Cross-Chapter Paper 5: Mountains

Cross-Chapter Paper Leads: Carolina Adler (Switzerland/Chile/Australia), Philippus Wester (Nepal/The Netherlands)

Cross-Chapter Paper Authors: Indra Bhatt (India), Christian Huggel (Switzerland), Gregory Insarov (Russian Federation), Michael Morecroft (United Kingdom), Veruska Muccione (Switzerland/Italy), Anjal Prakash (India)

Cross-Chapter Paper Contributing Authors: Irasema Alcántara-Ayala (Mexico), Simon K. Allen (Switzerland/New Zealand), Maaike Bader (Germany), Sophie Bigler (Switzerland), James Camac (Australia), Ritodhi Chakraborty (New Zealand/India), Aida Cuni Sanchez (Norway/Spain), Nicolás Cuvi (Ecuador), Fabian Drenkhan (Peru/Germany), Abid Hussain (Nepal/Pakistan), Amina Maharjan (Nepal), Robert Marchant (United Kingdom), Graham McDowell (Canada/USA), Samuel Morin (France), Laura Niggli (Switzerland), Ana Ochoa (Ecuador), Avash Pandey (Nepal), Julio Postigo (USA/Peru), Estelle Razanatsoa (South Africa/Madagascar), Valeria M. Rudloff (Chile), Christopher Scott (USA), Madison Stevens (Canada), Daithi Stone (New Zealand), Jessica Thorn (United Kingdom/Namibia), James Thornton (Switzerland/United Kingdom), Daniel Viviroli (Switzerland), Saskia Werners (The Netherlands)

Cross-Chapter Paper Review Editor: Georg Kaser (Austria)

Cross-Chapter Paper Scientist: Valeria M. Rudloff (Chile)

Date of Draft: 1 October 2021

Notes: TSU Compiled Version

Table of Contents

Executive Summary

Mountains are highly significant regions in the context of climate change and sustainable development, at the intersection of accelerated warming and a large population depending directly or indirectly on them. They are regions of high biological and cultural diversity and provide vital goods and services to people living in and around mountain regions and in downstream areas. Building on the IPCC's Fifth Assessment Report (AR5), Chapter 2 "High Mountain Areas" of the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), and the IPCC Working Group I contribution to AR6, this Cross-Chapter Paper (CCP) assesses new evidence on observed and projected climate change impacts in mountain regions, their associated key risks and adaptation measures.

Observed changes, their impacts, and adaptation responses in mountains

Climate change impacts in mountains and their attribution to human influence have increased in recent decades with observable and serious consequences for people and ecosystems in many mountain regions (*high confidence*[1]). Observed changes include increasing temperatures, changing seasonal weather patterns, reductions in snow cover extent and duration at low elevation, loss of glacier mass, increased permafrost thaw, and an increase in the number and size of glacier lakes (*high confidence*). {CCP5.2.7, Figure CCP5.4, SROCC Chapter 2, WGI Section 9.5}

The spatial distributions of many plant species have shifted to higher elevations in recent decades, consistent with rising temperatures across most mountain regions (*high confidence*). Around two-thirds of treeline ecotones have also shifted upwards in recent decades, though these shifts are not ubiquitous and slower than expected based on rising temperatures (*high confidence*). Impacts on biological communities and animal species are also increasingly being reported, with species of lower elevations increasing in mountain regions, creating more homogeneous vegetation and increasing risks to mountain top species (*medium confidence*). {CCP5.2.1; Chapter 2.4}

Climate and cryosphere change have negatively affected the water cycle in mountains, including variable timing of glacier- and snow-melt stream discharge (*high confidence*). These changes have variable impacts on water availability for people and economies, contributing to increasing tensions or conflicts over water resources, especially in seasonally dry regions (*medium confidence*). Mountains are an essential source of freshwater for large, and growing populations; the number of people largely or fully dependent on water from mountains has increased worldwide from ~0.6 billion in the 1960s to ~2 billion in the past decade and globally two-thirds of irrigated agriculture depends on essential runoff contributions from the mountains. {CCP5.2.2; Figure CCP5.2; SROCC Chapter 2; 4.2.2.3; 4.4.4.1}

Climate change-driven changes in precipitation, river flow regimes and landslides affect the production and use of energy in mountain regions, in particular hydropower (*high confidence*). Billions of USD in investment and assets of energy production are exposed to changing mountain hazards. Combined effects of climate change, hydropower development and other human interventions have exacerbated water security problems and social injustice (*medium confidence*). {CCP5.2.2, SROCC Chapter 2}

Observed climate-driven impacts on mountain ecosystem services, agriculture and pastoralism are largely negative in most mountain regions (*medium confidence*). Agriculture has been negatively affected through increased exposure to hazards such as droughts and floods, changes in the onset of seasons, the timing and availability of water, increasing pests and decreasing pollinator diversity, which in turn have negatively influenced overall production, dietary diversity and nutritional value (*medium confidence*). Negative climate impacts on pastoralism, such as drought induced degradation of rangelands and pastures, have affected livestock productivity and livelihood of pastoralists, while other non-climatic factors such as

[1] In this Report, the following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

land-use change and management also play a role (*medium confidence*). {CCP5.2.3; CCP5.2.5; Table CCP5.2; SROCC Section 2.3.1.3.2; SROCC Section 2.3.7}

While contributing to poverty reduction in some mountain regions, there is *limited evidence* of adaptations effectively contributing to remediating the underlying social determinants of vulnerability such as gender and ethnicity (*medium confidence*). Exposure and vulnerability exacerbate the negative effects of climate impacts on livelihoods, and intertwines with power imbalances, gender and other inequalities (*medium confidence*). {CCP5.2.7; CCP5.3.2.2}

Observed changes in seasonality (timing and extent) are negatively affecting mountain winter tourism and recreation (*high confidence*), and variably affect tourism and recreation activities in other seasons (*medium confidence*). For winter activities such as skiing, diminishing snow at lower elevations has challenged their operating conditions (*medium confidence*), increasing the demand for and dependence on snow management measures such as snow-making (*high confidence*). Climate-induced hazards are negatively affecting some climbing, mountaineering, and hiking routes (*medium confidence*). In some regions, options to change routes or shift seasons to reduce hazard exposure have been employed as adaptation strategies, with variable outcomes (*medium confidence).* In some cases, higher temperatures and extreme heatwave conditions at lower elevations have made some mountain destinations more appealing, increasing the potential for summer visitation demand (*medium confidence*). {CCP5.2.5; Table CCP5.2; SROCC Ch2.3.5}

Climate-related hazards, such as flash floods and landslides, have contributed to an increase in disasters affecting a growing number of people in mountain regions and further downstream (*high confidence*). The resulting number of disasters has increased, however there is *limited evidence* that this is due to changes in the underlying hazard processes, pointing mainly to increasing levels of exposure (*medium confidence*). {CCP5.2.6; CCP5.2.7; CCP5.3.2.1}.

Adaptation responses to climate-driven impacts in mountain regions vary significantly in terms of goals and priorities, scope, depth and speed of implementation, governance and modes of decision-making, and the extent of financial and other resources to implement them (*high confidence*). Observed adaptation responses in mountains are largely incremental and mainly focus on early warning systems and the diversification of livelihood strategies in smallholder agriculture, pastoralism, and tourism. However, there is *limited evidence* of the feasibility and long-term effectiveness of these measures to address climate-related impacts and related losses and damages, including in cities and settlements experiencing changing demographics. {CCP5.2.4; CCP5.2.7.2}

Projected impacts, key risks and limits to adaptation in mountains

Increasing temperatures will continue to induce changes in mountain regions throughout the 21st century, with expected negative consequences for mountain cryosphere, biodiversity, ecosystem services and human wellbeing (*very high confidence*). Many low elevation and small glaciers around the world will lose most of their total mass at 1.5°C GWL (*high confidence*). A large majority of endemic mountain species will be at risk of extinction; regions heavily relying on glacier- and snow-melt for irrigation will face erratic water supply and increased food insecurity, whereas agriculture in some regions might see positive changes. Damages and losses from water related hazards such as floods and landslides are projected to increase considerably between 1.5 and 3° GWL. {CCP5.3.1}

Projected changes in hazards, such as floods and landslides, as well as changes in the water cycle, will lead to severe risk consequences for people, infrastructure and the economy in many mountain regions (*high confidence*). These risks will be more pervasive and also increase more rapidly in South and Central Asia and Northwestern South America. However, nearly all mountain regions will face at least moderate and some regions even high risks at around 2°C GWL (*medium confidence*). {CCP5.3.2.1, CCP5.3.2.2; 16.B.4}

There is an increasing risk of local and global species extinctions where they are not able to move to higher elevations or other cooler locations (*high confidence*), with risks from extreme events such as wildfire potentially exacerbating those risks (*medium confidence*). The topographic variation in mountains may mean that some species can survive in cooler microclimates with aspect as well as elevation.

Mountain regions may act as refugia for some species from lower elevations, if they can move into them. This may enable some species to persist in a region, although it can present a threat to cold-adapted species, including endemics, which may be outcompeted (*high confidence*); invasive non-native species may become an increasing problem in some places. {CCP5.3.2.3, Box CCP5.1; CCP1.2.2.1; 2.6.6; 16.6.3.1}

Climate change is projected to lead to profound changes and irreversible losses in mountain regions with negative consequences for ways of life and cultural identity (*medium confidence*). Intangible losses and loss of cultural values will become increasingly more widespread in mountain regions mainly driven by a decline in snow and ice and an increase in intangible harm to people from hazards (*medium confidence*). However, there is *limited evidence* on the magnitude of the consequences. {CCP5.3.2.4; 16.5.2.1; 16.5.2.3.7}

Options for future adaptation and climate resilient sustainable development in mountains

The current pace, depth and scope of adaptation is insufficient to address future risks in mountain regions, particularly at higher warming levels (*high confidence*). While the incremental nature of most implemented adaptations will not be sufficient to reduce severe risk consequences, options exist which offer practical and timely prospects to address risks before limits to adaptation are reached or exceeded. Reducing climate risks will depend on addressing the root causes of vulnerability, which include poverty, marginalization, and inequitable gender dynamics *(high confidence*). {CCP5.4.1, Figure CCP5.7; CCP5.4.2, Cross-Chapter Box DEEP in Chapter 17; Cross-Chapter Box LOSS in Chapter 17; 17.3, 17.6}

Adaptation decision-making processes that engage with and incorporate people's concerns and values and address multiple risks are more robust than those with a narrow focus on single risks (*medium confidence*). Risk management strategies that better integrate the adaptation needs of all affected sectors, account for different risk perceptions and build on multiple and diverse knowledge systems, including Indigenous knowledge and local knowledge, are important enabling conditions to reduce risk severity (*medium confidence*). {CCP5.2.6, CCP5.4.2; 17.3; 17.4; Cross-Chapter Box PROGRESS in Chapter 17; Cross-Chapter Box DEEP in Chapter 17}

Regional cooperation and transboundary governance in mountain regions, supported by multi-scale knowledge networks and monitoring programmes, enable long-term adaptation actions where risks transcend boundaries and jurisdictions (*medium confidence*). Collectively, they show potential to form an important component of the adaptation solution space in mountains. There are increasing calls for more ambitious climate action in mountains, providing impetus for stronger cooperation within and across mountain regions, and downstream areas (*medium confidence*). {CCP5.4.2; CCP5.4.3}

With warming above 1.5°C, the need for adaptation to address key risks in mountains becomes increasingly urgent (*high confidence*). Pathways and system transitions that strengthen climate-resilient sustainable mountain development are starting to receive attention, but current levels of resourcing are substantially insufficient to support timely action. {CCP5.4.2; CCP5.4.3; CCP5.5; 18.1; 18.2}

CCP5.1 Point of Departure

Mountains are an extensive and significant *typological region* (Section 1.3.3 and AR6 Glossary) in the context of climate change and sustainable development, with a large population directly or indirectly depending on mountains. These are areas of high biological and cultural diversity that provide vital goods and services – such as water, food, energy, minerals, medicinal plants, tourism and recreation, and aesthetic and spiritual values – to people living in and around these mountain regions and in downstream areas. Mountain regions are hotspots of climate related losses in, for example, ecosystems, landscapes, culture, and habitability, and while mountain people are adaptive, resourceful, and independent, they live in highly fragile environments and in some regions under challenging socioeconomic circumstances that enhance their vulnerability to climate change (Alfthan et al., 2018).

Chapter 2 “High Mountain Areas” (Hock et al., 2019) of the IPCC Special Report on the Ocean and the Cryosphere in a Changing Climate (SROCC), presented an assessment of observed changes in the high mountain cryosphere, their resulting impacts in-situ and further downstream, and the state of adaptation responses to these impacts. Before SROCC, the last time climate change in mountain regions were systematically assessed in IPCC reports was in Chapter 5 of the Second Assessment Report (SAR) (Beniston et al., 1996). Projections made at the time for climate-related changes in mountain regions were expected towards the middle and the second half of the twenty-first century, rather than as early as the past decades (Haeberli and Beniston, 2021), underscoring the striking pace of change already observed in mountain regions.

Whereas SROCC focused on impacts from a changing climate on high mountain cryosphere, this Cross-Chapter Paper (CCP) on “Mountains” synthesizes key relevant content from across the AR6 WGII report with a broader scope on the impacts and adaptation to climate change in mountain regions as defined for this assessment (Figure CCP5.1, SMCCP5.1). It provides a wider assessment of the solutions space and consequences for sustainable development due to climate change in mountain regions and downstream areas.

To define the geographical scope of the assessment in this CCP and to quantify the human population residing within these regions, the mountain characterization given by Kapos et al. (2000) (Figure CCP5.1a and SMCCP5.1), minus Antarctica, Svalbard and Greenland (which fall under the assessment scope of CCP6 Polar Regions), was employed. This characterization is consistent with the mountain region extents used in the AR6 WGI report (see AR6 WGI Atlas) and yields a global mountainous area of 31.74 million km^2, which corresponds to approximately 23.5% of the global land surface. In 2015, a total of 1.28 billion people resided in mountain regions as delineated for this CCP (SMCCP5.1).

The scope of the assessment presented in this CCP covers observed and projected climate change impacts in mountains, present, emerging and future key risks and observed adaptation responses, leading to an exploration of the adaptation solution space and climate-resilient development (pathways) in mountains. Section 5.2 presents observed impacts and adaptation responses by synthesizing information on mountains in the sectorial and regional chapters of WGII AR6, additional supporting evidence found in the literature, a Detection and Attribution assessment (SMCCP5.2) and a reanalysis of the mountain literature collected and synthesised in the Global Adaptation Mapping Initiative (GAMI) (SMCCP5.3). Section 5.3 presents an assessment of future key risks in mountains drawing from the regional and sectorial chapters and a key risks assessment for this CCP (SMCCP5.4). Section 5.4 explores the solution space for future adaptation opportunities and constraints as well as climate resilient development in mountains. This CCP concludes with key assessment limitations and knowledge gaps and prospects to address these gaps in Section 5.5.

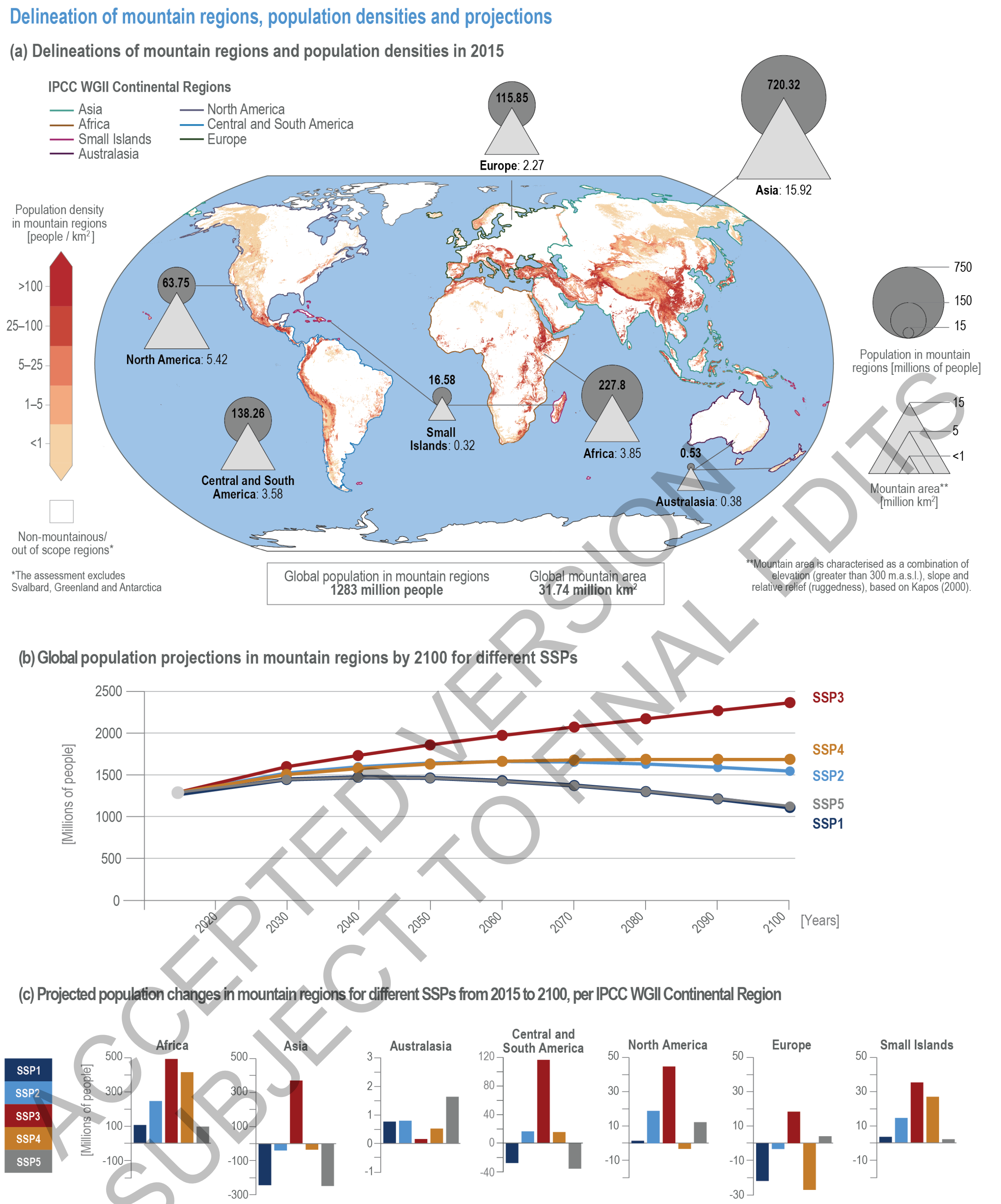

Figure CCP5.1: Delineation of mountain regions in CCP Mountains, population numbers and densities in 2015, and their projections to 2100. a) Population in mountain regions in 2015 aggregated per IPCC WGII Continental Regions, considering population densities, mountain areas and total population in mountain regions. b) Population projections in mountain regions by 2100 for different Shared Socioeconomic Pathways (SSP) scenarios. c) Projected changes in population in mountain regions from 2015 to 2100 across five different SSP scenarios, per IPCC WGII Continental Region (see SMCCP5.1 and Tables SMCCP5.1-5.4).

