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ISBN 978-3-319-40771-5 ISBN 978-3-319-40773-9 (eBook)
DOI 10.1007/978-3-319-40773-9

Library of Congress Control Number: 2016954087

Cover illustration: View towards the village of Kara-Jygach and the plains surrounding the inflow of the Naryn river into Toktogul reservoir, Jalal-Abad Province, Kyrgyzstan (photograph by Horst Machguth, 13 August 2013).

Printed on acid-free paper

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Foreword

Climate change and the related adverse impacts are among the greatest challenges facing humankind in the twenty-first century. As a result of the significant increase of greenhouse gases in the atmosphere largely caused by human activities, the global phenomenon of climate change affects many different sectors including agriculture and water supply. Emitted greenhouse gases distribute homogeneously across the Earth's atmosphere, irrespectively of their source of emission, leading to global climate trends that do not recognize nor respect our man-made boundaries. Still, the impacts of climate variability or change become manifest on a local or regional level, asking for tailor-made solutions on the very same level, guided by national responsibility and global solidarity.

In such a framework, questions of how to tackle the challenge of adapting to climate change in upstream-downstream areas become increasingly important. Mountains as typical upstream areas are highly sensitive to global changes, as evidenced for instance by glacier retreat among the most obvious signs of climate change. At the same time, mountains are key contexts for sustainable development because of the indispensable goods and services they provide locally and to their adjacent downstream areas. Mountains are the world's water towers, providing freshwater to more than the half of humankind. They are centres of biological diversity, key sources of raw materials and important tourist destinations. Still, mountains are among the most disadvantaged regions in the world, with some of the highest poverty rates and greatest ecological vulnerability to global climatic, environmental and socio-economic change.

The obvious mismatch between the vulnerability and disregard of mountains at the one hand and their importance for the provision of key mountain ecosystem services on the other hand calls for urgent changes, which basically include four components, namely, (1) the recognition of mountain areas as key development contexts in global and national policy frames, (2) a scientifically sound information base related to mountains, (3) innovative approaches for action on the ground and (4) sufficient funding for (2) and (3). Fortunately, we thereby do not need to start from scratch, as evidenced, e.g., by the inclusion of mountains in three targets of the

Agenda 2030. But more is needed as obvious from the global climate change policy framework, where mountains only figure as a marginalia in the original UN Framework Convention on Climate Change (Art. 4.8.g) but not in the new Paris Agreement concluded at UNFCCC's COP 22 in Paris 2015.

The present book, prepared under the umbrella of the Swiss initiated and facilitated mountain programme SMD4GC[1], aims at creating a better understanding of how to tackle the four components mentioned above. It thereby provides an insight on how to reduce or avoid the adverse impacts and risks from climate change and to move towards a sustainable future in mountain regions. After an introductory part, which sets the scene on the current state of adaptation in mountainous regions and its challenges, the book highlights a dedicated number of selected case studies that introduce good adaptation practices from all over the world. The book concludes with some global considerations related to aspects of resilience building and science-policy dialogue for climate change adaptation in mountain regions, showing that important and encouraging inroads have been made.

We hope that this book will raise the awareness of the challenges of climate change adaptation in mountainous areas. At the same time, we expect the book to foster a comprehensive understanding of the role and importance of mountain ecosystem goods and services for global sustainable development. This, in turn, will hopefully contribute to trigger practical action to tackle climate change in the often neglected yet so important mountain regions of this world.

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[1] SMD4GC is the acronym for Sustainable Mountain Development for Global Change, a programme induced and supported by the Swiss Agency for Development and Cooperation, which aims at contributing to sustainable mountain development under uncertain changes in climatic, environmental and socio-economic conditions, focusing on poverty and risk reduction.

Acknowledgements and Disclaimer

This book is a contribution to the *Sustainable Mountain Development for Global Change (SMD4GC)* programme that is supported by the Swiss Agency for Development and Cooperation. Special thanks for providing reviews for the individual chapters are due to numerous anonymous referees.

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Contents

Part A

Setting the Scene: Adapting to Climate Change – A Large-Scale Challenge with Local-Scale Impacts

Nadine Salzmann, Christian Huggel, Samuel U. Nussbaumer, and Gina Ziervogel

Abstract This chapter's main objective is to provide the context of the book and to introduce the subsequent chapters.

The physical basis of the global climate change challenge is briefly outlined and the consequences for the societies primarily at the local scale are discussed. A short overview of how the international policy level responds to the challenge of global climate change impacts and risks is provided. Key terms related to different types of adaptation are also introduced and reasons for the complexity of climate change adaptation discussed. Then, the evidence for the importance of mountain ecosystems and adjacent downstream areas, which are critically linked through water, is briefly reviewed. Finally, each chapter of the book is introduced, followed by key conclusions we can draw from the book concerning the state and experiences of adaptation in upstream and downstream areas.

Keywords Mountain regions • Climate change • Vulnerability • Hazards and risks • Types of adaptation • Upstream and downstream areas • Global-local scale

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N. Salzmann et al. (eds.), *Climate Change Adaptation Strategies – An Upstream-downstream Perspective*, DOI 10.1007/978-3-319-40773-9_1

1 Introduction

Global climate change and the related adverse impacts and risks are among the greatest challenges facing humankind in the twenty-first century. This is recognized by all governments of the world, as clearly showcased through the UNFCCC (United Nations Framework Convention on Climate Change) Agreement of Paris in December 2015 signed by all 196 countries. Only a few months earlier, the UN's 193 Member States adopted the 2030 Agenda for Sustainable Development, with the broader aim of achieving sustainable development, of which climate change adaptation and mitigation is one part. Whether these agreements are worth the paper they are written on will depend on the actions that follow, both on emission reduction and adaptation. This book focuses on the adaptation part of the challenge, on how to reduce or avoid the adverse impacts and risks from climate change and to move towards a sustainable future. The focus is narrowed down further to examine mountain regions and their adjacent downstream areas. Upstream-downstream areas are among the ecosystems most vulnerable to climate change impacts and risks and essential for sustainable development. These areas are therefore also key regions for international cooperation and development. Switzerland as a small mountain country has a long-standing tradition, interest and expertise in sustainable development of upstream and downstream regions. In Switzerland as in other mountain and downstream countries, people have been living for centuries from the benefits, goods and services provided by mountain ecosystems and at the same time have been living with the constant risks inherent in these topographically complex and highly dynamic landscapes. With changing climatic conditions a key factor for sustainable development is altering and calls for adequate response. It is in this consequence, that the Swiss government has launched the programme 'Sustainable Mountain Development for Global Change' (SMD4GC) under the Global Programme Climate Change (GPCC) of the Swiss Agency for Development and Cooperation (SDC). This book, which is supported by SMD4GC is a contribution to the challenges arising from global climate change for societies.

