ADAPTATION TO GLACIO-HYDROLOGICAL CHANGE IN HIGH MOUNTAINS

by

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Abstract

The intersection of climate-related glacio-hydrological changes and persistent socio-economic marginalization is leading to widespread vulnerabilities in many high mountain communities. This situation has raised awareness of significant gaps in our understanding of human adaptation in mountain areas, including what constitutes cogent adaptation research in mountainous contexts, what we know (or do not know) about the diverse vulnerabilities and adaptation needs of mountain communities at the frontlines of climate change, and how responses to glacio-hydrological changes can proceed in ways that are both socially and ecologically tenable. In response, this dissertation: 1) develops an analytical framework for robust adaptation research in high mountain areas; 2) uses formal systematic review methods to critically evaluate existing mountain-focused adaptation research and actions *vis-à-vis* an original typology for the challenge of climate change in high mountain areas; 3) conducts a multi-sited, community-level assessment of lived experiences of glacio-hydrological changes in the Nepal Himalayas (upper Manaslu region) and Peruvian Andes (Cordillera Huayhuash region); and 4) evaluates prospects for meeting community-identified adaptation needs with adaptation support organized through the United Nations Framework Convention on Climate Change (UNFCCC). These efforts are informed by theoretical insights from glacio-hydrological sciences, human dimensions of climate change research, and socio-ecological systems thinking, as well as 160 household interviews, 34 key informant interviews, and 4 focus groups conducted in Nepal and Peru. The dissertation makes substantive contributions to how adaptation is studied in mountain systems as well as what we know about and can do to address growing adaptation needs in high mountain communities.

Lay summary

Climate change is melting mountain glaciers, diminishing snowfields, and changing precipitation patterns in high mountain areas, leading to increases in hydrological hazards and water scarcity as well as impacts on water quality. These hydrological changes have important implications for mountain people, many of whom suffer from poverty, marginalization, and other socio-economic difficulties that limit their ability to adapt effectively to climate-related changes in glacio-hydrological systems. However, there is currently limited understanding of how best to study these issues as well as how to address the resultant vulnerabilities being experienced by mountain communities. In response, this dissertation weaves together an integrative theoretical framework, mixed methods, and community-level research with mountain people in the Nepal Himalayas and Peruvian Andes to makes substantive contributions to how adaptation is studied in mountain systems as well as what we know about and might do to address growing adaptation needs in high mountain communities.

Preface

This dissertation is my original, independent work. I identified the research problem, designed the research program, gathered and analyzed the data (with some assistance, as specified below), and wrote the chapters. My advisory committee (Drs. Leila Harris, Michele Koppes, Kai Chan, and Martin Price) provided valuable feedback on my research design, initial results, and draft chapters.

Chapters 2 through 5 were written as stand-alone pieces for publication in peer-reviewed journals. This has led to some overlap in the introductory content of the chapters. Furthermore, the final publications for these chapters are co-authored; terms like "we" instead of "I" are used to reflect co-authorship. The nature of my contributions to each chapter is elaborated below:

Chapter 2 is adapted from an article published in the journal Water (special issue on 'Global Warming Impacts on Mountain Glaciers and Communities'). I am the lead author and wrote the first draft of this paper in its entirety. I developed the project idea and core arguments. Dr. Michele Koppes and I worked together to refine arguments and the manuscript.

> McDowell, G. & Koppes, M. (2017) Robust adaptation research in high mountains: Integrating the scientific, social, and ecological dimensions of glacio-hydrological change. Water 9: 739.

Chapter 3 is adapted from an article published in the journal Global Environmental Change. I oversaw all aspects of this study, and was involved in all stages of the project. I am the lead author and wrote the first draft of this paper in its entirety. I developed the project idea, research methods, and review and assessment materials; collected and evaluated documents included in the study; and led data analysis and writing. Drs. Christina Huggel and Holger Frey contributed to the refinement of the project idea, fine-tuning of the research protocol, and interpretation of study results. Frances Wang and Rae Cramer completed data extraction for peer-reviewed and grey literature documents, respectively. Vincent Ricciardi produced an interactive online map depicting study results. All co-authors provided feedback on article drafts.

> McDowell, G., Huggel, C., Frey, H., Wang, F., Cramer, R., Ricciardi, V. (2019) Adaptation action and research in glaciated mountain systems: Are they enough to meet the challenge of climate change? Global Environmental Change. 54: 19-30.

In the course of this project, I was invited to serve as a Contributing Author for the 'High Mountain Areas' chapter of the Intergovernmental Panel on Climate Change (IPCC) Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC). Drawing on results from the Global Environmental Change article, I provided analysis and writing related to adaptation for the 'High Mountain Areas' chapter. Elements of my contributions to the SROCC are featured in Chapters 4 and 5.

> Hock, R., Rasul, G., … McDowell, G., et al. (2019) Intergovernmental Panel on Climate Change (IPCC). Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC). High Mountain Areas chapter.

Chapter 4 has been prepared for submission to a peer-reviewed journal. I oversaw all aspects of this study. I am the lead author and wrote the first draft of this paper in its entirety. I developed the project idea and research methods, trained and coordinated local research assistants, and led data analysis and writing. My supervisory committee contributed to the refinement of the project idea and research protocols. Dhawa Gyanjen Lama and Gladys Jiménez provided logistical support for field research and led data collection in Nepal and Peru, respectively, following health issues that required my return to Canada (as explained in the preface of Chapter 4). All co-authors provided substantive feedback on chapter drafts.

Chapter 5 has been prepared for submission to a peer-reviewed journal. I am the lead author and wrote the first draft of this paper in its entirety. I developed the project idea and research methods, and led data analysis and writing. My supervisory committee provided substantive feedback on the project idea and subsequent chapter drafts.

Ethics approval was obtained from the UBC Behavioral Research Ethics Board in October 2018 and has been renewed each year and amended as necessary (certificate number H17-00295, project title 'Adaptation to glacio-hydrological change in high mountains).

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My efforts were also informed by conversations with colleagues beyond UBC, including Drs. Christian Huggel, Mark Carey, Carolina Adler, Alton Byers, Rune Bennike, and Vaibhav Kaul, among others. Furthermore, my dissertation builds on ideas conferred to me by prior supervisors and mentors: Drs. James Ford and Thomas Thornton, and Mr. Jeff Petty.

I am indebted to the community members of the upper Manaslu region of the Nepal Himalaya and the Cordillera Huayhuash region of the Peruvian Andes, whose willingness to share information about their lives was extremely generous. I am also grateful for the prodigious efforts of my local research partners in Nepal and Peru: Dhawa Gyanjen Lama, Tsering Dekyi Lama, Gladys Jiménez, and Jim Sykes. The International Centre for Integrated Mountain Development (ICIMOD) and Instituto de Montaña (TMI) provided important assistance related to field research.

I am deeply appreciative of the financial support provided by the Vanier Canada Graduate Scholarship, the IDRC Doctoral Research Award, the Liu Institute for Global Issues, the UBC Institute for Asian Research, the Public Scholars Initiative, the UBC Four Year Doctoral Fellowship, the UBC Faculty of Science, and my PhD supervisors, all of which was essential for the completion of this dissertation.

My wife Vanessa Kiss deserves special recognition, as her exceptional skills as a mother and partner were the foundation that underpinned all of my efforts. I am in awe of her poise and ever-grateful for her wonderful personality. I truly could not have done this without her. Thank you, Vanessa, for everything. Likewise, my mother Christa Hendrick has been a dedicated supporter of my doctoral work. She provided vital encouragement, perspective, and advice throughout my doctoral training, including as I navigated becoming a parent in the middle of my program. Finally, my grandfather Dr. John R. Hendrick has been a constant source of inspiration. Indeed, his example of how scholarly work (combined with meaningful action) can advance social and environmental justice played a significant role in my decision to pursue a PhD.

At the conclusion of my formal academic training, I am filled with appreciation and reverence for the places and people I have come to know through my research in high mountains and the Arctic. What I have experienced in these 'high places' has been both humbling and formative in my outlook as a scholar. The words of Barry Lopez come to mind:

> *There are simply no answers to some of the great pressing questions. You continue to live them out, making your life a worthy expression of leaning into the light.*

Dedication

For

My grandmother

Dorothy Layne Hendrick

The brightest star in the Southern sky

Chapter 1: Introduction

1.1 Dissertation rationale, research questions, and structure

Humanity is facing profound and growing challenges related to global environmental change, with a changing climate, biodiversity loss, and impacts on ecosystem services reshaping societies and ecosystems across geographies (Díaz et al., 2019; Masson-Delmotte et al., 2018). These largely human-driven impacts on socio-ecological systems are far greater than at any point in human history, and are inextricably linked to dominant modes of socio-economic development and attendant greenhouse gas emissions, land-use changes, and environmental contamination (Steffen et al., 2015a). The magnitude of these and other environmental changes is leading to the transgression of critical ‘planetary boundaries’, posing a substantial risk of destabilizing the 11,700-year-long Holocene state in which modern societies evolved (Rockström et al., 2009). Understood in this way, global environmental change poses an existential threat to humanity, with climate change emerging as one constituent issue of substantial concern.

According to Steffen et al. (2015b) the planetary boundary for climate change is an atmospheric concentration of CO_2 of greater than 350 – 450 parts per million (ppm). The atmospheric CO_2 concentration in 2018 was 407.4 ppm, the highest level at any point in the past 800,000 years (NOAA, 2019). Cumulative global CO_2 emissions—the majority of which have been released by countries in the Global North (Wei et al., 2016)—are perturbing the climate system and leading to wide-ranging biogeophysical effects without recent precedent (Stocker et al., 2013). For example, marked increases in the intensity and frequency of extreme events, ocean acidification, and changes in the composition and distribution of ecological communities (Masson-

Delmotte et al., 2018; Stocker et al., 2013). However, climate-related changes are having particularly dramatic impacts in the cryosphere—the parts of the planet where water is in its frozen form—given the high sensitivity of ice and snow to warming as well as warming rates in excess of the global average (i.e. 'Arctic amplification' and 'elevation dependent warming') (Cohen et al., 2014; Pepin et al., 2015). This has led to significant reductions in the extent and duration of Arctic sea ice, sustained mass loss from the Greenland and Antarctic ice sheets, and the nearly ubiquitous recession of mountain glaciers (Pörtner et al., 2019). Thus, although the transgression of the climate change boundary identified by Steffen et al. (2015b) is globally important, its effects manifest in geographically and system specific ways. Growing impacts on mountains and alpine hydrological systems (Hock et al., 2019) are one such manifestation.

The unprecedented rate and magnitude of climate-related impacts on mountain hydrology is increasingly well documented globally (Hock et al., 2019). Hydrological changes are affecting all mountain regions. However, they are particularly significant in 'high mountain areas'—which I define as mountain areas with present day glaciation—where glaciers and snowfield comprise important components of hydrological systems (Huss et al., 2017; Milner et al., 2017). In high mountain areas, glacier recession is driving threshold dynamics in glacial meltwater generation known as 'peak water' while also reducing the important role of glaciers in reducing the variability of streamflow (Baraer et al., 2012; Huss and Hock, 2018). Concurrent changes in the amount and timing of rain and snowfall are also affecting discharge generation, and can both attenuate or magnify changes in glacier-sourced meltwater (Stewart, 2009) Combined, these manifestations of climate change produce broadly similar but nevertheless contextually distinct processes of glacio-hydrological change across high mountain socio-ecological systems.

A growing body of research highlights the potential impacts of glacio-hydrological changes on mountain communities (as summarized in Carey et al., 2017), yet relatively few scientific studies have evaluated the role of human adaptations in navigating the challenges and opportunities of changing hydrological conditions (as summarized in McDowell et al., 2014). Moreover, the existing literature is dominated by individual case studies, making it difficult to identify similarities and differences across sites (*ibid*.). The paucity of global syntheses and multi-sited assessments limits scholarly understanding of adaptation to hydrological change and, in turn, the ability to appropriately target scarce adaptation resources. As well, despite awareness that social factors strongly influence experiences of, and responses to, environmental change (Adger, 2006; Smit et al., 2000), only a limited number of mountain-focused adaptation studies evaluate social differentiation *vis-à-vis* glacio-hydrological change (McDowell et al., 2014). This leads to overly simplistic understandings of lived experiences of hydrological change, which has important implications for our ability to recognize underlying drivers of vulnerability and, consequently, to devise responses that address the root causes of susceptibility to harm.

Additionally, despite growing consensus that socio-ecological systems approaches are needed in environmental change research (Berkes and Folke, 2000; Gleeson et al., 2016), few mountain-focused adaptation assessments consider the socio-ecological interdependencies, feedbacks, and tradeoffs inherent in human adaptations to glacio-hydrological change (Carey et al., 2014b; McDowell et al., 2014). Without explicitly recognizing the embedded nature of mountain people in highland environments, adaptation research may inadvertently recommend human adaptations that threaten the structure and function of mountain ecosystems as well as facets of human well-being that are linked to the flow of ecosystem services from mountain environments. Conversely, opportunities to leverage synergies between human well-being, ecosystem services, and biodiversity conservation may be missed in adaptation assessments that lack a socio-ecological systems lens (Egan and Price, 2017; Jones et al., 2012; Lavorel et al., 2019).

Notwithstanding these shortcomings, there is a small but growing body of research focusing on human adaptation in mountain areas. For example, pioneering work in the Andes has advanced the study of coupled human-hydrological systems in the context of climate change (e.g. Bury et al., 2013; Carey et al., 2014a; Drenkhan et al., 2015; Huggel et al., 2015; Mark et al., 2017; Mills-Novoa et al., 2017; Salzmann et al., 2009), drawing attention to strong linkages between mountain hydrology and human well-being. Likewise, some community-level work in the Himalayas has focused on revealing differing adaptive capacity and social determinants of vulnerability (e.g. Gentle and Maraseni, 2012; Gioli et al., 2019; Kaul and Thornton, 2014; Pandey et al., 2015), including my own prior efforts in the region (McDowell, 2011; McDowell et al., 2013). Furthermore, there has been some effort focused on cross-site synthesis in the peer-reviewed (McDowell et al., 2014; Muccione et al., 2016; Sud et al., 2015) and grey literature (Alfthan et al., 2018; UNEP, 2015). Such synthesis work has helped to illuminate initial patterns in adaptation action across regions, including significant gaps in adaptation action. These empirical-grounded and synthesis-focused efforts have contributed to calls for more integrative approaches to the study of adaptation in mountain areas, as seen in research needs outlined in the 'High Mountain Areas' chapter of the Intergovernmental Panel on Climate Change (IPCC) Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC) (Hock et al., 2019). This dissertation is informed by, builds upon, and contributes to these prior research efforts and contemporary research needs.

The rationale for this dissertation emerges from the nexus of trajectories of glacio-hydrological change; the spectre of widespread vulnerability in mountain communities, particularly in the Global South; and significant opportunities for analytical, theoretical, and empirical improvements in the study of adaptation in mountain areas. In response, this dissertation engages with four research questions:

1. How can adaptation research adequately address interdependencies between climate-related glacio-hydrological changes, people, and ecosystems in mountain areas; can relevant research topics be organized into a coherent analytical framework?

2. What do we know, not know, and need to know about adaptation in high mountain areas; are existing efforts in adaptation research and practice sufficient to meet the scientific, human, and socio-ecological challenges posed by climate change?

3. How and why do lived experiences of glacio-hydrological change vary within and across high mountain communities in Nepal and Peru; do these experiences agree with characteristics of vulnerability hypothesized in model driven studies of glacio-hydrological change?

4. What are the prospects for, and potential perils of, addressing adaptation needs in high mountain communities through formal adaptation support organized through the United Nations Framework Convention on Climate Change (UNFCCC); what specific opportunities exist for enhancing support in high mountain areas?

In answering these questions, my dissertation makes substantive scholarly and practical contributions to our understanding of human adaptation to glacio-hydrological change in high mountain socio-ecological systems, as described at the end of this chapter.

These remainder of this chapter is focused on providing an introduction to 'mountain worlds', including details that are needed to fully appreciate my research choices as well as the arguments developed in subsequent chapters; my theoretical framework and research objectives; and the substantive contributions of the dissertation. Chapter 2 (research approach chapter) develops an analytical framework for robust adaptation research in high mountain areas, addressing my first research questions and providing an organizing framework for subsequent chapters. Chapter 3 (literature review chapter) uses formal systematic review methods to critically evaluate existing adaptation actions and research across mountain areas globally, providing answers to my second research question and informing my field research. Chapter 4 (empirical chapter) elaborates multi-sited, community-level research that was conducted in the upper Manaslu region of Nepal and the Cordillera Huayhuash region of Peru, attending to my third research question and identifying adaptation needs that are examined in the following chapter. Chapter 5 (policy chapter) examines the prospects and perils of meeting adaptation needs in high mountain communities through the provision of adaptation support organized through the UNFCCC, responding to my fourth research question and providing a capstone to the dissertation research. Chapter 6 elaborates the key findings, contributions, and limitations of the dissertation as well as future research needs and opportunities.

1.2 Mountain worlds

1.2.1 Mountain environments

Mountain formation (orogenesis) is the result of both constructive and destructive processes operating over vast periods of time. Contemporary explanations of orogenesis build upon the theory of continental drift proposed by Alfred Wegener in 1912, and are related to fundamental aspects of plate tectonics: earthquakes and volcanism (Shroder Jr. and Price, 2013). Due to their association with tectonic activity, mountain ranges tend to run in linear belts along continental margins (e.g. Andes) and interiors (e.g. Himalayas) or along island arcs (e.g. Aleutian Range) (*ibid*.). Orogenesis produces varied rock strata, which is then subjected to the force of gravity and erosional processes such as glaciation, resulting in complex mountain topography (Janke and Price, 2013). According to the criteria used by Kapos et al. (2000) and recent calculations by the Food and Agricultural Organizations (FAO, 2015), mountains cover ~22% of the Earth's land surface. However, there is no universally accepted delineation for mountains areas (Price et al., 2019).

Mountains are found on every continent, but environmental conditions are highly diverse within and across mountain regions as a function of latitude, continentality, altitude, and topography (Barry, 2008). Latitude effects solar radiation patterns and budgets, with implications for temperature and precipitation characteristics (Barry, 2008). Likewise, mountains located near coasts tend to exhibit reduced daily and seasonal temperature extremes relative to inland locations. They also tend to receive greater amounts of precipitation than inland areas (assuming on-shore prevailing wind patterns). Based on latitude (primarily) and continentality, mountain ranges can be classified as Arctic, boreal, temperate, sub-tropical, or tropical (Nagy and Grabherr, 2009).

Altitude also plays a central role in mountain weather and climate (Barry, 2008). Temperature declines at an average rate of -6.5 °C per vertical kilometer (environmental lapse rate), but atmospheric moisture conditions affect the actual rate of change. Where temperatures are sufficiently low, snow and ice processes become significant and can lead to physical conditions (e.g. increased albedo) that further reduce temperatures. (Benn and Evans, 2010). Topography is another major factor in mountain weather and climate (Barry, 2008). Large-scale effects relate to mountain height, length, width, and ridge spacing, which together strongly influence air flow and precipitation dynamics. Finally, relationships between slope angle and orientation with solar angle (a function of latitude, season, and time of day), albedo, and atmospheric conditions produce complex mosaics of local surface energy budgets (and subsequently living conditions) within mountain ranges.

Mountain ecosystems reflect dynamic, contextually specific interactions of abiotic factors and terrestrial, aquatic, and avian flora and fauna. In general, terrestrial and aquatic species diversity is greatest in the less harsh montane zone and declines at higher elevations (Körner and Ohsawa, 2005; Nagy and Grabherr, 2009). However, there are exceptions. Along the arid western slope of the Peruvian Andes, for example, biological diversity peaks at higher elevations where temperature and precipitation conditions are more suitable than at lower elevations (*ibid*.). At higher elevations, survival requires highly specialized physiological adaptations, behavioral strategies, and reproductive tactics (Hadley et al., 2013; Price and Geist, 2013). As such, more mountain-hardy and mountain-adapted flora and fauna are observed at higher elevations. Adaptation to particular living conditions combined with widespread topographic fragmentation leads to high occurrences of endemism in alpine and nival zones (Körner and Ohsawa, 2005).

Mountains are globally significant centers of biodiversity, with several ranges containing world-leading levels of species richness and endemism (e.g. the tropical Andes) (Spehn et al., 2010). For example, mountains support about one quarter of all terrestrial species and up to 50% of regional mountain species can be endemic (Ariza et al., 2013; Körner and Ohsawa, 2005). However, mountain ecosystems are particularly sensitive to environmental change. For example, snow and ice environments are dramatically affected by even small changes in temperature and precipitation, soil development is slow and subject to downslope erosion, flora are often long-lived and therefore slow to adapt, and terrestrial and aquatic fauna are often adapted to extreme environmental conditions and a narrow range of interspecific competition dynamics (Nagy and Grabherr, 2009; Price and Geist, 2013; Price and Harden, 2013). For these reasons, climate change, and its interaction with other processes of change—land-use intensification, the arrival and introduction of exotic species, and the deposition of long range pollutants—is particularly concerning (Kohler et al., 2014; Körner and Ohsawa, 2005). In view of this situation, it is perhaps not surprising that 25 of 34 'biodiversity hotspots' (threatened areas with high endemism) recognized by Conservation International are located partially or entirely in mountain areas (Price and Kohler, 2013).

Finally, changes in temperature, precipitation, and evapotranspiration with altitude lead to disproportionally high water generation in mountains (Bach and Price, 2013). For example, mountains are the source of all major rivers and produce at least 32% of global discharge (Barry, 2008). However, the FAO estimates that mountains might provide up to 80% of the Earth's fresh water (FAO, 2015). This overall discharge value masks significant spatial variation in mountain-sourced water generation, which can account for as much as 95% of surface water in arid regions (Viviroli and Weingartner, 2004). Moreover, glaciers and snow in high mountain areas reduce discharge variability by storing water in cool periods and releasing meltwater in warmer and drier periods (van Tiel et al., 2019). Such redistribution can account for a substantial proportion of seasonal flow in many regions (Kaser et al., 2010) and represents an important ecosystem service for people living downstream of glacierized catchments (Palomo, 2017a). Likewise, numerous mountain flora and fauna are adapted to the unique characteristics of high mountain hydrological systems (Bundi, 2010). Given their overall, spatial, and temporal importance in water provision and regulation, mountains are considered essential 'Water Towers' for downstream socio-ecological systems (Immerzeel et al., 2019; Immerzeel et al., 2010; Messerli et al., 2004; Viviroli et al., 2011; Viviroli et al., 2007; Viviroli et al., 2019).

1.2.2 Mountain people

The 915 million individuals classified by the FAO as 'mountain people' represent a rich tapestry of cultural, ethnic, and linguistic groups (FAO, 2015; Gardner et al., 2013). This diversity is related to related to mountain areas' environmental heterogeneity and relative isolation as well as specific socio-cultural and political histories in and beyond mountains (Debarbieux and Rudaz, 2015; Gardner et al., 2013). Mountain communities are found in all major ranges outside of Antarctica and the high Arctic, and take forms ranging from small seasonal outposts to large cities

(Mathieu and Brun, 2011; Stevens, 1993). Likewise, habitation is found across a spectrum of elevations, from a maximum of 5,100m to near sea-level in high latitude mountain areas. A characteristic feature of people living in mountains is adaptability; that is, the ability to respond effectively to the challenges and opportunities of highland environments. Adaptability is primarily expressed through activities and settlement patterns (e.g. transhumance, terracing), but physiological adaptations are also apparent in some mountain populations (e.g. more hemoglobin in the blood of high elevation populations in the Andes and Himalayas) (Gardner et al., 2013).

The number of people living in mountain areas is increasing, especially in developing countries where 90% of mountain people reside (835 million people). Today, half of mountain people live in ranges in Asia. Population increase is occurring at all but the highest elevations; however, most mountain people (70%) live below 1,500m where environmental conditions are generally more hospitable. The locations of mountain settlements are correlated with river discharge volumes (Meybeck et al., 2001), highlighting the paramount importance of water in the lives of mountain people.

Mountain livelihoods include cash- and resource-based endeavors, but in developing countries and in more remote ranges in developed nations resource-based livelihoods are most common (Gardner et al., 2013). Resource-based livelihoods typically require capitalizing on environmental differences related to altitude, seasonality, and micro-climates (Mathieu and Brun, 2011). Such livelihoods can be broadly classified as agricultural, animal husbandry, mixed agriculture, and agroforestry (Cunha and Price, 2013). Hunting and fishing have received less attention in the literature, but are also essential resource-based livelihoods in some areas (e.g. high-altitude areas in the Altai Mountains). The products of mountain peoples' efforts are consumed directly or traded and sold for other goods and cash income (Gardner et al., 2013). In some areas, tourism-related activities augment resource-based livelihoods (Debarbieux et al., 2014). However, the remoteness of many mountain communities, and the prevalence of resource-based livelihoods, means that mountain people are often highly reliant on goods and services from mountain ecosystems (Körner and Ohsawa, 2005; Martín-López et al., 2019; Palomo, 2017b). Moreover, the widespread socio-economic and political isolation of mountain communities *vis-à-vis* lowland populations and institutions has tended to increase the reliance of mountain people on their immediate surroundings.

Geographical, socio-economic, and political isolation have engendered widespread poverty, marginalization, and food insecurity in mountain communities, particularly in the Global South (FAO, 2015). To an extent, the realities of mountain geography have limited the penetration of transportation and communication networks into highland areas, reducing mountain peoples' ability to engage with and benefit from interactions with lowland economies (Gardner et al., 2013). However, State preferences combined with limited State capacity has often perpetuated this configuration by concentrating resources on priority issues such as urban development in lowlands (Debarbieux and Rudaz, 2015; Hewitt and Mehta, 2012). In the same vein, a focus on 'modernization' has often relied on the exploitation of mountain resources and labor for the benefit of lowland populations (Perlik, 2015).

Unequal relations also manifest in political representation, where the preferences of mountain peoples have often fared poorly in policy outcomes (Rudaz, 2011; Wymann von Dach, 2016). These realities echo colonial legacies where mountain ranges were often treated as geo-political spaces (i.e. objects for advancing or securing state interests) not living environments (Debarbieux and Rudaz, 2015). Such systematic bias has had sweeping impacts on mountain people. Today, 45% of those who live in rural mountain areas in developing countries are food insecure and susceptible to malnutrition—far higher than the developing country average of 12.5% (FAO, 2015). This proportion has been increasing over time, outpacing demographic change (*ibid*.). Thus, notwithstanding the high resilience of many mountain people, socio-economic and political isolation can undermine the capacity to live well in mountain environments. In contrast, the emergence of welfare states and identity politics in the Global North has generally enabled mountain communities to achieve more inclusive and equitable relations with lowland populations and institutions (Debarbieux and Rudaz, 2015).

1.2.3 Mountain research, policy, and institutions

Mountain research is contingent on the idea that mountains are relevant objects of interest and germane targets for knowledge production. Debarbieux and Rudaz (2015) argue that the concept of mountains *per se* as well as their particular significance has been constructed, and reflects a particular 'configuration' of thought and action. In the western context, this configuration emerged as systematic scientific analysis (Enlightenment) and the sense that mountains are pure, natural, and sacred (Romanticism) began to replace the wariness of mountains that was pervasive in the Medieval period (Bernbaum and Price, 2013). Contemporaneously, politicians began to realize the role of science in helping them understand, utilize, and control their territory (Debarbieux and Rudaz, 2015). This analytical, philosophical, and political nexus sparked interest in mountain research, with early practitioners such as Johann Jakob Scheuchzer, Horace Benedict de Saussure, and Alexander von Humboldt making significant early contributions to the field. Alexander von Humboldt, in particular, is credited with being the forefather of long-term, systematic, integrative studies in mountains (Humboldtian science) (Jackson, 2019).

Early mountain research was firmly rooted in the natural sciences and primarily focused on classification, but that changed in 1934 with the publication of Jules Blache's book 'Man and the Mountain' (Mathieu and Brun, 2011). Although elements of Blache's work on the human dimensions of mountains seem antiquated by today's standards (e.g. racialized descriptions), his contributions represent an essential turning point in mountain science. By the mid-twentieth century, natural and social science approaches to mountain research were established, providing the empirical and theoretical basis needed for Carl Troll to advance his holistic, interdisciplinary, and comparative approach to the study of mountains (*ibid*.). Notwithstanding integrative research efforts by Humboldt and Troll, much research in the nineteenth- and twentieth-centuries was characterized by deep rifts between disciplines. However, today's multidimensional mountain-related challenges and opportunities are stimulating more integrative approaches to mountain research (Gleeson et al., 2016; Gurung et al., 2012; Price, 2013).

Improved scientific understanding of mountain worlds provided a basis for mountain-specific policy development. An important trend in modern mountain policy has been the globalization of mountain issues, a trajectory that reflects the world views, problem framing, and favored initiatives of a specific epistemic community of mountain researchers, development practitioners, and institutions (Debarbieux and Price, 2016). This community began to coalesce in the 1970s with initiatives such as ‘Project 6’ of UNESCO’s Man and Biosphere Programme and the United Nations University 'Highland Lowland Interactive Systems' program (Rudaz, 2011). In 1990, a group known as the Mountain Agenda was established to formally advocate for mountains as a political object at the global level (Debarbieux and Rudaz, 2015; Rudaz, 2011).

The 1992 United Nations Conference on Environment and Development, colloquially known as the Rio Earth Summit, was a watershed event for mountain policy. Here, the Mountain Agenda, with the support of Swiss diplomats, was able to successfully advocate for the inclusion of a mountain chapter in Agenda 21 (Mathieu and Brun, 2011). Agenda 21 is a comprehensive plan of action for sustainable development that guides global, national, and local efforts to address human impacts on the environment (United Nations, 1992). Its Chapter 13—Managing Fragile Ecosystems: Sustainable Mountain Development—outlines a strategy for sustainable mountain development, including specific programme areas, programme objectives, essential activities, and means of implementation (United Nations, 1992). Notably, Chapter 13 emphasizes that “Mountains are an important source of water” and are among “the areas most sensitive to all climatic changes” (United Nations, 1992 p. 119). The Summit also led to the creation of the UNFCCC, which has specific provisions for mountains. The Rio Earth Summit emphasized sustainable development, and the terminology of ‘sustainable mountain development’ has continued to animate conversations about mountain issues (Price, 2015).

A diverse constellation of research, advocacy, and development institutions are actively working on mountain issues, representing an important complement to the high-level developments mentioned above (Balsiger and Debarbieux, 2015; Messerli, 2012). For example, institutions such as the International Centre for Integrated Mountain Development (ICIMOD), which focuses on the Hindu-Kush Himalaya, and The Mountain Institute (TMI) have been active since the 1980s. In addition to their current work, they played a role in early international-level policy formulation. In 2002, at the World Summit on Sustainable Development, the FAO, the governments of Italy and Switzerland, and the United Nations Environment Programme (UNEP) founded The International Partnership for Sustainable Development in Mountain Regions (Mountain Partnership) (Rudaz, 2011). This is an umbrella organization comprised of >300 governments, organizations, and other stakeholders interested in mountain issues (Mountain Partnership, 2019). It aims to "stimulate concrete initiatives at all levels that will ensure improved quality of life and environments in the world's mountain regions"; it is the most significant mountain-specific institution to date (*ibid*.). A key member of the Mountain Partnership is the Mountain Research Initiative. It was established in 2001, and is the leading global-scale mountain research organization; it plays an important role in organizing, facilitating, and promoting environmental and social research in mountain areas. The efforts of such organizations are leading to growing recognition of mountains in broader efforts to understand and address global change challenges, as evidenced by the inclusion of mountain-focused chapters in contemporary assessments by the IPCC (i.e. SROCC and AR6).

1.3 Theoretical Framework

This dissertation draws on insights from three core bodies of theory to advance understanding of human adaptation to glacio-hydrological change in high mountain areas. It is rooted primarily in theoretical work from vulnerability-based approaches to adaptation. However, given my focus on hydrological change and human-environment interactions, the integration of insights from glacio-hydrological analysis and socio-ecological systems research is appropriate. Each of these respective bodies of theory represents its own interdisciplinary domain of research that emerged from prior integrative research efforts. Some of this prior research has been reasonably well integrated in mountain-focused adaptation research (i.e. glacio-hydrology), but my theoretical framework also infuses such research with theoretical insights that have only appeared in nascent forms to date. This integrative framework also helps to counter the current trend of splintering among interdisciplinarity research fields (as documented in Echeverri et al., 2018).

1.3.1 Glacio-hydrology and peak water

Glacio-hydrology is a sub-field of Earth System Science that evaluates the relationships between the atmosphere (e.g. climate change), cryosphere (e.g. glaciers and snow), and hydrosphere (i.e. freshwater systems). The field informs my understanding of the nature, dynamics, and complexities of climate-related hydrological change in high mountain systems. This dissertation focuses on three key components of hydrological change in high mountains: peak water; changes in the short-term compensation effect of glacier meltwater; and changes in amount, timing, and phase state (snow vs. rain) of precipitation (Table 1.1). Together, these components represent the key climate-related hydrological changes that may be experienced by residents of high mountains.

Table 1.1: Key components of climate-related hydrological change in high mountains	
Component	**Hydrological effects**
Peak water	Long-term, non-linear pattern of glacier meltwater generation following glacier recession
Changes in the short-term compensation effect of glacier meltwater	Inter-annual discharge variability following glacier recession, seasonal shifts in timing and magnitude of discharge
Changes in amount, timing, and phase state (snow vs. rain) of precipitation	Masking or enhancing the importance of changes in glacier meltwater generation, affects the 'flashiness' of discharge (rapid runoff of rain vs accumulation of snow)

The peak water model suggests that, over many years, glacial discharge 1) will initially exhibit a rising trend in response to increasing temperatures, 2) will reach a peak discharge value, and 3) will then decline to a value less than that observed prior to contemporary climate warming (Figure 1.1) (Baraer et al., 2012). Insightfully, Gleick and Palaniappan (2010) refer to this process as "peak nonrenewable water" because eventual discharge reductions are not reversible on socially-relevant timescales. Initial discharge increases are expected primarily as a function of rising equilibrium line altitudes (ELAs), a phenomenon that increases the surface area subject to melt. The peak water threshold occurs when discharge gains from a sustained negative mass balance begin to be offset by melt area reductions following sustained mass loss. After this threshold is crossed, discharge begins to decline. Although the peak water model is well established, the actual timing of peak water dynamics is highly variable across mountain regions (Huss and Hock, 2018). Moreover, the model holds precipitation constant, an assumption that does not reflect the reality of concurrent precipitation changes in many high mountain regions.

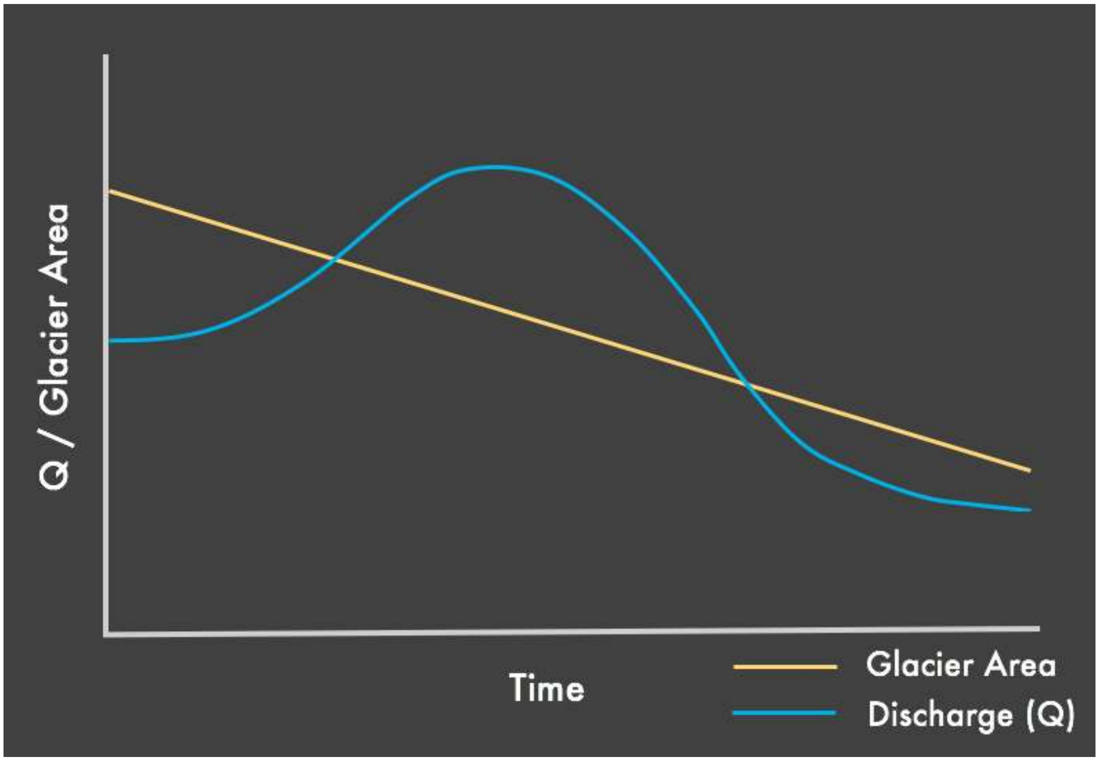

Figure 1.1: Peak water model

The above discharge pattern reflects the long-term effects of glacial recession on discharge. However, the processes driving peak water also imply changes in the inter-annual variability of discharge in high mountain watershed. Glaciers reduce the variability of water availability by storing water in cool periods and releasing meltwater in warmer and drier periods (van Tiel et al., 2019). Glaciers also delay peak runoff through a lag in meltwater generation related to the seasonal evolution of glacier hydrological systems (Jansson et al., 2003). The recession of mountain glaciers implies significant changes to these discharge patterns, although regional patterns will vary as a result of glacier regime type and concurrent precipitation changes. The 'temporal redistribution effect' of mountain glaciers plays an essential role in dry season water availability and agriculture in many mountain regions (Kaser et al., 2010), suggesting that such changes may represent a significant socially-relevant process of hydrological change.

Climate-related changes in mountain precipitation are subject to considerable uncertainty but are generally expected to manifest as enhancements to existing spatial and temporal precipitation patterns (e.g. drier areas get drier, wetter seasons get wetter) (IPCC, 2013). Here, climate change will affect snowfall amounts, the length of the melt seasons, and thus the altitudes of end of melt season snowlines (Stewart, 2009). Hydrologically, changes in snowfall amounts and the length of the melt season affect snow-sourced discharge volumes as well as timing of freshets (*ibid*.). Likewise, an increase in the end of melt season snowline implies a larger catchment area subject to rainfall and thus more variable annual discharge profiles (*ibid*.). Moreover, changes from snow- to rain-dominated systems, as well as changes in the timing and amount of precipitation, will have important effects on terrestrial moisture content, with implications for rain-fed agriculture. Furthermore, climate-related glacio-hydrological changes are often magnified or modified by other processes such as the deposition of black carbon, which increases melt rates, or land-use practices that affect sedimentation (Dagsson-Waldhauserova and Meinander, 2019; Khoi and Suetsugi, 2014).

Siloed approaches to the study of mountain hydrology—such as focusing only on peak water—are attractive because they reduce complexity. However, a first-order assessment of adaptation to hydrological change in high mountain areas requires openness to the range of hydrological processes that may be relevant to highland residents, including the differing temporal scales at which these processes operate: seasonal (rainfall and snowmelt), inter-annual (glacier recession), and decadal (peak water). For this reason, I use the general framework of glacio-hydrological change to avoid assuming *a priori* the most salient hydrological dynamics motivating adaptation in high mountain socio-ecological systems.

1.3.2 Vulnerability-based adaptation research

Climate change adaptation research is a subset of work focused on human dimensions of climate change. Vulnerability-based approaches to adaptation are rooted in insights from natural hazards, political economy, political ecology, and development studies (e.g. Blaikie et al., 1994; Hewitt, 1983; O'Keefe et al., 1976; Watts, 1983) and are primarily concerned with how people experience and respond to climate change in the context of concurrent socio-ecological stressors (Adger, 2006; Ribot, 2010; Smit and Wandel, 2006; Turner et al., 2003). 'Vulnerability-based' implies an emphasis on how social factors produce differentiated experiences of environmental change among social actors and, consequently, the treatment of vulnerability and adaptability as dynamics *of* society (Bassett and Fogelman, 2013; Kelly and Adger, 2000). This more critical approach to adaptation research emphasizes the importance of vulnerability reduction through adaptations that address underlying determinants of vulnerability (Brown et al., 2017; Ribot, 2010). This is a key difference from mainstream climate change adaptation research, which tends to focus on the act of adaptation and adaptation planning rather than vulnerability reduction *per se*. Vulnerability-based approaches to adaptation examine the relationship between exposure-sensitivity, adaptive capacity, and vulnerability (Smit and Wandel, 2006).

Exposure refers to the characteristics of environmental changes (e.g. nature and magnitude of hydrological changes) and defines whether such changes intersect with inhabited areas (Ford and Smit, 2004). Sensitivity clarifies whether exposure is of consequence to exposed populations (*ibid*.). Differential exposure-sensitivity is common and often related more to non-climatic factors than environmental 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 future increases in discharge. Thus, vulnerability-based approaches to adaptation reveal where exposure-sensitivities exists, for whom, and why.

The ability to devise and implement adaptations—known as adaptive capacity—can vary greatly among and within populations according to factors such as income, age, and educational attainment. Thus, adaptive capacity helps to reveal how social factors produce differentiated experiences of environmental change by clarifying who can/or cannot adapt and why (Engle, 2011). For example, in Khumbu, Nepal, highland residents who own trekking lodges have been able to afford rooftop water collection systems to address seasonal water shortages (McDowell et al., 2013). Those primarily involved in agriculture do not have the capacity to access this adaptive response and, therefore, have been more vulnerable to water shortages (*ibid*.). Adaptive capacity is evaluated through a focus on determinants (factors that support) and barriers (factors that constrain) adaptation (Smit and Wandel, 2006). Well documented determinants include access to economic resources, technology, and information; high levels of social and cultural capital, equitable socio-economic conditions, and supportive social networks; and well-functioning governance arrangements (Adger et al., 2007). Poverty, marginalization (and attendant challenges like limited education and poor health), and attitudes towards risk are documented barriers to adaptation (Adger et al., 2009; Biesbroek et al., 2013). The uneven distribution of determinants and barriers produces differences in adaptive capacity across space and through time.

Adaptation refers to individual or collective responses to stimuli that stress a system or present new opportunities (Smithers and Smit, 1997). Adaptations are undertaken in the pursuit of several broadly identifiable goals, including preventing loss, spreading or sharing loss, diversifying livelihoods to moderate harm or take advantage of new opportunities, migrating to reduce exposure to climate stimuli, and restoring climate-affected systems (Smit et al., 1999). Adaptations can be pursued individually or collectively, and can be classified in terms of their timing, intent, scope, and form (Smit and Wandel, 2006). Timing is an indication of when adaptations occur relative to climatic stressors; adaptations can be reactive or anticipatory. Adaptations that occur in preparation for climatic stress are often viewed as preferable, as they are thought to have the greatest potential for reducing harm (Ebi and Burton, 2008). Intent describes the extent to which adaptations are conceived and implemented through formalized processes. Autonomous adaptations are viewed as less formal in their development and implementation whereas planned adaptations represent a more formalized approach to adaptation.

Scope refers to the spatial and temporal extent of adaptation efforts. Adaptations may be conceived and enacted at various spatial scales: individual, household, community, regional, or national. Similarly, adaptations can range from short-term interventions to longer-term system adjustments (e.g. institutional changes), with the appropriate scale of adaptation depending on variables such as the goal of the adaptation, the level of knowledge about the system adapting, and the resources available. Form describes the adaptation approach, with commonly employed strategies being behavioral, technological, institutional, and informational (Smit et al., 1999). An extensive body of empirical work has established that adaptations rarely occur in response to climate change alone; adaptation to multiple, often interacting stressors is the norm (Lennox, 2015; Wilbanks and Kates, 2010). Finally, the implications of adaptations are of increasing interest, with the topics of unintended consequences, maladaptation, and transformational adaptation growing in importance (Barnett and O'Neill, 2010; Kates et al., 2012; O'Brien, 2012). The themes above provide an accepted framework for classifying and comparing adaptations.

Vulnerability-based approaches to adaptation provide a proven foundation for understanding the factors influencing human experiences of, and responses to, climatic changes. A key contribution is that adaptations to climate change will only be palliative if the socio-economic and political factors influencing sensitivity and adaptive capacity are not understood and addressed: the functional relationship between exposure-sensitivity, adaptation, and vulnerability must be considered. Corollary contributions are that the ability to adapt is differentiated among social actors and that this differentiation is linked to social factors operating across spatial and temporal scales. This insight highlights the broader political economy of adaptation, and disrupts the tacit assumption that adaptation is a local responsibility (Nalau et al., 2015). More broadly, this suggests that identifying drivers of vulnerability should be prioritized over the cataloguing of adaptive responses. Such insights imply that transformational responses may be necessary in some cases. According to Ribot (2010), adaptation "cannot be limited to treating incremental effects from climate change so as to maintain or bring people back to their pre-change deprived state" (p. 3). Notwithstanding these important contributions, vulnerability-based approaches to adaptation continue to suffer from a dearth of engagement with system dynamics, including the socio-ecological interdependencies, feedbacks, and tradeoffs inherent in adaptations to environmental change.

1.3.3 Socio-ecological systems

This study draws on theoretical insights from socio-ecological system literature—and allied fields—to more explicitly address interdependencies, feedbacks, and tradeoffs between mountain people and highland ecosystems in the context of human adaptation to glacio-hydrological change. Socio-ecological systems literature promotes systems thinking. Broadly, a system is a "set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviours" (Meadows, 2008 p. 188). A key insight from systems thinking is that while systems may be affected by outside forces like climate change, their response to external stimuli is a characteristic of the system itself (Meadows, 2008). Here, work on complex adaptive systems has been particularly salient. The structure and function of complex adaptive systems are linked to chance, spatial variation, historical events, the magnifying effects of nonlinearity, and threshold effects; consequently, they are characterized by non-linear behavior and limited predictability (Levin, 1992; Levin, 1998). Ecosystems are the classic example, but similar insights have been applied to social systems and extended to socio-ecological systems (Berkes and Folke, 2000; Holling, 2001; Levin, 1998). A key insight from this work that any given socio-ecological pattern or change is simultaneously the product of multiple processes operating at multiple scales (Levin et al., 2013). This point is echoed in research examining 'cumulative environmental impacts', which suggests, for example, that hydrological changes are often driven by multiple human activities (climate-related or otherwise) as well as the cumulative impact of these activities (Seitz et al., 2011). These insights share similarities with the observations about the multiple drivers of human vulnerability presented above, and signal a need to look beyond reductionist interpretations of social and environmental processes. Complex adaptive systems theory supports the idea of multiple basins of attraction where regime shifts and numerous system states are possible (Folke et al., 2004).

The character of a (high mountain) socio-ecological system's function, structure, identity, and feedbacks can be understood as being contained within a given 'basin of attraction' (Walker et al., 2004). The dimensions of the basin, or stability domain, provide essential insights about system characteristics. Walker et al. (2004) note four important attributes:

1. *Latitude* - The width of the basin of attraction, which is an indicator of the maximum amount the system can be changed before losing its essential character.
2. *Resistance* - The depth of the basin of attraction, which is an indicator of the ease or difficulty of changing the system.
3. *Precariousness* – The location of the current system in relation to the lip of the basin, which is an indicator of how close the current system is to crossing a threshold/tipping point.
4. *Cross-scale relations* – The influence of systems at scales above and below the scale of interest on the three attributes above.

In this context, adaptations are viewed as actions that expand the latitude of a basin, deepen a basin, move the current system away from basin thresholds, or manage cross-scale interactions that influence system characteristics (Walker et al., 2004). Although abstract, these concepts help to link human-focused adaptation research to a more systems-oriented understanding of responses to hydrological change. For example, while adaptations to hydrological change may at first seem suitable from a human perspective, resultant effects on socio-ecological system characteristics may inadvertently degrade highland ecosystems with implications for people who rely on mountain-sourced ecosystem services (e.g. construction of a dam that moderates discharge variation but also impacts ecosystem services and thus natural resource-based livelihoods). Unintended consequences and maladaptation are well-theorized and documented outcomes of omitting socio-ecological dynamics in environmental change research (Barnett and O'Neill, 2010; Folke et al., 2010).

More broadly, the allied field of ecosystem services provides a theoretically and empirically rich body of literature examining lived experiences of environmental change. Work on ecosystem services examines the benefits that people obtain from ecosystems, and engages explicitly with interdependencies and tradeoffs between ecosystem processes and human well-being (Daily, 1997). These benefits are classified into various services: supporting, provisioning, regulating, and cultural (MEA, 2005). Brauman et al. (2007) have extended these ideas to work on socio-hydrological systems, arguing that the assessment of water-related services should focus on the quantity, quality, location, and the timing of flow. These analytical contributions help to frame lived experiences of changing hydrological regimes, including helping to clarify where, how, and form whom hydrological changes matter. Consistent with work on cumulative environmental impacts, a focus on ecosystem services also helps to clarify how the nexus of proximate and distal factors shape observed environmental changes. In turn, this can reveal opportunities for targeted adaptations that address the root causes of impacts on ecosystem services and, consequently, that help to protect human well-being. This inherently socio-ecological approach is reflected in efforts to promote nature-based solutions to climate change (Jones et al., 2012; Lavorel et al., 2019), for example.

Socio-ecological systems research calls attention to the importance of system dynamics as well as the broader implications of, and possibilities for, responses to environmental change (Jones et al., 2012). These insights address key gaps in climate change vulnerability and adaptation research. Notwithstanding, critics (e.g. Cretney, 2014; MacKinnon and Derickson, 2013; Turner, 2013) argue that such research often obscures differential vulnerability and adaptability by naturalizing social actors through the extension of ecological concepts to society.

Both vulnerability and socio-ecological systems research provide insights that can enhance understanding of adaptation to climate change. However, it is also clear that they differ significantly. This has tended to perpetuate separation between the two fields, an unfortunate consequence given that the limitations of each field appear to be addressed by strengths of the other. Given my interest in consilience between these fields, my research efforts are guided by Moser and Ekstrom's (2010) definition of adaptation:

> Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting nonclimatic 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 definition echoes many of the key issues raised above and is therefore viewed as a cogent reference point for my evaluation of adaptation to glacio-hydrological change in high mountain socio-ecological systems.

1.4 Dissertation objectives

The overarching aim of this dissertation is to advance integrative approaches to the study of adaptation, and to generate insights capable of supporting more socially and ecologically tenable responses to climate change in high mountain areas. To accomplish this, I pursue four specific objectives.

1.4.1 Define principles for robust adaptation research

Climate-related changes in glacierized watersheds are widely documented, stimulating adaptive responses among the 370 million people living in glacier-influenced watersheds as well as aquatic and riparian ecosystems (Schaner et al., 2012). The situation denotes important interdependencies between science, society, and ecosystems, yet integrative approaches to the study of adaptation remain scarce in both the mountain- and non-mountain-focused adaptation research. This analytical limitation makes it difficult to identify sustainable autonomous adaptations and to devise cogent adaptation policies and programs. In response, my first objective is to define guiding principles for robust adaptation research in glaciated mountain regions. These principles—which are developed in Chapter 2—offer a point of departure for subsequent dissertation chapters.

