference program in Appendix S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00027.1.S1). A rather experimental conference format—with short presentations (apart from the keynotes), posters, and defined time slots for discussions—was designed to support the aims of the conference.

FIGURE 1 Geographical (A) origin of participants and (B) focus of presentations.



Synthesis methodology and structure

This paper was produced by a "synthesis team," consisting of the 4 members of the Local Organizing Committee (all from the University of Innsbruck, Austria), the organizer of the 3 previous conferences in Perth, Scotland, the executive director of the Mountain Research Initiative, and a coauthor of the 2 Perth synthesis papers. Following substantial discussions with session moderators, the team designed a template to obtain consistent information for each session on key findings presented, issues discussed, knowledge gaps to be urgently addressed, and recommendations for future research (see Appendix S2, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00027.1.S1). The session moderators received a manual that included this template prior to the conference, and they were invited to participate in training sessions so that they could efficiently guide discussions toward general questions and conclusions. The resulting summaries, including the recommendations presented in this paper, are available on the conference website, representing the achievement of the third conference goal. They were used as the basis for this synthesis, which was produced as follows. First, the "synthesis team" condensed and synthesized the summaries. The resulting document was then reviewed by the moderators (see Appendix S3, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00027.1.S1), who added key references to substantiate the current knowledge. This final version was prepared by the synthesis team.

This synthesis has 8 thematic sections, organized, to a certain extent, along a continuum from the natural sciences to the social and applied sciences. The first section considers perspectives from the paleosciences, particularly archaeology, a theme that was not considered during the previous 3 conferences in Perth. The following 3 sections emphasize (bio)physical systems—the climate system, the cryo- and hydrosphere, and the biosphere—and their relationships to human systems. The fifth section considers natural hazards and risks. The final 3 sections focus on topics that are primarily within the scope of the social and applied sciences: demographic and sociocultural trends; globalization (energy and transport networks, tourism, food supplies); and policymaking, development, and research. Each section provides an overview of knowledge presented and discussed by the participants in the respective sessions, supported by key references provided by the session chairs as part of the process of producing the synthesis, and presents recommendations for future research that emerged.

The recommendations are structured in terms of future research priorities; the need for new data, information, and analyses; and the need for improved knowledge exchange within science and also among science, practice, and policy. While the categorization is sometimes not clear-cut, it enables a better comparison across the 8 sections. For some sections, there are no recommendations in certain categories.

Figure 2 shows the percentage of abstracts (here 534 because a few contributions to one session were counted in 2 sections) considered in each of the 8 sections.

Prehistoric perspectives on the human use of mountain systems

Detailed studies of past patterns of human migration, settlement, and uses of mountain ecosystems, including

FIGURE 2 The percentage of abstracts considered in each of the 8 sections.

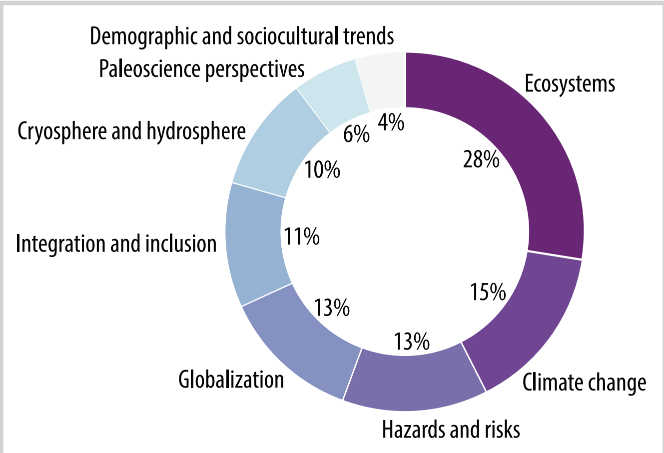


TABLE 1 Prehistoric perspectives on the human use of mountain systems: recommendations for research priorities and related activities.

Category	Recommendations
Research priorities	Increase the number of sites and investigated time slices and apply novel methods to (1) improve understanding of operational sequences and (2) facilitate more accurate reconstructions of human–environmental interactions, including subsistence strategies and genetic and cultural connections between past and present mountain societies.
Data, information, analyses	Include the cultural dimension when modeling past migration routes and human movement in mountain landscapes (eg through parameterization of the sacred and social dimensions of landscapes).
Knowledge exchange	Bring together, in open workshop-based conferences, specialists working in different mountain ranges and focusing on different time periods.

subsistence strategies, are limited to a few mountain areas and time periods. These include, for example, certain subranges of the Rocky Mountains (Paleolithic, Neolithic; Brunswig and Pitblado 2007), the Central Asia Steppe Corridor/Silk Road (Bronze Age; Frachetti 2009), and certain Alpine catchments and passes (various time slices; Bortenschlager and Oeggl 2012; Goldenberg et al 2012). For mountain ranges worldwide, there are large data and knowledge gaps regarding these patterns. These gaps are exacerbated by preservation issues and erosion, and they become larger for successively earlier periods (Chen et al 2019; Ardelean et al 2020). Thus, more robust interpretations are possible for more recent time slices, as data and evidence for relationships among humans, mountains, and migration in older periods are more limited. Nevertheless, recent research suggests that mountain ranges have been attractive living spaces, and even refugia, since Paleolithic times, and that people have been influencing mountain ecosystems since Neolithic times (eg Meyer et al 2009, 2017; Breitenlechner et al 2010; Miehe et al 2014).

Novel analysis techniques (eg sedimentary deoxyribonucleic acid [DNA], stable isotopes) and “big data” are helping to close knowledge gaps (Reindel and Wagner 2009; Grupe et al 2017). In terms of bridging past and present process understanding and enhancing our ability to model modern ecosystems and ecosystem services, the paleosciences can provide valuable insights into natural baseline processes and the time-depth of the human influence on landscape dynamics, ecosystems, and soil development (Briggs et al 2006; Kintigh et al 2014; Johnson 2019).

The recommendations from this section are presented in Table 1.

