Chapter 3: Adaptation action and research in glaciated mountain systems: Are they enough to meet the challenge of climate change?

3.1 Introduction

Climate change has arrived for glaciated mountain systems, with major reductions in glacier cover, changes in hydrological dynamics, amplified geohazards, and unusual ecological patterns observed across many high mountain areas (Haeberli et al., 2017; Huss et al., 2017; IPCC, 2013; Milner et al., 2017; Steinbauer et al., 2018). These changes portend significant repercussions for the ~915 million people living in mountain areas as well as the socio-ecological relationships that sustain livelihoods in fragile mountain environments (FAO, 2015; Korner and Ohsawa, 2005; Palomo, 2017). However, despite widespread observations of climate-related changes, understanding of how climate change is actually affecting mountain people remains limited (Carey et al., 2017; McDowell et al., 2014). Here we contribute to a small but growing literature on adaptation to climate change in mountain regions, using formal systematic review methods and an integrative theoretical framework to critically evaluate adaptation action and research in light of the challenge posed by climate change in glaciated mountain systems.

This paper focuses on human adaptation while remaining attentive to the broader socio-ecological implications of human responses to climate change. We draw on insights from mountain-focused climate science, human dimensions of climate change research, and socio-ecological resilience literature, reflecting growing recognition that interpreting the effectiveness of adaptation action and research requires engagement with the scientific, human, and socio-ecological dimensions of climate change (McDowell and Koppes, 2017 - Chapter 2). Accordingly, our treatment of adaptation follows the definition proposed by Moser and Ekstrom (2010): “Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities” (p. 22026). This slightly modified version of the traditional IPCC definition is more consistent with our integrative approach to adaptation while still enabling comprehensibility between the paper's analysis and IPCC concepts and reports.

In this study, adaptation ‘action’ and ‘research’ are treated as distinct but related aspects of responding to the challenge of climate change. Adaptation action refers to individual or collective responses to climatic stimuli (Smithers and Smit, 1997). These are the tangible efforts through which climate-related changes are addressed. Adaptation research, in contrast, involves the use of (more or less) formalized methods to evaluate adaptation actions and options. Research generates theoretical and empirically-grounded insights that deepen understanding of both existing adaptation actions and future adaptation possibilities. For these reason, adaptation action and research are both essential elements of meeting the challenge of climate change in glaciated mountain systems.

To date, synthesized knowledge about the status of adaptation action and research in glaciated mountain systems has been limited. The first effort to systematically assess the state of knowledge demonstrated the emergence of limited adaptation action in mountain systems, finding that adaptations were only documented in 40% of countries with alpine glaciation (McDowell et al., 2014). That review focused on evaluating adaptation actions reported in the peer-review literature over a relatively short 10-year period (2003–2013). More recently, Sud et al. (2015) synthesized what is known about adaptation policy and practice in densely populated glacier-fed river basins in the Himalayas while Muccione et al. (2016) evaluated the contribution of scientific knowledge to the development of climate adaptation policies in eight high mountain regions. These reviews have helped to deepen knowledge about adaptation for particular regions and topics, particularly the broader governance and decision-making contexts of adaptation planning. Moreover, recent reviews of mountain-focused climate change vulnerability literature by Carey et al. (2017), Shukla et al. (2017), and Tucker et al. (2015) have helped to reveal the nature of climatic and non-climatic stressors likely to motivate adaptation. Finally, important contributions to understanding adaptation have come from synthesis reports produced outside of academia (e.g. UNEP/GRID Arendal Mountain Adaptation Outlook Series). Notwithstanding these important knowledge synthesis efforts, we still lack the kind of consistent, comparable, and comprehensive information needed to determine if adaptation actions and research are enough to meet the challenge of climate change in glaciated mountain systems. In response, this paper engages with the following research questions:

- What do we know about adaptation action and research in glaciated mountain systems, and are observed efforts enough to meet the challenges of climate-related changes?
- What are the consequences of shortcomings in these efforts, and what changes are needed to more fully meet the challenge of climate change in glaciated mountain systems?

3.2 The challenge of climate change in glaciated mountain systems

In this paper, the 'challenge of climate change' in glaciated mountain systems is defined as having three interwoven components: 1. The nature of observed and projected climate-related changes; 2. The inherently social nature of exposure-sensitivity, adaptation, and vulnerability to climate-related changes; and 3. The potentially cascading effects of human adaptation on broader socio-ecological dynamics. These challenges bring together core themes from fields working on climate change in mountain systems, providing a common-sense framework for conceptualizing the challenge of climate change vis-à-vis adaptation action and research. We examine the nature of each challenge below.

Challenge 1: The high sensitivity of glaciated mountain systems to changes in temperature and precipitation combined with the rate and magnitude of climate change poses a major challenge for adaptation. Globally rising temperatures of close to 1 °C since the pre-industrial period (IPCC, 2013) are being outpaced in many mountain regions by the amplifying effects of elevation-dependent warming (Pepin et al., 2015; Rangwala and Miller, 2012). As a consequence, glaciers are shrinking, permafrost is thawing, and snowlines are rising at historically unprecedented rates (Vaughan et al., 2013; Zemp et al., 2015). Water resources are dramatically altered by these changes, including through alterations to the timing and amount of meltwater runoff generation (Casassa et al., 2009; Huss and Hock, 2018; Pritchard, 2017). Rapidly changing high mountain environments also imply increased hazards and risks for populations and infrastructure surrounding the high mountain cryosphere. For example, glacier retreat is accompanied by formation of potentially dangerous glacial lakes (Zhang et al., 2015). Combined with reduced slope stability due to thawing permafrost and more sediment exposed to heavy precipitation events, far-reaching mass movements can reach tens of kilometers downstream (Allen et al., 2016; Haeberli et al., 2017). Climate change is also alerting the structure and function of high mountain ecosystems by driving phenological changes, upslope migrations, and novel inter and intra-specific species interactions (Jacobsen et al., 2012; Shrestha et al., 2012). The effects of climate change on the physical and biological characteristic of glaciated mountain systems are significant, with trajectories of change implying transformational changes by the end of the century (Huss et al., 2017; IPCC, 2013). The need to understand and address observed and projected biophysical changes without historical precedence is a key challenge posed by climate change in glaciated mountain systems.

Challenge 2: Climate-related changes are mapped onto diverse social, economic, and cultural settings, where characteristics reflect the nexus of specific geographies and socio-political histories in (and beyond) mountain regions (Debarbieux and Rudaz, 2015; Gardner et al., 2013). The significance of such diversity is highlighted in the human dimensions of climate change literature, which emphasizes that the effects of climate-related changes are rarely a direct product of climatic changes (Kelly and Adger, 2000; Ribot, 2010). Instead, socioeconomic and political factors play a key role in shaping differentiated experiences of climate change by influencing exposure-sensitivity, adaptive capacity, and vulnerability (Ford et al., 2006). Exposure-sensitivity links climatic changes to existing social conditions, highlighting both the nature of biophysical changes as well as the differing susceptibility of social actors to be harmed by such changes (Smit and Wandel, 2006). For example, land in flood-prone areas may be inexpensive, leading to a concentration of low-income residents in such areas. These inhabitants are likely to be both exposed and sensitive to flood events. Adaptive capacity refers to the ability to devise and implement adaptations, an ability known to vary greatly among and within populations due to factors such as access to information and financial resources (Engle, 2011). Vulnerability implies a reduction in material or psychological well-being and is experienced when exposed and sensitive populations are not able to adapt effectively to climate related changes (Adger, 2006). A focus on the human dimensions of climate change helps to de-naturalize the impacts of climate change by revealing the social conditions that both necessitate and constrain adaptation, including who is (or is not) adaptable, why, and with what implications (Bassett and Fogelman, 2013). Consequently, the need to recognize, understand, and respond to the inherently social nature of exposure-sensitivity, adaptive capacity, and vulnerability is a key challenge posed by climate change in glaciated mountain systems.