1.4.2 Clarify the state of adaptation research and action

The challenge of climate change in glaciated mountain systems is significant and cannot be met without adaptation actions and research that address the interwoven scientific, human, and socio-ecological dimensions of climate change. However, our understanding of the effectiveness of existing efforts in meeting this challenge is lacking, a shortcoming compounded by a lack of consistent and comparable information about adaptation action and research in glaciated mountain systems. Therefore, my second objective is to clarify the state of adaptation research and action in high mountain areas globally. This is accomplished in Chapter 3, which develops a typology of the challenge of climate change in glaciated mountain systems and uses formal systematic review methods to critically evaluate existing adaptation actions and research in light of this framework. This assessment informs the empirical work in Chapter 4.

1.4.3 Advance understanding of lived experiences of glacio-hydrological change

The physical principles of glacio-hydrological change are well understood and accepted, yet there remains little empirical work evaluating what processes of hydrological change such as peak water mean for residents of high mountain communities. In particular, there is a paucity of work that utilizes community-level research approaches as well as a lack of empirically-grounded cross-site comparisons. Accordingly, my third objective is to advance understanding of lived experiences of peak water in high mountain areas through multi-sited, community-level research in two high mountain regions: the Nepal Himalaya and Peruvian Andes (Chapter 4). These ranges are recognized as conspicuous bellwethers of climate-related hydrological changes in mountain systems as well as highly populated centres of biocultural diversity (Sharma et al., 2019; Vuille et al., 2018). My analytical entry point in Chapter 4 is peak water, as this framing is becoming common in mountain-focused research (see Hock et al., 2019). However, the chapter examines peak water issues alongside concurrent processes of hydrological change to advance a more holistic understanding of life in rapidly changing high mountain watersheds. Findings from Chapter 4 provide a point of departure for Chapter 5.

1.4.4 Identify opportunities for addressing adaptation needs

There is a growing need for adaptation support in high mountain communities, as demonstrated in Chapters 3 and 4. Contemporaneously, formal mechanisms of adaptation support organized through the UNFCCC are becoming well established. However, there is currently little clarity about specific opportunities for matching such support with adaptation needs in high mountain communities. In this context, my fourth goal is to identify opportunities for addressing adaptation needs in high mountain communities through adaptation support organized through the UNFCCC (Chapter 5). To accomplish this, I clarify the architecture of UNFCCC adaptation support mechanisms, explain idealized linkages between these adaptation initiatives and meeting local adaptation needs; and then evaluate actual progress in connecting such support with discrete adaptation needs. Here, my analysis is focused on developments in Nepal and adaptation needs identified in Chapter 4. Identifying opportunities for increasing the flow of support for adaptation to vulnerable mountain communities provides a capstone for the dissertation research.

1.5 Methods

This dissertation uses mixed methods to evaluate human adaptation to glacio-hydrological change. It combines targeted and systematic literature reviews, community-level research in the high mountain of Nepal and Peru, and content analysis of adaptation policies and programs. These methods are based primarily on engagement with human subjects and academic and grey literature. Consistent with my core focus on human adaptation, I did not conduct direct glacio-hydrological or ecological assessments. Instead, investigation of these topics was guided by theory, literature reviews, and insights from study participants. In the context of a PhD dissertation, this approach provided a tractable set of mixed methods for answering my research questions and meeting the objectives of the dissertation. These methods are introduced here (Table 1.2) and elaborated in subsequent chapters.

1.5.1 Targeted literature review

Targeted literature reviews were conducted to illuminate hydrological, social, and ecological issues and interdependencies relevant to human adaptation in mountain regions broadly, and in my study regions in particular. My comprehensive exam reading lists were the backbone of targeted search efforts. However, numerous additional targeted reviews were conducted, which were guided by key word searches, recommendations from colleagues, and the bibliographies of particularly relevant texts. All dissertation chapters are informed by my comprehensive exam reading lists and additional targeted literature reviews. However, targeted reviews are the basis of Chapter 2, which profiles cross-cutting insights that emerged from synthesis of my comprehensive exam readings; they are also integral to the broader methodological approach utilized in Chapter 5.

1.5.2 Formal systematic review

I conducted a formal systematic review to clarify the state of adaptation research and action in high mountain areas globally. This 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 vulnerability and adaptation (e.g. Berrang-Ford et al., 2011; Ford et al., 2014; McDowell et al., 2016a; McDowell et al., 2014; Muccione et al., 2016; Shukla et al., 2017). Systematic reviews represent a scientific approach to literature synthesis; they 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). They also benefit from widely accepted reporting guidelines (e.g. PRISMA), which leads to increased 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).

The data source for my systematic review was information reported in peer-reviewed and grey literature documents published since the Rio Earth Summit and the establishment of the UNFCCC (June 1992 - December 2017). This temporal frame captures the concurrent emergence of mountains and climate change as focal points of policy, international aid programs, and research.

1.5.3 Multi-sited community-level case study research

Studies that utilize vulnerability-based approaches to adaptation tend to focus on specific place-based case studies where the implications of multiple processes of change can be observed in particular contexts. Such vulnerability assessments prioritize the integration of local knowledge and perceptions, provide rich insights into lived realities of climate change, and aim to identify adaptation options that are meaningful to affected individuals and communities (Ford et al., 2010). However, the high contextual specificity of individual case studies can make it difficult to generalize from case study findings (Stake, 2013). In response, research reported in Chapter 4 is based on multi-sited, community-level research in the upper Manaslu region of Nepal and the Cordillera Huayhuash region of the Peruvian Andes (2 communities in each region). The same research protocols were employed in both study regions, enabling direct comparison of results from two distinct mountain ranges (following guidance from Egan and Price, 2017; Mills et al., 2010; Yin, 2014).

Data were generated through household interviews, key informant interviews, and focus groups. Household interviews documented community members' biographical information; perceptions of hydrological changes; and the nature of exposure-sensitivities, adaptations, and vulnerabilities. Key informant interviews were conducted with government officials, community leaders, resource managers, researchers, and members of the private sector, and were focused on garnering additional details about topics relevant to the study. Focus groups were conducted to gain a deeper understanding of salient topics identified through household and key informant interviews and to discuss broader socio-ecological realities that condition lived experiences of glacio-hydrological change.

Field research methods were implemented by local researchers working under my guidance, who were familiar with local languages, cultural norms, and socio-ecological conditions. This approach enabled fieldwork to be carried out by those intimately familiar with local realities while also providing training and knowledge co-production opportunities for local mountain residents. I initially intended to lead data collection efforts with the support of local research assistance; however, medical issues while in the Himalayas required me to return to Canada, as elaborated at the beginning of Chapter 4.

1.5.4 Content analysis

Content analysis involves the systematic assessment of information recorded in data sources such as interview text or institutional reports, and aims to identify and distill key themes, patterns, and trends (Bengtsson, 2016; Payne and Payne, 2004). My content analysis efforts focused on clarifying the architecture, mandates, and protocols for action of major UNFCCC adaptation initiatives and tracing how UNFCCC adaptation assistance has been integrated into Nepal's adaptation planning activities. Materials reviewed include UNFCCC, Government of Nepal, and Global Environment Facility documents, web portals, and databases, all of which were collected through a purposive selection process that targeted content explicitly relevant to support for planned adaptations in low income countries. The content analysis in Chapter 5 was used to identify keyword terms for a subsequent targeted literature review of peer-reviewed articles.

Table 1.2: Overview of methods and data sources used in each chapter		
	Methods	**Primary data sources**
Chapter 2	Targeted literature reviews*	Comprehensive exam reading lists (170 books and peer-reviewed articles). Additional peer-reviewed documents.
Chapter 3	Formal systematic review	Peer-reviewed (*n* = 107) and grey literature documents (*n* = 63) published over the last 25-years.
Chapter 4	Multi-sited community-level case study research	Household interviews (*n* = 160), key informant interviews *n* = 34), and focus groups *n* = 4).
Chapter 5	Content analysis, Targeted literature review	UNFCCC, Government of Nepal, and Global Environment Facility documents, web portals, and databases. Additional peer-reviewed articles.

*Targeted literature reviews informed all chapters, but were only integral to the methodological approach in chapters 2 and 5.

1.6 Substantive contributions of the dissertation

This dissertation advances integrative approaches to the study of adaptation in high mountain areas, provides detailed global and multi-sited analyses, and identifies salient prospects for meeting adaptation needs in high mountain communities. It therefore addresses key limitations in the existing literature and, consequently, contributes substantively to mountain-focused adaptation research and practice.

First, the analytical framework developed in Chapter 2 weaves together theoretical traditions in ways that are both generative and novel in the context of mountain research. While a small body of work has called for integrative approaches to the study of adaptation in mountain areas (e.g. Bury et al., 2013; Carey et al., 2014a; Mark et al., 2010), this work focused primarily on balancing hydrological and social considerations. Before this dissertation there was no framework explicitly linking the science of glacio-hydrology, insights from vulnerability research, and concepts from socio-ecological systems in the context of adaptation in mountain areas. This framework provides a robust analytical approach for future climate change adaptation research in high mountain areas, clarifying how the approach can support the identification and development of more 'successful' adaptations to glacio-hydrological change.

Second, the systematic review developed in Chapter 3 is the most exhaustive and detailed assessment of adaptation research and action in high mountain regions globally. It builds on an initial systematic review of adaptation in mountain areas that I published in 2014 (McDowell et al., 2014) in important ways; namely, it evaluates peer-reviewed *and* grey literature documents, characterizes adaptation actions *and* research approaches, evaluates documents published over longer period of time, and is substantially more methodologically rigorous. Moreover, the chapter develops a typology for the challenge of climate change in mountain systems, and evaluates the state of adaptation research and action in light of this framework. This adds an important theoretical dimension to the interpretation of the study results. Insights from Chapter 3 have directly influenced contemporary research and policy conversations related to adaptation in mountain areas. For example, the publication based on this chapter (McDowell et al., 2019) has been cited by thought leaders in the mountain research community (e.g. in Adler et al., 2019; Haeberli, 2019; Rasul et al., 2019) and is the basis of information about adaptation reported in the 'High Mountain Areas' chapter of the IPCC SROCC (Hock et al., 2019).

Third, the empirical research reported in Chapter 4 offers a multi-sited, community-level assessment of lived experiences of glacio-hydrological change across globally significant high mountain Water Towers; namely, the Nepal Himalaya and Peruvian Andes. Work reported in the chapter represents the first effort to substantively examine the human dimensions of 'peak water'. The study shows how the nexus of hydrological changes and context-specific socio-political realties lead to patterns of vulnerability within and across high mountain communities that do not follow the characteristics of vulnerability hypothesized in the glacio-hydrological modeling literature. As such, the results call attention to the importance of deeply contextual studies in understanding the differentiated vulnerabilities and diverse adaptation needs of mountain people living in rapidly changing high mountain watersheds. For these reasons, findings from the chapter are poised to stimulate productive discussions and collaborations between social and hydrological scientists concerned with addressing vulnerability to glacio-hydrological changes in high mountain areas.

Fourth, Chapter 5 provides a substantive assessment of progress in, and opportunities for, addressing adaptation needs in vulnerable mountain communities with adaptation support organized through the UNFCCC. This is an important contribution to adaptation practice, as the

UNFCCC plays a paramount role in establishing principles and priorities for adaptation, normalizing adaptation action, and facilitating the distribution of significant adaptation resources. Moreover, there is a moral imperative to elaborate opportunities for planned adaptations, as leaving mountain communities who have contributed little to GHG emissions to shoulder the burden of adaptation is a contravention of established norms of climate justice. In response, this chapter provides actionable information that can be capitalized on to advance more just, equitable, and sustainable futures for mountain people at the frontlines of climate change, consistent with objectives outlined in the Paris Agreement (UNFCCC, 2015).

Finally, although the substantive contributions of the dissertation target mountain-focused adaptation research and practice, the dissertation also makes contributions to the respective theoretical traditions that frame the dissertation chapters. For example, the community-level work in the high mountains of Nepal and Peru illustrates how fine-scale observations of mountain people can markedly increase understanding of the nature and implications of glacio-hydrological changes in specific contexts. In addition, the dissertation provides an example of the use of formal concepts from vulnerability research in mountainous contexts, increasing the geographical scope of research on the human dimensions of climate change. Likewise, the dissertation elaborates the benefits of socio-ecological systems thinking in a mountain adaptation context, helping to broaden the scope of topics germane to socio-ecological analysis. More generally, the dissertation is situated within the wider history of mountain research described earlier, and represents modest but salient contribution to the larger endeavor of advancing understanding of mountain systems.

Chapter 2: Robust adaptation research in high mountains: Integrating the scientific, social, and ecological dimensions of glacio-hydrological change

2.1 Introduction

Mountains are the source of all major river systems, are important centers of biocultural diversity, and are conspicuous bellwethers of climate change (Huss et al., 2017; Stepp et al., 2005). Climate-related changes in mountain glaciers are already affecting water availability in many regions (Roe et al., 2017), with Intergovernmental Panel on Climate Change (IPCC) AR5 projections indicating further reductions in global glacier volumes of up to 85% by 2100 (IPCC, 2013). A small but growing body of research demonstrates how highland residents experience and respond to hydrological changes, and outlines how factors such as geographical isolation, dependence on resource-based livelihoods, and political underrepresentation increase susceptibility to the harmful effects of climate change (as summarized by Carey et al., 2017; McDowell et al., 2014). Likewise, recent ecological research has shown how the structure and function of mountain ecosystems is being altered by ice loss as well as how such changes threaten biodiversity and mountain-sourced ecosystem services (Korner and Ohsawa, 2005; Palomo, 2017; Sphen and Korner, 2006). Insights from these diverse strands of research suggest important interdependencies between science, society, and ecosystems, yet integrative approaches to the study of adaptation remain scarce in both mountainous and non-mountainous regions. Here we argue that this lack of integration impedes the identification, development, and implementation of 'successful' adaptations.

Using the example of glacio-hydrological change, this paper outlines key principles for robust mountain-focused adaptation research, providing a template for future studies in glaciated mountain regions and beyond. We are concerned primarily with adaptations in human systems and the role of integrative research in understanding and informing responses to climate change. This paper builds upon calls for more integrative climate change adaptation research in mountain environments (e.g. Bury et al., 2013; Byers et al., 2014; Carey et al., 2012; Carey et al., 2014b; Huggel et al., 2015; McDowell et al., 2014; Mills-Novoa et al., 2017; Muccione et al., 2016, Salzmann et al., 2009), and delineates a set of three guiding principles for robust adaptation research in glaciated mountain regions.

2.2 Scientific, social, and ecological context

Mountain glaciers moderate the inter-annual variability of streamflow by storing water in wet periods and augmenting flow during dry periods (e.g. Jansson et al., 2003). This 'temporal redistribution effect' can account for a substantial proportion of seasonal flow in many regions (Kaser et al., 2010). However, climate-related changes in mountain glaciers are altering this important hydrological service, with implications for human well-being and ecosystem structure and function (Huss et al., 2017; Marzeion et al., 2014). The IPCC AR5 reports with *very high confidence* that "almost all glaciers worldwide have continued to shrink as revealed by the time series of measured changes in glacier length, area, volume, and mass" (IPCC, 2013 p. 319). In addition, most general circulation model (GCM) projections indicate that the average global surface temperature change is *likely* to increase 1.5°C by 2100, with warming of 4°C within the realm of possibility (IPCC, 2013). Reductions in glacier area drive a non-linear response in glacial meltwater generation known as peak water. Peak water suggests that enhanced energy fluxes from the atmosphere to glacier surfaces will increase meltwater generation until a discharge peak is reached; increased melt will then cause discharge to decrease as glacier area declines, ending at a discharge level less than that observed prior to contemporary climate warming (e.g. Moyer et al., 2016). Peak water will have important implications for human populations and ecosystems that depend on glacially-sourced water (Carey et al., 2017; Kohler et al., 2014). Importantly, however, future precipitation characteristics will have a strong bearing on actual discharge dynamics, and will either weaken (more precipitation) or strengthen (less precipitation) the peak water profile at regional scales (Jansson et al., 2003; Kaser et al., 2010; Mark and McKenzie, 2007). Likewise, regionally specific factors such as glacier regime (e.g. whether accumulation occurs in the summer or winter) can have a strong effect on the relative importance of peak water dynamics for overall water availability (Kaser et al., 2010). Thus, while high mountain hydrology is rapidly changing across the planet, the particular glacio-hydrological dynamics experienced by people and ecosystems will reflect the interaction of regionally specific climatic, glaciological, and hydrological conditions.

The 915 million people living in mountains represent a rich tapestry of cultural, ethnic, and linguistic groups (FAO, 2015; Gardner et al., 2013). Mountain livelihoods include cash- and resource-based endeavors, but in the developing countries where most mountain people live and in more remote ranges in developed nations, resource-based livelihoods are most common (Gardner et al., 2013). Such livelihoods can be broadly classified as agricultural, animal husbandry, mixed agriculture, and agroforestry (Cunha and Price, 2013). Hunting and fishing have received less attention in the literature, but are also essential resource-based livelihoods in some areas (Gardner et al., 2013). For many mountain communities, remoteness, dependence on resource-based livelihoods, and exclusion from state services means that they are highly reliant on local ecosystem services, including freshwater from mountain glaciers (Korner and Ohsawa, 2005). In view of this dependence, it is worrying that ~370 million people live in watersheds where glaciers provide a at least 10% of annual discharge and ~119 million people live in watersheds where glacial meltwater comprises at least 50% of total discharge for at least one month per year (Ariza et al., 2013; La Frenierre and Mark, 2014; McKenzie et al., 2014).

Mountains are significant centers of biodiversity, with several ranges containing world-leading levels of species richness and endemism (Spehn et al., 2010). However, despite their diversity, mountain ecosystems are exceptionally sensitive to environmental change (Nagy and Grabherr, 2009). For example, numerous mountain flora and fauna are adapted to the unique thermal, sediment, and nutrient dynamics of snow- and ice-influenced rivers (Bundi, 2010), suggesting that changes in glacio-hydrological dynamics will significantly impact aquatic ecosystems (Milner et al., 2017; Robinson et al., 2010). Impacts on downstream marine ecosystems are also expected (O'Neel et al., 2015). It is concerning that the ecological roles of species reliant on cold water are largely unknown, and the possible consequences of their loss for higher trophic levels such as fish, amphibians, birds and mammals (including humans) are highly uncertain (Jacobsen et al., 2012). Given strong interdependencies between highland communities and mountain environments (Korner and Ohsawa, 2005), glacio-hydrological changes are likely to drive socio-ecological system level impacts.

2.3 Existing mountain-focused adaptation research

Adaptation research provides insights about how people and institutions respond to changes in the environment, including who adapts, how they adapt, and what effect their adaptations have on reducing harm or accessing new opportunities (Smit et al., 1999). Adaptations can take various forms, such as efforts to prevent loss, spread or share loss, diversify livelihoods, or migration to reduce exposure to climatic stimuli (Smit and Wandel, 2006). Adaptation research also elucidates how and why the ability to devise and implement adaptations varies according to socio-economic and political factors (e.g. access to information, poverty, marginalization), and therefore plays a key role in targeting efforts to increase adaptive capacity and reduce vulnerability (Engle, 2011; Kelly and Adger, 2000). There is also an emerging focus on the unintended consequences of adaptation, including how human adaptations impact ecosystems and the supply of ecosystem services that ultimately underpin human well-being (Barnett and O'Neill, 2010; Turner et al., 2010). For more, McDowell et al. (2016) provide a mountain-focused summary of core themes in the climate change adaptation literature.

According to McDowell et al.'s (2014) global assessment of adaptation in glaciated mountain regions, peer-reviewed publications documenting human adaptations are relatively rare in the mountain-focused literature (n = 36). However, this number does not reflect studies published in non-peer-reviewed reports, peer-reviewed studies that have been published since the McDowell et al. 2014 review, or studies published in non-English language journals. Here, contributions such as UNEP's Mountain Adaptation Outlook series and High Mountains Adaptation Partnership (HiMAP) publications, recent studies such as Mills-Novoa, *et al.* (2017), and non-English language works such as Llosa et al. (2009), are increasing our understanding of adaptation in mountain regions. The existing literature suggests that changes to hydrological systems are the most common climate-related issue driving adaptations; that most adaptations are reactionary rather than anticipatory; that most adaptations are carried out at the community level; and that adaptations are frequently embedded within responses to concurrent non-climatic stressors (McDowell et al., 2014). Although autonomous adaptations (i.e. devised without external support) have been most widely documented to date (*ibid.*), evidence of planned adaptations (i.e. deliberate policy development) is becoming more common, particularly in program reports and policy documents (e.g. Sviensson, 2015). Adaptation research is clustered in sub-ranges within a select number of mountainous countries (e.g. Cordillera Blanca, Peru), is methodologically heterogeneous, and is based primarily on individual case studies (McDowell et al., 2014). Little is known about the outcomes of adaptation initiatives (*ibid.*). Moreover, research focusing on the socio-ecological interdependencies, feedbacks, and tradeoffs inherent in adaptation to climate change are critically lacking, paralleling the broader adaptation literature (*ibid.*). Although mountain-focused adaptation research remains limited compared to other glaciated regions such as the Arctic (Ford et al., 2014), there is now a sufficient level of understanding to begin synthesizing key insights and identifying guiding principles for more robust adaptation research in rapidly changing high mountain watersheds.

2.4 Principles for robust mountain-focused adaptation research

Robust mountain-focused adaptation research is defined here as research that supports the identification, development, and implementation of ‘successful’ adaptations. We distinguish the role of research in *identifying* successful adaptations from its role in *developing* and *implementing* adaptations. The former relates to the capacity to recognise success, including the success of autonomous adaptations, whereas the latter points relate to the role of research in the process of adaptation planning. Here, we emphasize that research only plays a supporting role in adaptation planning, and that the achievement of successful adaptations hinges on far more than just robust research, for instance decision-making contexts and available resources. Finally, in lieu of a commonly accepted definition of successful adaptation (Olazabal et al., 2017), we draw on Adger et al. (2005) and Eriksen and Brown (2011) to distill five criteria of successful adaptation (see Moser and Boykoff 2013 for more on the challenges of defining and achieving 'success'):

- Effective - Adaptation achieves its goals.
- Efficient - Benefits of adaptation outweigh the cost of implementation.
- Equitable - Distributional consequences of adaptation benefit the most vulnerable.
- Legitimate - Inclusive decision-making processes underpin adaptation.
- Sustainable - Attentive to social and ecological needs now and into the future.

When these criteria are not met, responses to glacio-hydrological change may be ineffectual or even maladaptive. We argue that there are three guiding principles that must be addressed for research to be capable of supporting the identification, development, and implementation of successful adaptations to glacio-hydrological change.

2.4.1 Principle 1 - Attention to watershed-specific conditions

Adaptation research should be attentive to watershed-specific glacio-hydrological conditions; glacio-hydrological changes are context specific and therefore cannot be assumed to follow idealized trajectories of 'peak water'. For example, in the Peruvian Andes, rapid warming, relatively small glaciers, and high ice turnover rates, have led to short reaction times between climate forcing and mass balance/discharge changes (Casassa et al., 2009). Hydrological research suggests that glacial discharge in the Peruvian Andes has already passed peak water, and that discharge values will continue to decline as glaciers shrink and disappear (Casassa et al., 2009). In the Indus River watershed, streamflow is dominated by glacier melt, contributing 41% of total annual discharge in the river, with runoff projected to increase until at least 2080 due to accelerating melt of large glaciers in the upper basin (Koppes et al., 2015; Lutz et al., 2014). In this region, increasing discharge is consistent with the rising limb of the peak water curve. In the Central and Eastern Himalaya, the peak water signal is much weaker due to the relatively small proportion of glacially-derived runoff during peak discharge (i.e. during the summer monsoon) (Kaser et al., 2010). Given such variability, the integration of regional scale glaciological and hydro-meteorological observations is essential in order to accurately characterize contemporary hydrological changes at the watershed scale, complimenting local insights about socially-relevant hydrological dynamics (as per Mark et al., 2010). As well, regional scale research is needed to clarify the nature of hydrological changes experienced by aquatic and riparian ecosystems. Moreover, and critically, integrated regional climate, glaciological, and hydrological modeling is essential for understanding trajectories of change and informing evidence-based anticipatory adaptation planning. Here, addressing data gaps and integrating glacio-hydrological models into adaptation studies will be critical (Naz et al., 2014; Salzmann et al., 2014).

2.4.2 Principle 2 - Attention to the human dimensions of hydrological change

Adaptation research should consider the complex interplay between glacio-hydrological changes and socio-economic and political conditions. It is well established in the wider human dimensions of climate change literature that adaptive capacity (and therefore vulnerability) varies widely within and among communities due to the effects of power, marginalization, and difference (Adger, 2006; Ford and Smit, 2004a). In view of this, mountain-focused adaptation research must endeavor to understand the role of non-climatic factors in influencing how people experience and respond to glacio-hydrological change (McDowell et al., 2013). This requires fieldwork in climate-affected areas as well as the integration of local voices in problem identification, description, and resolution. Such 'human dimensions' studies in the mountain-focused literature include Mark et al. (2010) Macchi et al. (2015), and McDowell et al. (2013). Adaptation studies that do not assess social conditions will be incapable of identifying vulnerability hotspots, determining whether autonomous adaptations are adequate, or providing appropriate information for adaptation planning. For example, theory suggests (e.g. Adger, 2006; Ford and Smit, 2004b; Kelly and Adger, 2000; Ribot, 2010; Smit and Wandel, 2006) that regions experiencing significant hydrological changes may not be the areas most in need of assistance in developing adaptation initiatives. If residents in such regions have high levels of social and cultural capital, experience equitable socio-economic conditions, and are embedded within supportive social networks, their vulnerability to hydrological changes may be relatively low (such as some communities in the European Alps) (e.g. European Environment Agency, 2009). Conversely, through evaluating the human dimensions of glacio-hydrological change, researchers can recognise regions where high vulnerability to even minor hydrological changes is likely as a function of difficult non-climatic circumstances (for instance, several communities in the Eastern Himalaya) (e.g. McDowell et al., 2013). Understanding the socio-economic and political conditions that influence lived experiences of glacial-hydrological change is therefore a precondition of robust adaptation research.

2.4.3 Principle 3 - Attention to socio-ecological dynamics

Adaptation research should be attentive to interdependencies, feedbacks, and tradeoffs between human and ecological responses to glacio-hydrological change. This principle is particularly relevant in the context of mountain systems, where there are strong and consequential connections between highland communities and ecosystems (Palomo, 2017; Xu et al., 2009). For example, highland agriculture in the Peruvian Andes—which is threatened by glacio-hydrological changes—is essential for both household sustenance and the persistence of biodiversity-sustaining heterogeneity in the landscape (Bury et al., 2013; Korner and Ohsawa, 2005). Theory suggests (e.g. Berkes et al., 2008; Berkes et al., 2000; Folke, 2006; Gunderson and Holling, 2002; Liu et al., 2007; Walker et al., 2004) that when research does not attend to socio-ecological dynamics, there is an increased possibility that study findings will lead to adaptation projects that generate unintended consequences. For example, while building a large dam downstream of a retreating glacier may reduce the impacts of glacio-hydrological change for mountain communities, its effect on environmental flows will adversely impact downstream ecosystems (Poff and Zimmerman, 2010). This is an example of a maladaptive response that shifts the burden of environmental change from humans to ecosystems (Barnett and O'Neill, 2010; Turner et al., 2010). Likewise, without due attention to how ecosystems are changing in response to climate forcing, it will be difficult to devise adaptations that accommodate the needs of non-human organisms. However, research that is attentive to interdependencies, feedbacks, and tradeoffs between human and ecological systems will be better able to recognize such problems and, consequently, to inform the development of adaptations that are both socially and ecologically tenable (Berkes et al., 2008). For example, such research can help to identify opportunities for leveraging synergies between human well-being, ecosystem services, and biodiversity conservation. Thus, to avoid unintended consequences and maladaptation, and to capitalize on the benefits of coupled systems analysis, we strongly suggest that future mountain-focused adaptation research embrace a socio-ecological systems lens.

Combined, the principles described here contribute to understanding all criteria of successful adaptation and therefore provide a solid analytical basis for understanding and informing responses to glacio-hydrological change (Table 2.1).

Table 2.1: Relationship of principles to criteria of successful adaptation

Principle	Main relationship to Criteria of Success	Example	Illustrative studies
Attention to watershed-specific conditions	Effectiveness Efficiency	Assessment of watershed-specific glacio-hydrological dynamics enhances understanding of current climate stimuli and trajectories of hydrological change, supporting evidence-based adaptation planning.	Naz et al., 2014 Immerzeel et al., 2010 Viviroli and Weingartner, 2004
Attention to the human dimensions of hydrological change	Equitability Legitimacy	Inclusion of local perspectives in adaptation research supports the identification of vulnerability hotspots as well as appreciation for the diverse	Mark et al., 2010 McDowell et al., 2013 Macchi et al., 2015

		concerns, preferences, and aspirations of climate-affected communities.	
Attention to socio-ecological dynamics	Sustainability	Evaluation of socio-ecological system dynamics helps identify critical social and ecological interdependencies as well as adaptation options that attend to both human well-being and biodiversity conservation.	Presently undeveloped in the mountain-focused adaptation literature. Cognate work includes: Bury et al., 2013 Carey et al., 2012 Xu et al., 2009

2.5 Discussion

The guiding principles outlined above provide a necessary analytical framework for studies intent on supporting the identification, development, and implementation of successful adaptations to glacio-hydrological change in mountain regions. The principles are intentionally broad to allow for project specific interpretations, the inclusion of multiple conceptual and theoretical traditions, and engagement with diverse methodologies. Nonetheless, we emphasize that the integration of all three principles is essential for robust mountain-focused adaptation research (i.e. to generate information that engages with all five criteria of successful adaptation). For example, scientific research on glacio-hydrological change is of limited utility for adaptation planning if it is not understood in the context of human and ecological water needs. Likewise, although socio-economic and political conditions have a strong influence on lived experiences of climate change, hydrological changes are a material reality affecting life in mountains, suggesting that scientific research on glacio-hydrological change should continue to inform adaptation plans. Moreover, human adaptations to glacio-hydrological change could become a major driver of environmental degradation if socio-ecological dynamics and unintended consequences are not considered and evaluated in research that supports adaptation planning.

We expect that such complexities are the norm and therefore contend that integrating insights from hydrological sciences, the human dimensions of climate change, and socio-ecological systems research is essential for understanding and supporting adaptations that improve human well-being while also protecting fragile mountain ecosystems. At present, studies integrating principles one (watershed science) and two (human dimensions) are evident in the mountain-focused adaptation literature (e.g. Carey et al., 2014a). However, despite growing consensus about the importance of integrated systems approaches in mountain research (Gleeson et al., 2016; Mountain Sentinels, 2017), substantive engagement with principle three (socio-ecological systems) is conspicuously lacking. Consequently, despite an expanding corpus of good and informative mountain-focused adaptation research, studies meeting our definition of robust adaptation research are presently lacking. The situation is indicative of the substantial the challenges of transdisciplinary research but also an exciting opportunity for productive collaborations and meaningful innovation.

Finally, although this paper focused on adaptation, in some instances socio-ecological conditions may require responses that are transformational in nature (see (Feola, 2015; Kates et al., 2012; O'Brien, 2012; Walker et al., 2004) for more). Studies embracing the principles described herein will be better able to recognize situations where adaptive responses fall short, for whom/what, and why.

2.6 Conclusion

This paper outlined three guiding principles for studies intent on supporting the identification, development, and implementation of successful adaptations to changes in mountain glaciers. In doing so, it responded to calls for more integrative climate change adaptation research in mountain environments, identifying why insights from regional scale glaciological and hydro-meteorological observations and modeling, the human dimensions of climate change, and socio-ecological systems literature will be essential for achieving a robust understanding of adaptation to glacio-hydrological change in mountain regions. However, our emphasis on the integration of science, society, and system dynamics has broader applicability, and can be used to frame research evaluating adaptation to other climate-related changes in and beyond mountain regions. We suspect that the principles outlined in this paper will resonate with adaptation researchers working in mountain environments and look forward to seeing them integrated into future assessments of adaptation to glacio-hydrological change in mountain regions.

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).

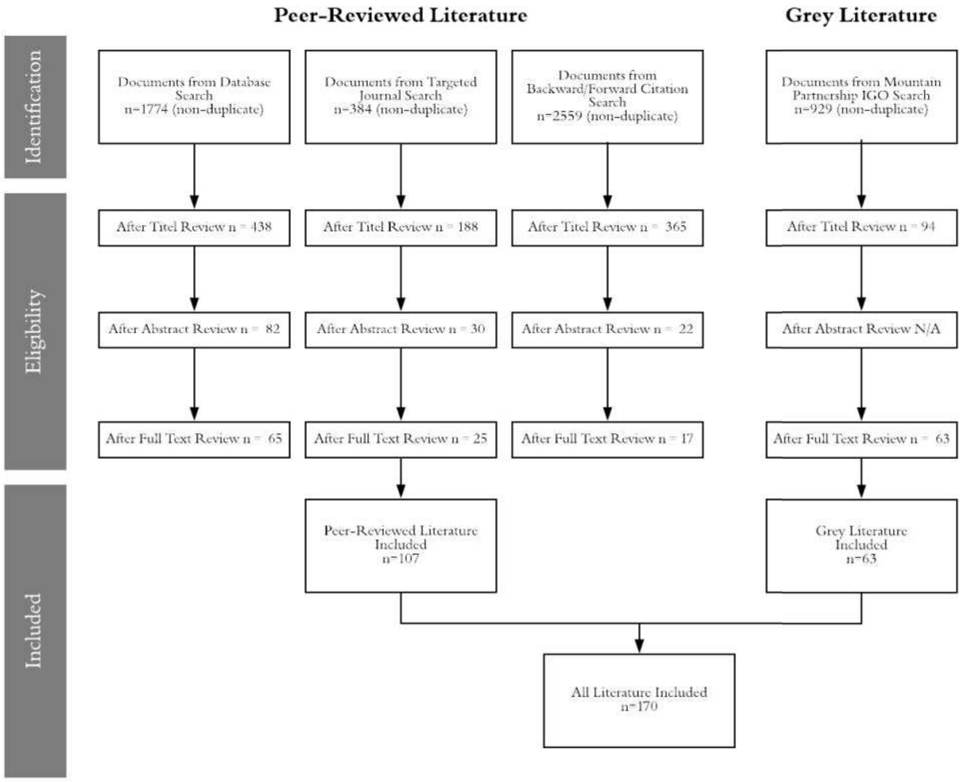

Figure 3.1: Document identification, eligibility, and inclusion progression

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).

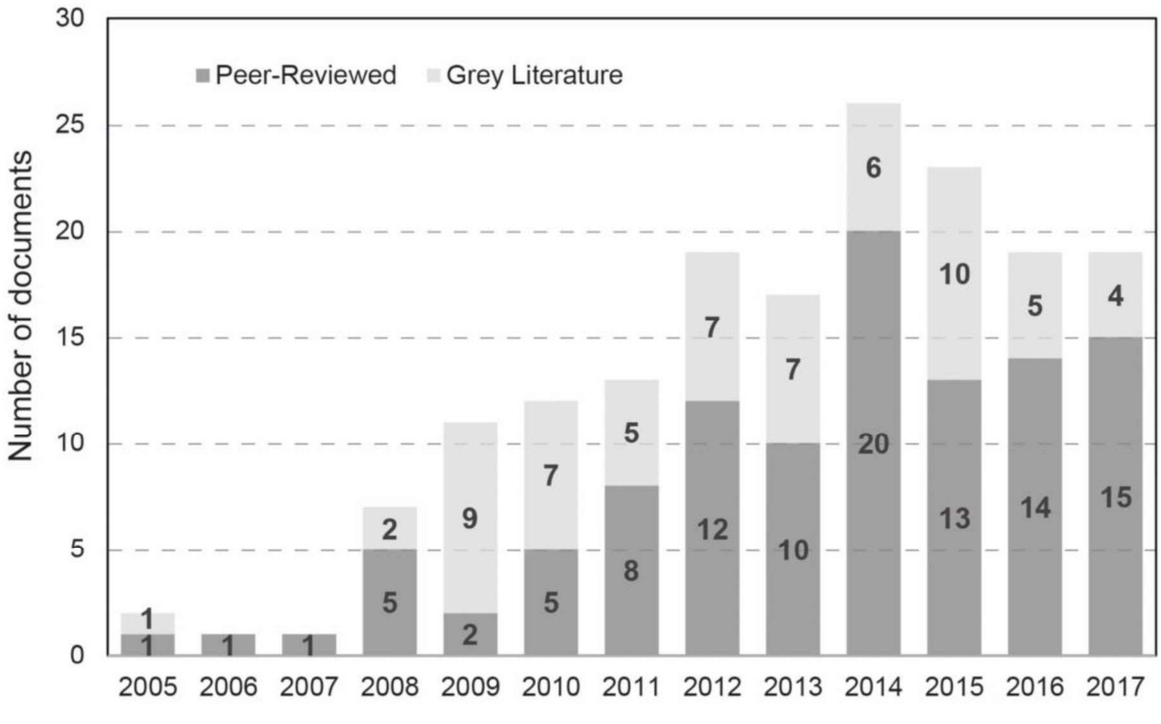

Figure 3.2: Peer-reviewed and grey literature by publication year

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/).

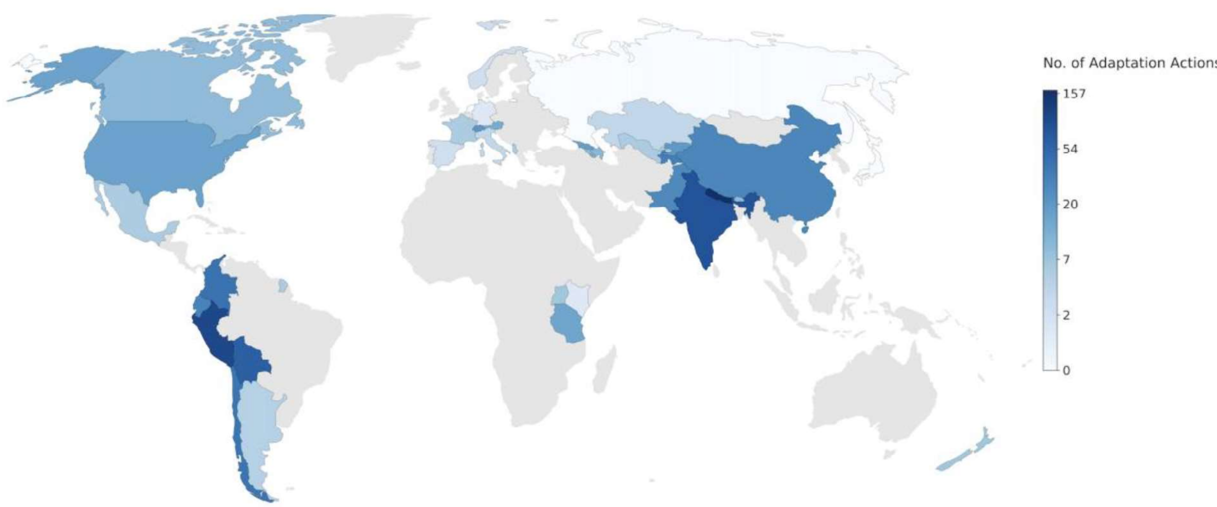

Figure 3.3: Discrete adaptations per country

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.

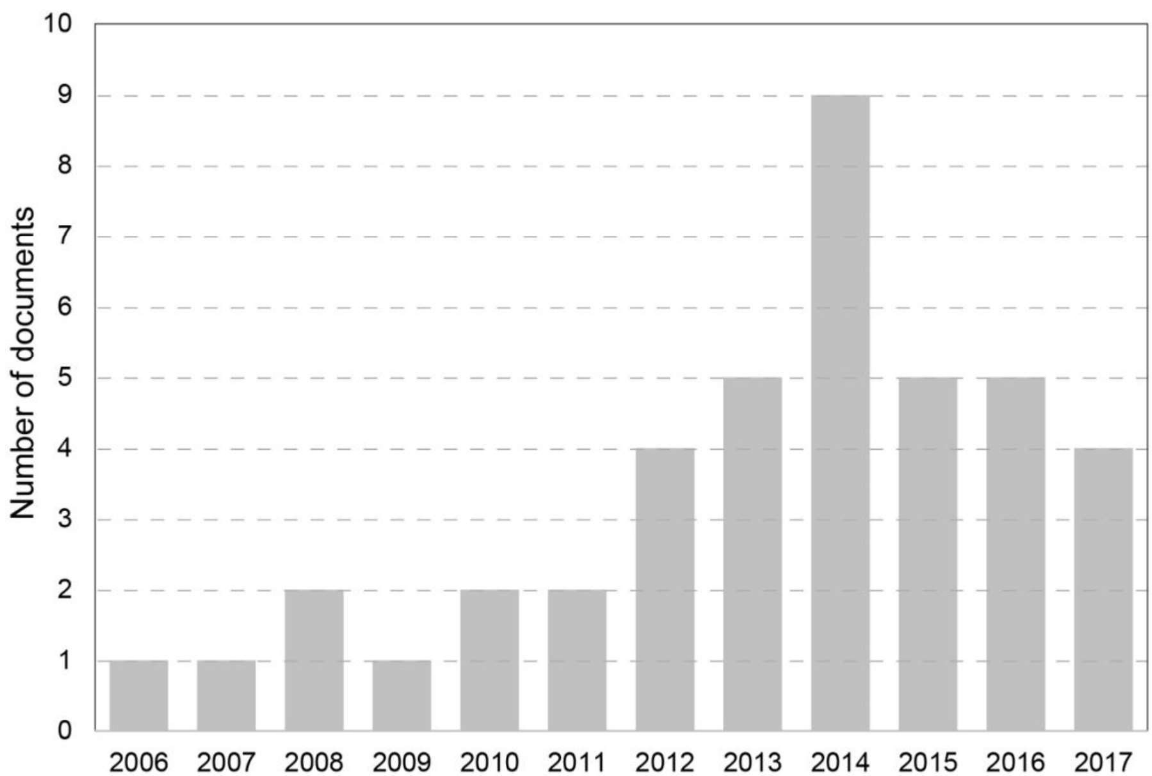

Figure 3.4: Mountain focused adaptation research by publication year

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.

Chapter 4: Lived experiences of 'peak water' in the high mountains of Nepal and Peru

4.1 Preface - A note on health complications

I planned and fully prepared for six months of fieldwork in the high mountains of Nepal and Peru between September 2018 and June 2019 (3 months in each field site). In June 2018, three months prior my fieldwork in Nepal, I underwent an emergency appendectomy. Thinking I had recovered sufficiently for fieldwork, I left for Nepal in September 2018. I conducted key informant interviews and other research and planning activities in Kathmandu, before departing for fieldwork in upper Manaslu in early October. My study region was only accessible by a day-long 4x4 ride from Kathmandu; my study communities were a further 6 to 8 day walk from the nearest road. In the course of packing and lifting duffle bags, the 4x4 drive, and the initial days of trekking, I began to develop significant abdominal pain and mobility challenges.

Given my recent surgery, persistent and undiagnosed abdominal pain, and non-existent medical facilities, I made the decision to return to Kathmandu for medical evaluation. Before leaving the upper Manaslu region, I trained my research assistant to conduct the interviews and focus groups I had planned to carry out, doing my best to provide a lucid training while navigating a stressful health situation. After arriving in Kathmandu, I was examined by a doctor who affirmed by decision to leave the mountains; he advised me to return to Canada for further assessment. I had spent 1.5 months in Nepal. I subsequently underwent a second abdominal surgery to repair structural problems that had developed after the appendectomy (a cholecystectomy was also deemed necessary and was performed during this surgery). Naturally, I was advised not to travel to Peru for fieldwork. I subsequently trained my Peruvian research assistant by Skype to carry out interviews and focus groups on my behalf. I communicated with my Nepalese and Peruvian research assistants—who ultimately became core local research partners—through the data collection process to provide guidance and to assist with questions (Note: I had some contextual familiarity with both study sites from previous trips to the Nepal Himalayas and Peruvian Andes).

These health complications significantly impacted my research plans, dramatically altered my PhD experience, and affected the nature of the study reported below (attendant limitations are discussed in the Conclusion). The experience was humbling. However, it also deepened my understanding of, experience with, and commitment to, research that puts local people at the center of research activities. This, perhaps, is the silver lining.

4.2 Introduction

The transformative effects of climate change on high mountain glacial hydrology are increasingly well understood and documented (Huss et al., 2017; Immerzeel et al., 2013; Milner et al., 2017; Vuille et al., 2018), with peak water emerging as an accepted framework for the hydrological implications of glacial recession (Hock et al., 2019; Huss and Hock, 2018). The peak water model illustrates the hydrological response of glacier-fed rivers to climate change over many years, indicating that warming initially drives increasing discharge until a glacier mass loss threshold is surpassed and discharge falls below values observed prior to contemporary climate warming (Baraer et al., 2012). These dynamics also have inter-annual effects on glacier-fed rivers, with glacier recession driving increases in discharge variability as well as seasonal shifts in regional hydrographs (Jansson et al., 2003; La Frenierre and Mark, 2014; van Tiel et al.). Glacio-hydrological studies have revealed where and when peak water is expected to occur across glaciated mountain ranges (e.g. Baraer et al., 2012; Bliss et al., 2014; Chesnokova et al., 2020; Duethmann et al., 2016; Farinotti et al., 2012; Huss and Hock, 2018; Lutz et al., 2014; Ragettli et al., 2016), providing essential insights into the varied geography of hydrological changes across glaciated mountain areas. They have also raised the spectre of widespread socio-hydrological disruptions for the 671 million people living in glaciated mountain regions (Hock et al., 2019), many of whom are already struggling with poverty, social exclusion, and the inherent challenges of living in highland environments (Adler et al., 2019; Carey et al., 2017; Huggel et al., 2019; McDowell et al., 2019 - Chapter 3; Rasul and Molden, 2019; Vuille et al., 2018). In this context, research on peak water is beginning to inform thinking about the adaptation needs of populations in regions with glacier-influenced hydrological systems (Hock et al., 2019). This paper evaluates this development through an analysis of lived experiences of peak water in high mountain communities in Nepal and Peru; it examines 1) whether a focus on peak water *per se* provides a sufficient analytical lens for understanding lived experiences of contemporary climate-related hydrological changes as well as 2) whether the characteristics of vulnerabilities hypothesized in the glacio-hydrological modeling literature provide an appropriate basis for adaptation planning.

Many assessments of peak water are focused primarily on defining the spatial and temporal dynamics of discharge variability in glacier-fed rivers, but several also advance implicit claims about human vulnerability and consequent adaptation needs. These claims largely reflect ideas developed in earlier efforts to define the importance of mountain-sourced water for downstream populations (e.g. Kaser et al., 2010; Viviroli et al., 2007). Three characteristics of vulnerability are common in the emerging discourse about vulnerability to peak water: vulnerability will be driven by reductions in *water availability* in glacier-fed rivers; will be concentrated in *arid regions* where glacier-fed rivers help to offset moisture deficits; and will be most pronounced in populous areas *downstream* of mountain areas where water demand is greatest. These hypotheses have come from model-driven, impacts-focused analyses that have conceptualized vulnerability primarily as a consequence of hydrological changes; they result in a specific geography of vulnerability, with implications for where and for whom adaptation aid might be mobilized. Importantly, however, contemporary work on the human dimensions of climate change has demonstrated that vulnerabilities often emerge from the interplay of diverse environmental and social dynamics in specific socio-ecological contexts. This suggests that assumptions about vulnerability embedded in impacts-focused assessments could be leading to incomplete or inaccurate portrayals of vulnerability to glacio-hydrological change, as evidenced by findings from more contextualized studies (e.g. Bury et al., 2013; Carey et al., 2014; Drenkhan et al., 2015; Mark et al., 2010; Mark et al., 2017; McDowell et al., 2013). Therefore, this study draws on a contextual vulnerability approach (Ford and Smit, 2004; O'Brien et al., 2007; Smit and Wandel, 2006; Turner et al., 2003) and multi-sited fieldwork with communities in the Nepal Himalayas and Peruvian Andes to advance understanding of lived experiences of peak water in high mountains. Herein, the usage of 'lived experiences' refers broadly to individual- and community-level experiences stemming from encounters between mountain people and changing hydrological systems. This terminology is used as shorthand for our focus on the human dimensions of hydrological change, and does not indicate deeply ethnographic work, for example.

The Nepal Himalayas and Peruvian Andes are globally significant ‘Water Towers’ as well as conspicuous bellwethers of climate-related hydrological changes in mountain systems (Immerzeel et al., 2019; Viviroli et al., 2019). They are also home to millions of highland residents who rely directly on rapidly changing pro-glacial environments (FAO, 2015; Scott et al., 2019; Vuille et al., 2018). According to the in the IPCC Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC) (Hock et al., 2019), annual discharge in glacier-fed rivers in Nepal is generally increasing while annual discharge in glacier-fed rivers in Peru is generally declining. Thus, this multi-sited, community-based assessment provides insights into who is vulnerable (or adaptable), to what stresses, why, and with what implications along both the ‘rising’ and ‘falling’ limbs of the peak water profile.

This study contributes to a growing literature on the human dimensions of hydrological change in mountain regions (see Carey et al., 2017; McDowell et al., 2019 - Chapter 3), and provides insights that are urgently needed to identify, understand, and address differentiated vulnerabilities to hydrological changes within and across high mountain communities.

4.3 Research approach

4.3.1 Vulnerability approach

This study uses a vulnerability approach to evaluate lived experiences of peak water in the high mountains of Nepal and Peru. Vulnerability research draws primarily on antecedent work in natural hazards, political economy, political ecology, and development literatures (Adger, 2006;

Ribot, 2010; Smit and Wandel, 2006), and is characterized by two distinct research paradigms: impacts-driven approaches and contextual vulnerability approaches (these approaches have also been referred to as ‘end point’ and ‘starting point’, ‘Type I’ and ‘Type II’) (Ford et al., 2010; Füssel and Klein, 2006; Kelly and Adger, 2000; O'Brien et al., 2007).

‘Impacts-driven’ approaches are rooted in the natural sciences and conceptualize vulnerability as an outcome of exposure to climatic stimuli that are assumed a priori to be relevant for society (Ford et al., 2010; O'Brien et al., 2007). Here, vulnerability is the endpoint of analyses which are focused primarily on the effects of climate change *on* society. Many studies evaluating the implications of glacio-hydrological change for mountain communities work within an impacts-oriented framework, and doing so have effectively characterized the nature of hydrological changes taking place in mountain systems. However, contemporary theoretical and empirical work on the human dimensions of climate change has illustrated shortcomings of impacts-driven approaches in realistically portraying the nature, causes, and consequences of vulnerability (e.g. Bassett and Fogelman, 2013; Ensor et al., 2019). In this context, we laud the pioneering impacts-driven work of the glacio-hydrological modeling community, but aim to demonstrate additional ways of approaching the problem of hydrological change in high mountains.

‘Contextual’ approaches, which are rooted in social science traditions, treat vulnerability as a pre-existing condition *of* society which precedes climate-related stresses. Here, the analytical starting point is social factors that create, magnify, or attenuate susceptibility to the effects of climate change, including poverty, gender and ethnic discrimination, and educational attainment (Adger, 2006; Ribot, 2010). Contextual vulnerability approaches examine the relationship between exposure-sensitivity, adaptive capacity, and vulnerability (Smit and Wandel, 2006). Exposure describes the nature of climate-related changes (e.g. magnitude, frequency) and defines whether such changes intersect with inhabited areas (Ford and Smit, 2004). Sensitivity clarifies whether exposure is of consequence to the persons in question and is often linked to characteristics of resource use and livelihoods as well as social conditions that determine proximity to exposures. For example, land in flood-prone areas may be inexpensive, leading to a concentration of low-income residents in such areas. Adaptive capacity refers to the ability to respond to exposure-sensitivities in order to reduce harm or take advantage of new opportunities; this capacity can vary greatly among and within populations according to factors such as access to information and financial and material resources (Adger et al., 2007; Smit and Wandel, 2006).