Understanding and modeling climate change and its impacts in mountain regions in the past, present, and future

The processes and impacts of climate change in mountain regions have been recognized as a global concern in successive reports of the Intergovernmental Panel on Climate Change (IPCC) (eg Hock et al 2019). To assess present and future states and developments, however, an ongoing challenge is that global climate models do not provide outputs that are suitable for assessing impacts in these regions. Regional climate modeling has started to reach 10 km horizontal resolution, and exploratory studies into “convection resolving climate modeling” are reaching horizontal grid spacing of a few kilometers (Schär et al 2020). Models are also increasing in complexity (eg more complex snow modeling, explicit simulation of convection). More data are becoming available (eg Gobiet and Kotlarski 2020) via coordinated projects (such as the Coordinated Regional Downscaling Experiment [CORDEX]; eg Frei et al 2018) and data portals. These developments have led impact-oriented modelers to expect more accurate and reliable, spatially distributed regional climate information. However, in many regions, there are too few weather stations with which to parameterize models (eg Pepin et al 2019), and increased grid resolution does not necessarily mean that modelers’ expectations with respect to accuracy and reliability are fulfilled. Mountain terrain is complex, and a valid theoretical framework of land–atmosphere exchange is lacking (Rotach et al 2014). Thus, both modeling and measurements of key processes of land–atmosphere exchange in mountain terrain (eg turbulence and advection) are challenged by large uncertainties. A particular challenge is that such processes take place at an extremely wide range of scales (Serafin et al 2020).

Concurrently, as numerical weather prediction has evolved to the order of 1 km model grid spacing (eg Chow et al 2019), impact-oriented modelers have started to use model output rather than point observations (climate data, long time series) as their “atmospheric input.” Parallel to the increasing significance of climate models in atmospheric science, numerical (ie environmental) models are increasingly used and important tools in paleoclimate research (eg Goosse et al 2018). For research on past climate evolution, mountain regions are particularly important because they are often characterized by numerous climate archives and preserve data from related proxy sources in a comparatively small area. The modeling of future climates may also be facilitated by the outcomes of recent advances in paleoclimate research. These include, for example, higher-resolution measurements from new devices, the introduction of new proxy sources (eg ancient DNA analyses to link genetic and climate data), more precise radiometric dating techniques with more sophisticated statistical evaluation, and extended data exchange. These will allow the production and analysis of new regional and global datasets.

In assessing impacts of climate change on mountain societies, economies, and politics, 2 particular challenges arise. To facilitate and uncover different ways of knowing, understanding, and responding to climate change, regional and local stakeholders and communities should be involved in the development of regional climate models. This improves model outputs and makes them helpful for specific decision-making processes for diverse actors. However, when

TABLE 2 Climate change and its impacts in mountain regions: recommendations for research-related activities.

Category	Recommendations
Data, information, analyses	Prepare a review paper of the development and use of climate models in mountain environments to (1) guide users on how to deal with the uncertainties of different climate models and (2) summarize the various methods and products for downscaling model output and correcting bias.
	Provide more explicit information sources for climate scenarios and their underlying assumptions.
Knowledge exchange	Develop and implement facilitation skills among scientists undertaking research on the impacts of climate change.
	Integrate local people in research design and model development, in order to build relationships on the ground and address local priorities and perspectives within climate models.
	Include budget in project applications to allow the participation of local citizen scientists, and for researchers to discuss the results of impact studies with the communities where they were undertaken.
	Provide guidance on the interpretation of climate scenarios, especially regarding limitations of climate information inputs and how these relate to information from other sources.

involving regional and local actors, it is important to consider social inequalities and power relations within societies, to avoid the (unintended) reinforcement of these inequalities by providing model outputs that may be misused by powerful actors for their own interests. To ensure that local people's perspectives and priorities are considered in equal dialogue with scientists and to support mutual understanding of actual and potential impacts of climate change, various tools and models can be used. These include facilitation, participatory mapping, photographs, and citizen science (eg Cunliffe and Scaratti 2017).

Recommendations from this section are presented in Table 2. Following these recommendations would stimulate stronger exchanges among climate modelers, impact modelers, and proxy researchers on their needs and opportunities.

A specific set of issues discussed during the conference relates to the need to adapt mountain socioeconomic systems, and particularly agrofood systems, to climate change. While past research has focused on the identification of challenges deriving from climate change and the erosion of traditional knowledge, a shift in emphasis recognizes the need for constructive transitions and societal transformations toward climate and environmental justice, and development of the knowledge on how to achieve them. This includes developing an understanding of power and dependency relations between actors and within food systems, and in multiple interacting collective action arenas. The likelihood that climate change may bring new opportunities should also be recognized. With regard to mountain value chains (going beyond mountain areas), ways to build urban–rural, consumer–producer, and local–global solidarity should be explored.

Mountain cryosphere and hydrosphere/water resources

Mountains are the world's "water towers": They are critically—and increasingly—important for a significant part of the global population (Viviroli et al 2020). In particular, the world's glacier-based high mountain systems, estimated to supply water to 1.9 billion (Immerzeel et al 2020), will be influenced to varying degrees by the ongoing substantial changes occurring in the mountain cryosphere (Hock et al 2019). In this context, the order of uncertainty with regard to future trends in the main components appears to be the following (from most to least): (1) Snow—A particularly uncertain factor is snow–water equivalent, and how climate change might alter atmospheric circulation, as well as the phases and patterns of precipitation. (2) Permafrost—It is uncertain how much mountain permafrost there is and its significance. Mechanisms relating to gas emissions and hazards remain poorly understood and poorly represented in hydrological models of glacierized catchments. In addition, potential impacts on water quality are unclear. (3) Glaciers—Recent efforts have improved understanding on both global (Huss and Hock 2018) and local scales (Mark et al 2017). However, there are critically data-scarce regions (limiting model validation and calibration) and issues with global/regional assessments that might not adequately account for processes or that might be inheriting upstream errors.

For glaciers, while new satellites are providing a significant increase in the number and quality of observations (eg Paul et al 2020), the quality of widely available digital elevation models and discrepancies in acquisition dates of different products remain challenges that limit the potential benefits. While predicting snow patterns may be more challenging than predicting the behavior of mountain glaciers, studies of snow could be underutilizing the potential of satellite radar products. Consequently, there may be benefits in communicating the needs of this field more explicitly to the high-resolution climate modeling community, in order to codevelop products that are meaningful for future snow projections.