This first chapter of the book is setting the scene by providing an introduction into the overall thematic and context of the book and thus for the chapters following.

2 Global-Scale Changes with Local-Scale Impacts

Global climate change as a result of the significant increase of greenhouse gases (GHGs) in the atmosphere since the pre-industrial times is largely caused by human activities (IPCC 2013). This includes how food is produced, how mobility, transportation and industry have developed, and the type of energy used to enable these activities. Because emitted GHGs distribute homogeneously across the Earth's atmosphere, irrespectively of where they are emitted, the warming trend is observed globally and varies only in its spatial-temporal magnitudes, which is caused by regional and local surface properties and meteorological characteristics. In addition to air temperature, precipitation is another key climate variable in the climate system with significant impacts to the environment and society when patterns change. For precipitation, however, there is no such clear global trend in one direction as for air temperature. Precipitation amounts and intensities nevertheless tend to more extremes values either towards dry periods in some regions or heavy precipitation events in others (Donat et al. 2016). Impacts of global climate change affect every place on Earth, independent on where and when the effective emissions are released (Knutti and Rogelj 2015). Accordingly, negative impacts of climate change on natural and human systems have been reported all over the world and evidence is provided by a great number of scientific assessment studies, including those assessed by the Intergovernmental Panel on Climate Change (IPCC). There is evidence for instance of reducing and/or altering of water resource regimes from snow and glaciers, changing characteristics of hazards and risks in high-mountain regions, loss in crop production and extremes such as heat waves or droughts in downstream regions and related impacts on socio-economic activities and life. The effective dimension of the impacts finally felt by a society at a specific location depends however not only on the magnitude of changed climate variables or how much of the changes are caused by anthropogenic GHG emissions; but importantly on a societies' vulnerability and exposure to climatic changes. Vulnerability moreover depends on the propensity to be adversely effected and the capacity of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets to respond to the risks faced. The core concept of integrated vulnerability, hazard and risks and the related terms as used by IPCC is illustrated by their respective figure (Fig. 1).

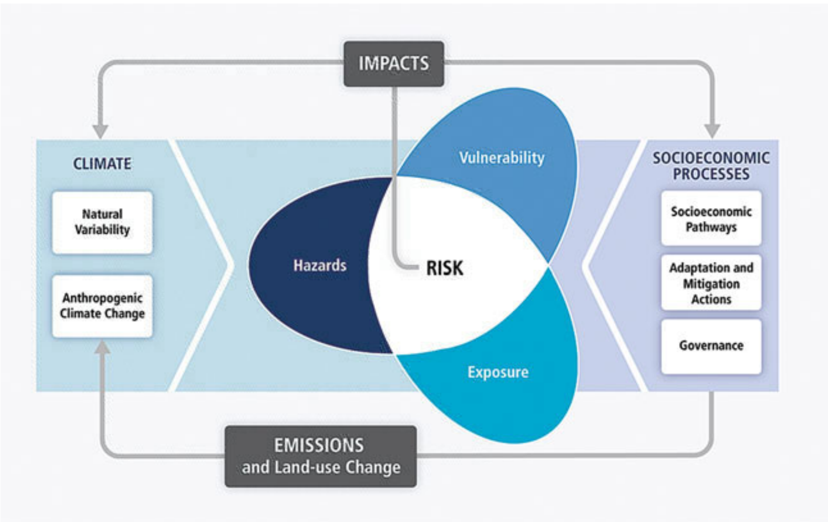

Fig. 1 The core concept and terms related to risks of climate related impacts and hazards as introduced by IPCC (2014) (Source: IPCC 2014)

Generally, increasing temperatures raise the risks for natural and human systems as often illustrated by using the so-called ‘burning embers’ diagram (IPCC 2014). Since projections from climate models suggest significant warming for the coming decades, irrespective of the emission scenario considered (RCP, Representative Concentration Pathways; van Vuuren et al. 2011), increases of related risks to ecosystems, economy, and daily life over the coming decades are hence very likely. The challenge is meanwhile recognized at the international level. Governments agreed in 2010 at the UNFCCC Conference of the Parties (COP16) in Cancún (Mexico) of the need to limit warming in order to keep climate change impacts at a manageable level. In December 2015 in Paris, all 196 countries finally adopted a new Climate Agreement as the follow-up agreement of the Kyoto Protocol. The Paris Agreement aims at a target of below 2 °C global average warming, and states at the same time that efforts should be pursued to limit warming to 1.5 °C. These targets refer about to a two in three probability of keeping warming to 2 °C or less. Or in other words, there is a remaining carbon budget of about 20 years’ worth of current levels of emissions. Although these targets are not based on scientific evidence, it is assumed by the policy that limiting global warming to 2 °C compared to the pre-industrial level will keep the impacts of climate change at a manageable and thus safe level.

Regardless of the debate around the ‘two-degree target’, the most import part of the discussion is the recognition of the need to drastically decrease emissions to zero or even below by the end of the twenty-first century, and that this calls for tremendous efforts at all levels (international, regional and national) and by all players, including policy, public and private sectors, and the society. In addition to the mitigation efforts and liberated from any discussion whether limiting warming to agreed targets is sufficient and at all still reachable, it is also clear that along with decarbonization, there is an urgent need for strategies to adapt to impacts which already happened or are unavoidable. This is particularly true for the most vulnerable regions and populations on Earth.

3 The Adaptation Challenge

The increasing number of climate change adaptation programmes and related conferences and events from UN organizations, international climate and other monitoring programmes, scientific consortia etc. clearly demonstrates that the challenge has been understood and is being addressed up to the highest political levels. In this regard, among the clearest signals in the international policy arena is the creation of the Green Climate Fund (GCF) by the UNFCCC during the COPs in Cancún (Mexico) and Durban (South Africa) in 2010 and 2011, respectively. The GCF is intended to support projects, programmes, policies and other activities in developing countries (first projects started in 2015) and be the operating entity of the UNFCCC’s financial mechanism for both mitigation and adaptation. Finally, the Paris Agreement emphasized again the urgency of adaptation efforts and support, particularly for the most vulnerable regions, which are often found in developing countries.