Challenge 3: Socio-ecological resilience literature highlights interdependencies, feedbacks, and tradeoffs between people and ecosystems in times of system change (Berkes et al., 2008; Folke, 2006; Gunderson and Holling, 2002; Walker et al., 2004), suggesting that human adaptations cannot be separated from their socio-ecological setting. This is particularly important in fragile mountain environments, where livelihoods and highland biodiversity are often sustained through delicate socio-ecological relationships (Korner and Ohsawa, 2005). Accordingly, adaptations that only consider the human dimensions of climate change may inadvertently disrupt important socio-ecological interactions, increasing the potential for maladaptation and unintended consequences for people, ecosystems, or entire socio-ecological systems (Barnett and O'Neill, 2010; Folke et al., 2010; Liu et al., 2007). For example, building a large dam downstream of a retreating glacier may reduce some hydrological impacts of climate change, but it will also disrupt environmental flows with potentially adverse effects on downstream ecosystems and aquatic resource users. However, with attentiveness to socioecological dynamics, it may actually be possible to identify and leverage synergies between human well-being, ecosystem services, and biodiversity conservation (Haines-Young and Potschin, 2010). Hence, the need to recognize, understand, and attend to the cascading effects of human adaptation on broader socio-ecological dynamics is another key challenge posed by climate change in glaciated mountain systems.

The stakes in meeting the challenge of climate change in glaciated mountain systems are high. Observed and projected climatic changes are among the most dramatic reported globally (Huss et al., 2017; IPCC, 2013), socio-economic and political marginalization is widespread among mountain populations (Debarbieux and Rudaz, 2015; FAO, 2015), and unique socio-ecological characteristics are linked to the integrity of inherently fragile mountain environments (Korner and Ohsawa, 2005). If adaptation action and research are unable to meet the challenge of climate change, potentially severe impacts can be expected across glaciated mountain systems. Moreover, given that mountains provide ecosystem services to a significant proportion of the global population, (e.g. freshwater, timber, recreation opportunities) (Egan and Price, 2017; Palomo, 2017), failure in adapting to climate change in a sustainable manner is likely to have cascading effects well beyond mountain systems. Such impacts within and beyond mountain regions would represent an affront to internationally recognized commitments to the protection of human well-being and biodiversity conservation, including objectives recently delineated in the Paris Agreement's ‘Global Goal on Adaptation’ (Article 7) and the UN Sustainable Development Goals (SDGs) (UNFCCC, 2015; United Nations, 2015). Thus, failing to meet the challenge of climate change in glaciated mountain systems should be viewed as a global concern. In response, we evaluate the extent to which adaptation action and research are meeting the abovementioned scientific, human, and socio-ecological challenges of climate change in glaciate mountain systems.

3.3 Methods

3.3.1 Research approach

This study used a formal systematic review methodology to characterize adaptation action and research in glaciated mountain systems. The methodology was originally developed in the health sciences to promote standardization and transparency in knowledge synthesis efforts; however, it has also been utilized as a rigorous approach for evaluating climate change adaptation (e.g. Berrang-Ford et al., 2011; Biesbroek et al., 2013; Ford et al., 2014; Lesnikowski et al., 2016; McDowell et al., 2014; Sherman et al., 2016). Systematic reviews are focused assessments of the literature that use pre-defined eligibility criteria for documents and clearly outlined methods to answer specific research questions (Berrang-Ford et al., 2015). They are distinct from other approaches to literature synthesis in their methodological systematization, transparency, and reproducibility (Gough et al., 2012). Furthermore, systematic reviews benefit from widely accepted reporting guidelines (e.g. PRISMA), which increase understanding of review procedures as well as the nature of review results (Moher et al., 2015). This formalization underpins the power of systematic reviews in providing credible information about topics of interest to researchers, decision makers, and the broader public (Ford and Berrang-Ford, 2016). Notwithstanding these strengths, the methodology has only seen limited application in the context of mountain systems.

3.3.2 Research procedures

The data source for this study was information reported in peer-reviewed and grey literature documents published over a 25-year period that we define as the modern era of mountain research and development (June 1992 - December 2017). The beginning of this period is marked by the Rio Earth Summit, which was the first time the global significance of mountains was codified by the international community (see Agenda 21 Chapter 13, United Nations, 1992). Incidentally, the Rio Earth Summit also led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC). As such, our temporal frame captures the concurrent emergence of mountains and climate change as focal points of policy, international aid programs, and research. We limited our analysis to English-language documents.

A search string based on terms related to climate change, adaptation, and glaciers was used to identify potentially relevant peer-reviewed articles catalogued in Web of Science, Scopus, PubMed, and PAIS International. To avoid double counting, books, thesis, and conference papers where not considered as it is typical for adaptations reported in such documents to also appear in peer-reviewed articles. The search of these databases produced 1774 non-duplicate returns. Next, key word searches were conducted in the native search interfaces for 9 pertinent peer-reviewed journals (e.g. Mountain Research and Development). This effort produced 384 additional non-duplicate returns. Finally, backwards/forward citation tracking was carried out for peer-reviewed articles included for full review (details below) using Web of Science. This produced an additional 2559 non-duplicate returns. In total, 4717 unique peer-reviewed articles were considered for this review.

A grey literature search targeted documents published by member organizations of Mountain Partnership, a UN voluntary alliance that is widely regarded as the keystone institution for mountain issues. We focused specifically on documents published by affiliated Intergovernmental Organizations (IGOs) with a global mandate (e.g. United Nations Environment Programme) to balance inherent tradeoffs between systematization (e.g. avoiding selection bias), comprehensiveness (i.e. capturing all potentially relevant grey literature), and tractability (i.e. feasibility of document identification, retrieval, and review). However, this protocol led to the omission of documents by several important regionally focused organizations, including The International Centre for Integrated Mountain Development (ICIMOD) and the Consortium for Sustainable Development of the Andean Ecoregion (CONDESAN), among others. Furthermore, it precluded consideration of documents produced by actors not affiliated with Mountain Partnership, such as mining and energy companies. Key word searches were conducted in the native search interfaces of Mountain Partnership IGOs with a global mandate, leading to 929 non-duplicate returns.

The initial 5646 documents (peer-reviewed + grey literature returns) were imported to the citation management program EndNote X8. An inclusion/exclusion criteria was then used to evaluate the suitability of these documents for inclusion in the study. To be included, documents had to be 1. A peer-reviewed journal article or a grey literature document, 2. Published between 1 June 1992 and 31 December 2017, 3. Written in English, 4. Focused on contemporary human adaptation to experienced or anticipated effects of climate change, and 5. Conducted in or focused on adaptation in glaciated mountain areas. Our definition of glaciated mountain areas was reached through a two-step process. The World Glacier Monitoring Service provided a list of countries with alpine glaciation based on a spatial intersect of the ESRI World Countries Shapefile and the Randolph Glacier Inventory 5.0 (n=45). The Kapos et al. (2000) definition of mountain regions was then used to delineate mountain areas within countries with alpine glaciers. The location of adaptation action and research in potentially relevant documents was cross-checked with our definition of glaciated mountain areas using the Global Mountain Explorer platform and the Global Land Ice Measurements from Space (GLIMS) Viewer.