Changes in the cryosphere result in impacts on societies (Hock et al 2019). In a changing climate, there is limited understanding of the extent to which hazards may change as a result of changes in glaciers, and also of the hydrological interactions between cryospheric runoff and groundwater (La Frenierre and Mark 2014; Schmieder et al 2018). More broadly, with regard to the hydrosphere, quantitative assessments of the dependencies on mountain water resources—up to the global scale—are becoming available as hydrological models improve (Viviroli et al 2020). However, the models are constrained by limited numbers of observations, and, as model developers mainly have physical

TABLE 3A Mountain cryosphere: recommendations for research priorities and related activities.

Category	Recommendations	
Research priorities	Develop the best possible physically based projections of snow conditions through collaborations between cryosphere scientists and the high-resolution climate modeling community.	Undertake continual, detailed field measurements to improve process understanding, to guide the choice of appropriate snow models, and to understand the role of "complicating" factors, such as interactions of organisms and the cryosphere.
Data, information, analyses	Implement novel approaches (eg machine learning) to improve models of the distribution of discontinuous permafrost.	
	Improve global digital elevation models (DEMs) in order to capitalize on the potential of Sentinel-2 imagery for glacier mapping and evaluation.	
	Increase open sharing of field data to address data shortages and develop and make available open-source models.	

science backgrounds, socially relevant aspects are often inadequately considered. While sociohydrology represents an integrative approach to address challenges of sustainable water management in coupled human–water systems and ecohydrology (Sivapalan et al 2012; Nüsser 2017), tools for integrating hydrological and social science methods and data are still in their infancy. Collaboration and true integration are needed between hydrologists who apply social sciences methods and social scientists who apply hydrological tools, although there has been some recent progress (Pande and Sivapalan 2017).

Expected future changes in climate conditions, as well as the availability of and demand for water in mountain regions, will result in novel stakeholder constellations in water use and lead to new social and legal requirements for water management. Conflicts over the use and management of water resources may arise from many sources (Füreder et al 2018). In relation to water quantity, these include the relative distribution, scarcity, and storage of water in mountain regions and lowlands; the need to balance availability and use for irrigation, hydropower, and other purposes; and changing drought and flood patterns. In relation to water-quality issues, these include the need to reduce water pollution and preserve the remaining near-natural aquatic ecosystems and landscapes; and a need to reduce alterations of ecosystem services. In all of these contexts, there has been a notable shift from engineering for flood protection and hydropower development toward nature-based solutions (eg restoration) (Ruangpan et al 2020)

Recommendations from this section are presented in Table 3A and B.

Mountain ecosystems, biosphere processes, and ecosystem services

Mountain regions are recognized as hotspots of biodiversity (Rahbek et al 2019). For mountain biodiversity in general, recent research has identified species-specific responses to climate change, even among functional groups and close relatives. While models indicate increasing extinction risks, these extinctions have not yet been observed, despite decades of warming and changing land uses in mountain areas. A particular reason is that models are based on

TABLE 3B Mountain hydrosphere and water resources: recommendations for research priorities and knowledge-exchange activities.

Category	Recommendations
Research priorities	Undertake research on hydropower, particularly on its efficiency and relative benefits in terms of minimizing carbon dioxide emissions versus impacts on both ecosystem services (eg biodiversity, water quality) and spiritual meanings for local people.
Knowledge exchange	Promote sociohydrology by: • Developing a common language to facilitate more robust communication between scientists from different disciplinary backgrounds and overcome boundaries between disciplines; • Improving coupling between methodological approaches typical of both social sciences and hydrological sciences; • Translating new mathematical tools into software to provide reliable quantitative predictions useful for decision-makers and other user groups; • Recognizing that not only quantitative, but also qualitative, approaches are necessary to explain past and current challenges in integrated water resources management (IWRM); • Communicating more effectively the motivations of sociohydrology for addressing justice and inequalities, and improving governance and decision-making; and • Identifying relevant experts, stakeholders, and social movements to be involved in minimizing and preventing conflict over water resources, and providing effective means for them to cooperate (often across regional and national boundaries), considering power relations and inequalities in participation processes.

climate databases, which are built from weather station data. Weather station data cannot represent the small-scale mosaic of topography-driven microenvironments. While some habitats may persist, the overall habitat area decreases, which increases the risk of species extinction (Scherrer and Körner 2011; Scherrer et al 2011). This implies that one should not generalize too much from case studies and that research is needed to prioritize those species that should be studied in more detail. Long-term changes in biodiversity are being monitored through the Global Observation Research Initiative in Alpine Environments (GLORIA) (eg Steinbauer et al 2018). More broadly, long-term ecological research platforms have been developing into long-term socioecological research (LTSER) platforms, although the social element is not yet adequately included, and there is scope for more investigation of ecosystem functioning in regions such as the Himalaya and South Africa (Dick et al 2018). Heterogeneity of the data and representativeness of the observational unit are still major issues for such long-term research.

Mountain ecosystems are well adapted to their environment, and even during the winter, the activity of soil microbial communities under snow can be high, though winter processes are still poorly understood and require more research efforts. Mountain ecosystems are highly vulnerable to global changes, and they are particularly affected by changes in climate and land use and their interactions, as suggested by several studies across elevational and land-use gradients (Becker et al 2007; Peters et al 2019). Recent experiments also suggest that mountain ecosystems are highly responsive to precipitation changes. These result in snow-cover changes and seasonal drought, with differential effects on different species and functional groups. For example, slow-growing plant species and their associated fungal-dominated soil microbial communities, which are typical of abandoned grassland, are less affected by drought but also recover more slowly than fast-growing plant species associated with bacterial-dominated soil microbial communities, which are typical of managed mountain grassland (Karlowsky et al 2018).

Mountains are unique because they host the forest–alpine transition. The climatic tree line is one of the few biogeographical boundaries that can be predicted with high confidence because of the overwhelming influence of temperature (Paulsen and Körner 2014). Climate warming is expected to cause a shift of the tree line to higher elevations. However, tree line research networks have shown that very few tree lines have risen only in response to warming (Bader et al 2021), and that tree species differ in their responses to temperature (Oberhuber et al 2020). This indicates complex responses of mountain forest ecosystems to climate change. Forests are, and will also be, affected by elevational range shifts of species within the forest belts (which may be modified by management), altered disturbance regimes, variations in animal browsing, shifts of native pathogens and pests, and the introduction of new pathogens and neobiota. To safeguard these forests, key actions include adjusting their species composition and demographic structures to climate change.