Contextual approaches emphasize the importance of sensitivity and adaptive capacity in revealing how and why similar exposures lead to differentiated experiences of environmental change (Engle, 2011). Although the factors that influence sensitivity and adaptive capacity manifest locally, they are often linked to socio-economic and political stressors operating across space and time (Adger et al., 2008; O'Brien and Leichenko, 2000). For example, Ford et al. (2013) show that the vulnerability of Inuit hunters to changing sea ice conditions is closely linked to colonial legacies that have eroded traditional knowledge and land-based skills, with consequent effects on the ability of hunters to identify and respond to unsafe sea ice conditions. Attentiveness to cross-scale connections between climatic and non-climatic stressors is a core tenet of contextual vulnerability approaches (Adger et al., 2008; Ford et al., 2018).

The relationship between exposure-sensitivity and adaptive capacity firmly locates vulnerability within the dynamics of society; however, the nature and magnitude of climatic exposures matter—holding sensitivity and adaptive capacity constant, larger exposures will lead to greater vulnerability. Thus, vulnerability approaches still rely on insights from natural science research that characterizes the nature and magnitude of climatic stimuli (e.g. the glacio-hydrological modeling work discussed herein). Notwithstanding, larger climatic exposures are not *necessarily* linked to greater vulnerability; low sensitivity or high adaptive capacity can render significant climatic exposures inconsequential. For example, ski areas in the Pyrenees and French Alps have been able to remain open despite major changes in snowfall and snow cover given their access to artificial snowmaking machinery (Spandre et al., 2019). Conversely, seemingly minor exposures can elicit significant vulnerabilities if sensitivity is especially high or adaptive capacity especially low. For example, declining discharge in snow-fed streams near communities in the Khumbu region of Nepal has presented a formidable challenge for elderly residents who find it difficult to reach reliable water sources that are only marginally further from their homes (McDowell et al., 2013).

A contextual vulnerability approach provides a cogent theoretical foundation for making sense of the complex human-environment dynamics that influence lived experiences of peak water. It also enables the generation of insights capable of informing appropriate, effective, and durable responses to glacio-hydrological change in mountain regions, consistent with objectives stated in the Paris Agreement's Global Goal on Adaptation (UNFCCC, 2015, Article 7), research needs identified in the IPCC SROCC 'High Mountain Areas' chapter (Hock et al., 2019), and, indeed, calls for more cross-disciplinary research from the glacio-hydrological modeling community (e.g.

Huss and Hock, 2018; Vuille et al., 2018). For these reasons, this study uses a contextual vulnerability approach to evaluate the human dimensions of glacio-hydrological change in the high mountains of Nepal and Peru.

We acknowledge that other literatures—especially those that examine socio-ecological systems (as per Alessa et al., 2018; Klein et al., 2019; McDowell and Koppes, 2017 - Chapter 2), ecosystem services (e.g. Palomo, 2017), cumulative effects (Clerici et al., 2019), disaster risk reduction (e.g. Hewitt and Mehta, 2012), and risk perception (e.g. Scolobig et al., 2012)—are relevant to understanding lived experience of hydrological change. Although we do not engage substantively with these literatures herein, we weave in occasional insights and concepts from scholarly traditions beyond vulnerability-based approaches.

4.3.2 Multi-sited case study research

Contextual vulnerability research tends to focus on specific place-based case studies where the implications of multiple processes of change can be observed in particular contexts. Such vulnerability assessments prioritize the integration of local knowledge and perceptions, provide rich insights into lived realities of climate change, and aim to identify adaptation options that are meaningful to affected individuals and communities (Ford et al., 2010; O'Brien et al., 2007).

Case studies provide detailed understanding of processes not readily acquired from other methods and are useful for evaluating the consistency of hypothesized phenomena as well as generating nuanced information that can be used to advance scientific understanding more broadly

(Ford et al., 2010). They are also ethically important, as they provide opportunities for local and indigenous people to be involved in the production of knowledge about their experiences of climate change, consistent with tenets of the United Nations Declaration on the Rights of Indigenous Peoples (UN General Assembly, 2007). For these reasons, community-based case-study research is a well-established methodological approach in vulnerability research (McDowell et al., 2016). However, the high contextual specificity of individual case studies can make it difficult to generalize from case study findings (Stake, 2013). Multi-sited case studies are one way of addressing this concern.

We adopted a multi-sited community-based research approach to evaluate the consistency of hypothesized vulnerabilities to peak water with lived realities of hydrological change in diverse contexts. Multi-sited case studies evaluate defined phenomena that are common to two or more real-world settings (Stake, 2013). Individual case study sites have unique characteristics (e.g. socio-economic development status) as well as characteristics that are common across sites (e.g. located in glaciated mountain areas) (Mills et al., 2010). The same units of analysis, data collection procedures, and reporting approaches are used for all sites, enabling comparable site-specific insights as well as valid cross-site synthesis (Yin, 2014). By combining systematic methods with research in multiple socio-ecological contexts, multi-sited research supports the identification of salient similarities and differences across study sites, leading to a richer and deeper understanding of phenomenon of interest (Mills et al., 2010).

4.4 Study Sites: Upper Manaslu and Cordillera Huayhuash

This study evaluates lived experiences of peak water in the upper Manaslu region of the Nepal Himalaya and the Cordillera Huayhuash region of the Peruvian Andes. These regions are characterized by significant glaciation and glacial retreat, tremendous biocultural diversity, and reliance on resource-based economies (INAIGEM, 2018; Sharma et al., 2019), hallmarks of many high mountain regions (Hock et al., 2019; Klein et al., 2019; Martín-López et al., 2019). However, regional peak water dynamics differ considerably, with discharge across the Nepal Himalaya generally increasing and discharge across the Peruvian Andes generally decreasing (Huss and Hock, 2018) (Figure 4.1). Thus, these study sites support our efforts to characterize life in high mountain communities along both the rising and falling limbs of the peak water profile. These particular regions were selected to augment and diversify existing mountain-focused human dimensions of climate change research, which is currently concentrated in a limited number of mountain regions (e.g. Cordillera Blanca) (Carey et al., 2017; McDowell et al., 2019). The selection of specific study communities aimed to capture some of the socio-ecological diversity within each study region. To achieve this aim, specific communities were identified in consultation with local research partners D. Lama and G. Jiménez.

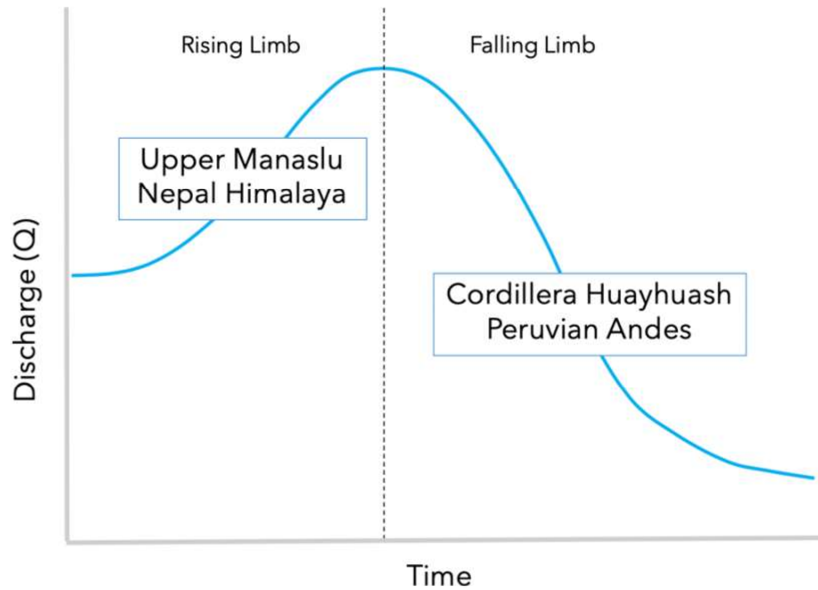

Figure 4.1: Location of study sites on hypothetical peak water profile

4.4.1 Upper Manaslu, Nepal Himalaya

The upper Manaslu region (~28˚ 26′ N, 84˚ 54′ E) is located in the central Nepal Himalayas approximately 100 km from the capital city of Kathmandu. It occupies ∼1663 km² of mountainous terrain in the upper Ghorka District, is the location of Mt Manaslu (8,156m), and is home to ~9,000 highland residents who rely heavily on agropastoral livelihoods (NTNC, 2019). Its complex terrain and extreme elevation range has led to high levels of biodiversity, including over 2,000 species of plants, 39 mammals, and 201 birds (*ibid*.). In view of this diversity and with the aim of improving well-being in rural communities, the region was declared a conservation area—Manaslu Conservation Area (MCA)—in 1998. However, the region remains relatively poor and underserviced (KC and Thapa Parajuli, 2015). Compounding long-standing socio-economic challenges, the Ghorka District was the epicenter of the devastating April 2015 Nepal earthquake, an event that caused widespread destruction and trauma and continues to influence regional socio-economic realities in upper Manaslu (Bennike, 2017). Moreover, socio-ecological characteristics are being reshaped by road building efforts that aim to connect lowland Nepal and India to China (Bennike, 2018, 2019), a process wrapped up in Nepalese state-building exercises more broadly (Beazley and Lassoie, 2017; Campbell, 2010).

The region has summer accumulation type glaciers (maximum accumulation and ablation are synchronous) and hydrological dynamics that are strongly influenced by the Asian Monsoon (Rangwala et al., 2015). Total discharge and proportional contributions of glacier melt to river flow are greatest during the summer months when warm temperature and maximum precipitation coincide (Scott et al., 2019). Recent work by Robson et al. (2018) suggests that glacier coverage in upper Manaslu declined by 6.7% between 1999 and 2013, consistent with other assessment of glacial recession in the central Himalayas, which indicate that glacier area in the region has been declining at a rate of ~0.4% per year for the 1970-2010 period (see Bolch et al., 2019). Because the region has large glaciers, melt water generation is expected to increase with climate forcing for several decades (Hock et al., 2019). Indeed, Huss and Hock (2018)—who calculated runoff for all glaciers in the Randolph Glacier Inventory until year 2100—found that annual glacier runoff is projected to increase until at least mid-century, followed by steady declines thereafter. This finding is reinforced by glacio-hydrological modeling studies focused specifically on the Himalayan region. For example, Immerzeel et al. (2013), Lutz et al. (2014), and Ragettli et al. (2016) all found melt water generation trends consistent with the rising limb of the peak water profile. Notwithstanding this general pattern, the extreme topographical, glaciological, and climatological diversity of the Nepal Himalaya leads to substantial variability in meltwater dynamics across the range (Scott et al., 2019).

The study communities are located in the Nubri and Tsum valleys. The ethnic Tibetan residents of these remote valleys on the border of China's Tibet Autonomous Region have limited access to basic services such as health care facilities and formal education (Childs, 2004). Here, agriculture, pastoralism, the collection of non-timber forest products (e.g. 'yartsa gunbu' a caterpillar fungus that is prized in Chinese medicine), and trekking support are livelihood activities that enable residents to persist despite limited state support and the demands of life in high mountain environments (Childs and Choedup, 2014). Samagaun (pop. ~1,100) is located at an elevation of 3,500m in the more frequently visited Nubri Valley, directly downstream from large, rapidly retreating glaciers flanking the east face of Mt Manaslu. Chhule (pop. ~500) is located in the seldom visited Tsum Valley, where strong Buddhist traditions dictate life under the smaller glaciers of the Buddha, Ganesh, and Sringi Himal (Plachta, 2018). Samagaun is a community transitioning under the influence of an emerging trekking economy (KC and Thapa Parajuli, 2015) while Chhule represents a community where customary ways have been less affected by Nepal's expanding tourism economy. Given their distinctive upstream glacial environments and differing social conditions, Samagaun and Chhule represent some of the socio-ecological diversity of the upper Manaslu region (Figure 4.2).

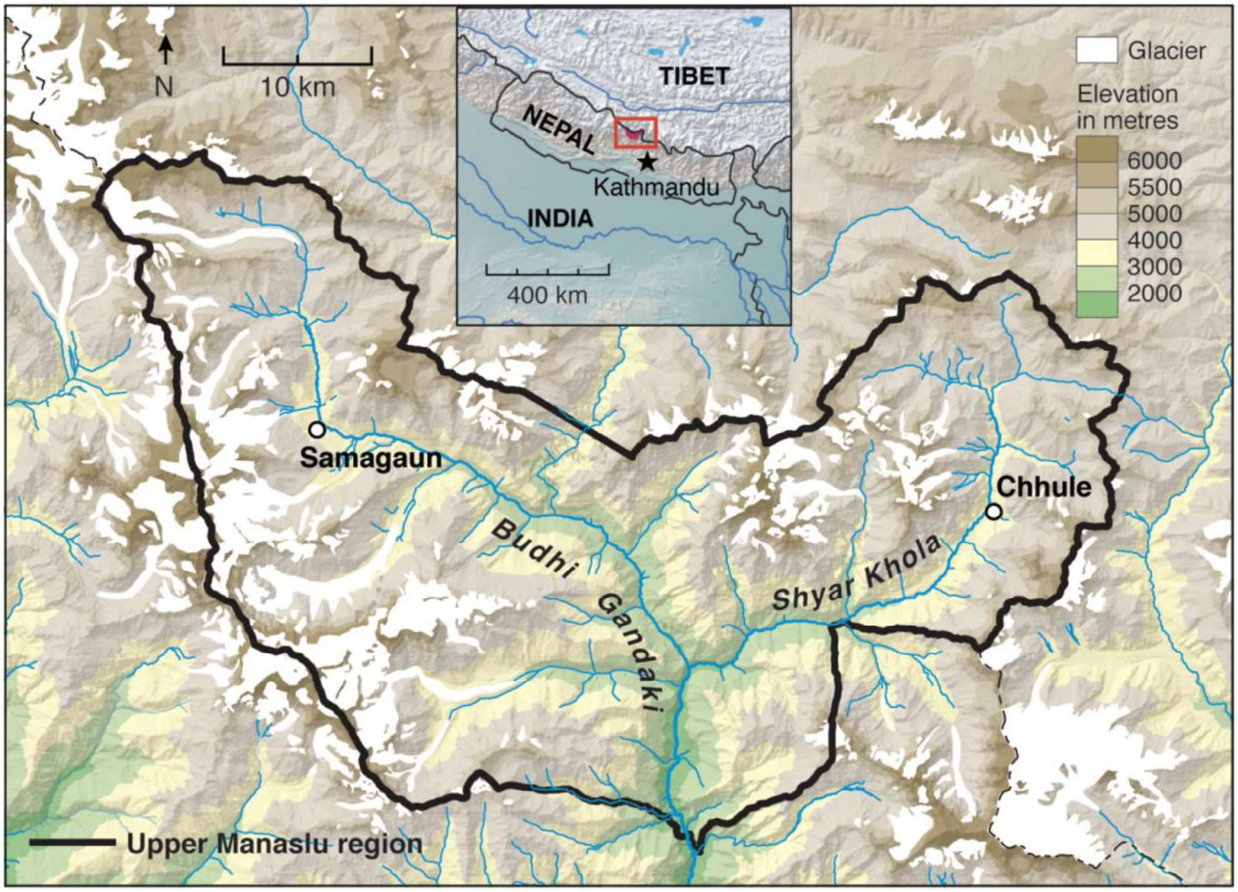

Figure 4.2: Upper Manaslu, Nepal – Region and target communities

Map data sources: Nepal Department of National Parks and Wildlife Conservation (DNPCWC), Randolph Glacier Inventory 6.0, OpenStreetMap, and NASA Shuttle Radar Topography Mission (SRTM); Compiled by Eric Leinberger

4.4.2 Cordillera Huayhuash, Peruvian Andes

The Cordillera Huayhuash region (~10˚ 16′ S, 76˚ 57′ W) is located in the central Peruvian Andes approximately 190 km from the capital city of Lima. It covers 1,167 km²; spans the Ancash, Lima, and Huanuco administrative districts; and is home to around 13,000 mountain residents (INAIGEM, 2018). It is also the location of Peru's second tallest mountain, Yerupajá (6,634m), as well as 5 other peaks over 6,000m. The regions extreme vertical relief gives rise to at least six distinct ecological zones and subsequently high biodiversity, including more than 1000 plant species, 60 bird species, and 12 mammal species (Bury, 2006, 2008). Most human habitation is concentrated along the lower flanks of the range (*ibid*.). In 2002, a national conservation zone was established ('Reserved Zone of the Cordillera Huayhuash'); local communities responded by devising their own management scheme to oversee tourism and resource development, consistent with a history of strained relations with the Peruvian government (see Bury and Norris, 2013 for elaboration).

The region experiences a pronounced dry season between April and September with a rainy period taking place between October and March; year-round ablation type glaciers augment stream flow in dry periods and increase overall base flow (Rabatel et al., 2017). Glacial recession in the Cordillera Huayhuash has been significant, with ~39% of glacier cover lost since 1962 (~85km km^2 in 1962 to ~53 km^2 2018) (INAIGEM, 2018). Because of their relatively small size (Rabatel et al., 2017), melt water generation from glaciers in the region is expected to peak quickly (Hock et al., 2019). Indeed, Huss and Hock (2018) found that peak water in the low latitude Andes was reached for 82-95% of the glaciated area before 2019. This finding is reinforced by glacio-hydrological modeling studies focused specifically on the tropical Andes. For example, Baraer et al. (2012), working just north of the Cordillera Huayhuash in the Cordillera Blanca, found that glacier recession has been sufficient for glacier-fed rivers to exhibit decreasing dry-season discharge since the 1980s. Likewise, Polk et al. (2017) and Frans et al. (2015) find meltwater production trends from Andean glaciers that are consistent with the falling limb of the peak water profile. Although the overall pattern is of declining meltwater generation (Hock et al., 2019), variation in the results of regional studies highlight the sensitivity of projections to methodologies, assumptions, and climate scenarios (Vuille et al., 2018).

The study communities are Pacllon and Huayllapa, 'campesino' communities that are inhabited primarily by Indigenous Quechua residents. In both communities there is high reliance on agriculture and pastoralism, as minimal state services and often acrimonious relations with the central government and mining companies have limited other economic development opportunities (Bury and Norris, 2013). Pacllon (pop. ~1,700) is located downstream of the heavily glaciated Mt Jirishanca (6,094m), along the Rio Achin at an elevation of approximately 3,300m. Livelihoods in Pacllon are focused on agriculture and pastoralism; trekking traffic is limited. Huayllapa (pop. ~800) is located in an adjacent valley to the south along the Rio Huayllapa at an elevation of approximately 3,600m. Agriculture and pastoral activities are the backbone of local livelihoods, but a mixed cash-subsistence based economy has begun emerging following an influx of intrepid trekkers set on traveling beyond well-established hiking routes in the Cordillera Blanca. Pacllon and Huayllapa are together representative of some of the socio-ecological diversity of the Cordillera Huayhuash (Figure 4.3).

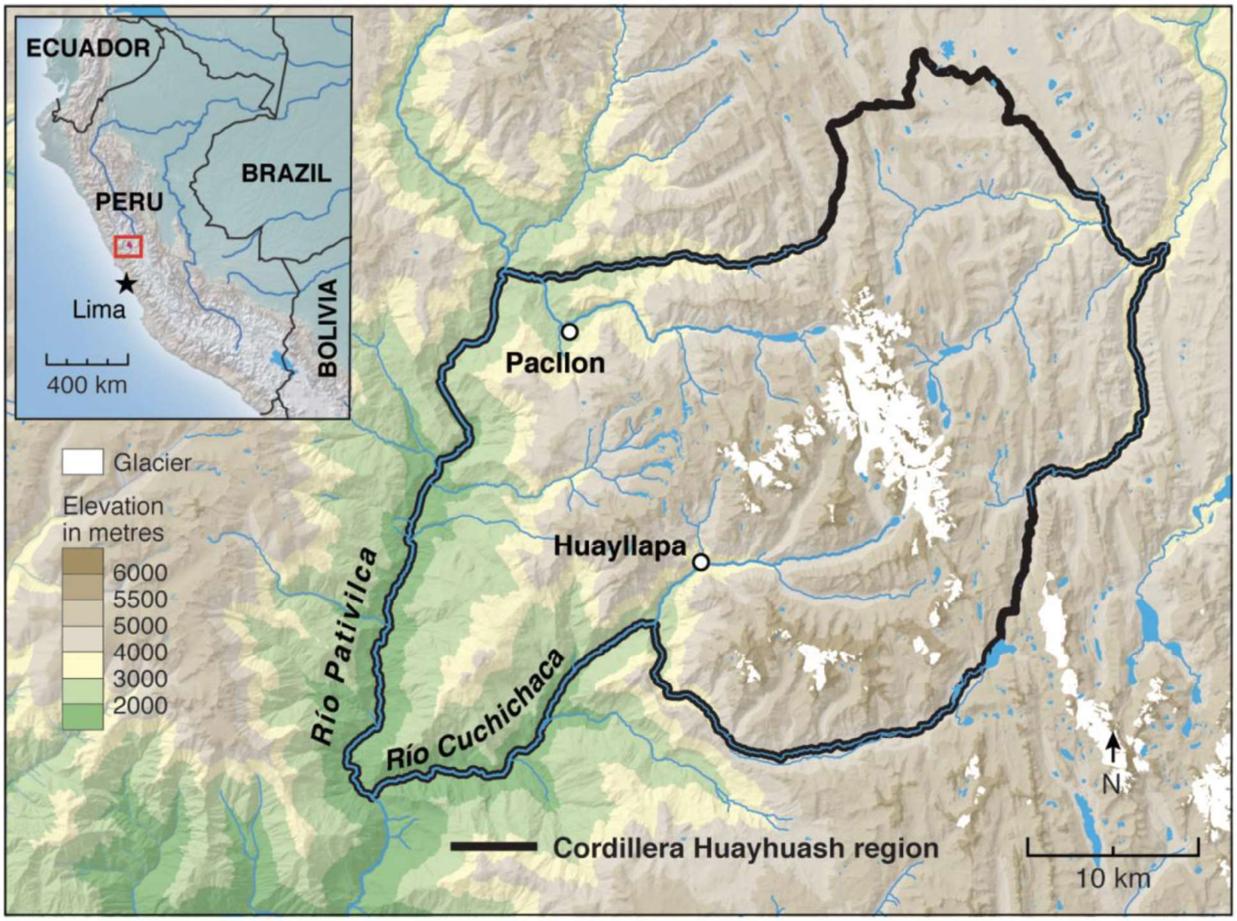

Figure 4.3: Cordillera Huayhuash, Peru – Region and target communities

Map data sources: INAIGEM 2018, Randolph Glacier Inventory 6.0, OpenStreetMap, and NASA Shuttle Radar Topography Mission (SRTM); Compiled by Eric Leinberger

4.5 Methods

This study utilized household interviews, key informant interviews, and focus groups to reveal lived experiences of peak water in the high mountains of Nepal and Peru. The same research protocols were employed in both study regions, enabling direct comparison of results from two distinct mountain ranges (following guidance from Egan and Price, 2017; Mills et al., 2010 and;

Yin, 2014). Field research methods were implemented by local research partners D. Lama and G. Jimenez, who are familiar with local languages, cultural norms, and socio-ecological conditions. This approach enabled fieldwork to be carried out by those intimately familiar with local realities while also providing training and knowledge co-production opportunities for local mountain residents. Project assistants had previous research experience but were provided with additional instruction in core concepts and research protocols as well as tenets of ethical community-based research. The study was approved by the University of British Columbia's Research Ethics Board. Fieldwork in upper Manaslu, Nepal was carried out in October and November 2018 and in the Cordillera Huayhuash, Peru in February and March 2019.

Household interviews documented community members' biographical data; perceptions of hydrological changes; and the nature of exposure-sensitivities, adaptations, and vulnerabilities. A questionnaire comprised of both closed and open choice questions was used to collect information in a manner that promoted flexibility between known topics of interest and topics that emerged during discussion (Appendix B). The questionnaire approached study themes using plain language, avoided specific reference to climate change or other potentially loaded concepts, and provided space for consideration of other intersecting issues and processes of change. It was informed by critical work on cross-cultural survey design (Harkness et al., 2003), developed in consultation with regional and thematic experts, and piloted with mountain residents in Nepal and Peru prior to data collection. Participants were asked to recall hydrological conditions over the last decade, a temporal scope short enough to enable coherent recollection of past events while long enough to provide insights into the effects of recent, rapid climatic changes in the mountains of Peru and Nepal. Forty household interviews were conducted in each study community (total $n = 160$) with individuals 18 and older following a stratified random participant selection protocol that prioritized the inclusion of equal numbers of men and women and age group members (18-35, 36-55, 56 and older). Free and informed consent was prioritized and obtained before interviews were conducted.

Quantitative data from household interviews were analyzed using IBM SPSS Statistics Version 25 to identify and summarize observations of hydrological changes as well as patterns of exposure-sensitivity, adaptation, and vulnerability. Qualitative content from interviews was examined using manifest (explicitly stated) and latent (implicit) content analysis (Bengtsson, 2016; Payne and Payne, 2004), where responses were grouped and analyzed according to their relationship to exposure, sensitivity, adaptation, and vulnerability. Quantitative and qualitative data were evaluated for coherence and logical consistency (see Limitations section for elaboration of data quality issues). Problematic responses were flagged so that they would not contaminate study results. For numerical data, this meant that erroneous responses were fully excluded from analysis. For textual data, this meant that erroneous responses were not included when considering textual answers to specific question; however, several such responses still contained insight relevant to the study (e.g. a response that only mentioned vulnerabilities in response to a question about adaptive responses). Such insights were integrated into the results as appropriate.

Key informant interviews were conducted with government officials, community leaders, resource managers, researchers, and members of the private sector. A purposive expert selection process was followed, which focused on interviewing individuals possessing knowledge of topics relevant to the study, including resource management, highland livelihoods, glacial hydrology, mountain ecology, and adaptation policy. The majority of key informants were from or working in the study regions, although several interviews were also completed with relevant experts in Kathmandu and Huaraz (large cites near the study sites). Such participants were able to elaborate topics that could not be thoroughly evaluated through household interviews.

Focus groups were conducted to gain a deeper understanding of topics identified through household and key informant interviews and to discuss broader socio-ecological realities that condition lived experiences of peak water. These events also provided an opportunity to cross-check information obtained through previous household and key informant interview efforts. One focus group was conducted in each study community (total $n = 4$) following the completion of household interviews. Participants were recruited from household interview cohorts, with an aim of including community members with a range of perspectives, livelihoods, and socio-economic backgrounds in focus group conversations.

Validity metrics for qualitative data has been widely theorized (e.g. Creswell and Poth 2016). In this study, data validation was based on the premises of structural corroboration, consensual validation, and referential adequacy (Eisner 1991). In practice, this meant that our interpretation of validity stemmed from agreement in findings across multiple methods (structural corroboration)—household interviews, key information interviews, and focus groups; affirmation of results by community members and local research partners (consensual validation); and coherence with empirical and theoretical insights from the broader literature (referential adequacy). Through this three-pronged approach to validation, we were able have confidence in our observations, interpretations, and conclusions about lived experiences of peak water.

4.6 Results and Discussion

One-hundred and sixty household interviews were completed by the local research partners during fieldwork in upper Manaslu and the Cordillera Huayhuash; stratification objectives for sex and age inclusion were achieved (note: we use 'sex' to refer to whether respondents were biologically male or female; gender dynamics were beyond the remit of this dissertation). On the whole, livelihoods in the study regions are centered in and dependent upon highland socio-ecological systems. Livelihoods in both study regions are dominated by involvement in agriculture (upper Manaslu = 85%, Cordillera Huayhuash = 95%) and pastoralism (upper Manaslu = 76%, Cordillera Huayhuash = 89%), although involvement in other income earning activities such as harvesting yartsa gunba or running small shops is also common (upper Manaslu = 76%, Cordillera Huayhuash = 58%). Involvement in tourism-based activities, particularly trekking and related support services, is limited in upper Manaslu (14%), but is somewhat more common in the Cordillera Huayhuash (31%). As expected, tourism-focused livelihood activities are concentrated almost exclusively in Samagaun and Huayllapa, respectively. Wage-based employment and tourism-focused activities usually represent livelihood diversification and do not replace involvement in agriculture and pastoralism. Work outside of one's home community is limited for residents of upper Manaslu (5%) but is somewhat more common for residents of the Cordillera Huayhuash (23%) Relatively few respondents report receiving remittances from family members working in other locales (upper Manaslu = 8%, Cordillera Huayhuash = 18%).

In the upper Manaslu study communities, educational experiences involving the intergenerational transmission of local ecological knowledge are most common. Formal educational attainment is low, with only 29% of the population having any primary school, high school, university, or Buddhist monastic education. For those with formal education, primary school (48%) or monastic education (26%) is most common. In the Cordillera Huayhuash, primary school, high school, and university-level education is common, with 94% of the study population having received some level of formal education. Many people have a high school degree (46%) or higher (18%), although local ecological knowledge is still valued for its contextual specificity. Most respondents indicate living the majority of their lives in their home communities (upper Manaslu = 88%, Cordillera Huayhuash = 79%). Accordingly, our survey results speak primarily to the perspectives of the *de jure* population of the study communities (see Childs et al., 2014). The perspectives of mountain residents who migrate to lowland cities in search of perceived socio-economic opportunities are underrepresented in our survey results.

Thirty-four key informant interviews were completed, including with government officials, community leaders, resource managers, researchers, members of the private sector, and other relevant specialists (Table 4.1). Most key informants were men, an outcome that speaks to existing inequities in leadership positions in Nepal and Peru (World Economic Forum, 2018). Four focus groups were completed (one in each study community), with a total of 43 participants. Two-thirds of focus group respondents were men, reflecting cultural norms that prioritize male involvement in community events.

Table 4.1: Outcome of field research methods			
Method	**Outcome**	**Composition of participants**	
Household interviews	*n* = 160	Manaslu *n* = 80	Sex: M (41), F (39) Age: 18-35 (28), 36-55 (31), ≥56 (21)
		Huayhuash *n* = 80	Sex: M (43), F (37) Age: 18-35 (25), 36-55(32), ≥56 (23)
Key informant interviews	*n* = 34	Manaslu *n* = 24	Sex: M (18), F (6) Age: 18-35 (9), 36-55(13), ≥56 (2) Sector: Government/Community leader (10), Resource manager (3) Research (4), Private sector (1), Other specialist (6)
		Huayhuash *n* = 10	Sex: M (10), F (0) Age: 18-35 (0), 36-55(5), ≥56 (5) Sector: Government/Community leader (5), Resource manager (3), Research (0), Private sector (1), Other specialist (1)
Focus groups	*n* = 4	Manaslu *n* = 18	Sex: M (13), F (5) Age: 18-35 (9), 36-55(5), ≥56 (3)
		Huayhuash *n* = 25	Sex: M (20), F (5) Age: 18-35 (8), 36-55(10), ≥56 (7)

Numbers in text below represent findings from the household surveys. In some cases, reported trends from household interviews have less than 50% agreement. Such findings are reported if 1) key informant and/or focus group insights bolstered support for the observation or 2) response rates for opposing response options were markedly lower.

4.6.1 EXPOSURE - Observations of hydrological changes

Hydrological changes were widely reported in both study regions (Table 4.2). Reductions in glacier cover and thickness are commonly reported by household interview respondents in both upper Manaslu (reduced cover = 84%, reduced thickness = 90%) and the Cordillera Huayhuash (reduced cover = 96%, reduced thickness = 76%). Likewise, observations of reduced snow cover and thickness are nearly ubiquitous in upper Manaslu (reduced cover = 93%, reduced thickness = 98%) and the Cordillera Huayhuash (reduced cover= 91%, reduced thickness = 76%): “I see more rock on the faces of mountains like Yerupajá, Rajucollota, Siula Grande, and Sarapo” (household interviewee #14, Huayllapa). Such observations are consistent with perceptions of declining snowfall amounts in upper Manaslu (73%) and the Cordillera Huayhuash (76%), where increases in the frequency of periods with unusually low snowfall are also reported (upper Manaslu = 84%, Cordillera Huayhuash = 56%). As one interviewee from the Cordillera Huayhuash observed: “thirty years ago when my children were little, we used to go up to the puna [and] play making snowmen [but] it doesn’t snow like it used to” (household interviewee #21, Huayllapa).

Perceptions of trends in total rainfall amounts are divergent for the study regions, with household interview respondents in upper Manaslu citing an increase in net rainfall inputs (68%) while those in the Cordillera Huayhuash observe strong declines in rainfall (93%), particularly during the austral spring. However, observations of increases in both heavy rainfall events (upper Manaslu = 94%, Cordillera Huayhuash = 80%) and low rainfall periods (upper Manaslu = 61%, Cordillera Huayhuash = 88%) are common across both regions, implying increases in overall rainfall variability in both study regions. Perceptions of precipitation change from upper Manaslu are generally consistent with findings from observational and modeling studies focused on the central Himalayas (Hock et al., 2019; Scott et al., 2019). The signal for precipitation trends from scientific studies focused on the Peruvian Andes is less clear (Schoolmeester et al., 2018), although some regional observational and modeling work has identified a drying trend (e.g. Neukom et al., 2015).

In upper Manaslu, 41% of household interview respondents have observed a trend of increasing discharge in the region's glacier-fed rivers, mirroring expectations from glacio-hydrological modeling studies (e.g. Immerzeel et al., 2013; Lutz et al., 2014). They also report increases in both the frequency (65%) and intensity (69%) of flooding events, particularly in the summer months. Increased flooding is consistent with accelerated melt rates (i.e. increased discharge generation) as well as reductions in the buffering effects of glaciers; however, increases in precipitation amounts and variability could also influence discharge variability. Likewise, 43% of respondents observed reductions in dry season base flow in glacier-fed rivers, suggestive of a reduction in the seasonal water redistribution capacity of regional glacier systems (Fountain and Tangborn, 1985). However, reduced snow cover could also be contributing to this trend. On whole, both total discharge and discharge variability appear to be increasing in glacier-fed rivers in the upper Manaslu region.

In the Cordillera Huayhuash, 48% of household interview respondents noted a decrease in discharge in glacier-fed rivers along with decreases in the frequency (49%) and intensity (50%) of flooding events. Low flow periods are reported to be increasing in both frequency (55%) and intensity (58%). However, as for upper Manaslu, reported discharge trends can be explained by changes in both glacial and non-glacial hydrological components (e.g. precipitation); it is therefore difficult to decouple the underlying drivers of discharge characteristics based solely on participants' perceptions. On whole, discharge from glacier-fed rivers in the Cordillera Huayhuash appears to be declining with the occurrence of flooding events and low flow periods exhibiting departures from historical patterns.

A quarter of household interview respondents as well as many key informants and focus group participants in upper Manaslu report reductions in discharge in non-glacial (rain- and snow-fed) streams, particularly in winter months. This temporal pattern is consistent with reported reductions in snow cover in the headwater areas of smaller streams. Thus, although a net increase in rainfall is reported, respondents indicated that it often manifests as heavy rainfall events in summer, a phenomenon that increases summertime flooding but does not produce an increase in winter baseflow. Finally, many respondents indicated that several streams had either disappeared or appeared in new locations following the 2015 earthquake.

Perceptions of trends in discharge in non-glacial streams among household interview respondents in the Cordillera Huayhuash are more definitive, with reductions in total discharge widely reported (74%). From a seasonal perspective, reduced discharge is most evident in the austral spring (74%) and winter (94%), consistent with temporal patterns of reported declines rain and snowfall. Relatedly, observations of reduced water availability in highland springs and lakes were common among household interview respondents in the Cordillera Huayhuash (50%), as these water bodies are also precipitation dependent.

Table 4.2: Patterns of hydrological change reported by respondents					
Hydrological Components		**UPPER MANASLU**		**C. HUAYHUASH**	
General component	**Specific variable**	**Direction of change**	**Agreement**	**Direction of change**	**Agreement**
Cryosphere	Glacier cover amount	↘	High	↘	High
	Glacier thickness	↘	High	↘	High
	Snow cover amount	↘	High	↘	High
	Snow cover thickness	↘	High	↘	High
Precipitation	Snowfall amount	↘	High	↘	High
	Snowfall variability	↗	Moderate	↗	Moderate
	Rainfall amount	↗	Moderate	↘	High
	Rainfall variability	↗	Moderate	↗	High
Discharge	Discharge amount in glacier-fed rivers	↗	Moderate	↘	High
	Flooding in glacier-fed rivers	↗	High	↘	Moderate
	Low flow periods in glacier-fed rivers	↗	Moderate	↗	High
	Discharge amount in non-glacial streams	↘	Moderate	↘	High
	Flooding in non-glacial streams	↗	High	↘	Moderate
	Low flow periods in non-glacial streams	↗	Moderate	↗	High
	Amount of water from springs	No Trend	N/A	↘	High

Level of agreement reflects consistency in reporting across household, key informant, and focus group interviews. High = Consistent observations across data sources, Moderate = Generally *consistent observations across data sources, with some discrepancies, Low = Limited consistency across data sources.*

Study participants' observations of hydrological exposures reinforce expectations that glacial change is already leading to peak water dynamics in the study regions. However, they also highlight trends in rainfall and snowfall that make it difficult to separate a glacier melt water signal from each study region's broader hydrological contexts. These observations offer a higher degree of spatial and temporal specificity than is currently available in model-driven assessments of hydrological change for the study regions, making them invaluable for understanding the specific hydrological exposures that influence life in upper Manaslu and the Cordilleras Huayhuash. Importantly, although we focus on climate-related drivers of hydrological change, we acknowledge that other non-climatic factors such as the deposition of black carbon, which increases melt rates, or land-use practices that affect infiltration, sedimentation, and evapotranspiration may have also influenced regional hydrological changes (Dagsson-Waldhauserova and Meinander, 2019; Khoi and Suetsugi, 2014).

4.6.2 SENSITIVITY - Water access, use, and proximity

Hydrological changes are widely observed by study participants, but mountain residents are not necessarily sensitive to all hydrological exposures; water access and use as well as proximity to waterways are key factors that influence sensitivity. For example, in upper Manaslu, only 18% of household interview respondents access water from glacier-fed rivers. Water from glacier-fed rivers is used primarily for household uses and watering livestock and also to power water mills and irrigate crops. Most of those accessing water from glacier-fed rivers consider the source to be of medium importance (57%), particularly in the winter months when rainfall and discharge from non-glacial streams are at their lowest levels. In the Cordillera Huayhuash, 50% of household interview respondents access water from glacier-fed rivers. For those accessing water from glacier-fed rivers, the most common uses are irrigation (88%), watering livestock (38%), and home uses (15%); 83% of these people consider this water to be of high importance, particularly in the dry season.

Non-glacial streams are the primary source of 'blue water' (i.e. surface and subsurface flow) (see Falkenmark and Rockström, 2006) in the study regions, with 98% of household interview respondents in upper Manaslu and 84% of respondents in Cordillera Huayhuash indicating reliance on such streams. In both regions, non-glacial streams are considered highly important sources of water for home uses, irrigation, watering livestock, and tourism/trekking activities. Furthermore, in the Cordillera Huayhuash, 94% of household interview respondents rely on water from rain- and snow-fed springs, particularly for household and agricultural uses. Unlike other mountain regions where exposure to foreign tourist is driving socio-cultural changes that increase overall household water demand (see McDowell et al., 2013; Palomo, 2017), increasing water demand does not yet appear to be a driver of exposure-sensitivity in upper Manaslu or the Cordillera Huayhuash.

Rainfall and snowfall are also vital sources of 'green water' (i.e. soil moisture) (see Falkenmark and Rockström, 2006); they contribute directly to crop productivity and the quality of high-altitude pasturelands in both study regions. Here, sensitivity is greatest among those entirely dependent on agro-pastoralism, commonly older community members and those without foreign language training (which increases the ability to work in the trekking sector).

Sensitivity is also related to the proximity of settlements and human activities to hydrological exposures. Thus, while many community members may not be sensitive to changes in the amount of water in glacier-fed streams, certain people and infrastructure may be sensitive to other climate-related hydrological changes taking place in glacier-fed rivers, as discussed below.

4.6.3 ADAPTATION and VULNERABILITY - Too much, too little, and unpredictable water availability

Changes in the frequency and magnitude of times of too much water, too little water, and unpredictable water availability are lived realities of hydrological change in high mountains. These patterns are consistent with hydrological dynamics associated with peak water—the rising limb (too much water), the falling limb (too little water), and attendant effects on discharge variability (unpredictable availability)—but often reflect the combined effects of change in various hydrological components.

4.6.3.1 Too much water

The glacio-hydrological modeling literature has not engaged substantively with the effects of rising limb dynamics on vulnerability, reflecting a strong focus on the consequences of decreasing water availability. As such, residents of moisture-laden regions such as the Nepal

Himalaya are not usually considered particularly vulnerable in the near term, although some studies have alluded to potential impacts such as flooding and declining water quality for regions on the rising limb (e.g. Milner et al., 2017; Ragettli et al., 2016). Significantly, however, our findings from field research in Nepal reveal notable vulnerabilities related to increasing discharge. For example, household interview respondents in upper Manaslu report increases in the frequency and intensity of flooding events in summer. Such flooding events have destroyed local homes, watermills, bridges, and trails; tragically, they have also led to the drowning of several children. While some effects of flooding impact the whole community (e.g. trail damage), other effects are differentiated across space as a function of proximity to rivers and streams: "People living near the river are psychologically disturbed because floods have taken the lives of kids and animals" (household interviewee #11 Samagaun). These flood hazards compound concurrent threats posed by glacial lake outburst floods (GLOFs) (Bolch et al., 2019), which are a related but lower frequency type of extreme event.

Community members have responded to intensifying hydrological extremes by building makeshift stone barriers along waterways adjacent to key infrastructure and repairing damaged facilities on an ad-hoc basis. The reactive, short-term nature of these responses reflects communities' geographical and political isolation from centralized state services; insufficient material, financial, and technical capacity as well as limited knowledge about trajectories of climate-related hydrological changes are widely cited as barriers to adaptation. This situation also limits opportunities for more deliberative adaptation planning, including time to devise 'soft' adaptations (Sovacool, 2011) that attend to interdependencies and tradeoffs between human adaptations and the structure and function of aquatic ecosystems (Brauman et al., 2007). Thus, although we documented community-level effort to respond to flooding hazards, barriers of socio-political origin have severely constrained the scope and effectiveness of local adaptations while increasing prospects for unintended consequences and maladaptation. In point of fact, only 14% of household interview respondents who are exposed and sensitive to flooding state that their adaptations have moderated harm—damage to infrastructure and threats to life remain a reality for many community members. This is leading to widespread emotional duress among community members, compounding already significant trauma from the 2015 earthquake. This combination of climatic and non-climatic stressors has increased residents' sense of fear and precariousness, leading some to feel "mentally tortured" (household interviewee #16, Chhule).

Enhanced discharge has also increased the entrainment capacity of rivers. Combined with the increased erosive action and sediment production of receding glaciers (Koppes et al., 2015), this is leading to heavier sediment loads and reduced water quality: "It is leading to impurities in our drinking water" (household interviewee #12, Chhule). Because of reliance on local rivers and streams for drinking water, minimal water filtration infrastructure, and limited capacity to remediate water quality issues, many community members are vulnerable to reduced drinking water quality; we cannot speculate about specific health effects based on our analysis. Here again, the ability to moderate exposure-sensitivities is closely linked to geographical and socio-political realities that have reduced the involvement of the Nepalese state in providing basic infrastructure and social services to remote mountain communities. Although concern about changes in water quality were not widely reported in in the Cordillera Huayhuash, some evidence of increased sediment loads was recorded: "I have noticed that the [glacier-fed] Rio Achin has changed color. It used to be turquoise but now it is dark grey" (household interviewee #32, Pacllon). Observations of study participants from Nepal and Peru about sediment fluxes are consistent with glacio-hydrological research (Koppes et al., 2015; Milner et al., 2017), and suggest that enhanced erosion and sediment transport are beginning to impact drinking water quality in high mountain areas without adequate water treatment facilities. However, we acknowledge that increased sedimentation could also be related to non-climatic drivers, as mentioned below.

Intensified melt and a reduction in the buffering capacity of glaciers suggests that peak water dynamics influence reported increases in flooding and declines in water quality. Thus, in upper Manaslu, limited reliance on glacier-fed streams for water access does not preclude vulnerability to peak water dynamics; the combination of socially relevant exposures (hydrological hazards and water quality issues) and constraints on adaptation is leading to substantial vulnerability in a region squarely associated with the rising limb of the peak water model. However, because flooding and water quality issues are also reported in non-glacial streams, we believe that increases in summertime rainfall and enhanced snowmelt rates are contemporaneously driving reported exposures. Adding further complexity, household interview respondents indicate that sedimentation increased following the 2015 earthquake, pointing to important interactive effects between slow variables (increasing discharge) and fast variables (the earthquake) (Walker et al., 2012) and cumulative effects more broadly (Graf et al., 2019; Pant et al., 2018). These observations help to situate the effects of rising limb dynamics within context-specific hydrological, social, and environmental realities, and reveal unanticipated vulnerabilities related to times of increasing water availability.

4.6.3.2 Too little water

The glacio-hydrological modeling literature is focused primarily on the implications of times of too little water availability, an emphasis that draws concern to arid regions such as the western slope of the Peruvian Andes that are already on the falling limb of the peak water profile. Consistent with this framing, 86% of household interview respondents in the Cordillera Huayhuash indicate that times of water scarcity are increasing; scarcity was not cited as an issue in upper Manaslu. Interestingly, however, most respondents in the Cordillera Huayhuash report that declining water availability is most evident in non-glacial streams and rain- and snow-fed springs as well as overall rainwater availability. Only 10% of household interview respondents cited reductions in glacier-fed rivers as a concern, suggesting that discharge reductions are not yet sufficient to jeopardize the viability of glacier-fed rivers as a water source.

Ninety-seven percent of household interview respondents in the Cordillera Huayhuash indicate being adversely affected by times of too little water. In particular, reduced stream flow and precipitation are threatening agricultural activities and reducing the productivity of grasses in high altitude pasture lands [the puna]: “It hurts crops if there isn’t enough rain and not enough grass grows [in the puna] for the animals” (household interviewee #32, Huayllapa). Community efforts to address agriculture-related challenges involve building water reservoirs and canals to increase water supply, establishing community water boards to organize the equitable use of available water, and adopting improved irrigation technologies to reduce water use. These efforts address both perennial agropastoral difficulties linked to natural climate variability as well as emerging challenges related to contemporary climate-related hydrological changes.

Local adaptations have improved water access and use but have not been sufficient to offset emerging water availability challenges. For example, although community water boards have increased equitable access to available water, the lack of funding and technical expertise for the construction of more extensive water reservoirs and canals means that scarcity is still common in some areas within study communities. Indeed, several sectors in Pacllon and Huayllapa do not have irrigation connections, leaving residents of those areas highly sensitive to changing rainfall patterns: "Because there isn't enough water…we haven't planted corn, wheat, or lima bean in the Agash or Tsimsu sectors in three years" (household interviewee #9 Huayllapa). These residents are often younger families who have had to move onto less desirable plots as a result of population pressure in more central locations. Furthermore, while NGO-led initiatives aimed at increasing access to improved irrigation technologies have reduced overall agricultural water use, some household interview respondents, particularly older residents with limited formal education, report confusion about how to properly use improved irrigation technologies. Such misunderstanding has led to failed harvests amongst a subset of the population already facing numerous other hardships. Household interview respondents report that full or partial crop failures require them to purchase staple crops from coastal regions to meet nutritional needs. A similar situation is reported by pastoralists. When highland pastures are unproductive as a result of declining precipitation, pastoralists buy grasses from the coast and, when purchasing feed becomes financially prohibitive, sell livestock.

Despite such burdens, many residents report knowledge of and concern about the ecological effects of further increasing water abstraction, citing numerous examples of how reductions in water availability are already impacting regional flora and fauna. For example, one respondent noted that when the community "channels all of the water from the Tacra Raqra [Tacra River], we leave all of the trees and wild plants that grow on its banks to die." (household interviewee #33 Pacllon). Another community member commenting on over-abstraction lamented: "I no longer hear the song of the toads" (household interviewee #30 Pacllon). Impacts on wild foods as a result of regional drying are also observed: "I have noticed that lakes Tuctu, Turpa, and Argocancha no longer have Cushuro [a nutrient and protein rich algae that is commonly eaten]" (household interviewee #20 Pacllon). Conversely, there is also recognition of how human hardship can present opportunities for non-humans: "if we plant and there isn't enough water, we abandon the crops and the wild birds take advantage of what is left" (household interviewee #13 Huayllapa). Responsibility, kinship, and reciprocity shape conceptions of people and place in the Cordillera Huayhuash (and upper Manaslu), and speak to relevance of socio-ecological systems analysis as well as emerging work on relational values (Klain et al., 2017) in identifying and navigating tradeoffs in future adaptation plans.

Because discharge reductions in glacier-fed rivers are not especially relevant for study participants in Peru, exposures related to falling limb dynamics do not appear to be a significant component of current vulnerability. But this situation could change if water from non-glacial sources continues to decline and greater reliance is placed on glacier-fed rivers. Several household and key informant interview respondents cited this possibility, suggesting that piping water in from glacier-fed rivers may become necessary if patterns of hydrological change intensify. However, some respondents fear that clandestine mining might already be polluting glacial rivers, noting fish die offs and declining birdlife in glacier-fed waterways (this could also be related to leaching from mineral seams exposed by glacier recession) (see Guittard et al., 2017 for illustrative work on this issue). We cannot corroborate these claims based on our analysis, but recognize that co-stressors such as pollution in glacier-fed rivers could foreclose important backstop adaptation options.

Finally, falling limb dynamics may have some local benefits for communities in the Cordillera Huayhuash. About half of the household interview respondents indicated declines in the frequency and intensity of flooding in glacier-fed rivers, which is reducing exposure to hydrological hazards and decreasing the frequency of damage to infrastructure and agricultural land (although observations of hydrometeorological extremes were still widely reported). This contrasts with the situation in upper Manaslu where rising limb dynamics are driving increasing exposure to hydrological hazards. On the whole, declining discharge in glacier-fed rivers in the Cordillera Huayhuash appear to be having negligible or even somewhat positive effects for local communities.

4.6.3.3 Unpredictable water availability

Observations of the increased unpredictability of water availability were noted by household interview respondents in upper Manaslu (41%) and ubiquitous among respondents in the Cordillera Huayhuash (90%). Glacier recession can be viewed as a component of such variability in upper Manaslu; however, respondents in both study sites are primarily concerned with predictability challenges related to rainfall. In upper Manaslu unpredictable rainfall manifests as both more intense heavy rainfall events and unexpected dry periods. Heavy rainfall magnifies flooding issues and damages crops while dry periods pose fundamental threats to rain-dependent agriculture: "The unpredictability of rainfall has had a huge impact on our crops" (household interviewee #2, Chhule). Adaptations are few and include the abovementioned construction of flood barriers as well as accessing water from the main river for rudimentary irrigation efforts in dry periods. In the Cordillera Huayhuash, reduced predictability in the onset of rainfall poses major problems for agriculture: "The climate has changed a lot. We no longer know exactly when to plant. It damages the growing season." (household interviewee #32, Huayllapa). Household-level response in the Cordillera Huayhuash include planting crops and accepting that the harvest might be lost if rainfall does not arrive in time for seeds to germinate (risk acceptance), postponing planting until the rainy season begins (risk moderation), and avoiding planting crops all together (risk avoidance). Specific strategies chosen are often based on "knowledge left to us by our grandparents" (household interviewee #36 Pacllon), highlighting the importance of intergenerational knowledge transmission in contemporary adaptation efforts. Notwithstanding flooding issues in upper Manaslu, peak water dynamics appear to have relatively little effect on lived experiences of unpredictable water availability in both study regions. Illustrative adaptations documented in community-level work are presented in Table 4.3.