CCP5.2 Observed Impacts and Adaptation in Mountain Social-Ecological Systems

CCP5.2.1 Ecosystems and Ecosystem Services

Changes in climate over short distances in mountains are reflected in large ecological gradients. AR5 reported new evidence that plant species of mid and low elevations were starting to colonise high elevations in mountains. Since AR5, new studies have been published (e.g. Steinbauer et al., 2018; Payne et al., 2020), including in some previously less well studied areas such as the Andes (e.g. Morueta-Holme et al., 2015; Báez et al., 2016) and parts of Asia (e.g. Telwala et al., 2013; Artemov, 2018). There is now *high confidence* that many plant species distributions have shifted to higher elevations in recent decades, consistent with climatic warming (Sections 2.4.2; 10.4.2.1.1; 13.3.1.1). In recent years publications have also started to show similar trends in some animal species include those on birds (Freeman et al., 2018; Bani et al., 2019; Lehikoinen et al., 2019) and snails (Baur and Baur, 2013). Other climatic variables besides temperature can also affect elevational limits of species (Section 2.4.2) and sometimes in contrasting ways to temperature, for example increasing precipitation can allow some species to occur at lower elevations in dry climates (Crimmins et al., 2011; Coals et al., 2018). Tsai et al. (2015) reported large changes in the montane bird community in Taiwan which they link to changes in weather patterns including more severe typhoons. Changes in the amplitude and frequency of bank vole population waves in the Ilmen Nature Reserve, Middle Urals can be linked to a longer frost-free periods (Kiseleva, 2020).

There are interactions with land use, for example a decrease in forest cover can exacerbate the effects of rising temperatures (Guo et al., 2018). In contrast, Bhatta et al. (2018) showed a downward shift of species assemblages in Langtang National Park, Nepal, most likely related to interactions with land use, especially reduced grazing. Where glaciers are retreating, new areas become available for pioneer species to colonise and new communities to form (Cuesta et al., 2019; Hock et al., 2019; Muhlfeld et al., 2020). The risk of extreme events such as wildfire, drought, floods and landslips is increasing in a wide range of places as a result of climate change and the evidence of the disturbance they cause to ecosystems has grown in recent decades (Section 2.3.1, Box CCP5.1). The impacts of such extreme events may be larger than those of incremental changes.

For species at lower elevations, mountains may represent refugia to which they can retreat. In this respect, Elsen et al. (2018) have highlighted the importance of protecting areas along elevational gradients. This applies in freshwater as well as terrestrial habitats with mountain streams acting as potential refugia (Isaak et al., 2016). In contrast, species restricted to the highest elevations are increasingly at risk, including from competition with colonising species (Britton et al., 2016; Winkler et al., 2016). Mountain top species are often separated from potential new habitat by large areas with unsuitable climates and tropical mountain species often have particularly narrow thermal tolerance and limited dispersal capacity (Polato et al., 2018).

The risks posed by non-native species may increase with climate change (Carboni et al., 2018; Shrestha et al., 2018; Thapa et al., 2018). Koide et al. (2017) found that non-native plant species on Hawaii were moving to higher elevations, whereas native species distributions were retracting at their lower elevational limit. Dainese et al. (2017) found that non- native plant species spread to higher elevations approximately twice as fast as native species. Following recent climate warming, invasive bamboo *Phyllostachys edulis* and *Phyllostachys bambusoides* (Poaceae) in Japan has shifted northward and upslope in the last three decades (Takano et al., 2017). New evidence has shown that variations in microclimate, with topography and cold groundwater seeps, can provide micro-refugia small areas of locally suitable conditions where cold adapted species can survive (Bramer et al., 2018; Muhlfeld et al., 2020) (Section 2.6.2). Some alpine species have thrived in recent years, and the range of microclimates may partly explain this (Rumpf et al., 2018).

Treeline elevation is linked to temperature (Paulsen and Körner, 2014) but may also be affected by water supply (Sigdel et al., 2018; Lu et al., 2021) and land management. A recent summary of treeline shifts worldwide found that 67% of studied alpine treelines had shifted upwards while 33% remained stable (based on 142 published studies); 88.8% of the 143 undisturbed alpine treelines across the northern Hemisphere had shifted upwards (Hansson et al., 2021; Lu et al., 2021). Since AR5, new evidence of shifting treeline ecotones has emerged for a wide variety of species in different locations including in Siberia (Pospelova et al., 2017), various parts of the Ural Mountains (Shiyatov and Mazepa, 2015; Zolotareva and Zolotarev, 2017; Sannikov et al., 2018), in Canadian Rocky Mountains (Trant et al., 2020) and Himalaya (Tiwari and Joshi, 2015; Chakraborty et al., 2016; Gaire, 2016; Yadava et al., 2017). Recent studies of treelines that have not or hardly shifted include the Himalaya (Singh et al., 2015; Sigdel et al., 2018), eastern Tibetan Plateau (Wang et al., 2020), and the Andes (Lutz et al., 2014). Migration rates are not proceeding as fast as warming climate, implying other processes also limit treeline ecotone response (e.g. Sigdel et al., 2020; Lu et al., 2021).

Whether treeline shifts occur, and if so at what rate, depends on a range of factors including: land use (especially livestock grazing and fire), species interactions, wildfires, and climatic stress factors (wind, frost, drought, excess or shortage of snow) interacting with tree population processes (viable seed production, dispersal, seedling establishment, clonal propagation, growth, dieback, mortality). Differences in treeline shifts between North- and South-facing slopes have been demonstrated in the Rocky Mountains (Elliott and Cowell, 2015). Grigorieva and Moiseev (2018) showed that significant factors limiting the number of seedlings and shoots are the snow depth, the topsoil temperature dependent on it, and the degree of competition from the parental tree stand and grass–shrub vegetation. There is also an influence of land use and management in many mountains around the world. Suwal et al. (2016) found that elevational shifts in Himalayan silver fir in Nepal were larger when areas were protected from management. Similarly, Lutz et al. (2014) found faster treeline shifts in the Peruvian Andes in protected areas than that in other areas, where cattle grazing and fires are more frequent. Treeline ecotones can also change independent of climate change if land use changes (Vitali et al., 2019; Körner, 2020).

Changes in community composition are also happening within ecosystem types. Duque et al. (2015) showed a change in the composition of north Andean forests, and Feeley et al. (2013) in that of forests up to 2800 m in Costa Rica. In both cases the proportion of species adapted to warmer conditions increased, driven primarily by patterns of mortality, indicating that the changes in composition are mostly via range retractions, rather than range shifts or expansions. An analysis of 200 forest inventory plots in the Andes likewise indicated a widespread, though not ubiquitous, thermophilization of the tree species' composition (Fadrique et al., 2018). Within a period of eight years (2003–2010), significant shifts in communities of vascular plants, butterflies and birds were found in Switzerland (Roth et al., 2014). At lower elevations, communities of all species groups changed towards warm-dwelling species, corresponding to an average uphill shift of 8 m, 38 m and 42 m in plant, butterfly and bird communities, respectively. However, rates of community changes decreased with elevation in plants and butterflies, while bird communities shifted towards warm-dwelling species at all elevations (Roth et al., 2014).

Changes in mountain biodiversity and ecosystems have a wide range of impacts on ecosystem services and effects on people. Some mountain ecosystems, particularly those with peatlands or forests are important carbon stores and climate change presents a risk to these in some locations (Dwire et al., 2018) (Sections 2.4.3.8; 2.4.4.4; 2.4.4.5). Palomo (2017) identified a wide range of threats to the lives, livelihoods and culture of mountain people as a consequence of the impacts of climate change on ecosystems. However, impacts are very heterogeneous between locations, even within the same region and ecosystem type (for example mountain forests in Europe; Mina et al. (2017) and are not necessarily all negative. As well as changes in services, other impacts on humans from a changing climate may be mediated through species and ecosystems, for example changes in vector distribution shifting disease incidence into higher elevation areas (Escobar et al., 2016).

[START BOX CCP5.1 HERE]

Box CCP5.1: Wildfires and Mountain Ecosystems

Mountain ecosystems have long been known to be highly sensitive to the direct impacts of climatic warming and drying (Beniston et al., 1994; Nogués-Bravo, 2009; Gottfried et al., 2012; Guisan et al., 2019). Furthermore, wildfires in these ecosystems, as with many others (Sections 2.4.4.2 and 2.5.3.2), are also expected to increase (Abatzoglou et al., 2019). This is because the occurrence and severity of fire is governed by four fundamental processes that are intricately linked to climate: 1) fuel biomass growth; 2) fuel moisture and type; 3) ignition source; and 4) favourable weather conditions for fire spread (Bradstock, 2010).

In temperate and tropical mountain ecosystems, increases in fire activity are potentially linked to changing climate on most continents, including Europe (Dupire et al., 2017), North America (Westerling, 2016; Halofsky et al., 2020; Burke et al., 2021), South America (Román-Cuesta et al., 2014), Africa (Hemp, 2005), Asia (Tian et al., 2014) and Australia (Bradstock et al., 2014; Abram et al., 2021). In these ecosystems, fire frequency, severity and extent (i.e. the fire regime) are increasing because of climate-induced impacts on fuel moisture (Gergel et al., 2017; Littell et al., 2018), vegetation composition (i.e. fuel types) (Camac et al., 2017; Prichard et al., 2017; Zylstra, 2018), fire-conducive weather patterns and the length of fire seasons (Westerling, 2016; Fill et al., 2019; Di Virgilio et al., 2020).

Fire in mountain ecosystems alters many ecological processes and ecosystem services across all elevational zones, from foothill montane forests to the high elevation alpine (treeless) zones (Turner et al., 2003; Williams et al., 2008; Oliveras et al., 2014; Rocca et al., 2014; Oliveras et al., 2018). However, the magnitude of short-term and long-term fire impacts depends on the degree of novelty of future fire regimes and the capacity of species to adapt to change (Camac et al., 2017; Archibald et al., 2018; Camac et al., 2021).

Montane and subalpine ecosystems have variable ecological responses to fire that are ultimately influenced by long-term, historical fire regimes and the evolutionary forces that have governed post-fire regeneration strategies of the biota. Two contrasting strategies in temperate forests are illustrated here. SE Australian mountain ash (*Eucalyptus regnans*) forests are adapted to a high severity fire regime, consisting of infrequent (>100 years), large stand-replacing wildfires (Bowman et al., 2016). Mountain ash is a long-lived obligate seeder but is slow to reach reproductive maturity (>20 years; Bowman et al., 2016). As such, natural post-fire regeneration takes decades to centuries to recover to pre-fire conditions, and if fire recurs before reproductive maturity is reached, the species can be eliminated. By contrast, ponderosa pine (*Pinus ponderosa*) forests of the SW United States have evolved with a low- or mixed-severity fire regime, where fire is frequent (5-25 year), low intensity, less likely to kill the dominant stand, and thus, allow faster post-fire recovery (Prichard et al., 2017). However, post-fire recovery times in this ecosystem are also becoming longer due to a century of effective fire suppression shifting the fire regime to one which is more infrequent, high-intensity, extensive and stand replacing (Prichard et al., 2017).

Above the treeline, fire is less common than in foothill forests. Post-fire recovery times also tend to be shorter (Williams et al., 2008; Camac et al., 2013; Verrall and Pickering, 2019) because of the dual influences of the low flammability traits coupled with most alpine plant species exhibiting strong resprouting strategies that have evolved in response to harsh climate conditions (Körner, 2003). However, fires in alpine treeless landscapes can still have long-term and catastrophic impacts on fire-sensitive vegetation types such as ground-water dependent wetlands dominated by hygrophilous plants and peat soils (De Roos et al., 2018). Similar impacts can be severe on long-lived, slow growing vegetation such as coniferous heathlands (Bowman et al., 2019), and highly restricted and threatened fauna (e.g. Mountain pygmy possum) that depend on these plant communities (Gibson et al., 2018). Such fires have even been found to have significantly impact subalpine treeline mortality rates (Fairman et al., 2017), and in some cases have resulted in treelines shifting to lower elevations (e.g. Hemp, 2005).

The long-term implications of a warmer global climate, coupled with more frequent and/or severe fires in mountain ecosystems, are expected to be transformative for mountain biota. Fire sensitive montane forests, such as Australia's alpine ash (*Eucalyptus delegatensis*) are expected to become highly susceptible to population collapse and local extinction as intervals between fire events contract and become too short for species to reach reproductive maturity (Bowman et al., 2014; Enright et al., 2015) – an impact that will *likely* be further exacerbated by recruitment failure caused by post-fire drought and moisture deficiencies (Davies et al., 2019; Halofsky et al., 2020; Rodman et al., 2020). Fire and climate change are also *likely* to act synergistically in mountainous ecosystems, via positive feedbacks that increase fire frequency by changing vegetation composition to more flammable fuel types, and thus increasing landscape susceptibility to future fire (Camac et al., 2017; Tepley et al., 2018; Zylstra, 2018; Lucas and Harris, 2021). More frequent fires in these ecosystems will also exacerbate native and exotic species invasions (Catford et al., 2009; McDougall et al., 2011; Gottfried et al., 2012; Kueffer et al., 2013), faunal population declines (Ward et al., 2020), poor air quality (de la Barrera et al., 2018; Burke et al., 2021), soil erosion and landslide risk (de la Barrera et al., 2018), and reduce freshwater catchment volumes and quality (Rust et al., 2018; Niemeyer et al., 2020), all of which will impact negatively on human health and wellbeing (Ebi et al., 2021).

Taking this evidence together, there is a significant risk of wildfire exacerbating other impacts of climate change on already vulnerable ecosystems in many mountain regions (*medium confidence*).

[END BOX CCP5.1 HERE]

CCP5.2.2 Water and Energy

CCP5.2.2.1 Water

Water is a fundamental source of life in mountain regions; it is also a central element and 'connector' in coupled natural-human systems and bears diverse meanings in different socio-cultural contexts, including in indigenous ontologies (Boelens, 2014). Water is also a key component connecting upstream mountains and downstream lowlands (Salzmann et al., 2016; Di Baldassarre et al., 2018; Encalada et al., 2019). Mountains are of paramount importance as water towers for people in the mountains and for around 2 billion people living in connected lowland areas (Immerzeel et al., 2020; Viviroli et al., 2020).

Mountain river systems are especially sensitive to, and affected by, climate change and continuing anthropogenic disturbance, including water pollution, hydropower development, water withdrawals for agriculture and human consumption, and biodiversity loss and ecosystem changes (Honda and Durigan, 2016; Encalada et al., 2019; Bissenbayeva et al., 2021; Chen et al., 2021) (*high confidence*). The effect of climate and cryosphere change in mountains on downstream water and river systems has been studied and quantified for many regions worldwide (Barnett et al., 2005; Huss, 2011; Lutz et al., 2014; O'Neel et al., 2015; Huss and Hock, 2018). Comprehensive approaches focusing on both water demand and supply aspects provide regionally or locally specified information on water availability, scarcity and security (Buytaert et al., 2014; Drenkhan et al., 2015; Brunner et al., 2019) (Chapter 4). Present and potential future hotspot regions of water scarcity that rely heavily on mountainous water sources include Central Asia, South Asia, tropical and subtropical western South America, and southwestern North America (*robust evidence, medium agreement*) (Kummu et al., 2016; Biemans et al., 2019; Immerzeel et al., 2020; Viviroli et al., 2020).

Figure CCP5.2 represents different levels of dependences of lowland areas on mountain water. At a global scale, 68% of irrigated agricultural areas in lowlands depend on essential runoff contributions from the mountains. The dependence of lowland populations on essential mountain runoff contributions increased by a factor of more than three from the 1960s to the 2000s, with increases of up to ten-fold in some major river catchments (Viviroli et al., 2020).