Document titles, abstracts, and then full texts where reviewed vis-a-vis the inclusion criteria; unsuitable documents were removed at each stage. The majority of documents removed during the inclusion/exclusion process were focused exclusively on glaciology, climatology, organism-level adaptation, climate change impacts, or adaptation action and research outside of glaciated mountain areas. As well, some grey literature documents reported the same program in multiple texts. In such cases, the most comprehensive document was identified and redundant texts were removed. In total, 170 documents were identified for inclusion in the study (Figure 3.1).

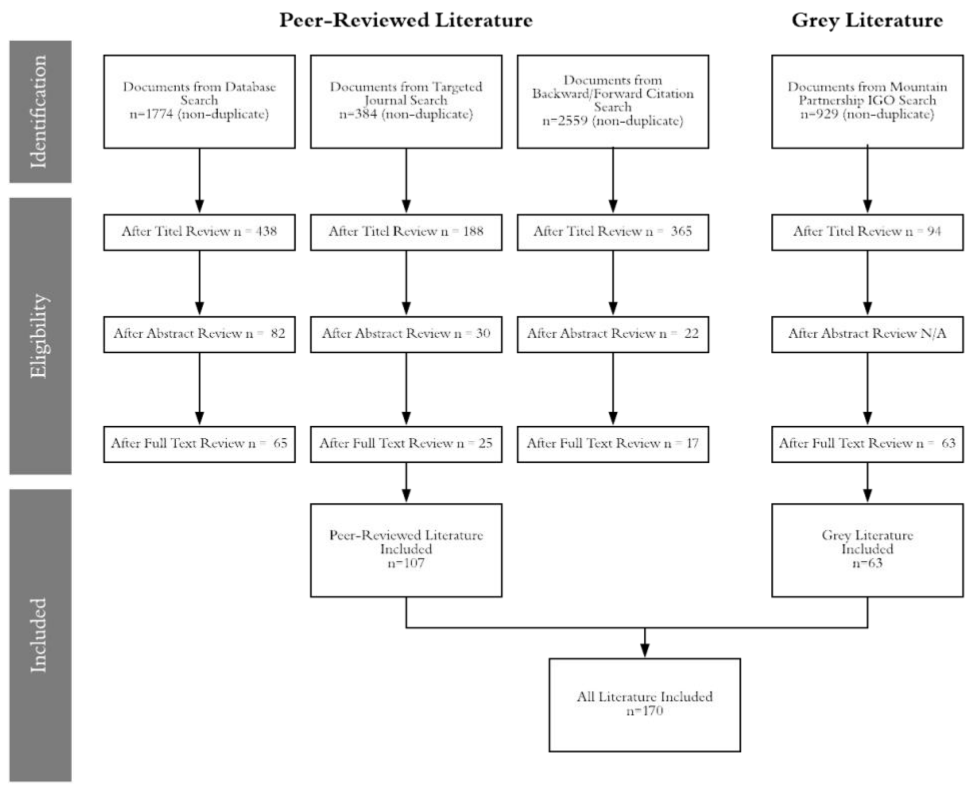

Figure 3.1: Document identification, eligibility, and inclusion progression

Data extraction for the included documents was guided by a questionnaire targeting information about adaptation action and research. The questionnaire was comprised of 30 questions, which focused on bibliometric information, the nature of adaptation research (for peer-reviewed articles only), the characteristics of adaptation actions, and open-ended summaries of adaptation measures (e.g. name of adaptation program). Importantly, because individual documents often reference multiple adaptations, data was extracted for each 'discrete adaptation initiative'. Here, discrete adaptation initiatives are defined as actions that are distinct in their timing, form, intent, or scope. For example, building a barrier to protect a house from flooding and raising a house above flooding levels would represent separate discrete adaptation initiatives.

The questionnaire was accompanied by a codebook defining all key terms and the meaning of possible response options. The codebook supports consistency in the understanding of key concepts among the review team as well as end-users of review results.

Results were calculated for: 1. All peer-reviewed and grey literature documents meeting our inclusion criteria and 2. Peer-reviewed documents that were explicitly framed as mountain-focused adaptation assessments. Some texts in the first set of documents were only incidentally relevant to adaptation and glaciated mountain systems (i.e. met our inclusion criteria but were not necessarily explicitly framed as adaptation or mountain focused). This set of documents helped us generate a broad view of adaptation action in glaciated mountain systems by including information from all texts with relevant content about adaptation in glaciated mountain regions, regardless of how that content was framed. The second set of documents represents a subset of the above documents, those which were peer-reviewed and explicitly framed as assessments of adaptation in mountain regions. We used these documents to evaluate the state of adaptation research in glaciated mountain systems. All steps of the review process were carefully recorded, and can be viewed along with the questionnaire, codebook, and included documents in Appendix A.

3.4 Results

170 documents met the inclusion criteria for this study, including 107 peer-reviewed articles (63%) and 63 grey literature documents (37%). Results in this section summarize insights about adaptation action based on information reported in the full sample. Relevant publication in both the peer-reviewed and grey literature first appeared in 2005; however, only four publications

were available before 2008. Thereafter, the peer-reviewed literature shows a modest increasing trend while the grey literature is more stable through time (Figure 3. 2).