For all mountain ecosystems, management strategies for building resilience at different scales (field, farm, landscape) need to recognize the diversity of management intensities and options, and to take a socioecological approach. Management options must be adapted for different stakeholders (including tourism, agriculture, and environmental protection).

Together with the hydrosystems described in the previous section, mountain ecosystems provide many ecosystem services (ES) to people living both in the mountains and outside them (Grêt-Regamey et al 2012; Schirpke et al 2019; Grêt-Regamey and Weibel 2020). For example, alpine grasslands can be net CO_2 and methane absorbers and provide fodder for cattle and sheep; mosses protect soils from atmospheric extremes; mountain lakes and rivers provide water and both regulating (eg soil humidity) and cultural services (eg aesthetics and recreational sites) (Grizzetti et al 2016); and mountain forests protect against soil erosion, rockfalls, and avalanches, provide timber, and store carbon. Both short-term, often local, disturbances, such as fires, windthrows, or pest outbreaks, and regional long-term influences, such as pollution or eutrophication (including nitrogen deposition and warming-driven acceleration of the nutrient cycle), may affect these ES.

The ES framework, which focuses on the interface between ecosystems and society, not only stimulates interdisciplinary research, but it is also advantageous in building support for environmental conservation and promoting the societal relevance of relatively intact ecosystems (Rüdisser et al 2020). Well-designed ES indicators can be useful tools to facilitate the understanding of highly complex human–environmental systems, though possible trade-offs and conflicts between different ES and different types of users must be recognized (King et al 2015). For estimating ES provision from mountain lakes under future climate scenarios, an alternative approach to temperature recording and extrapolation (eg Thompson et al 2005) is to use lake surface temperature (LST) modeling (eg Matulla et al 2019).

While there is a broad knowledge about ES that can be assessed biophysically (Payne et al 2020), intangible ES, such as most cultural ecosystem services (CES), remain neglected (Schirpke et al 2020). Hence, a common framework to define conflicts and limits related to CES is lacking. This is of special concern because CES, such as outdoor recreation, aesthetic appreciation, and symbolic values, are of great significance in many mountain socioecological systems. This has long been recognized by both mountain and lowland people, for instance, through the designation of national parks since the mid-19th century, even if the concepts of ES and CES have emerged more recently. While these concepts have gained increasing attention among scientists, public awareness remains very limited, and there is little knowledge about past communication of ES in mountains. Yet, the concept offers opportunities to foster cross-sectoral communication among science, business, administration, policymakers, and civil society, as a basis for constructive dialogues, proactive and holistic planning, and the empowerment of diverse stakeholders, especially in the context of climate change (Lavorel et al 2019; Thonicke et al 2020). This is particularly relevant in the context of ES that derive from mountain areas but are of great importance in the lowlands (Schirpke et al 2019). While these connections are often not recognized, some progress is being made (eg Hock et al 2019).

Recommendations from this section are presented in Table 4A, B, and C.

TABLE 4A Mountain biodiversity in general, mountain soils, and mountain grasslands: recommendations for research priorities.

Topic	Recommendations
Mountain biodiversity in general	Undertake experimental studies to identify and disentangle environmental driving forces, and their interactions, across scales from micro to macro.
	Implement multisectoral and/or interdisciplinary (within different fields of ecology) studies in order to gain a more holistic view.
	Ensure long-term monitoring, not only to identify changes but also to calibrate and evaluate species distribution models and contribute to phylogenetic studies and understanding of ecosystem functioning.
Mountain soils	Use environmental gradients to explore soil biodiversity.
	Develop strong multifactor experiments that accurately simulate projected changes in micrometeorological conditions.
	Better integrate soil functional ecology into research networks.
Mountain grasslands	Use experimental manipulations to unravel how different community attributes respond differently to environmental gradients.
	Investigate the effects of climate warming in all seasons, taking a long-term perspective and a focus on climate extremes, to (1) improve understanding of the impact of intensity versus frequency of extremes, (2) identify early warning signals, (3) assess the effects of species composition on resilience, (4) evaluate how species and ecosystems cope with co-occurring extremes and the interactions of press and pulse mechanisms, and (5) understand the mechanisms underlying ecological memory.

Natural hazards and risks

The high variability of climate conditions, steep topography, and areas of intensive human activity in mountain regions make them particularly susceptible to many natural hazards and thus prone to risks of disasters and damage (Stäubli et al 2017). In recent years, new observation technologies have become available to support natural hazards research, including high-resolution hyperspectral, multispectral, microwave, radar, and topographic light detection and ranging (LiDAR) remote sensing from space, air, and the ground. For example, high-definition topography mapping using topographic LiDAR has been used to analyze surface changes (eg Kerle 2013; Lissak et al 2020), and precipitation estimations have been obtained by combined radar and microwave remote sensing (eg Tang et al 2020). However, accurate and comprehensive ground truth data for calibration and validation are not always available.

Earth observations are often connected to process models to simulate and assess different types of hazards. As there are many modeling approaches and model implementations, each requiring a certain set of input parameters, it can be challenging to identify the most appropriate and reliable model and select appropriate input data for parameterization. Running ensembles of models can aid in better understanding of the uncertainties of results. With regard to early warning and protection systems, a further challenge is the realization of real-time monitoring and modeling approaches, given the very short lead time in many cases for issuing reliable alerts (Beven, Almeida et al 2018; Beven, Aspinall et al 2018).

An important concept for better understanding and managing the impacts of hazards on society is the concept of risk. Risk is defined as potential negative consequences expressed as a function of a hazard or multiple hazards (eg a drought or landslides following an earthquake), exposure factors (eg land used for agriculture or deforested areas), and vulnerability factors (eg a lack of irrigation or insufficient knowledge about appropriate land-use systems). Experience has shown that effective risk management requires community-focused and holistic approaches to governance, with transdisciplinary collaboration among scientists, policymakers, and a wide diversity of other stakeholders, taking local ecoknowledge and epistemologies into account

TABLE 4B Mountain forests and mountain lakes: recommendations regarding data, information, and analyses.