Many mountain regions have one or more cryosphere components (glaciers, permafrost and perennial or seasonal snow), and the mountain cryosphere is among the natural systems most sensitive to climate change worldwide (*high confidence*). The SROCC assessed a decline in all cryosphere components due to climate change over the past decades, i.e. for low-elevation snow cover (*high confidence*), permafrost (*high confidence*), and glaciers (*very high confidence*) (Hock et al., 2019). More recent studies using globally more complete data sets show a considerably higher glacier mass loss (267 ±16 Gt yr^{-1}) for 2000-2019 as compared to a (*very likely*[2]) range of 123 ±24 Gt yr^{-1} for 2006-2015 in SROCC, with a mass loss acceleration of 48 ±16 Gt per year and decade over 2000-2019 (Hugonnet et al., 2021). Assessment conclusions in SROCC found with *high confidence* that glacier shrinkage and snow cover changes over the past two decades has led to changes in the amount and timing of runoff in many mountain regions (Hock et al., 2019).

The effects of climate and environmental changes in upstream areas on downstream water quantity and quality, including nutrient, pollutant, heavy metals and sediment flux, have only been assessed in a limited number of catchments (Rakhmatullaev et al., 2009; Dong et al., 2015; Milner et al., 2017; Ilyashuk et al., 2018; Lane et al., 2019; Li et al., 2020; Chen et al., 2021). Groundwater contributions to streamflow are highly variable in mountains, but can be substantial (up to 70 to 80% or more) during low-flow periods (Frisbee et al., 2011; Baraer et al., 2015; Gordon et al., 2015; Käser and Hunkeler, 2016; Somers et al.,

[2] In this Report, the following terms have been used to indicate the assessed likelihood of an outcome or a result: Virtually certain 99–100% probability, Very likely 90–100%, Likely 66–100%, About as likely as not 33–66%, Unlikely 0–33%, Very unlikely 0–10%, and Exceptionally unlikely 0–1%. Additional terms (Extremely likely: 95–100%, More likely than not >50–100%, and Extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*). This Report also uses the term '*likely* range' to indicate that the assessed likelihood of an outcome lies within the 17-83% probability range.

2019). Groundwater may provide some resilience to loss of melt water from glacier and snow decline but in the longer term groundwater recharge and contribution to streamflow is expected to decrease with ongoing climate change (*medium confidence*) (Somers and McKenzie, 2020). In some mountain regions springs are a particularly important source of water, e.g. in the Himalayan region where large populations depend on them. Observations indicate reduction of water provision from springs in recent years in the Himalaya, caused by multiple causal factors (human interventions, climatic) (section 10.4.4.).

Both small-scale interventions (e.g. livestock grazing in sensitive high-elevation wetlands) as well as high-investment interventions (e.g. hydropower dams and plants) in upstream regions can strongly affect water availability, river connectivity, biodiversity and catchment management (Anderson et al., 2018; Ramsar Convention on Wetlands, 2018; Encalada et al., 2019), and are often contested and have led to conflict (*medium evidence, high agreement*) (Drenkhan et al., 2015; French et al., 2015). Climate change often exacerbates tensions or conflicts between different users over water at local, national and transboundary or regional scales; many tensions and social or political conflicts are documented, especially in seasonally dry regions; where large power inequalities among users exists; where clear and established regulations are lacking; and especially also in transboundary settings (e.g. Central Asia, Hindu-Kush-Himalaya, Andes) (Carey et al., 2014; Bocchiola et al., 2017; Yapiyev et al., 2017; Hock et al., 2019; Mukherji et al., 2019).

Water plays a fundamental role in climate change adaptation in mountains. A majority of documented adaptation efforts in mountain regions address water-related aspects (precipitation variability and extremes, including drought, water availability, floods) (McDowell et al., 2019; McDowell et al., 2020) (*high confidence*). This is a robust finding across different mountain regions and adaptation project and program types, and also in line with findings for cryosphere change related adaptation as reported in SROCC (Hock et al., 2019). Water also plays a role for adaptation in other sectors such as agriculture, disaster management and tourism and recreation (McDowell et al., 2019). There is *high confidence* that water conservation efforts, also including restoration and protection of particularly vulnerable areas (e.g., wetlands), and increase of efficiency in water use, are robust, low-regret adaptation measures.

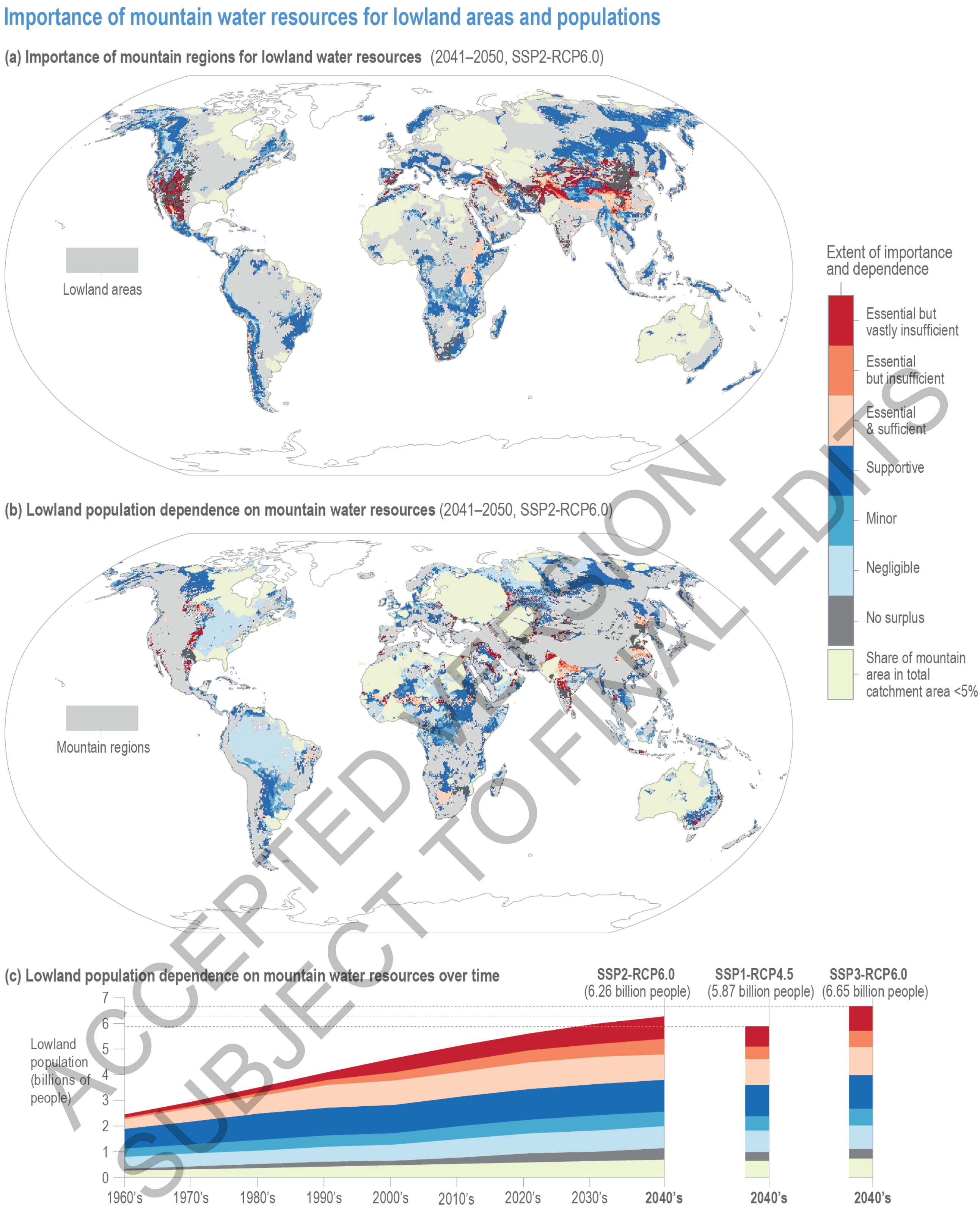

Figure CCP5.2: Dependence of land surface areas and population on mountain water resources 1961–2050. Results are shown as decadal averages for lowland population in each category of dependence on mountain water from no surplus and negligible to essential; a) map of global mountain regions and their differentiated importance for lowland water resources; b) map of lowland population and their differentiated dependence on mountain water resources, both for the scenario combination SSP2-RCP6.0 and for the time period 2041-2050; c) number of lowland population and their differentiated dependence on mountain water resources from the 1960's to the 2040's for three different scenario combinations (based on Viviroli et al., 2020).

CCP5.2.2.2 Energy

Increasing temperatures and variability in precipitation and river flow affect energy availability and use in mountain regions. Mountain peoples, more so than national or global populations, are dependent on local sources of energy, accentuating climate adaptation cost and barriers (*medium evidence, high agreement*) while also offering opportunities for mountain-specific solutions (*medium evidence, high agreement*). In mountain regions, inadequate infrastructure (Tiwari et al., 2018), remoteness, and reliance on traditional forms of energy that may be difficult to diversify (Dhakal et al., 2019), exacerbating impacts of climate change on energy use and demand.

A review of the renewable energy transition in the context of adaptation across global mountain regions, including hydropower, wind, solar and biomass, shows that observed climate change impacts on these energy sources include altered seasonality, timing as related to snow and glacial melt runoff (30.9% of analysed cases), variable or declining precipitation and runoff (26.4%), increased flooding (15.5%), altered wind patterns (8.2%), and other/not specified effects (19.1%) (Scott et al., 2019). Combined effects of climate change, hydropower development and further anthropogenic effects in upstream mountain basins, have increased and are expected to further negatively affect several aspects of ecosystem functions and water security (e.g. negative effects on river geometry, water chemistry, sediment transport, fish composition and migration) (Anderson et al., 2018; Encalada et al., 2019; Lepcha et al., 2021) (*high confidence*).

With respect to hydropower, mountains have a unique role for the production of renewable energy for large downstream populations, but it also comes with important trade-offs affecting mountain ecosystems and populations (*high confidence*) (Farinotti et al., 2019; Viviroli et al., 2020; Vaidya et al., 2021). Climate change requires adaptation in the hydropower sector; for instance, some advocate for increased water storage in dams and the importance of mountains for pumped hydropower storage systems (Gurung et al., 2016; Hunt et al., 2020), while others emphasize adaptive water management (Gaudard et al., 2014; Caruso et al., 2017b). An example is multi-purpose use of water strategies where water management storage is designed to accommodate different uses, including hydropower, agriculture, and flood risk reduction (Haeberli et al., 2016a; Drenkhan et al., 2019) (Section 12.6.3). Hydropower is also particularly exposed to glacier and snow decline (Schaefli et al., 2019), and is subject to risks from extreme events (Rangecroft et al., 2013; Schwanghart et al., 2016; Mishra et al., 2020; Shugar et al., 2021), social and political opposition (Ahlers et al., 2015; Díaz et al., 2017) and the resulting financial uncertainty for hydropower investors. There is still *limited evidence* on how climate change impacts wind, solar and biomass energy production, and use.

Overall, synergies between adaptation to climate change and renewable energy transition can be successfully generated where benefit-sharing improves local involvement and support, adaptive capacity is enhanced, local health and livelihoods supported, Sustainable Development Goals (SDGs) met, and environmental justice considered and sustainable mountain development pursued (*high agreement, medium evidence*).

CCP5.2.3 Food, Fibre, and Other Mountain Ecosystem Products

There is *high confidence* that climate change is largely negatively impacting on food, fibre and other ecosystem products, including agriculture (Porter et al., 2014; Ingxay et al., 2015; Upgupta et al., 2015; Chirwa et al., 2017; Rojas-Downing et al., 2017; Chitale et al., 2018; Pretzsch et al., 2018; Barberán et al., 2019; Sultan et al., 2019; Huang and Hao, 2020; Godde et al., 2021), and ecosystem services (Grêt-Regamey and Weibel, 2020) across many different mountainous region e.g. Africa (Bondé et al., 2019; Musakwa et al., 2020), Asia (Guo et al., 2018; Sunderland and Vasquez, 2020), Europe (Nair, 2019), North America (Hupp et al., 2015; Prevéy et al., 2020), South America (Herman-Mercer et al., 2020) (Section 5.4, 5.4.1, 5.5.1, 5.6.2, 5.7, 5.11.1.1).

Ecosystem products are vital to support the livelihoods and economic prospects for communities living in and around mountains (Figure CCP5.3). For instance, collection and trade of caterpillar fungus contributed to 53.3 - 64.5% annual household cash income in Nepal (Shrestha and Bawa, 2014; Shrestha et al., 2019); 40-80% in Bhutan (Thapa et al., 2018); 60-78% in Uttarakhand, India (Laha et al., 2018; Yadav et al., 2019) (Section 5.7.1). Livelihood support from ecosystem products in Southern Malawi region (Pullanikkatil et al., 2020), south-western Ethiopian mountains (Nischalke et al., 2017) and Southern China (Min et al., 2017), Himalayan mountains (Nepal et al., 2018), South Africa (Ngwenya et al., 2019) is reported. Additionally, the sacredness of mountains in different religions and cultures is widely acknowledged (Ceruti, 2019; Benedetti et al., 2021).

Climate change and associated impacts on multiple ecosystem services and related products (timber production, carbon sequestration, biodiversity and protection against natural hazards) have been observed across European mountains, e.g. in central Iberian Mountains (Spain), Western and Eastern Alps (France, Austria) and Dinaric Mountains (Slovenia) (Mina et al., 2017). Dumont et al. (2015) demonstrated that climate change negatively affects the forage nitrogen (N) content by 8% but increase the total non-structural carbohydrate content by 25% in European mountains. Positive impacts have been reported on mushroom productivity in the mountains of Spain (Karavani et al., 2018) (Section 5.7.3.3), yet negative impacts on the *Ophiocordyceps* in the Himalayan region (Hopping et al., 2018), likewise on apple production in Himachal Pradesh, India, which declined by 9.4 tonnes per hectare in the past two decades (Das, 2021). Shifts in crop wild relatives richness from south to north, and increase in the numbers of threatened taxa with an increase of 1.5 and 3^0C temperature rise, have been observed in European mountains (Phillips et al., 2017).

Medicinal and aromatic plants and their secondary metabolites are also observed to be affected by climate change (Das et al., 2016; Zhang et al., 2019a) *(medium confidence)*. Phenological changes like early flowering and reduced vegetative phase are negatively affecting the productivity of such plants (Harish et al., 2012; Gaira et al., 2014; Maikhuri et al., 2018). While increasing atmospheric temperature and CO_2 are reported to improve the biomass of *Gynostemmapentaphyllum* (Chang et al., 2016) (Section 5.7.3.3), they adversely affect its antioxidant compounds/activity, health-promoting properties and phytochemical content (Gairola et al., 2010; Das et al., 2016; Kumar et al., 2020). Experimental trials have shown that when medicinal plants are stressed by drought there is an increase in phytochemical content, either by decreasing biomass or by increasing actual production of the metabolites (Selmar and Kleinwächter, 2013; Al-Gabbiesh et al., 2015) *(medium confidence)*. Strong effects of climatic and non-climatic factors have been observed to affect the distribution of selected medicinal plants species in northern Thailand (Tangjitman et al., 2015), as well as in Egypt, Sub-Saharan Africa, Spain, Central Himalaya, China, Nepal, with some species at risk of being lost (Munt et al., 2016; Yan et al., 2017; Brunette et al., 2018; Chitale et al., 2018; Zhao et al., 2018; Applequist et al., 2020). Negative climate-related impacts on the distribution range of forty one medicinal plant species have been predicted for Spanish and Asian mountains (Munt et al., 2016) (Section5.7.3.3), and decreasing size of fruits of *Myrica esculenta* in Himalaya (Shah and Tewari, 2016).

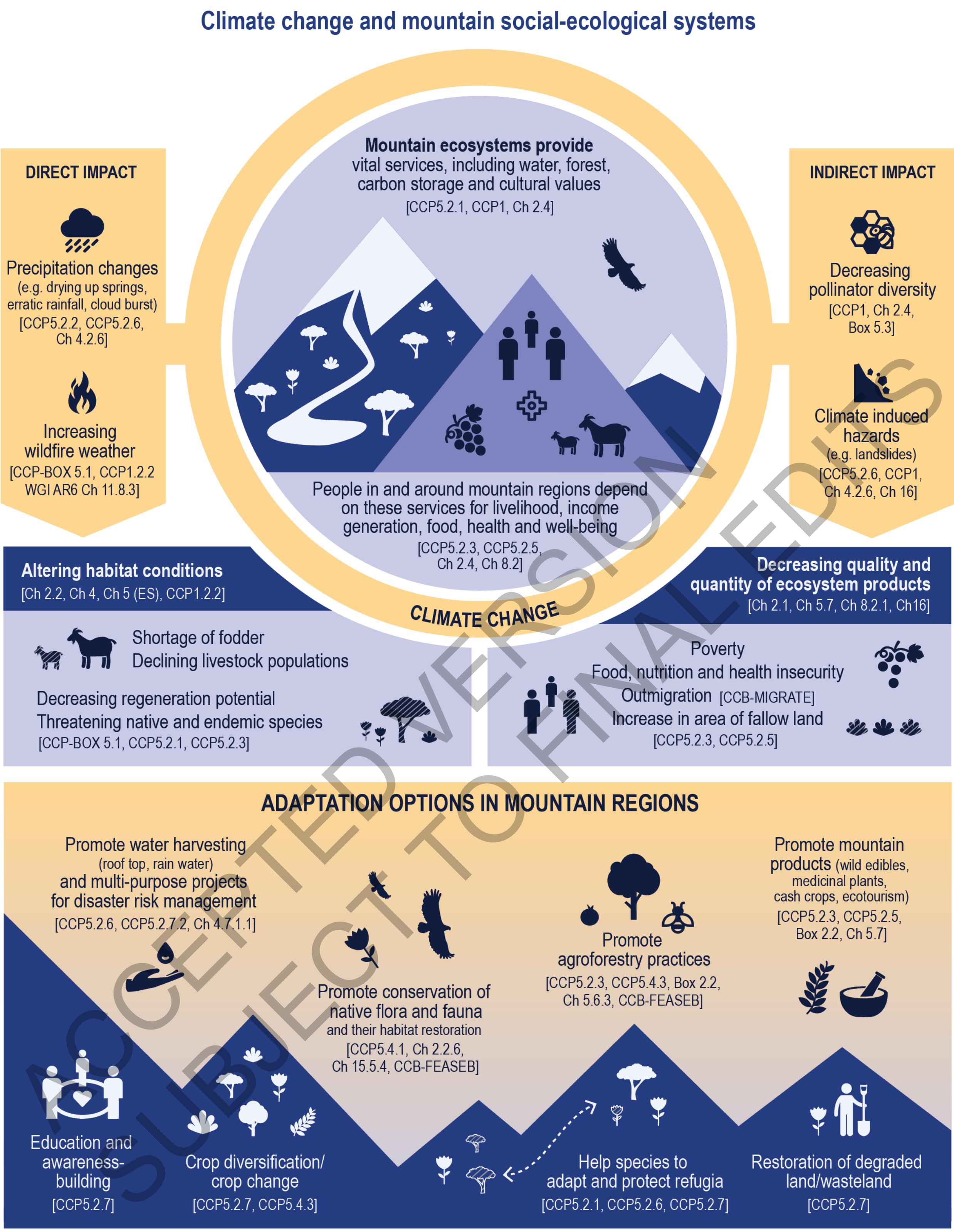

Figure CCP5.3: Impact of climate change on mountain social-ecological systems, including ecosystem services and products, livelihoods of mountain people and examples of adaptation options to address direct and indirect impacts.