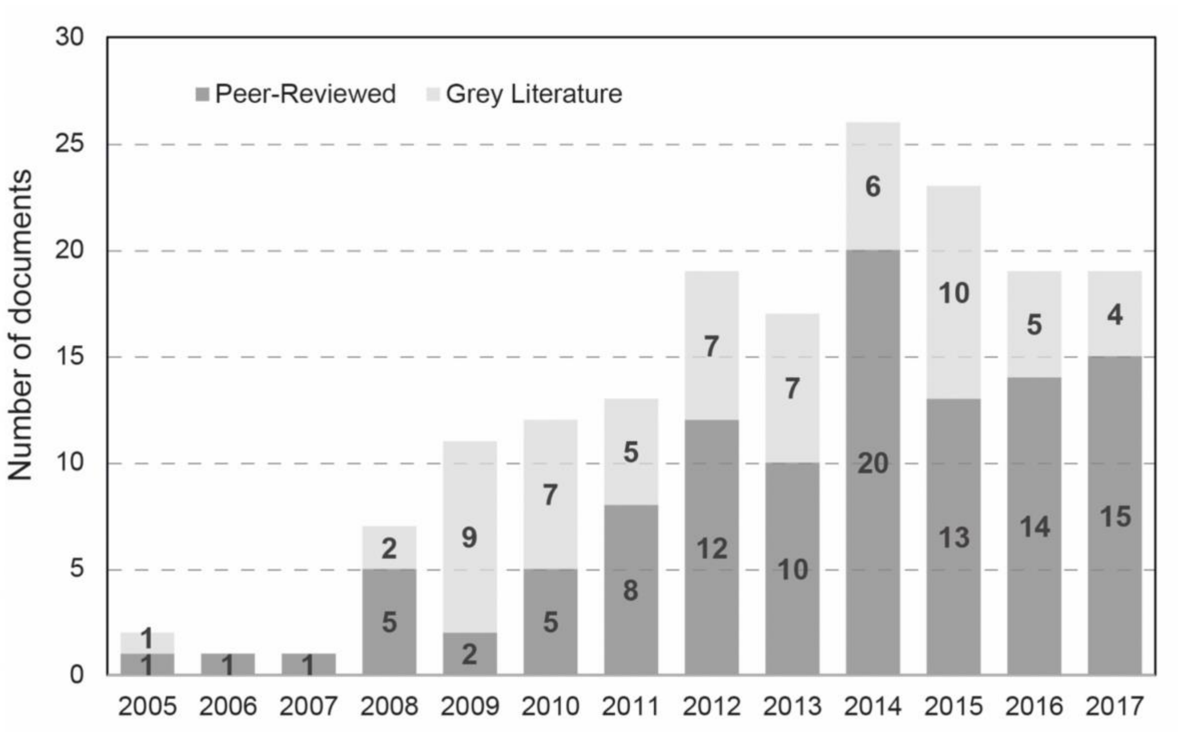

Figure 3.2: Peer-reviewed and grey literature by publication year

Lead authors of peer-reviewed articles represent 28 countries. Authors are most often based in the United States (n=31, 18%) and Switzerland (n=14, 13%); however, the number of lead authors from India (n=7, 7%) and Canada (n=6, 6%) is also above the per country average (per country author $\bar{x}$=4). For the grey literature, documents are most commonly published by institutions headquartered in the United States (n=29, 46%) and Italy (n=16, 25%), reflecting work by World Bank and the FAO, respectively. Most of the literature reviewed was focused on the Himalayas and Andes, with publications focused on Peru (n=34, 20%), Nepal (n=30, 18%), India (n=20, 12%), and Bolivia (n=19, 11%) being the most common.

3.4.1 Mountain-focused adaptation action

A total of 690 discrete adaptation initiatives were documented, with 411 (60%) appearing in peer-reviewed articles and the remaining 279 (40%) reported in the grey literature. These adaptations occur in 36 countries, indicating that we have some level of information about adaptation action in 78% of countries with mountain glaciers. Notwithstanding, the spatial distribution of these initiatives is heavily skewed towards countries in the Himalayas and Andes; namely Nepal (n=157, 23%) Peru (n=99, 14%), India (n=79, 11%), and Bolivia (n=62, 9%) (Figure 3.3). Adaptation actions also tend to be clustered in sub-ranges within these countries, indicating coverage gaps even in 'popular' focal countries. The location and characteristics of documented adaptations can be explored on our interactive map platform (https://mtn-adaptation.shinyapps.io/mcdowell_etal_2018/).

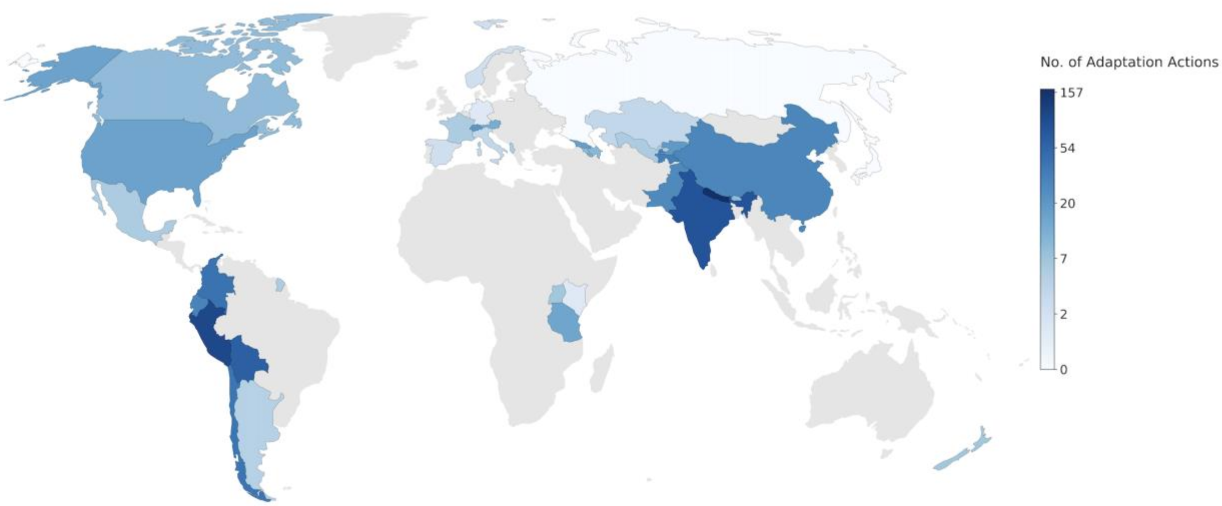

Figure 3.3: Discrete adaptations per country

Map data source: Natural Earth Countries layer. Compiled by Vincent Ricciardi

Observed or anticipated climatic stimuli were the sole motivation for 31% of documented adaptations. Here, the grey literature more frequently reports climatic stimuli as the sole motivation for adaptations (51% vs. 17%), indicative of the high number of reported IGO-led adaptation programs that specifically target climate change. However, consistent with the broader adaptation literature (e.g. Wilbanks and Kates, 2010), the majority of documented adaptations were motivated by combination of climatic and non-climatic stressors (68%). For example, some agriculturalists in the Peruvian Andes have shifted to livestock-based livelihoods in response to climatic impacts on staple crops and evolving market conditions for dairy products (Lennox, 2015). Leading climatic stimuli included experienced or anticipated changes in glacier hydrology (71%), the amount or timing of precipitation (69%), water generation from snow melt (51%), extreme hydrological events (24%), seasonality (11%), and flora and fauna (11%). The most commonly reported non-climatic stimuli for adaptations were economic stress (37%), non-climatic processes of environmental change (e.g. soil erosion, deforestation) (29%), food insecurity (23%), and economic opportunities (e.g. rebranding the loss of glaciers as an opportunity for promoting 'last chance tourism'; Kaenzig et al., 2016) (10%). Population pressure and resource development were infrequently mentioned (≤ 5% each), but nevertheless notable given trajectories of demographic and socio-economic change in some mountain regions (see FAO, 2015).

Most adaptations are made by those involved in the agricultural (38%), water (24%), emergency management (7%), forestry (7%), tourism (6%), and environmental conservation (6%) sectors. Approximately 21% of documented adaptations could not be classified by sector, and included activities such as migration, borrowing money, and adaptation planning activities. Most adaptations are led by community members (33%). However, this finding is driven by the peer-reviewed literature, where 52% of reported adaptations are led by those living in mountain communities (grey literature=6%). IGOs led 23% of reported adaptations, but again the result is driven by a subset of the sample (grey literature=47%, peer-reviewed=7%). National governments led 20% of documented adaptation, a finding that is consistent across literature types. Less common but consistently reported leaders of adaptation initiatives include local governments (7%), regional governments (6%), academic institutions/researchers (6%), and NGOs (5%). As a percentage of adaptations in a given year, community led initiatives have been declining slightly while IGO-led initiatives have been increasing over time. This temporal pattern indicates increasing engagement from the international community in adaptation in glaciated mountain systems. However, we observe modest negative trends in in leadership at all levels of government.

Only 43% of adaptations where characterized as explicitly addressing the needs of vulnerable groups; however, adaptations led by affected populations often implicitly address the needs of vulnerable groups. Economically disadvantaged persons (37%) and indigenous persons (19%) are the most common vulnerable groups mentioned in documented adaptation initiatives. However, adaptations explicitly addressing the needs of other historically vulnerable populations such as women (1%), youth (0%), the elderly (0%), migrants (4%), and persons with chronic illness or disabilities (0%) were conspicuously lacking in the literature reviewed.