According to the definition by IPCC, climate change adaptation refers to the adjustment of natural or human systems as a response to actual or expected climatic stimuli or their effects, which moderates harms or exploits beneficial opportunities. Thereby adaptation can be ‘anticipatory’, ‘autonomous’ or ‘planned’. Adaptation is anticipatory (or proactive) when it takes place before any impacts are observed. Autonomous adaptation means spontaneous adjustment to changes that does not necessarily constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Finally, planned adaptation is the result of a deliberate policy decision, based on the awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

As outlined above, the need for adaptation actions (anticipatory and planned) is urgent and scientists, governments, non-governmental organizations and the private sector alike have been putting efforts into the development and implementation of adequate adaptation measures for several years. However, the challenge of adaptation is multidimensional and highly complex. There are still lots of remaining open questions and numerous aspects to be clarified around how to best respond and adapt to climate change impacts and risks, and also how to assess the effective potential and the limitation of adaptation measures to reduce adverse effects of climate change (Adger et al. 2009; Dow et al. 2013). The reasons for the adaptation’s complexity are multifold as outlined in the following paragraphs (key issues in bold), and include the multidisciplinary nature of the scientific assessments required behind, future uncertainties, the close link with the policy level, and the need to embed responses into the local context of societies.

An important prerequisite for anticipatory or planned adaptation is the knowledge of the characteristics and magnitudes of changes and trends of key climate variables and the associated (potential) impacts, risks and vulnerabilities. In other words, to which changes, impacts and risks does a society need to adapt to. To provide this basic information, **reliable**, **long-term and continuous baseline data** of climatic and societal characteristics is necessary in order to derive trends and detect and determine changes. Ideally, such (climate) data sets are available over a time span of about 30 years, as recommended by the World Meteorological Organization (WMO) for climate-related assessments. As changes and impacts are often local in scale, respective data are needed on site. This is often a serious impediment for adaptation planning because of a general scarcity of reliable, spatially and temporally continuous data series, particularly in remote mountain regions (Salzmann et al. 2014). In addition, the effective risks for a specific location and its society are often not known at a level of details, as would ideally be required for appropriate adaptation planning. As a consequence, adaptation measures must often be developed based on incomplete or weak databases.

As climate will very likely continue to change, **modelled future projections of climate**, **impacts and risks** need to be taken into account when aiming at sustainable adaptation measures. Outputs from models, and in particular model output of climate projections, have by definition a certain range of **uncertainty** inherent, which typically increases from global to local scales and the further they project into the future (Hawkins and Sutton 2009). Adaptation measures must therefore be flexible and adjustable as time evolves and incorporate different strategies for handling uncertainties from the various sources including those from limited physical knowledge and uncertain behavior of societies.

These broad sources of uncertainties call for **inter-, multi- and transdisciplinary** investigations and integrated approaches. While the investigations of changes and impacts mainly demand scientific approaches, the development of adaptation measures requires a participative approach that engages the affected local communities and the decision makers within their respective **socio-economic context**. Only this way, any measures have a chance to be accepted, to be effective and thus to be sustainable. This means that the process of adaptation is also strongly **linked to**, **and needs to be mainstreamed into the policy and decision-making level**, which requires a high and mature level of science-policy dialogues and openness, confidence and trust between the different players. As such, adaptation efforts are naturally long-term processes, where measures must periodically be evaluated and adjusted to new climatic patterns, societal changes or socio-economic realities.

This is however in contrast to the often applied '**project**'-**approaches**, where adaptation measures are developed and implemented within a specific funded project and thus within a limited time period of typically about 3–4 years. Consequences of project-based approaches that are not embedded in long-term processes mean that there is often not enough time available to implement the measures. Or, priority is given to '**robust**' **and** '**no-regret**' (**standard**) **measures** that can be implemented relatively easily and quickly. Such measures may have been applied in other contexts before, and are then simply transferred to other regions. However, can measures simply be transferred from one context to another without risks of maladaptation or benefit to some but harm to others? There are questions on the extent to which adaptation measures are able to neutralize adverse impacts of climate change. In general, there is a lack of monitoring and evaluation of the success (or failure) of measures and their appropriateness for other regions. This is certainly also due to the relatively short period of available experience in adaptation to climate change impacts and risks. Nevertheless, it is obvious that important open questions remain about the effective potentials and limits of adaptation measures. Therefore, a systematic documentation, analyses and synthesis of experiences from the past years are urgently needed in order to share the gathered know-how so far and to derive best practices and guidelines. Such analyses will help to support decision-making processes and maximize possible co-benefits and minimize potential adverse side-effects of adaptation measures. As such, this know-how will facilitate, and enable efficient use of resources that are going to be released for instance through the aforementioned GCF by UNFCCC and moreover be an important step towards sustainable development.

4 Mountain Regions and Adjacent Downstream Areas: Vulnerable Systems

Only a few months before the Paris Agreement, the UN's 193 Member States adopted the 2030 Agenda for Sustainable Development. These new Sustainable Development Goals (SDGs) build on the eight Millennium Development Goals (MDGs) that had come to conclusion by end of 2015, and address and emphasize the needs of people in both developed and developing countries in 17 goals and 169 targets. They center all on the three fundamental dimensions of sustainable development (social, economic and environmental) as well as on important aspects related to peace, justice and effective institutions. The SDGs highlight mountain environments as among the ecosystems most essential for sustainable development. Mountains, including the indigenous people and local communities that live there, are considered as vulnerable and fragile ecosystems to the adverse impacts of climate change. Mountain regions and their embedded socio-economic systems are in addition typically remote, not only by means of spatial distances but also in the sense of poor transport, infrastructure and connections to larger cities or modern infrastructure, and national decision makers, and making them potentially even more vulnerable. High-mountain environments are also naturally extreme in terms of climatic and environmental conditions caused by steep and complex topography. As a result, highly specialized and adapted natural ecosystems and societies have been evolving over long time scales. Despite their remoteness and their often marginalized status, mountain regions are of high importance for many of the Earth's populations as recognized by the aforementioned SDGs. They provide many important goods and service directly and indirectly to the highly populated downstream areas, in particular water, for consumption, irrigation or power production. As hotspots of change, high-mountain ecosystems and their services are becoming increasingly important, in upstream and downstream areas alike. Mountain ecosystems have significant capacity to support adaptation to global change for instance through ecosystem-based adaptation. Upstream and downstream areas are closely linked to and depend on each other, which become obvious when looking through the lens of water – a globally and fundamentally essential resource.