CCP5.2.4 Cities, Settlements and Key Infrastructure

Mountain settlements and people are globally distributed and represent a significant proportion of the total global population that is exposed to the effects of climate change (Section CCP5.1, SMCCP5.1). Cities with one or several million inhabitants located in mountainous environments or at high elevations are predominantly found in Latin America e.g., in El Alto and La Paz (Bolivia), Quito (Ecuador), Mexico City (Mexico) and Bogotá (Colombia); Asia e.g., Kabul (Afghanistan), Kathmandu (Nepal), Srinagar (India), Peshawar (Pakistan), Quetta (Pakistan), Xining and Kunming (China), and Dehradun (India); and in Africa e.g., Harare (Zimbabwe) and Addis Ababa (Ethiopia) (Wang and Lu, 2018; Balderas Torres et al., 2021; Ehrlich et al., 2021). Mountain regions also host many settlements with fewer than 500,000 inhabitants (Alfthan et al., 2016). In many cases, particularly in developing countries, portions of the population also reside in informal and low-income settlements (French et al., 2021), where rates of poverty and inequality exacerbate their vulnerability and exposure to climate-related hazards such as landslides (Alfthan et al. 2018) (Section CCP5.2.5.1), environmental pollution or even pandemic diseases (Marazziti et al., 2021).

In many mountain regions, particularly in developing countries, the increasing urban population has put considerable pressure on water services and basic amenities for urban dwellers (Singh et al., 2021), for example in cities such as La Paz (Kinouchi et al., 2019), which are regions already under pressure due to the negative effects of climate change coupled with poor water availability and governance (Chapter 4; Section CCP5.2.2.1; FAQ CCP5.1; Hock et al. (2019). In many areas of the Hindu Kush Himalaya (HKH) region, water demand far exceeds municipal supply and people often cope with water insecurity in myriad ways (Bharti et al., 2020; Sharma et al., 2020; Singh et al., 2020), such as turning to inter-basin water transfers and deep pumping to supply their water needs (Ojha et al., 2020). Additionally, the influx of migrants, tourists and retirees, combined with the growth of the incumbent population, places considerable stress on urban infrastructure to supply adequate clean water and sewage disposal (Prakash and Molden, 2020), which is also observable in other regions (Chapter 4; Section 6.4.7; Case Study 6.1 in Chapter 6). Energy provision in and around mountain settlements, is another key sector affected by climate-related impacts (Hock et al., 2019) (CCP5.2.2.2), and which bear relevance for the adaptation prospects for urban mountain settlements (*medium confidence*).

CCP5.2.5 Mountain Communities, Livelihoods, Health and Wellbeing

People living in and around mountain regions strongly depend on the ecosystem functions, services and resources available in these areas for their livelihoods, health and wellbeing. Overall, subsistence agriculture and livestock remain key sources of livelihood in many mountain regions (FAO, 2019), with non-agricultural income sources such as remittances, small businesses, medicinal plants, wage labour and tourism also contributing to these economies (Montanari and Koutsoyiannis, 2014; Palomo, 2017; Minta et al., 2018). This section provides an illustrative overview of key reported observed impacts and adaptation responses to climate change on mountain communities (Table CCP5.1), and livelihood activities and economic sectors such as agriculture and pastoralism, and tourism and recreation (Table CCP5.2), reported since AR5.

Table CCP5.1: Overview of key observed impacts and adaptation on mountain communities – livelihoods and poverty; migration, habitability, and displacement; health and wellbeing.

Overview of key observed impacts and adaptation on mountain communities		References and relevant AR6 WGII Sections
Mountain livelihoods and poverty		
Impacts	• In some mountain regions, the incidence of poverty can be higher compared to other areas, with observed impacts of climate change intensifying the deterioration of socio-economic conditions that support livelihoods, thereby exacerbating already existing conditions of non-climate related vulnerabilities and livelihood insecurity (*medium confidence*).	Gioli et al. (2019); Tiwari and Joshi (2012); Rasul and Hussain (2015); Hussain et al. (2019); McDowell and Hess (2012); FAO (2015); FAO (2019); Shrestha et al. (2015); Motschmann et al. (2020a); Section 8.3
Responses and adaptation	• Diversification of livelihoods through the integration of drought-resilient livestock and crops and changes in farming practices (i.e. water management or migration of crops from low to high land) with some shifting to non-agricultural livelihood options, reported for cases such as in the HKH, the Andes, Rwenzori mountains of Uganda and Simien Mountains of Ethiopia.	Ashraf et al. (2014); Hussain et al. (2016a); Skarbø and VanderMolen (2016); Nkuba et al. (2020); Yohannes et al. (2020); CCP5.4.1

	Overview of key observed impacts and adaptation on mountain communities	References and relevant AR6 WGII Sections
Migration, habitability and displacement		
Impacts	• There is growing evidence of links between climate change impacts and migration and mobility through a complex web of causal links (*medium confidence*). In mountain contexts, migration and mobility are indirectly impacted by climate change through adverse effects on mountain livelihoods that are dependent on mountain ecosystem services.	Wrathall et al. (2014); Hunter et al. (2015); Brandt et al. (2016); Mastrorillo et al. (2016); Gautam (2017); Sagynbekova (2017); Cattaneo et al. (2019); Maharjan et al. (2020)
	• Extreme events are resulting in temporary and in some cases permanent displacement of populations in mountains (*medium confidence*), with hazards such as floods and mass movement (avalanche, flood, landslide) leading to population displacements e.g., in Afghanistan, Pakistan, Peru, Thailand, and Uganda.	Iribarren Anacona et al. (2015); Stäubli et al. (2018); IDMC (2020); Wang et al. (2020)
	• Cases of entire settlements either abandoned or relocated due to prolonged slow onset events such as water shortage, drought, and heat stress have been reported.	Mueller et al. (2014); Nawrotzki and DeWaard (2016); Prasain (2018)
	• In contrast, place attachment is increasingly cited as one of the reasons for the immobility choices for some people. However, in some cases, vulnerability to climatic events contribute to the in-migration decisions of vulnerable populations exposed to hazards from downstream to upland areas.	Adams (2016); Dandy et al. (2019); Khanian et al. (2019); Islam et al. (2020)
Responses and adaptations	• Migration, in turn, is often cited as a risk management strategy, where migration can lead to the diversification of livelihood options, improves access to information and resources, and expands social networks, all of which can support households in their capacity to adapt to climate change impacts • Migration is often gendered, with men migrating and leaving women to manage households at origin. Women's capacities are often constrained due to institutional barriers and social norms, resulting in low adaptive capacity and increased vulnerability to hazards. Capacity-building interventions strengthens adaptation capacity as well as links to access institutional support (*medium confidence*).	Banerjee et al. (2018); Banerjee et al. (2019); Siddiqui et al. (2019); Maharjan et al. (2020); Maharjan et al. (2021)
Health and wellbeing		
Impacts	• Direct links between climate change and health in mountain regions are reported in terms of physical injury or fatality due to exposure to climate-related hazards such as floods or landslides, or exposure to vector-borne diseases such as malaria or dengue fever reported at higher elevations with warming temperatures (*medium confidence*), such as in Mexico, Nepal, Ethiopia, and Colombia.	Dantés et al. (2014); Siraj et al. (2014); Dhimal et al. (2015); Wu et al. (2016); Equihua et al. (2017); Alfthan et al. (2018); Gilgel et al. (2019); Chapter 7
	• Indirect impacts to health by climate change are linked to water-borne diseases and pathogens associated with floods and droughts.	Table 7.6
	• Whilst reports on the ongoing challenges associated with the COVID-19 pandemic are emerging in relation to their compounding impacts on adaptive capacities, there is *limited evidence* to assess those effects with respect to other climate-related impacts on health.	Baiker et al. (2020); Cross-Chapter Box COVID in Chapter 7
	• Mental health issues associated with climate-related impacts are reported with respect to climate anxiety and ecological grief and their effects on the wellbeing of individuals. For example, the grief and loss associated with changes in glaciated landscapes, such as the 'death' of the Okjökull glacier in Iceland. However, there is *limited evidence* on mountain-specific cases and experiences that would allow for an assessment of the broader and longer-term impacts to mental health associated with a changing climate in the mountains.	Trombley et al. (2017); Cunsolo and Ellis (2018); Clayton (2020); Sideris (2020)
	• Other heightened vulnerability to climate-related impacts on health and wellbeing are also experienced by specific groups, for example	Furberg et al. (2011); Section 7.1.7.2

Overview of key observed impacts and adaptation on mountain communities		References and relevant AR6 WGII Sections
	Sami pastoralists facing changes in mountain snow cover that negatively affect their reindeer herding, a key activity for their identity and spiritual health.	
Responses and adaptations	• Approximately a fifth of observed adaptations reported in the GAMI mountain re-analysis address health and wellbeing as an aspect of vulnerability. This includes raising communities' awareness of and coping strategies climate change-induced health issues.	Furu and Van (2013); Section CCP5.4.1

Table CCP5.2: Overview of key observed impacts and adaptation on select livelihood activities and economic sectors – mountain agriculture and pastoralism; and tourism and recreation.

Overview of key observed impacts and adaptation on select livelihood activities and economic sectors		References and relevant AR6 WGII Sections
Mountain Agriculture and Pastoralism		
Impacts	• Changes in temperature and seasonal precipitation patterns are affecting the timing and availability of water for agricultural activities (*high confidence*), e.g. in the Bolivian Andes, Andean-Amazon foothills of Colombia, Ecuador, and Peru, High Atlas of Morocco, the Hindu Kush Himalaya (HKH), and Golestan province of Iran.	Rangecroft et al. (2013); Kaboosi and Kordjazi (2017); Hussain et al. (2018); Kalbali et al. (2019); Zkhiri et al. (2019); Beltrán-Tolosa et al. (2020); Torres-Batlló and Martí-Cardona (2020)
	• Changes in temperature and seasonal precipitation patterns are reported to affect nutrient depletion of soils and increased incidence of pest attacks in crops, e.g. in cases in the HKH and in Peru, however there is generally *limited evidence* on directs links to climate-related changes in mountain regions, specifically.	Oliver-Smith (2014); Hussain et al. (2016b)
	• Climate-induced hazards such as erratic precipitation (rain, snow and hail), floods, droughts and landslides have negatively affected the stable supply and transport of agricultural products in and out of remote mountain areas, such as in the Peruvian Altiplano and HKH.	Hussain et al. (2016b); Gonzales-Valero (2018); Thapa and Hussain (2020)
	• Warming temperatures and changes in timing of seasons and frost conditions needed for seeding of certain tree crops, are impacting lower elevation mountain areas, such as in Oman.	Buerkert et al. (2020)
	• Drought conditions are negatively affecting mountain grasslands (*medium confidence*), as reported in cases in Tyrol (Austria), Nepal, Afghanistan, Pakistan and China, which can contribute to a decline in agrobiodiversity.	Ashraf et al. (2014); Zomer et al. (2014b); Grüneis et al. (2018); Adhikari et al. (2019); Chaudhary et al. (2020); Hussain and Qamar (2020)
	• In some cases, climate-related hazards are leading to outmigration in mountain areas, with indirect negative impacts on labour deficits to support agricultural practices and productivity in mountain areas (*medium confidence*), e.g. in Ghana, Tanzania, Thailand and HKH.	Warner and Afifi (2014); Wester et al. (2019)
	• Positive impacts (favourable growing conditions) are reported for the production of some fruits and vegetables in Gilgit-Baltistan province of Pakistan, and for the production of traditional crops (e.g. local beans) in the Karnali region of Nepal.	Hussain et al. (2016b); Thapa and Hussain (2020)
	• Impacts on pastoralism include changes in growing conditions associated with warming temperatures and declining precipitation, which in turn leads to negative impacts on livestock productivity, food security and livelihoods of pastoralist communities, including drought-induced degradation of rangelands (*medium confidence*) e.g. in mountainous areas of Mongolia, Tanzania, Nepal, and Ethiopia, which exacerbate impoverished conditions for pastoral communities.	Batima et al. (2013); Rasul et al. (2014); Gentle and Thwaites (2016); Kimaro et al. (2018); Mekuyie et al. (2018); Tiwari et al. (2020)

Overview of key observed impacts and adaptation on select livelihood activities and economic sectors		References and relevant AR6 WGII Sections
Responses and adaptations	• Recharging groundwater and adopting rainwater harvesting (including appropriate tillage methods to improve soil moisture), restoration and rehabilitation of land, diversification of agricultural crops (including introduction of stress resistant crop varieties), promotion of in situ (protected areas, conservation areas) and ex situ (nurseries, gene banks, home gardens) conservation strategies, afforestation and agro-forestry.	Sections 4.7.1.1; 5.6.3; Cross-Chapter Box FEASIB in Chapter 18
	• Local knowledge is being used to help maintain the productive and cultural value of mountain agriculture and pastoralism, such as in the French and Italian Alps, Western Himalaya in India, and mountains in northern Morocco.	Fassio et al. (2014); Kmoch et al. (2018); Das (2021)
	• Ecosystem-based and community-based adaptation are contributing to supporting the diversity and complementarily of management options, permaculture, and local capacities to adapt and support ecosystem functions vital for agrobiodiversity (*medium confidence*).	Reid (2016); Grêt-Regamey and Weibel (2020); Cross-Chapter Box NATURAL in Chapter 2
Tourism and Recreation		
Impacts	• Since SROCC, the literature on climate change impacts on ski winter tourism has remained dominated by studies focused on future climate change impacts and projected risks due to decreasing seasonal snow reliability (see CCP5.3.1), most relevant when considering snow management and in particular snowmaking.	Hock et al. (2019); Sauri and Llurdés (2020); AR6 WG1 Sections 9.5.3 and 12.4.10.4
	• Climate-induced hazards in mountains, such as rockfalls, are negatively affecting access to some climbing, mountaineering, and hiking routes in summer (*medium confidence*), with cases mainly reported in the European Alps.	Hock et al. (2019); Mourey et al. (2019); Mourey et al. (2020)
	• Higher temperatures and extreme heatwave conditions at lower elevations have made some mountain destinations more appealing for human comfort, increasing the potential summer visitation demand and opportunities for tourism and recreation in mountains, such as in the European Alps and the Catalan Pyrenees (*medium confidence*). However, there is *limited evidence* reported for similar trends in mountain regions outside of Europe.	Serquet and Rebetez (2011); March et al. (2014); Pröbstl-Haider et al. (2015); Steiger et al. (2016); Juschten et al. (2019a); Juschten et al. (2019b)
Responses and adaptation	• Diversification of tourism activities to non-snow activities is reported as an adaptation approach to maintain economic viability in some winter ski areas, partly due to the high cost of running snowmaking infrastructure in winter e.g. in the Pyrenees (Europe) and Australian Alps.	Morrison and Pickering (2013); Sauri and Llurdés (2020)
	• In some cases, managing the availability and demand for water resources used for snowmaking is reported, with destination and large-scale governance highlighted as critical aspects for managing trade-offs, including overcoming conflicts arising from competing demands for environmental resources and land use, e.g. in the French Alps and in Scandinavia.	Demiroglu et al. (2019); Gerbaux et al. (2020)
	• For snow management, there are examples of dedicated climate services designed to enable better-informed decision making on appropriate long-term adaptation e.g. through a dedicated Copernicus Climate Change Service, or real-time early warning systems.	Köberl et al. (2021); Morin et al. (2021)
	• Barriers to adaptation strategies such as snowmaking, for instance in Switzerland, have been linked to perceived economic constrains to their implementation, as well as the social acceptability of these measures.	Matasci et al. (2014); Moser and Baulcomb (2020)
	• Adaptation options to limit exposure to hazards in hiking, climbing or mountaineering activities, include shifting the seasonal timing for practicing these activities, or changing routes entirely.	Hock et al. (2019); Mourey et al. (2019); Mourey et al. (2020)

Overview of key observed impacts and adaptation on select livelihood activities and economic sectors	References and relevant AR6 WGII Sections
• In some cases, such as in Bolivia, Peru, and New Zealand, and more recently reported in the French Alps, 'last chance' tourism has increased the appeal of some mountain destinations, resulting in visitation demand to witness the effects of climate change on iconic mountain landscape features such as glaciers.	Hock et al. (2019); Salim and Ravanel (2020)

Other sections in this CCP provide detailed assessments that synthesise impacts and adaptation on the detection and attribute of impacts to anthropogenic climate change (CCP5.2.7), projected impacts and key risks (CCP5.3), and adaptation responses to reduce those key risks (CCP5.4.1).