The scale of reported adaptations differs markedly in the peer-reviewed and grey literature. In the peer-reviewed literature, the majority of adaptations are focused at smaller scales, with most adaptations occurring at the household (30%) or community (20%) level. In contrast, adaptations reported in the grey literature are more likely to be carried out at larger scales, with 38% taking place at the regional scale. This is an artifact of the predominance of reporting on larger scale IGO-led adaptation programs in the grey literature. Overall, 71% of adaptations occur at the scale of the region, community, or household.

The majority of documented adaptation initiatives were reactionary (74%), representing responses to experienced climatic stimuli. These responses were characterized in the literature as responses to climatic changes, not climate variability. This finding is consistent across the literatures reviewed and suggest that socially-relevant climate-related changes are already manifesting in glaciated mountain systems. Only 21% of documented adaptations were devised in anticipation of future climatic stresses or opportunities. Most adaptations were behavioral in nature (27%), including changes in the structure and nature of farming systems (Aase et al., 2013) and rural to urban migration (FAO, 2012). Other adaptations were based on the generation of knowledge for adaptation action (19%), the creation or revision of regulations (15%), the development or implementation of technologies (15%), or the creation or modification of infrastructure (13%). Behavioral adaptations were the most commonly reported form of adaptation in the peer-reviewed literature (34%) while regulatory adaptations were most common in the grey literature (27%).

The majority of documented adaptations were autonomous (45%), occurring without guidance from a formal adaptation plan, strategy, framework, or policy. While autonomous adaptations can be indicative of the high adaptive capacity of mountain populations (Ingty, 2017), in many cases they are the result of a paucity of relevant social safety nets (e.g. Gentle and Maraseni, 2012). Here, the fact that 42% of autonomous adaptations (19% of sample) were classified as ‘coping’—unplanned and unstrategic responses focused on maintaining functioning in the short-term—is indicative of ongoing exclusion from relevant services. Unfortunately, as a percentage of adaptations in a given year, the trend for coping has been modestly increasing over time. Coping was most commonly documented in the peer-reviewed literature (26%), as the grey literature tends to report more on planned adaptation actions. Thirty-seven percent of adaptations represented formal standalone adaptation programs. Only 11% of documented adaptations were mainstreamed into existing programs, and we see no progress in increasing the proportion of mainstreamed adaptations over time. Standalone and mainstreamed initiatives were most commonly reported in the grey literature (46% and 22%, respectively). In terms of timing, most adaptations represent groundwork—preparatory activities to devise adaptation responses (34%). A further 16% of adaptations were fully implemented and on-going while 12% had been initiated but were not yet fully implemented. Only 3% of reported adaptations had been fully implemented and completed. As a percentage of adaptations in a given year, groundwork is declining over time while partially implemented, implemented and on-going, and completed adaptation initiates all show increasing trends. However, to date, the formal evaluation of adaptations is extremely limited (1%), consistent with findings in the broader adaptation tracking literature (e.g. Ford et al., 2014).

The implications of adaptation were only discussed in 34% of the actions reviewed (groundwork initiatives, n=238, were excluded from calculation). The most commonly reported implications were harm reduction (24%) and access to new opportunities (9%), positive effects that indicate progress in meeting the basic objectives of climate change adaptation. However, maladaptation was noted, too, both social (6%) and ecological (3%) in nature. For example, seasonal migration driven by the nexus of poverty and climate change may be resulting in land abandonment and reduced food security in the highlands of Nepal, especially among already marginalized households (Gautam, 2017). As well, increased pesticides use to address the impacts of unusual temperatures on potato production in the highlands of Peru is suspected of impacting water quality and adversely affecting Andean frog populations (Postigo, 2014). Engagement with the distribution of 'winners' and 'losers' of adaptation actions (0%) was notably absent in the documents reviewed as was evidence of transformative interventions (0%). We see little change in reporting on the implications of adaptation over time (as a percentage of total adaptations per year), a concerning finding given increasing recognition of the need to understand the socio-ecological effects of adaptation actions.

3.4.2 Mountain-focused adaptation research

Of 107 peer-reviewed documents reviewed, only 41 (38%) were explicitly framed as mountain-focused adaptation assessments. These 41 articles are the basis of our results about mountain-focused adaptation research.

Research that is explicitly focused on adaptation in glaciated mountain systems is limited. Such work first appears in 2006, and there are no more than 2 publications per year until 2012 (Figure 3.4). Lead authors represent 16 countries, but the majority are based in the United States (n=16, 39%) and Switzerland (n=8, 20%). Mountain-focused adaptation research has been carried out in 46% (n=21) of countries with alpine glaciers. Assessments focused on mountain systems in Peru (n=11, 24%), India (n=9, 20%), Nepal (n=8, 17%), and Switzerland (n=5, 11%) are most common, but the absolute number of studies is low for all regions. In total, 188 discrete adaptation initiatives were documented in the mountain-focused adaptation research reviewed; 86% of these actions take place in the Andes and Himalayas. Information about these adaptation actions is embedded in the results presented above. Here, we focus specifically on the characteristics of mountain-focused adaptation research.

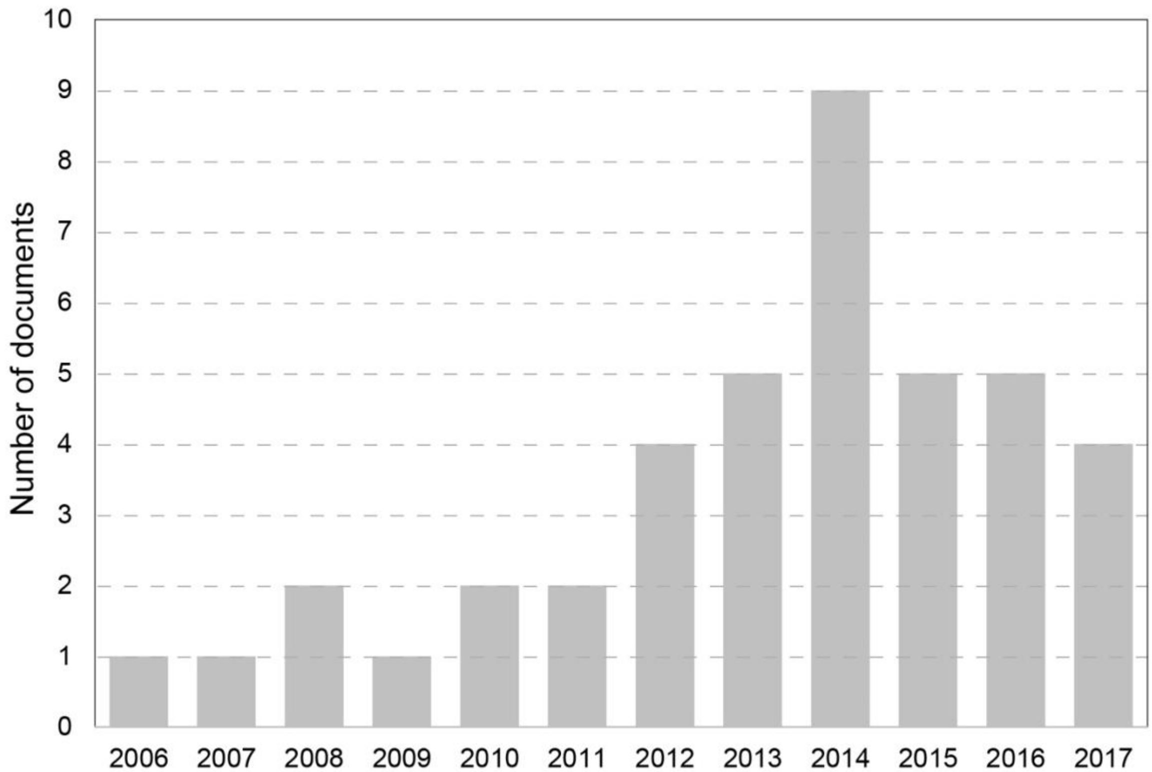

Figure 3.4: Mountain focused adaptation research by publication year

The most common analytical scale of mountain-focused adaptation research is a single region (61%) (e.g. Cordillera Blanca). Analyses of single communities (5%), multiple communities (12%), multiple regions within one mountain range (7%), and multiple mountain ranges (7%) are less common. Methodologically, community-based methods are most common