5 Water: Or the Link Between Upstream and Downstream Areas

Water is central to ecosystems, people and economies in both upstream and downstream areas. Changes in climate, including temporal and spatial variability and magnitudes of precipitation, have impacts directly on water quality and quantity and hence on the impacts of climate change across scales.

The general characteristic pattern of precipitation at specific locations is primary determined by large-scale climate circulation. Mountain topography plays an important role in the regional and local spatial-temporal distribution of precipitation and determines whether it hits the ground as snow or rain. Mountain ranges can block moisture transport, which results in dry areas in the rain shadow, cause heavy precipitation systems in front of mountain ranges, or provoke precipitation through convection potentially leading to thunderstorms. Heavy precipitation events can provoke floods or trigger debris flows, and may interrupt and destroy routes of transportation or infrastructure. On the other side, droughts can cause significant reduction or damage to food production, hydropower generation or lead to contamination of fresh water in both upstream and downstream areas. In high-elevation regions, precipitation often falls in solid form (snow), and mountain areas can thus dump the impact of heavy precipitation events through delayed and decelerated runoff. Glaciated high-mountain environments can store precipitation in frozen form and as such act as important natural temporal water storage system, which store water during the wet seasons and release the water only during the dry season. In such regions, melt water from the cryosphere is often the only water resource available to cover the demand for fresh water to be used for irrigation in upstream and downstream regions. Sectors like agricultural or energy production have adapted to these naturally-driven timing of a reliable water source in many upstream and downstream regions.

The observed and projected increases in air temperatures cause on the one hand further significant glacier recession and on the other hand lead to more frequent rain than snow events. Both effects result in a reduction of the cryospheric storing capacity. Recent studies furthermore provided evidence that warming is enhanced with increasing elevation, yet not uniformly around the globe (Mountain Research Initiative EDW Working Group 2015). Changing precipitation pattern moreover influence also the amount and timing of precipitation. Consequently, changed runoff and extreme events such as heavy precipitation events or dry periods can pose risks to societies in upstream and downstream areas by floods, landslides, debris flows or droughts. Due to the close linkage of upstream and downstream areas through water, adaptation measures might be particularly complex in these regions, as measures taken at one site might impact other areas. For instance, if a dam is built to artificially store water in the upstream area as a response to reduced precipitation and/or loss of natural water storage capacities (e.g. glaciers), downstream areas are then likely to have even higher water scarcity, which can potentially lead to conflict situations, in particular in transboundary settings (Bichsel 2011). This example shows an additional challenge of climate change impacts and adaptation. As climate change impacts in mountain regions can affect downstream areas far away through the interlinkage of water, likewise can local adaptation measures implemented in upstream areas have (positive or negative) effects on downstream areas. This furthermore highlights again the importance of interdisciplinary approaches, the importance of considering local and regional aspects when taking action and hence the importance of engaging with policy and decision makers at different levels. And finally, it shows the importance to document and synthesize experiences in order to derive and share guidelines for good practices.

6 Organization of this Book

This book is a contribution to the important challenge of adapting to adverse impacts and risks of climate change in mountain ecosystems and the adjacent downstream areas, and as such supports the overarching goal of sustainable development. As adaptation measures must be streamlined with and mainstreamed into overall development and planning within the local and regional contexts, there are typically no standard solutions available for successful adaptation. Moreover, societies are currently only about to learn from and evaluate first experiences with the development and implementation of adaptation measures as there are only few long-term examples available. Therefore, and in view of the emerging needs of adaptation, it is time to pause for a moment and to summarize and synthesize the experiences and lessons learnt so far. To serve this purpose, this book provides insights from several case studies from different upstream and downstream regions of the world (Fig. 2) and syntheses from global perspectives. The book offers a range of rich and intriguing perspectives from experts with diverse background and context, including science, governmental and non-governmental organizations, private sector or international organizations.

The book is organized in three main parts (A, B, C). Part A provides an introduction into the main thematic of the book followed by ten case studies in Part B from different upstream and downstream regions (cf. Fig. 2) of the world, which report on actions taken as well as experiences and lessons learnt. In Part C the global perspectives enter the discussion and synthesize the adaptation efforts by including aspects of resilience, economy and the science-policy dialogue.

In Part A, McDowell et al. (chapter "Adaptation, Adaptation Science, and the Status of Adaptation in Mountain Regions") provide an overview on the scientific

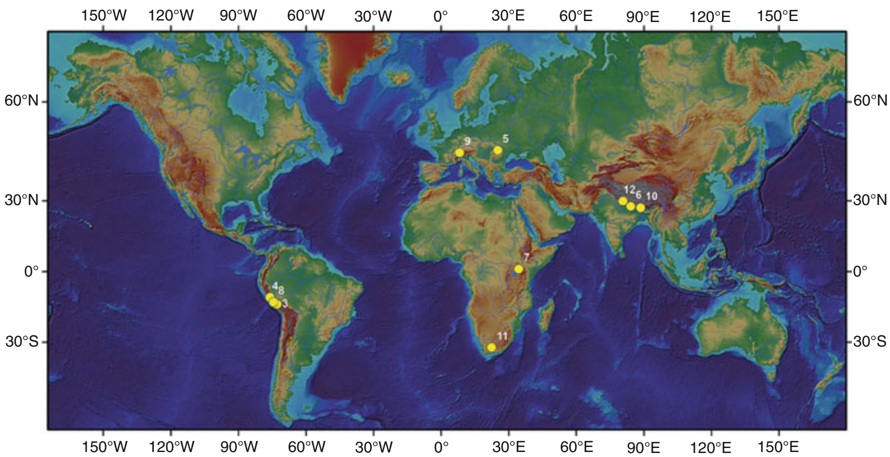

Fig. 2 Upstream and downstream regions indicated by topography and river systems. The *yellow dots* and *numbers* indicate the case study sites of the chapters in this book

status of climate change adaptation in upstream and downstream areas and draw out the linkages between adaptation scholarship and specific socio-economic and environmental conditions. As such, the chapter also points to the challenge of moving from the theory to the practice of adaptation.