Table 4.3: Illustrative adaptations to hydrological change

Region	**Adaptation**	**Hydro issue**	**Specific stimuli**
Manaslu	Constructing stone barriers along water ways to protect infrastructure, land, livestock, and people from flooding events – These responses utilize locally-available materials to reduce exposure-sensitivities, but stone walls tend to be damaged in severe flooding events. They require constant upkeep. Furthermore, they represent reactionary responses to experienced flooding. They do not	Too much water	Increasing glacier meltwater generation; intense precipitation events; enhanced snowmelt

	account for trajectories of glacio-hydrological change.		
Manaslu	No documented adaptations to reduced water quality.	Too much water	Increasing glacier meltwater generation; intense precipitation events; enhanced snowmelt; liberation of sediment following earthquake
Huayhuash	Establishment of water boards to manage allocation of water in dry periods among community members – Water boards were established in the context of long-standing water related challenges, but have also been well suited to addressing climate-related hydrological stresses. Inspectors for water boards determine which sector of town will have access to water during a given period of time, and then charge an hourly tariff to households for abstracting water. The system makes water access more equitable, and funds raised help to maintain sluices, pipes, and canals.	Too little water	Declining glacier meltwater generation; declining precipitation
Huayhuash	Construction of reservoirs and irrigation canals to redistribute water from water abundant times/water sources to water scarce times/areas – Improving water access by expanding water-related infrastructure is a key adaptation strategy and goal, with several reservoirs and irrigation canals already constructed and many others planned. However, the expansion of such infrastructure is limited	Too little water	Declining glacier meltwater generation; declining precipitation

	by financial constraints and government policies, both of which have slowed locally-led water infrastructure projects.		
Manaslu	Rudimentary irrigation infrastructure connected to glacier-fed rivers – Use of trench networks and small diameter pipes to channel water for rivers to agricultural fields. Efficacy depends on proximity to rivers.	Unpredictability	Increasing variability in glacier- and non-glacier-fed rivers; variable precipitation
Huayhuash	Planting crops according to when rain arrives not historical timelines; buy food from coast if harvest fails – Involves synchronizing agricultural activities with new inter-annual hydrological dynamics instead of traditional planting calendars. Driven primarily by variability in precipitation, but also related to discharge variability, which can affect irrigation opportunities.	Unpredictability	Variable precipitation; declining glacier meltwater generation

4.6.3.4 Expanded geographies of vulnerability peak water

Three characteristics of vulnerability are common in the emerging discourse about vulnerability to peak water: vulnerability will be driven by reductions in water availability in glacier-fed rivers; will be concentrated in arid regions where glacier-fed rivers help to offset moisture deficits; and will be most pronounced in populous areas downstream of mountain areas where water demand is greatest. This translates to a specific geography of vulnerability (see Huss and Hock, 2018), but one that is not well supported by our results. Declining water availability is not the only salient exposure related to peak water; flooding and impacts on water quality also matter, both of which are related to increasing water availability. Thus, moisture-laden regions on the rising limb of the peak water profile are also subject to exposures capable of engendering vulnerability. Indeed, vulnerability to exposures directly related to peak water may be higher in regions like upper Manaslu (rising limb) than the Cordillera Huayhuash (falling limb), a finding that is counter to prevailing intuition and that speaks to the importance of situated analyses. Nevertheless, some level of vulnerability to peak water is observed in both study regions, suggesting that ascribing higher vulnerability to lowland areas because of their relatively greater water demand may obscure vulnerabilities in frontline communities. Here, it is notable that the relative magnitude of glacio-hydrological changes faced by high mountain communities is also systematically underestimated in model-driven studies that aggregate results to the basin scale (because the contribution of glacier melt water to discharge increases with proximity to the glacierized headwaters).

Furthermore, our results indicate that from the perspective of 'lived experiences' it is the combined effects of all socially relevant hydrological changes that matter most to mountain people (e.g. precipitation change, snow cover change, glacial and non-glacial discharge change), not only changes in discharge in glacier-fed rivers (i.e. peak water *per se*). For example, while 49% of household interview respondents in this study report vulnerability to hydrological changes, only half of these cases are clearly linked to changes in glacial discharge. Consequently, the geography of vulnerability hypothesized in the existing glacio-hydrological modeling literature may inadvertently lead adaptation aid to be targeted in ways that miss vulnerable populations or reinforce inequities between highland and lowland populations (see Debarbieux and Rudaz, 2015; FAO, 2015; Mathieu and Brun, 2011 for more on persistent inequities).

The differing geographies of vulnerabilities identified in impacts-driven work and our contextual study highlight important practical implications of our analytical choices. While some discordance clearly stems from differing research objectives and approaches, a deeper question persists: Is vulnerability to hydrological change a problem *for* society or a problem *of* society? These respective precepts have profound effects on our understanding of where, why, and for whom hydrological changes matter most, and subsequently how adaptation assistance might be mobilized. Given that nearly 10% of the global population lives in watersheds affected by rapidly changing glacio-hydrological conditions (Hock et al., 2019), there is an urgent need to think carefully about how vulnerability is conceptualized and operationalized in research examining the implications of hydrological (and other) changes in mountain regions. Based on our results and those of allied studies (e.g. Bury et al., 2013; Carey et al., 2014; Drenkhan et al., 2015; Mark et al., 2010; Mark et al., 2017; McDowell et al., 2013), we tender the suggestion that examining the effects of glacio-hydrological change through the lens of contextual vulnerability approaches might help to more appropriately target scarce adaptation resources. However, we emphasize the nascent nature of research in this area and look forward to knowledge sharing and future collaboration with our colleagues in the glacio-hydrological modeling community (see Conway et al., 2019 for pertinent discussion).

4.6.4 Limitations

The results of this study are subject to several limitations. For example, we did not achieve a nuanced understanding of pertinent topics such as intra-community socio-cultural dynamics, limiting our ability to identify differentiated experiences of hydrological change within the study communities. Relatedly, we did not substantively evaluate our findings in relation to concurrent processes of socio-economic, political, and environmental changes in (or acting upon) the study regions. We are therefore unable to comment on the relative importance of glacio-hydrological changes *vis-a-vis* other issues faced by residents in our study communities. As well, our cursory engagement with socio-ecological dynamics leaves our analysis of hydrological changes, vulnerabilities, and adaptations insufficiently connected to the broader socio-ecological contexts of our study regions (see Huss et al., 2017; McDowell and Koppes, 2017 - Chapter 2). Here, future studies will benefit from deeper engagement with concepts and insights from ecosystem services––particularly hydrological services—and cumulative environmental impacts literature (e.g. Brauman et al., 2007; Clerici et al., 2019). Moreover, although representation of male and female respondents is almost balanced in the household survey, insights from key informant interviews and focus groups are biased towards male perspectives; we have fallen short of principles of inclusion outlined in the Thimphu Declaration for mountain women (FAO, 2002). Finally, we caution that our results reflect the nexus of contemporary glacio-hydrological changes and social conditions in upper Manaslu and the Cordillera Huayhuash specifically. Our insights about lived experiences of peak water may not be applicable to other communities in these regions or in other high mountain communities more broadly, particularly those located in the Global North.

4.7 Conclusions

This study used a contextual vulnerability approach to characterize lived experiences of peak water in remote communities in the upper Manaslu region of the Nepal Himalaya and the Cordillera Huayhuash region of the Peruvian Andes. It examined whether a focus on peak water *per se* provides a sufficient analytical lens for understanding lived experiences of contemporary climate-related hydrological changes as well as whether vulnerabilities hypothesized in the glacio-hydrological modeling literature provide an appropriate basis for adaptation planning. Our results reveal patterns of vulnerability within and across high mountain communities that do not follow the characteristics of vulnerability hypothesized in the glacio-hydrological modeling literature. Instead, we document socially relevant hydrological changes that are not adequately accounted for when focusing exclusively on long-term changes in glacier-fed river systems as well as the largely social origins of vulnerability to changing hydrological conditions. These insights raise questions about the sufficiency and appropriateness of findings from glacio-hydrological modeling as a basis for targeting adaptation efforts. Thus, while we emphasize the essential role of modelling work in advancing understanding of trajectories of glacio-hydrological change and supporting long-term planning, we argue that such work must be complemented by highly contextualized research and insights from the social sciences to more fully appreciate lived experiences of hydrological change in glacierized watersheds.

The results of this study illuminate several areas where future research is needed; namely, increasing situated knowledge of lived experiences of rising limb dynamics, especially changes in *water quality*, identifying locally appropriate opportunities for *addressing adaptation needs*, and revealing important *socio-ecological interdependencies* affected by both glacio-hydrological change and human adaptations. More broadly, there is a need for greater attention to lived experiences of hydrological change in *high mountain communities* (not just downstream areas), where widespread socio-political marginalization engenders vulnerability to even modest hydrological exposures. Such work should involve close collaboration with mountain residents and endeavor to gain a more *nuanced understating* of socio-economic, cultural, and political dynamics that animate lived experiences of hydrological change. Finally, given non-linear trajectories of glacio-hydrological change and ever-evolving social conditions, there is a need for *longitudinal assessments* of the human dimensions of hydrological change in high mountain communities.

Glacio-hydrological modeling assessments focused on identifying the spatial and temporal dynamics of peak water are essential, but on their own they are neither appropriate or sufficient for inferring susceptibility to harm—deeply contextual studies are required to understand the specific vulnerabilities and diverse adaptation needs of mountain people living in rapidly changing high mountain watersheds. This situated assessment of peak water represents a modest attempt to advance this vision.

Chapter 5: From needs to actions: Prospects for planned adaptations in high mountain communities

5.1 Introduction

Mountain regions are home to an array of cultural, ethnic, and linguistic groups as well as 25 of 34 biodiversity hotspots, making them globally important centers of biocultural diversity (Gardner et al., 2013; Price and Kohler, 2013). They are also conspicuous bellwethers of climate change (Huss et al., 2017), with emerging evidence suggesting that mountian regions are warming at twice the global average (Pepin et al., 2015). Such warming is dramatically altering living conditions for the ~915 million people residing in mountain areas, many of whom are already burdened by poverty, food insecurity, and exclusion from social support services (FAO, 2015). This combination of climatic changes and persistent socio-economic marginalization is leading to widespread vulnerability in mountain communities, particularly in mountain areas of the Global South (Carey et al., 2017; FAO, 2015; Hock et al., 2019). In this context, there is a growing focus in mountain research and development on human adaptation (Adler et al., 2019), with efforts to study and implement responses to climate change in mountain areas now well documented (McDowell et al., 2019 - Chapter 3). Contemporaneously, mechanisms of adaptation support organized through the United Nations Framework Convention on Climate Change (UNFCCC) are becoming well established, while international commitments to meeting the needs of the most vulnerable are becoming more specific and forceful (e.g. Paris Agreement's Global Goal on Adaptation) (Lesnikowski et al., 2017; Magnan and Ribera, 2016). Notwithstanding growing material and political support for adaptation at the international level, there is currently little clarity about progress in, and specific opportunities for, matching international adaptation support with adaptation needs in mountain communities at the frontlines of climate change. This knowledge gap constrains efforts to envision and pursue mountain-focused adaptation projects supported by resources that have been committed by the international community. This may lead to missed opportunities for lessening the burden of adaptation in mountain communities.

In response, this paper examines the architecture of formal adaptation support mechanisms organized through the UNFCCC and how such mechanisms might help to meet adaptation needs in mountain communities. To ground the analysis, the paper examines prospects for meeting two specific adaptation needs identified by study participants in community-level research in the upper Manaslu region of Nepal. It outlines key global adaptation initiatives organized through the UNFCCC, clarifies idealized linkages between these global adaptation initiatives and meeting local adaptation needs, and then evaluates actual progress in connecting such support with specific adaptation needs in the highlands of Nepal. The paper then critically examines observed shortcomings in matching adaptation support mechanisms organized through the UNFCCC with local adaptation needs, including complications stemming from the bureaucratic nature of UNFCCC adaptation support mechanisms, the intervening role of the State in delivering aid, and the ways in which these complexities intersect with the specific socio-cultural contexts of mountain communities. It concludes by identifying key prospects for better aligning formal adaptation support with adaptation needs in high mountain communities.

We acknowledge that adaptation support organized through the UNFCCC is not the only option for addressing vulnerabilities in (and beyond) mountain areas. For example, support for adaptation initiatives from multinational organizations and NGOs is important in many areas. Moreover, we emphasize that external support may not be necessary or appropriate where mountain communities are able to draw effectively on their own local knowledge, resources, and capabilities to address climate-related challenges and opportunities (McDowell et al., 2014). We therefore do not claim that leveraging support organized through the UNFCCC is the only or best approach to addressing the profound and growing challenges of climate change vulnerability in mountain areas. However, the UNFCCC plays a paramount role in establishing principles and priorities for adaptation, normalizing adaptation action, and facilitating the distribution of significant adaptation resources (Ford et al., 2016). Moreover, the Convention text specifically recognizes that "developing countries with fragile mountainous ecosystems are particularly vulnerable to the adverse effects of climate change" (UNFCCC, 1992 p. 2) and highlights the need for adaptation action in mountainous contexts (Article 4). For these reasons, we believe that an examination of adaptation initiatives organized by the UNFCCC is particularly germane for mountain researchers and development practitioners interested in prospects for addressing adaptation needs in mountain areas. However, this examination also contributes to broader debates about climate justice in the context of adaptation assistance mechanisms.

5.2 Adaptation to climate change in high mountains

5.2.1 Theoretical foundations

Our engagement with adaptation is informed by the definition of 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 definition encapsulates key themes from contemporary research on the human dimensions of climate change while maintaining fidelity with the classical IPCC definition of adaptation: "The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007 p.6).

The ability to adapt to climatic stressors is determined by social factors, such as educational attainment and gender dynamics, that affect access to information, assets, and social safety nets (Adger, 2006; Smit and Wandel, 2006). Accordingly, differentiated vulnerability to similar climatic stimuli is often observed as a function of pre-existing social inequities and depravations (Ribot, 2014), as increasingly documented in mountain areas (Carey et al., 2017; Gentle and Maraseni, 2012; McDowell et al., 2013; Shukla et al., 2017). Combating vulnerability therefore requires adaptations that address the root causes of susceptibility to harm—poverty, marginalization, discrimination (Ford and Smit, 2004; Lemos et al., 2007; Ribot, 2011)—although this is not often an explicit objective of mainstream climate change adaptation efforts (Bassett and Fogelman, 2013; Ensor et al., 2019). Similarly, adaptations are thought to be more effective when they are embedded within efforts to address concurrent social and environmental concerns (Wilbanks and Kates, 2010). This is consistent with insights from resilience thinking, which suggests that increasing 'specific resilience' (e.g. climate specific adaptations) can jeopardize 'general resilience' and the capacity of socio-ecological systems to persist or reorganize when faced with multiple stresses (Folke et al., 2010). Beyond addressing material constraints and other non-climatic social and environmental stressors, recent mountain-focused research highlights the importance of considering the socio-cultural dimensions of adaptation, including perceptions, values, and ontologically disparate local/traditional and Western/scientific understandings of climatic changes (Gagné et al., 2014; Kaul, 2019; Mills-Novoa et al., 2017; Orlove et al., 2019).

Adaptations can be thought of *inter alia* as either 'hard' or 'soft' (Sovacool, 2011). Hard adaptations represent responses that rely predominantly on human-built infrastructure, involve socio-ecological disturbances, and tend to lack flexibility (e.g. constructing a dam for flood protection). Hard adaptations can effectively protect life and property from acute threats like glacial lake outburst floods (GLOFs), but they can also exacerbate stresses on ecosystems already under threat from climatic changes and other more proximate stresses (Díaz et al., 2019; Turner et al., 2010). However, a growing body of literature is revealing viable alternatives to reliance on hard infrastructure. For example, work on green infrastructure (e.g. Matthews et al., 2015) and nature-based solutions (e.g. Cohen-Shacham et al., 2016) provides insights into adaptation options that can protect people and ecosystems by leveraging natural capital, local ecological knowledge, and low-impact technologies (e.g. restoring riparian ecosystems for flood protection) (see Jones et al., 2012 for elaboration). Such soft responses locate adaptations within broader concerns about biodiversity conservation and maintaining ecosystem services (Egan and Price, 2017), and aim to cultivate co-benefits between people and ecosystems in times of change (Chan et al., 2019).

Other soft adaptations draw on insights from contextual vulnerability and community-based adaptation literature (e.g. Ayers and Forsyth, 2009; Ford et al., 2010) and aim to reduce the abovementioned social inequities and depravations by building institutional capacity, increasing community assets, and reducing socio-economic disparities. These interventions draw attention to the broader political economy of adaptation and aim to ameliorate underlying determinants of susceptibility to harm. Here, growing recognition of entrenched social determinants of vulnerability is informing an emerging discourse on transformative adaptations (Kates et al., 2012; Ribot, 2011). Prospects for advancing socially and ecologically tenable soft adaptations are being improved through the consideration of insights from other relevant fields (see Echeverri et al., 2018; Gaston et al., 2019 for broader perspective), although a focus on hard adaptation is still prominent in mainstream adaptation planning.

Adaptations can also be classified as ‘autonomous’ or ‘planned’ (Smit et al., 2000). Autonomous adaptations are less formal in their development and implementation, and are widely observed in many rural and Indigenous communities at the frontlines of climate change (Ford et al., 2014; McDowell et al., 2019 - Chapter 3). They can be appropriate in areas where local resilience is high and knowledge of socio-ecological dynamics is well developed (Mishra et al., 2019; Thornton and Manasfi, 2010); however, can also signify situations were relations with formal planning entities are limited or strained (McDowell et al., 2014). Planned adaptations are the primary focus of international climate policy (Khan and Roberts, 2013); they represent more structured approaches to adaptation and include initiatives such as those supported through the UNFCCC (as discussed below). While planned adaptations are thought to play an important role in supporting well-informed and well-resourced responses to climate change (Füssel, 2007), some have argued that they can also represent ‘techno fixes’ that clash with specific socio-cultural and ecological realities (Khan and Roberts, 2013; Olsson et al., 2004; Thornton and Manasfi, 2010).

McDowell et al. (2016b) provide a fuller elaboration of adaptation concepts *vis-à-vis* mountain socio-ecological systems.

5.2.2 Status of adaptation in high mountain areas

The IPCC Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC) synthesizes available information about the status of adaptation action in high mountain systems (Hock et al., 2019). For example, the quantity and geography of adaptation action has grown since the first global assessment of adaptation in mountain areas (see McDowell et al., 2014). Importantly, however, most adaptations continue to be autonomous reactions to experienced climatic stimuli that are devised and carried out without guidance from a formal adaptation plan (McDowell et al., 2019 - Chapter 3; Rasul et al., 2019). Although some autonomous responses might represent effective adaptations by resilient mountain communities, the widespread marginalization of mountain people in the Global South (FAO, 2015) suggests that the prevalence of autonomous adaptations is indicative of inadequate adaptation support. This raises concern about the viability of adaptations that are devised under duress and in the context of limited resources and information. Indeed, widely documented vulnerabilities to climate change in the Himalayas and mountain areas more broadly suggest that many adaptation efforts—autonomous or otherwise—are insufficient to address even current levels of climatic stress (Carey et al., 2017; Hock et al., 2019). Furthermore, autonomous adaptations may deplete already scarce community resources, with the effect of worsening (not lessening) pre-existing socio-economic difficulties.

Leaving mountain communities who have contributed little to GHG emissions to shoulder the burden of adaptation is a contravention of established norms of climate justice, as enshrined in the UNFCCC Convention text (UNFCCC, 1992) and subsequent UNFCCC decisions such as the Paris Agreement (UNFCCC, 2015). Indeed, the Paris Agreement's Global Goal on Adaptation emphasizes action to support "those that are particularly vulnerable to the adverse effects of climate change" (*ibid.* p. 6), a description that is fitting for many high communities in the Global South. In view of the situation described above, concern about the status of adaptation in mountain areas is both well founded and widely reported (Adler et al., 2019; McDowell et al., 2019 - Chapter 3; McDowell et al., 2014; Muccione et al., 2016; Rasul et al., 2019; Sud et al., 2015).

5.2.3 Relevance of the Nepal context

Nepal is a mountainous developing country (HDI - 0.579) where there is evidence of acute adaptation needs in mountain areas as well as significant efforts to address climate related challenges (McDowell et al., 2019 - Chapter 3; Mishra et al., 2019; Rasul et al., 2019; Sud et al., 2015). Adaptation needs emerge largely as a result of climate related changes such as rising temperatures, glacial recession, and changing precipitation dynamics as well as social factors that increase sensitivity and reduce adaptability such as reliance on resource-based livelihoods, limited state support, and poverty (Bolch et al., 2019; Gioli et al., 2019; Sapkota et al., 2016). Such climatic and non-climatic drivers of vulnerability are also common in other high mountain areas of the Global South (Hock et al., 2019). However, Nepal stands out in terms of its focus on adaptation in mountain areas as well as its progress in securing formal support for adaptation programs and projects, including through UNFCCC adaptation initiatives. The Nepal context therefore provides a unique opportunity to evaluate a best-case scenario of progress in connecting formal adaptation support with adaptation needs in high mountain countries.

We focus specifically on progress in meeting adaptation needs in the upper Manaslu region, a high mountain area located in the northern Gorkha District (~28˚ 26′ N, 84˚ 54′ E). The region contains the planet's 8th highest peak—Manaslu (8,156m)—and is home to ~9,000 ethnic Tibetans who rely heavily on agropastoral livelihoods (NTNC, 2019). In situ studies of climate related changes for the region are lacking, but analysis by Robson et al. (2018) based on remotely sensed imagery reveals significant changes in regional glacial systems. The entire upper Manaslu region was designated as a conservation area in 1998. Subsequent programs by the Manaslu Area Conservation Program have brought some attention and investment to the area, but the region remains relatively poor and underserviced, with little in the way of infrastructure or health and education facilities (NTNC, 2019). Strong Buddhist traditions continue to dictate life among highly diverse mountain ecosystems and extensively glacierized landscapes (Childs, 2004; Plachta, 2018; Robson et al., 2018). However, road building efforts, the 2015 Nepal earthquake, and an emerging tourism economy also shape contemporary outlooks (Bennike, 2017, 2018, 2019). The nature of adaptation needs in upper Manaslu (discussed below) share characteristics with those reported across many high mountain areas. We therefore pursue an analysis of progress in meeting adaptation needs in upper Manaslu as a means for shedding light on the prospects (and perils) of meeting adaptation needs in high mountain areas through UNFCCC adaptation mechanisms more broadly.

5.3 Methods

This study used a mixed method approach to characterize the architecture of UNFCCC adaptation support initiatives and to trace connections between these initiatives and community-level adaptation needs in the high mountains of Nepal. It draws on 1) a content analysis of grey literature related to UNFCCC and Government of Nepal adaptation initiatives; 2) a targeted literature review of peer-reviewed articles focused on UNFCCC adaptation mechanisms, Government of Nepal adaptation programs and policies, and the dynamics of global to local adaptation assistance in Nepal; and 3) findings from previous community-level climate change vulnerability and adaptation research in the upper Manaslu region of Nepal.

The content analysis (method 1) focused on clarifying the architecture, mandates, and protocols for action of major UNFCCC adaptation initiatives as well as how UNFCCC adaptation assistance has been sought for, and woven into, Nepal's adaptation planning activities. Materials reviewed were collected through a purposive selection process that involved reviewing official web portals for the UNFCCC, Government of Nepal, and related institutions such as the Global Environment Facility (which manages several adaptation funds); scanning the bibliographies of key materials to identify additional relevant materials; and following recommendations by adaptation policy experts familiar with UNFCCC and/or Nepal adaptation initiatives. Materials reviewed included official documents and decisions as well as content provided in official websites/databases, all of which were analyzed for information explicitly relevant to support for planned adaptations in low income mountainous countries. Only materials available in English were evaluated. Content analysis aimed to identify and distill key themes, patterns, and trends (following Bengtsson, 2016; Payne and Payne, 2004), and involved identifying text related to the nature of adaptation support and any efforts specifically targeting or relevant to mountain areas. Germane textual content was collated in a Word document to distill key findings, but was not evaluated statistically.

A targeted literature review was then used to search for peer-reviewed articles focused on adaptation efforts organized through the UNFCCC, government-led adaptation action in Nepal, and critical appraisals of global to local adaptation support efforts (method 2). Documents were identified through Google Scholar searches using titles from key documents, decisions, and programs/projects as well as terms such as "UNFCCC" "Adaptation", "Mountains", and "Nepal". Relevant articles were then organized according to their focus: Adaptation mechanisms of the UNFCCC, planned adaptation efforts in Nepal, delivery of adaptation support from global to local levels. Each document was thoroughly reviewed, and germane arguments were summarized and collated in a Word document. This literature review helped to contextualize the grey literature materials from 'method 1' within broader scholarly debates, and led to a better understanding of congruence and discord between global adaptation initiatives, Government of Nepal efforts, and on-the-ground adaptation outcomes.

Community-level work (method 3) was carried out in the high mountain communities of Chhule and Samagaun (as elaborated in Chapter 4), both of which are located at ~3,500m in the upper Manaslu region of the central Nepal Himalayas. These communities are populated by ethnic Tibetan people who pursue mixed agropastoral livelihoods; Buddhist ethical and moral principles strongly influence social dynamics. The research methods—including 80 household interviews, 24 key informant interviews, and 2 focus groups—were carried out by local research partners from the study region, and benefited from the research team's contextual knowledge and fluency in local dialects. Fieldwork was conducted in October – November 2018. The region was selected as a case study, as it is home to the types of highly vulnerable populations that adaptation support organized through the UNFCCC aims to target (e.g. UNFCCC Article 4.8, Paris Agreement Article 7.2). Moreover, it is located within Nepal, which can be thought of as a best case scenario in terms efforts by a mountainous Least Developed Country (LDC) to secure and mobilize adaptation support available through UNFCCC channels. The case study is therefore pertinent for identifying community-level adaptation needs as well as evaluating progress in meeting those needs through adaptation support organized under the banner of UNFCCC.

The validity of the findings presented below is based on three criteria: structural corroboration, consensual validation, and referential adequacy (Eisner 1991). Here validity stems from consistency in findings across methods (structural corroboration); affirmation of results by study participants and local research partners (consensual validation); and coherence with debates in the broader literature (referential adequacy).

5.4 The architecture of UNFCCC adaptation initiatives

The UNFCCC plays a key role in establishing and reinforcing norms for international climate action and is the centerpiece of global climate governance (Betsill et al., 2015). The primary objective of the Convention is mitigation; that is, to "prevent dangerous anthropogenic interference with the climate system" (Article 2) (UNFCCC, 1992). Adaptation is rarely mentioned in the 1992 Convention text although two forms of adaptation support are recognized: capacity-building and financial assistance (Article 4) (Khan and Roberts, 2013). Here, assistance is viewed as coming from high-income countries and flowing to low-income countries, consistent with the principle of "common but differentiated responsibilities and respective capabilities" (Article 3). With growing awareness of unavoidable climatic changes, particularly following landmark IPCC assessment reports in 2001 and 2007, adaptation began to gain prominence in UNFCCC texts and decisions (Ford et al., 2016). However, it was not until the 16th meeting of the Conference of Parties (COP 16) in Cancun in 2010 that the international community formally agreed that "adaptation must be addressed with the same priority as mitigation" (Cancun Agreements - Section I, Paragraph 2(b)) (UNFCCC, 2011). The 'Lima call for climate action' (COP 20, Lima, 2014) went on to stress the specific needs of Indigenous peoples in adaptation planning and action while the 'Paris Agreement' (COP 21, Paris, 2015) includes a Global Goal on Adaptation (Goal 7) with concrete objectives for adaptation action (Ford et al., 2016; Lesnikowski et al., 2017; Magnan and Ribera, 2016).

Growing emphasis on adaptation in UNFCCC negotiations since the early 2000s has led to the establishment of a specific architecture of adaptation-focused 'workstreams' and funding entities (Figure 5.1). Such initiatives offer technical support and procedural guidance for country-led adaptation planning in low-income countries, as well as financial support for adaptation planning processes and the implementation of specific adaptation projects. The specific mandates of adaptation workstreams and funds differ slightly (Table 5.1), but all aim to advance specific normative goals agreed upon (or accepted) over the course of nearly three decades of UNFCCC negotiations. For example, while National Adaptation Programmes of Action (NAPA) and

National Adaptation Plans (NAP) focus on meeting immediate adaptation needs in LDCs and medium to long-term adaptation needs in all low income countries, respectively, both embody mechanisms for targeting equity-focused capacity building efforts and financial assistance, consistent with Article 3 of the Convention. Procedurally, requests for adaptation support are initiated (or endorsed) by low-income nation states while the provision of adaptation support is the responsibility of high-income countries. Notably, developed countries have committed to providing $100 billion USD per year by 2020 to support climate action in low-income countries (see Cancun Agreements), suggesting that funding organized through the UNFCCC will be highly relevant for adaptation projects in mountain areas in coming years. However, because of complex reporting and accounting procedures there is uncertainty about current levels of funding and therefore some concern that developed nations are not on track to meet this pledge (Donner et al., 2016; Weikmans and Roberts, 2019).

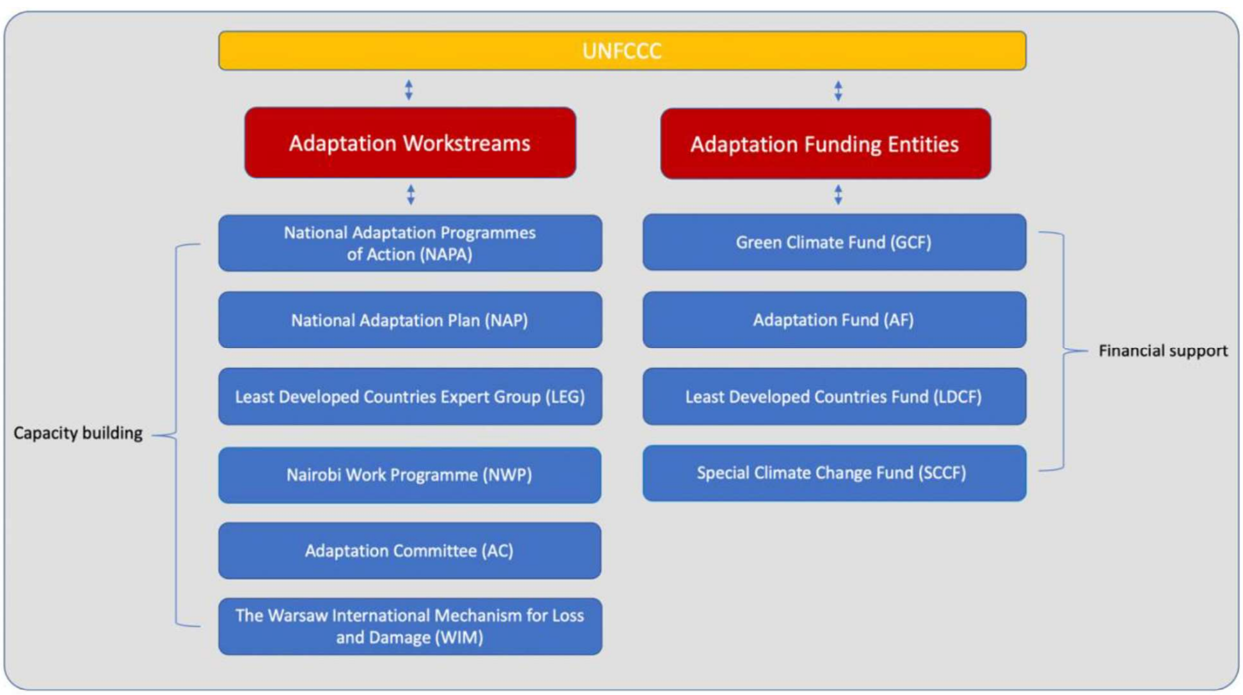

Figure 5.1: Architecture of UNFCCC adaptation initiatives

Table 5.1: Mandates of UNFCCC adaptation workstreams and funding entities	
Major Adaptation Workstreams	
Name	Relevance to Adaptation
National Adaptation Programmes of Action (NAPA)	Established in 2001, NAPAs provide a process for LDCs to identify priority activities that respond to their urgent and immediate needs with regard to adaptation. NAPAs are action-oriented, country-driven, flexible, and based on national circumstances. Once a NAPA has been submitted to the UNFCCC Secretariat, the LDC is eligible for funding under the Least Developed Countries Fund (LDCF).
National Adaptation Plan (NAP)	Established in 2010, the NAP process provides a means for all developing countries to identify medium- and long-term adaptation needs and developing and implementing programmes to address those needs. NAPs aim to build on each country's existing adaptation activities and help integrate adaptation into national decision-making. NAPs are not linked to specific funding entities; instead, planning and implementation stages can be supported by a variety of funding sources (see funding below).
Least Developed Countries Expert Group (LEG)	Established in 2001, the LEG provides technical guidance and support to LDCs on the preparation and implementation of NAPAs and NAPs, as well as the implementation of the LDC work programme more broadly. The LEG also provides technical guidance and advice on accessing adaptation funding.
Nairobi Work Programme (NWP)	Established in 2005, the NWP supports all Parties to the Convention in improving their understanding and assessment of impacts, vulnerability and adaptation, and making informed decisions on practical adaptation actions and measures on a sound, scientific, technical and socioeconomic basis, taking into account current and future climate change and variability.
Adaptation Committee (AC)	Established in 2010, the AC supports enhanced action on adaptation in a coherent manner under the Convention. It provides technical support and guidance; shares relevant information, knowledge, experience and good practices; promotes synergy and strengthens engagement; and supports the monitoring and review of adaptation actions.
The Warsaw International Mechanism for Loss and Damage (WIM)	Established in 2013, the WIM supports efforts to enhance knowledge and understanding of comprehensive risk management approaches to address loss and damage; strengthen dialogue, coordination, coherence and synergies among relevant stakeholders; and enhance action and support, including finance, technology and capacity-building.
Major Adaptation Funding Entities	

Least Developed Countries Fund (LDCF)	Established in 2001, the LDCF supports the world's most vulnerable countries in their efforts to adapt to the effects of climate change. It helps LDCs prepare and implement NAPA plans. LDCF funding focuses on reducing the vulnerability of key sectors identified through the NAPA process, financing on-the-ground adaptation activities that provide concrete results in support of vulnerable communities.
Special Climate Change Fund (SCCF)	Established in 2001, the SCCF is the only adaptation fund open to all vulnerable developing countries (not just LDCs). It provides funds for adaptation related to water resources management, land management, agriculture, health, infrastructure development, fragile ecosystems (*including mountainous ecosystems*) and integrated coastal zone management [emphasis added]. It also supports monitoring of diseases and vectors affected by climate change, and related early warning systems. It builds capacity for disaster prevention related to climate change, including for droughts and floods, and also provides catastrophe risk insurance. The SCCF also supports the transfer of climate-resilient technology for both mitigation and adaptation.
Adaptation Fund (AF)	Established in 2001 and operational in 2010, the AF finances concrete adaptation projects and programmes in developing countries that are particularly vulnerable to the adverse effects of climate change.
Green Climate Fund (GCF)	Established in 2010, the Green Climate Fund (GCF) supports the efforts of developing countries to respond to the challenge of climate change, to limit or reduce their greenhouse gas (GHG) emissions, and to adapt to climate change. It seeks to promote low-emission and climate-resilient development, taking into account the needs of nations that are particularly vulnerable to climate change impacts.

Text based on wording from relevant workstream and climate finance web portals.

5.5 The intervening role of the state

The Government of Nepal has sought and received adaptation support from various UNFCCC workstreams and funding entities. Adaptation became a focal area of national policy in 2009 with the establishment of the Climate Change Council, which is chaired by the Prime Minister and guides high-level planning and coordination related to Nepal's climate change activities. The country completed its NAPA in 2010. This specified nine adaptation priority areas including mountain-specific topics, such as GLOF monitoring, as well as mountain-relevant topics, such as supporting community-based disaster management and empowering vulnerable communities through improved water management schemes (MoE, 2010b). Notably, both the NAPA and the Government's 2011 Climate Change Policy have a heavy focus on community-level action, including mandates stating that at least 80% of the available climate finance budget be used to implement local-level programs (GoN, 2011a; MoE, 2010b).

To operationalize local action, the Government initiated a Local Adaptation Plans for Action (LAPA) program in 2011 to aid the "delivery of adaptation services to the most climate-vulnerable areas and people" (GoN, 2011b p. 2). There are seven major steps in the LAPA process: sensitization, vulnerability and adaptation assessment, prioritization of adaptation options, formulation of the adaptation plan, integration of the adaptation plan into regular planning processes, implementation of the adaptation plan, and progress assessment (*ibid*.). This innovative model for supporting local adaptation action has been emulated in other mountains countries such as India, Pakistan, Kenya, and Tanzania (Maharjan, 2019). Nepal's LAPA program provided a formal framework for identifying local adaptation needs, integrating sub-national priorities into national-level adaptation planning, and, in turn, accessing support to implement local-level adaptations (Silwal et al., 2019). These efforts were complemented by subsequent policies aimed at facilitating the integration of climate concerns into broader development plans and programs (see NPC, 2011) and addressing the health dimensions of climate change (see MoH, 2015). Since 2015, Nepal has been involved in the NAP process, which has goals of identifying medium- to long-term adaptation needs and further integrating climate change adaptation in policies, programs, and activities across sectors and institutional levels (MoFE, 2018).

Nepal's adaptation efforts have led to the establishment of several Government planning and coordination institutions (Figure 5.2). These developments are indicative of envisioned connections between UNFCCC adaptation initiatives and climate action in low-income countries. Until 2018, the Ministry of Population and Environment (MoPE) was in charge of Nepal's adaptation-related activities and was the focal point for UNFCCC contact. However, following government restructuring in 2018, such responsibilities now fall under the purview of the Ministry of Forests and Environment (MoFE) (MoFE, 2018).

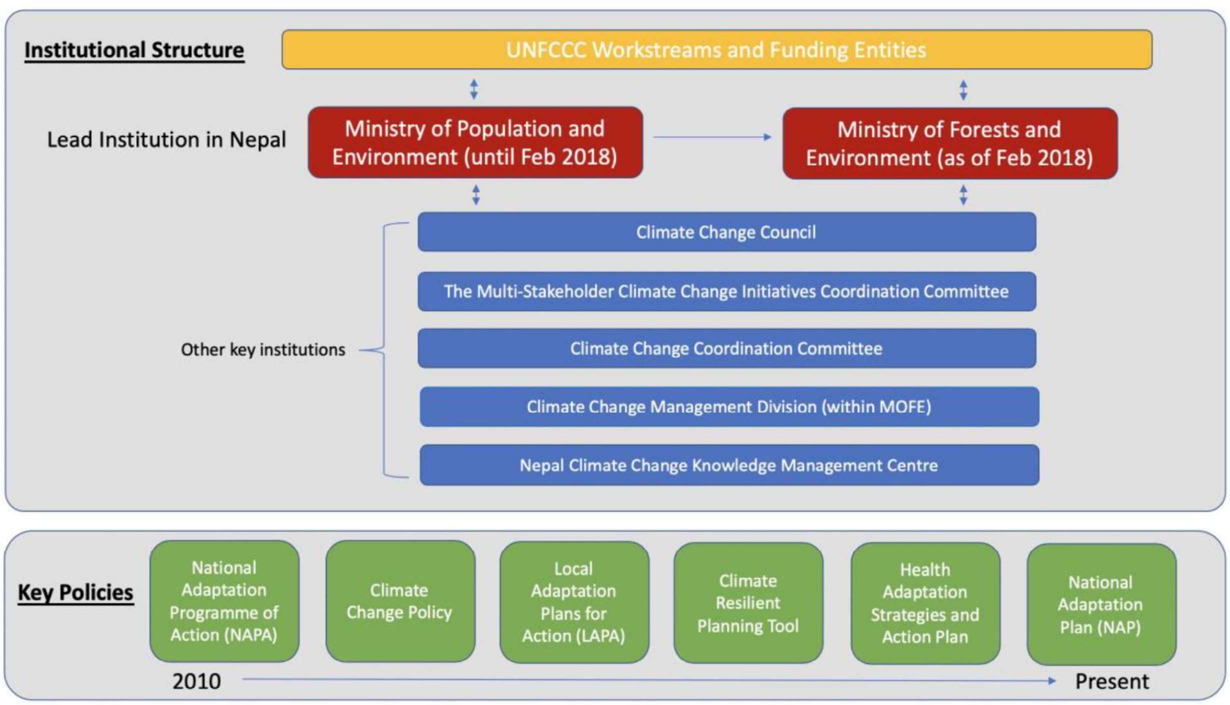

Figure 5.2: Government of Nepal institutional structure and policies related to adaptation

Since the early 2000s, Nepal has received ~$37 million (USD) in adaptation-specific funding from UNFCCC funding entities (Mahat et al., 2019). Such funds have supported numerous adaptation projects (in addition to the adaptation planning processes cited above), including *inter alia* a GLOF risk reduction program supported by the Lease Developed Countries Fund in Solukhumbu and a food security initiative in mountainous Karnali districts supported by the Adaptation Fund. However, both Dixit et al. (2016) and Mahat et al. (2019) note that, to date, multi- and bi-lateral funding for adaptation projects has been significantly greater than contributions from funding streams organized through the UNFCCC. Such support amounts to ~$168 million (USD) since the early 2000s, with major contributors including the UK Department for International Development, US Agency for International Development, Asian Development Bank, and the World Bank (Mahat et al., 2019). However, such contributions fall well short of the estimated $2.4 billion (USD) needed to secure climate resilience in agriculture, hydroelectricity, and water-induced disasters in Nepal by 2030 (MoSTE, 2014). Thus, while funding from multi- and bi-lateral arrangements is significant, it does not supplant the need for financial support from UNFCCC funding entities, which are growing in value. For example, in 2018 the Adaptation Fund received ~129 million (USD) in pledges for that year alone (Adaptation Committee, 2019). The need for additional funding is emphasized in Nepal's Nationally Determined Contributions submission to the UNFCCC, which highlights the need for additional funding to: "Formulate and implement [the] NAP and implementation of [the] NAPA and LAPAs" (MoPE, 2016 p. 12).

5.6 Adaptation needs in upper Manaslu, Nepal

Research in the upper Manaslu region focused on characterizing lived experiences of climate-related changes in glacio-hydrological systems (see Chapter 4 for elaboration), an analytical focus that responds to growing awareness of interdependencies between climate change, the cryosphere, and society in high mountain areas (Carey et al., 2017; Hock et al., 2019; Huss et al., 2017; McDowell and Koppes, 2017 - Chapter 2; Scott et al., 2019). More than 80% of residents reported reductions in glacier and snow cover over the last ten years. The most widely reported hydrological effects of these changes were trends of increasingly frequent and intense summer floods in local waterways; respondents indicated that these changes are exacerbated by increases in the intensity of summer rainfall events. These observations are consistent with scientific understanding of climate-related hydrological changes in the Nepal Himalayas (Bolch et al., 2019; Scott et al., 2019).

Recent flooding events have destroyed local homes, watermills, bridges, and trails; tragically, several children have also drowned during such floods. Community members have drawn on past experience with hydrological variability to cope with contemporary water-related challenges, and have built makeshift stone barriers along waterways adjacent to key infrastructure to protect lives and community assets. However, the increasing frequency and intensity of flooding in the context of limited material, financial, and technical capacity has outstripped local adaptative capacity. In point of fact, only 14% of community members who are affected by flooding state that their adaptive responses have moderated harm. This has increased stress and hardship among mountain people already faced with challenging living conditions. Thus, although we documented significant community-level effort to respond to increasing flooding hazards, damage to infrastructure and threats to livelihoods and well-being are a growing reality for community members in the region.

Community members emphasized two high-priority adaptation needs: Flood protection measures and climate change education programs. The former is needed to safeguard people and community assets from increasingly frequent and powerful floods. The latter is needed to enable anticipatory adaptation planning efforts through the provision of scientifically-sound information about trajectories of climate-related hydrological changes. Our intention here is not to elaborate specific adaptation options, but we note that there could be green infrastructure or nature-based solutions capable of supplanting the need for hard flood protection infrastructure. However, the unique high mountain context of upper Manaslu—high relief topography, fast flowing rivers, data scarcity—is substantially different than other environments where most green responses have been successfully deployed (e.g. most green infrastructure projects are focused on urban areas, see Maragno et al., 2018). Notwithstanding, the Ecosystem-Based Adaptation in Mountain Ecosystems program provides an important example of how such initiatives can be implemented despite such challenges (UNEP, 2015). We note that many community members view climate related stresses as being symptomatic of spiritual improprieties and 'imbalance' in socio-spiritual relations. They therefore view material adaptation actions and programs as secondary to remediating larger spiritual improprieties. However, material adaptation support is still cited as essential for navigating contemporary hydrological challenges. Given the focus of this paper, we focus primarily on material support, although we do comment on complexities emerging at the intersection of local world views and formal adaptation support initiatives later in the paper.

Meeting material adaptation needs identified by community members in upper Manaslu should not be overly complex or resource-intensive; these needs represent straightforward opportunities for reducing vulnerabilities in high mountain communities. These needs are also consistent with needs identified in recent empirical work downstream of the study region (Devkota et al., 2017) as well as the type of adaptation needs and efforts commonly reported in the mountain-focused adaptation literature (McDowell et al., 2019 - Chapter 3; Rasul et al., 2019), making progress in meeting these needs broadly illustrative. Finally, and importantly, these needs fall well within the purview of adaptation support envisioned through the UNFCCC broadly, and are consistent with the type of projects envisioned in Nepalese adaptation support efforts specifically (e.g. LAPAs).

5.7 Progress in meeting adaptation needs

Notwithstanding the apparently laudable adaptation programs and policies the Government of Nepal has advanced with support of UNFCCC initiatives, we found no evidence in published materials of adaptation projects supported by UNFCCC workstreams or funding entities in upper Manaslu. Importantly, we also found no evidence of adaptation projects supported by multi- or bi-lateral initiatives, which might have made projects supported by UNFCCC workstreams or funding entities redundant. This action gap was confirmed by community members, who reported no significant outside adaptation assistance in the region. This situation stands alongside NAPA vulnerability mapping efforts that ranked Gorkha District as highly vulnerable (MoE, 2010a), suggesting deficits in the delivery of adaptation support despite nearly ten years of acknowledged need. We recognize that some projects supported by UNFCCC initiatives in other districts have addressed adaptation needs comparable to those in upper Manaslu (e.g. the aforementioned GLOF risk reduction program in Solukhumbu), but nevertheless observe a pattern of gaps in the delivery of formal adaptation support to mountain communities facing vulnerabilities related to hydrological changes and other climatic stressors.

In some mountainous areas of Nepal, multi- and bi-lateral initiatives help to address adaptation needs (e.g. Building Climate Resilience of Watersheds in Mountain Eco-Regions project) However, in many areas—including upper Manaslu—support from NGOs, regional organizations, and individual donors are the primary source of outside assistance (for adaptation or otherwise). Although support from such entities plays an important role in many mountain communities, it may be insufficient to address climate change vulnerabilities in such contexts. For example, although low-cost NGO-led initiatives can be highly effective in some situations, such initiatives can sometimes lack adequate oversight or promote adaptation programs that reflect donor priorities instead of local needs and aspirations (Mishra et al., 2019). This suggests an important role for more structured and participatory adaptation assistance mechanisms, such as LAPAs. Likewise, while regional organizations and individual donors may be familiar with local conditions, they do not always have the resources and the technical expertise needed to carry out durable adaptation projects. In point of fact, despite various water infrastructure improvement projects supported by the Catholic Relief Service, the Manaslu Conservation Area Project, and French benefactors, water related stresses remain a salient issue for many residents of upper Manaslu, as evidence by results from our community-level research. Similarly, medical and educational support provided by organizations such as the Manaslu Foundation and Friends of Humanity (with logistical support from the World Food Program) has helped to address acute community needs, yet these efforts have only made modest inroads in improving overall human well-being. More broadly, existing assistance efforts have not been focused on addressing emerging climate-related challenges. In this context, increasing access to formal mechanisms of adaptation assistance seems desirable, even if only to augment other modalities of support. Why are formal adaptation projects lacking in climate-affected communities such as those in upper Manaslu despite significant support available through the UNFCCC initiatives, significant State-led adaptation efforts, and clear adaptation needs at the community-level?

One reason adaptation projects supported by UNFCCC workstreams and funding entities are not yet common in communities of the Nepal Himalayas is the complex and bureaucratic nature of accessing support from these programs. Progress is also hampered to some extent by mountain topography and limited transportation infrastructure; however, copious evidence of research and development organizations (e.g. ICIMOD) working in hard-to-reach areas of the Himalayas illustrates that remoteness does not pre-determine exclusion from outside assistance (Hewitt and Mehta, 2012). However, local action is slowed by the prodigious effort required to complete the LAPA process with communities across Nepal. For example, as of 2016, LAPAs were only being implemented in 90 Village Development Committees and 7 Municipalities, representing ~3% of these local-level administrative units (MoPE, 2016). Much of this effort has been concentrated in the far-west region, which is considered particularly vulnerable (Maharjan, 2019). According to Nepal's Nationally Determined Contributions submission, insufficient funding is one barrier to wider LAPA implementation (MoPE, 2016).

Adaptation planning and implementation can also be slowed by competing demands on the State. However, adaptation is clearly a central priority for the Government of Nepal; it has remained high on the agenda despite the dramatic effects of the 2015 earthquake, the promulgation of a new Constitution later that year, and the subsequent restructuring of the government in 2018. Thus, it appears as though the (limited) capacity of the Government rather than a lack of Government intention is the larger hurdle to action on the ground. Looking forward, state capacity should continue to grow with ongoing UNFCCC support (e.g. through the NAP process), and this will likely lead to increased project implementation in mountain communities. But greater State capacity will not necessarily translate into appropriate local-level adaptation initiatives.

Nightingale (2017) has demonstrated that struggles for authority and recognition have strongly influenced adaptation policy and institutions in Nepal, with attendant effects on where, how, and for whom adaptation assistance becomes available across rural Nepal. Similarly, Vij et al. (2019) highlight how power asymmetries among participants in LAPA planning meetings led to the prioritization of actions that reflected the preferences of specific actors: primarily meeting facilitators and local politicians, not community members. As such, adaptation planning activities can actually reinforce, rather than alleviate, the social conditions that shape differentiated vulnerabilities (Nagoda and Nightingale, 2017). This inauspicious situation has been documented in other studies of the LAPA process (e.g. Silwal et al., 2019), and points to the importance of power dynamics in shaping the implementation of planned adaptations (Few et al., 2007). Furthermore, some have argued that local adaptation planning efforts have tended to focus on addressing vulnerability to the impacts of climate change *per se* without addressing the wider social context within which susceptibility to harm is produced (Ensor et al., 2019; Ojha et al., 2016). Here, the UNFCCC tenet of supporting efforts that address the ‘additional effects of climate change’ can conflict with the fact that mountain communities often desire responses that address multiple, concurrent, and often long-standing environmental and social changes (Eriksen et al., 2015; O'Brien and Leichenko, 2000). For example, the desire for flood resistant infrastructure in upper Manaslu is entwined with broader economic development considerations related to the need for safe and reliable bridges for tourists.