(68%), reflecting recognition that insights from mountain residents are essential for understanding of lived experiences of climate change. Interestingly, 63% of assessments were participatory, although this classification was applied to all projects that involved any non-academic stakeholders in research design or assessment (e.g. community members, NGOs, government officials). Other common methods involved modelling projections of climate-related biophysical changes (24%) and textual analysis/policy assessment (32%). Methods based on modelling projections of social change (5%), spatial and temporal analogues (2% and 5%, respectively), longitudinal study design (2%), and adaptation scenarios/pathways (0%) were limited or lacking in the literature reviewed. Furthermore, although not quantified, evidence of comparative research approaches and cross-scale analyses was limited. We see little evidence of methodological diversification over time.

In terms of content, only 32% of the documents reviewed engaged substantively with the physical science basis of climate-related changes (e.g. detailed assessment of climate-related changes to watershed-specific hydrological dynamics). Instead, most documents relied on basic information and assumptions about the nature of climate change for the region of focus. Somewhat better, 51% of documents reviewed engaged substantively with the human dimensions of adaptation (e.g. how socioeconomic and political factors constrain or enable adaptation). The other half of documents reviewed tended to emphasize biophysical changes and technocratic approaches to adaptation. Nearly two-thirds of the documents reviewed (63%) engaged substantively with the socio-ecological dimensions of adaptation, but few invoked concepts from the socio-ecological resilience literature *per se*. Instead, these publications tend to provide informal, descriptive examinations of relationships between mountain people and environment in times of change. As a proportion of adaptation studies in a given year, research with a substantive focus on climate science is declining slightly, studies exhibiting nuanced treatment of the human dimensions of climate change are increasing modestly, and assessments meaningfully engaging with human-environment dynamics are stable over time. McDowell and Koppes (2017 – Chapter 2) have defined robust mountain-focused adaptation research as work that engages substantively with all three of the topics discussed here; only 12% of the studies reviewed meet this benchmark.

Some mountain-focused adaptation research engages with concepts from the broader global environmental change literature. Substantive engagement with the concepts of vulnerability (24%), governance (12%), and disaster risk reduction (7%) is most common. However, engagement with resilience (5%), transformation (5%), and sustainable development (5%) is very limited, highlighting an important difference between mountain-focused adaptation research and contemporary adaptation literature more generally. Engagement with all such concepts is scarce before 2012.

3.5 Discussion

Our review of the literature reveals a growing focus on adaptation action and research in mountain systems, but also highlights several shortcomings in applied and academic work on responses to climate change. In view of these findings, are existing efforts enough to meet the interwoven scientific, human, and socio-ecological challenges of climate change in glaciated mountain systems?

3.5.1 Meeting the challenge—adaptation action

The biophysical drivers motivating documented adaptations are generally consistent with observed climate-related changes in glaciated mountain systems; namely, hydrological changes related to the degradation of the high mountain cryosphere. However, the predominance of autonomous adaptations (and coping) suggests that the majority of adaptations are not underpinned by scientific information about changing mountain systems. Moreover, the preponderance of reactionary adaptations indicates that most adaptations are tailored to the characteristics of experienced climatic stimuli, not the nature of future climatic changes. The expected magnitude of future changes and growing evidence of non-linear dynamics such as peak water raise serious concerns about the long-term viability of many adaptations documented in this study. To ensure that social responses are commensurate with trajectories of climate change in mountain systems, our results suggest that efforts should be made to increase engagement with available scientific information in the development of adaptation actions. At the same time, adaptation planners should continue to seek out and integrate observations from stakeholders whose familiarity with local environments can complement scientific assessments of current climatic changes (Quincey et al., 2018). Finally, when planning adaptations, it is important to recognize that information about climatic changes is important but not sufficient for the enaction of effective adaptations.

The human dimensions of climate change featured in many documented adaptations. For example, nearly 70% of adaptations were motivated by a combination of climatic and non-climatic stressors, highlighting the importance of social factors such as marginalization and economic opportunities in influencing adaptation actions. Nevertheless, documented adaptations also revealed many shortcomings in addressing the human dimensions of climate change. For instance, the abovementioned predominance of autonomous and reactionary adaptations suggests that adaptation support such as that provided governmental and non-governmental actors may not be keeping pace with need in glaciated mountain systems (in some instances autonomous adaptations may be indicative of highly resilient mountain communities acting without the need or desire for external support). Moreover, the needs of women were only minimally addressed in documented adaptations, consistent with gender biases highlighted in the Thimphu Declaration (2002) for mountain women. Likewise, modest engagement with the vulnerability of indigenous peoples is inconsistent with the fact that many indigenous people live in mountain areas (FAO, 2015). In addition, few interventions were explicit about the role of adaptations in reinforcing, rearranging, or altering dominant social structures (see Eriksen et al., 2015). Here, the lack of transformative adaptations highlights the relatively conservative nature of existing adaptation efforts in glaciated mountain systems (see Bassett and Fogelman, 2013; Ribot, 2011). Our results suggest a need for more resolute engagement with the broader political economy of adaptation in adaptation planning, including through increased attention to the causes and consequences of differential vulnerability as well as the potential of transformative adaptations in reducing the exposure-sensitivity and increasing adaptive capacity. Progress in these areas is predicated on inclusive, open-minded, and fair adaptation planning processes.

As mentioned in Section 3.4.2, nearly two-thirds of the mountain-focused research reviewed engaged substantively with nature or relationships between mountain people and mountain environments. However, the adaptations reviewed showed little evidence of explicit engagement with socio-ecological interdependencies, feedbacks, and trade-offs in the context of climate change adaptation. For example, the implications of adaptation were only discussed in about a third of documented adaptations, with only 13 documents noting any consequences relevant to mountain ecosystems. However, tacit engagement with socio-ecological dynamics in adaptations is probably higher given the sectors adapting (e.g. agriculture, water management) as well as the fact that most adaptations are led by mountain residents familiar with local environments. Nevertheless, our results suggest that—to avoid maladaptation and devise sustainable adaptations—there is a need for more explicit engagement with how human adaptations influence and are influenced by high mountain socio-ecological dynamics. Developing a reasonable understanding of such entangled dynamics will require the integration of insights from scientific studies and local knowledge holders.

Notwithstanding the limitations outlined above, we observed many laudable adaptation initiatives, ranging from local-scale autonomous efforts to large-scale multi-agency programs. For example, local stakeholders in Ladakh, India, have built artificial glaciers and 'ice stupas' that help augment changes in dry season glacial meltwater generation (Clouse, 2017); the instillation of early warning system to protect tourists and downstream communities from potential GLOFs in the Swiss Alps (Haeberli et al., 2016); and IGO-led Ecosystem-Based Adaptation projects in Nepal, Peru, and Uganda have made progress in addressing the socio-ecological dimensions of climate change (UNEP et al., 2015). Such efforts are an essential part of protecting human well-being; safeguarding ecological integrity; and improving opportunities for safe, healthy, and self-determined lives in mountain areas. That is, in meeting the challenge of climate change in glaciated mountain systems. Notably, we also observed that adaptation actions are taking place in more countries than documented in the McDowell et al. (2014) systematic review (n=36 vs n=19).