CCP5.2.6 Natural Hazards and Disasters

Climate and weather-related disasters in mountain regions have increased over the last three decades (*medium confidence*). Disaster frequency shows increasing trends in the Hindu Kush Himalaya, the Andes and mountain regions in Africa, whereas no clear trends for the European Alps and Central Asia are observed (*medium confidence*) (Froude and Petley, 2018; Stäubli et al., 2018).

Floods, debris flows, landslides and avalanches are the most frequent hazards affecting the highest number of people in mountain regions (*medium confidence*) (Stäubli et al., 2018). Landslides count amongst the deadliest hazards globally with over 150,000 reported fatalities for the period 1995-2014 (Haque et al., 2019). There is *high confidence* that the number of fatalities from landslides has increased globally over the past twenty years (Froude and Petley, 2018; Haque et al., 2019), but there is *limited evidence* that this is due to changes in landslide event frequency and/or magnitude. Infrastructure expansion on unstable terrain can increase disaster risk (Zimmermann and Keiler, 2015; Huggel et al., 2019; Kirschbaum et al., 2019; Schauwecker et al., 2019; Terzi et al., 2019; Motschmann et al., 2020a; Shugar et al., 2021). A study from western Nepal concludes that the exposure of people and infrastructure has been the main cause of disasters (Muñoz-Torrero Manchado et al., 2021). Decreasing numbers of fatalities from disasters resulting from decreasing vulnerabilities have been reported in Europe and North America (see Section 13.2.2.1*)* (Gariano and Guzzetti, 2016; Strouth and McDougall, 2021). Evidence from Africa suggests that disasters from climate induced natural hazards in mountain areas are often due to droughts, pests and changes to rainfall and associated impacts on smallholder farmers' agricultural livelihoods (Shikuku et al., 2017).

Characteristics of natural hazards in mountain areas have been largely explored and evidence suggests that conditions favouring cascading impacts are a common feature (*high confidence*) (Section 8.2.1.1) (Zimmermann and Keiler, 2015; Huggel et al., 2019; Kirschbaum et al., 2019; Schauwecker et al., 2019; Terzi et al., 2019; Motschmann et al., 2020a; Shugar et al., 2021). Compound and cascading impacts have affected people, ecosystems and infrastructure and generate significant spillovers across numerous sectors, resulting in destructive impacts (Nones and Pescaroli, 2016; Kirschbaum et al., 2019; Schauwecker et al., 2019).

Most adaptation responses to natural hazards in mountain regions are reactive and autonomous to specific climate stimuli or post-disaster recovery (*robust evidence, medium agreement*) (McDowell et al., 2019; Rasul et al., 2020). Hard structural measures such as dikes, dam reservoirs and embankments have largely been employed to contain the hazards alongside early warning systems, zonation and land management (Sections 4.4.1.3, 10.3, 12.5.3, 13.2.2). Awareness raising, preparedness and disaster response plans are increasingly used in the context of more unpredictable hazard trends (see Cross-Chapter Box DEEP in Chapter 17) (Allen et al., 2016; Allen et al., 2018; Hovelsrud et al., 2018). Ecosystem based adaptations (EbA) are widely implemented to mitigate risks from shallow landslides (e.g. afforestation and. reforestation and improved forest management), floods (e.g. river restoration and renaturation) (Renaud et al., 2016; Klein et al., 2019b) and droughts (e.g. adapting watershed) (Renaud et al., 2016; Klein et al., 2019b; Palomo et al., 2021).

Evidence from different mountain regions show that adaptation and risk reduction efforts are less successful if they focus on hazards or risks, without considering diverse risk and value perceptions of affected people (*medium confidence*) (French et al., 2015; Allen et al., 2018; Hovelsrud et al., 2018; Kadetz and Mock, 2018; Klein et al., 2019b). Previous experience and local social contexts of exposure to climate-related disasters affect the perception of people and influence the patterns associated with disaster risk management and associated coping strategies (*high confidence*) (see SROCC Chapter 2) (Kaul and Thornton, 2014; Shijin and Dahe, 2015; Landeros-Mugica et al., 2016; Wirz et al., 2016; Carey et al., 2017; Adler et al., 2019).

Important synergies exist between disaster risk reduction, climate change adaptation and sustainable development in mountain regions (*medium confidence*) (Zimmermann and Keiler, 2015), where the multiple and diverse perceptions of risk and risk tolerance to natural hazards are relevant considerations (Schneiderbauer et al., 2021). Global agreements for integrated disaster risk management and climate change adaptation (Alcántara-Ayala et al., 2017), including the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR, 2015), the SDGs (UN, 2015), the Paris Agreement (UNFCCC, 2015) and the New Urban Agenda-Habitat III (UN, 2016) create opportunities for synergies to address disaster risks (see also Section 6.3). Although these agreements are well established in the international agendas, there is *limited evidence* of their implementation to address disaster risk reduction and adaptation in mountains (Alcántara-Ayala et al., 2017).

CCP5.2.7 Synthesis of Observed Impacts and Attribution and Observed Adaptation

CCP5.2.7.1 Observed Impacts and Attribution to Anthropogenic Climate Change

The assessment of observed impacts identified a large number of impacts across all major mountain regions of the world and for a large variety of systems, based on more than 300 references (see SMCCP5.2). The literature was assessed, and results classified on a per regions and systems basis. Confidence statements on detection and attribution are based on expert judgement following IPCC guidelines (see Section 1.3.4), building on evidence from multiple sources in the literature (Mach et al., 2017) (see SMCCP5.2). Figure CCP5.4 provides an overview of the assessment results.

Climate change impacts have been documented in mountains of all continents. A wide range of human and natural systems have been affected by climate change to date, including the cryosphere, water resources, terrestrial and aquatic ecosystems, agriculture, tourism, energy production, infrastructure, health and life, migration, disasters and community and cultural values. The confidence levels for detection of impacts are generally in the range of medium to high. The contribution of climate change to the detected impact varies depending on the affected system, and climatic and non-climatic drivers. The highest levels of confidence for attribution of detected impacts to anthropogenic climate change is assigned to the cryosphere. More generally, those impacts are more strongly driven by increasing temperatures and show higher confidence for attribution than those impacts mainly driven by precipitation changes. The level of contribution of climate change to observed impacts is predominantly medium or high, indicating the high sensitivity of natural and human systems in mountains to climate change. Furthermore, the vast majority of detected impacts imply negative impacts on natural and human systems (*high confidence*).

Local knowledge plays an important role in documenting impacts of climate change in mountain regions. Since IPCC AR5 the evidence of meaningful climate change impacts being reported using local knowledge sources has increased substantially (*high confidence*). Similarly, important regional gaps present in the IPCC AR5 have been addressed here (e.g. Africa), resulting in a much more comprehensive and regionally balanced assessment and perspective.

Furthermore, the science of attributing negative impacts of climate change to anthropogenic emissions or even individual polluters is becoming increasingly important for climate litigation (Marjanac et al., 2017; McCormick et al., 2017; Otto et al., 2017; Setzer and Vanhala, 2019) and there is emerging evidence that mountains are becoming sites of litigation cases, with cases for instance in Peru, Colombia, and India (UNEP, 2017). Recent studies put litigation cases such as the Lliuya vs RWE case on risk of glacier lake floods in Peru in a broader context of differentiated responsibilities and justice (Huggel et al., 2020b).

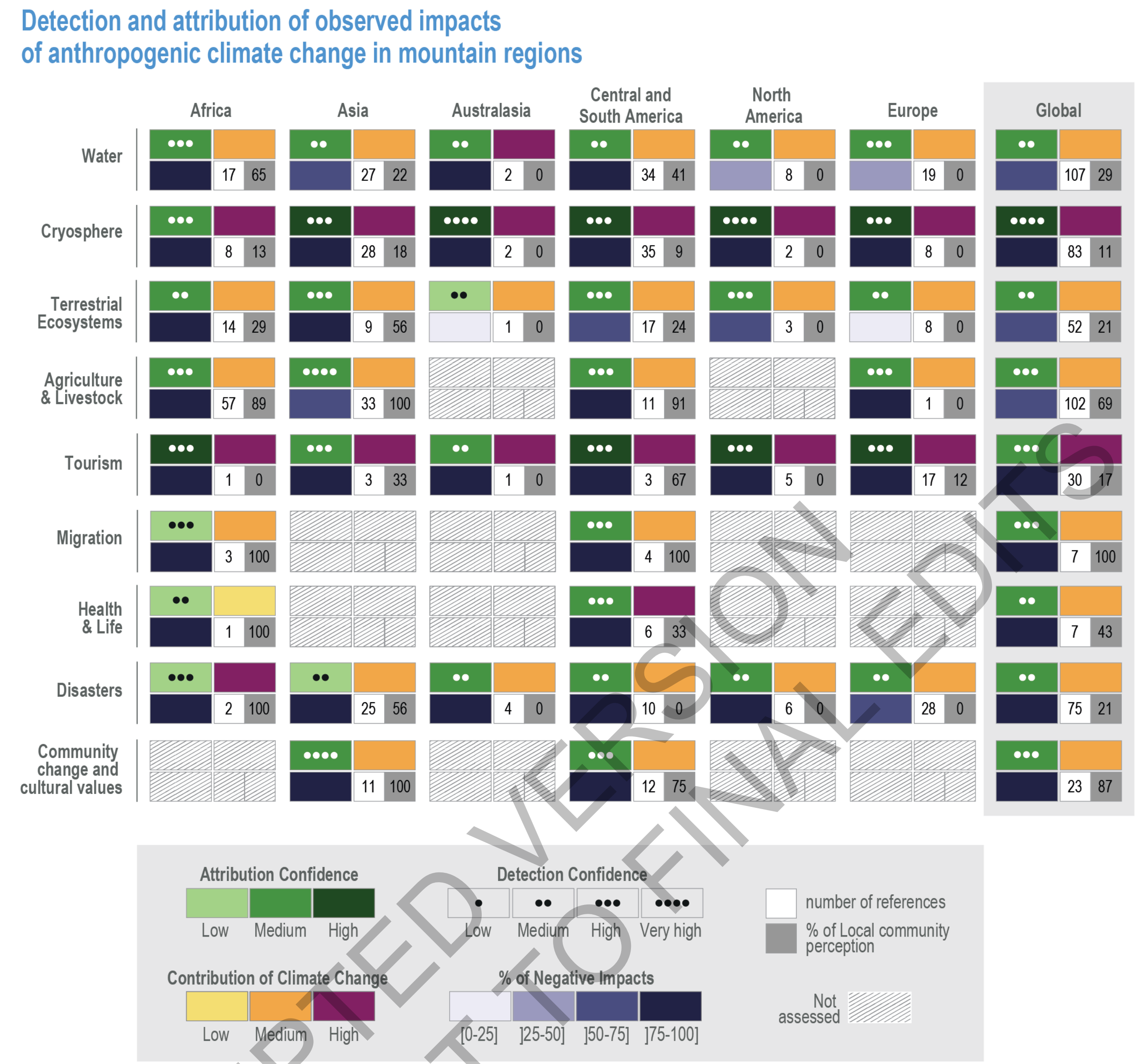

Figure CCP5.4: Synthesis of detection and attribution of impacts of anthropogenic climate change on different natural and human systems in mountain regions. For each system and region assessed, the level of confidence for detection and for attribution to anthropogenic climate change is indicated. Also indicated is how strong the contribution of climate change is to the observed changes, considering climatic and non-climatic causal factors. Observed impacts were analysed in terms of negative impacts (e.g. economic or non-economic damages, losses, contribution to increasing risks for society), where the numbers refer to the percentage of references indicating negative impacts for a given impact. The percentage of local community perception indicates the percentage of all literature references for a given system and region that account for local knowledge. The number of references refers to the total number of literature references considered for an impact to a specific system and region. "Not assessed" refers to *limited evidence* in the literature (see SMCCP5.2 and Table SMCCP5.5-5.14).

CCP5.2.7.2 Synthesis of Observed Adaptation

Extending from recent assessments of observed adaptation in high mountain areas (Hock et al., 2019; McDowell et al., 2019) new evidence for the geographically larger space for mountains assessed in this CCP is available from a mountain specific re-analysis of the GAMI dataset, which contains 423 articles reporting adaptation in mountains (Berrang-Ford et al., 2021; McDowell et al., 2021b) (SMCCP5.3), some of which also include those reported in section CCP5.2. In these articles, adaptation measures in mountains are reported from all regions worldwide, with predominance from Asia and Africa. Of all reported adaptations, 91% involve individuals or households, frequently engaged in smallholder agriculture and/or pastoralism; local governments are also often involved (31%) and sub-national or local civil society actors (29%) while private sector involvement remains scarce (below 10%). Food, fibre and other ecosystem products (76%) and poverty, livelihoods and sustainable development (55%) are by far most often involved in reported adaptation in mountains, followed by water and sanitation (28%) and health, well-being and communities (26%) (McDowell et al., 2021b) (SMCCP5.3.2).

Adaptation measures most commonly found include farming-related changes (e.g. resilient or drought-tolerant crop varieties, irrigation techniques, crop storage, and livestock insurance schemes), infrastructure development, Indigenous knowledge, community-based capacity building, and ecosystem-based adaptation (McDowell et al., 2021b) (SMCCP5.3.2) (*high confidence*). Nature-based solutions (NbS) are an adaptation component in NDC's of many mountain countries around the world (UNEP, 2021). Furthermore, Indigenous knowledge and local knowledge are often reported as informing adaptation efforts, and Indigenous Peoples, marginalized people and gender issues are recognized in several national adaptation strategies but autonomous responses are often insufficiently understood (Mishra et al., 2019).

The GAMI based re-analysis for mountains indicates that food security (75%), poverty (47%), consumption and production (36%), terrestrial and freshwater ecosystem services (19%) and clean water and sanitation (18%) are important aspects of vulnerability that adaptations address, with an emphasis on responses to climate-related shocks and stressors (McDowell et al., 2021b) (SMCCP5.2). The re-analysis also shows that more than 80% of adaptations in mountains are behavioural/cultural in nature, and more than 50% ecosystem-based, or technological or infrastructural.

About a third of the assessed adaptation activities are in the planning and early implementation stage, and around one-fifth in a stage of advanced implementation (McDowell et al., 2021b) (SMCCP5.3.2). Several lines of evidence converge, indicating that most observed adaptation in mountains is incremental in nature and not transformative (*high confidence*) (Mishra et al., 2019 ; McDowell et al., 2021b) (SMCCP5.3.2). Nevertheless, some adaptation measures such as NbS were found to bear important transformative potential in mountains if different knowledge types are combined, and community engagement and ecosystem management processes are in place (Palomo et al., 2021).

Overall, and consistent with findings in SROCC, there are still limited systematic monitoring and evaluation processes implemented to track adaptation progress, and there is *limited evidence* and prevailing uncertainties on the extent to which observed adaptation efforts reduce risks (Hock et al., 2019; McDowell et al., 2021b; UNEP, 2021) (SMCCP5.3.2).

Limits to adaptation are found in a majority (>80%) of the assessed adaptation studies; around half of the studies reported soft limits and less than a third identified both hard and soft limits to adaptation (McDowell et al., 2021b) (SMCCP5.3.2) (*high confidence*). Soft limits are frequently related to governance, economics, and social/cultural constraints, and can be overcome in principle through targeted efforts to address social conditions that impede adaptation planning and action. Hard limits are more frequently described as biophysical, such as precipitous declines in water supply. Examples of adaptation limits include lack of access to credit and markets, fixed livelihoods, insufficient awareness of climate risk, poor access to technology, and the erosion of existing skills and knowledge, social inequities, lack of trust and social cohesion, inequitable gender norms, and perceptions of conflict or scarcity. Furthermore, land tenure insecurity, poor integration of adaptation programmes across governing scales, and lack of decision-making power among vulnerable groups, along with inadequate funding for government-implemented adaptation programmes are reported to limit adaptation (Mishra et al., 2019; McDowell et al., 2021b) (SMCCP5.3.2). Hard limits imply that further adaptation action is unfeasible, ineffective, or unacceptable, resulting in inevitable losses and damages in mountain areas (Huggel et al., 2019) (*medium evidence, medium agreement*).

Overall, adaptation in mountain regions is taking place in various ways, in different sectors, scales, levels, quality, and effectiveness (*high confidence*). Most responses are incremental, with asymmetries of power among state, institutions and individuals, costs or capital requirements of adaptation, lack of coordinated planning, resistance to institutional change, household risk aversion, and lack of access to information inhibiting more transformational responses (SMCCP5.3.2). Aside from poverty reduction, there is *limited evidence* of adaptations effectively remediating the underlying social determinants of vulnerability (e.g. gender, ethnic identity).