The first case study (chapter "Science in the Context of Climate Change Adaptation: Case Studies from the Peruvian Andes") of Part B centers on the role of scientific studies in the process of assessing the needs for adaptation. In this chapter presented by Orlowksy et al. it is shown how scientific assessments are motivated by the local community's perception on climate change impacts. In this context the authors also stress that they found an important lack of social sciences studies compared to those from natural science. Chapters "Science in the Context of Climate Change Adaptation: Case Studies from the Peruvian Andes" and "Managing Glacier Related Risks Disaster in the Chucchún Catchment, Cordillera Blanca, Peru" focus both on the Andes. In chapter "Managing Glacier Related Risks Disaster in the Chucchún Catchment, Cordillera Blanca, Peru", Muñoz et al. report on a case from the Cordillera Blanca, Peru, where a village is in risk of glacier lake outburst floods (GLOFs) and document how the affected community manages these risks. Jointly with an international multidisciplinary team of experts, the community has planned and implemented a comprehensive early warning system, where particular emphasis was given to technical and social aspects.

A comprehensive analysis of climatic trends, impacts and adaptation options follows in chapter "Climate Change Adaptation in the Carpathian Mountain Region" for the case of the Carpathian mountain region, which represents a significant natural refuge on the European continent and stretches over several countries. The assessments undertaken by Werners et al. had inspired a strategic agenda on adaptation to be implemented under the Carpathian Convention. The chapter thus illustrates the important and clear link needed between science and policy and across borders. Chapter "Community Forest Management as Climate Change Adaptation Measure in Nepal's Himalaya" centers on forest management as a measure to adapt to climate change. Raj and Bharat show how community forest management in Nepal's Himalayas has led to conservation of biological diversity, ecosystem management etc. which ultimately turned into positive effects on overall livelihood of the local people depending of forest resources in both upstream and downstream areas. In particular, these measures have increased the population's adaptive capacity and the resilience of forest to changing climatic conditions.

The following chapters "Ecosystem-based Adaptation (EbA) of African Mountain Ecosystems: Experiences from Mount Elgon, Uganda", "Vulnerability Assessments for Ecosystem-based Adaptation: Lessons from the Nor Yauyos Cochas Landscape Reserve in Peru" and "The Role of Ecosystem-based Adaptation in the Swiss Mountains" focus on the concept of Ecosystem-based Adaptation (EbA). Defined by the Convention on Biological Diversity (CBD) 10th Conference of the Parties (COP) in October 2010, EbA is one way of adapting to climatic changes by using biodiversity and ecosystem services to help people to adapt to the adverse effects of climate change and thus links ecosystem services, sustainable resource management and climate change adaptation. In chapter "Ecosystem-based

Adaptation (EbA) of African Mountain Ecosystems: Experiences from Mount Elgon, Uganda", Musonda et al. discus in-depth an EbA approach which was implemented in the Mount Elgon region (Africa). They document all steps from initial vulnerability analyses to the implementation of an EbA method, here a gravity water scheme. Dourojeanni et al. in chapter "Vulnerability Assessments for Ecosystem-based Adaptation: Lessons from the Nor Yauyos Cochas Landscape Reserve in Peru" focus particularly on the vulnerability assessment for EbA. They analyze the results from a unique opportunity given at Nor Yauyos Cochas Landscape Reserve in Peru where three different vulnerability assessment approaches had been applied in the same location. Although all three approaches resulted in similar recommendation for adaptation measures, it also becomes obvious from the comparative study that only the application of a participatory approach did not require additional studies to implement measures following the vulnerability assessment. In chapter "The Role of Ecosystem-based Adaptation in the Swiss Mountains", Muccione and Daley explore the role of EbA in a highly developed region as for instance the Swiss Alps are. They identified EbA interventions taken particularly in the field of risk management, water management and agriculture and conclude that challenges and opportunities of EbA in Switzerland can mostly be attributed to knowledge, acceptance and other socio-economic factors.

The topic of community perception is tackled in chapter "Community Perceptions and Responses to Climate Variability: Insights from the Himalayas". Pandit et al. present the results of a survey on community perception and response to climate variability in the Himalayas (Bhutan, India, Nepal). Their findings show that the communities' challenges are complex and seldom only related to climate variability and change. However, climate change importantly exacerbates their basic challenges. The chapter further points towards the needs of the communities to enhance adaptive capacity and resilience. Chapter "Drought: In Search of Sustainable Solutions to a Persistent, 'Wicked' Problem in South Africa" focuses on particular climate-related stress inherent for many countries in South Africa. Vogel and van Zyl provide a historical, comparative assessment of the role of the State and other institutional settings for the reduction of drought risks with particular focus on sustainable solutions.

In the last contribution of the book's case study part, Trabacchi and Stadelmann raise in chapter "Making Climate Resilience a Private Sector Business: Insights from the Agricultural Sector in Nepal" the importance of including the private sector as a complement to the limited and often not sufficient public finances in fighting against climate change impacts in developing countries. At the example of the agricultural sector in Nepal the authors investigate leverages, which international public finance can use to involve domestic private actors. Based on semi-structured interviews with project stakeholders, finance modeling, risk assessment and a cost-benefit analysis they found key elements that help to involve and raise interest of the private sector.

Part C of the book finally takes a global view on the thematic presented in the case studies in Part B. The first chapter of Part C (chapter "Shaping Climate Resilient Development: Economics of Climate Adaptation") takes up the issue of the previous chapter and focuses on the private sector and its role for shaping climate resilient development. Bresch introduces the methodology of Economics of Adaptation (ECA) and synthesizes the results from 20 ECA studies. As an overall result of these studies, it was found that the key drivers are mostly today's weather and climate risks and economic development. In chapter "Building Resilience: World Bank Group Experience in Climate and Disaster Resilient Development", Kull et al. provide the perspective from several years of experiences gathered by the World Bank Group. They conclude that integrating climate and disaster resilience into the development planning processes leads to immediate and sustainable development gains, particularly in the most vulnerable countries. Along with these findings from Parts B and C of this book, it becomes obvious that communication plays a critical role for climate change adaptation and thus sustainable development. In the final chapter of the book, Kohler et al. take up the issue of science-policy dialogue and show how these processes have been institutionalized in both developed and developing countries. In their chapter "The Science-Policy Dialogue for Climate Change Adaptation in Mountain Regions", they propose to strengthen the science-policy dialogue by closing the data and information gap relating to mountain climates and existing adaptive actions.