More broadly, UNFCCC adaptation workstreams and funding entities—and by extension State-led planning programs like LAPAs—tend to embody a specific globalized discourse that can conflict with the material and symbolic ways in which mountain populations understand climate-related changes (Gagné et al., 2014; Jurt et al., 2015; Mills-Novoa et al., 2017). For example, while the UNFCCC focuses on mitigation and adaptation to address climate change (climate change as a problem to be solved), residents of upper Manaslu often conceive climate change as a symptom of larger social-spiritual improprieties (climate change as a call to piety), as mentioned above. Indeed, deep commitments to Buddhism lead many residents to prioritize proper religious practices over efforts to address material threats posed by climatic changes, believing that piety is in fact the means of addressing the root causes of susceptibility to harm. Differing problem framing can make it difficult for communities to secure support for locally relevant responses that do not resonate with the discursive norms of the UNFCCC (Nagoda, 2015). Such complexities have been well elaborated in pioneering work by Kaul (2019) on traditional metaphysical convictions, spiritualities, moralities, and emotionalities associated with geohazards in the Indian Himalayas, work that highlights the importance of ‘two eyed seeing’ in navigating responses to climatic stressors in mountain regions. More broadly, Oh (2019) has documented the emergence in discursive contestation around the appropriateness of technology transfer and innovation in advancing the goals of the Paris Agreement. These insights call attention to the complex ways formal adaptation support intersects with specific socio-cultural contexts, and suggests a need for attentiveness not only to what support is available, but also whose voice counts in adaptation planning, who can meaningfully access adaptation support, and how such support can be utilized.

Despite significant progress in Nepal in initiating large-scale, cross-sectoral, and locally-focused adaptation programs and policies at the national level, progress in implementing actual adaptation projects in vulnerable mountain communities such as those in upper Manaslu remains limited. Although the abovementioned reasons for observed shortcomings in the quantity and quality of adaptation support were identified in relation to the Nepal experience, we believe they represent generalizable barriers likely to be encountered in other mountainous countries in the Global South (e.g. limited state capacity, funding constraints, power struggles, different worldviews of adaptation planning officials and local communities). However, we also think there are generalizable opportunities for increasing the flow of formal adaptation support to vulnerable mountain communities.

5.8 Prospects for connecting UNFCCC initiatives with needs in mountain communities

There are at least four opportunities for increasing the quantity and quality of adaptation support from UNFCCC workstreams and funding entities to high mountain communities in Nepal and the Global South more broadly.

5.8.1 Prospects for increasing formal adaptation support

First, projects supported by the Adaptation Fund (AF) and the Green Climate Fund (GCF) can be designed, proposed, and implemented by non-state actors. Specifically, a Direct Access modality allows for the accreditation and subsequent flow of funds to organizations working at regional, national, or sub-national scales (called Implementing Entities under the AF and Direct Access Entities under the GCF). In principle, such entities could include organizations working at these scales in mountain areas of the Global South. Such accreditation will likely be easier to secure for well-established organizations such as the International Centre for Integrated Mountain Development (ICIMOD) and the Consortium for the Sustainable Development of the Andean Eco-region (CONDESAN); however, the GCF provides capacity building funds to support smaller or less well-established organizations in preparing applications for accreditation. Once accredited, such organizations could work collaboratively with mountain communities to develop proposals for locally appropriate adaptation initiatives, serving as ‘translators’ between the world views and aspirations of mountain residents and the objectives of UNFCCC funding entities. For example, ICIMOD has been working with communities in the Hindu Kush Himalaya region since 1983 and has a tremendous amount of expertise relevant to improving livelihoods in a sustainable and culturally appropriate manner. Organizations such as CONDESAN have similar expertise, making them uniquely positioned to facilitate the development and delivery of locally appropriate programs funded through the AF and CGF. This is a key opportunity to prioritize the preferences and aspirations of mountain people in adaptation efforts, and in the process to begin addressing some the power dynamics and knowledge politics cited above.

It is important to recognize, however, that organizational accreditation requires an endorsement from the national government; this could be difficult to obtain in countries where the State is complicit in the marginalization of highland populations and might not want to draw attention to mountain inequities (Debarbieux and Rudaz, 2015). Nevertheless, the fact that organizations working in mountain areas can seek accreditation as Implementing Entities/Direct Access Entities represents an important opportunity for increasing the amount of support for, and quality of, planned adaptations in high mountain communities. In the context of Manaslu, accreditation of the Manaslu Conservation Area Project (sub-national entity) or the International Centre for Integrated Mountain Development (ICIMOD) (regional entity) could facilitate the delivery of culturally and environmentally appropriate flood protection and education programs.

Second, while the two remaining UNFCCC funding entities do not have a direct access modality for non-state actors, the Special Climate Change Fund (SCCF) explicitly mentions support for projects in mountains as well as water management, flood protection, and risk reduction efforts. Coherence between the mandate of this fund and issues relevant to mountain communities such as those in upper Manaslu could make the SCCF a germane target for governments seeking support for mountain-focused projects (e.g. funding to implement LAPA projects across the Nepal Himalaya). Indeed, the SCCF has already funded several mountain-specific projects (e.g. Integrating climate change risks into water and flood management by vulnerable mountainous communities in the Greater Caucasus region of Azerbaijan) (GEF, 2019b). Furthermore, while the mandate of the SCCF states that support is limited to projects addressing the additional impacts of climate change (often interpreted as a prioritization of hard adaptations), in practice several projects that have been supported by the SCCF actually take the form of soft adaptations (see *ibid*.). Thus, the SCCF might offer support for proposals that take a more holistic approach to addressing climate change vulnerability in mountain communities, including nature-based approaches that might better serve mountain people who rely directly on mountain-sourced ecosystem services. Finally, the SCCF is the only funding entity that provides support for projects in all low income countries (i.e. Non-Annex I), not just LDCs, making it relevant for other mountainous countries like Peru, that do not qualify for support from other UNFCCC funding entities.

Access to SCCF funds requires governments to co-develop proposals with a Global Environment Facility (GEF) Partner Agency. Fortuitously, the Food and Agriculture Organization of the United Nations (FAO), which hosts the Mountain Partnership Secretariat, is one such agency. This serendipitous thematic (mountains) and institutional (FAO/Mountain Partnership) alignment represents another salient opportunity for increasing support for planned adaptation projects in mountain areas.

Third, the growing focus on Indigenous peoples in UNFCCC decisions and processes is another positive development for securing formal adaptation support for Indigenous people living in mountain areas, although significant shortcomings remain (see Belfer et al., 2019; Shawoo and Thornton, 2019). The number of Indigenous people living in mountain is uncertain given limitations of currently available data (F. Parisi, FAO, pers. Comm., 10 January 2020); however, Indigenous people are thought to represent a large proportion of the global mountain population (e.g. ~50% of population in Ecuadorian Andes) (FAO, 2015). Here, greater awareness of the often-disproportionate effects of climate change in Indigenous communities as well as the essential role of Indigenous knowledge in adaptation planning (as enshrined in UNFCCC, 2015 Article 7.5) echoes insights from community-based vulnerability and adaptation research in high mountain communities (as summarized in Hock et al., 2019), including our work with Indigenous peoples in upper Manaslu. There is an opportunity to highlight these synergies in project proposals by both State and accredited non-state actors, and a growing likelihood that UNFCCC funding entities will be receptive to projects that address the needs of Indigenous peoples in mountain regions. Furthermore, principles and obligations outlined in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) can be highlighted to increase justification for support for locally appropriate adaptation projects with Indigenous communities.

Of course, not all mountain communities are inhabited by Indigenous peoples, and even where proposals are framed around Indigenous issues, governments that are not sympathetic to the needs or representation of Indigenous peoples might foreclose this opportunity. Despite these caveats, growing recognition of Indigenous peoples in UNFCCC decisions and among UN institutions more broadly can be (rightly) leveraged to justify support for adaptation projects in high mountain communities inhabited by Indigenous peoples. Such framing would be appropriate in proposals for adaptation support in upper Manaslu.

Lastly, adaptation support organized through the UNFCCC is now being conceptualized within the goals of other global initiatives; namely, the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction (UN Climate Change Secretariat, 2017). In this context, proposals that refer to these global initiatives are likely to be viewed more favorably, a fortunate development given the recognized relevance of these initiatives for mountain areas (Wymann von Dach et al., 2017; Wymann von Dach et al., 2018). For example, in sensitive mountain environments where hard adaptations could lead to unintended ecological impacts, striving for coherence with the SDGs can lead to more environmentally sound responses to climate change (e.g. Goal 15.4 – "Ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development"). Recognition of such complementarities can also help to justify support for soft adaptations that are attentive to the human and ecological dimensions of climate change. The LDCF funded 'Ecosystem-Based Adaptation for climate-resilient development in the Kathmandu Valley, Nepal' project is one example of the type of initiatives that can emerge when adaptation is situated within broader sustainability considerations (GEF, 2019a).

Likewise, given the growing frequency and magnitude of hazards being faced by mountain communities (Hock et al., 2019; Huss et al., 2017), aligning proposals with the Sendai Framework for Disaster Risk Reduction represents an opportunity to operationalize key recommendations from the broader risk reduction community. This could be a particularly salient framing in adaptation proposal focused on upper Manaslu, where flooding hazards are the primary climate related vulnerability faced by community members. Mountain-focused adaptation initiatives are an ideal venue for showcasing complementarities between adaptation, SDGs, and the Sendai Framework, and proposals with this laudable objective are likely to be especially attractive in the current funding context.

According to McDowell et al. (2019 - Chapter 3), the challenge of climate change in high mountains cannot be met without adaptation actions that address the interwoven scientific, human, and socio-ecological dimensions of climate change. While adaptations implemented with support from UNFCCC initiatives do not guarantee success in these areas, we believe that the focus of such initiatives on supporting science-based, stakeholder-engaged, and sustainability-focused adaptations provides a promising basis for planned adaptation actions in mountain areas. However, we also acknowledge the important challenges and complex politics of adaptation support organized through the UNFCCC. Our hope is that this paper serves to clarify some of the apparent prospects and perils of linking UNFCCC adaptation support mechanisms with needs in high mountain communities, such that efforts to engage with these mechanisms become more straightforward and strategic as well as better informed.

5.8.2 Limitations

This assessment is subject to several limitations. For example, our insights were primarily developed in relation to one mountainous country and a sub-region therein. Although we suspect that many of our observations are broadly applicable, our findings are inevitably skewed by our focus on the Nepal experience. Furthermore, UNFCCC and many Government of Nepal materials are published in English, but we did encounter some primary texts that were only available in Nepalese. In such cases, we sought out and reviewed English-language translations or descriptions of these materials, with the assumption that these provided faithful representations of the original Nepali texts. In addition, we have not outlined the full procedural details for securing adaptation support from the respective workstreams and funding entities described herein. Actors seeking formal adaptation support through such initiatives are advised to carefully review respective eligibility criteria and application procedures (e.g. Adaptation Fund, 2017). Moreover, we have alluded to some power dynamics at play in UNFCCC and government-led adaptation programs, but have not evaluated the potentially problematic nature of interactions between mountain organizations and mountain communities. Organizational work with mountain communities motivated by this paper must be cognizant of issues related to power and positionality; ethical engagements between mountain organizations and communities are a precondition of tenable co-developed proposals for adaptation support. More broadly, we have only focused on adaptation support organized through the UNFCCC, yet there is an ever-growing assemblage of other formal adaptation support mechanisms that may be relevant to mountain communities (e.g. direct project funding from multinational agencies). We recognize that funding and implementation support from both UNFCCC initiatives and other formal adaptation support mechanisms will be required to meet adaptation needs in (and beyond) mountain areas. In view of these limitations, this assessment represents a provisional and partial view of prospects for planned adaptations in high mountain communities.

5.9 Conclusions

This chapter represents an effort to move from aspirations of more just, equitable, and sustainable futures for mountain people at the frontlines of climate change, to a focus on the means of achieving such outcomes. It clarified the architecture of available adaptation support organized through the UNFCCC and provides an empirically grounded evaluation of whether such formalized support mechanisms are having tangible effects on addressing adaptation needs in high mountain communities. Drawing on a case study of Nepal and adaptation needs in the upper Manaslu region, it identified country-specific and generalizable reasons for discordance between idealized pathways of adaptation support from global institutions to local communities, including complications stemming from the bureaucratic nature of formal adaptation mechanisms, the intervening role of the State in delivering aid, and the ways in which these complexities intersect with the specific socio-cultural contexts of mountain communities. It then highlighted several prospects for increasing the quantity and quality of adaptation support to mountain communities; namely, 1) formalizing relationships between organizations working in mountain areas and UNFCCC funding entities, 2) targeting support from funding bodies with mandates specifically relevant to mountain areas, 3) developing proposals that address the growing challenges faced by Indigenous peoples in a changing climate, and 4) devising adaptation projects that address concurrent priorities related to sustainable development and disaster risk reduction. These opportunities were considered alongside several salient concerns about formal adaptation support mechanisms in an effort to provide a well-rounded assessment of the prospects for planned adaptations in high mountain communities.

Efforts to link mountain communities with adaptation support organized through the UNFCCC are complementary to objectives already being pursued as part of the broader ‘mountain agenda’ (Makino et al., 2019; Rudaz, 2011). However, increasing the flow of formal adaptation support to mountain communities will require additional advocacy and awareness raising efforts. Mountain Partnership is especially well positioned in this regard given its affiliation with the United Nations and formal relationships with >300 governments, organizations, and other stakeholders interested in mountain issues (Mountain Partnership, 2019). Such advocacy efforts will bolster the growing recognition of adaptation needs in mountain regions that has followed the release of the IPCC SROCC ‘High Mountain Areas’ chapter as well as mountain-focused events at the recent UNFCCC COP 25 meeting in Madrid (e.g. the launch of a Global Programme on Climate Change Adaptation in Mountains). This awareness, in turn, will strengthen calls for urgent action on climate mitigation.

We hope that this paper has helped to reveal the considerable opportunities for increasing the quantity and quality of adaptation support organized through the UNFCCC to high mountain communities. At the same time, there is a need for prudence. International adaptation support mechanisms and local communities are often worlds apart, literally and figuratively. Building bridges between these worlds may be appropriate in many instances, but our assessment also suggests potential perils that should be considered in efforts to address local adaptation needs through planned adaptation initiatives. Taking account of such complexities will require additional research examining the political economy of delivering adaptation support from global mechanisms through the State to local communities, the politics of securing State endorsement for the accreditation of organizations working in mountain areas, and the conditions under which autonomous adaptations might be superior to externally resourced interventions.

Chapter 6: Conclusion

The work described in this dissertation is the result of problem-driven, insight-oriented, and solution-focused research efforts. It emerged from growing awareness that climate change is causing profound hydrological changes across high mountain areas, changes that compound already difficult socio-economic conditions in many mountain communities. This nexus is leading to widespread but differentiated vulnerabilities among mountain populations, and calls attention to the need for greater understanding of the specific causes of susceptibility to harm as well as prospects for enhancing adaptation action in mountain areas. Contemporaneously, growing awareness of the importance of socio-ecological perspectives suggests that the study of vulnerability and adaptation cannot be separated from broader socio-ecological dynamics in mountain areas. In this context, I have argued that the study of adaptation to glacio-hydrological change must be informed by sound hydrological science, grounded in normative commitments to social justice, and attentive to socio-ecological interdependencies and feedbacks. The preceding chapters of this dissertation built the case for this position and provided insights that emerged from research guided by these tenets. This chapter distills the key findings and contributions of the dissertation, discusses important limitations for my research efforts, and proposes numerous strands of inquiry ripe for further investigation.

6.1 Summary of key findings and contributions

Chapter 2 codified the interdisciplinary theoretical framework outlined in the Introduction. It clarified important interdependencies between science, society, and ecosystems in the context of adaptation to glacio-hydrological change, tracing a dearth of contemporary adaptation research that addresses these issues in an integrative manner. It then examined the potential implications of this situation, drawing on prior work by Adger et al. (2005) and Eriksen and Brown (2011) to show how this analytical limitation impedes the identification, development, and implementation of 'successful' adaptations (here defined as effective, efficient, equitable, legitimate, and sustainable). In response, it was argued that research capable of supporting successful adaptations to glacio-hydrological change must be framed according to three guiding principles:

1. Adaptation research should integrate detailed analyses of watershed-specific glaciological and hydro-meteorological conditions; glacio-hydrological changes are context-specific and therefore cannot be assumed to follow idealized trajectories of peak water.

2. Adaptation research should consider the complex interplay between glacio-hydrological changes and socio-economic, cultural, and political conditions; responses to environmental changes are non-deterministic and therefore not deducible from hydrological changes alone.

3. Adaptation research should be attentive to interdependencies, feedbacks, and tradeoffs between human and ecological responses to glacio-hydrological change; research that does not evaluate these socio-ecological dynamics may lead to maladaptive adaptation plans.

This chapter built on a small body of antecedent research that has called for integrative approaches to the study of adaptation in mountain areas (e.g. Bury et al., 2013; Carey et al., 2014;

Mark et al., 2010; Mills-Novoa et al., 2017). However, this prior work focused primarily on balancing hydrological and social considerations and did not provide an explicit analytical framework for future studies. In response, this chapter provided a framework for explicitly linking the science of glacio-hydrology, insights from vulnerability research, and concepts from socio-ecological systems in the context of adaptation to glacio-hydrological change. Its structured, yet flexible analytical framework offers an important point of departure for future adaptation research in mountain areas. Indeed, it has already begun to inform thinking in the field (as cited in Hock et al., 2019; Kieslinger et al., 2019; Rasul et al., 2019). Finally, although the principles developed in the chapter are focused on adaptation to glacio-hydrological changes in mountain areas, they can be easily amended for research focused on other climatic stressors and geographies (e.g. adaptation to sea ice change in the Arctic).

Chapter 3 addressed substantial gaps in our understanding of adaptation action and research in high mountain areas. To accomplish this, it developed a typology of the challenge of climate change in glaciated mountain systems—extending ideas developed in Chapter 2—and used formal systematic review methods to critically evaluate existing adaptation actions and research in light of this typology. It documented evidence of socially-relevant climate-related changes 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. It also revealed the importance of multiple stressors in shaping adaptations, highlighting the influence of broader socio-ecological dynamics on responses to change. Adaptation actions were identified in 78% of countries with glaciated mountain ranges, yet most of these adaptations were reactions to experienced climatic stimuli and carried out without guidance from a formal adaptation plan. The chapter also documented the emergence of explicitly mountain-focused adaptation research; however, studies framed in this way were relatively scarce and have only been carried out in about half of the countries with glaciated mountain ranges. The chapter indicated that few adaptation action and research initiatives have adequately addressed the issues outlined in the chapter's evaluation framework for the challenge of climate change. It discussed the consequences of this shortcoming and identified ways in which adaptation action and research might more fully meet the challenge of climate change in glaciated mountain systems.

The systematic review developed in Chapter 3 is the most exhaustive and detailed assessment of adaptation research and action in high mountain regions globally. However, it is not the first or only effort to synthesize knowledge of adaptation in mountain areas. In 2014, I published the first systematic review of adaptation in mountain areas (McDowell et al., 2014). The methodology was subsequently utilized by other mountain researchers who focused on adaptation efforts in specific regions (Muccione et al., 2016; Rasul et al., 2019; Sud et al., 2015). However, the review reported in Chapter 3 is substantially more comprehensive than these prior efforts; it is also significantly more methodologically rigorous. Moreover, the chapter developed a typology for the challenge of climate change in mountain systems, and evaluates the state of adaptation research and action in light of this framework. This added an important theoretical dimension to our understanding of adaptation in mountain systems. Insights from Chapter 3 have directly influenced contemporary research and policy conversations related to adaptation in mountain areas. For example, findings from this chapter are the basis of information about adaptation reported in the 'High Mountain Areas' chapter of the IPCC SROCC (Hock et al., 2019). Moreover, findings based of this systematic review provide an "evidentiary basis for future assessments of adaptation to cryosphere changes in the high mountains" (Hock et al., 2019 p. 58), a contribution that advances broader efforts to track progress on adaptation action and research over time (Ford et al., 2015).

Chapter 4 responded to substantial gaps in our understanding of what glacio-hydrological changes mean for residents of high mountain communities at the frontlines of glacial change, including whether peak water *per se* provides a sufficient analytical basis for understanding lived experiences of climate-related hydrological changes. It also responded to the paucity of multi-sited, community-level assessments of the human dimensions of glacio-hydrological change. Drawing on research conducted in the upper Manaslu region of Nepal and Cordillera Huayhuash region of Peru, the chapter revealed the inherently social origins of vulnerability, unanticipated vulnerabilities among communities situated on both the rising and falling limb of the peak water profile, and socially relevant hydrological changes that are obscured by focusing exclusively on hydrological dynamics associated with peak water. These insights emerged at the intersection of complex social-cultural and glacio-hydrological realities and indicate the importance of situating peak water dynamics in specific socio-ecological contexts. The chapter suggests that, while glacio-hydrological modeling assessments that focus on identifying the spatial and temporal dynamics of peak water are essential, they are not sufficient for inferring susceptibility to harm. Instead, deeply contextual studies are required to understand the specific vulnerabilities and diverse adaptation needs of mountain people living in rapidly changing high mountain watersheds.

This chapter contributes to a growing body of research investigating the effects of hydrological change for mountain communities (as summarized in Carey et al., 2017), including several prior community-level studies of note (e.g. Gentle and Maraseni, 2012; Mark et al., 2010; Sapkota et al., 2016). However, many studies to date have been underpinned by theoretical foundations and methodological approaches—including modeling approaches—that make it difficult to identify the underlying causes of vulnerability to hydrological change. In turn, this has constrained efforts to devise robust responses to changing hydrological conditions. And, as mentioned above, multi-sited work is nearly absent. In this context, Chapter 4 is noteworthy for its integration of social-theoretical insights form vulnerability research as well as its multi-sited research approach. Moreover, it is the first study to substantively examine the human dimensions of peak water *per se*. The study has also expanded the geographical scope of human dimensions of climate change research in mountain areas through its focus on upper Manaslu and the Cordillera Huayhuash. For these reasons, findings from the chapter are poised to stimulate productive discussions and collaborations between mountain researchers concerned with addressing vulnerability to glacio-hydrological changes in high mountain areas.

Chapter 5 responded to the pressing need to know more about prospects for implementing externally resourced adaptation initiatives in high mountain areas, a need related both to increasing vulnerabilities in many mountain communities and to the moral imperative to provide adaptation support to vulnerable people who have contributed little to GHG emissions. The chapter clarified several issues essential for addressing this knowledge gap, including the specific architecture of adaptation initiatives organized through the UNFCCC, idealized linkages between these initiatives and meeting local adaptation needs, and actual progress in connecting such support with discrete adaptation needs in high mountain areas. It critically examined observed shortcomings in matching adaptation support with local adaptation needs in the upper Manaslu region of Nepal (as identified in Chapter 4), including complications stemming from the bureaucratic nature of UNFCCC adaptation support mechanisms, the intervening role of the State in delivering aid, and the ways in which these complexities intersect with the specific socio-cultural contexts of mountain communities. Importantly, however, it also identified specific opportunities for increasing the quantity and quality of formal adaptation support in mountain areas, such as formalizing relationships between organizations working in mountain areas and UNFCCC funding entities and targeting support from funding bodies with mandates specifically relevant to mountain areas.

This chapter represents a substantive assessment of progress in, perils of, and opportunities for, addressing adaptation needs in high mountain communities through adaptation support organized through the UNFCCC. It is informed by, and contributes to, an emerging body of research that critically examines how global adaptation support mechanisms intersect with local socio-cultural realties in mountainous countries of the Global South, particularly the pioneering work of Ensor et al. (2019); Nagoda and Nightingale (2017); Nightingale (2017); and Vij et al. (2019). However, this chapter responds directly to knowledge needs of the mountain research and development community. In this context, it represents an effort to move from aspirations of more just, equitable, and sustainable futures for mountain people at the frontlines of climate change, to a focus on the means of achieving such outcomes. It also stands as an important contribution to emerging efforts to situate the human dimensions of climate change in mountain areas within international climate change policy developments and discourses (see Huggel et al., 2019). In particular, the chapter provides the type of information that is needed to advance the Global Goal on Adaptation (Paris Agreement, Article 7) in mountainous contexts. For example, it advances understanding of how international adaptation support intersects with socio-cultural and political realties in mountainous countries of the Global South, and identifies opportunities for consilience between UNFCCC adaptation initiatives and the context-specific aspirations of mountain people, both of which are needed for "Improving the effectiveness and durability of adaptation actions" (Global Goal on Adaptation, Goal 7e) in mountain areas.

The dissertation chapters also yield cross-cutting insights. For example, this dissertation has provided overwhelming evidence that human adaptations in response to changes in glacio-hydrology are already occurring across high mountain communities, a fundamental insight that calls attention to the urgent need for increased understanding of adaptation to hydrological changes in high mountain areas. However, the dissertation has also shown that how we approach the study of adaptation has important implications for what we are able to 'see' (or not see) and therefore what types of insights or proposed actions might follow from adaptation studies. Such blind spots were highlighted in chapter 3, which revealed that existing adaptation studies tend to fall short of substantive engagement with at least one of the scientific, human, or socio-ecological dimensions of adaptation. Attendant implications were illustrated in chapter 4, which showed how limited engagement with social dynamics in impacts driven research has led to conceptions of vulnerability that do not track with lived experiences reported by residents in high mountain areas. Such a lack of engagement with social dynamics portends the misallocation of adaptation assistance and the development of adaptation initiatives that do not address to root causes of susceptibility to harm, maladaptive eventualities this dissertation has helped to reveal theoretically and empirically. Unintended consequences of analytical choices in adaptation research were highlighted across chapter, but so too were bright spots for scientifically, socially, and ecologically tenable responses to climate related hydrological changes. Through such contributions, this dissertation has substantially advanced understanding of climate change adaptation research in high mountain areas, particularly by acting on calls to operationalize more integrative and reflexive global environmental change research (Emmenegger et al., 2017; Carey et al., 2014b; Gleeson et al., 2016; Price, 2013).

Finally, although the dissertation targeted mountain-focused adaptation research and practice, it also makes contributions to the respective theoretical traditions that informed its chapters. For example, the community-level work in the high mountains of Nepal and Peru illustrated how detailed observations of mountain people can improve understanding of the nature and implications of glacio-hydrological changes in specific contexts. In addition, the dissertation increases the geographical scope of research on the human dimensions of climate change; provides an example of the use of formal concepts from vulnerability research in mountainous contexts; and addresses shortcoming highlighted in recent critical reviews of the state of the field, including the need for greater engagement with the socio-ecological dimensions of vulnerability and adaptation (Ford et al., 2018; McDowell et al., 2016a). Likewise, the dissertation elaborated the benefits of socio-ecological systems thinking in a mountain adaptation context, helping to broaden the scope of topics that might be of interest in future socio-ecological studies. More broadly, the dissertation has helped to advance mountain research and our understanding of mountain systems, while raising the profile of mountain issues within broader scholarly debates related to global environmental change.

Figure 6.1: Contributions of dissertation	
Contribution	**Chapter**
Defined principles for robust adaptation research in high mountain areas, providing a framework for more scientifically, socially, and ecologically tenable adaptation research in mountain regions.	CH 2
Clarified the state of adaptation research and action in high mountain areas in relation to the challenges posed by climate change, identifying key issues that can be addressed in future adaptation research and practice.	CH 3
Improved understanding of lived experiences of glacio-hydrological change, clarifying important shortcomings in existing hypotheses about vulnerability to peak water as well as the need for deeper collaboration between natural and social scientists when defining vulnerabilities and adaptation needs.	CH 4
Identified opportunities for addressing adaptation needs in mountain areas through support from UNFCCC initiatives, outlining the architecture of available support as well as strategic opportunities for increasing the flow of support to mountain communities.	CH 5
Advanced mountain focused human dimensions of climate change research, providing new analytical, empirical, and practice-oriented insights related to adaptation in high mountain areas.	Full dissertation
Raised profile of mountain-specific issues, challenges, and opportunities within broader debates related to global environmental change.	Full dissertation

6.2 Limitations

The work reported in this dissertation is subject to several limitations. Fundamental limitations are discussed here, while additional specific limitations are elaborated in the respective dissertation chapters.

The systematic review reported in Chapter 3 only reviewed English-language documents. I initially endeavored to include documents published in other major languages used in mountainous countries, such as Spanish, French, German, Mandarin and Russian. However, I eventually decided to surrender this goal given the scope of the project, the substantial challenge of producing commensurate search and review protocols across numerous languages, and my lack of colleagues with the requisite language skills. Although most scientific literature is published in English (Drubin and Kellogg, 2012), I doubtlessly missed some relevant content given my exclusive focus on English-language materials. Furthermore, I only examined a subset of the (potentially) relevant grey literature. I believe my focus on a subset of organizations affiliated with the Mountain Partnership was appropriate for a first-order assessment of the grey literature; however, the omission of work by institutions such as ICIMOD and CONDESAN, as well as actors not affiliated with Mountain Partnership, leads to an underestimation of planned adaptation actions. Here, future assessments are advised to also evaluate the efforts of organizations and government agencies receiving adaptation support from UNFCCC funding entities (see Chapter 5). Finally, Chapter 3 assumes that information reported in documents provides a thorough and accurate reflection of the state of adaptation action and research. Although I am confident that the chapter thoroughly synthesizes adaptation research (notwithstanding the linguistic scope issues above), I know that many adaptive responses to climate change in mountain areas are not catalogued in peer-reviewed or grey literature documents. Thus, although Chapter 3 represents the most exhaustive and detailed assessment of adaptation in mountain areas to date, it underestimates the state of adaptation action.

My health issues in Nepal had marked effects on the research reported in Chapter 4. In particular, my engagement with socio-ecological interdependencies and feedbacks (Principle 3 from Chapter 2) was severely constrained by my inability to conduct sustained observations of socio-ecological dynamics in the field. I have attempted to distill applicable insights from the interview data and to consider these insights in relation to relevant literatures. However, the chapter is substantially less engaged with the socio-ecological dimensions of adaptation than I had envisioned. Likewise, my limited time in the field means that I was unable to provide a satisfactory level of nuance of *vis-à-vis* socio-economic, cultural, and political conditions that shape vulnerability in my study communities (Principle 2 from Chapter 2). Health issues also prevented me from evaluating a fuller range of possible drivers of glacio-hydrological change in my study sites (e.g. the deposition of black carbon, changing land-use practices), which has led to findings that might over-emphasize the role of climatic-related drivers of changing hydrological conditions. However, this bias is also related to my own academic background as a climate change vulnerability and adaptation researcher. With an expanded theoretical and methodological repertoire (e.g. Brauman et al., 2007; Clerici et al., 2019), I might have been better prepared to investigate other drivers of hydrological change (and therefore to attend more completely to Principle 1 from Chapter 2). In view of these limitations, Chapter 4 does not fulfill my criteria for robust adaptation research.

Furthermore, although my local research partners did exceptional work, their more limited familiarity with adaptation theory and practice, as well as interview protocols, meant that the subsequent data were not as lucid as I had hoped. This is especially true for the data from Nepal, where my research partner was trained during efforts to arrange my timely return to Kathmandu for medical assessment. Because the data were not strictly consistent across study regions, I did not feel it was appropriate to pursue more advanced statistical evaluations of similarities and differences in lived experiences of glacio-hydrological change. Again, this led to a project that was substantially different than I had envisioned before my health problems. In the context of the issues above, data from Nepal and Peru were discussed and cross-checked with my local research partners following field research and during data analysis. More broadly, the lived experiences of glacio-hydrological change reported in Chapter 4 are based on research in specific communities in the high mountains of Nepal and Peru. These experiences may not be comparable to those of other communities in these regions or in other high mountain communities more broadly, particularly those located in the Global North.

Insights from Chapter 5 should be read in light of several caveats. For example, the chapter suffers from shortcomings related to an exclusive focus on English-language documents as well as the previously mentioned concerns about extending results from specific socio-ecological contexts to mountain areas more broadly. However, I believe the effect of these issues on the chapter findings are limited—English is the lingua franca of UNFCCC communications, and Nepal shares numerous socio-ecological attributes with other mountainous countries of the Global South. Differently, the chapter's focus on adaptation efforts supported through UNFCCC workstreams and funding entities provides a partial picture of prospects for planned adaptations in mountain areas. Although support organized through the UNFCCC will arguably be the most significant source of adaptation assistance going forward (i.e. commitment to providing $100bn/year in climate finance by 2020), it is currently overshadowed by planned adaptations organized outside of the purview of the UNFCCC (many of which are documented in Chapter 3). Notwithstanding this shortcoming, it was neither my goal nor within the scope of the chapter to evaluate the entire landscape of prospects for planned adaptation support in mountain areas. Lastly, because of health issues, my time for *in situ* observations of power dynamics at play between UNFCCC-supported adaptation programs and mountain communities in Nepal was limited, constraining my ability to comment on such dynamics (see work by Nightingale, 2017 for a cogent example of such grounded analysis).

Chapters 4 and 5 do not sufficiently address the principles for robust adaptation research developed in Chapter 2 or, relatedly, the challenge of climate change in mountain areas articulated in Chapter 3. On one hand, it is tempting to scapegoat my health challenges—this certainly affected my progress in important ways. On the other hand, however, my research efforts over the course of my PhD made me acutely aware of the significant intellectual, practical, and financial challenges imposed by the type of integrative work I called for in Chapters 2 and 3, particularly when it involves multi-sited research in remote areas of the Global South. Thus, while I stand behind my emphasis on the importance of integrative adaptation research, I now have a fuller appreciation of the substantial difficulties involved in operationalizing such studies.

The context of knowledge production for this dissertation also results in important limitations. My research is inevitably conditioned by the fact that I am a Caucasian male, raised in a middle-class family in the United States, and educated at universities in Canada and England. My upbringing and education have filled me with Western conceptions of people and places; these ideas shape my understanding of mountains, mountain people, and global environmental change more broadly. And while my core training in environmental change research has been informed by topics such as postcolonial theory and engagement with traditional ecological knowledge holders, it was nevertheless founded on ideas rooted in Western scientific traditions and my particular socio-cultural background. Accordingly, I am aligned with a specific epistemic community of mountain and global environmental change researchers (Debarbieux and Price, 2016). This inevitably conditions how I conduct my research, what I come to know (or not know), and my authority (or lack thereof) to speak on behalf of those featured in my research. For these reasons, I emphasize that the content of my dissertation reflects my own partial and situated understanding of life in high mountain watersheds.

6.3 Research needs and opportunities

The findings and limitations of this dissertation research point to several avenues for future research. For example, there is pressing need to improve understanding of the *implications of adaptations*. Adaptations that are effective in one place, at one period in time, or for one specific group or sector, can have harmful effects for other places, times, or people/sectors. These ideas have been reasonably well theorized (Barnett and O'Neill, 2010; Juhola et al., 2016; Magnan et al., 2016), yet examination of such topics in mountain-focused adaptation research is limited. Here, the extent to which adaptations in upstream areas affect downstream populations is one obvious topic that requires greater attention. Conversely, there is historical precedent for expecting that disruptive hard adaptations benefitting downstream populations (e.g. the construction of dams to moderate discharge variability) might be imposed on mountain people without proper consultation, consent, or compensation (Grumbine and Pandit, 2013; Perlik, 2015). Future research should anticipate and evaluate such situations. This dissertation has also called attention to the ways in which human responses to climate change can lead to unintended, potentially cascading consequences for mountain ecosystems. Given the profound threats already facing biodiversity, research examining unintended impacts on ecosystems—and efforts to reduce such impacts—is essential to ensure that adaptations do not contribute to the pervasive human-driven decline of life on Earth (Díaz et al., 2019a; Díaz et al., 2019b; Turner et al., 2010). This is especially important in mountain areas where high levels of biodiversity coincide with high environmental fragility; imprudent adaptations could have particularly significant impacts on flora and fauna. Ultimately, unintended consequences of adaptation could have system level effects, as when impacts on mountain environments lead to the degradation of ecosystem services that underpin well-being (Lavorel et al., 2019). Improving understanding of the implications of adaptation will require adaptation researchers to engage with a much broader body of literatures (e.g. ecosystem services, cumulative effects), to pursue collaborations with colleagues from disparate disciplines, and to foreground the knowledge of mountain residents who are intimately familiar with socio-ecological interdependencies, feedbacks, and tradeoffs.

There is a need for greater clarity about the conditions under which *autonomous adaptations* are appropriate and sufficient. Autonomous adaptations are often associated with exclusion from necessary support services; this is accurate for many—but certainly not all—situations where autonomous adaptations are pursued. Several community-based adaptation studies (e.g. Ingty, 2017; Li et al., 2013; Negi et al., 2017; Postigo, 2014), as well as my own time with communities in high mountains and the Arctic, has made me aware of the profound resilience and self-reliance of many frontline communities (inter-community differences notwithstanding); framing autonomous adaptations as options of last resort in such situations can obscure this significant social capital. Worse, this can lead to situations where outside adaptation assistance is brought into communities that do not need or want external support; this can pose an affront to local autonomy and represents a misuse of scarce adaptation resources. However, overstating the adaptive capacity of mountain people can also undermine the rationale for delivering adaptation resources that are urgently needed in many mountain areas (Gagné, 2016). These stakes suggest a need for much greater clarity about the demarcation between autonomous adaptations that are appropriate and sufficient and those that connote exclusion from necessary support services. Importantly, evaluating the cogency of autonomous adaptations will require critical reflection on the developmental logics that underpin much adaptation research, including reflexivity about the tendency to map normative predilections of ‘progress’ onto mountain communities. For example, autonomous adaptations are not necessarily unacceptable because they are undertaken by people who have limited financial means (who need to be made ‘better off’ through planned adaptions). Such evaluations will also require explicit consideration of the ecological implications of adaptation, as discussed above. Autonomous adaptions that meet local needs but that adversely impact local ecosystems can be maladaptive (i.e. not appropriate). The integrative research approach developed in Chapters 2 provides a point of departure for future studies aimed at revealing the conditions under which autonomous adaptation are appropriate and sufficient.

We also need to know more about best practices for *implementing planned adaptations*. This requires first clarifying where, why, and for whom external adaptation assistance is needed (see Chapter 4 and comments on autonomous adaptation above) and then examining the political economy of delivering adaptation support to those in need. Chapter 5 suggested that, despite best intentions, planned adaptations can actually reinforce, rather than alleviate, the social conditions that shape differentiated vulnerabilities to climatic stressors. This is an inauspicious insight that points to the importance of critically interrogating the power dynamics involved in implementing planned adaptations (Few et al., 2007), including who is (or is not) involved, how, and with what prospects for influence. For example, Vij et al. (2019) demonstrate how elite capture can steer planned adaptations toward immediate needs at the expense of more strategic, long-term initiatives. This raises equity concerns, and can also have broader socio-ecological reverberations if powerful actors foreclose opportunities for response that do not serve their immediate interests and priorities (e.g. foreclosing consideration of long-term ecosystem-based adaptations). Cultivating the capacity to identify, understand, and remediate the power dynamics involved in implementing adaptations is essential for ensuring that adaptation support is mobilized in ways that leads to socially and ecologically tenable outcomes. The use of formal social network analysis could help to reveal these inherently relational dynamics (Cunningham et al., 2017; Ingold et al., 2010; McDowell, 2012).

Widespread vulnerabilities across mountain areas suggest a need to know more about *limits to adaptation*. Theory suggests that limits emerge from the rate and magnitude of climatic change as well as social conditions that constrain adaptation options (Adger et al., 2009; Dow et al., 2013; Moser and Ekstrom, 2010). However, despite early work by Orlove (2009) and the analysis I performed for the IPCC SROCC High Mountain Areas chapter (based on data from Chapter 3), we know very little about the specific nature of limits to adaptation in mountain regions. This topic explicitly requires collaboration between social and natural scientists. Contextual vulnerability-based studies can help to identify which climatic changes are socially relevant as well as thresholds in those changes beyond which adaptation would not be possible according to affected populations.

With such information, climate modelers can help to clarify the nature of forthcoming changes in socially-relevant climatic stressors, including when such thresholds might be approaching. This work can then inform anticipatory interventions aimed at increasing adaptability to impending biophysical thresholds (Folke et al., 2004). However, in some cases, the nature of climatic changes and/or social constraints on adaptability might render ‘incremental adaptations’ ineffectual. This suggests a need to improve understanding of *transformational adaptations* (Kates et al., 2012; O’Brien, 2012), including challenging questions related to who or what transforms, how and to what, and who/what wins or loses (Shah et al., 2018). As understanding of limits to adaptation increases, the topic of transformative adaptations will likely grow in importance. At present, both themes are poorly understood in mountainous contexts.

It is apparent that climatic stimuli might not fully explain the nature of current and future hydrological changes in mountain areas. This suggests a need to improve understanding of *interactive effects* between climatic and non-climatic drivers of hydrological change (e.g. mining, road-building, deposition of black carbon). Such knowledge can be used support the development of adaptation options that are responsive to the broader range of factors affecting trajectories hydrological change, factors that might lead to hydrological futures that differ from those depicted in climate-driven models. Here, adaptation research could benefit from deeper engagement with theoretical work on complex adaptive systems (Levin et al., 2013) and ecosystem services (Brauman et al., 2007) as well as insights from applied work on cumulative effects assessment (Seitz et al., 2011). The need for more integrative approaches to the assessment of changing environmental systems—and the ecosystem services that they provide—has been highlighted by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

(Díaz et al., 2019b) and will be necessary to meet cross-cutting social and environmental objectives set forth in the Sustainable Development Goals (e.g. Goal 6 - Sustainable management of water).

More broadly, the preponderance of adaptation research to date has been conducted by those aligned with a specific epistemic community of global environmental change researchers. In this context, I suggest that *emic studies* (research from the perspective of the subject) that embody the epistemologies and ontologies of mountain people are urgently needed to counterbalance the predominance of etic adaptation research (research from the perspective of the observer) rooted in the western scientific and socio-cultural traditions (see Kaul, 2019 for such emic work). This will mean vastly increasing the latitude of what counts as valid knowledge; actively creating opportunities for mountain people to conduct studies about their own lives and communities; and receptiveness to critiques of, and recommendations for, work conducted in the Western scientific tradition (see TallBear, 2014; Whyte, 2017). This kind of meaningful engagement with local/Indigenous knowledge holders will inevitably add additional layers of complexity and power dynamics to adaptation research. However, willingness to embrace this processes is essential for the realization of aspirations codified in the Charter for World Mountain People (APMM, 2003) as well as the advancement of tenets outlined in the United Nations Declaration on the Rights of Indigenous Peoples (UN General Assembly, 2007). Furthermore, most mountain-focused adaptation research has focused on the Global South (Chapter 3). While such a focus is critically important, it is also appropriate to conduct substantive adaptation research in the *Global North*. For example, in mountainous countries such as Canada, there are Indigenous populations that also face challenges related colonial legacies and socio-economic marginalization (Ford and Berrang-

Ford, 2011). Thus, the goal of 'leaving no one behind in mountains' (Wymann von Dach et al., 2018) will require an increase in mountain-focused adaptation research in the Global North.

6.4 Summary and conclusion

This dissertation aimed to advance understanding of adaptation to glacio-hydrological change in high mountains. It 1) developed an analytical framework for robust adaptation research in high mountain areas; 2) used formal systematic review methods to critically evaluate existing mountain-focused adaptation research and actions *vis-à-vis* an original typology for the challenge of climate change in high mountain areas; 3) conducted a multi-sited, community-level assessment of lived experiences of glacio-hydrological changes in the upper Manaslu region of Nepal and Cordillera Huayhuash region of Peru; and 4) evaluated prospects for meeting community-identified adaptation needs with adaptation support organized through the UNFCCC, including how such efforts can help to advance objectives outlined in the Paris Agreement and the Sustainable Development Goals. The research was informed by theoretical insights from glacio-hydrological sciences, human dimensions of climate change research, and socio-ecological systems thinking, as well as 160 household interviews, 34 key informant interviews, and 4 focus groups conducted in Nepal and Peru. The dissertation made substantive contributions to how adaptation is studied in mountain systems as well as what we know about and can do to address growing adaptation needs in high mountain communities. More generally, the dissertation represents a modest but salient contribution to mountain research and the larger endeavor of advancing understanding of mountain systems.

Mountain regions are at the forefront of climate change, with the degradation of the high mountain cryosphere leading to significant impacts on biophysical systems, particularly glacio-hydrological systems. These changes are complicating living conditions for the ~915 million people residing in mountain areas, many of whom already face challenging socio-economic circumstances—the situation is leading to growing concern about the well-being of mountain people in a changing climate. Notwithstanding, mountain regions have received relatively little attention in global environmental change research compared to other climatically-sensitive regions such as the Arctic. This is particularly true for adaptation-focused research, which has only begun to reveal the causes and consequences of differentiated vulnerability and adaptability in high mountain communities. My dissertation responded to this situation by advancing understanding of adaptation to glacio-hydrological change in high mountain regions, while also helping to raise the profile of mountain issues in global environmental change research (e.g. through its contributions to the IPCC). Ultimately, it is my hope that these efforts will make a positive difference in the lives of mountain people living at the frontlines of climate change, including through bringing greater awareness to the context specific hydrological and socio-ecological factors that shape lived experiences of climate change in high places.

References

Adaptation Committee (2019). 25 Years of Adaptation under the UNFCCC. Bonn, Germany, Adaptation Committee, p. 36.

Adaptation Fund, (2017) Operational Policies And Guidelines For Parties To Access Resources From The Adaptation Fund, p. 12.

Adger, W.N. (2006) Vulnerability. Global Environmental Change 16, 268-281.

Adger, W.N., Arnell, W.N., Tompkins, L.E. (2005) Successful adaptation to climate change across scales. Global environmental Change 15, 77-86.

Adger, W.N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D.R., Naess, L.O., Wolf, J., Wreford, A. (2009) Are there social limits to adaptation to climate change? Climatic Change 93, 335-354.

Adger, W.N., Eakin, H., Winkels, A. (2008) Nested and teleconnected vulnerabilities to environmental change. Frontiers in Ecology and the Environment 7, 150-157.

Adler, C., Huggel, C., Orlove, B., Nolin, A. (2019) Climate change in the mountain cryosphere: impacts and responses. Regional Environmental Change 19, 1225-1228.

Alessa, L., Kliskey, A., Gosz, J., Griffith, D., Ziegler, A. (2018) MtnSEON and social–ecological systems science in complex mountain landscapes. Frontiers in Ecology and the Environment 16, S4-S10.

Alfthan, B., Gjerdi, H.L., Puikkonen, L., Andresen, M., Semernya, L., Schoolmeester, T., Jurek, M., (2018) Mountain Adaptation Outlook Series – Synthesis Report. United Nations Environment Programme and GRID-Arendal, Nairobi, Vienna, and Arendal, p. 52.

Allen, S.K., Linsbauer, A., Randhawa, S., Huggel, C., Rana, P., Kumari, A. (2016) Glacial lake outburst flood risk in Himachal Pradesh, India: An integrative and anticipatory approach considering current and future threats. Natural Hazards 84, 1741-1763.

APMM, (2003) Charter for World Mountain People. Association des Populations des Montagnes du Monde Paris. p. 3.

Ariza, C., Maselli, D., Kohler, T., (2013) Mountains: Our Life, Our Future, Progress and Perspectives on Sustainable Mountain Development. Swiss Agency for Development and Cooperation and Centre for Development and Environment, p. 90.

Ayers, J., Forsyth, T. (2009) Community-based adaptation to climate change. Environment: Science and Policy for Sustainable Development 51, 22-31.

Bach, A., Price, L.W., (2013) Mountain Climate, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 41-84.

Balsiger, J., Debarbieux, B. (2015) Should mountains (really) matter in science and policy? Environmental Science & Policy 49, 1-7.

Baraer, M., Mark, B.G., McKenzie, J.M., Condom, T., Bury, J., Huh, K.-I., Portocarrero, C., Gómez, J., Rathay, S. (2012) Glacier recession and water resources in Peru's Cordillera Blanca. Journal of Glaciology 58, 134-150.

Barnett, J., O'Neill, S. (2010) Maladaptation. Global Environmental Change 20, 211-213.

Barry, R.G. (2008) Mountain Weather and Climate, 3rd ed. Cambridge University Press, Cambridge. p. 532.

Bassett, T.J., Fogelman, C. (2013) Déjà vu or something new? The adaptation concept in the climate change literature. Geoforum 48, 42-53.

Beazley, R.E., Lassoie, J.P. (2017) Himalayan Mobilities: An Exploration of the Impact of Expanding Rural Road Networks on Social and Ecological Systems in the Nepalese Himalaya. Springer, Cham. p. 166

Belfer, E., Ford, J.D., Maillet, M., Araos, M., Flynn, M. (2019) Pursuing an Indigenous platform: Exploring opportunities and constraints for Indigenous participation in the UNFCCC. Global Environmental Politics 19, 12-33.

Bengtsson, M. (2016) How to plan and perform a qualitative study using content analysis. NursingPlus Open 2, 8-14.

Benn, D., Evans, D. (2010) Glaciers and Glaciation. Routledge, New York. p. 816.

Bennike, R.B. (2017) Aftershock: reflections on the politics of reconstruction in Northern Gorkha. HIMALAYA, the Journal of the Association for Nepal and Himalayan Studies 37, 9.

Bennike, R.B. (2018) Dangerous Development. Republica, 6.

Bennike, R.B. (2019) Himalayan futures: tourism and the anticipation of development. Canadian Journal of Development Studies/Revue Canadienne D'Études du Développement, 1-17.

Berkes, F., Colding, J., Folke, C. (2008) Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge. p. 476.

Berkes, F., Folke, C., (2000) Linking social and ecological systems for resilince and sustainability, in: Berkes, F., Folke, C., Colding, J. (Eds.), Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, p. 1-25.

Berkes, F., Folke, C., Colding, J. (2000) Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press. p. 476.

Bernbaum, E., Price, L.W., (2013) Attitudes Toward Mountains, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 253-266.

Berrang-Ford, L., Ford, J.D., Paterson, J. (2011) Are we adapting to climate change? Global environmental change 21, 25-33.

Berrang-Ford, L., Pearce, T., Ford, J.D. (2015) Systematic review approaches for climate change adaptation research. Regional Environmental Change 15, 755-769.

Betsill, M., Dubash, N.K., Paterson, M., Asselt, H.v., Vihma, A., Winkler, H. (2015) Building Productive Links between the UNFCCC and the Broader Global Climate Governance Landscape. Global Environmental Politics 15, 1-10.

Biesbroek, G.R., Klostermann, J.E., Termeer, C.J., Kabat, P. (2013) On the nature of barriers to climate change adaptation. Regional Environmental Change 13, 1119-1129.

Blaikie, P., Cannon, T., Davis, I., Wisner, B. (1994) At Risk: Natural Hazards, People's Vulnerability and Disasters. Routledge, London. p. 496.

Bliss, A., Hock, R., Radić, V. (2014) Global response of glacier runoff to twenty-first century climate change. Journal of Geophysical Research: Earth Surface 119, 717-730.

Bolch, T., Shea, J.M., Liu, S., Azam, F.M., Gao, Y., Gruber, S., Immerzeel, W.W., Kulkarni, A., Li, H., Tahir, A.A., (2019) Status and change of the cryosphere in the Extended Hindu Kush Himalaya Region, The Hindu Kush Himalaya Assessment. Springer, p. 209-255.