Topic	Recommendations
Mountain forests	Focus particularly on less economically developed countries and use participatory approaches, inclusive of local communities and considering social inequalities and power relations at the local level.
	Characterize changes in disturbance regimes (overexploitation, as well as abandonment of appropriated land).
	Identify disturbance factors and their interactions (including climate extremes, fire, pests and pathogens, and human intervention).
	Conduct cost–benefit analyses of forest management regimes for different ES and regions.
Mountain lakes	Use lake surface temperature (LST) modeling to estimate ES from mountain lakes under future climate scenarios and to understand physical, chemical, and biological consequences in both time and space, depending on lake topography, morphometry, and catchment influence.

TABLE 4C Ecosystem services and LTSER platforms: recommendations for research priorities and related activities.

Topic and category	Recommendations
Ecosystem services (ES)	
Research priorities	Conduct research on the aspects of biodiversity that are most important for ecosystem function and therefore the delivery of specific ES.
	Undertake both financial and nonmonetary valuation of groups of ES rather than individual ES to inform investments in ES.
Data, information, analyses	Develop a common framework for the definition of conflicts between cultural ES, disentangle interacting processes, and agree on limits of use or access to mountain ecosystems. Facilitate interdisciplinary approaches and systems thinking, with greater involvement from social scientists and anthropologists.
Knowledge exchange	Increase the involvement of (1) educators and businesses, through the use of relevant examples and contextualized delivery mechanisms, and (2) policymakers, through the use of appropriate indicators of ES.
LTSER platforms	
Data, information, analyses, and knowledge exchange	Increase attention to human aspects through better integration of natural and human/social scientists, through increased trust, respect for different epistemologies, and consideration of differences of scale in datasets.
	Use standardized frameworks to integrate data and modeling and deliver knowledge on the status and trends of ES.

(eg Posch et al 2019). Local communities need to have agency in risk management strategies and to have trust in local authorities; this requires open communication using all possible means. Nevertheless, while general principles and approaches should be developed, they must be applied according to the specificities of local socioeconomic and cultural contexts. One example, in many mountain areas in Europe, is that the aging of mountain populations, coupled with preexisting conditions of contextual vulnerability (eg poverty), is leading to increased exposure to natural hazards and hence to increasing risk—and these trends are likely to continue.

Integrative assessment of climate-related risks requires a profound understanding of mountain-specific risk processes, including climate-related hazards, as well as natural, socioeconomic, and cultural aspects (vulnerability and exposure factors). On the climate side, long-term data in mountains are often scarce, monitoring locations may have changed (leading to changes in underlying time series), and datasets may require reanalysis (Hock et al 2019; Shahgedanova et al 2021; Thornton et al 2021). Future climate projections need mountain-specific downscaling and bias adjustment. Data on vulnerability and exposure are usually limited for both past and current situations; future projections hardly exist. This deficit applies particularly to socioeconomic (eg buildings, population demographics, economic capacities), sociopolitical, and sociocultural aspects. All of these factors increase uncertainties and may have influences on the planning of adaptation measures, land-use planning, and communication.

Ensemble modeling may be useful for considering individual uncertainties and their collective effect on the results, as their associated variations can be included and displayed (Fischer et al 2020). In the current era of climate change, concepts of frequency (eg return periods) and magnitude may need to be reconsidered.

Recommendations from this section are presented in Table 5.

Demographic and sociocultural trends in mountain areas

Significant demographic and economic changes are taking place in mountain areas, linked particularly to migration and urbanization, as well as to changes in natality and longevity (Romeo et al 2015, 2020; Bachmann et al 2019; Perlik 2019). Long-term negative demographic trends, including certain changes in age structure, in many mountain regions have led to a perception that mountains can be characterized as places of weak economic performance, limited economic potential, and therefore significant outmigration. Where they occur, such developments pose challenges to the social and economic fabric of mountain regions. In addition, changes in lifestyles, increasingly flexible working arrangements, and persistent gender inequalities (eg in division of labor, power relations, and access to resources) lead to social transformation and increasing social and cultural diversity (Gämperli Krauer et al 2017). While there is a great variety of individual, local, and regional situations from household to global level, 2 contrasting sets of issues can be highlighted, though research on these issues, and their implications, remains limited and primarily based on case studies, some at national scale (eg Perlik et al 2019).

First, many, particularly rural, mountain areas are experiencing considerable outmigration, implying trends toward aging and the loss of skilled workers in these regions. Such trends have particular relevance for women (Schmitt 2014; Verma et al 2014), who have long been disadvantaged through inequalities in the division of labor, power relations, and access to resources. In such cases, younger women are particularly likely to leave. Furthermore, scholars and stakeholders are often skeptical of the need to link and implement gender and diversity issues (age, qualification, ethnic group, etc) within programs, projects, and measures. To date, the lack of gender awareness, as well as individual

TABLE 5 Natural hazards and risks: recommendations for research priorities and related activities.

Category	Recommendations
Research priorities	Develop improved indicators of vulnerability with regard to the impacts of natural hazards on the built environment and infrastructure, based on detailed and standardized loss and damage data and documentation.
	Undertake research on how risk perception, awareness, and epistemological framings are linked to factors that influence willingness to invest in measures to minimize risk, in order to improve tools and instruments for holistic risk assessment and governance.
Data, information, analyses	Standardize remote-sensing variables, to evaluate the potential and limitations of remote-sensing data and analyses.
	Develop and implement open-data and open-science approaches, for fast innovation of methods and techniques in natural hazard applications.
	Develop approaches to mainstream climate adaptation into existing legal, institutional, or financial tools (eg regional plans, landscape plans, financial incentives), and restructure decision-making processes, in order to integrate populations that are most at risk.
Knowledge exchange	Explore ways to improve collaboration between scientific and nonscientific applications, as well as citizen science approaches, to improve datasets for early warning.
	In climate risk analysis: • Consider the institutional context and power relations; • Involve appropriate stakeholders from the beginning; • Ensure that stakeholders are aware of slow-onset changes, especially where they may have little or no prior experience, or precedent, of associated impacts; and • Within the limits of available information and analyses, discuss the relative costs of adaptation versus climate impacts and risks with decision-makers and other stakeholders.

and institutional resistance, has prevented the effective implementation of gender equality and diversity initiatives in mountain development processes. For these vulnerable living spaces to be resilient, it is important to acknowledge the role of women as drivers for sustainable and social inclusive development in mountain regions (Oedl-Wieser 2020).