In summary, the knowledge gathered in this book allows us to draw a number of important conclusions concerning the state and experiences of adaptation in upstream and downstream areas. The first set of the following conclusions does not necessarily imply upstream and downstream specific issues and therefore shows that many mechanisms of adaptation operate along the same or similar lines independent on the regions:

- Climate change, variability and extremes represent the immediate threats and needs and are therefore generally at the forefront of current adaptation practices.
- Well-designed adaptation comes with several important co-gains, in particular for sustainable development and disaster risk reduction. Adaptation thus contributes to, and needs to be seen in the context of the Sustainable Development Goals (Agenda 2030) and the Sendai Framework for Disaster Risk Reduction.
- Non-climatic factors often outweigh the climatic factors in terms of contributing to, or enhancing risks and negative effects of climate change, and therefore need to be considered for adaptation.
- Adaptation implies an iterative learning process.

In addition to the more generally applicable points above we can draw a number of specific issues for mountain regions and adjacent downstream areas from this book:

- A major challenge for adaptation in mountains is due to limited availability of data, both for the natural as well as social environment. This limitation is even more pronounced in developing countries, especially in terms of long-term observation series that are important to design reasonably robust and sustainable adaptation strategies and measures.

- There is now a considerable number and diversity of adaptation experiences in upstream and downstream regions available. Adaptation experiences in mountains primarily relate to water resources, forest and ecosystem management, and risk reduction of extreme events, in particular mass flows and movements.
- The involvement of the private sector is minimal so far in adaptation planning in mountain regions, which contrasts with some of the current strategies of international climate policy. There are also only very few experiences concerning economic evaluation of adaptation in mountains.
- The participatory work with local mountain communities is an essential element for success in adaptation efforts.
- The different types of remoteness of mountain communities need to be considered in the adaptation planning.

References

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., Naess, N. O., Wolf, J., & Wreford, A. (2009). Are there social limits to adaptation to climate change? *Climatic Change, 93*(3), 335–354.

Bichsel, C. (2011). Liquid challenges. Contested water in Central Asia. *Sustainable Development Law and Policy, 12*(1), 24–30.

Donat, M. G., Lowry, A. L., Alexander, L. A., O'Gorman, P. A., & Maher, N. (2016). More extreme precipitation in the world's dry and wet regions. *Nature Climate Change, 6*(5), 508–513.

Dow, K., Berkhout, F., Preston, B. L., Klein, R. J. T., Midgley, G., & Shaw, M. R. (2013). Limits to adaptation. *Nature Climate Change, 3*(4), 305–307.

Mountain Research Initiative EDW Working Group (2015). Elevation-dependent warming in mountain regions of the world. *Nature Climate Change, 5*(5), 424–430.

Hawkins, E., & Sutton, R. (2009). The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society, 90*, 1095–1107.

IPCC (2013). Climate change 2013: The physical science basis. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 1535). Cambridge: Cambridge University Press.

IPCC (2014). Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 688). Cambridge: Cambridge University Press.

Knutti, R., & Rogelj, J. (2015). The legacy of our CO_2 emissions: A clash of scientific facts, politics and ethics. *Climatic Change, 133*(3), 361–373.

Salzmann, N., Huggel, C., Rohrer, M., & Stoffel, M. (2014). Data gaps and research needs on glacier and snow cover change and related runoff – A climate change adaptation perspective. *Journal of Hydrology, 518, Part B*, 225–234.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., et al. (2011). The representative concentration pathways: An overview. *Climatic Change, 109*(1), 5–31.

Adaptation, Adaptation Science, and the Status of Adaptation in Mountain Regions

Graham McDowell, Eleanor Stephenson, and James Ford

Abstract This chapter introduces the conceptual foundations of, and core themes within, the climate change adaptation scholarship; outlines common approaches to adaptation science; presents key critiques of how adaptation is conceptualized and examined; and discusses the status of adaptation in upstream-downstream environments. The chapter draws out linkages between adaptation scholarship and mountain-specific socio-economic and environmental conditions. It also addressed an important gap in the broader adaptation scholarship, where there have been few studies characterizing and examining adaptation in mountain regions. Topics covered clarify key conceptual and analytical aspects of climate change adaptation and strengthen rationale for efforts to increase understanding of adaptation in upstream-downstream systems. The chapter also facilitates more informed engagement with subsequent chapters in *Climate Change Adaptation Strategies – An Upstream-downstream Perspective*.

Keywords Adaptation • Adaptation science • Climate change • Mountains • Upstream-downstream

1 Introduction

Interest in how society can respond to the effects of climate change in upstream-downstream systems is growing as the fingerprint of environmental change becomes more conspicuous in mountain regions. Compounding present-day concerns, IPCC AR5 projections indicate further reductions in global glacier volumes of 15–85 % by 2100, with northern hemisphere snowcover contracting by 7–25 % over the same period (IPCC 2013). Because mountain regions and immediately proximate

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N. Salzmann et al. (eds.), *Climate Change Adaptation Strategies – An Upstream-downstream Perspective*, DOI 10.1007/978-3-319-40773-9_2

lowlands are home to 26 % of the global population and contain some of the most biodiverse ecosystems on the planet, climate-related changes in upstream-downstream systems portend potentially significant and far-reaching implications (Huddleston et al. 2003; Ariza et al. 2013; Price and Weingartner 2012). However, caution is warranted in presuming that such figures signify unavoidable and necessarily adverse impacts; the pathways through which climate change affects society are rarely straightforward, inevitable, or immutable (Turner et al. 2003). Accordingly, efforts to identify and address the effects of climate change in upstream-downstream systems must recognize the unique circumstances that affect how people and institutions navigate the challenges and opportunities of environmental change; that is, there is a need to understand adaptation.