Although this increase is partially related to the longer time frame evaluated in this study and the inclusion of select grey literature, expanded geographical coverage is also explained by the growth of adaptation efforts since the McDowell et al. (2014) review.

3.5.2 Meeting the challenge—adaptation research

Only one third of the mountain-focused adaptation research reviewed engaged substantively with nuanced, scale-appropriate scientific information about climate-related changes. The more commonly observed reliance on high-level information about the nature of climate change increases the likelihood that adaptation assessments are informed by contextually inaccurate information. For example, many studies characterize local scale processes of change by extending global and regional-scale information from IPCC Assessment Reports to specific locales. Data scarcity—an important reason for limited consideration of scale-appropriate climate information (Salzmann et al., 2014)—necessitates certain assumptions about down-scalability. However, this carries the risk of mischaracterizing local-level climatic exposures and thus adaptation recommendations that target inapplicable processes of change. On the other hand, the high proportion of studies using participatory methods suggests that credible information about current climate-related changes is being incorporated through consultation with local stakeholders. As well, several studies that did engage with detailed scientific information were components of groundwork initiatives (e.g. Byers et al., 2014). Such adaptation research provides a mechanism for delivering scientific information to local communities and decision makers, a key need for the development of planned adaptations targeting future climatic changes. Thus, while the majority of mountain-focused adaptation research may not be meeting the scientific challenge of climate change in a strict sense, it does exhibit a reasonably high degree of engagement with relevant knowledge holders/systems. On balance, our results indicate that mountain-focused adaptation research should strive for deeper engagement with nuanced, scale-appropriate assessments of current and projected climatic changes. Here, adaptation researchers may need to be more active in signaling information needs to colleagues in the natural sciences. Mountain-focused adaptation research should also continue to foster knowledge sharing between adaptation researchers and other stakeholders possessing complimentary knowledge about climate-related changes in glaciated mountain systems (Quincey et al., 2018).

About half of the mountain-focused adaptation research exhibited substantial engagement with the human dimensions of climate change. In these studies, the predominance of community-based and participatory methods as well as regional and sub-regional scale analyses illustrates recognition of the inherently social and place-specific nature of exposure-sensitivity, adaptive capacity, and vulnerability. However, many studies continue to conceptualize the effects of climate-related changes as direct products of climatic changes *per se*, a framing that naturalizes experiences of climate change by obscuring the social conditions that shape (differentiated) vulnerability and adaptability. We also observed minimal engagement with other literatures that are well positioned to augment understanding of human adaptation in glaciated mountain systems; namely, social vulnerability, socio-ecological resilience, environmental governance, and sustainable development. This limits the theoretical and analytical tools available for understanding lived experiences of climate change. Moreover, the lack of engagement with sustainable development represents a missed opportunity to connect adaptation with the predominant ‘sustainable mountain development’ paradigm (Debarbieux and Rudaz, 2015; Rudaz, 2011). Finally, we observed little comparative research, multi-scale analyses, forward-looking scenario planning efforts, or longitudinal studies. These methodological limitations constrain understanding of adaptation across both space and time. In view of these findings, our results suggest that mountain-focused adaptation research should increase its engagement with the human dimensions of climate change, with a goal of moving away from environmentally deterministic narratives about vulnerability and adaptation. It will also be important to expand the repertoire of theoretical, analytical, and methodological tools used in adaptation assessments to enrich understanding of adaptation in mountain systems and to contribute to contemporary debates in mountain research and policy.

Nearly two-thirds of the mountain-focused adaptation research engaged substantively with the socio-ecological dimensions of adaptation. Many of these studies included insightful analyses of the embedded nature of mountain people in highland environments based on literature reviews, researcher observations, and insights from local knowledge holders (e.g. Carey et al., 2012). However, very few actually drew on theoretical, analytical, and methodological approaches used in the socio-ecological resilience literature (a notable exception being increasing engagement with ecosystem services). Consequently, we observed few explicit assessments of socio-ecological interdependencies, feedbacks, and trade-offs in the context of adaptation to climatic stressors. Likewise, few assessments discussed maladaptation or leverage points for steering adaptations towards more sustainable outcomes. Here, a lack of systems modelling and scenario analysis (both participatory and researcher led) was notable, as these tools can greatly increase the ability to identify consequential socio-ecological dynamics. Given our results, it is apparent that future mountain-focused adaptation research should more explicitly consider how human adaptations influence and are influenced by socio-ecological dynamics in glaciated mountain systems.

Notwithstanding the limitations outlined above, we observed many praiseworthy adaptation assessments, for instance the integration of scientific and local perspectives in understanding adaptation to climate extremes in the Chenab Basin of the Indian Himalaya (Kaul and Thornton, 2014); a critical evaluation of the limits of existing adaptation efforts in overcoming structural determinants of vulnerability in communities on Mount Kilimanjaro in Tanzania (Holler, 2014); an evaluation of how adaptations to hydrological change in the Andes can reinforce, magnify, or correct long-standing hydro-social disparities (Mills-Novoa et al., 2017); and the utilization of a socio-environmental framework for identifying factors that facilitate and impede glacier hazard management in Peru's Cordillera Blanca (Carey et al., 2012). Such efforts are an essential in helping to reveal the suite of scientific, human, and socio-ecological factors relevant to understanding and supporting socially and ecologically tenable responses to climate change. Significantly, however, no research has been conducted in 54% of countries with glaciated mountain ranges, and what research has been carried out is concentrated in the Andes and Himalayas. There are many opportunities for creative and impactful mountain-focused adaptation research in the years ahead.

3.5.3 Meeting the challenge—synthesis and outlook

Are adaptation actions and research meeting the challenges of climate change in glaciated mountain systems? Our results show that progress is certainly being made, with many discrete adaptation initiatives and a growing number of adaptation assessments documented in our review. Furthermore, adaptation actions are now being carried out in the majority of countries with glaciated mountain ranges, representing the closing of a major gap identified in McDowell et al. (2014). Despite these encouraging results, we cannot say that actions and research are meeting the challenges of climate change. As detailed above, important shortcomings were documented with respect to the scientific, human, and socio-ecological challenges of climate change in glaciated mountain systems. Moreover, evidence of engagement with the interwoven nature of these challenges remains elusive, with most actions and assessments being focused on only one or two challenge areas. Finally, although the number of countries with adaptation actions and assessments is growing, the majority of work is concentrated in the Himalayas and Andes.

The Paris Agreement's 'Global Goal on Adaptation' as well as the SDGs such as Goal 13 (Climate Action) have outlined ambitious objectives for improving human well-being and safeguarding ecological integrity in the face of profound global changes. Given the social and ecological characteristics of mountain systems, the shortcomings documented here represent particularly salient barriers to progress on these worthy agreements. To remedy this situation, steps must be taken to ensure that future adaptation action and research is informed by detailed scientific information, underpinned by knowledge of the social factors that condition lived experiences of climate change, and attentive to interdependencies between people and ecosystems (Table 3.1).