Brauman, K.A., Daily, G.C., Duarte, T.K.e., Mooney, H.A. (2007) The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu. Rev. Environ. Resour. 32, 67-98.

Brown, K., Ecclestone, K., Emmel, N. (2017) The Many Faces of Vulnerability. Social Policy and Society, 1-14.

Bundi, U., (2010) Features of Alpine Waters and Management Concerns, in: Bundi, U. (Ed.), Alpine Waters. Springer, Heidelberg, p. 1-14.

Bury, J. (2006) New community led conservation efforts in the Cordillera Huayhuash, Peru. Mountain Research and Development 26, 180-182.

Bury, J. (2008) New Geographies of Tourism in Peru: Nature-based Tourism and Conservation in the Cordillera Huayhuash. Tourism Geographies 10, 312-333.

Bury, J., Mark, B.G., Carey, M., Young, K.R., McKenzie, J.M., Baraer, M., French, A., Polk, M.H. (2013) New geographies of water and climate change in Peru: Coupled natural and social transformations in the Santa River watershed. Annals of the Association of American Geographers 103, 363-374.

Bury, J., Norris, T. (2013) Rocks, rangers, and resistance: mining and conservation frontiers in the Cordillera Huayhuash, Peru. Subterranean struggles: new dynamics of mining, oil, and gas in Latin America. University of Texas Press, Austin, TX, 91-118.

Byers, A.C., McKinney, D.C., Thakali, S., Somos-Valenzuela, M. (2014) This Changing World: Promoting science-based, community-driven approaches to climate change adaptation in glaciated mountain ranges: HiMAP. Geography 99, 143.

Campbell, B. (2010) Rhetorical routes for development: a road project in Nepal. Contemporary South Asia 18, 267-279.

Carey, M., Baraer, M., Mark, B.G., French, A., Bury, J., Young, K.R., McKenzie, J.M. (2014a) Toward hydro-social modeling: Merging human variables and the social sciences with climate-glacier runoff models (Santa River, Peru). Journal of Hydrology 518, 60-70.

Carey, M., et al. (2014b). Integrated Approaches to Adaptation and Disaster Risk Reduction in Dynamic Socio-cryospheric Systems. Snow and Ice-related Hazards, Risks and Disasters. Elsevier, p. 219-261.

Carey, M., Huggel, C., Bury, J., Portocarrero, C., Haeberli, W. (2012) An integrated socio-environmental framework for glacier hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. Climatic Change 112, 733-767.

Carey, M., Molden, O.C., Rasmussen, M.B., Jackson, M., Nolin, A.W., Mark, B.G. (2017) Impacts of Glacier Recession and Declining Meltwater on Mountain Societies. Annals of the American Association of Geographers 107, 350-359.

Casassa, G., Lopez, P., Pouyaud, B., Escobar, F. (2009) Detection of changes in glacial run-off in alpine basins: examples from North America, the Alps, central Asia and the Andes. Hydrological Processes 23, 31-41.

Chan, K.M.A., Agard, J., Liu, J., al., e., (2019) IPBES Global Assessment on Biodiversity and Ecosystem Services - Chapter 5. Pathways towards a Sustainable Future. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, p. 157.

Chesnokova, A., Baraer, M., Laperrière-Robillard, T., Huh, K. (2020) Linking Mountain Glacier Retreat and Hydrological Changes in Southwestern Yukon. Water Resources Research 56, e2019WR025706.

Childs, G. (2004) Tibetan Diary: From Birth to Death and Beyond in a Himalayan Valley of Nepal. University of California Press. Berkerly. p. 228.

Childs, G., Choedup, N. (2014) Indigenous management strategies and socioeconomic impacts of Yartsa Gunbu (Ophiocordyceps sinensis) harvesting in Nubri and Tsum, Nepal. HIMALAYA, the Journal of the Association for Nepal and Himalayan Studies 34, 7.

Childs, G., Craig, S., Beall, C.M., Basnyat, B. (2014) Depopulating the Himalayan highlands: education and outmigration from ethnically Tibetan communities of Nepal. Mountain Research and Development 34, 85-95.

Clerici, N., Cote-Navarro, F., Escobedo, F.J., Rubiano, K., Villegas, J.C. (2019) Spatio-temporal and cumulative effects of land use-land cover and climate change on two ecosystem services in the Colombian Andes. Science of The Total Environment. 685, 1181-1192.

Cohen, J., Screen, J.A., Furtado, J.C., Barlow, M., Whittleston, D., Coumou, D., Francis, J., Dethloff, K., Entekhabi, D., Overland, J., Jones, J. (2014) Recent Arctic amplification and extreme mid-latitude weather. Nature Geoscience 7, 627-637.

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S. (2016) Nature-based solutions to address global societal challenges. IUCN, Gland, Switzerland 97.

Conway, D., Nicholls, R.J., Brown, S., Tebboth, M.G.L., Adger, W.N., Ahmad, B., Biemans, H., Crick, F., Lutz, A.F., De Campos, R.S., Said, M., Singh, C., Zaroug, M.A.H., Ludi, E., New, M., Wester, P. (2019) The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. Nature Climate Change 9, 503-511.

Creswell, J. W. and C. N. Poth (2016). Qualitative inquiry and research design: Choosing among five approaches, Sage publications, p. 488.

Cretney, R. (2014) Resilience for Whom? Emerging Critical Geographies of Socio-ecological Resilience. Geography Compass 8, 627-640.

Cunha, S., Price, L.W., (2013) Agricultural Settlement and Land Use in Mountains, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 301-331.

Cunningham, R., Jacobs, B., Measham, T., Harman, M.P., Cvitanovic, C., (2017) Social network analysis: a primer on engaging communities on climate adaptation in New South Wales, Australia. Institute for Sustainable Futures, UTS, Sydney, Australia, p. 1-18.

Daily, G.C. (1997) Nature's Services: Societal Dependence On Natural Ecosystems Island Press, Washington, DC. p. 412.

Debarbieux, B., Oiry Varacca, M., Rudaz, G., Maselli, D., Kohler, T., Jurek, M. (2014) Tourism in mountain regions: Hopes, fears and realities. Department of Geography and Environment, University of Geneva, the Centre for Development and Environment, University of Bern, and the United Nations Environment Program. p. 109.

Debarbieux, B., Price, M.F., (2016) Mountain Regions: A Global Common Good?, Globalization and Marginalization in Mountain Regions. Springer, p. 45-53.

Debarbieux, B., Rudaz, G. (2015) The Mountain: A Political History from the Enlightenment to the Present. University of Chicago Press, Chicago. p. 367.

Devkota, R.P., Pandey, V.P., Bhattarai, U., Shrestha, H., Adhikari, S., Dulal, K.N. (2017) Climate change and adaptation strategies in Budhi Gandaki River Basin, Nepal: a perception-based analysis. Climatic Change 140, 195-208.

Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Chowdhury, R.R., Shin, Y.-J., Visseren-Hamakers, I., Willis, K.J., Zayas, C.N. (2019a) Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366, eaax3100.

Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., al., e., (2019b) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany, p. 1753.

Dixit, A., Subedi, Y., Aryal, N., Wenju, R., Shrestha, A. (2016) Climate finance: Fund flow from national to sub-national level in Nepal. ISET-Nepal, Kathmandu. p. 88.

Donner, S.D., Kandlikar, M., Webber, S. (2016) Measuring and tracking the flow of climate change adaptation aid to the developing world. Environmental Research Letters 11, 054006.

Dow, K., Berkhout, F., Preston, B.L., Klein, R.J.T., Midgley, G., Shaw, M.R. (2013) Limits to adaptation. Nature Climate Change 3, 305.

Drenkhan, F., Carey, M., Huggel, C., Seidel, J., Oré, M.T. (2015) The changing water cycle: climatic and socioeconomic drivers of water-related changes in the Andes of Peru. Wiley Interdisciplinary Reviews: Water 2, 715-733.

Drubin, D.G., Kellogg, D.R., (2012) English as the universal language of science: opportunities and challenges. American Society for Cell Biology. 23, 1399.

Duethmann, D., Menz, C., Jiang, T., Vorogushyn, S. (2016) Projections for headwater catchments of the Tarim River reveal glacier retreat and decreasing surface water availability but uncertainties are large. Environmental Research Letters 11, 054024.

Echeverri, A., Karp, D.S., Naidoo, R., Zhao, J., Chan, K.M.A. (2018) Approaching human-animal relationships from multiple angles: A synthetic perspective. Biological Conservation 224, 50-62.

Eisner, E. (1991). The Enlightened Eye: Qualitative Inquiry and the Enhancement of Educational Practice. New York, MacMillan.

Egan, P., Price, M., (2017) Mountain Ecosystem Services and Climate Change: A Global Overview of Potential Threats and Strategies for Adaptation. UNESCO, Paris, p. 33.

Emmenegger, R., et al. (2017). Ontology and integrative research on Global Environmental Change: towards a critical GEC science. Current Opinion in Environmental Sustainability 29, 131-137.

Engle, N.L. (2011) Adaptive capacity and its assessment. Global Environmental Change 21, 647-656.

Ensor, J.E., Wennström, P., Bhatterai, A., Nightingale, A.J., Eriksen, S., Sillmann, J. (2019) Asking the right questions in adaptation research and practice: Seeing beyond climate impacts in rural Nepal. Environmental Science & Policy 94, 227-236.

Eriksen, S., Brown, K. (2011) Sustainable adaptation to climate change. Climate and Development 3, 3-6.

Eriksen, S.H., Nightingale, A.J., Eakin, H. (2015) Reframing adaptation: the political nature of climate change adaptation. Global Environmental Change 35, 523-533.

Falkenmark, M., Rockström, J., (2006) The new blue and green water paradigm: Breaking new ground for water resources planning and management. American Society of Civil Engineers. 123, 4.

FAO, (2002) Thimphu Declaration of the Celebrating Mountain Women conference Thimphu, Bhutan. p. 3.

FAO, (2015) Mapping the vulnerability of mountain peoples to food insecurity, in: Romeo, R., Vita, A., Testolin, R., Hofer, T. (Eds.). FAO, Rome, p. 68.

Farinotti, D., Usselmann, S., Huss, M., Bauder, A., Funk, M. (2012) Runoff evolution in the Swiss Alps: projections for selected high-alpine catchments based on ENSEMBLES scenarios. Hydrological Processes 26, 1909-1924.

Feola, G. (2015) Societal transformation in response to global environmental change: a review of emerging concepts. Ambio 44, 376-390.

Few, R., Brown, K., Tompkins, E.L. (2007) Public participation and climate change adaptation: avoiding the illusion of inclusion. Climate Policy 7, 46-59.

Folke, C. (2006) Resilience: The emergence of a perspective for social-ecological systems analyses. Global Environmental Change 16, 253-267.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C. (2004) Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics, 557-581.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockstrom, J. (2010) Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society 15, 20.

Ford, J., Berrang-Ford, L., Biesbroek, R., Araos, M., Austin, S., Lesnikowski, A. (2015) Adaptation tracking for a post-2015 climate agreement. Nature Climate Change 5, 967.

Ford, J., Maillet, M., Pouliot, V., Meredith, T., Cavanaugh, A., Lwasa, S., Llanos, A., Berrang-Ford, L., Carcamo, C., Namanya, D.B., Harper, S., Team, I.R. (2016) Adaptation and Indigenous peoples in the United Nations Framework Convention on Climate Change. Climatic Change 139, 429-443.

Ford, J.D., Berrang-Ford, L. (2011) Climate change adaptation in developed nations: from theory to practice. Springer Science & Business Media, Dordrecht. p. 492.

Ford, J.D., Berrang-Ford, L. (2016) The 4Cs of adaptation tracking: consistency, comparability, comprehensiveness, coherency. Mitigation and Adaptation Strategies for Global Change 21, 839-859.

Ford, J.D., Keskitalo, E., Smith, T., Pearce, T., Berrang-Ford, L., Duerden, F., Smit, B. (2010) Case study and analogue methodologies in climate change vulnerability research. Wiley Interdisciplinary Reviews: Climate Change 1, 374-392.

Ford, J.D., McDowell, G., Jones, J. (2014) The state of climate change adaptation in the Arctic. Environmental Research Letters 9, 104005.

Ford, J.D., McDowell, G., Shirley, J., Pitre, M., Siewierski, R., Gough, W., Duerden, F., Pearce, T., Adams, P., Statham, S. (2013) The dynamic multiscale nature of climate change vulnerability: an Inuit harvesting example. Annals of the Association of American Geographers 103, 1193-1211.

Ford, J.D., Pearce, T., McDowell, G., Berrang-Ford, L., Sayles, J.S., Belfer, E. (2018) Vulnerability and its discontents: the past, present, and future of climate change vulnerability research. Climatic Change 151, 189-203.

Ford, J.D., Smit, B. (2004) A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. Arctic, 389-400.

Ford, J.D., Smit, B., Wandel, J. (2006) Vulnerability to climate change in the Arctic: a case study from Arctic Bay, Canada. Global environmental change 16, 145-160.

Fountain, A.G., Tangborn, W.V. (1985) The effect of glaciers on streamflow variations. Water Resources Research 21, 579-586.

Frans, C., Istanbulluoglu, E., Lettenmaier, D.P., Naz, B.S., Clarke, G.K., Condom, T., Burns, P., Nolin, A.W. (2015) Predicting glacio-hydrologic change in the headwaters of the Zongo River, Cordillera Real, Bolivia. Water Resources Research 51, 9029-9052.

Füssel, H.-M. (2007) Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustainability Science 2, 265-275.

Füssel, H.-M., Klein, R.J. (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change 75, 301-329.

Gagné, K. (2016) Cultivating Ice over Time: On the Idea of Timeless Knowledge and Places in the Himalayas. Anthropologica 58, 193-210.

Gagné, K., Rasmussen, M.B., Orlove, B. (2014) Glaciers and society: Attributions, perceptions, and valuations. Wiley Interdisciplinary Reviews: Climate Change 5, 793-808.

Gardner, J., Rhoades, R., Stadel, C., (2013) People in Mountains, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 267-300.

Gaston, K.J., Aimé, E., Chan, K.M.A., Fish, R., Hails, R.S., Maller, C. (2019) People and Nature—A journal of relational thinking. People and Nature 1, 4-5.

GEF, (2019a) Ecosystem-Based Adaptation for climate-resilient development in the Kathmandu Valley, Nepal. https://www.thegef.org/project/ecosystem-based-adaptation-climate-resilient-development-kathmandu-valley-nepal

GEF, (2019b) Projects. Global Environment Facility. https://www.thegef.org/projects

Gentle, P., Maraseni, T.N. (2012) Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. Environmental Science & Policy 21, 24-34.

Gioli, G., Thapa, G., Khan, F., Dasgupta, P., Nathan, D., Chhetri, N., Adhikari, L., Mohanty, S.K., Aurino, E., Scott, L.M., (2019) Understanding and Tackling Poverty and Vulnerability in Mountain Livelihoods in the Hindu Kush Himalaya, The Hindu Kush Himalaya Assessment. Springer, p. 421-455.

Gleeson, E.H., von Dach, S.W., Flint, C.G., Greenwood, G.B., Price, M.F., Balsiger, J., Nolin, A., Vanacker, V. (2016) Mountains of Our Future Earth: Defining Priorities for Mountain Research-A Synthesis From the 2015 Perth III Conference. Mountain Research and Development 36, 537-548.

Gleick, P.H., Palaniappan, M. (2010) Peak water limits to freshwater withdrawal and use. Proceedings of the National Academy of Sciences 107, 11155-11162.

GoN, (2011a) Climate Change Policy, 2011. Unofficial translation. Government of Nepal, Kathmandu. p. 11.

GoN, (2011b) National Framework on Local Adaptation Plans for Action. Ministry of Environment, Singhdurbar, p. 56.

Gough, D., Thomas, J., Oliver, S. (2012) Clarifying differences between review designs and methods. Systematic Reviews 1, 28.

Graf, E., Attal, M., Sinclair, H., (2019) Evacuation of earthquake-triggered landslide sediment in the Nepalese Himalaya, Geophysical Research Abstracts.

Grumbine, R.E., Pandit, M.K. (2013) Threats from India's Himalaya dams. Science 339, 36-37.

Guittard, A., Baraer, M., McKenzie, J.M., Mark, B.G., Wigmore, O., Fernandez, A., Rapre, A.C., Walsh, E., Bury, J., Carey, M. (2017) Trace-metal contamination in the glacierized Rio Santa watershed, Peru. Environmental Monitoring and Assessment 189, 649.

Gunderson, L.H., Holling, C.S. (2002) Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington DC. p. 536.

Gurung, A.B., Von Dach, S.W., Price, M.F., Aspinall, R., Balsiger, J., Baron, J.S., Sharma, E., Greenwood, G., Kohler, T. (2012) Global change and the world's mountains: Research needs and emerging themes for sustainable development: A synthesis from the 2010 Perth II conference. Mountain Research and Development 32, S47-S54.

Hadley, K., Price, L.W., Grabherr, G., (2013) Mountain Vegetation, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 183-220.

Haeberli, W. (2019) Vanishing high-mountain ice causing hydrological challenges at global to local scales: An overview with notes on Central Asia. Central Asian Journal of Water Research (CAJWR). 5, 44-63.

Haeberli, W., Schaub, Y., Huggel, C. (2017) Increasing risks related to landslides from degrading permafrost into new lakes in de-glaciating mountain ranges. Geomorphology 293, 405-417.

Haines-Young, R., Potschin, M., (2010) The links between biodiversity, ecosystem services and human well-being, in: Raffaelli, D.G., Frid, C.L. (Eds.), Ecosystem Ecology: a new synthesis. Cambridge University Press, Cambridge, p. 110-139.

Harkness, J.A., van de Vijver, F.J., Mohler, P.P., Wiley, J. (2003) Cross-cultural survey methods. Wiley-Interscience Hoboken, NJ. p. 432.

Hewitt, K. (1983) Interpretations of Calamity from the Viewpoint of Human Ecology. Unwin Hyman, Crows Nest. p. 304.

Hewitt, K., Mehta, M. (2012) Rethinking risk and disasters in mountain areas. Journal of Alpine Research| Revue de Géographie Alpine 100, 1.

Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., Jackson, M., Kääb, A., Kang, S., Kutuzov, S., Milner, A., Molau, U., Morin, S., Orlove, B., Steltzer, H., and Contributing Authors, (2019) High Mountain Areas chapter - IPCC Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC). Intergovernmental Panel on Climate Change (IPCC). p. 94.

Holling, C.S. (2001) Understanding the complexity of economic, ecological, and social systems. Ecosystems 4, 390-405.

Huggel, C., Muccione, V., Carey, M., James, R., Jurt, C., Mechler, R. (2019) Loss and Damage in the mountain cryosphere. Regional Environmental Change 19, 1387-1399.

Huggel, C., Scheel, M., Albrecht, F., Andres, N., Calanca, P., Jurt, C., Khabarov, N., Mira-Salama, D., Rohrer, M., Salzmann, N. (2015) A framework for the science contribution in climate adaptation: Experiences from science-policy processes in the Andes. Environmental Science & Policy 47, 80-94.

Huss, M., Bookhagen, B., Huggel, C., Jacobsen, D., Bradley, R., Clague, J., Vuille, M., Buytaert, W., Cayan, D., Greenwood, G. (2017) Toward mountains without permanent snow and ice. Earth's Future 5, 418–435.

Huss, M., Hock, R. (2018) Global-scale hydrological response to future glacier mass loss. Nature Climate Change 8, 135-140.

Immerzeel, W.W., Lutz, A., Andrade, M., Bahl, A., Biemans, H., Bolch, T., Hyde, S., Brumby, S., Davies, B., Elmore, A. (2019) Importance and vulnerability of the world's water towers. Nature 577, 364-369.

Immerzeel, W.W., Pellicciotti, F., Bierkens, M.F.P. (2013) Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. Nature Geoscience 6, 742.

Immerzeel, W.W., Van Beek, L.P., Bierkens, M.F. (2010) Climate change will affect the Asian water towers. Science 328, 1382-1385.

INAIGEM, (2018) Inventario Nacional de Glaciares: Las Cordilleras Glaciares del Perú. Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña, Huaraz. p. 198.

Ingold, K., Balsiger, J., Hirschi, C. (2010) Climate change in mountain regions: how local communities adapt to extreme events. Local Environment 15, 651-661.

Ingty, T. (2017) High mountain communities and climate change: adaptation, traditional ecological knowledge, and institutions. Climatic Change 145, 41-55.

IPCC, (2007) AR4 Climate Change 2007: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge. p. 987.

IPCC, (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge. p. 1552.

Jackson, S.T. (2019) Humboldt for the Anthropocene. Science 365, 1074-1076.

Jacobsen, D., Milner, A.M., Brown, L.E., Dangles, O. (2012) Biodiversity under threat in glacier-fed river systems. Nature Climate Change 2, 361-364.

Janke, J.R., Price, L.W., (2013) Mountain landforms and Geomorphic Processes, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 127-166.

Jansson, P., Hock, R., Schneider, T. (2003) The concept of glacier storage: a review. Journal of Hydrology 282, 116-129.

Jones, H.P., Hole, D.G., Zavaleta, E.S. (2012) Harnessing nature to help people adapt to climate change. Nature Climate Change 2, 504-509.

Juhola, S., Glaas, E., Linnér, B.-O., Neset, T.-S. (2016) Redefining maladaptation. Environmental Science & Policy 55, 135-140.

Jurt, C., Burga, M.D., Vicuña, L., Huggel, C., Orlove, B. (2015) Local perceptions in climate change debates: insights from case studies in the Alps and the Andes. Climatic Change 133, 511-523.

Kapos, V., Rhind, J., Edwards, M., Price, M., Ravilious, C., (2000) Developing a map of the world's mountain forests, in: Price, M., Butt, N. (Eds.), Forests in Sustainable Mountain Development. CABI Publishing, Wallingford, p. 4-9.

Kaser, G., Großhauser, M., Marzeion, B. (2010) Contribution potential of glaciers to water availability in different climate regimes. PNAS 107, 20223-20227.

Kates, R.W., Travis, W.R., Wilbanks, T.J. (2012) Transformational adaptation when incremental adaptations to climate change are insufficient. Proceedings of the National Academy of Sciences 109, 7156-7161.

Kaul, V., (2019) Holistically understanding and enhancing the adaptation of remote high-mountain communities to hydrometeorological extremes and associated geohazards in a changing climate, Department of Geography. University of Sheffield, p. 265.

Kaul, V., Thornton, T.F. (2014) Resilience and adaptation to extremes in a changing Himalayan environment. Regional Environmental Change, 1-16.

KC, A., Thapa Parajuli, R.B. (2015) Climate change and its impact on tourism in the Manaslu conservation area, Nepal. Tourism Planning & Development 12, 225-237.

Kelly, P.M., Adger, W.N. (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Climatic Change 47, 325-352.

Khan, M.R., Roberts, J.T. (2013) Adaptation and international climate policy. Wiley Interdisciplinary Reviews: Climate Change 4, 171-189.

Khoi, D.N., Suetsugi, T. (2014) Impact of climate and land-use changes on hydrological processes and sediment yield—a case study of the Be River catchment, Vietnam. Hydrological Sciences Journal 59, 1095-1108.

Kieslinger, J., Pohle, P., Buitrón, V., Peters, T. (2019) Encounters Between Experiences and Measurements: The Role of Local Knowledge in Climate Change Research. Mountain Research and Development 39.

Klain, S.C., Olmsted, P., Chan, K.M., Satterfield, T. (2017) Relational values resonate broadly and differently than intrinsic or instrumental values, or the New Ecological Paradigm. PLoS ONE 12, e0183962.

Klein, J.A., Tucker, C.M., Nolin, A.W., Hopping, K.A., Reid, R.S., Steger, C., Grêt-Regamey, A., Lavorel, S., Müller, B., Yeh, E.T., Boone, R.B., Bourgeron, P., Butsic, V., Castellanos, E., Chen, X., Dong, S.K., Greenwood, G., Keiler, M., Marchant, R., Seidl, R., Spies, T., Thorn, J., Yager, K., Network, t.M.S. (2019) Catalyzing Transformations to Sustainability in the World's Mountains. Earth's Future 7, 547-557.

Kohler, T., Wehrli, A., Jurek, M., (2014) Mountains and Climate Change—A Global Concern, Sustainable Mountain Development Series, Bern, p. 136.

Koppes, M., Hallet, B., Rignot, E., Mouginot, J., Wellner, J.S., Boldt, K. (2015) Observed latitudinal variations in erosion as a function of glacier dynamics. Nature 526, 100-103.

Körner, C., Ohsawa, M., (2005) Mountain Systems, Millennium Ecosystem Assessment, Washington D.C., p. 681-716.

La Frenierre, J., Mark, B.G. (2014) A review of methods for estimating the contribution of glacial meltwater to total watershed discharge. Progress in Physical Geography 38, 173-200.

Lavorel, S., Colloff, M.J., Locatelli, B., Gorddard, R., Prober, S.M., Gabillet, M., Devaux, C., Laforgue, D., Peyrache-Gadeau, V. (2019) Mustering the power of ecosystems for adaptation to climate change. Environmental Science & Policy 92, 87-97.

Lemos, M.C., Boyd, E., Tompkins, E.L., Osbahr, H., Liverman, D. (2007) Developing adaptation and adapting development. Ecology and society 12, 26.

Lennox, E. (2015) Double exposure to climate change and globalization in a Peruvian highland community. Society & Natural Resources 28, 781-796.

Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., Heymann, S.J. (2016) National-level progress on adaptation. Nature Climate Change 6, 261-264.

Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., Maillet, M., Araos, M., Austin, S.E. (2017) What does the Paris Agreement mean for adaptation? Climate Policy 17, 825-831.

Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.-G., Polasky, S., Troell, M., Vincent, J.R., Walker, B. (2013) Social-ecological systems as complex adaptive systems: modeling and policy implications. Environment and development economics 18, 111-132.

Levin, S.A. (1992) The problem of pattern and scale in ecology. Ecology 73, 1943-1967.

Levin, S.A. (1998) Ecosystems and the biosphere as complex adaptive systems. Ecosystems 1, 431-436.

Li, C., Tang, Y., Luo, H., Di, B., Zhang, L. (2013) Local farmers' perceptions of climate change and local adaptive strategies: a case study from the Middle Yarlung Zangbo River Valley, Tibet, China. Environmental Management 52, 894-906.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J. (2007) Complexity of coupled human and natural systems. Science 317, 1513-1516.

Llosa, J., Pajares, E., Toro, O. (2009) Cambio climático, crisis del agua y adaptación en las montañas andinas. Reflexión, denuncia y propuesta desde los Andes. Centro de Estudios y Promoción del Desarrollo–desco, y RAP-Red Ambiental Peruana. Lima. p. 374.

Lutz, A., Immerzeel, W., Shrestha, A., Bierkens, M. (2014) Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nature Climate Change 4, 587.

Macchi, M., Gurung, A.M., Hoermann, B. (2015) Community perceptions and responses to climate variability and change in the Himalayas. Climate and Development 7, 414-425.

MacKinnon, D., Derickson, K.D. (2013) From resilience to resourcefulness: A critique of resilience policy and activism. Progress in Human Geography 37, 253-270.

Magnan, A., Schipper, E., Burkett, M., Bharwani, S., Burton, I., Eriksen, S., Gemenne, F., Schaar, J., Ziervogel, G. (2016) Addressing the risk of maladaptation to climate change. Wiley Interdisciplinary Reviews: Climate Change 7, 646-665.

Magnan, A.K., Ribera, T. (2016) Global adaptation after Paris. Science 352, 1280-1282.

Maharjan, S.K. (2019) Local adaptation plan of action framework and process in the agriculture sector in Nepal. International Journal of Conservation Science 10, 351-364.

Mahat, T.J., Bláha, L., Uprety, B., Bittner, M. (2019) Climate finance and green growth: reconsidering climate-related institutions, investments, and priorities in Nepal. Environmental Sciences Europe 31, 46.

Makino, Y., Manuelli, S., Hook, L. (2019) Accelerating the movement for mountain peoples and policies. science 365, 1084-1086.

Maragno, D., Gaglio, M., Robbi, M., Appiotti, F., Fano, E.A., Gissi, E. (2018) Fine-scale analysis of urban flooding reduction from green infrastructure: An ecosystem services approach for the management of water flows. Ecological modelling 386, 1-10.

Mark, B.G., Bury, J., McKenzie, J.M., French, A., Baraer, M. (2010) Climate change and tropical Andean glacier recession: Evaluating hydrologic changes and livelihood vulnerability in the Cordillera Blanca, Peru. Annals of the Association of American Geographers 100, 794-805.

Mark, B.G., French, A., Baraer, M., Carey, M., Bury, J., Young, K.R., Polk, M.H., Wigmore, O., Lagos, P., Crumley, R., McKenzie, J.M., Lautz, L. (2017) Glacier loss and hydro-social risks in the Peruvian Andes. Global and Planetary Change 159, 61-76.

Mark, B.G., McKenzie, J.M. (2007) Tracing increasing tropical Andean glacier melt with stable isotopes in water. Environmental science & technology 41, 6955-6960.

Martín-López, B., Leister, I., Cruz, P.L., Palomo, I., Grêt-Regamey, A., Harrison, P.A., Lavorel, S., Locatelli, B., Luque, S., Walz, A. (2019) Nature's contributions to people in mountains: A review. PLoS ONE 14, e0217847.

Marzeion, B., Cogley, J.G., Richter, K., Parkes, D. (2014) Attribution of global glacier mass loss to anthropogenic and natural causes. Science 345, 919-921.

Masson-Delmotte, V., Zhai, P., Pörtner, H., Roberts, D., Skea, J., Shukla, P., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., (2018) Summary for Policymakers: Global Warming of 1.5 C. An IPCC Special Report on the Impacts of Global Warming of 1.5 C Above pre-Industrial Levels., Global Warming of 1.5 C. An IPCC Special Report on the Impacts of Global Warming of 1.5 C Above Pre-Industrial Levels and Related Global Greenhouse gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change. p. 24.

Mathieu, J., Brun, K. (2011) The Third Dimension: A Comparative History of Mountains in the Modern Era. White Horse Press, Cambridge. p. 194.

Matthews, T., Lo, A.Y., Byrne, J.A. (2015) Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners. Landscape and Urban Planning 138, 155-163.

McDowell, G., (2011) The Human Dimensions of Climate Change in the Khumbu Region of Nepal: Implications of Hydrological Modification, Geography. McGill University, Montreal. p. 103.

McDowell, G., (2012) The Role of Bridging Organizations in Facilitating Socio-Ecological Transformation: A Case Study of the Great Northern Landscape Conservation Cooperative, Geography. University of Oxford. p. 120.

McDowell, G., Ford, J., Jones, J. (2016a) Community-level climate change vulnerability research: trends, progress, and future directions. Environmental Research Letters 11, 033001.

McDowell, G., Ford, J., Stephenson, E., (2016b) Adaptation, Adaptation Science, and the Status of Adaptation in Mountain Regions, in: Huggel, C., Salzmann, N., Ziervogel, G., Nussbaumer, S. (Eds.), Climate Change Adaptation Strategies: An upstream - downstream lens. Springer, pp. 17-38.

McDowell, G., Ford, J.D., Lehner, B., Berrang-Ford, L., Sherpa, A. (2013) Climate-related hydrological change and human vulnerability in remote mountain regions: a case study from Khumbu, Nepal. Regional Environmental Change 13, 299-310.

McDowell, G., Huggel, C., Frey, H., Wang, F.M., Cramer, K., Ricciardi, V. (2019) Adaptation action and research in glaciated mountain systems: Are they enough to meet the challenge of climate change? Global Environmental Change 54, 19-30.

McDowell, G., Koppes, M. (2017) Robust adaptation research in high mountains: Integrating the scientific, social, and ecological dimensions of glacio-hydrological change. Water 9, 739.

McDowell, G., Stephenson, E., Ford, J. (2014) Adaptation to climate change in glaciated mountain regions. Climatic Change 126, 77-91.

McKenzie, J.M., Gordon, R.P., Baraër, M., Lautz, L.K., Chavez, D., Aubry-Wake, C., (2014) Hydrogeology in glaciated high-elevation Andean watersheds-results from the Cordillera Blanca, Peru, 2014 GSA Annual Meeting in Vancouver, British Columbia.

MEA (2005) Millennium Ecosystem Assessment - Ecosystems and human well-being. Island Press, Washington, DC.

Meadows, D.H. (2008) Thinking in systems: A primer. Chelsea Green Publishing, Hartford. p 240.

Messerli, B. (2012) Global change and the world's mountains: Where are we coming from, and where are we going to? Mountain Research and Development 32, S55-S63.

Messerli, B., Viviroli, D., Weingartner, R. (2004) Mountains of the world: Vulnerable water towers for the 21st century. Ambio, 29-34.

Meybeck, M., Green, P., Vörösmarty, C. (2001) A new typology for mountains and other relief classes: an application to global continental water resources and population distribution. Mountain Research and Development 21, 34-45.

Mills, A.J., Durepos, G., Wiebe, E. (2010) Encyclopedia of Case Study Research, 1st ed. Sage Publications, Los Angeles. p. 1140.

Mills-Novoa, M., Borgias, S.L., Crootof, A., Thapa, B., de Grenade, R., Scott, C.A. (2017) Bringing the Hydrosocial Cycle into Climate Change Adaptation Planning: Lessons from Two Andean Mountain Water Towers. Annals of the American Association of Geographers 107, 393-402.

Milner, A.M., Khamis, K., Battin, T.J., Brittain, J.E., Barrand, N.E., Füreder, L., Cauvy-Fraunié, S., Gíslason, G.M., Jacobsen, D., Hannah, D.M. (2017) Glacier shrinkage driving global changes in downstream systems. Proceedings of the National Academy of Sciences 114, 9770-9778.

Mishra, A., Appadurai, A.N., Choudhury, D., Regmi, B.R., Kelkar, U., Alam, M., Chaudhary, P., Mu, S.S., Ahmed, A.U., Lotia, H., (2019) Adaptation to climate change in the Hindu Kush Himalaya: Stronger action urgently needed, The Hindu Kush Himalaya Assessment. Springer, p. 457-490.

MoE, (2010a) Climate Change Vulnerability Mapping for Nepal. Government of Nepal, Ministry of Environment (MoE), Kathmandu, p. 96.

MoE, (2010b) National Adaptation Programme of Action (NAPA) to Climate Change. Government of Nepal, Ministry of Environment (MoE), Kathmandu, p. 96.

MoFE, (2018) Nepal's National Adaptation Plan (NAP) Process: Reflecting on Lessons Learned and the Way Forward. Government of Nepal, Ministry of Forests and Environment (MoFE), NAP Global Network, Action on Climate Today (ACT) and Practical Action Nepal., Kathmandu, p. 54.

MoH, (2015) Climate Change Health Adaptation Strategies and Action Plans of Nepal (2016 2020). Government of Nepal, Ministry of Health (MoH), Kathmandu, p. 38.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A. (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Reviews 4, 1.

MoPE, (2016) Nationally Determined Contributions. Government of Nepal, Ministry of Population and Environment (MoPE), Kathmandu, p. 12.

Moser, S.C., Boykoff, M.T., (2013) Climate change and adaptation success: The scope of the challenge, in: Moser, S.C., Boykoff, M.T. (Eds.), Successful adaptation to climate change: Linking science and policy in a rapidly changing world. Routledge, New York, p. 1-33.

Moser, S.C., Ekstrom, J.A. (2010) A framework to diagnose barriers to climate change adaptation. Proceedings of the National Academy of Sciences 107, 22026-22031.

MoSTE, (2014) Economic Impact Assessment of Climate Change in Key Sectors in Nepal. Government of Nepal, Ministry of Science, Technology and Environment (MoSTE), Kathmandu, p. 25.

Mountain Partnership, (2017) 2030 Agenda for Mountains. Mountain Partnership, Rome. p. 2.

Mountain Partnership, (2019) Mountain Partnership. http://www.fao.org/mountain-partnership/about/en/

Moyer, A.N., Moore, R., Koppes, M.N. (2016) Streamflow response to the rapid retreat of a lake-calving glacier. Hydrological Processes 30, 3650-3665.

Muccione, V., Salzmann, N., Huggel, C. (2016) Scientific knowledge and knowledge needs in climate adaptation policy: A case study of diverse mountain regions. Mountain Research and Development 36, 364-375.

Nagoda, S. (2015) New discourses but same old development approaches? Climate change adaptation policies, chronic food insecurity and development interventions in northwestern Nepal. Global environmental change 35, 570-579.

Nagoda, S., Nightingale, A.J. (2017) Participation and Power in Climate Change Adaptation Policies: Vulnerability in Food Security Programs in Nepal. World Development 100, 85-93.

Nagy, L., Grabherr, G. (2009) The Biology of Alpine Habitats. Oxford University Press, Oxford. p. 390.

Nalau, J., Preston, B.L., Maloney, M.C. (2015) Is adaptation a local responsibility? Environmental Science & Policy 48, 89-98.

Naz, B.S., Frans, C., Clarke, G., Burns, P., Lettenmaier, D. (2014) Modeling the effect of glacier recession on streamflow response using a coupled glacio-hydrological model. Hydrology and Earth System Sciences 18, 787-802.

Negi, V.S., Maikhuri, R.K., Pharswan, D., Thakur, S., Dhyani, P.P. (2017) Climate change impact in the Western Himalaya: people's perception and adaptive strategies. Journal of Mountain Science 14, 403-416.

Neukom, R., Rohrer, M., Calanca, P., Salzmann, N., Huggel, C., Acuña, D., Christie, D.A., Morales, M.S. (2015) Facing unprecedented drying of the Central Andes? Precipitation variability over the period AD 1000–2100. Environmental Research Letters 10, 084017.

Nightingale, A.J. (2017) Power and politics in climate change adaptation efforts: Struggles over authority and recognition in the context of political instability. Geoforum 84, 11-20.

NOAA, (2019) Climate Change: Atmospheric Carbon Dioxide. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

NPC, (2011) Climate-Resilient Planning: A Tool for Long-term Climate Adaptation. Government of Nepal, National Planning Commission, Kathmandu, p. 50.

NTNC, (2019) National Trust for Nature Conservation - Manaslu Conservation Area Project (MCAP). https://ntnc.org.np/project/manaslu-conservation-area-project-mcap

O'Brien, K., Eriksen, S., Nygaard, L.P., Schjolden, A. (2007) Why different interpretations of vulnerability matter in climate change discourses. Climate Policy 7, 73-88.

O'Brien, K., Leichenko, R.M. (2000) Double exposure: Assessing the impacts of climate change within the context of economic globalization. Global Environmental Change 10, 221-232.

O'Keefe, P., Westgate, K., Wisner, B. (1976) Taking the naturalness out of natural disasters. Nature 260, 566-567.

O'Neel, S., Hood, E., Bidlack, A.L., Fleming, S.W., Arimitsu, M.L., Arendt, A., Burgess, E., Sergeant, C.J., Beaudreau, A.H., Timm, K. (2015) Icefield-to-ocean linkages across the northern Pacific coastal temperate rainforest ecosystem. Bioscience 65, 499-512.

O’Brien, K. (2012) Global environmental change II: From adaptation to deliberate transformation. Progress in Human Geography 36, 667-676.

Oh, C. (2019) Discursive Contestation on Technological Innovation and the Institutional Design of the UNFCCC in the New Climate Change Regime. New Political Economy, 1-15.

Ojha, H.R., Ghimire, S., Pain, A., Nightingale, A., Khatri, D.B., Dhungana, H. (2016) Policy without politics: technocratic control of climate change adaptation policy making in Nepal. Climate Policy 16, 415-433.

Olazabal, M., Galarraga, I., Ford, J., Lesnikowski, A., de Murieta, E.S. (2017) Towards successful adaptation: a checklist for the development of climate change adaptation plans. Basque Centre for Climate Change Working Papers, p. 22.

Olsson, P., Folke, C., Berkes, F. (2004) Adaptive Comanagement for Building Resilience in Social–Ecological Systems. Environmental Management 34, 75-90.

Orlove, B. (2009) Glacier retreat: reviewing the limits of human adaptation to climate change. Environment: Science and Policy for Sustainable Development 51, 22-34.

Orlove, B., Milch, K., Zaval, L., Ungemach, C., Brugger, J., Dunbar, K., Jurt, C. (2019) Framing climate change in frontline communities: anthropological insights on how mountain dwellers in the USA, Peru, and Italy adapt to glacier retreat. Regional Environmental Change 19, 1295-1309.

Palomo, I. (2017) Climate Change Impacts on Ecosystem Services in High Mountain Areas: A Literature Review. Mountain Research and Development 37, 179-187.

Pandey, R., Meena, D., Aretano, R., Satpathy, S., Semeraro, T., Kumar Gupta, A., Rawat, S., Zurlini, G. (2015) Socio-ecological vulnerability of smallholders due to climate change in mountains: Agroforestry as an adaptation measure. Change and Adaptation in Socio-Ecological Systems 2, 26-41.

Pant, R.R., Zhang, F., Rehman, F.U., Wang, G., Ye, M., Zeng, C., Tang, H. (2018) Spatiotemporal variations of hydrogeochemistry and its controlling factors in the Gandaki River Basin, Central Himalaya Nepal. Science of The Total Environment 622, 770-782.

Payne, G., Payne, J. (2004) Content analysis. Key concepts in social research, Sage Research Methods, London. p. 51-55.

Pepin, N., Bradley, R.S., Diaz, H.F., Baraer, M., Caceres, E.B., Forsythe, N., Fowler, H., Greenwood, G., Hashmi, M.Z., Liu, X.D., Miller, J.R., Ning, L., Ohmura, A., Palazzi, E., Rangwala, I., Schöner, W., Severskiy, I., Shahgedanova, M., Wang, M.B., Williamson, S.N., Yang, D.Q. (2015) Elevation-dependent warming in mountain regions of the world. Nature Climate Change 5, 424-430.

Perlik, M. (2015) Mountains as global suppliers: New forms of disparities between mountain areas and metropolitan hubs. Journal of Alpine Research 103, 3.

Plachta, N., (2018) Himalayan Borderland Communities: Identity, Belonging, and Place among the Tsumpas, Institute for the Science of Religion and Central Asian Studies. University of Bern, p. 260.

Poff, N.L., Zimmerman, J.K. (2010) Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55, 194-205.

Polk, M.H., Young, K.R., Baraer, M., Mark, B.G., McKenzie, J.M., Bury, J., Carey, M. (2017) Exploring hydrologic connections between tropical mountain wetlands and glacier recession in Peru's Cordillera Blanca. Applied Geography 78, 94-103.

Pörtner, H., Roberts, D., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Nicolai, M., Okem, A., Petzold, J. (2019) Summary for Policy Makers: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. IPCC Intergovernmental Panel on Climate Change: Geneva, Switzerland. p. 36.

Postigo, J.C. (2014) Perception and Resilience of Andean Populations Facing Climate Change. Journal of Ethnobiology 34, 383-400, 318.

Price, L.W., Geist, V., (2013) Mountain Wildlife, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 221-252.

Price, L.W., Harden, C., (2013) Mountain Soils, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 167-182.

Price, M.F., (2013) Integrated Approaches to Research and Management in Mountain Areas: An Introduction in: Price, M.F. (Ed.), Mountain Area Research and Management: Integrated Approaches. Earthscan, London, p. 1-23.

Price, M.F. (2015) Transnational governance in mountain regions: Progress and prospects. Environmental Science & Policy 49, 95-105.

Price, M.F., Arnesen, T., Gløersen, E., Metzger, M.J. (2019) Mapping mountain areas: learning from Global, European and Norwegian perspectives. Journal of Mountain Science 16, 1-15.

Price, M.F., Kohler, T., (2013) Sustainable Mountain Development, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 333-365.

PRISMA, (2018) PRISMA - Transparent Reporting of Systematic Reviews and Meta-analyses. http://www.prisma-statement.org/

Pritchard, H.D. (2017) Asia's glaciers are a regionally important buffer against drought. Nature 545, 169.

Quincey, D., Klaar, M., Haines, D., Lovett, J., Pariyar, B., Gurung, G., Brown, L., Watson, C., England, M., Evans, B. (2018) The changing water cycle: the need for an integrated assessment of the resilience to changes in water supply in High-Mountain Asia. Wiley Interdisciplinary Reviews: Water 5, 1-10.

Rabatel, A., Francou, B., Soruco, A., Gomez, J., Ceballos, J., Basantes, R., Vuille, M., Sicart, J., Huggel, C. (2017) Current state of glaciers in the tropical Andes: A multi-century perspective on glacier evolution and climate change. The Cryosphere 7, 81-102.

Ragettli, S., Immerzeel, W.W., Pellicciotti, F. (2016) Contrasting climate change impact on river flows from high-altitude catchments in the Himalayan and Andes Mountains. Proceedings of the National Academy of Sciences 113, 9222-9227.

Rangwala, I., Miller, J.R. (2012) Climate change in mountains: a review of elevation-dependent warming and its possible causes. Climatic Change 114, 527-547.

Rangwala, I., Pepin, N., Vuille, M., Miller, J., (2015) Influence of climate variability and large-scale circulation on the mountain cryosphere, in: Huggel, C., Carey, M., Clague, J.J., Kääb, A. (Eds.), The High-Mountain Cryosphere. Cambridge University Press, Cambridge, p. 9-27.

Rasul, G., Molden, D. (2019) The Global Social and Economic Consequences of Mountain Cryospheric Change. Frontiers in Environmental Science 7, 91.

Rasul, G., Pasakhala, B., Mishra, A., Pant, S. (2019) Adaptation to mountain cryosphere change: issues and challenges. Climate and Development, 1-13.

Ribot, J., (2010) Vulnerability does not fall from the sky: toward multiscale, pro-poor climate policy, in: Mearns, R., Norton, A. (Eds.), Social dimensions of climate change: Equity and vulnerability in a warming world. The World Bank, p. 47-74.

Ribot, J. (2011) Vulnerability before adaptation: Toward transformative climate action. Global environmental change 21, 1160-1162.

Ribot, J. (2014) Cause and response: vulnerability and climate in the Anthropocene. Journal of Peasant Studies 41, 667-705.

Robinson, C.T., Kawecka, B., Fureder, L., Peter, A., (2010) Biodiversity of Flora and Fauna in Alpine Waters, in: Bundi, U. (Ed.), Alpine Waters. Springer, Heidelberg. p. 193.

Robson, B.A., Nuth, C., Nielsen, P.R., Girod, L., Hendrickx, M., Dahl, S.O. (2018) Spatial Variability in Patterns of Glacier Change across the Manaslu Range, Central Himalaya. Frontiers in Earth Science 6, 12.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J. (2009) Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14, 32.

Roe, G.H., Baker, M.B., Herla, F. (2017) Centennial glacier retreat as categorical evidence of regional climate change. Nature Geoscience 10, 95-99.

Rudaz, G. (2011) The cause of mountains: The politics of promoting a global agenda. Global Environmental Politics 11, 43-65.

Salzmann, N., Huggel, C., Calanca, P., Díaz, A., Jonas, T., Jurt, C., Konzelmann, T., Lagos, P., Rohrer, M., Silverio, W. (2009) Integrated assessment and adaptation to climate change impacts in the Peruvian Andes. Advances in Geosciences 22, 35-39.

Salzmann, N., Huggel, C., Rohrer, M., Stoffel, M. (2014) Data and knowledge gaps in glacier, snow and related runoff research–A climate change adaptation perspective. Journal of Hydrology 518, 225-234.

Sapkota, P., Keenan, R.J., Paschen, J.-A., Ojha, H.R. (2016) Social production of vulnerability to climate change in the rural middle hills of Nepal. Journal of Rural Studies 48, 53-64.

Schaner, N., Voisin, N., Nijssen, B., Lettenmaier, D.P. (2012) The contribution of glacier melt to streamflow. Environmental Research Letters 7, 034029.

Schoolmeester, T., Johansen, K.S., Alfthan, B., Baker, E., Hesping, M., Verbist, K., (2018). The Andean Glacier and Water Atlas – The Impact of Glacier Retreat on Water Resources., UNESCO and GRID-Arendal.

Scolobig, A., De Marchi, B., Borga, M. (2012) The missing link between flood risk awareness and preparedness: findings from case studies in an Alpine Region. Natural Hazards 63, 499-520.

Scott, C.A., Zhang, F., Mukherji, A., Immerzeel, W., Mustafa, D., Bharati, L., (2019) Water in the Hindu Kush Himalaya, The Hindu Kush Himalaya Assessment. Springer, p. 257-299.

Seitz, N.E., Westbrook, C.J., Noble, B.F. (2011) Bringing science into river systems cumulative effects assessment practice. Environmental Impact Assessment Review 31, 172-179.

Shah, S.H., Rodina, L., Burt, J.M., Gregr, E.J., Chapman, M., Williams, S., Wilson, N.J., McDowell, G. (2018) Unpacking social-ecological transformations: Conceptual, ethical and methodological insights. The Anthropocene Review 5, 250-265.

Sharma, E., Molden, D., Rahman, A., Khatiwada, Y.R., Zhang, L., Singh, S.P., Yao, T., Wester, P., (2019) Introduction to the Hindu Kush Himalaya Assessment, The Hindu Kush Himalaya Assessment. Springer, p. 1-16.

Shawoo, Z., Thornton, T.F. (2019) The UN local communities and Indigenous peoples' platform: A traditional ecological knowledge-based evaluation. Wiley Interdisciplinary Reviews: Climate Change 10, e575.

Sherman, M., Berrang-Ford, L., Lwasa, S., Ford, J., Namanya, D.B., Llanos-Cuentas, A., Maillet, M., Harper, S. (2016) Drawing the line between adaptation and development: a systematic literature review of planned adaptation in developing countries. Wiley Interdisciplinary Reviews: Climate Change 7, 707-726.

Shrestha, U.B., Gautam, S., Bawa, K.S. (2012) Widespread climate change in the Himalayas and associated changes in local ecosystems. PLoS ONE 7, e36741.

Shroder Jr., J.F., Price, L.W., (2013) Origins of Mountains, in: Price, M.F., Byers, A.C., Friend, D.A., Kohler, T., Price, L.W. (Eds.), Mountain Geography: Physical and Human Dimensions. University of California Press, Berkeley, p. 11-39.

Shukla, R., Sachdeva, K., Joshi, P. (2017) Demystifying vulnerability assessment of agriculture communities in the Himalayas: a systematic review. Natural Hazards, 1-21.

Silwal, P., Roberts, L., Rennie, H.G., Lexer, M.J. (2019) Adapting to climate change: an assessment of local adaptation planning processes in forest-based communities in Nepal. Climate and Development 11, 886-898.

Smit, B., Burton, I., Klein, R.J., Street, R. (1999) The science of adaptation: a framework for assessment. Mitigation and Adaptation Strategies for Global Change 4, 199-213.

Smit, B., Burton, I., Klein, R.J., Wandel, J. (2000) An anatomy of adaptation to climate change and variability. Climatic Change 45, 223-251.

Smit, B., Wandel, J. (2006) Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282-292.

Smithers, J., Smit, B. (1997) Human adaptation to climatic variability and change. Global Environmental Change 7, 129-146.

Sovacool, B.K. (2011) Hard and soft paths for climate change adaptation. Climate Policy 11, 1177-1183.

Spandre, P., François, H., Verfaillie, D., Pons, M., Vernay, M., Lafaysse, M., George, E., Morin, S. (2019) Winter tourism under climate change in the Pyrenees and the French Alps: relevance of snowmaking as a technical adaptation. Cryosphere 13, 1325-1347.