CCP5.3 Projected Impacts and Risks in Mountains

CCP5.3.1 Synthesis of Projected Impacts

Declines and extinctions have been projected in a range of montane plants and animal species, including rare endemic species and subspecies due to climate change (*medium evidence, high agreement*) (Li et al., 2017; Ashrafzadeh et al., 2019; Brunetti et al., 2019; Zhang et al., 2019b; Manes et al., 2021). Up to 84% of endemic mountain species are found to be at risk of extinction (Manes et al., 2021). By using a simple model, Helmer et al. (2019) predict a large-scale contraction in the next 25 years of alpine ecosystems above tropical mountains cloud forest in the Andes due to tree invasion. Topographic complexity can smoothen and delay transition of montane forests in terms of size and composition for warming up to 3°C GWL (Albrich et al., 2020).

Hydrological changes will determine how some ecosystems change, more than changes in temperature. For example, (Dwire et al., 2018) found that changes in riparian areas, wetlands and forests were likely under climate change in the Blue Mountains, Oregon, USA, as a result of altered snowpack, hydrologic regimes, drought and wildfire. In the Bolivian Cordillera Real, wetland cover variations were associated with increases in precipitation extreme events and glacier melting over the 1984-2011 period but might be reversed with predicted future decrease in both total precipitations and glacier run-off (Dangles et al., 2017). About 30% of the wetland area in the Great Xing'an Mountains, northeastern China has been projected to disappear by 2050, with this value doubling by 2100 under CGCM3-B1 scenario (Liu et al., 2011).

Climate change impacts on food, fibre and ecosystem products will be highly variable across mountain regions (*medium confidence*) (Briner et al., 2013; Rasul and Hussain, 2015; Mina et al., 2017; Palomo, 2017; Said et al., 2019; Xenarios et al., 2019) (Sections 10.4; 12.3; 13.5; 14.4). In some regions, tree crops that are cultivated at certain elevations may reach the limit of their agroclimatic plasticity, for instance for crop types that require winter chills and where projected growing conditions would be too warm (Buerkert et al., 2020). In the European Alps, agricultural production in some areas may benefit from temperature rises, as total productivity in grasslands is projected to increase (Mitter et al., 2015; Grüneis et al., 2018), whereas some areas in Asia and South America heavily depended on glacier- and snow fed irrigation will be at risk of food insecurity (Rasul and Molden, 2019). In a study in the Eastern Pamir, (Mętrak et al., 2017) found that summer droughts and water changes lead to functional transformations of the wetland ecosystems which can affect food security of the local population. Climate change affects the phenology of plants (Harish et al., 2012; Gaira et al., 2014; Maikhuri et al., 2018), secondary metabolites (Chang et al., 2016; Kumar et al., 2020), and pharmacological properties of medicinal plants (Gairola et al., 2010; Das et al., 2016).

Water resources in mountains and dependent lowlands will continue to be strongly impacted by climate change throughout the 21st century (*high confidence*). The difference in impacts will be particularly strong for regions that highly depend on glacier and snow melt, and in pronounced dry seasons (*high confidence*), regions including Central Asia, South Asia, tropical and subtropical western South America, and southwestern North America (Huss and Hock, 2018; Hock et al., 2019; Immerzeel et al., 2020). Glaciers are expected to continue to lose mass throughout the 21st century, with higher mass loss under high emission scenarios (AR6 WGI Chapter 9). Many low elevation and small glaciers around the world will lose most of their total mass at 1.5°C GWL (*high confidence*) (Marzeion et al., 2018; Vuille et al., 2018; Hock et al., 2019; Zekollari et al., 2020) (WGI 9.5). For tropical and mid-latitude mountains, around half of the current ice mass can be preserved under low-emission scenarios, while two-thirds up to more than 90% will be lost under high emission scenarios compared to the 2000's (*medium confidence*) (Schauwecker et al., 2017; Vuille et al., 2018; Hock et al., 2019) (WGI 9.5). Strong differences in impacts between the emission scenarios are also assessed for decline in snow depth or mass at lower elevation [10 to 40% for RCP2.6 and 50 to 90% for RCP 8.5 by the end of the century (Hock et al., 2019)]. However, limitations in long-term climate, glaciological and hydrological monitoring data adds uncertainty to current understanding and adaptation support, e.g. when peak water is reached in different mountain catchments (Salzmann et al., 2014; Hock et al., 2019). Furthermore, context specific socio-cultural and economic factors can magnify, or moderate impacts related to hydrological change (McDowell et al., 2021a).

The dependence of lowland populations on mountain water resources will grow by mid-century across several climate and socio-economic scenarios, and several seasonally dry or semi-arid mountain regions (e.g. parts of South Asia, North America) are projected to be highly dependent (*medium confidence*) (Viviroli et al., 2020) (Figure CCP5.2). Changing sediment, nutrient and pollutant flows due to climatic and non-climatic drivers will impact populations and economic sectors (*medium evidence, high agreement*). Hydropower in all mountain regions will experience higher flux of water and sediment in some seasons, but lower water flow with demands from other water uses (e.g., irrigation) (Chevallier et al., 2011) in other seasons (Beniston and Stoffel, 2014; Gaudard et al., 2014; Majone et al., 2016; Caruso et al., 2017a; Caruso et al., 2017b; Patro et al., 2018). Recharge from groundwater and its buffer function is expected to decrease on the longer term (Somers and McKenzie, 2020). Glacier and snow depth or mass decline will impact current hydropower facilities and production in various complex ways, requiring changes in hydropower management, with further potential for evidence informed solutions (Gaudard et al., 2014; Schaefli, 2015; Schaefli et al., 2019). On the other hand, deglaciation in mountain regions opens topographic space and thus potential for additional long-term hydropower development and production (Haeberli et al., 2016a), with an estimated additional production of up to several hundred terawatt-hour per year, a potentially important contribution to national energy supplies, in particular in the High Mountain Asia region (Farinotti et al., 2019). However, water supply from glacier melt will decrease once source glaciers pass peak discharge (Huss and Hock, 2018), and the areas with available sediment will grow as glaciers shrink, posing potential risks to downstream populations and assets (Lane et al., 2019) (*high confidence*).

Since SROCC (Hock et al., 2019), several new studies have addressed projected impacts of future climate change on snow reliability in ski resorts, complementing previous findings or bridging existing knowledge gaps for winter tourism. This includes, in particular, new studies for China (An et al., 2019; Fang et al., 2019), showing that average ski seasons are projected to shorten (-4 to -61% for RCP4.5; -6 to -79% RCP8.5 in the 2050s) along with increases in snowmaking water demand (27 to 51% for RCP4.5; 46 to 80% for RCP8.5 in the 2050s), with large differences across the country. Changes in future snow reliability are projected across Europe at the national or pan-European scale (Demiroglu et al., 2019; Steiger and Scott, 2020; Morin et al., 2021), highlighting strong contrasts at the local (across ski resorts size and/or elevation range, or local social or environmental context) and continental scales. Higher latitude and high elevation locations generally exhibit delayed declines in snow reliability compared to lower latitude and lower-elevation locations (*high confidence*), consistent with assessment conclusions reached in SROCC (Hock et al., 2019). In general, climate change impacts and risks to ski tourism are found to be spatially heterogeneous, within and across local and international markets, with potential for significant disruptions to related socio-economic sectors due to a growing mismatch between ski area supply and skier demand in the coming decades (Fang et al., 2019; Hock et al., 2019; Steiger et al., 2020a) (*high confidence*). These disruptions are plausible, even though a fraction of current ski resorts could technically be able to operate under comparatively favourable locations (elevation, latitude) and operating models (business models, socio-cultural assets and conditions, governance) (Steiger et al., 2020b).

Severe damage and disruptions to people and infrastructure from floods are projected to increase in Northwestern South America (NWS), South Asia (SAS), Tibetan Plateau (TIB) and Central Asia (WCA) between 1.5°C to 3°C GWL mainly driven by river floods and an increase in the number of glacial lakes with high potential for outburst (*high confidence*) (Drenkhan et al., 2019; Motschmann et al., 2020b; Furian et al., 2021; Zheng et al., 2021). For example, the formation of new lakes at the foot of steep icy peaks largely extends the hazard zones with respect to the earlier situation without lakes (Haeberli et al., 2016b). Projected changes in ice and snow-melt, as well as seasonal increases in extreme rainfall and permafrost thaw, will favour chain reactions and cascading processes which can have devastating downstream effects well beyond the site of the original event (Cui and Jia, 2015; Beniston et al., 2018; Terzi et al., 2019; Vaidya et al., 2019; Shugar et al., 2021) (*high confidence*). The incidence of disasters is projected to increase in the future due to some hazards becoming more pervasive, with an increase in the exposure of people and infrastructure with future environmental and socio-economic changes either contributing to reduce or enhance these disaster risks (Klein et al., 2019b) (*medium confidence*).

CCP5.3.2 Key Risks Across Sectors and Regions

Key risks are derived from the detection and attribution assessment (CCP5.2.7) and from the projected impact and risks (CCP5.3.1). The assessment is informed by evidence in the regional and sectoral chapters and supports the key risk assessment in Chapter 16. Four key risks (KR1 to KR4) have been identified in this CCP and are presented in Sections CCP5.3.2.1-CCP5.3.2.4 (see SMCCP5.4 for methodology and references).

CCP5.3.2.1 KR1: People and Infrastructures at Risks from Landslides and Floods

The amount of people and infrastructure at risk of landslides will increase in regions where the frequency and intensity of rainfall events is projected to rise (Gariano and Guzzetti, 2016; Haque et al., 2019). Extreme precipitation in major mountain regions is projected to increase leading to consequences such as floods and landslides (AR6 WGI TS, *medium confidence*). Rain-on-snow events which can accelerate all flood stages and result in widespread consequence for societies are projected to increase between 2-4°C GWL (but decrease afterwards) (SROCC Chapter 2; WG I Chapter 12). There is *high confidence* that glacial retreat, slope instabilities and heavy precipitation will affect landslides and flood activities although for landslides there are considerable uncertainties in the direction of change (Patton et al., 2019) (AR6 WGI Chapter 12).

Future risk consequences which are considered severe include for example an increase of 10-20% compared to present of the population exposed to landslides activities in certain regions (e.g. High Mountain Asia) (Kirschbaum et al., 2020). This does not consider the expected increase in landslide activity relating to glacier and permafrost changes (Picarelli et al., 2021) (see SROCC Chapter 2) and therefore it is expected to be a conservative estimate. Other severe consequences are on average a projected twofold increase in the number of people exposed to inland flooding between 2°C and 4°C with highest increases in South Asia, Southeast Asia and South America (*high confidence* in the direction of change and *medium confidence* in the absolute values because based on global studies) (Hirabayashi et al., 2013; Allen et al., 2016; Arnell and Gosling, 2016; Zheng et al., 2021). Therefore, high to very high risks are expected between 2°C and 4°C GWL in several mountain regions (Figure CCP5.5 red and violet shaded bars). Many regions are projected to experience high risks due to the timing (potentially for severe consequences to happen sooner rather than later), the magnitude in terms of number of people and infrastructure affected) and the persistence of hazard conditions (Figure CCP5.5, AR6 WGI Chapter 12). Comparatively, more severe risks consequences are expected under SSP3 and/or SSP4 given the high population projections in certain regions compared to SSP1 (Kirschbaum et al., 2020) (see Figure CCP5.1) (*medium confidence*).

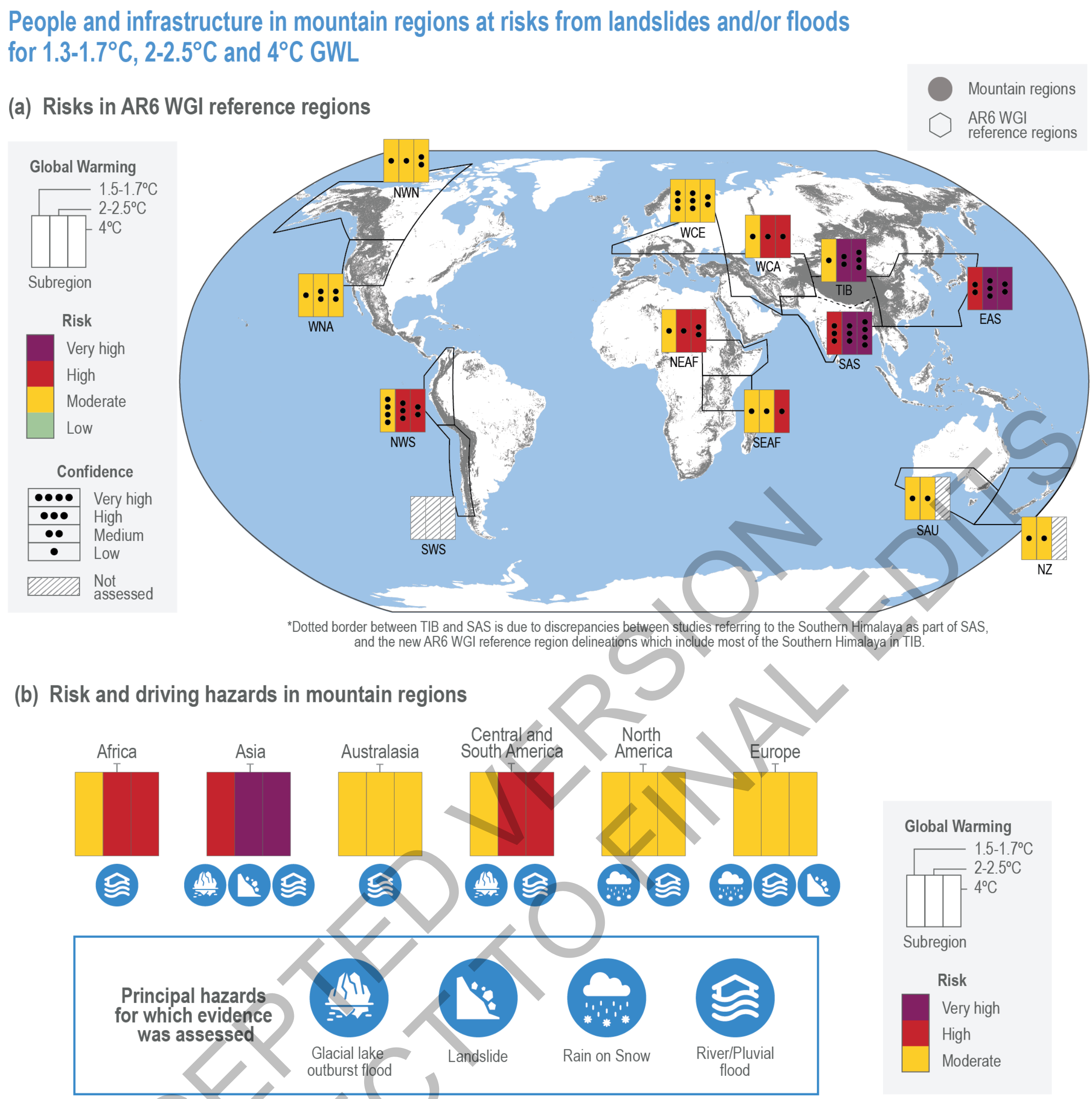

Figure CCP5.5: People and infrastructure in mountain regions at risk from landslides and/or floods for various Global Warming Levels (GWLs). Panel a) shows the level of risk assessed per AR6 WGI reference regions (see AR6 WGI Atlas). For some mountain regions, there is limited evidence to adequately assess the level of risks against GWLs, therefore this is labelled as "not assessed". Panel b) shows the level of risk aggregated at the continent scale and the principal hazards for which evidence was available and assessed. Methodological details and traceability are provided in SMCCP5.4, Figure SMCCP5.1, Table SMCCP5.15 and SMCCP5.17.

CCP5.3.2.2 KR2: Risks to Livelihoods and the Economy from Changing Water Resources

KR2 encompasses the relative and absolute dependency on water resources for economic activities and livelihood sustainment in mountain regions and in the lowlands. Particularly affected by changes in water resources will be regions with (seasonally) high dependence on snow and glacier melt, i.e. arid and semi-arid zones in the Andes, Central Asia and the Upper Indus Basin (Huss et al., 2017; Huss and Hock, 2018; Viviroli et al., 2020) (Section CCP5.3.1).

Consequences that are considered severe refer to the magnitude (number of people and economic activities affected), the timing (increase of water stress as early as mid-century in several regions) and the likelihood (severe risk consequences are more *likely* where high population density is projected) (see Figure CCP5.1,

Figure CCP5.6, Section 4.2.2.3) (Fuhrer et al., 2014; Wijngaard et al., 2018; Biemans et al., 2019; Immerzeel et al., 2020; Viviroli et al., 2020) (*high confidence*). Severe consequences are that by mid-century more than a half of agriculture regions equipped for irrigation are projected to be dependent on mountain runoff and could therefore be unsustainably using blue water (e.g. water from river, lakes and aquifers) (Viviroli et al., 2020) or that the number of people being water stressed will increase by 50% to 100% in areas already water stressed today (Munia et al., 2020). Hotspot regions are those with large lowland populations depending on essential mountain water resource contributions and include river catchments such as Ganges, Brahmaputra, Meghna, Yangtze, Nile, Niger, Indus, Euphrates-Tigris or Pearl (Viviroli et al., 2020) (*high confidence*) (see Figure CCP5.6). Limited governance and integrated management of water resources, power and gender inequalities and level of disruption of local community practices also contribute to make risks more severe (*medium confidence*) (Lynch, 2012; Boelens, 2014; Wijngaard et al., 2018; Scott et al., 2019; Immerzeel et al., 2020). Consequences for hydropower are comparatively less severe than for agriculture and domestic/municipal use although this depends on region and timing (see also Section 5.2.2.2). For example, a study shows low risk to hydropower production in High Mountain Asia until the end of the century and even for warming levels beyond 3°C (Mishra et al., 2020) *(robust evidence, moderate agreement).*

Large scale and transformative interventions can reduce the high-end impacts of changing water resources and in particular the risks of water scarcity (see Section CCP5.4.1). These interventions have long lead times, are costly and may face institutional constraints (see Section 4.5.3), resulting in adaptation shortfall. Therefore, high to very high-risk levels cannot be excluded in regions where other key risks characteristics such as magnitude, timing and likelihood are assessed as high due to potential losses (e.g. in many Asian regions, see Figure CC5.6, SMCCP5.4 and Table SMCCP5.16).