Second, other mountain regions are recording the immigration of different groups of people, such as amenity migrants, returnees, or labor migrants, and, more recently, forced migrants (asylum seekers and refugees) (McAreavey and Argent 2018). Such trends can lead to conflicts (eg over land or water resources, but also over cultural values). However, newcomers from various backgrounds can play important roles in social innovation, in demographic regeneration, and in driving local and regional development trajectories toward sustainability (Gretter et al 2017).

Both of these issues reflect the reality that diversity (including gender and migration issues) is a fundamental resource for local development, resilience, and demographic regeneration in mountain regions. Recent research has addressed how demographic change and diversity influence local development in mountain areas, and the forms of governance that may untap social innovation and development potential at the local level (Perlik and Membretti 2018; Tschumi et al 2020).

Recommendations from this section are presented in Table 6.

Mountain regions in a globalized world

Mountain regions are embedded in all aspects of globalization (Debarbieux and Rudaz 2015; Chand and Leimgruber 2016). These include, for example, energy and transport networks, tourism (Scott et al 2012; Pröbstl-Haider et al 2019), and supplies of food (Grocke and McKay 2018; Aubriot et al 2019) and minerals (Franks 2015).

Mountains may be regarded as “ideal” locations for generating renewable energy for the energy transition, but benefits must be fairly shared between mountain and lowland areas, and negative impacts should be compensated, based on principles of environmental justice. Hydropower is well established in mountain areas. These areas are often also suitable for the production of wind energy, solar power (including floating photovoltaic [PV] panels), and bioenergy because of their topographic, meteorological, and biophysical characteristics (Huber et al 2017; Bartlett et al 2018; Kahl et al 2019; Piana 2019). However, remoteness and inaccessibility can hamper the installation of infrastructure and the feasibility for transmission of electricity. The development of renewable resources can redirect energy consumption toward sustainable local development pathways that involve not only energy production, but also energy security, savings (eg through increased efficiency), and storage. Yet, the extent to which this can be done is unclear, and initiatives must consider issues such as fairness and hydro-solidarity (Kellner and Brunner 2021), landscape protection and other environmental concerns, and public preferences (Wissen Hayek et al 2019) and acceptance (Díaz et al 2017; Scherhaufer et al 2018; Müller et al 2020). Public preferences and acceptance change over time (eg Frolova et al 2015; Daus et al 2019) and also depend on the character of the landscapes in which new infrastructure is proposed. The largest controversies relate to balancing renewable energy construction with both environmental and social concerns (eg Llamosas and Sovacool 2021). The largest uncertainties pertain to the interactions of the impacts of climate change on energy production and energy demands (eg for hydropower, changes in precipitation from snow to rain and over time) and changes in demands from heating to cooling

TABLE 6 Demographic and sociocultural trends in mountain areas: recommendations for future research priorities.

Category	Recommendations
Research priorities	Undertake research on the dynamics and key drivers of socioeconomic and demographic sustainability and unsustainability in mountain areas, both urban and rural, around the world.
	Conduct research to strengthen understanding of how climate change, land use, and risks of natural hazards influence demographic changes (particularly in/outmigration flows), and of the overall impacts of these changes on the development of mountain areas.
	Implement research on how access to new information and communication technologies (or lack thereof), social media, the shaping of local identities, and networking for social struggles influence innovation and competitiveness.
	Strengthen understanding of social transformation processes in mountain areas.
	Undertake research to enhance understanding of how the “modern lifestyle” is changing mountain communities.

(Brunner et al 2019; Schaefli et al 2019). Other uncertainties include political and economic boundary conditions (eg subsidies for renewables infrastructure) and the construction of infrastructure to replace carbon- or nuclear-based production.

The topography, climate, and natural hazards of mountain areas lead to higher costs and other challenges for contributing and maintaining transport infrastructure. Land-use planning, suitably located services, and traffic management can make transport systems more efficient and resilient, but their implementation depends on consumer and local community acceptance, business decisions, and regulations. Mobility services (eg car or ride sharing, mobility as a service), and autonomous vehicles may have roles to play, for instance, in complementing public transport in less-populated areas and facilitating commuting, but they are currently mainly being developed for urban areas. However, autonomous vehicles could result in more traffic. These developments need to be considered in the context of the different users of transport systems: both residents and tourists (eg Schlemmer et al 2019).

Adequate transport infrastructure is a prerequisite for tourism, which plays an important, and often increasing, role in many mountain economies (Debarbieux et al 2014), with concomitant risks of overtourism (Dodds and Butler 2019) in some destinations. Consequently, a balance is needed between increasing demands for access to mountain areas for recreation and tourism and the capacity of transport infrastructures and landscapes to absorb visitation pressures, recognizing that one of the principal features is the original attractiveness of these areas, which draws people to visit in the first place (Tischler and Mailer 2014). In the context of climate change, it is important that this is done in ways that are both as energy efficient as possible and take the overall costs of travel to mountain destinations into account (Unger et al 2016). However, while there are uncertainties about both the likely course and impacts of climate change, there is an even greater need to understand uncertainties in the behaviors of mountain residents and the many types of recreational users, and how to change these behaviors (Abegg et al 2019).

The framework conditions (eg political, legislative, socioeconomic) for tourism in different parts of the world differ. It is therefore necessary to consider these conditions before making comparisons or suggesting possible solutions. Nevertheless, to move toward sustainable tourism, participatory community-oriented tourism development processes are desirable (Duglio et al 2019; Khartishvili et al 2020). These need to be harmonized with the activities of destination management organizations that link tourism enterprises to local heritage—both natural and cultural—and to other economic sectors, such as farming and food production, and it is important to recognize the need to adapt to changing conditions (Salukvadze and Backhaus 2020). Events, particularly major ones, need to fit the destination: The stronger the fit between the destination image and the event image, the more both tourists and local people are satisfied (eg Schnitzer et al 2021).

Recommendations from this section are presented in Table 7.