Spehn, E.M., Rudmann-Maurer, K., Korner, C., Maselli, D., (2010) Mountain Biodiversity and Global Change. FAO, Basel, p. 59.

Sphen, M., Körner, C., (2006) A Global Assessment of Mountain Biodiversity and its Function in: Huber, U.M., Bugmann, H.K., Reasoner, M.A. (Eds.), Global Change and Mountain Regions: An Overview of Current Knowledge. Springer, Dordecht, p. 393-400.

Stake, R.E. (2013) Multiple case study analysis. Guilford Press. New York. p. 342.

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., Ludwig, C. (2015a) The trajectory of the Anthropocene: the great acceleration. The Anthropocene Review 2, 81-98.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S. (2015b) Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855.

Steinbauer, M.J., Grytnes, J.-A., Jurasinski, G., Kulonen, A., Lenoir, J., Pauli, H., Rixen, C., Winkler, M., Bardy-Durchhalter, M., Barni, E. (2018) Accelerated increase in plant species richness on mountain summits is linked to warming. Nature 556, 231-234.

Stepp, J.R., Castaneda, H., Cervone, S. (2005) Mountains and biocultural diversity. Mountain Research and Development 25, 223-227.

Stevens, S.F. (1993) Claiming the High Ground: Sherpas, Subsistence, and Environmental Change in the Highest Himalaya. University of California Press, Berkeley. p. 546.

Stewart, I. (2009) Changes in snowpack and snowmelt runoff for key mountain regions. Hydrol. Process 23, 78-94.

Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., (2013) Summary for Policy Makers: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. p. 28.

Sud, R., Mishra, A., Varma, N., Bhadwal, S. (2015) Adaptation policy and practice in densely populated glacier-fed river basins of South Asia: a systematic review. Regional Environmental Change 15, 825-836.

TallBear, K. (2014) Standing with and speaking as faith: A feminist-indigenous approach to inquiry. Journal of Research Practice 10, 17.

Thornton, T.F., Manasfi, N. (2010) Adaptation Genuine and Spurious: Demystifying Adaptation Processes in Relation to Climate Change. Environment and Society: Advances in Research 1, 132-155.

Tucker, J., Daoud, M., Oates, N., Few, R., Conway, D., Mtisi, S., Matheson, S. (2015) Social vulnerability in three high-poverty climate change hot spots: What does the climate change literature tell us? Regional Environmental Change 15, 783-800.

Turner, B., Kasperson, R., Matson, P., McCarthy, J., Corell, R., Christensen, L., Eckley, N., Kasperson, J., Luers, A., Martello, M. (2003) A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America 100, 8074.

Turner, M.D. (2013) Political ecology I An alliance with resilience? Progress in Human Geography, 0309132513502770.

Turner, W.R., Bradley, B.A., Estes, L.D., Hole, D.G., Oppenheimer, M., Wilcove, D.S. (2010) Climate change: helping nature survive the human response. Conservation Letters 3, 304-312.

UN Climate Change Secretariat, (2017) Opportunities and options for integrating climate change adaptation with the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction 2015–2030. United Nations Climate Change Secretariat, Bonn. p. 27.

UN General Assembly, (2007) United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) New York. p. 32.

UNEP, (2015) Making the case for ecosystem-based adaptation: The global mountain EbA programme in Nepal, Peru and Uganda, p. 136.

UNFCCC, (1992) United Nations Framework Convention on Climate Change. Rio de Janeiro. p. 25.

UNFCCC, (2011) Cancun Agreements. United Nations Framework Convention on Climate Change. Cancun. p. 31.

UNFCCC, (2015) Paris Agreement in: United Nations Framework Convention on Climate Change (Ed.), Paris, p. 16.

United Nations, (1992) Agenda 21. United Nations, New York, p. 351.

United Nations, (2015) Transforming our world: the 2030 Agenda for Sustainable Development, Geneva. https://sustainabledevelopment.un.org/post2015/transformingourworld

van Tiel, M., Kohn, I., Van Loon, A.F., Stahl, K. (2019) The compensating effect of glaciers: Characterizing the relation between interannual streamflow variability and glacier cover. Hydrological Processes 34, 553-568.

Vaughan, D.G., Comiso, J.C., Allison, I., Carrasco, J., Kaser, G., Kwok, R., Mote, P., Murray, T., Paul, F., Ren, J. (2013) Observations: cryosphere. Climate Change 2103, 317-382.

Vij, S., Biesbroek, R., Groot, A., Termeer, K., Parajuli, B.P. (2019) Power interplay between actors: using material and ideational resources to shape local adaptation plans of action (LAPAs) in Nepal. Climate Policy 19, 571-584.

Viviroli, D., Archer, D., Buytaert, W., Fowler, H., Greenwood, G., Hamlet, A., Huang, Y., Koboltschnig, G., Litaor, M., López-Moreno, J. (2011) Climate change and mountain water resources: Overview and recommendations for research, management and policy. Hydrology and Earth System Sciences 15, 471-504.

Viviroli, D., Dürr, H.H., Messerli, B., Meybeck, M., Weingartner, R. (2007) Mountains of the world, water towers for humanity: Typology, mapping, and global significance. Water Resources Research 43, W07447.

Viviroli, D., Kummu, M., Meybeck, M., Wada, Y. (2019) Increasing dependence of lowland population on mountain water resources. EarthArXiv, preprint.

Viviroli, D., Weingartner, R. (2004) The hydrological significance of mountains: from regional to global scale. Hydrology and Earth System Sciences Discussions 8, 1017-1030.

Vuille, M., Carey, M., Huggel, C., Buytaert, W., Rabatel, A., Jacobsen, D., Soruco, A., Villacis, M., Yarleque, C., Elison Timm, O., Condom, T., Salzmann, N., Sicart, J.-E. (2018) Rapid decline of snow and ice in the tropical Andes – Impacts, uncertainties and challenges ahead. Earth-Science Reviews 176, 195-213.

Walker, B., Carpenter, S., Rockstrom, J., Crépin, A.-S., Peterson, G. (2012) Drivers," slow" variables," fast" variables, shocks, and resilience. Ecology and Society 17, 30.

Walker, B., Holling, C.S., Carpenter, S.R., Kinzig, A. (2004) Resilience, adaptability and transformability in social-ecological systems. Ecology and Society 9, 5.

Watts, M., (1983) On the Poverty of Theory: Natural Hazards Research in Context, Interpretation of Calamity: From the Viewpoint of Human Ecology. Unwin Hyman, Crows Nest, pp. 231-262.

Watts, N., Adger, W.N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A. (2015) Health and climate change: policy responses to protect public health. The Lancet 386, 1861-1914.

Wei, T., Dong, W., Yan, Q., Chou, J., Yang, Z., Tian, D. (2016) Developed and developing world contributions to climate system change based on carbon dioxide, methane and nitrous oxide emissions. Advances in Atmospheric Sciences 33, 632-643.

Weikmans, R., Roberts, J.T. (2019) The international climate finance accounting muddle: is there hope on the horizon? Climate and Development 11, 97-111.

Whyte, K. (2017) Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene 55, 153-162.

Wilbanks, T.J., Kates, R.W. (2010) Beyond adapting to climate change: embedding adaptation in responses to multiple threats and stresses. Annals of the Association of American Geographers 100, 719-728.

World Economic Forum, (2018) The Global Gender Gap Report 2018, Geneva, p. 367.

Wymann von Dach, S. (2016) Investing in sustainable mountain development. Centre for Development and Environment (CDE): University of Bern. p. 75.

Wymann von Dach, S., Bachmann, F., Alcántara-Ayala, I., Fuchs, S., Keiler, M., Mishra, A., Sötz, E. (2017) Safer lives and livelihoods in mountains: Making the Sendai Framework for Disaster

Risk Reduction work for sustainable mountain development. Centre for Development and Environment (CDE), University of Bern. p. 82.

Wymann von Dach, S., Bracher, C.P., Peralvo, M., Perez, K., Adler, C. (2018) Leaving no one in mountains behind: Localizing the SDGs for resilience of mountain people and ecosystems. ssue Brief on Sustainable Mountain Development. Bern, Switzerland: Centre for Devel-opment and Environment and Mountain Research Initiative. p. 12.

Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y., Wilkes, A. (2009) The melting Himalayas: Cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology 23, 520-530.

Yin, R.K. (2014) Case study research: Design and methods, 5th ed. Sage Publications, Thousand Oaks. p. 312.

Yoccoz, N.G., Delestrade, A., Loison, A. (2010) Impact of climatic change on alpine ecosystems: inference and prediction. Journal of Alpine Research 98, 4.

Zemp, M., Frey, H., Gärtner-Roer, I., Nussbaumer, S.U., Hoelzle, M., Paul, F., Haeberli, W., Denzinger, F., Ahlstrøm, A.P., Anderson, B. (2015) Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology 61, 745-762.

Zhang, G., Yao, T., Xie, H., Wang, W., Yang, W. (2015) An inventory of glacial lakes in the Third Pole region and their changes in response to global warming. Global and Planetary Change 131, 148-157.

Appendices

Appendix A Supporting materials for Chapter 3

A.1 Project overview

<table>
<tr><th colspan="3">Summary of Systematic Review</th></tr>
<tr><td>Temporal scope</td><td colspan="2">Start: 1 June 1992 (i.e. founding of Agenda 21, Chapter 13, UNFCCC)
End: 31 December 2017
Duration: 25 years, 7 months</td></tr>
<tr><td>Geographical scope</td><td colspan="2">Global, glaciated mountain areas

'Glaciated mountain area' =

1. Located in country with mountain glaciers (country list provided World Glacier Monitoring Service); Also see: http://www.glims.org/maps/gtng
2. And Located within Kappos et al., 2000 mountain area definition; see: https://rmgsc.cr.usgs.gov/gme/gme.shtml</td></tr>
<tr><td>Linguistic scope</td><td colspan="2">English</td></tr>
<tr><td>Materials included</td><td colspan="2">1. Peer-reviewed journals articles
2. Select grey literature (i.e. documents produced by Mountain Partnership key 'Intergovernmental Organizations')</td></tr>
<tr><td>Search terms</td><td>Themes</td><td>Synonyms (if relevant)</td></tr>
<tr><td></td><td>Climate change</td><td>“climat* change*” OR “global warming”</td></tr>
<tr><td></td><td>Adaptation</td><td>adapt*</td></tr>
<tr><td></td><td>Glacier</td><td>glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance"</td></tr>
<tr><td>Search databases for peer-reviewed documents</td><td colspan="2">Database Name</td></tr>
<tr><td></td><td colspan="2">Web of Science</td></tr>
<tr><td></td><td colspan="2">Scopus</td></tr>
<tr><td></td><td colspan="2">PubMed</td></tr>
<tr><td></td><td colspan="2">PAIS International</td></tr>
<tr><td>Journals searched directly for peer-</td><td colspan="2">Journal Name</td></tr>
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reviewed documents	
	Mountain Research and Development
	Journal of Alpine Research
	Journal of Mountain Science
	Arctic, Antarctic, and Alpine Research
	Global Environmental Change
	Regional Environmental Change
	Climatic Change
	Natural Hazards
	Ecology & Society
Intergovernmental Organizations Searched for Grey Literature	**Organization Name**
	Food and Agriculture Organization of the United Nations (FAO)
	International Union for Conservation of Nature (IUCN)
	United Nations Development Programme (UNDP)
	United Nations Educational, Scientific and Cultural Organization (UNESCO)
	United Nations Environment Programme (UNEP), including *UNEP/GRID-Arendal (Mountain Outlook Series*
	World Bank (WB)
	United Nations Development Programme (UNDP)

A.2 Inclusion/exclusion criteria

Inclusion /Exclusion Criteria - Peer-Reviewed

Inclusion/Exclusion Criteria – Peer-Reviewed
Working definition of adaptation for inclusion/exclusion
"Adaptation involves changes in social-ecological systems [human adaptation focus here] 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" (Moser & Ekstrom, 2010).

Included if	**Excluded if**
Peer-reviewed journal article	*Not* peer-reviewed journal article
Published between 1 June 1992 and 31 December 2017	*Not* published between 1 June 1992 and 31 December 2017
Written in English	*Not* written in English
Substantial focus on contemporary human adaptation to experienced or anticipated effects of climate change	*Unsubstantial* focus on contemporary human adaptation to experienced or anticipated effects of climate change
Can include: 1. Empirical assessments of adaptation (e.g. case studies) 2. Assessments of adaptation programs or policies (e.g. policy evaluation) 3. Non-adaptation focused articles that nevertheless include substantial evaluations of adaptation (e.g. a vulnerability focused article that also evaluates adaptation) 4. Scientific studies that explicitly support actual or planned adaptation initiatives (e.g. modeling work that supports existing adaptation program). 5. Scientific studies that initiate adaptation actions (e.g. action research) Note: 'Substantial focus' implies engagement with the details of adaptation. An article that mentions an adaptation but does not include *any* evaluation of that adaptation does not qualify as a substantial focus (If even a small amount of evaluation is included, keep the article). Note: Human adaptation can include conservation-focused adaptations carried out by people/institutions.	Cannot include: 1. Studies focused on paleo-adaptation 2. Studies focused on adaptation in biological systems 3. Studies focused primarily on methodological or theoretical development in adaptation research 4. Articles that mention but do not evaluate adaptations 5. Scientific studies that only make adaptation recommendations 6. Scientific studies that only support hypothetical adaptations
Study conducted in or focused on adaptation in glaciated mountain area(s)	Study *not* conducted in or focused on adaptation in glaciated mountain area(s)
'Glaciated mountain area' =	

	3. Located within Kappos et al., mountain area definition; see: https://rmgsc.cr.usgs.gov/gme/gme.shtml 4. *And* located in country with glaciers (country list provided World Glacier Monitoring Service); Also see: http://www.glims.org/maps/gtng	

Inclusion /Exclusion Criteria - Grey Literature

Inclusion/Exclusion Criteria – Grey Literature	
Working definition of adaptation for inclusion/exclusion	
"Adaptation involves changes in social-ecological systems [human adaptation focus here] 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" (Moser & Ekstrom, 2010).	
Included if	**Excluded if**
Grey literature document	*Not* grey literature document
Published between 1 June 1992 and 31 December 2017	*Not* published between 1 June 1992 and 31 December 2017
Written in English	*Not* written in English
Substantial focus on contemporary human adaptation to experienced or anticipated effects of climate change	*Unsubstantial* focus on contemporary human adaptation to experienced or anticipated effects of climate change
Can include: 1. Reports about adaptation projects or programs 2. Evaluations of adaptation projects or programs 3. Non-adaptation focused documents that nevertheless include substantial evaluation of adaptation projects or programs	Cannot include: 1. Documents focused on paleo-adaptation 2. Documents focused on adaptation in biological systems 3. Documents focused primarily on methodological or

	4. Assessments of adaptations that are not led by organization/institutions authoring document (e.g. assessments of autonomous adaptations) Note: 'Substantial focus' implies engagement with the details of adaptation projects or programs. A document that mentions adaptation but does not include *any* evaluation of that adaptation does not qualify as a substantial focus (If even a small amount of evaluation is included, keep the document). Note: Human adaptation can include conservation-focused adaptations carried out by people/institutions.		theoretical development in adaptation research 4. Documents that mention but do not evaluate adaptations 5. Documents that only make adaptation recommendations
Study conducted in or focused on adaptation in glaciated mountain area(s)		Study *not* conducted in or focused on adaptation in glaciated mountain area(s)	
	'Glaciated mountain area' = 5. Located within Kappos et al., mountain area definition; see: https://rmgsc.cr.usgs.gov/gme/gme.shtml 6. *And* located in country with glaciers country list provided World Glacier Monitoring Service); Also see: http://www.glims.org/maps/gtng		

A.3 Document search information

Document Search Information - Peer-Reviewed

Database Searches				
Database	**Search string**	**Date**	**Returns**	**Other Info**
WoS Core Collection	TOPIC: ("climat* change*" OR "global warming") AND TOPIC: (adapt*) AND TOPIC: (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo*	2 Jan 18	1,204	1. Limit timespan to: 1992 – 2017; 2. Limit Indexes to:

	OR "mass balance" OR "energy balance")			-Science Citation Index Expanded -Social Sciences Citation Index -Arts & Humanities Citation Index 3. Run Search, refine document type to 'Article'
Scopus	("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance")	5 Jan 18	1,063	1. Limit timespan to: 1992 – 2017 2. Limit document type to: Article 3. Run search
PubMed	("climate change" OR "climate changes" OR "climatic change" OR "climatic changes" OR "global warming" OR "Climate Change"[Mesh] OR "Global Warming"[Mesh]) AND (adaptation OR adapt OR adapts OR adapting OR adaptive OR "Adaptation, Psychological"[Mesh] OR "Adaptation, Physiological"[Mesh]) AND (glacier OR glaciers OR glacial OR glaciated OR glaciation OR **glacierized** OR glacierised OR cryosphere OR ice OR "mass balance" OR "energy balance")	2 Jan 18	226	1. Run Search 2. Limit timeframe to: 1 June 1992 to 31 Dec 2017
PAIS Int.	ti,ab,su("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance")	2 Jan 18	163	1. Limit timespan to: 1 June 1992 to 31 Dec 2017 2. Limit to 'Peer-reviewed'

				3. Limit language to English 4. Limit document type to 'Article' 5. Limit to source to 'Scholarly Journals' 6. Run search

Targeted Journal Searches				
Journal	**Search string**	**Date**	**Returns**	**Other Info**
Mountain Research and Development	BioOne (All issues since 2000) = "[All: "climat* change*"] OR [[All: "global warming"] AND [All: adapt*] AND [All: glacier*]] OR [All: glacial*] OR [All: glacio*] OR [All: glaciat*] OR [All: ice] OR [All: cryo*] OR [All: "mass balance"] OR [All: "energy balance"] AND [Publication Date: (06/01/1992 TO 12/31/2000)] AND [in Journal: Mountain Research and Development]" JSTOR (All issues from 1981 to 1999) = ("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance") AND jid:(j100622) Searched at (BioOne): http://www.bioone.org/loi/mred	2 Jan 18	306	*For both search engines:* 1. Limit date to: June 1992 to December 2017 2. Limit journal to: 'Mountain Research and Development' 3. Run search

	Searched at (JSTOR): http://www.jstor.org/journal/mounresedeve			
Journal of Alpine Research	"climate change" "global warming" adapt Searched at: http://journals.openedition.org/rga/?lang=en	2 Jan 18	23	Used simplified search terms to maximizes results in context of limited search interface
Journal of Mountain Science	("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance") Searched at: https://link.springer.com/journal/volumesAndIssues/11629	2 Jan 18	84	1. Run search
Arctic, Antarctic, and Alpine Research	("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance") Searched at: http://aaarjournal.org/?code=iaar-site	2 Jan 18	46	1. Run search 2. Limit to “research-article” 3. Limit search to: Title, Abstract, Keywords 4. Limit timeframe to: 1992 to 2017
Global Environmental Change	adapt and glacier AND LIMIT-TO(cids, "271866","Global Environmental Change" Searched at: https://www.sciencedirect.com/science/search	3 Jan 18	54	-Used simplified search terms to maximizes results in context of limited search interface 1. Run search

Regional Environmental Change	("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance") Searched at: https://link.springer.com/journal/10113	3 Jan 18	196	1. Run search
Climatic Change	("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance") Searched at: https://link.springer.com/journal/10584	3 Jan 18	992	1. Run search 2. Exclude returns published before 1992
Natural Hazards	("climat* change*" OR "global warming") AND adapt* AND (glacier* OR glacial* OR glacio* OR glaciat* OR ice OR cryo* OR "mass balance" OR "energy balance") Searched at: https://link.springer.com/journal/11069	3 Jan 18	188	1. Run search
Ecology & Society	ice adapt* climat* change* Searched at: https://www.ecologyandsociety.org/issues/search.php	3 Jan 18	75	-Used simplified search terms to maximizes results in context of limited search interface 1. Select ‘Match all of these words’

				2. Run search, note: 'ice' was only cryosphere related term that yielded potentially relevant results & most returns contained 'ice' within other words, e.g. 'services'

Backward/Forward Citation Tracking Search				
Database	**Search string**	**Date**	**Returns**	**Other Info**
Web of Science	N/A	11 Feb 18	3470	1. Search WoS for the title of each included article from the database search 2. Import all documents cited by the included article 3. Import all documents that have cited the included article.

Document Search Information - Grey Literature

Search Protocol for Grey Literature	
Search and review protocol	1. Open organization website 2. Identify native 'search' function and/or 'publications' page 3. Search key terms (e.g. adapt, glacier, climate change) 4. Evaluate returns to ensure all key 'AND' terms are included, exclude as necessary (text skim/key word search as necessary)

	5. Evaluate relevant returns against inclusion/exclusion criteria for grey lit., exclude as necessary
Additional criteria	1. Website and search interface must be in English 2. Document must pass critical appraisal (in addition to inclusion/exclusion criteria): a. Intelligible – Written in a clear and understandable manner (e.g. not a rough translation that does not make sense in English) b. Sufficient – Of sufficient detail to allows for evaluation of adaptation (e.g. not a bulleted PowerPoint slide) 3. Document must be searchable through organization's website and available through organization's website or Google search

MP Intergovernmental Organizations and Relevant Documents		
Relevant Organizations	**Search Date**	**Returns**
Food and Agriculture Organization of the United Nations (FAO)	25 Jan 2018	322
International Union for Conservation of Nature (IUCN)	27 Jan 2018	199
United Nations Development Programme (UNDP)	31 Jan 2018	104
United Nations Educational, Scientific and Cultural Organization (UNESCO)	31 Jan 2018	83
United Nations Environment Programme (UNEP)	27 Jan 2018	56
**UNEP/GRID-Arendal (Mountain Outlook Series only)*	17 Feb 2018	5
World Bank (WB)	6 Feb 2018	160
TOTAL		**929**

** In this study, UNEP/GRID-Arendal documents were considered to be UNEP-affiliated products and therefore products of a MP IGO member.*

A.4 Types of documents included in review

Types of Documents Included in Review	
Peer-Reviewed	**Grey Literature**
6. Empirical assessments of adaptation (e.g. case studies) 7. Assessments of adaptation programs or policies (e.g. policy evaluation)	5. Reports about adaptation projects or programs 6. Evaluations of adaptation projects or programs

8. Non-adaptation focused articles that nevertheless include substantial evaluations of adaptation (e.g. a vulnerability focused article that also evaluates adaptation) 9. Scientific studies that explicitly support actual or planned adaptation initiatives (e.g. modeling work that supports existing adaptation program). 10. Scientific studies that initiate adaptation actions (e.g. action research)	7. Non-adaptation focused documents that nevertheless include substantial evaluation of adaptation projects or programs (e.g. documents focused on human development) 8. Assessments of adaptation that are not led by organization/institutions authoring document (e.g. assessments of autonomous adaptations)

A.5 Included documents

Included Documents - All (*n* = 170)

***Peer-reviewed* (*n* = 107)**

Aase, T.H., Chapagain, P.S., Tiwari, P.C. (2013) Innovation as an Expression of Adaptive Capacity to Change in Himalayan Farming. Mountain Research and Development 33, 4-10.

Adler, C.E., McEvoy, D., Chhetri, P., Kruk, E. (2013) The role of tourism in a changing climate for conservation and development: A problem-oriented study in the Kailash Sacred Landscape, Nepal. Policy Sciences 46, 161-178.

Aldunce, P., Borquez, R., Adler, C., Blanco, G., Garreaud, R. (2016) Unpacking Resilience for Adaptation: Incorporating Practitioners' Experiences through a Transdisciplinary Approach to the Case of Drought in Chile. Sustainability 8.

Anguelovski, I., Chu, E., Carmin, J. (2014) Variations in approaches to urban climate adaptation: Experiences and experimentation from the global South. Global Environmental Change 27, 156-167.

Bardsley, D.K., Hugo, G.J. (2010) Migration and climate change: examining thresholds of change to guide effective adaptation decision-making. Population and Environment 32, 238-262.

Bastakoti, R.C., Bharati, L., Bhattarai, U., Wahid, S.M. (2017) Agriculture under changing climate conditions and adaptation options in the Koshi Basin. Climate and Development 9, 634-648.

Beniston, M., Stoffel, M. (2014) Assessing the impacts of climatic change on mountain water resources. Sci Total Environ 493, 1129-1137.

Beniston, M., Stoffel, M., Hill, M. (2011) Impacts of climatic change on water and natural hazards in the Alps: Can current water governance cope with future challenges? Examples from the European "ACQWA" project. Environmental Science & Policy 14, 734-743.

Bhadwal, S., Groot, A., Balakrishnan, S., Nair, S., Ghosh, S., Lingaraj, G.J., van Scheltinga, C.T., Bhave, A., Siderius, C. (2013) Adaptation to changing water resource availability in Northern India with respect to Himalayan Glacier retreat and changing monsoons using participatory approaches. Sci Total Environ 468-469 Suppl, S152-161.

Bhatta, G.D., Ojha, H.R., Aggarwal, P.K., Sulaiman, V.R., Sultana, P., Thapa, D., Mittal, N., Dahal, K., Thomson, P., Ghimire, L. (2017) Agricultural innovation and adaptation to climate change: empirical evidence from diverse agro-ecologies in South Asia. Environment Development and Sustainability 19, 497-525.

Bizikova, L., Pintér, L., Tubiello, N. (2015) Normative scenario approach: a vehicle to connect adaptation planning and development needs in developing countries. Regional Environmental Change 15, 1433-1446.

Boillat, S., Berkes, F. (2013) Perception and Interpretation of Climate Change among Quechua Farmers of Bolivia: Indigenous Knowledge as a Resource for Adaptive Capacity. Ecology and Society 18.

Bury, J., Mark, B.G., Carey, M., Young, K.R., McKenzie, J.M., Baraer, M., French, A., Polk, M.H. (2013) New Geographies of Water and Climate Change in Peru: Coupled Natural and Social Transformations in the Santa River Watershed. Annals of the Association of American Geographers 103, 363-374.

Byers, A.C., McKinney, D.C., Thakali, S., Somos-Valenzuela, M. (2014) Promoting science-based, community-driven approaches to climate change adaptation in glaciated mountain ranges: HiMAP. Geography 99, 143-152.

Carey, M., French, A., O'Brien, E. (2012a) Unintended effects of technology on climate change adaptation: an historical analysis of water conflicts below Andean Glaciers. Journal of Historical Geography 38, 181-191.

Carey, M., Huggel, C., Bury, J., Portocarrero, C., Haeberli, W. (2012b) An integrated socio-environmental framework for glacier hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. Climatic Change 112, 733-767.

Christmann, S., Aw-Hassan, A., Rajabov, T., Rabbimov, A. (2015) Collective Action for Common Rangelands Improvement: A Climate Change Adaptation Strategy in Uzbekistan. Society & Natural Resources 28, 280-295.

Christmann, S., Aw-Hassan, A.A. (2015) A participatory method to enhance the collective ability to adapt to rapid glacier loss: the case of mountain communities in Tajikistan. Climatic Change 133, 267-282.

Clarvis, M.H., Allan, A. (2014) Adaptive capacity in a Chilean context: A questionable model for Latin America. Environmental Science & Policy 43, 78-90.

Clouse, C. (2014) Learning from artificial glaciers in the Himalaya: design for climate change through low-tech infrastructural devices. Journal of Landscape Architecture 9, 6-19.

Clouse, C. (2016) Frozen landscapes: climate-adaptive design interventions in Ladakh and Zanskar. Landscape Research 41, 821-837.

Clouse, C. (2017) The Himalayan Ice Stupa Ladakh's Climate-adaptive Water Cache. Journal of Architectural Education 71, 247-251.

Clouse, C., Anderson, N., Shippling, T. (2017) Ladakh's artificial glaciers: climate-adaptive design for water scarcity. Climate and Development 9, 428-438.

Cochrane, L., Cundill, G., Ludi, E., New, M., Nicholls, R.J., Wester, P., Cantin, B., Murali, K.S., Leone, M., Kituyi, E., Landry, M.-E. (2017) A reflection on collaborative adaptation research in Africa and Asia. Regional Environmental Change 17, 1553-1561.

Condom, T., Escobar, M., Purkey, D., Pouget, J.C., Suarez, W., Ramos, C., Apaestegui, J., Tacsi, A., Gomez, J. (2012) Simulating the implications of glaciers' retreat for water management: a case study in the Rio Santa basin, Peru. Water International 37, 442-459.

Dewan, T.H. (2015) Societal impacts and vulnerability to floods in Bangladesh and Nepal. Weather and Climate Extremes 7, 36-42.

Doughty, C.A. (2016) Building climate change resilience through local cooperation: a Peruvian Andes case study. Regional Environmental Change 16, 2187-2197.

Espiner, S., Becken, S. (2014) Tourist towns on the edge: conceptualising vulnerability and resilience in a protected area tourism system. Journal of Sustainable Tourism 22, 646-665.

Fang, Y.P., Qin, D.H., Ding, Y.J. (2011) Frozen soil change and adaptation of animal husbandry: a case of the source regions of Yangtze and Yellow Rivers. Environmental Science & Policy 14, 555-568.

Fischer, A., Olefs, M., Abermann, J. (2011) Glaciers, snow and ski tourism in Austria's changing climate. Annals of Glaciology 52, 89-96.

Fricke, K., Sterr, T., Bubenzer, O., Eitel, B. (2009) The Oasis as a Megacity: Urumqi's Fast Urbanisation in a Semiarid Environment. Erde 140, 449-463.

Fu, Y., Grumbine, R.E., Wilkes, A., Wang, Y., Xu, J.C., Yang, Y.P. (2012) Climate Change Adaptation Among Tibetan Pastoralists: Challenges in Enhancing Local Adaptation Through Policy Support. Environmental Management 50, 607-621.

Furunes, T., Mykletun, R.J. (2012) Frozen Adventure at Risk? A 7-year Follow-up Study of Norwegian Glacier Tourism. Scandinavian Journal of Hospitality and Tourism 12, 324-348.

Gagné, K. (2016) Cultivating ice over time: On the idea of timeless knowledge and places in the Himalayas. Anthropologica 58, 193-210.

Gao, Q.Z., Li, Y., Xu, H.M., Wan, Y.F., Jiangcun, W.Z. (2014) Adaptation strategies of climate variability impacts on alpine grassland ecosystems in Tibetan Plateau. Mitigation and Adaptation Strategies for Global Change 19, 199-209.

Gautam, Y. (2017) Seasonal Migration and Livelihood Resilience in the Face of Climate Change in Nepal. Mountain Research and Development 37, 436-445.

Gentle, P., Maraseni, T.N. (2012) Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. Environmental Science & Policy 21, 24-34.

Gentle, P., Thwaites, R. (2016) Transhumant Pastoralism in the Context of Socioeconomic and Climate Change in the Mountains of Nepal. Mountain Research and Development 36, 173-182.

Giacomelli, P., Rossetti, A., Brambilla, M. (2008) Adapting water allocation management to drought scenarios. Natural Hazards and Earth System Science 8, 293-302.

Gioli, G., Khan, T., Scheffran, J. (2014) Climatic and environmental change in the Karakoram: making sense of community perceptions and adaptation strategies. Regional Environmental Change 14, 1151-1162.

Haeberli, W., Buetler, M., Huggel, C., Friedli, T.L., Schaub, Y., Schleiss, A.J. (2016) New lakes in deglaciating high-mountain regions – opportunities and risks. Climatic Change 139, 201-214.

Halofsky, J.E., Peterson, D.L., Prendeville, H.R. (2017) Assessing vulnerabilities and adapting to climate change in northwestern U.S. forests. Climatic Change.

Hill, M. (2013) Adaptive Capacity of Water Governance: Cases From the Alps and the Andes. Mountain Research and Development 33, 248-259.

Hill, M., Wallner, A., Furtado, J. (2010) Reducing vulnerability to climate change in the Swiss Alps: a study of adaptive planning. Climate Policy 10, 70-86.

Holler, J. (2014) Is Sustainable Adaptation Possible? Determinants of Adaptation on Mount Kilimanjaro. Professional Geographer 66, 526-537.

Hopkins, D. (2014) The sustainability of climate change adaptation strategies in New Zealand's ski industry: a range of stakeholder perceptions. Journal of Sustainable Tourism 22, 107-126.

Huggel, C., Scheel, M., Albrecht, F., Andres, N., Calanca, P., Jurt, C., Khabarov, N., Mira-Salama, D., Rohrer, M., Salzmann, N., Silva, Y., Silvestre, E., Vicuna, L., Zappa, M. (2015) A framework for the science contribution in climate adaptation: Experiences from science-policy processes in the Andes. Environmental Science & Policy 47, 80-94.

Huntington, H.P., Begossi, A., Gearheard, S.F., Kersey, B., Loring, P.A., Mustonen, T., Paudel, P.K., Silvano, R.A.M., Vave, R. (2017) How small communities respond to environmental change: patterns from tropical to polar ecosystems. Ecology and Society 22, 9.

Ingty, T. (2017) High mountain communities and climate change: adaptation, traditional ecological knowledge, and institutions. Climatic Change 145, 41-55.

Jones, L., Boyd, E. (2011) Exploring social barriers to adaptation: Insights from Western Nepal. Global Environmental Change-Human and Policy Dimensions 21, 1262-1274.

Kaenzig, R., Rebetez, M., Serquet, G. (2016) Climate change adaptation of the tourism sector in the Bolivian Andes. Tourism Geographies 18, 111-128.

Kaul, V., Thornton, T.F. (2014) Resilience and adaptation to extremes in a changing Himalayan environment. Regional Environmental Change 14, 683-698.

Kelkar, U., Narula, K.K., Sharma, V.P., Chandna, U. (2008) Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India. Global Environmental Change 18, 564-574.

Knapp, C.N., Chapin Iii, F.S., Kofinas, G.P., Fresco, N., Carothers, C., Craver, A. (2014) Parks, people, and change: the importance of multistakeholder engagement in adaptation planning for conserved areas. Ecology and Society 19.

Konchar, K.M., Staver, B., Salick, J., Chapagain, A., Joshi, L., Karki, S., Lo, S., Paudel, A., Subedi, P., Ghimire, S.K. (2015) Adapting in the shadow of Annapurna: A climate tipping point. Journal of Ethnobiology 35, 449-471.

Lagos, P. (2007) Peru's Approach to Climate Change in the Andean Mountain Region: Achieving Multidisciplinary Regional Cooperation for Integrated Assessment of Climate Change. Mountain Research and Development 27, 28-31.

Lasage, R., Muis, S., Sardella, C.S.E., van Drunen, M.A., Verburg, P.H., Aerts, J. (2015) A Stepwise, Participatory Approach to Design and Implement Community Based Adaptation to Drought in the Peruvian Andes. Sustainability 7, 1742-1773.

Lee, D.R., Edmeades, S., De Nys, E., McDonald, A., Janssen, W. (2014) Developing local adaptation strategies for climate change in agriculture: A priority-setting approach with application to Latin America. Global Environmental Change 29, 78-91.

Lennox, E. (2015) Double Exposure to Climate Change and Globalization in a Peruvian Highland Community. Society & Natural Resources 28, 781-796.

Lennox, E., Gowdy, J. (2014) Ecosystem governance in a highland village in Peru: Facing the challenges of globalization and climate change. Ecosystem Services 10, 155-163.

Li, C., Tang, Y., Luo, H., Di, B., Zhang, L. (2013) Local farmers' perceptions of climate change and local adaptive strategies: a case study from the Middle Yarlung Zangbo River Valley, Tibet, China. Environ Manage 52, 894-906.

Lopez-i-Gelats, F., Paco, J.L.C., Huayra, R.H., Robles, O.D.S., Pena, E.C.Q., Filella, J.B. (2015) Adaptation Strategies of Andean Pastoralist Households to Both Climate and Non-Climate Changes. Human Ecology 43, 267-282.

Macchi, M., Gurung, A.M., Hoermann, B. (2015) Community perceptions and responses to climate variability and change in the Himalayas. Climate and Development 7, 414-425.

Maikhuri, R.K., Nautiyal, A., Jha, N.K., Rawat, L.S., Maletha, A., Phondani, P.C., Bahuguna, Y.M., Bhatt, G.C. (2017) Socio-ecological vulnerability: Assessment and coping strategy to environmental disaster in Kedarnath valley, Uttarakhand, Indian Himalayan Region. International Journal of Disaster Risk Reduction 25, 111-124.

Manandhar, S., Vogt, D.S., Perret, S.R., Kazama, F. (2011) Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices. Regional Environmental Change 11, 335-348.

McDowell, G., Ford, J.D., Lehner, B., Berrang-Ford, L., Sherpa, A. (2013) Climate-related hydrological change and human vulnerability in remote mountain regions: a case study from Khumbu, Nepal. Regional Environmental Change 13, 299-310.

McDowell, J.Z., Hess, J.J. (2012) Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. Global Environmental Change 22, 342-352.

McNeeley, S.M. (2017) Sustainable Climate Change Adaptation in Indian Country. Weather Climate and Society 9, 392-403.

Meenawat, H., Sovacool, B.K. (2011) Improving adaptive capacity and resilience in Bhutan. Mitigation and Adaptation Strategies for Global Change 16, 515-533.

Mills-Novoa, M., Borgias, S.L., Crootof, A., Thapa, B., de Grenade, R., Scott, C.A. (2017) Bringing the Hydrosocial Cycle into Climate Change Adaptation Planning: Lessons from Two Andean Mountain Water Towers. Annals of the American Association of Geographers 107, 393-402.

Montana, E., Diaz, H.P., Hurlbert, M. (2016) Development, local livelihoods, and vulnerabilities to global environmental change in the South American Dry Andes. Regional Environmental Change 16, 2215-2228.

Moors, E.J., Groot, A., Biemans, H., van Scheltinga, C.T., Siderius, C., Stoffel, M., Huggel, C., Wiltshire, A., Mathison, C., Ridley, J., Jacob, D., Kumar, P., Bhadwal, S., Gosain, A., Collins, D.N. (2011) Adaptation to changing water resources in the Ganges basin, northern India. Environmental Science & Policy 14, 758-769.

Mourey, J., Ravanel, L. (2017) Evolution of Access Routes to High Mountain Refuges of the Mer de Glace Basin (Mont Blanc Massif, France): An Example of Adapting to Climate Change Effects in the Alpine High Mountains. Journal of Mountain Science.

Muccione, V., Salzmann, N., Huggel, C. (2016) Scientific Knowledge and Knowledge Needs in Climate Adaptation Policy. Mountain Research and Development 36, 364-375.

Negi, V.S., Maikhuri, R.K., Pharswan, D., Thakur, S., Dhyani, P.P. (2017) Climate change impact in the Western Himalaya: people's perception and adaptive strategies. Journal of Mountain Science 14, 403-416.

O'Brien, G., O'Keefe, P., Meena, H., Rose, J., Wilson, L. (2008) Climate adaptation from a poverty perspective. Climate Policy 8, 194-201.

Onta, N., Resurreccion, B.P. (2011) The Role of Gender and Caste in Climate Adaptation Strategies in Nepal Emerging Change and Persistent Inequalities in the Far-Western Region. Mountain Research and Development 31, 351-356.

Orlove, B. (2009) Glacier Retreat: Reviewing the Limits of Human Adaptation to Climate Change. Environment 51, 22-34.

Peduzzi, P., Herold, C., Silverio, W. (2010) Assessing high altitude glacier thickness, volume and area changes using field, GIS and remote sensing techniques: the case of Nevado Coropuna (Peru). Cryosphere 4, 313-323.

Petrakov, D.A., Tutubalina, O.V., Aleinikov, A.A., Chernomorets, S.S., Evans, S.G., Kidyaeva, V.M., Krylenko, I.N., Norin, S.V., Shakhmina, M.S., Seynova, I.B. (2012) Monitoring of Bashkara Glacier lakes (Central Caucasus, Russia) and modelling of their potential outburst. Natural Hazards 61, 1293-1316.

Picketts, I.M., Andrey, J., Matthews, L., Déry, S.J., Tighe, S. (2016) Climate change adaptation strategies for transportation infrastructure in Prince George, Canada. Regional Environmental Change 16, 1109-1120.

Picketts, I.M., Curry, J., Déry, S.J., Cohen, S.J. (2013) Learning with practitioners: climate change adaptation priorities in a Canadian community. Climatic Change 118, 321-337.

Pons, M., López Moreno, J.I., Esteban, P., Macià, S., Gavaldà, J., García, C., Rosas-Casals, M., Jover, E. (2014) Climate change influence on winter tourism in the Pyrenees: Experience from the NIVOPYR research project. Pirineos 169.

Pons-Pons, M., Johnson, P.A., Rosas-Casals, M., Sureda, B., Jover, E. (2012) Modeling climate change effects on winter ski tourism in Andorra. Climate Research 54, 197-207.

Postigo, J.C. (2014) Perception and resilience of Andean populations facing climate change. Journal of Ethnobiology 34, 383-400.

Postigo, J.C., Young, K.R., Crews, K.A. (2008) Change and continuity in a pastoralist community in the high Peruvian Andes. Human Ecology 36, 535-551.

Rai, S.C., Gurung, A. (2005) Raising Awareness of the Impacts of Climate Change: Initial Steps in Shaping Policy in Nepal. Mountain Research and Development 25, 316-320.

Raoul, K. (2015) Can glacial retreat lead to migration? A critical discussion of the impact of glacier shrinkage upon population mobility in the Bolivian Andes. Population and Environment 36, 480-496.

Raymond, C.L., Peterson, D.L., Rochefort, R.M. (2013) The North Cascadia Adaptation Partnership: A Science-Management Collaboration for Responding to Climate Change. Sustainability 5, 136-159.

Ritter, F., Fiebig, M., Muhar, A. (2012) Impacts of Global Warming on Mountaineering: A Classification of Phenomena Affecting the Alpine Trail Network. Mountain Research and Development 32, 4-15.

Sapkota, P., Keenan, R.J., Paschen, J.A., Ojha, H.R. (2016) Social production of vulnerability to climate change in the rural middle hills of Nepal. Journal of Rural Studies 48, 53-64.

Shaffer, L.J. (2014) Making sense of local climate change in rural Tanzania through knowledge co-production. Journal of Ethnobiology 34, 315-334.

Shah, A.A., Ye, J., Abid, M., Ullah, R. (2017) Determinants of flood risk mitigation strategies at household level: a case of Khyber Pakhtunkhwa (KP) province, Pakistan. Natural Hazards 88, 415-430.

Somos-Valenzuela, M.A., McKinney, D.C., Byers, A.C., Rounce, D.R., Portocarrero, C., Lamsal, D. (2015) Assessing downstream flood impacts due to a potential GLOF from Imja Tsho in Nepal. Hydrology and Earth System Sciences 19, 1401-1412.

Sorg, A., Mosello, B., Shalpykova, G., Allan, A., Clarvis, M.H., Stoffel, M. (2014) Coping with changing water resources: The case of the Syr Darya river basin in Central Asia. Environmental Science & Policy 43, 68-77.

Spies, M. (2016) Glacier thinning and adaptation assemblages in Nagar, northern Pakistan. Erdkunde 70, 125-140.

Steiger, R., Mayer, M. (2008) Snowmaking and Climate Change: Future Options for Snow Production in Tyrolean Ski Resorts. Mountain Research and Development 28, 292-298.

Stensrud, A.B. (2016) Climate Change, Water Practices and Relational Worlds in the Andes. Ethnos 81, 75-98.

Stewart, E.J., Wilson, J., Espiner, S., Purdie, H., Lemieux, C., Dawson, J. (2016) Implications of climate change for glacier tourism. Tourism Geographies 18, 377-398.

Strauch, R.L., Raymond, C.L., Rochefort, R.M., Hamlet, A.F., Lauver, C. (2015) Adapting transportation to climate change on federal lands in Washington State, U.S.A. Climatic Change 130, 185-199.

Stucker, D., Kazbekov, J., Yakubov, M., Wegerich, K. (2012) Climate Change in a Small Transboundary Tributary of the Syr Darya Calls for Effective Cooperation and Adaptation. Mountain Research and Development 32, 275-285.

Wang, S., He, Y., Song, X. (2010) Impacts of climate warming on Alpine glacier tourism and adaptive measures: A case study of Baishui Glacier No. 1 in Yulong Snow Mountain, Southwestern China. Journal of Earth Science 21, 166-178.

Wehrli, A. (2014) Why Mountains Matter for Sustainable Development. Mountain Research and Development 34, 405-409.

Wrathall, D.J., Bury, J., Carey, M., Mark, B., McKenzie, J., Young, K., Baraer, M., French, A., Rampini, C. (2014) Migration Amidst Climate Rigidity Traps: Resource Politics and Social-Ecological Possibilism in Honduras and Peru. Annals of the Association of American Geographers 104, 292-304.

Yao, T., Thompson, L.G., Mosbrugger, V., Zhang, F., Ma, Y., Luo, T., Xu, B., Yang, X., Joswiak, D.R., Wang, W., Joswiak, M.E., Devkota, L.P., Tayal, S., Jilani, R., Fayziev, R. (2012) Third Pole Environment (TPE). Environmental Development 3, 52-64.

Young, G., Zavala, H., Wandel, J., Smit, B., Salas, S., Jimenez, E., Fiebig, M., Espinoza, R., Diaz, H., Cepeda, J. (2010) Vulnerability and adaptation in a dryland community of the Elqui Valley, Chile. Climatic Change 98, 245-276.

Young, K.R., Lipton, J.K. (2006) Adaptive governance and climate change in the tropical highlands of Western South America. Climatic Change 78, 63-102.

***Grey literature* (*n* = 63)**

FAO, (2009a) Bhutan Forestry Outlook Study, Asia-Pacific Forestry Sector Outlook Study II Working Paper Series, p. 73.

FAO, (2009b) Unasylva: Adapting to climate change, An international journal of forestry and forest industries, p. 92.

FAO, (2011a) Climate Change Adaptation and Disaster Risk Management in Agriculture - Priority Framework for Action 2011-2020, p. 58.

FAO, (2011b) Climate change, water and food security, FAO Water Reports, p. 200.

FAO, (2011c) Highlands and Drylands: Mountains, a source of resilience in arid regions. FAO and Centre for Development and Environment of the University of Bern, p. 115.

FAO, (2011d) Mountain Forests in a Changing World: Realizing values, addressing challenges, p. 84.

FAO, (2012a) Adaptation in action: FAO's work on climate change adaptation, p. 20.

FAO, (2012b) Mountain Biodiversity and global change, p. 59.

FAO, (2012c) Mountains and Climate Change, p. 80.

FAO, (2013a) In the protegonists' own words: the case of Ecuador, p. 179.

FAO (2013b) Mountain Farming Is Family Farming. 102.

FAO, (2014a) Managing climate risks and adapting to climate change in the agriculture sector in Nepal, p. 162.

FAO (2014b) Water and the Rural Poor. 162.

FAO, (2015a) Restoration of overgrazed páramo grasslands for hydrological benefits, p. 4.

FAO (2015b) Understanding Mountain Soils: A Contribution from mountain areas to the International Year of Soils 2015. 169.

FAO, (2016a) Ecuador's Banana Sector under Climate Change, p. 165.

FAO, (2016b) National Institutional Assessment on the Integration of Disaster Risk Management(DRM) into the Agriculture Sector of Pakistan, p. 160.

FAO, (2017) Mountains Under Pressure, p. 4.

IUCN, (2009) Ecosystem-based adaptation: a natural response to climate change p. 20.

IUCN, (2010a) Addressing climate change: issues and solutions from around the world p. 42.

IUCN, (2010b) Building resilience to climate change: ecosystem-based adaptation and lessons from the field p. 85.

IUCN, (2014) Safe havens: protected areas for disaster risk reduction and climate change adaptation, p. 168.

IUCN, (2015a) Making the case for ecosystem-based adaptation : the global mountain EbA programme in Nepal, Peru and Uganda, p. 136.

IUCN, (2015b) Synergies between climate mitigation and adaptation in forest landscape restoration, p. 61.

IUCN, (2016) Adapting to climate change : guidance for protected area managers and planners, p. 152.

IUCN, (2017) Ecosystems protecting infrastructure and communities, p. 110.

UNDP, (2010a) Community Based Adaptation to Climate Change, p. 17.

UNDP, (2010b) UNDP Community Water Initiative: Fostering Water Security, p. 39.

UNDP, (2015) UNDP and Climate Change, p. 52.

UNDP, (2017a) Listening to our Land - Stories of Resilience, p. 39.

UNDP, (2017b) RESILIENT: Zero Carbon, Risk-Informed, Sustainable, p. 107.

UNDP/GRID-Arendal, (2015) Outlook on climate change adaptation in the Western Balkan mountains.

UNDP/GRID-Arendal, (2016) Outlook on climate change adaptation in the Tropical Andes mountains.

UNEP, (2008) Climate Change Adaptation and Mitigation in the Tourism Sector: Frameworks, Tools and Practices, p. 152.

UNEP/GRID-Arendal, (2015) Outlook on climate change adaptation in the South Caucasus mountains.

UNESCO, (2015a) The Impact of glacier retreat in the Andes: international multidisciplinary network for adaptation strategies, p. 4.

UNESCO, (2015b) Resilience in a time of uncertainty: indigenous peoples and climate change, p. 65.

UNESCO, (2016) Key outcomes of the inception workshop: Addressing Water Security, climate impacts and adaptation responses in Africa, Americas and Asia, p. 8.

World Bank, (2005) Adapting to climate change : lessons learned, work in progress, and proposed next steps for the World Bank in Latin America, p. 117.

World Bank, (2008) Transitioning to climate resilient development: perspectives from communities in Peru, p. 113.

World Bank, (2009a) Agricultural development under a changing climate : opportunities and challenges for adaptation, p. 198.

World Bank, (2009b) Assessing the potential consequences of climate destabilization in Latin America, p. 117.

World Bank, (2009c) Bolivia - Country note on climate change aspects in agriculture, p. 14.

World Bank, (2009d) Chile - Country note on climate change aspects in agriculture, p. 9.

World Bank, (2009e) Ecuador - Country note on climate change aspects in agriculture, p. 9.

World Bank, (2009f) Vulnerability to climate change in agricultural systems in Latin America and the Caribbean - building response strategies: final report, p. 95.

World Bank, (2010a) Assessment of the impacts of climate change on mountain hydrology : development of a methodology through a case study in Peru, p. 69.

World Bank, (2010b) Indigenous peoples and climate change in Latin America and the Caribbean, p. 190.

World Bank, (2010c) The social dimensions of adaptation of climate change in Bolivia, p. 72.

World Bank, (2011) Building community resilience to climate change : Testing the adaptation coalition framework in Latin America, p. 50.

World Bank, (2012a) Adapting to climate change: assessing the World Bank Group experience - phase three of the World Bank Group and climate change, p. 193.

World Bank, (2012b) Armenia - Climate change and agriculture country note, p. 21.

World Bank, (2012c) Azerbaijan - Climate change and agriculture country note, p. 20.

World Bank, (2012d) Georgia - Climate change and agriculture country note, p. 20.

World Bank, (2013a) Kazakhstan - Overview of climate change activities, p. 19.

World Bank, (2013b) Kyrgyz Republic - Overview of climate change activities, p. 18.

World Bank, (2013c) Overcoming institutional and governance challenges in environmental management: case studies from Latin America and the Caribbean region, p. 30.

World Bank, (2013d) Tajikistan - Overview of climate change activities, p. 17.

World Bank, (2013e) Uzbekistan - Overview of climate change activities, p. 18.

World Bank, (2014a) Building resilience to climate change in South Caucasus agriculture, p. 142.

World Bank, (2014b) Climate-resilient, climate-friendly world heritage cities, p. 44.