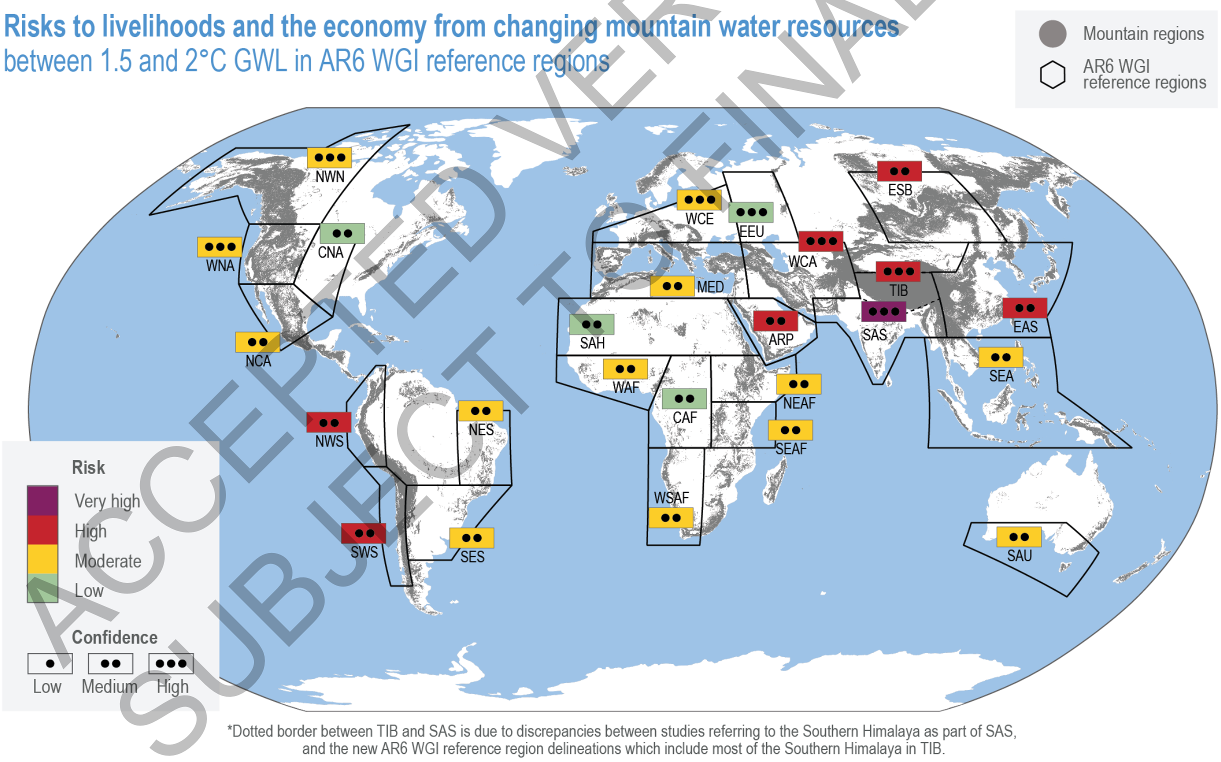

Figure CCP5.6: Risk levels assessed per AR6 WGI reference regions (see AR6 WGI Atlas). The majority of studies assessed focus on impacts up to mid-century (2030-2060) and for RCP-2.6, RCP-4.5 and RCP-6.0, which was converted into the corresponding warming level range 1.5-2.0°C GWL (see Cross-Chapter Box CLIMATE in Chapter 1). Methodological details are provided in Section SMCCP5.4, Figure SMCCP5.1, Table SMCCP5.16 and SMCCP5.18. Due to the *limited evidence* available to determine risks against high Global Warming Levels (GLWs), and the relatively high uncertainties associated with future irrigation trends for the second half of the century (see e.g. Viviroli et al., 2020), assessment of risks associated with GLWs greater than 2.0°C GWL was not conducted.

CCP5.3.2.3 KR3: Risks of Ecosystem Change and Species Extinction

Risks to mountain ecosystems and the services they provide to people are varied in magnitude, timing, likelihood and potential to adapt and place specific (see Table SMCCP5.19). However, many mountain ecosystems are already showing impacts of climate change (CCP5.3.1), reflecting the strong influence climate has in many situations and indicative that risks are large, immediate and will *likely* increase in the near as well as long-term. There is *robust evidence (high agreement*) of vegetation zones and individual species shifting to higher elevations (Section 5.2.1; Chapter 2.4) and projections indicate that current will continue and accelerate at higher rates of warming (*medium evidence, high agreement*) (Section 2.5).

Many mountain species are at risk of range contraction and ultimately extinction if dispersal at the upper range limit is slower than losses due to mortality at the lower range limit (observed for trees in the Neotropics; (Feeley et al., 2013; Duque et al., 2015), or if mountains are not high enough to allow species to move to higher elevations. Ramirez-Villegas et al. (2014) modelled 11,012 species of birds and vascular plants in the Andes, finding large decreases by 2050 (SRES-A2 scenario); in absence of dispersal 10% of species could become extinct. Even assuming unlimited dispersal, most of the Andean endemics would become severely threatened. Other modelling studies have also projected declines in a range of communities and species, including rare endemics (Zomer et al., 2014a; Rashid et al., 2015; Bitencourt et al., 2016; Li et al., 2017; Rehnus et al., 2018; Ashrafzadeh et al., 2019; Zhang et al., 2019b; Cuesta et al., 2020; Hoffmann et al., 2020).

Many treelines will continue to shift to higher elevations with increasing temperatures (Chhetri and Cairns, 2018), although very few are changing as fast as climate change (Liang et al., 2016; Hansson et al., 2021) and some are not moving or even shifting to lower elevations (CCP5.2.1). If treelines fail to shift uphill, this presents a risk for species of the upper-montane forest that experience range contraction at their lower range limit but lack a suitable habitat to expand into beyond their upper range limit (Rehm and Feeley, 2015). Changes in phenology can also present risks to species and ecosystems (Chapter 2), including a potential desynchronization of mutualistic relationship such as pollination and increased freezing damage due to premature emergence from winter dormancy. In European broadleaved trees, for example, the upper elevational limits of different species involve a trade-off between maximizing growing season length and limiting the risk of spring freezing damage (Vitasse et al., 2012; Körner and Spehn, 2016).

A wide range of mechanisms can cause changes within ecological communities, some of which are hard to predict but there are an increasing number of studies illustrating some of the risks which are expected to be most common. If treelines shift upwards, this presents a risk for alpine species, which cannot compete with trees. This may lead to extinction of alpine species on mountains where there is insufficient room for the alpine zone to shift uphill. Shifts in species distributions, and in particular shifts in ecosystem types, can cause changes in ecosystem function, which may in turn have cascading impacts on people, for example leading to increased exposure to diseases such as malaria at high elevation (Section 2.4.2.7.2) as vector distribution changes and wider impacts on ecosystem services (Section 2.5.3) such as water supply, flood alleviation and food.

CCP5.3.2.4 KR4: Risk of Intangible Losses and the Loss of Cultural Values

The risk of intangible losses and loss of cultural values is associated with the decline of ice and snow cover and temperature increase, as well as the increase in intangible harm from hazards such as floods and droughts (*high agreement, medium evidence*) (Diemberger et al., 2015; Jurt et al., 2015; Vuille et al., 2018; Tschakert et al., 2019; Vander Naald, 2020). Losses are intangible because they characterise aspects which are difficult to quantify, i.e. loss of identity, loss of self-reliance, loss of rituals and traditions and place attachment (Allison, 2015; Baul and McDonald, 2015; Motschmann et al., 2020a; Schneiderbauer et al., 2021). A global systematic analysis of case studies shows that this risk is more prevalent in the Andes, the Himalaya and the Alps (Tschakert et al., 2019). Often mentioned across studies is the loss of intrinsic memories and culture related to changes in world heritage landscapes and iconic sites (Jurt et al., 2015; Sherry et al., 2018; Bosson et al., 2019). Changes in the hazard landscapes are also reported to contribute to the loss of peace of mind and loss of well-being (Diemberger et al., 2015). Overall, there is *limited evidence but medium agreement* that the risk of intangible losses and the loss of cultural identity will rapidly increase and that consequences will go from reversible damage to irreversible losses (Tschakert et al., 2019).

CCP5.4 Options for Adaptation and Climate Resilient Development Pathways

CCP5.4.1 Synthesis of Adaptation Responses to Reducing (Key) Risks

More than half of the studies having a focus on mountains (423 articles) extracted from the GAMI dataset report that adaptation responses are contributing to reducing climate risks (Berrang-Ford et al., 2021; McDowell et al., 2021b) (see SMCCP5.3.2). However, the extent of adaptation in terms of time (i.e. speed), the scale of change (i.e. scope) and its depth (i.e. degree to which a change is substantial) is low in mountain regions, with the level of agreement across studies varying from one region to the other (*medium confidence*) (Figure CCP5.7, SMCCP5.3.2). In regions where risk levels remain moderate, a low adaptation extent might be sufficient to constrain risks (see Figure CCP5.5 and Figure 5.6; Section 16.3.2.5).

Adaptation responses in mountains are mainly incremental changes from existing practices (*high confidence*) (McDowell et al., 2019; Rasul et al., 2020; McDowell et al., 2021b), signalling that the potential of current and planned adaptation responses to reduce risks in the future will not be adequate to mitigate high to very high risks. For example, measures to contain floods or landslides (KR1) are designed with specific magnitudes and types in mind often assuming stationarity of return periods (Montanari and Koutsoyiannis, 2014; Gariano and Guzzetti, 2016). In the case of events showing decreasing return periods, risk mitigation standards need to be elevated to provide for more protection in the future (Felder et al., 2018; François et al., 2019). The portfolio of adaptation options to mitigate risks from changing water resources (KR2) is large but challenging and includes integrated catchment management, implementation of multiple use of water strategies, improved water governance (including community based and participatory water governance), overcoming power inequalities among users and sectors, and balancing economic pressure and sustainable development (*high confidence*) (Bekchanov and Lamers, 2016; Yapiyev et al., 2017; Jalilov et al., 2018; Drenkhan et al., 2019; Allen et al., 2020; Aggarwal et al., 2021; Huang et al., 2021) (SMCCP5.3.2). There is *limited evidence* on the effectiveness of adaptation responses to reduce the severity of ecosystem change (KR3) (also see Section 16.3.1). Prevention rather than control and eradication efforts can contribute to curbing biological invasions of alien species in the short turn, whereas colonisation by native trees following land use abandonment can be more effective in the long run (Carboni et al., 2018). Reducing intensified grazing, agricultural expansion, and conservation management in buffer zones of protected areas can limit the altitudinal range shift of endemic species (Kidane et al., 2019).

EbA has been effective in mountain regions to reduce risks from floods (e.g. restoration of buffer zones and floodplains) and landslides (e.g. protective forests) (Muccione and Daley, 2016; Klein et al., 2019b; Lavorel et al., 2019). Ecosystem based measures have been implemented for water management purposes to supply clean water and improve water quality (see Section 4.5.2.1). Furthermore, they provide scope for conservation and improvement of habitats, e.g. forest ecosystems (Nagel et al., 2017; Lamborn and Smith, 2019) (*high agreement, medium evidence*). However, repeated, and recurrent disturbances that increase recovery times can reduce the effectiveness of EbA (Sebald et al., 2019; Scheidl et al., 2020) (*medium confidence*).

Adaptation in mountain areas is currently constrained predominantly by soft limits related to existing social, economic, and political conditions (*high confidence*) (Gioli et al., 2014; Sansilvestri et al., 2016). Progress in overcoming soft limits is currently minimal due to insufficient engagement with socio-economic and political issues in existing adaptation (*medium confidence*) (McDowell et al., 2019; McDowell et al., 2021b) (Sections 8.4.5.3, Cross-Chapter Box LOSS in Chapter 17). This is expected to lead to an expansion of residual risks as risk severity increases (McDowell et al., 2021b).

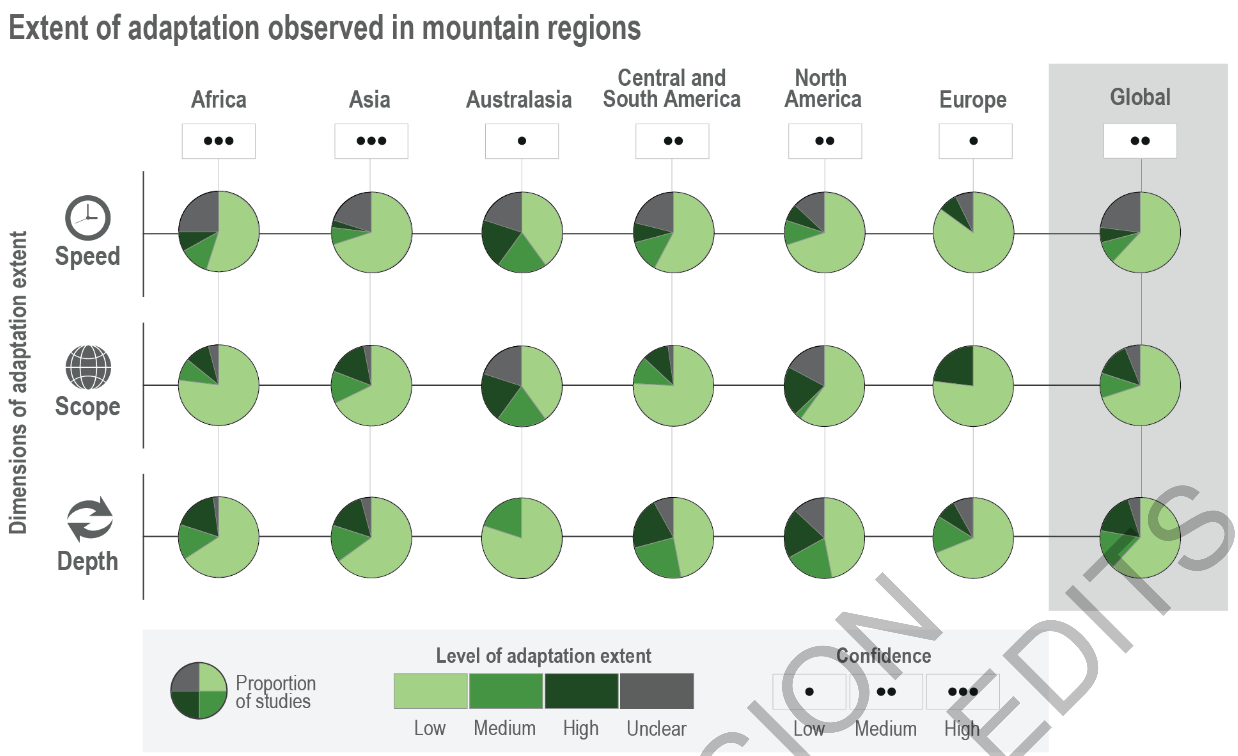

Figure CCP5.7: Extent of planned and implemented adaptation actions observed in mountain regions shown in terms of three dimensions: i) speed (timeframe within which adaptations are being implemented), ii) scope (the scale of changes observed from the adaptation action), and iii) its depth (i.e., degree to which a change reflects something new) (see Section 16.3.2.5). The data are obtained from the Global Adaptation Mapping Initiative (GAMI) re-analysis for mountains (see SMCCP5.3.2 and Berrang-Ford et al., 2021; McDowell et al., 2021b).

CCP5.4.2 Challenges, Opportunities and the Solution Space for Adaptation in Mountains

The effects of climate change on mountain environments pose significant challenges for people, ecosystems, and sustainable development, with issues such as difficult access, environmental sensitivity, and socio-economic marginalization making adaptation particularly complex. Furthermore, varied and dynamic biophysical characteristics as well as high socio-cultural diversity preclude one-size-fits-all responses; adaptation planning and action in mountains rooted in context-specific socio-ecological and climatic realities are more effective (Hock et al., 2019; Lavorel et al., 2019; McDowell et al., 2020) (*high confidence*). Despite these challenges, there is growing evidence of opportunities for advancing effective responses to climate risks in mountain areas (McDowell et al., 2020) (Section 16.3; Cross-Chapter Box NATURAL in Chapter 2).

The solution space for adaptation represents a realm of possibility for addressing climate risks; it is shaped by both socio-economic and climatic factors that influence who adapts, when they adapt, and how they adapt to climate change (Haasnoot et al., 2020) (Sections 1.5.1 and 17.4). The space includes both planned and autonomous responses (Hock et al., 2019; McDowell et al., 2019). Autonomous response can be appropriate when local resilience is high (Mishra et al., 2019; Ford et al., 2020); however, many mountain communities continue to face socio-economic challenges that constrain their adaptive capacity (*high confidence*). Planned adaptations are a critical component of the solution space, although external interventions can also reinforce, redistribute, or create new vulnerabilities when they proceed without sincere engagement with local communities (Eriksen et al., 2021). The solution space also evolves as social and climatic conditions change and can be capped by social and biophysical limits to adaptation that render further responses to climate change inaccessible, unfeasible, or ineffectual. Such limits are already observed and are *likely* to become more widespread as climatic stressors move beyond historical experience (IPCC, 2018; Hock et al., 2019; McDowell et al., 2020) (Section 17.3; Cross-Chapter Box DEEP in Chapter 17) (*high confidence*).