This chapter is concerned primarily with adaptation in humans systems, and engages with three overarching questions: What is adaptation, how is adaptation studied, and what do we know about adaptation in upstream-downstream systems? The chapter aims to draw out linkages between the adaptation scholarship and mountain-specific socio-economic and environmental conditions in an effort to support more advanced work on the socio-ecological dimensions of climate change in mountain regions. In pursuit of this objective, the chapter: (i) introduces the conceptual foundations of, and core themes within, the climate change adaptation scholarship; (ii) outlines common approaches to adaptation science; (iii) presents key critiques of how adaptation is conceptualized and examined; (iv) and discusses the status of adaptation in upstream-downstream environments. The chapter concludes by setting out some of the current challenges in adaptation scholarship and science, as well as the particular contributions of this book to adaptation science in mountain regions. More broadly, the chapter addresses an important gap in the adaptation scholarship, where there have been few studies characterizing and examining approaches to adaptation, and their implications for adaptation research, in mountain regions.

2 Conceptual Foundations

The term *adaptation* has become part of the lexicon of climate change scholarship and policy, but its origins predate the climate change field by many decades. Adaptation was first theorized in early evolutionary biology scholarship, where it refers to genetic or behavioral characteristics that support fitness and survival in the face of environmental pressures (Smit and Wandel 2006). Mid-twentieth century anthropologists were the first to extend the concept to social spheres, where they argued that humans are inherently adaptive in the face of social and environmental stressors (Engle 2011; Smit and Wandel 2006); sociologists, psychologists, and geographers also played a role in advancing early theories of adaptation in human systems (Simonet 2010). This work laid the foundation for problematizing environmentally deterministic conceptualizations of human-environment relations, and informed how natural hazards, political ecology, and development studies scholars' conceptualized the impacts of climate variability and change on people and social systems (Bassett and Fogelman 2013). These fields, in turn, underpin much of the contemporary work on adaptation to climate change.

Today, the IPCC's definition of climate change 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"—provides the benchmark conceptualization for academic and policy work in this area (IPCC 2013). However, notwithstanding this important reference point, the proliferation of scholarly work on climate change adaptation is driving conceptual thinking, and aspects of climate change adaptation theory continue to evolve as new ideas are proposed and debated. Scholars working on environmental change in mountains are contributing to this evolution of thinking, although their contributions are still limited compared to those working in climate-affected regions such as the Arctic. Herein, key concepts in climate change adaptation scholarship, including some emerging conceptual trajectories, are introduced and discussed.

2.1 Adaptation

Adaptation is a response to phenomena that stress a system or present new opportunities. In the context of climate change, these phenomena can be broken down into several types of stimuli: inter-annual or decadal variability such as changing precipitation patters, long-term changes in climate norms like shifting discharge regimes, and isolated extreme events like glacial lake outburst floods (GLOFs). Adaptation to such stimuli is undertaken in the pursuit of several broadly identifiable goals, including *preventing loss*, *spreading or sharing loss*, *diversifying* to moderate harm and/or take advantage of new opportunities, *migrating* to reduce exposure to climate stimuli, and *restoring* climate-affected systems (Smit et al. 1999). More recently theorized goals of adaptation include *transforming* affected systems and *preserving ecosystem services* (Jones et al. 2012; Folke et al. 2010).

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 (occurred after climatic stress) or anticipatory (occurring in preparation for climatic stress). 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 are viewed as representing a more formalized approach to adaptation. In areas where access to formal decision-making processes is limited or local customs and livelihoods conflict with state led planning (e.g. some mountain communities), autonomous adaptation may be more appropriate (Thornton and Manasfi 2010; McDowell et al. 2014). However, autonomous adaptation may also represent exclusion from relevant services in geopolitically marginalized regions, a situation common to many highland communities (McDowell et al. 2014). Mainstreaming—embedding climate change adaptation efforts within existing management and development processes—is a frequently referenced objective of planned adaptations (Berrang-Ford et al. 2011; Lesnikowski et al. 2011), although this presupposes the existence of institutions capable of responding to adaptation needs. *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 levels. Similarly, adaptations can range from short-term interventions (e.g. short-term investments) 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 technological, behavioral, financial, institutional, regulatory, and informational. There is no theoretically best form of adaptation. Rather the most appropriate form is contingent on the goal of adaptation and a range of contextual factors.

Adaptations can also be thought of as either 'soft' or 'hard' (Sovacool 2011). These implementation approaches reflect differing ideas about how adaptation is best carried out and, to a lesser extent, efforts to deal with different climatic stimuli. *Hard adaptations* rely primarily on infrastructure development, are complex and capital intensive, and often lack community consultation. Sea walls that protect against sea level rise and storm surges are the archetypal hard adaptation example. Although hard adaptations have been critiqued for being socially and ecologically disruptive and inflexible to uncertain future climate conditions (Sovacool 2011), they remain a commonly advocated adaptation approach. This is especially true of adaptations supported by international funding mechanisms such as the UNFCCC Adaptation Fund, which favor measureable adaptation activities vis-à-vis climate change (Khan and Roberts 2013). *Soft adaptations* are often less tangible, focusing on empowering communities, drawing on local skills and knowledge, utilizing locally appropriate technologies, and promoting flexibility to changing climatic conditions. A soft adaptation might focus on identifying intrinsic adaptive abilities within a community, then working to promote and enhance these abilities, for example by promoting the transmission of local ecological knowledge and insights about effective responses to past experiences of climatic change. Soft adaptations may also involve working with existing natural capital to moderate the effects of climate change, as is the case with ecosystem-based adaptation (discussed in Sect. 3). Although many scholars posit that soft adaptation approaches are preferable in many cases, such adaptations can be limited in their scope (e.g. community focused), are difficult to evaluate, and are subject to elite capture (Khan and Roberts 2013). Hard and soft adaptations are different approaches to implementing adaptation, but they can be complimentary (Carey et al. 2014). For example, in a highland agricultural community exposed to GLOFs and changing precipitation regimes, installing infrastructure to protect against floods (hard adaptation) while also supporting food sharing networks (soft adaptation) could be appropriate.