World Bank, (2014c) Reducing the vulnerability of Georgia's agricultural systems to climate change: Impact assessment and adaptation options, p. 116.

World Bank, (2015) Robust Decision-Making in the Water Sector: A Strategy for Implementing Lima's Long-Term Water Resources Master Plan p. 47.

Included Documents - Explicitly Mountain *and* Adaptation Focused (subset of documents above) (*n* = 58)

***Peer-reviewed* (*n* = 41)**

Aase, T.H., Chapagain, P.S., Tiwari, P.C. (2013) Innovation as an Expression of Adaptive Capacity to Change in Himalayan Farming. Mountain Research and Development 33, 4-10.

Adler, C.E., McEvoy, D., Chhetri, P., Kruk, E. (2013) The role of tourism in a changing climate for conservation and development: A problem-oriented study in the Kailash Sacred Landscape, Nepal. Policy Sciences 46, 161-178.

Beniston, M., Stoffel, M. (2014) Assessing the impacts of climatic change on mountain water resources. Sci Total Environ 493, 1129-1137.

Boillat, S., Berkes, F. (2013) Perception and Interpretation of Climate Change among Quechua Farmers of Bolivia: Indigenous Knowledge as a Resource for Adaptive Capacity. Ecology and Society 18.

Byers, A.C., McKinney, D.C., Thakali, S., Somos-Valenzuela, M. (2014) Promoting science-based, community-driven approaches to climate change adaptation in glaciated mountain ranges: HiMAP. Geography 99, 143-152.

Carey, M., French, A., O'Brien, E. (2012a) Unintended effects of technology on climate change adaptation: an historical analysis of water conflicts below Andean Glaciers. Journal of Historical Geography 38, 181-191.

Carey, M., Huggel, C., Bury, J., Portocarrero, C., Haeberli, W. (2012b) An integrated socio-environmental framework for glacier hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. Climatic Change 112, 733-767.

Christmann, S., Aw-Hassan, A.A. (2015) A participatory method to enhance the collective ability to adapt to rapid glacier loss: the case of mountain communities in Tajikistan. Climatic Change 133, 267-282.

Clarvis, M.H., Allan, A. (2014) Adaptive capacity in a Chilean context: A questionable model for Latin America. Environmental Science & Policy 43, 78-90.

Clouse, C. (2014) Learning from artificial glaciers in the Himalaya: design for climate change through low-tech infrastructural devices. Journal of Landscape Architecture 9, 6-19.

Clouse, C. (2016) Frozen landscapes: climate-adaptive design interventions in Ladakh and Zanskar. Landscape Research 41, 821-837.

Clouse, C., Anderson, N., Shippling, T. (2017) Ladakh's artificial glaciers: climate-adaptive design for water scarcity. Climate and Development 9, 428-438.

Fischer, A., Olefs, M., Abermann, J. (2011) Glaciers, snow and ski tourism in Austria's changing climate. Annals of Glaciology 52, 89-96.

Gagné, K. (2016) Cultivating ice over time: On the idea of timeless knowledge and places in the Himalayas. Anthropologica 58, 193-210.

Gentle, P., Maraseni, T.N. (2012) Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. Environmental Science & Policy 21, 24-34.

Gioli, G., Khan, T., Scheffran, J. (2014) Climatic and environmental change in the Karakoram: making sense of community perceptions and adaptation strategies. Regional Environmental Change 14, 1151-1162.

Hill, M. (2013) Adaptive Capacity of Water Governance: Cases From the Alps and the Andes. Mountain Research and Development 33, 248-259.

Hill, M., Wallner, A., Furtado, J. (2010) Reducing vulnerability to climate change in the Swiss Alps: a study of adaptive planning. Climate Policy 10, 70-86.

Holler, J. (2014) Is Sustainable Adaptation Possible? Determinants of Adaptation on Mount Kilimanjaro. Professional Geographer 66, 526-537.

Hopkins, D. (2014) The sustainability of climate change adaptation strategies in New Zealand's ski industry: a range of stakeholder perceptions. Journal of Sustainable Tourism 22, 107-126.

Huggel, C., Scheel, M., Albrecht, F., Andres, N., Calanca, P., Jurt, C., Khabarov, N., Mira-Salama, D., Rohrer, M., Salzmann, N., Silva, Y., Silvestre, E., Vicuna, L., Zappa, M. (2015) A framework for the science contribution in climate adaptation: Experiences from science-policy processes in the Andes. Environmental Science & Policy 47, 80-94.

Ingty, T. (2017) High mountain communities and climate change: adaptation, traditional ecological knowledge, and institutions. Climatic Change 145, 41-55.

Kaenzig, R., Rebetez, M., Serquet, G. (2016) Climate change adaptation of the tourism sector in the Bolivian Andes. Tourism Geographies 18, 111-128.

Kaul, V., Thornton, T.F. (2014) Resilience and adaptation to extremes in a changing Himalayan environment. Regional Environmental Change 14, 683-698.

Kelkar, U., Narula, K.K., Sharma, V.P., Chandna, U. (2008) Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India. Global Environmental Change 18, 564-574.

Konchar, K.M., Staver, B., Salick, J., Chapagain, A., Joshi, L., Karki, S., Lo, S., Paudel, A., Subedi, P., Ghimire, S.K. (2015) Adapting in the shadow of Annapurna: A climate tipping point. Journal of Ethnobiology 35, 449-471.

Lagos, P. (2007) Peru's Approach to Climate Change in the Andean Mountain Region: Achieving Multidisciplinary Regional Cooperation for Integrated Assessment of Climate Change. Mountain Research and Development 27, 28-31.

Lasage, R., Muis, S., Sardella, C.S.E., van Drunen, M.A., Verburg, P.H., Aerts, J. (2015) A Stepwise, Participatory Approach to Design and Implement Community Based Adaptation to Drought in the Peruvian Andes. Sustainability 7, 1742-1773.

Lopez-i-Gelats, F., Paco, J.L.C., Huayra, R.H., Robles, O.D.S., Pena, E.C.Q., Filella, J.B. (2015) Adaptation Strategies of Andean Pastoralist Households to Both Climate and Non-Climate Changes. Human Ecology 43, 267-282.

Manandhar, S., Vogt, D.S., Perret, S.R., Kazama, F. (2011) Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices. Regional Environmental Change 11, 335-348.

McDowell, J.Z., Hess, J.J. (2012) Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. Global Environmental Change 22, 342-352.

Mills-Novoa, M., Borgias, S.L., Crootof, A., Thapa, B., de Grenade, R., Scott, C.A. (2017) Bringing the Hydrosocial Cycle into Climate Change Adaptation Planning: Lessons from Two Andean Mountain Water Towers. Annals of the American Association of Geographers 107, 393-402.

Muccione, V., Salzmann, N., Huggel, C. (2016) Scientific Knowledge and Knowledge Needs in Climate Adaptation Policy. Mountain Research and Development 36, 364-375.

Negi, V.S., Maikhuri, R.K., Pharswan, D., Thakur, S., Dhyani, P.P. (2017) Climate change impact in the Western Himalaya: people's perception and adaptive strategies. Journal of Mountain Science 14, 403-416.

Orlove, B. (2009) Glacier Retreat: Reviewing the Limits of Human Adaptation to Climate Change. Environment 51, 22-34.

Postigo, J.C. (2014) Perception and resilience of Andean populations facing climate change. Journal of Ethnobiology 34, 383-400.

Raymond, C.L., Peterson, D.L., Rochefort, R.M. (2013) The North Cascadia Adaptation Partnership: A Science-Management Collaboration for Responding to Climate Change. Sustainability 5, 136-159.

Spies, M. (2016) Glacier thinning and adaptation assemblages in Nagar, northern Pakistan. Erdkunde 70, 125-140.

Steiger, R., Mayer, M. (2008) Snowmaking and Climate Change: Future Options for Snow Production in Tyrolean Ski Resorts. Mountain Research and Development 28, 292-298.

Wang, S., He, Y., Song, X. (2010) Impacts of climate warming on Alpine glacier tourism and adaptive measures: A case study of Baishui Glacier No. 1 in Yulong Snow Mountain, Southwestern China. Journal of Earth Science 21, 166-178.

Young, K.R., Lipton, J.K. (2006) Adaptive governance and climate change in the tropical highlands of Western South America. Climatic Change 78, 63-102.

***Grey literature* (*n* = 17)**

FAO, (2011a) Climate Change Adaptation and Disaster Risk Management in Agriculture - Priority Framework for Action 2011-2020, p. 58.

FAO, (2011b) Mountain Forests in a Changing World: Realizing values, addressing challenges, p. 84.

FAO, (2014) Managing climate risks and adapting to climate change in the agriculture sector in Nepal, p. 162.

FAO, (2016) National Institutional Assessment on the Integration of Disaster Risk Management(DRM) into the Agriculture Sector of Pakistan, p. 160.

FAO, (2017) Mountains Under Pressure, p. 4.

IUCN, (2015) Making the case for ecosystem-based adaptation : the global mountain EbA programme in Nepal, Peru and Uganda, p. 136.

UNDP/GRID-Arendal, (2015) Outlook on climate change adaptation in the Western Balkan mountains.

UNDP/GRID-Arendal, (2016) Outlook on climate change adaptation in the Tropical Andes mountains.

UNEP/GRID-Arendal, (2015) Outlook on climate change adaptation in the South Caucasus mountains.

UNESCO, (2015) The Impact of glacier retreat in the Andes: international multidisciplinary network for adaptation strategies, p. 4.

World Bank, (2009a) Bolivia - Country note on climate change aspects in agriculture, p. 14.

World Bank, (2009b) Chile - Country note on climate change aspects in agriculture, p. 9.

World Bank, (2009c) Ecuador - Country note on climate change aspects in agriculture, p. 9.

World Bank, (2010a) Assessment of the impacts of climate change on mountain hydrology : development of a methodology through a case study in Peru, p. 69.

World Bank, (2010b) The social dimensions of adaptation of climate change in Bolivia, p. 72.

World Bank, (2012) Adapting to climate change: assessing the World Bank Group experience - phase three of the World Bank Group and climate change, p. 193.

World Bank, (2014) Reducing the vulnerability of Georgia's agricultural systems to climate change: Impact assessment and adaptation options, p. 116.

A.6 Questionnaire

BIBLIOMETRIC INFORMATION

Q 1. Title?
_______________________________________(type response)

Q 2. Year published?
_______________________________________(type response)

Q 3. Lead author's name (last name, first initial for peer-reviewed; lead institution name for grey literature)?
_______________________________________(type response)

Q 4. Country of lead author's institutional affiliation (for peer-reviewed) or institutional headquarters (for grey literature) at time of publication?
_______________________________________(type response)

ADAPTATION RESEARCH (Complete for PEER-REVIEWED articles only)

Q 5. Analytical scale of assessment (select one)?

1. Single community
2. Multiple communities
3. Single region within mountain range
4. Multiple regions within mountain range
5. Single mountain range
6. Multiple mountain ranges
7. All mountain ranges (global)
8. Indeterminate

Q 6. Methods used in assessment (all that apply)?

1. Community-based research (e.g. interviews, focus groups)
2. Participatory methods (e.g. co-developing research objectives or questions)
3. Temporal analog methods
4. Spatial analog methods
5. Longitudinal study design
6. Adaptation scenarios/pathways
7. Modeling projections of climate-related biophysical changes
8. Modeling projections of social change
9. Textual analysis/policy assessment
10. Other_________________________(type response)
11. Indeterminate

Q 7. Assessment engaged substantively with …(all that apply)?

1. Scientific information about climate-related changes
2. The socio-economic, cultural, and/or political dimensions of adaptation
3. Socio-ecological system dynamics in relation to adaptation (e.g. interdependencies between people and ecosystems)

Q 8. Assessment engaged substantively with other concepts related to adaptation (all that apply)?

1. Vulnerability
2. Resilience
3. Transformation
4. Disaster risk reduction
5. Sustainable development
6. Governance
7. N/A

Q 9. Was this assessment explicitly framed as ‘adaptation research’ or ‘adaptation focused’ (select one)?

1. Yes
2. No

Q 10. Was this assessment explicitly framed as ‘mountain research’ or ‘mountain-focused’ (select one)?

3. Yes
4. No

ADAPTATION MEASURES (Complete for each DISCRETE adaptation measure reported)

Where are adaptation measures occurring?

Q 11. Country/countries in which adaptation is taking place/is focused?

____(type response)

Q 12. Major mountain range/ranges in which adaptation is taking place/is focused?

____(type response)

Q 13. Region/regions or community/communities in which adaptation is taking place/is focused, if applicable. Be as specific as possible?

____(type response)

Q 14. Page number(s) with most specific location information?

____(type response)

What stressors are motivating adaptation measure?

Q 15. Climatic stimuli motivating adaptation (all that apply)?

1. Temperature change
2. Precipitation change – Amount/timing
3. Precipitation change – Phase state (e.g. snow to rain)
4. Seasonality change
5. Weather uncertainty
6. Glacier change – Non-hydrological impacts
7. Glacial hydrology change
8. Snow cover change - Non-hydrological impacts
9. Snow hydrology change
10. Hydrological change - Not related to glacier or snow cover change
11. Extreme events - Hydrological
12. Extreme events - Non-hydrological

13. Thawing of frozen ground
14. Ecosystem change (flora and fauna)
15. Other_________________________(type response)
16. Indeterminate

Q 16. Non-climatic stimuli motivating adaptation, if relevant (all that apply)?

1. Livelihood diversification
2. Cultural change
3. Socio-political marginalization
4. Changing political circumstances
5. Economic stress
6. Economic opportunities
7. Food insecurity
8. Health-related factors
9. Resource development
10. Displacement/conflict
11. Environmental change (not related to climate change)
12. Other_________________________(type response)
13. Indeterminate
14. N/A

Q 17. Importance of climatic stimuli in motivating adaptation (select one)?

1. Sole reason for adapting
2. Primary reason along with non-climatic stressors
3. Secondary reason along with non-climatic stressors
4. Indeterminate

Who is adapting?

Q 18. Primary sectors involved in adaptation (all that apply)?

1. Agriculture
2. Forestry
3. Water
4. Energy
5. Health
6. Tourism
7. Education
8. Emergency management
9. Infrastructure

10. Transportation
11. Industry
12. Technology
13. Culture/heritage
14. Environmental conservation
15. Hunting / Fishing
16. Other_________________________(type response)
17. Indeterminate

Q 19. Who is leading adaptation (all that apply)?

1. Community members
2. Government - Local
3. Government - Regional
4. Government - National
5. Intergovernmental organizations
6. Non-Governmental Organization (NGO)
7. Academic institutions/researchers
8. Private sector
9. Other_________________________(type response)
10. Indeterminate

Q 20. Vulnerable populations addressed specifically in adaptation (all that apply)?

1. Women
2. Children/youth
3. Older persons
4. Indigenous persons
5. Economically disadvantaged persons
6. Persons with chronic illness or disabilities
7. Migrants
8. None
9. Other__________________________(type response)

What are the characteristics of adaptation measures?

Q 21. Scale of adaptation (select one)?

1. Household
2. Single community
3. Multiple communities
4. Single region

5. Multiple regions
6. Single mountain range
7. Multiple mountain ranges
8. All mountain ranges
9. Indeterminate

Q 22. Timing of adaptation (select one)?

1. Reactive - Occurring in response to experienced stressors
2. Anticipatory - Occurring in preparation for expected stressors
3. Indeterminate

Q 23. Form of adaptation (all that apply)?

1. Behavioral
2. Technological
3. Financial
4. Institutional
5. Regulatory
6. Informational (e.g. studies that generate knowledge for adaptation)
7. Infrastructure
8. Monitoring
9. Other________________________(type response)
10. Indeterminate

Q 24. Adaptation approach (select one)?

1. Formal policy or program - Stand alone
2. Formal policy or program - Mainstreamed into other programs
3. Autonomous adaptation
4. 'Coping' (e.g. *unplanned and unstrategic)*
5. Indeterminate

Q 25. Status of adaptation (select one)?

1. Groundwork
2. Partially implemented
3. Fully implemented and ongoing
4. Fully implemented and finished
5. Evaluated
6. Indeterminate

What are the implications of adaptation?

Q 26. What are the effects of the adaptation, if relevant (all that apply)?

1. Harm reduction
2. Access to new opportunities
3. Uneven distribution of 'winner' and 'losers'
4. Maladaptation - Social
5. Maladaptation - Ecological
6. Transformation
7. Effects of adaptation not discussed
8. N/A (for adaptation groundwork)

DOCUMENT SUMMARY INFORMATION

Q 27. What was the quality of the content reported in this document (select one)?

1. Excellent
2. Good
3. Average
4. Below average

Q 28. Provide brief summary of issue context and adaptation measures (3 sentences max)

____(type response)

Q 29. Name of adaptation initiative, if applicable?

____(type response)

Q 30. Additional Notes (e.g. same adaptation measures reported in another document)?

____(type response)

A.7 Codebook

Legend for Codebook Colors
Major questionnaire sections

Questionnaire sub-sections
Specific questions
Definitions for possible answers

Codebook for Questionnaire	
A. BIBLIOMETRIC INFORMATION	
Q 1. Title (type response)?	
Q 2. Year published (type response)?	
Q 3. Lead author's name (last name, first initial for peer-reviewed; lead institution name for grey literature) (type response)?	
Q 4. Country of lead author's institutional affiliation (for peer-reviewed) or institutional headquarters (for grey literature) at time of publication (type response)?	
B. ADAPTATION RESEARCH (Complete for PEER-REVIEWED articles only)	
Q 5. Analytical scale of assessment (select one)?	
9. Single community	Assessment was focused on one community.
10. Multiple communities	Assessment was focused on two or more communities.
11. Single region within mountain range	Assessment was focused on one region within a mountain range (e.g. Khumbu region in the Himalayas).
12. Multiple regions within mountain range	Assessment was focused on two or more regions within a mountain range (e.g. Khumbu & Manaslu regions in the Himalayas).
13. Single mountain range	Assessment was focused on one entire mountain range (e.g. the Andes)
14. Multiple mountain ranges	Assessment was focused on two or more entire mountain ranges (e.g. the Andes & Alps), but not all mountain ranges.
15. All mountain ranges (global)	Assessment was focused on all mountain ranges globally.
16. Indeterminate	Answer to question could not be determined based on information in document.
Q 6. Methods used in assessment (all that apply)?	
12. Community-based research	Assessment involved research in climate-affected communities (e.g. interviews, focus groups).
13. Participatory methods	Assessment involved the inclusion of non-academic stakeholders in research design and/or assessment.
14. Temporal analog methods	Assessment used past information about responses to environmental change to understand current or planned responses to climate change.

15. Spatial analog methods	Assessment used information about responses to environmental change from another location to understand current or planned responses to climate change in the region(s) assessed.
16. Longitudinal study design	Assessment was based on ongoing research, conducted repeat assessments of the same location or program, or was based on longitudinal data.
17. Adaptation scenarios/pathways	Adaptation assessment utilized scenarios or pathways to understand adaptation.
18. Modeling projections of climate-related biophysical changes	Adaptation assessment utilized modeling projections of climate-related biophysical changes to understand adaptation.
19. Modeling projections of social change	Adaptation assessment utilized modeling projections of social change to understand adaptation.
20. Textual analysis/policy assessment	Adaptation assessment utilized textual or policy analysis methods to understand adaptation.
21. Other_____(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
22. Indeterminate	Answer to question could not be determined based on information in document.
Q 7. Assessment engaged substantively with …(all that apply)?	
4. Scientific information about climate-related changes	Assessment of adaptation was informed by detailed information about the climatic stimuli influencing adaptation (e.g. detailed assessment of climatic stimuli such as watershed-specific hydrological dynamics). ***Note: Just mentioning scientific information does not count as substantial engagement.***
5. The socio-economic, cultural, and/or political dimensions of adaptation	Assessment of adaptation was informed by detailed information about social dynamics *vis-à-vis* adaptation (e.g. a focus on how socio-economic or political factors constrain or enable adaptation, and for whom). ***Note: Just mentioning human dimensions does not count as substantial engagement.***
6. Socio-ecological system dynamics in relation to adaptation	Assessment of adaptation was informed by detailed information about the relationship between people and the ecosystems *vis-à-vis* adaptation (e.g. evaluation of social and ecological interdependencies and feedbacks in the context of climate change adaptation) ***Note: Just mentioning socio-ecological systems does not count as***

	substantial engagement. While the assessment must engage with socio-ecological dynamics, the phrase 'socio-ecological systems' is not mandatory.
Q 8. Assessment engaged substantively with other concepts related to adaptation (all that apply)?	
8. Vulnerability	Assessment engaged wording and concepts form vulnerability research *vis-à-vis* adaptation. Just mentioning vulnerability does not count as substantial engagement.
9. Resilience	Assessment engaged wording and concepts form resilience research *vis-à-vis* adaptation. Just mentioning resilience does not count as substantial engagement.
10. Transformation	Assessment engaged wording and concepts form transformation research *vis-à-vis* adaptation. Just mentioning transformation does not count as substantial engagement.
11. Disaster risk reduction	Assessment engaged wording and concepts form disaster risk reduction research *vis-à-vis* adaptation. Just mentioning disaster risk reduction does not count as substantial engagement.
12. Sustainable development	Assessment engaged wording and concepts form sustainable development research *vis-à-vis* adaptation. Just mentioning sustainable development does not count as substantial engagement.
13. Governance	Assessment engaged wording and concepts form governance research *vis-à-vis* adaptation. Just mentioning governance does not count as substantial engagement.
14. N/A	Not applicable to assessment reviewed.
Q 9. Was this assessment explicitly framed as 'adaptation research' or 'adaptation focused' (select one)?	
1. Yes	Assessment used adaptation as a primary entry point for analysis. This document is clearly and explicitly an adaptation assessment. ***Note: While the assessment must be framed around 'adaptation', the specific terms 'adaptation research' or 'adaptation focused' are not mandatory.***

2. No	Assessment did not use adaptation as a primary entry point for analysis.; adaptation was secondary to other entry points such as vulnerability or resilience.
Q 10. Was this assessment explicitly framed as 'mountain research' or 'mountain-focused' (select one)?	
5. Yes	Assessment used mountains as its primary geographical focus. This document is clearly and explicitly a mountain-focused assessment. ***Note: While the assessment must be framed around 'mountains', the specific terms 'mountain research' or 'mountain-focused' are not mandatory.***
6. No	Assessment did not use mountains as its primary geographical focus; mountain regions are captured in the assessment but are not an explicit research focus.
C. ADAPTATION MEASURES (Complete for each DISCRETE adaptation measure reported)	
C 1. Where are adaptation measures occurring?	
Q 11. Country/countries in which adaptation is taking place/is focused (type response)?	
Q 12. Major mountain range/ranges in which adaptation is taking place/is focused (type response)?	
Q 13. Region/regions or community/communities in which adaptation is taking place/is focused, if applicable (type response)?	
Q 14. Page number(s) with most specific location information (type response)?	
C 2. What stressors are motivating adaptation measure?	
Q 15. Climatic stimuli motivating adaptation (all that apply)?	
17. Temperature change	Adaptation occurring in response to anticipated or experienced changes in temperatures
18. Precipitation change – Amount/timing	Adaptation occurring in response to anticipated or experienced changes in the amount or timing of precipitation.
19. Precipitation change – Phase state	Adaptation occurring in response to anticipated or experienced changes in the phase state of precipitation (e.g. form snowfall to rain)
20. Seasonality change	Adaptation occurring in response to anticipated or experienced changes in seasonality (e.g. longer growing season).
21. Weather uncertainty	Adaptation occurring in response to anticipated or experienced changes in the predictability of weather.

22. Glacier change – Non hydrological impacts	Adaptation occurring in response to anticipated or experienced changes in glaciers (e.g. effects on glacier travel or aesthetics).
23. Glacial hydrology change	Adaptation occurring in response to anticipated or experienced changes water generation from glaciers (e.g. effects on streamflow, formation of glacial lakes)
24. Snow cover change – Non-hydrological impacts	Adaptation occurring in response to anticipated or experienced changes in snow cover (e.g. effects on livestock grazing).
25. Snow hydrology change	Adaptation occurring in response to anticipated or experienced changes in water generation from snow melt (e.g. reductions in metlwater generation).
26. Hydrological change - Not related to glacier or snow cover change	Adaptation occurring in response to anticipated or experienced changes in rain-dominated hydrology (e.g. river flooding with no mention of snow or glaciers)
27. Extreme events - Hydrological	Adaptation occurring in response to anticipated or experienced changes in extreme hydrological events (e.g. glacial lake outburst floods)
28. Extreme events - Non-hydrological	Adaptation occurring in response to anticipated or experienced changes in extreme non-hydrological events (e.g. heat waves).
29. Thawing of frozen ground	Adaptation occurring in response to anticipated or experienced changes in the extent or timing of frozen ground (i.e. permafrost).
30. Ecosystem change (flora and fauna)	Adaptation occurring in response to anticipated or experienced changes in the flora and fauna.
31. Other_____(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
32. Indeterminate	Answer to question could not be determined based on information in document.
Q 16. Non-climatic stimuli motivating adaptation, if relevant (all that apply)?	
15. Livelihood diversification	Adaptation occurring in response to challenges or opportunities related to the pursuit of additional livelihood activities.
16. Cultural change	Adaptation occurring in response to changes in cultural (e.g. 'westernization' of remote communities).
17. Socio-political marginalization	Adaptation occurring in response to socio-political marginalization (e.g. racism, sexism, ageism)

18. Changing political circumstances	Adaptation occurring in response to challenges or opportunities related to circumstances.
19. Economic stress	Adaptation occurring in response to economic hardships (e.g. the loss of livelihoods).
20. Economic opportunities	Adaptation occurring in response to economic opportunities (e.g. new employment opportunities)
21. Food insecurity	Adaptation occurring in response to inadequate access to sufficient quantities of nutritious food.
22. Health-related factors	Adaptation occurring in response to health-related factors (e.g. reducing exposure to infectious diseases).
23. Resource development	Adaptation occurring in response to challenges or opportunities related to resource development.
24. Displacement/conflict	Adaptation occurring in response to pressures related to displacement or conflict.
25. Environmental change (not related to climate change)	Adaptation occurring in response to non-climate related environmental changes (e.g. soil erosion, deforestation).
26. Other_____(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
27. Indeterminate	Answer to question could not be determined based on information in document.
28. N/A	Not applicable to adaptation reviewed.
Q 17. Importance of climatic stimuli in motivating adaptation (select one)?	
5. Sole reason for adapting	Clear that only climate-related factors are motivating adaption.
6. Primary reason along with non-climatic stressors	Climate-related factors are the main driver of adaption in addition to non-climatic factors.
7. Secondary reason along with non-climatic stressors	Both climatic and non-climatic factors are influential in driving the adaptions. However, climate change is of secondary importance compared to non-climatic factors.
8. Indeterminate	Answer to question could not be determined based on information in document.
C 3. Who is adapting?	
Q 18. Primary sectors involved in adaptation (all that apply)?	
18. Agriculture	Sector defined by activities related to crop cultivation, animal husbandry, or the production of agricultural goods/products for human consumption.
19. Forestry	Sector defined by activities related to the extraction, processing, and production of forest products as well as the marketing of forested goods.

20. Water	Sector defined by activities associated with the management, extraction, treatment, storage, distribution, and general use of water in homes, buildings, and industrial/agricultural purposes.
21. Energy	Sector defined by activities related to the management of non-renewable and renewable energy sources.
22. Health	Sector defined by activities undertaken to minimize mortality and morbidity of humans.
23. Tourism	Sector defined by activities related to the provision of indoor or outdoor leisure/recreational activities.
24. Education	Sector defined by activities related to the education of people in contexts such as primary schools, colleges and universities, and community centers.
25. Emergency management	Sector defined by activities undertaken to avoid or minimize the effects of emergencies (e.g. natural hazards).
26. Infrastructure	Sector defined by activities related to the creation, modification, or maintenance of the built environment.
27. Transportation	Sector defined by activities related to the creation, modification, or maintenance of transportation services or infrastructure.
28. Industry	Sector defined by activities related to extraction and processing of raw materials or the manufacturing of products.
29. Technology	Sector defined by activities related to the development, distribution, or implementation of new technologies.
30. Culture/heritage	Sector defined by activities related to preserving or engaging with culturally significant activities or heritage. Practices considered important to identity.
31. Environmental conservation	Sector defined by activities related to conserving the natural environment including conservation-focused natural resources management.
32. Hunting / Fishing	Sector defined by activities involving culturally and or/economically important hunting or fishing activities.
33. Other_____(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
34. Indeterminate	Answer to question could not be determined based on information in document.
Q 19. Who is leading adaptation (all that apply)?	

11. Community members	One or more members of the public not associated with any particular company, organization, or government.
12. Government - Local	Community-level governing unit (e.g. city, community, or village government).
13. Government - Regional	Domestic, sub-national governing unit (e.g. provincial or territorial government).
14. Government - National	The common government of a federation or sovereign state.
15. Intergovernmental organizations	Global body or agency composed primarily of sovereign member states (e.g. World Bank, IMF, OECD, UN and its affiliated agencies).
16. Non-Governmental Organization (NGO)	Citizen-based associations that operate independently of government, usually to deliver resources or serve some social or environmental purpose.
17. Academic institutions/researchers	Non-governmental centers of research or non-governmental researchers. However, may receive funding or other support from government bodies.
18. Private sector	Business sector groups and individuals.
19. Other_____(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
20. Indeterminate	Answer to question could not be determined based on information in document.
Q 20. Vulnerable populations addressed specifically in adaptation (all that apply)?	
10. Women	Woman identified as vulnerable population.
11. Children/youth	Children/youth (i.e. under 18 years old) identified as vulnerable population.
12. Older persons	Older Persons identified as vulnerable population.
13. Indigenous persons	Indigenous persons identified as vulnerable population. May include aboriginal groups, native peoples, first people, tribal groups, etc.
14. Economically disadvantaged persons	Economically disadvantaged persons identified as vulnerable population.
15. Persons with chronic illness or disabilities	Individuals with persistent physical, sensory, or cognitive impairments identified as vulnerable population.
16. Migrants	Migrants to or from mountain areas identified as vulnerable population.
17. None	No vulnerable populations focus.

18. Other______(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
C 4. What are the characteristics of adaptation measures?	
Q 21. Scale of adaptation (select one)?	
10. Household	Adaptations undertaken by one or more people but not enough people to constitute a community level adaptation.
11. Single community	Adaptations undertaken as a community to deal with stimuli that affect the community, or an external adaptation program focused on one community.
12. Multiple communities	Adaptations undertaken collectively by several communities to deal with stimuli that affect the communities, or an external adaptation program focused on two or more specific communities.
13. Single region	Adaptations undertaken at the regional scale to deal with stimuli affecting a single region, or an external adaptation program focused on one specific region.
14. Multiple regions	Adaptations undertaken at the regional scale to deal with stimuli affecting two or more regions, or an external adaptation program focused on two or more specific regions.
15. Single mountain range	Adaptations undertaken at the mountain range scale to deal with stimuli affecting a single mountain range, or an external adaptation program focused on one mountain range.
16. Multiple mountain ranges	Adaptations undertaken at the mountain range scale to deal with stimuli affecting two or more mountain range, or an external adaptation program focused on two or more specific mountain range. ***NOTE: for global scale adaptations focused on all mountain areas select 8.***
17. All mountain regions	Adaptations undertaken at the global scale to deal with stimuli affecting all mountain ranges.
18. Indeterminate	Answer to question could not be determined based on information in document.
Q 22. Timing of adaptation (select one)?	
4. Reactive - Occurring in response to experienced stressors	Adaptations occurring in response to experienced climate change impacts.

5. Anticipatory - Occurring in preparation for expected stressors	Adaptations occurring prior to the onset of expected climate change impact.
6. Indeterminate	Answer to question could not be determined based on information in document.
Q 23. Form of adaptation (all that apply)?	
11. Behavioral	Adaptation involves changes in activity at the individual level.
12. Technological	Adaptation involves the development, distribution, and/or implementation of technologies to support responses to climate change (e.g. seed varieties, irrigation technology)
13. Financial	Adaptation involves the establishment of specific mechanisms to fund responses to climate change. Can include modification of existing funding mechanisms (i.e. mainstreaming).
14. Institutional	Adaptation involves the establishment of agencies, departments, working groups, or ministries with mandates that address climate change adaptation. Can include modification of existing institutions/organizations (i.e. mainstreaming).
15. Regulatory	Adaptation involves the establishment of specific regulations, rules, guidelines, laws, or statutes. Can include modification of existing regulations (i.e. mainstreaming).
16. Informational	Adaptation involves the generation of information to support adaptation. ***NOTE: Can include research projects that generate knowledge for adaptation action.***
17. Infrastructure	Adaptation involves the creation, modification, or maintenance of infrastructure projects to address climatic stimuli (e.g. building a dam, 'hard adaptations').
18. Monitoring	Adaptation involves systems for monitoring climate-related threats (e.g. glacial lake monitoring).
19. Other_____(type response)	Relevant option not listed in answer list, write relevant information in data entry form.
20. Indeterminate	Answer to question could not be determined based on information in document.
Q 24. Adaptation approach (select one)?	
1. Formal policy or program - Stand alone	New/stand alone plan, strategy, framework or policy developed to deal specifically with climate change adaptation.

2. Formal policy or program - Mainstreamed into other programs	Integrates climate change adaptation into an existing program, institution, framework, policy, or law.
3. Autonomous adaptation	Adaptation occurring without guidance from formal climate change adaptation plan, strategy, framework, or policy. However, autonomous adaptation can be devised and implemented through local planning processes.
4. 'Coping'	A response to *climate-related impacts that unplanned and unstrategic; focus on maintaining functioning in the short term.*
5. Indeterminate	Answer to question could not be determined based on information in document.
Q 25. Status of adaptation (select one)?	
1. Groundwork	Evidence of preparatory activities to plan for and inform adaptation responses, including the development of adaptation plans, strategies, frameworks, or policies.
2. Partially implemented	Adaptation is in the process of being implemented; pieces of the action have already been operationalized.
3. Fully implemented and ongoing	Adaptation has been implemented and will continue to function either to a date beyond the reporting date or indefinitely.
4. Fully implemented and finished	Adaptation was implemented and ended prior to the reporting date.
5. Evaluated	An ongoing or finished adaptation that has been assessed for effectiveness.
6. Indeterminate	Answer to question could not be determined based on information in document.
Q 26. What are the effects of the adaptation, if relevant (all that apply)?	
1. Harm reduction	Evidence of adaptation reducing the harmful effects of climate change.
2. Access to new opportunities	Evidence of adaptation enabling access to new opportunities related to climate change.
3. Uneven distribution of 'winner' and 'losers'	Evidence of adaptation having uneven distributional consequences.
4. Maladaptation - Social	Evidence of adaptation having negative consequences for society or specific social groups (e.g. disproportionately burdens the most vulnerable, increases emissions of greenhouse gases, reduces

	incentive to adapt, has high opportunity costs, drives path dependency).
5. Maladaptation - Ecological	Evidence of adaptation having negative consequences for ecosystems or specific species (e.g. human adaptation having an adverse impact on the environment).
6. Transformation	Evidence of adaptation leading to fundamentally new social, ecological, or socio-ecological conditions or dynamics.
7. Effects of adaptation not discussed	Document did not discuss the effects of adaptation.
8. N/A (for adaptation groundwork)	Not applicable to assessments of adaptation groundwork.
D. DOCUMENT SUMMARY INFORMATION	
Q 27. What was the quality of the content reported in this document (select one)?	
1. Excellent	Document has very strong theoretical and methodological foundations and provides novel or compelling insights.
2. Good	Document has strong theoretical and methodological foundations and provides interesting insights.
3. Average	Document has acceptable theoretical and methodological foundations and contributes to understanding.
4. Below average	Document has theoretical and/or methodological problems that make findings questionable or difficult to understand.
Q 28. Provide brief summary of issue context and adaptation measures (3 sentences max) (type response).	
Q 29. Name of adaptation initiative, if relevant (type response)?	
Q 291. Additional Notes (e.g. same adaptation measures reported in another document) (type response)?	

Appendix B Supporting materials for Chapter 4

B.1 Questionnaire

Q #	QUESTIONS	POSSIBLE ANSWERS
	Thank you for agreeing to be interviewed. Don't worry, there are no right or wrong answers. Feel free to ask us questions if anything is unclear.	
N/A	UID	OPEN
N/A	Date	OPEN
N/A	Community Name	OPEN
N/A	Consent	Y/N
	SECTION 1 - BASIC INFO	
	Before asking specific questions about water, I would like to ask some general questions about you.	
1	Sex	M/F
2	Age	OPEN
3	How long have you lived in this community?	1. Whole life (90 - 100%) 2. Most of life (50 - 90%) 3. Part of life (< 50%) 4. Temporary resident
4	What type of education have you received?	1. Informal 2. Primary school 3. High school 4. College or university 5. Religious education 6. Other education ____________ (ask respondent to name education received)
5	Was your education received outside of this community?	1. Yes - Fully 2. Yes - Partially 0. No
6	Are you involved in agriculture related activities?	**1. Yes** 0. No

6.1	How important are agricultural activities in supporting yourself and your family?	1. Low importance 2. Medium importance 3. High importance
7	Are you involved in animal husbandry activities?	**1. Yes** 0. No
7.1	How important is animal husbandry in supporting yourself and your family?	1. Low importance 2. Medium importance 3. High importance
8	Are you involved in tourism in any way?	**1. Yes - Guiding** **2. Yes - Lodge owner** **3. Yes - Other** ___________ (ask respondent to name activity) 0. No
8.1	How important are tourism related activities in supporting yourself and your family?	1. Low importance 2. Medium importance 3. High importance
9	Are you involved in any other activities that contribute to your livelihood (for example, yartsa gunbu harvesting)?	**1. Yes ___________** (ask respondent to name other activities) 0. No
9.1	How important are these activities in supporting yourself and your family?	1. Low importance 2. Medium importance 3. High importance
10	Do you also work outside of this community?	**1. Yes** 0. No
10.1	How important is work outside of this community in supporting yourself and your family?	1. Low importance 2. Medium importance 3. High importance
11	Does your household receive income from family members who works outside of this community?	**1. Yes** 0. No
11.1	How important is income received from family members working outside of this community in supporting yourself and your family?	1. Low importance 2. Medium importance 3. High importance

12	How would you describe your level of cash income?	1. No cash income 2. Lower than most in this community 3. About the same as most in this community 4. Higher than most in this community
	SECTION 2 - WATER ACCESS AND USE	
	Next, I will ask a few questions about how you access and use water. When I ask about water, I am asking about <u>water for all purposes</u>, for example, drinking water, cooking, growing crops, watering livestock and all other uses.	
	Questions about Main River	
13	Do you use water from the main river for any purposes?	**1. Yes** 0. No
13.1	What are your primary uses of water from the main river (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
13.2	How important is the main river as a source of water for your household and livelihood activities?	1. Low importance 2. Medium importance 3. High importance
13.3	What time of year is water from the main river most important (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
	Questions about Smaller Streams	
14	Do you use water from smaller streams for any purposes?	**1. Yes** 0. No

14.1	What are your primary uses of water from smaller streams (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
14.2	How important are smaller streams as a source of water for your household and livelihood activities?	1. Low importance 2. Medium importance 3. High importance
14.3	What time of year is water from smaller streams most important (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
	Questions about Rainfall	
15	Do you rely on direct rainfall for any purposes?	**1. Yes** 0. No
15.1	What are your primary uses of rainwater (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
15.2	How important is rainfall as a source of water for your household and livelihood activities?	1. Low importance 2. Medium importance 3. High importance
15.3	What time of year is rainwater most important (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
	Questions about Snowfall	

16	Do you rely on water from snowfall for any purposes?	**1. Yes** 0. No
16.1	What are your primary uses of water from snow (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
16.2	How important is snow as a source of water for your household and livelihood activities?	1. Low importance 2. Medium importance 3. High importance
16.3	What time of year is water from snow most important (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
	Questions about Other Water Sources	
17	Do you rely on water from any other sources?	**1. Yes**____________ (ask respondent to identify source) 0. No
17.1	What are your primary uses of water from this source (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
17.2	How important is this source of water for your household and livelihood activities?	1. Low importance 2. Medium importance 3. High importance

17.3	What time of year is water from this source most important (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
	Questions about Water Use	
18	Over the last 10 years, has the amount of water you use:	**1. Increased** 2. Stayed the same **3. Decreased**
18.1	Please briefly explain why your water use is changing.	OPEN
	SECTION 3 - CHANGES IN WATER, ICE, AND SNOW	
	Next, I will ask questions about changes you might have observed in the main river, smaller streams, rainfall, snowfall, snow cover, and glaciers. For each water source, I will ask a similar set of questions.	
	Questions about Main River	
19	Over the last 10 years, has the total amount of water in the main river increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
20	Over the last 10 years, has the frequency of floods in the main river increased, decreased, or stayed the same? *-Frequency = Number* *-Flood = Very high discharge*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
21	Over the last 10 years, has intensity of floods in the main river increased, decreased, or stayed the same? *-Intensity = Size of floods*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know

22	What time of the year is flooding most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
23	Over the last 10 years, has the frequency of low flow events in the main river increased, decreased, or stayed the same? *-Frequency = Number* *-Low flow = Periods with little water flowing*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
24	Over the last 10 years, has intensity of low flow events in the main river increased, decreased, or stayed the same? *-Intensity = How much discharge is changing, more dry = more intense*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
25	What time of the year are low flow events most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
	Questions about Smaller Streams	
26	Over the last 10 years, has the total amount of water in smaller streams increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
27	Over the last 10 years, has the frequency of floods in smaller streams increased, decreased, or stayed the same? *-Frequency = Number* *-Flood = Very high discharge*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
28	Over the last 10 years, has intensity of floods in smaller streams increased, decreased, or stayed the same? *-Intensity = Size of floods*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know

29	What time of the year is flooding most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
30	Over the last 10 years, has the frequency of low flow events in smaller streams increased, decreased, or stayed the same? *-Frequency = Number* *-Low flow = Periods with little water flowing*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
31	Over the last 10 years, has intensity of low flow events in smaller streams increased, decreased, or stayed the same? *-Intensity = How much discharge is changing, more dry = more intense*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
32	What time of the year are low flow events most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
	Questions about Rainfall	
33	Over the last 10 years, has total amount of rainfall increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
34	Over the last 10 years, has the frequency of heavy rainfall events increased, decreased, or stayed the same? *-Frequency = Number*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
35	Over the last 10 years, has the intensity of rain falling during heavy rainfall events increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know

	-Intensity = Amount of rain falling, more rain = more intense	
36	What time of the year are heavy rainfall events most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
37	Over the last 10 years, has the frequency of dry periods increased, decreased, or stayed the same? *-Frequency = Number* *-Dry period = Periods with little rainfall*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
38	Over the last 10 years, has the intensity of dry periods increased, decreased, or stayed the same? *-Intensity = Relative dryness, more dry = more intense* *-Dry period = Periods with little rainfall*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
39	What time of the year are dry periods most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
	Questions about Snowfall	
40	Over the last 10 years, has total amount of snowfall increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
41	Over the last 10 years, has the frequency of heavy snowfall events increased, decreased, or stayed the same? *-Frequency = Number*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know

42	Over the last 10 years, has the intensity of snow falling during heavy snowfall events increased, decreased, or stayed the same? *-Intensity = Amount of snow falling, more snow = more intense*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
43	What time of the year are heavy snowfall events most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
44	Over the last 10 years, has the frequency of dry periods increased, decreased, or stayed the same? *-Frequency = Number* *-Dry period = Periods with little snowfall*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
45	Over the last 10 years, has the intensity of dry periods increased, decreased, or stayed the same? *-Intensity = Relative dryness, more dry = more intense* *-Dry period = Periods with little snowfall*	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
46	What time of the year are dry periods most common (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter 6. N/A
	Questions about Snow cover	
47	Over the last 10 years, has the area covered by snow increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know

48	Over the last 10 years, has the depth of snow cover increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
49	Over the last 10 years, has the amount of water coming from snow covered areas increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
	Questions about Glaciers	
50	Over the last 10 years, has the area covered by glaciers increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
51	Over the last 10 years, has the thickness of glaciers increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
52	Over the last 10 years, has the amount of water coming from glaciers increased, decreased, or stayed the same?	1. Increased 2. Stayed the same 3. Decreased 4. Do not know
	Questions about Other Changes in Water, Ice, and Snow	
53	Have you observed any other changes in water, ice, or snow that we have not already talked about? *-Translator can mentions lakes, permafrost, frost, etc.*	**1. Yes** 0. No
53.1	Please briefly describe what changes you have observed.	OPEN
	Questions about Ecological effects	
54	Have changes in water, ice, and snow affected the local environment?	**1. Yes** 2. Do not know 0. No
54.1	Please briefly describe the changes you have observed.	OPEN
	SECTION 4 - RESPONSES TO CHANGES IN WATER AVAILABILITY	

	Thanks, now I will ask about how you are affected by and responding to changes in water availability.	
	Questions about water scarcity	
55	Over the last 10 years, have times of water scarcity increased, decreased, or stayed the same? *-Water scarcity = Times when there is not enough water to meet your needs.*	**1. Increased** 2. Stayed the same **3. Decreased**
55.1	Where do you notice water shortages (**all that apply**)?	1. Main river 2. Smaller streams 3. Rainfall 4. Other source____________(ask respondent to identify source)
55.2	What time of the year are water shortages most noticeable (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
55.3	What activities are most affected by water shortages (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) _____________ (ask respondent to identify use)
55.4	Please briefly explain how these activities are affected by water shortages.	OPEN
55.5	Please briefly explain how you respond to times of water shortage.	OPEN

55.6	Considering these responses, are water shortages having a:	1. Negative impact on you and your family 2. No noticeable impact you and your family 3. Beneficial impact you and your family 4. N/A if no responses mentioned
55.7	Do you think any of the responses you mentioned have an impact on people outside of your household, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No
55.8	*IF YES TO Q ABOVE - Please briefly describe these impacts.*	OPEN
55.9	Do you think any of the responses you mentioned have an impact on the local environment, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No
55.10	*IF YES TO Q ABOVE - Please briefly describe these impacts.*	OPEN
55.11	Overall, do you think any of the responses you mentioned represent very major changes to your way of life, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No
55.12	*IF YES TO Q ABOVE - Please briefly describe these major changes.*	OPEN
	Questions about Too Much Water	

56	Over the last 10 years, have times when there is too much water increased, decreased, or stayed the same? *-Too much = Flooding or heavy rainfall.*	**1. Increased** 2. Stayed the same **3. Decreased**
56.1	Where do you notice too much water (**all that apply**)?	1. Main river 2. Smaller streams 3. Rainfall 4. Other source___________(ask respondent to identify source)
56.2	What time of the year is too much water most noticeable (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
56.3	What activities are most affected by too much water (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
56.4	Please briefly explain how these activities are affected by too much water.	OPEN
56.5	Please briefly explain how you respond to times of too much water.	OPEN
56.6	Considering these responses, are times of too much water having a:	1. Negative impact on you and your family 2. No noticeable impact you and your family 3. Beneficial impact you and your family 4. N/A if no responses mentioned

56.7	Do you think any of the responses you mentioned have an impact on people outside of your household, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No
56.8	*IF YES TO Q ABOVE - Please briefly describe these impacts.*	OPEN
56.9	Do you think any of the responses you mentioned have an impact on the local environment, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Bot**h 4. N/A if no responses mentioned 0. No
56.10	*IF YES TO Q ABOVE - Please briefly describe these impacts.*	OPEN
56.11	Overall, do you think any of the responses you mentioned represent very major changes to your way of life, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No
56.12	*IF YES TO Q ABOVE - Please briefly describe these major changes.*	OPEN
	Questions about Unpredictable Availability	
57	Over the last 10 years, have times when water availability is unpredictable increased, decreased, or stayed the same? *-Unpredictable = Times when there is more or less water available than you expect.*	**1. Increased** 2. Stayed the same **3. Decreased**

57.1	What sources of water can be unpredictable (**all that apply**)?	1. Main river 2. Smaller streams 3. Rainfall 4. Other source___________(ask

		respondent to identify source)
57.2	What time of the year is water availability most unpredictable (**all that apply**)?	1. All year 2. Spring 3. Summer 4. Fall 5. Winter
57.3	What activities are most affected by unpredictable water availability (**all that apply**)?	1. Home uses (cooking and cleaning) 2. Agricultural uses 3. Animal husbandry uses 4. Tourism related uses 5. Other) ____________ (ask respondent to identify use)
57.4	Please briefly explain how these activities are affected by unpredictable water availability.	OPEN
57.5	Please briefly explain how you respond to times of unpredictable water availability.	OPEN
57.6	Considering these responses, are times of unpredictable water availability having a:	1. Negative impact on you and your family 2. No noticeable impact you and your family 3. Beneficial impact you and your family 4. N/A if no responses mentioned
57.7	Do you think any of the responses you mentioned have an impact on people outside of your household, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No

57.8	*IF YES TO Q ABOVE - Please briefly describe these impacts.*	OPEN
57.9	Do you think any of the responses you mentioned have an impact on the local environment, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Bot**h 4. N/A if no responses mentioned 0. No
57.10	*IF YES TO Q ABOVE - Please briefly describe these impacts.*	OPEN
57.11	Overall, do you think any of the responses you mentioned represent very major changes to your way of life, either positive or negative?	**1. Yes - Positive** **2. Yes - Negative** **3. Yes - Both** 4. N/A if no responses mentioned 0. No
57.12	*IF YES TO Q ABOVE - Please briefly describe these major changes.*	OPEN
	SECTION 4 - ADAPTIVE CAPACITY AND ADAPTATION SUPPORT	
	These are the last few questions. We're almost done! I will ask a few more questions about responses to changes in water availability.	
58	What factors influence how you respond to changes in water availability? *-Translator can mention social, political, economic, spiritual, or environmental factors.*	OPEN -N/A if no responses mentioned
59	What factors help you respond to changes in water availability? *-Translator can mention social, political, economic, spiritual, or environmental factors.*	OPEN -N/A if no responses mentioned

60	What factors limit your ability to respond to changes in water availability? *-Translator can mention social, political, economic, spiritual, or environmental factors.*	OPEN -N/A if no responses mentioned
61	Has this community developed a formal plan for responding to changes in water availability?	**1. Yes** 2. Do not know 0. No
61.1	Please briefly explain the community's plan.	OPEN
61.2	Were you included in making this plan?	1. Yes 0. No
61.3	Do you feel the plan responds to your needs?	1. Yes 2. Do not know (plan not active yet) 0. No
61.4	Is this a new plan or an update of an existing water management plan?	1. New plan 2. Update of existing plan
62	Have non-local organizations or the government helped this community respond to changes in water availability?	**1. Yes** 0. No
62.1	Please briefly explain who has helped and how they have helped.	OPEN
62.2	Overall, how satisfied have you been with this assistance?	1. Very dissatisfied 2. Dissatisfied 3. Somewhat satisfied 4. Satisfied 5. Very satisfied
63	Is additional assistance from non-local organizations or the government needed for this community to effectively respond to changes in water availability?	**1. Yes -** This community needs help in responding **0. No -** This community is able to respond without help
63.1	IF YES - Please briefly explain what kind of additional assistance is needed and who should provide it:	OPEN
63.2	IF NO - Please briefly explain why help from outsiders is not needed:	OPEN

64	Do you have any recommendations for improving response to changes in water availability in the future? What can be done better or differently?	OPEN
65	Is there anything else you would like to tell me?	OPEN
	Thanks very much for sharing your time and knowledge with us.	
	ADDITIONAL NOTES ABOUT INTERVIEW	*OPEN*
END		