Table 3.1: Recommendations for adaptation action and research	
Challenge 1: Scientific dimensions of climate change	
Action	➢ Increase the integration of scientific information in adaptation planning processes ➢ Complement scientific assessments with observations from mountain residents familiar with local environments ➢ Acknowledge that detailed information about climate-related changes is important but not sufficient for effective adaptations
Research	➢ Strive for deeper engagement with nuanced, scale-appropriate assessments of current and projected climatic changes ➢ Clarify information needs for colleagues in the natural sciences ➢ Foster knowledge sharing between adaptation researchers and other stakeholders with knowledge about climate-related changes
Challenge 2: Human dimensions of climate change	
Action	➢ Recognize the broader political economy of adaptation when planning adaptations ➢ Aim to address the causes and consequences of differential vulnerability, including through transformative adaptations ➢ Ensure that adaptation planning processes are inclusive, open-minded, and fair
Research	➢ Increase engagement with the human dimensions of climate change ➢ Aim to move away from environmentally deterministic narratives about vulnerability and adaptation through place-based assessments that involve mountain populations ➢ Expand repertoire of theoretical, analytical, and methodological tools used in adaptation assessments
Challenge 3: Socio-ecological dimensions of climate change	
Action	➢ Encourage adaptation planning processes that consider how human adaptations influence and are influenced by socio-ecological dynamics ➢ Utilize understanding of socio-ecological dynamics to avoid maladaptation and to devise more sustainable adaptations ➢ Draw on complementarities between local knowledge and scientific studies when characterizing system dynamics
Research	➢ Explicitly evaluate how human adaptations influence and are influenced by socio-ecological dynamics ➢ Expanded engagement with concepts and methods from socio-ecological resilience literature ➢ Explore diverse scenario and systems modeling approaches
General recommendations	
Action	➢ Address remaining geographical gaps in adaptation action

	➢ Cultivate participatory, forward looking adaptation planning processes ➢ Strengthen engagement with the sustainable mountain development paradigm ➢ Increase monitoring and evaluation efforts
Research	➢ Address large geographical gaps in adaptation research ➢ Embrace transdisciplinary research approaches ➢ Strengthen engagement with the sustainable mountain development paradigm ➢ Support monitoring and evaluation efforts

Although climate-related changes in glaciated mountain systems are on par with regions such as the Arctic, recognition of the need for adaptation in mountains by researchers and institutions concerned with global environmental change has been relatively limited to date. This has made it difficult to generate support and momentum for necessary adaptation efforts in mountain systems, partially explaining shortcomings in action and research identified in this study. Fortunately, this situation is beginning to change. The forthcoming IPCC Special Report on the Oceans and Cryosphere's 'High Mountain Areas' chapter as well as IPCC AR6's 'Cross-Chapter Paper on Mountains' are indicative of increasing engagement with adaptation in mountain systems. Likewise, mountains are mentioned in several SDGs (targets 6.6, 15.1, and 15.4), with effective adaptation in mountain systems being recognized as a prerequisite for advancing the 2030 Agenda for Sustainable Development (Mountain Partnership, 2017). These developments signal growing recognition of the importance of adaptation action and research in glaciated mountain systems.

3.5.4 Study limitations

The results of this study should be read with several caveats in mind. We only reviewed English-language documents and a subset of the (potentially) relevant grey literature. Future studies including the non-English literature as well as different grey literature sources would complement our findings. In particular, evaluating the adaptation-related work of major regionally focused institutions such as ICIMOD and CONDESAN as well as actors not affiliated with Mountain Partnership would enhance understanding of adaptation in mountain systems. A predictable effect of including such literature would an increase in the number of adaptations documented in the Himalayas and Andes as well as in the industry and energy sectors. Furthermore, the review likely underreports adaptation projects carried out by the private sector, as such initiatives are rarely reported in the peer-reviewed literature. For example, existing efforts by hydropower companies in Peru and Switzerland to manage the hydrological effects of glacial recession and deglaciation were not captured in our review. This study is also affected by limitations common to all systematic reviews: relevant documents may have been missed; findings are based on reported information, which is assumed to be a thorough and accurate reflection of the phenomena interest; and data extraction is affected by some level of researcher subjectivity. Finally, while the themes addressed in our definition of ‘the challenge of climate change’ highlighted several important issues for adaptation action and research, the definition is not comprehensive. For example, we did not engage substantively with challenges highlighted in the biological and health sciences (e.g. Watts et al., 2015; Yoccoz et al., 2010). A reanalysis of the documents we reviewed could focus on challenges not examined in this study.

3.6 Conclusion

Life in glaciated mountain systems is strongly affected by climate-related changes such as glacial recession, modifications in the extent and duration of snow-cover, and thawing permafrost, all of which intersect with already challenging living conditions in high mountains. Without adaptation, climate-related changes in glaciated mountain systems portend significant, widespread, and far reaching socio-ecological impacts. However, our understanding of adaptation action and research in these systems has been relatively limited to date, constraining our ability to determine whether existing efforts are sufficient to meet the challenge of climate change. This paper addressed this gap by using an integrative theoretical framework and formal systematic review methods to evaluate documents reporting information about adaptation action and research in glaciated mountain systems. Our findings are based on a comprehensive assessment of the existing peer-reviewed literature and a targeted assessment of the grey literature.

Study results indicated that socially-relevant climate-related changes are already manifesting in glaciated mountain systems, with the most commonly documented stimuli for adaptation being hydrological changes related to the degradation of the high mountain cryosphere. They also revealed the importance of multiple stressors in shaping adaptations, highlighting the influence of broader socio-ecological dynamics on responses to change. The study documented some level of adaptation action in the majority of the countries with glaciated mountain ranges, although most actions are concentrated in the Himalayas and Andes. Adaptations involving agricultural and water-related sectors were most common, with reactionary responses to experienced climatic stimuli being the norm. Although the majority of adaptations were carried out without guidance from a formal adaptation plan, increasing engagement from the international community was observed and may signal a shift towards more formal, forward-looking adaptation planning. However, despite evidence of many praiseworthy adaptation initiatives, shortcomings in meeting the scientific, human, and socio-ecological challenges of climate change were conspicuous. The study also identified the emergence of explicitly mountain-focused adaptation research, yet studies framed in this way are still relatively scarce and have only been carried out in around half of the countries with glaciated mountain ranges. Such studies are generally regional-scale assessments that draw on a relatively small range of theoretical and methodological approaches. Nevertheless, some disciplinarily diversity is apparent in these studies, a promising sign given the need for inter- and transdisciplinary approaches to the study of adaptation. Several commendable mountain-focused adaptation assessments were documented, but again consequential shortcomings in meeting the challenge of climate change were observed.

Addressing shortcomings in adaptation action and research is both necessary and achievable. Mountain regions are globally significant centers of biocultural diversity, home to a rich tapestry of cultural, ethnic, and linguistic groups as well as important reservoirs of biological diversity. Finding ways to ensure that adaptations safeguard these attributes is imperative, as failing to do so would jeopardize internationally recognized commitments to the protection of human wellbeing and biodiversity conservation. Key needs for adaptation action include increasing the integration of scientific information in adaptation planning processes, recognizing the broader political economy of adaptation when planning adaptations, and encouraging adaptation planning processes that consider how human adaptations influence and are influenced by socio-ecological dynamics. Likewise, future mountain-focused adaptation research will benefit from deeper engagement with nuanced, scale-appropriate assessments of current and projected climatic changes; increased engagement with the causes and consequences of differential vulnerability and adaptability; and explicitly evaluating socio-ecological dynamics in the context of climate change adaptation. More broadly, there is a need to address remaining geographical gaps in adaptation action and research; to cultivate participatory, forward looking adaptation planning processes; and to strengthen engagement with researchers and practitioners working under the banner of sustainable mountain development.