Adaptation is thought to be successful when it is effective, efficient, equitable, and legitimate (Adger et al. 2005). *Effectiveness* refers to an adaptation action achieving its goals. *Efficiency* can be broadly defined as a situation where the benefits of an adaptation outweigh the cost of its implementation, including the opportunity cost of not using resources for other socially beneficial ends. *Equity* is greater when the benefits of adaptation reduce or do not worsen underlying disparities within a system. That is, adaptation is more equitable when the distributional consequences of adaptation tend to benefit the most vulnerable. *Legitimacy* concerns the process of adaptation planning and implementation, with legitimacy increasing when inclusive decision-making processes underpin adaptation. Defining success in the context of mountain regions can be especially complex due to the interlinked nature of ecosystem services in upstream-downstream systems as well as the often complex socio-economic and political circumstances within alpine catchments (e.g. marginalization of highland communities).

Long-term trajectories of adaptation are the subject of much contemporary work on adaptation, with mal-adaptation, sustainable adaptation, and transformative adaptation emerging as important themes. *Mal-adaptation* refers to situations in which adaptation increases emissions of greenhouse gases; disproportionately burdens the most vulnerable, other groups/systems, or time periods; has high opportunity costs; reduces incentives to adapt; or promotes inflexibility and path dependency (Barnett and O'Neill 2010). Empirical work has begun to revel the existence of mal-adaptation in the context of climate change adaptation (Adger and Barnett 2009; Ford et al. 2013b), leading to efforts to identify why mal-adaptation emerges and how it can be avoided. This work has promoted a corresponding line of questioning about *sustainable adaptation* among development scholars, where mal-adaptation is conceptualized as a problem for sustainable development (Eriksen and Brown 2011). Kates et al. (2012) describes *transformative adaptation* as adaptations that "are adopted at a much larger scale, that are truly new to a particular region or resource system, and that transform places and shift locations" (p. 7165). Others such as Folke et al. (2010) go beyond this definition, suggesting that transformational change implies as a system scale step change from a less desirable state to a more desirable state. In all cases, it is argued that climate change poses risks in some systems that are so significant they will require novel or dramatically different approaches in order to be managed effectively. For example, the dramatic changes in snow and ice environments projected over the coming century could present unprecedented water and hazard management challenges. Implementing and sustaining transformational adaptations, however, is expected to be very difficult, especially in light of institutional and behavioral inertia that favors the persistence of existing socio-economic conditions (Pelling 2011; O'Brien 2012). See Table 1 for a summary of key adaptation themes.

Finally, a now extensive body of empirical work has established that adaptations rarely occur in response to climate change alone (Berrang-Ford et al. 2011; Ford et al. in press; Lesnikowski et al. 2015); adaptation to multiple, often interacting stressors is the norm. Thus, although it is tempting to assume that adaptation is a direct product of climatic change, it is important to appreciate that adaptation often

Table 1 Adaptation goals, classifications, implementation, success, and long-term outlook

Theme	Key themes
Goals	Prevention of loss
	Spreading or sharing loss
	Diversification
	Migration
	Restoration
	Transformation
	Preservation of ecosystem services
Classifications	Timing
	Intent
	Scope
	Form
Implementation	Hard adaptation
	Soft adaptation
Success	Effective
	Efficient
	Equitable
	Legitimate
Long-term outlook	Mal-adaptation
	Sustainable adaptation
	Transformative adaptation

addresses interlinked environmental and socio-economic opportunities and constraints. For example, a highland farmer's decision to switch to a more drought resistant crop may be driven both by changing precipitation dynamics and better market prices for the new crop.

2.2 Adaptive Capacity

Adaptive capacity refers to the ability to devise and implement adaptations (Engle 2011). High adaptive capacity can enable stressors to be addressed without incurring harm, whereas low adaptive capacity can engender vulnerability to seemingly minor perturbations. Importantly, adaptive capacity is not a homogenous feature; it is differentiated within and between systems due to a range of socio-economic and political factors (Adger et al. 2007; Ford and Smit 2004). As such, adaptive capacity provides insights about who can adapt, how they adapt, and what effect their adaptations have on reducing harm and/or accessing new opportunities (Smit et al. 2000).

Adaptive capacity can be evaluated by exploring the factors that support (determinants) and constrain (barriers) adaptation. Frequently identified 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). When such conditions exist, higher levels of adaptive capacity are often observed. Notwithstanding, barriers can undermine adaptive capacity, often leading to uneven distributions of adaptability (Moser and Ekstrom 2010; Biesbroek et al. 2013). IPCC AR5 defines barriers as “factors that make it harder to plan and implement adaptation actions or that restrict options” (IPCC 2014). Poverty, social and political marginalization, and attendant challenges are among the most commonly documented barriers to adaptation at the community level, whereas institutional fragmentation, conflicting timescales, and lack of resources are commonly reported institutional barriers (Eisenack et al. 2014; Ford and King 2015; Gupta et al. 2010). Such barriers lead to complex mosaics of adaptive capacity across scales (e.g. within communities, between upstream and downstream areas, between nations) and through time (as socio-economic and political factors change so too does the nature and distribution of adaptive capacity).

Increasing adaptive capacity is a critical aspect of policies aimed at reducing vulnerability to climate change. Enhancing adaptive capacity is often, although not always, analogous to human development (e.g. poverty reduction, access to education), pointing up synergistic opportunities to improve well-being while also reducing the adverse impacts of a changing climate (Ayers and Huq 2009; Conway and Mustelin 2014; Lemos et al. 2007). This realization should be encouraging for mountain scholars, given the human development work happening in many mountain ranges. However, climate change may produce novel challenges requiring targeted capacity-building endeavors above and beyond human development initiatives (Füssel 2007). Regardless of how adaptive capacity is strengthened, knowledge of how determinants and barriers are distributed within and between systems can help target the allocation of scarce resources.

3 Approaches to Adaptation Science

Adaptation science refers to research efforts aimed at understanding the factors driving adaptation (stimuli), who or what adapts (systems), how they adapt (processes), and the effects of their adaptation (outcomes) (Smit et al. 1999; Mustelin et al. 2013). It is a form of practice-oriented scholarship, where providing insights relevant to the development of adaptation policies guides many research projects (Swart et al. 2014). Although assessments typically represent transdiciplinary endeavors, particular disciplines (e.g. geography, natural hazards) have tended to focus on specific research foci, leading to several distinct approaches to adaptation science. Although each approach has distinct strengths and weaknesses, all provide worthwhile analytical, methodological, and practical considerations for the study of adaptation in upstream-downstream systems. A selection of common adaptation science approaches is presented below.