Integration and inclusion in policymaking, development, and research

Mountain areas around the world are set in highly diverse cultural contexts and have different needs for sustainable development (Kohler et al 2015; Price, Gløersen, et al 2016; Wymann von Dach and Ruiz Peyré 2020). Identifying and responding to these needs means more than just improving the design and implementation of policies and addressing the lack of uptake of scientific knowledge in many political and policy processes. These efforts need to recognize that, while framework conditions at higher (geographical) levels are important, external funds and investments are not always consistent with local expectations and potentials. Stakeholders have many divergent views on policy strategies, and these need to be respected in effective participatory processes. Furthermore, it is necessary to work with policy mixes and to recognize that development processes that are initiated locally may be longer lasting.

Inclusive local development of mountain areas involves both rural and urban areas, and it is inextricably linked to that of nearby, and also more distant, lowland areas. Such development needs to take an integrative approach, considering both people and the environments in which they live, and recognizing that local communities are heterogeneous and spatial challenges are particularly complex in mountain areas. Consequently, building trust, mutual listening and understanding, willingness to compromise, minority representation (including gender gaps and different cultural, educational, and social backgrounds), and coproduction of knowledge are essential

TABLE 7 Mountain regions in a globalized world: recommendations for research priorities and related activities.

Category	Recommendations
Research priorities	Implement inter- and transdisciplinary research on energy solidarity, environmental and climate justice, effects of ownership, interconnectedness of supply chains, multipurpose use of limited resources (eg reservoirs), and acceptance of new infrastructure, and how these change over time.
	Conduct research to support "smart" combinations of technologies and users: for example, smart grids, multipurpose systems, linking wind and photovoltaic (PV) systems, and maximizing energy savings, especially in the construction sector.
	Implement research to understand the particular situations and challenges of mountain areas with regard to new mobility services and changes in travel to, from, and within mountain areas, and also within tourist destinations.
	Define tools, procedures, and guidelines to increase the quality of local food products and their markets both within mountain areas, especially tourist destinations, and more widely.
	Define tools, procedures, and guidelines to introduce and boost sustainable practices in the mountain tourism sector at both macro (destination) and micro (accommodation) levels.
Data, information, analyses	Improve knowledge of how farmers and tourism businesses using the same resources can address trade-offs, minimize competition, and improve synergies.
Knowledge exchange	Improve the integration of local people in destination development through participatory decision-making processes and through sharing revenues, thus encouraging stakeholders to look beyond their usual contexts.

starting points for sustainable pathways. Given the widespread lack of integrative modes of governance and excessive government intervention, building partnerships at different levels and between different regions is essential (Kratzer and Ammering 2019; Makino et al 2019). These must be based on cooperation, mutual responsibility, and leadership, and, where necessary, mediators should be used to avoid or minimize conflicts.

Academics can play crucial roles in such processes, building on increasing recognition within the academic community that adaptation and transformation research—on climate change and other issues—requires inter- and transdisciplinary approaches (McDowell and Koppes 2017). Transformative learning/teaching can promote knowledge transfer and foster the abilities of the younger generation (Balsiger et al 2017). While university departments and administrations do not always view such integrative work positively, policymakers and stakeholders perceive it as credible and useful. It also demonstrates the benefits (and challenges) of involving different stakeholders in codeveloping, implementing, and evaluating research projects (Knapp et al 2019). However, scientists often continue to lead in all these phases of research, and such top-down approaches can antagonize and disempower stakeholders. A further role for academics is to develop and deliver education and training programs as part of life-long learning to support sustainable mountain development (Ueno et al 2020).

The United Nations (UN) has addressed the aspects of global wellbeing and sustainable development within separate post-2015 frameworks, such as the 2030 Agenda for Sustainable Development (Sustainable Development Goals), the Sendai Framework for Disaster Risk Reduction, and Climate Change Adaptation (Paris Agreement). However, while the 2030 Agenda refers to mountain regions, they are often not explicitly considered in attempts to implement these agreements, nor is guidance provided to adequately monitor and report on them, though there are some positive exceptions (eg Wymann von Dach et al 2017). The coherent and coordinated implementation of post-2015 UN frameworks, drawing from collective experiences in mountain-specific contexts, is increasingly important. To do so, promising entry points must be identified at local, national, regional, and global level, focusing on mountains as a context in which to simultaneously strengthen mountain people's resilience, reduce their vulnerabilities and exposure to multihazard emerging risks, and enhance sustainable and inclusive livelihoods and wellbeing (United Nations General Assembly 2019).

Furthermore, evidence-informed policymaking and decision-making for the benefit of mountain communities is required, for instance, by reflecting on the Sendai Framework Monitor online monitoring system (UNDRR n.d.) and how this can be coordinated with monitoring and reviewing progress in other post-2015 UN frameworks. Finally, meaningful exchange between scientific and technological communities and the UN system is necessary so that they can collaborate in addressing existing knowledge gaps, thereby fostering the implementation of scientifically sound and consistent sustainable and inclusive approaches.

Recommendations from this section are presented in Table 8.

Discussion and conclusions

Like the syntheses of the conferences in Perth in 2010 and 2015 (Björnsen Gurung et al 2012; Gleeson et al 2016), this present paper represents a synthesis of research on a very wide-ranging set of themes, and it proposes recommendations for research and related activities. However, it is challenging to directly compare these syntheses, given differences in the overall topics of the conferences and the themes of their sessions, and the methodologies used to produce the syntheses. In particular, those from the previous conferences were structured according to the systemic frameworks of international

TABLE 8 Integration and inclusion in policymaking, development, and research: recommendations for research priorities and related activities.

Category	Recommendations
Research priorities, data, information, analyses	Undertake research on local potentials of and opportunities in, rather than the "handicaps" of, mountain regions.
	Assess policies that are designed for, or influence, mountain areas in the context of these complex socioecological systems.
Knowledge exchange	Codevelop transdisciplinary projects with stakeholders, in order to meaningfully integrate their needs.
	Recognize the importance of dialogue and reciprocal enrichment between different forms of knowledge production, giving new value to local and indigenous knowledge.
	Identify, understand, and—as far as possible—ameliorate unequal power dynamics with other stakeholders, including local and regional actors, decision-makers, and project partners.
	Use training events for disciplinary scholars to develop inter- and transdisciplinary skills and understand the necessary terminology to support sustainable mountain development.
	Consider the needs of specific stakeholders when developing education, training, and exchange programs to support sustainable mountain development, and involve them in these programs wherever possible.

scientific programs on global change (the Global Land Project, and Future Earth, respectively) and were cross-disciplinary (eg land systems and sustainability perspectives for the 2010 conference; Future Earth focal challenges and transformative knowledge for the 2015 conference), in contrast to the thematic approach taken at IMC2019. Accordingly, the recommendations differ in terms of their vantage points and levels of aggregation. Nevertheless, a few conclusions can be drawn regarding future synthesis work of mountain conferences, as well as progress achieved and suggestions for directions for mountain research, compared to the Perth conferences in 2010 and 2015.

Acknowledge and overcome bias

In all 3 efforts, preliminary synthesis activities took place during the conferences, with initial conclusions being presented during the final session. However, none of these syntheses represents true "state-of-the-art" of mountain research, as they are all based on a selection of presentations that is geographically uneven with regard to the distribution of both authors and study areas. To a certain extent, in contrast to the 2 previous syntheses, this may be mitigated in the present paper by the inclusion of key references. Nevertheless, it is likely that all of the conclusions are strongly influenced by the perceptions of the authors of papers presented at the conferences—in all cases, primarily from Europe and North America—as well as the conditions in their study areas and themes of study. As at the previous conferences, a further bias may stem from the fact that most of the IMC2019 session moderators, as well as the "synthesis team," were predominantly from countries of the global North. It is notable that both authors and papers from the global South—particularly Africa, but also Latin America and Asia—have been relatively few at all of these conferences. Gleeson et al (2016) suggested ways to address this imbalance, for example, encouraging participation in long-term capacity-building programs, particularly for early career researchers, and committing to long-term research programs that involve researchers from around the world. Future mountain conferences should continue to tap into the worldwide networks of existing initiatives, such as the Mountain Research Initiative (https://mountainresearchinitiative.org/), Geo Mountains (https://geomountains.org/), and the Global Mountain Biodiversity Assessment (GMBA: https://www.gmba.unibe.ch/), to encourage participation by regions that remain underrepresented.

Bring together a systemic sustainability and thematic perspective

The synthesis approach relating to systemic frameworks of the conferences in 2010 and 2015 provided pertinent insights and suggestions at a higher aggregation level. It revealed the disciplinary and multidisciplinary strength of the mountain research communities, and their increasing engagement in transdisciplinary research by interacting with societal partners (Gleeson et al 2016). The strong focus of interdisciplinary and multidisciplinary research on understanding socioecological systems was also confirmed by the work presented at IMC2019. Moreover, research priorities recommended in IMC2019 sessions are partially in line with the Future Earth research priorities, which were ranked as highly relevant for mountain regions (table 2 in Gleeson et al 2016). However, the priorities defined by IMC2019 are formulated more specifically to the mountain context.

Substantial shortcomings were identified in terms of transformative research in 2010 and 2015. Recommendations to address these gaps included effective communication and learning, and development of the capacity of mountain scientists to coproduce knowledge with stakeholders. Such recommendations remain on the agenda proposed by the sessions at IMC2019 (see rows on "Knowledge exchange" in Tables 1–8). However, due to the thematic and more "bottom-up" approach of IMC2019, the call for more transformative research was not raised in such a consolidated way as in 2015. Combining a more systemic with a thematic synthesis approach can both enable overarching prioritization of future research that promotes transformation in mountain regions and be sufficiently specific to address thematic knowledge gaps.

Methodological lessons learned from IMC2019

In retrospect, while the training for session moderators was successful, the output template was too detailed and included certain aspects that proved difficult to understand. In addition, the scientific cultures represented by the sessions and their participants, and the individual dynamics within sessions, were sometimes too diverse to allow easy categorization of session outputs using the matrix in the template. Consequently, the moderators completed it in many different ways, and at various levels of detail.

Nevertheless, moderators did produce summaries for all 41 sessions, and the synthesis team used these as the basis for this synthesis paper. The review by the moderators of the draft synthesis paper and their contribution of recent and relevant references were very valuable for proofing, completing, and underpinning all statements. Overall, these efforts yielded an insightful and substantiated overview of international mountain research as discussed at IMC2019. While this synthesis should not be regarded as comprehensive, it provides valuable orientation and arguments for future mountain research and might help to identify underrepresented regions and their perspectives (Figure 1B) and missing or underrepresented general topics (Figure 2). However, systematic review papers focusing on specific topics (eg on climate modeling, as suggested in Table 2) are still needed to define progress and knowledge gaps in mountain research for sustainable development. In view of the need for more transformative research, the mountain research communities would benefit greatly from including in their review efforts not only academic papers but also knowledge from practice, which is often not presented in peer-reviewed papers (McDowell et al 2021; Vij et al 2021).

Events such as the Perth conferences and IMC2019 aim to discuss and provide an overview of the growing volume of data and information across the disciplines involved in mountain research. They also help to increase cross-disciplinary understanding of mountain systems and delineate knowledge gaps and future directions for mountain research. This synthesis will also assist in developing preparation and synthesis strategies for future conferences, including the forthcoming IMC 2022.

ACKNOWLEDGMENTS

The preparation of this article was a collaborative effort. We would like to thank the following for their contributions to the synthesis effort and earlier versions of this paper: all the contributing session moderators (see Appendix 3, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00027.1.S1); Christian Körner, University of Basel; Aino Kulonen, the Mountain Research Initiative; and Annelies Voordendag, University of Innsbruck. We would also like to thank participants in IMC2019 for their contributions, and the reviewers for their valuable suggestions.

OPEN PEER REVIEW

This article was reviewed by H. Ricardo Grau and Davnah Payne. The peer review process for all MountainAgenda articles is open. In shaping target knowledge, values are explicitly at stake. The open review process offers authors and reviewers the opportunity to engage in a discussion about these values.

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Supplemental material

APPENDIX S1 IMC2019 program.
APPENDIX S2 Template for IMC2019 workshop output.
APPENDIX S3 Alphabetic list of IMC2019 moderators contributing to the paper.

Found at: https://doi.org/10.1659/MRD-JOURNAL-D-21-00027.1.S1