Evidence shows the significant potential of adaptation actions such as Nature-based Solutions or multiple use of water approaches but with a need to carefully evaluate environmental, economic and social co-benefits, trade-offs (Yang et al., 2016; Drenkhan et al., 2019; Lavorel et al., 2019; McDowell et al., 2019; Palomo et al., 2021) (*high agreement, medium confidence*). The potential for adaptation to contribute to sustainable development and transformative change in mountains is also becoming increasingly evident (Palomo et al., 2021) (*medium confidence*), yet there is currently *limited evidence* with respect to the long-term effectiveness of adaptations in achieving such outcomes (Balsiger et al., 2020). To better achieve the adaptation potential in mountains, adaptation finance and private sector inclusion and contribution are key enablers (Mishra et al., 2019; UNEP, 2021) (*high confidence*).

There is increasing recognition that inclusive and comprehensive adaptation approaches can be more successful (Allen et al., 2018; Hock et al., 2019; Huggel et al., 2020a; Huggel et al., 2020b) (*medium evidence, high agreement*). Stakeholders such as local communities and government entities often prioritize different dimensions of climate related risks (López et al., 2017; McDowell et al., 2020). Adaptation initiatives that identify locally-relevant climate stressors and risks through knowledge co-production have the potential to be more acceptable and effective (*medium evidence, high agreement*) (Huggel et al., 2015; Muccione et al., 2016; Allen et al., 2018; Quincey et al., 2018; Balsiger et al., 2020; McDowell et al., 2020; McDowell et al., 2021b) (Cross Chapter Box DEEP in Chapter 17). However, tenable co-production requires recognition of the validity and integrity of diverse knowledges systems, including those held by Indigenous Peoples and local communities, as well as the provision of sufficient time and resources for meaningful engagement between stakeholder groups (Howarth and Monasterolo, 2016; Bremer and Meisch, 2017; Schoolmeester and Verbist, 2018; McDowell et al., 2019; Ford et al., 2020). Power imbalances and knowledge politics continue to impede the inclusion of historically underrepresented voices in adaptation planning and action(Ojha et al., 2016; Mills-Novoa et al., 2017). Citizen science plays an additional role in facilitating the inclusion of multiple knowledges (Buytaert et al., 2014; Dickerson-Lange et al., 2016; Tellman et al., 2016; Njue et al., 2019).

Progress in addressing climate risks requires targeting the root causes of vulnerability, which are often socio-economic in origin and can include poverty, marginalization, and inequitable gender dynamics (Ribot, 2014; Carey et al., 2017; Shukla et al., 2018; McDowell et al., 2019) (*high confidence*). Promoting resilience in many mountain regions requires responses that address the social determinants of susceptibility to harm. Context-specific manifestations of such determinants (and leverage points for positive action) can be identified through participatory processes with affected populations, with action on social determinants of climate change vulnerability having important co-benefits for equity, justice, and sustainability. Addressing the root causes of vulnerability can also resolve soft limits to adaptation, thereby increasing the solution space (McDowell et al., 2020).

There is growing evidence of the potential for coordination and monitoring networks to overcome existing data deficiencies, to fill knowledge gaps, and to streamline implementation, all of which currently impede adaptation in mountains (Salzmann et al., 2014; Muccione et al., 2016; Ryan and Bustos, 2019; McDowell et al., 2020; Shahgedanova et al., 2021; Thornton et al., 2021; Price et al., Accepted/In press). Furthermore, there is increasing evidence that key conventions related to mountains, such as the Alpine Climate Board (SROCC 2.4), provide opportunities for accelerating adaptation efforts through mainstreaming responses into other policies aimed at addressing climate-related risks (Balsiger et al., 2020) (*medium confidence*). Regional cooperation among countries and transboundary landscape and river basin governance initiatives are an important mechanism for advancing adaptation in mountains (Molden et al., 2017; Mishra et al., 2019; Balsiger et al., 2020) (*high agreement, medium evidence*), particularly as many mountain ranges and mountain ecosystem services are transboundary in nature.

Access to major adaptation support programs such as through the UNFCCC, national governments, multi- and bi-lateral aid arrangements, the private sector, and non-governmental organizations (NGOs) has been relatively limited to support adaptation action in mountain regions, indicating significant unutilized support options for increasing the solution space in mountains (McDowell et al., 2020). Enhanced uptake of available support and funding could help to ease the adaptation burden for mountain communities. This will require addressing soft limits to adaptation, which currently constrain the ability of actors to identify, access, and mobilize resources for planned adaptations (McDowell et al., 2020).

More inclusive adaptation approaches, engagement with the root causes of vulnerability, improved coordination and monitoring activities, and upscaling of support for adaptation are key enablers and are indicative of a substantial solution space for adaptation in mountains regions (*high confidence*). However, trajectories of climate change and the prospect of hard limits to adaptation, which are often biophysical in origin, portend climate futures that could overwhelm adaptation efforts. Success therefore hinges on increasing the quality and quantity of adaptation efforts, including through transformative action, as well as enhanced mitigation efforts, consistent with the recommendations of IPCC SR 1.5C (IPCC 2018) (Cross-Chapter Box PROGRESS in Chapter 17).

CCP5.4.3 Climate Resilient and Sustainable Development in Mountains

With accelerating warming and compounding risks increasing above 1.5ºC warming, the need for climate resilient development in mountains is evident, and intricately linked to achieving the SDGs and equity (*high confidence*). In this context, Chapter 18 draws attention to climate resilient development pathways (CRDP), as processes that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar adaptation and mitigation. Pathways that strengthen climate-resilient sustainable mountain development are starting to receive attention (Chelleri et al., 2016; Trabacchi and Stadelmann, 2016; AlpineConvention, 2021). This section treats four domains of emerging evidence related to climate resilient development in mountains: 1) climate actions that support both adaptation and mitigation; 2) Indigenous knowledge and local knowledge in support of climate resilient development; 3) climate resilient development in climate policy and planning; and 4) mainstreaming of climate action into development pathways.

Nature-based Solutions (NbS) can be pursued in mountains that will mitigate climate change and its impacts while at the same time contributing to improving livelihoods, social and economic well-being, and sustainable environmental management *(high confidence).* A global review of 93 Nature-based Solutions in mountains, such as afforestation, protection of existing forests, agroforestry and climate smart agriculture, confirm the potential of NbS for change towards sustainable trajectories (Palomo et al., 2021). Agroforestry is widely cited for delivering on food security as well as increasing resilience and mitigating climate change (Mbow et al., 2014; Amadu et al., 2020; Gidey et al., 2020). Also, the prudent use of biomass for wood-based bioenergy in mountains can mitigate the impacts of climate change, reduce vulnerability to disturbance events such as fires, and enhance rural socioeconomic development (Beeton and Galvin, 2017). Yet, there can be trade-offs contingent upon place-based and context-specific social and environmental factors, such as between the use of bio-energy, agricultural production and conservation concerns (Beeton and Galvin, 2017). Evidence from the world's mountains highlights the importance of cross-scale partnerships and interdisciplinary, bottom-up approaches that facilitate stakeholders in envisioning locally tailored, climate-resilient and sustainable development pathways (Chelleri et al., 2016; Capitani et al., 2019; Klein et al., 2019b; Pandey et al., 2021).

Mountains are the home of many cultures and diverse Indigenous knowledge and local knowledge (systems), which can and do provide strong support for place-based integrated adaptation and mitigation strategies (Merino et al., 2019). Indigenous knowledge and local knowledge reinforce community adaptive capacity, yet governance structures and processes, including the deliberate design and implementation of climate policy, can constrain that capacity from being realised (Hill, 2013; McDowell et al., 2014; Wyborn et al., 2015; Klepp and Chavez-Rodriguez, 2018; Lavorel et al., 2019) (*high confidence)*. Communities, particularly poor and remote mountain communities, are vulnerable to climate change and there is a need for capacity building in research, policy development and implementation for pursuing climate resilient development (Manton and Stevenson, 2014). Climatic stressors and socio-economic changes are changing traditional genderscapes in mountain communities (Goodrich et al., 2019). There is increasing evidence on the roles that gendered diversity in knowledge, institutions, and everyday practices can play in addressing barriers and creating opportunities for achieving resilience, adaptive capacity and sustainability in societies (Gioli et al., 2014; Ravera et al., 2016; Su et al., 2017; Udas et al., 2018; Goodrich et al., 2019; Sujakhu et al., 2019).

Concerning climate policy and planning for climate resilient development in mountains, a review of mountain specific priorities in the National Adaptation Programmes of Action (NAPA) submitted to the UNFCCC shows that countries have prioritized improving agricultural outputs by introducing climate smart crops and upgrading and building climate resilient irrigation infrastructure (UNFCCC, 2020c). Countries that have submitted their NAPs to the UNFCCC have prioritized improving ecosystem resilience through conserving agro-biodiversity in mountains. Countries have also focused on achieving food security in mountain regions and laying the foundations for food availability, stability, access and safety amidst increasing climate risks (UNFCCC, 2020a).

In the Nationally Determined Contributions (NDCs) where mountain regions are specifically mentioned, countries have prioritized climate resilient solutions, including, developing a low carbon green economy through implementing low carbon transport systems and encouraging sustainable waste management practices, as well as developing infrastructure for climate resilient agriculture, the sustainable management of forests and the conservation of biodiversity. Several countries have specifically pledged to build climate resilient mountain infrastructure taking into account future climate uncertainties. Countries have also identified the need for capacity building of national stakeholders and have pledged to provide relevant climate information (UNFCCC, 2020b).

Similar pledges are announced in formal institutional arrangements such as the Alpine Convention and the Carpathian Convention. The Alpine Convention's climate action plan prioritises reaching climate-neutral and climate resilient Alps by 2050. For this, implementation pathways on specific sectors have been identified ensuring coherence to global and regional goals such as the Paris agreement, SDGs, EU legislations and climate laws (AlpineConvention, 2021). Likewise, the Carpathian Convention's working group on climate change has presented a long-term vision towards combating climate change thorough amending the article of the convention to focus specifically on climate change adaptation and mitigation (CarpathianConvention, 2020).

Sustainable and climate resilient mountain development is predicated on effective and timely climate action building on cross-scalar partnerships among researchers, stakeholders, and decision makers to jointly identify desired futures and pathways and assess trade-offs and synergies between climate action and the SDGs (Klein et al., 2019a; Pandey et al., 2021) (*high agreement, medium evidence*). Understanding of the complexity of mountain ecosystems as well as path-dependency from earlier and current decisions is of critical importance for the sustainable future of mountain regions (Satyal et al., 2017; Chanapathi and Thatikonda, 2020; Berkey et al., 2021). Framing pathways through questions such as "to whom or to what is climate action positive" and "which trade-off should be accepted, and why" can serve as a tool for addressing sustainable development goals, while avoiding lock-ins or unsustainable path dependencies (Chelleri et al., 2016). Increasingly, climate action is mainstreamed into sustainable development, which signifies a shift from climate policy as an end-point to a continuing process for managing change and facilitating long-term sustainable development. The Ethiopian government's Climate Resilient Green Economy (CRGE) strategy is an example of such a shift (Simane and Bird, 2017) as are emerging initiatives to build-back-greener in response to COVID-19 impacts (Schipper et al., 2020).

CCP5.5 Key Assessment Limitations and Relevant Knowledge Gaps

The assessment presented in this CCP has several limitations, principally in terms of the amount, often fragmented and biased geographic coverage, or lack of relevant thematic scope covered in the literature published since AR5 and SROCC. Key assessment limitations and relevant knowledge gaps identified in this CCP fall within the following broad categories: 1) detection and attribution of observed impacts to climate change; 2) limitations and uncertainties associated with predictive models of projected impacts and risks; 3) integrated and systems-oriented research on mountain ecosystem services and their limits under climate change; and 4) measurable tracking of adaptation action implemented in mountain regions and their suitability for addressing climate risks. These are summarised in Table CCP5.3. While these limitations and assessment-relevant gaps in knowledge offer important caveats for the interpretation of this assessment, they also highlight prospects to address and improve the evidence basis in future assessments.

Table CCP5.3: Summary of key assessment-relevant knowledge gaps and limitations identified in CCP5.

Key assessment-relevant knowledge gaps and limitations	**Relevant WGII report sections**
Detection and attribution of observed impacts to climate change	

<table>
<tr><th colspan="2">Key assessment-relevant knowledge gaps and limitations</th><th>Relevant WGII report sections</th></tr>
<tr><td>Limited amount and scope of literature available on impacts for assessment of detection and attribution to climate change.</td><td>• While there is high confidence on the links between future impacts and risks associated with climate change, there is medium evidence available on robust detection and attribution of past changes in mountain regions.
• Considerable assessment gaps exist given the limited scope (temporal, spatial, or thematic coverage) and number of published studies reporting data and information that capture how mountains social-ecological systems function, and their trends over the past decades, that may be applicable for detection and attribution of changes to climatic change.
• Additionally, there are limitations in current methodologies to include and account for other knowledges with respect to detection and attribution of impacts to climate change in mountain regions (e.g. Chakraborty and Sherpa, 2021).</td><td>CCP5.2.7; Figure CCP5.4; SMCCP5.2.</td></tr>
<tr><td>Consequences of shifting treelines and their interactions with other ecosystem functions</td><td>• The net effects of ongoing climate change with treeline advance and vegetation change on ecosystem carbon exchange, or possible effects on mountain hydrology, remain unresolved in the literature.
• Uncertainties remain regarding effects to ecosystem-level carbon storage, given that above-ground biomass is higher in forests than in alpine vegetation and (new) trees may change soil carbon fluxes, for instance by introducing new soil organisms, thereby increasing soil carbon flux (e.g. Tonjer et al., 2021).
• Short- and long-term effects of combined warming and changed species cover on mountain soils are complex and insufficiently quantified (Hagedorn et al., 2019).</td><td>CCP5.2.1; CCP1-Biodiversity Hotspots</td></tr>
<tr><td colspan="3">Limitations and uncertainties associated with predictive models of projected impacts and risks</td></tr>
<tr><td>Shared socioeconomic pathways (SSPs)</td><td>• There are relevant knowledge gaps in the understanding of future vulnerabilities in mountain social-ecological systems in relation to highly variable and dynamic trends in projected demographic change, socio-economic development pathways, and demands for resources.</td><td>CCP5.3.1; SMCCP5.1</td></tr>
<tr><td>Species distribution models (SDM)</td><td>• Species distribution models (SDMs), which rely on statistical correlations between occurrence records and environmental variables to make spatially explicit predictions, are commonly used to project climate change impacts on mountain ecosystems (Guisan et al., 2017).
• However, they are associated with some limitations that can limit their utility to derive reliable predictions of future mountain vegetation distributions, and therefore ability to provide a sound basis for mountain nature conservation and climate change adaptation.
• In particular, they only indicate the potential future species distributions based on the static relationships between species and predictors in the calibration data; in reality, vegetation dynamics will be heavily modulated by phenomena that are commonly overlooked by such models like changing species interactions and competition due to variance in response rates amongst different species, dispersal limitations, and demographic processes (Scherrer et al., 2020).
• In addition, SDMs are often limited by data availability and therefore tend to omit several environmental factors known to be important for plants such as soil formation processes, disturbances (e.g. rockfalls, avalanches), and microclimatic conditions (Scherrer et al., 2011; Enright, 2014; Mod et al., 2015; Bråthen et al., 2018).
• More complex dynamic and process-based models are available, but still rarely represent all potentially influential vegetation co-variates; applying both model types in conjunction demonstrates potential (Horvath et al., 2021).</td><td>CCP5.2.1</td></tr>
<tr><td>Quantifiable estimates of monetary costs and potential material losses</td><td>• There is limited evidence on climate-related risks to economic sectors that are vital for mountain regions, specifically on quantifiable estimates of monetary costs and potential material losses for economic sectors and communities in mountains, adjacent lowlands, and other regions dependent on these economic activities.</td><td>CCP5.3.1</td></tr>
</table>

Key assessment-relevant knowledge gaps and limitations		Relevant WGII report sections
Other model limitations	• Ecological models which could allow to better forecast the effectiveness of EbA as NbS, under different climate scenarios, are not fully developed (Seddon et al., 2020).	CCP5.4
Integrated and systems-oriented research on mountain ecosystem services and their limits under climate change		
Water	• Few assessment-relevant integrative studies are available in the published literature that address relevant aspects of water security, beyond water availability from glacier-fed meltwater, or snow, groundwater, other water stores, such as wetlands, sediments, etc. Likewise, few studies address seasonality with respect to a more systems-oriented approach to supply (e.g. water availability) and demand (irrigated agriculture, and other multiple uses and user groups).	CCP5.2.2 Chapter 4
Measurable tracking of adaptation action implemented in mountain regions and their suitability for addressing climate risks		
Conditions under which adaptation interventions work against stated goals	• Few studies report on how adaptation measures and programmes function in mountainous contexts that yield the outcomes reported (McDowell et al., 2020). • Despite transformative processes, to date there is *limited evidence* of how knowledge co-production activities support the planning and implementation of successful adaptations in mountain areas.	CCP5.4.2
Metrics and heuristics for tracking effectiveness	• Adaptation responses to intangible losses and loss of cultural values are reported and take different forms as demonstrated in studies from different world regions (de la Riva et al., 2013; Wang and Qin, 2015; Vander Naald, 2020). However, there is *limited evidence* on their adequacy for addressing increasing losses, which remains largely unexplored in the available literature.	CCP5.3.2.4; Section 4.4.3.3
Methods and frameworks for monitoring and evaluation	• Regarding adaptation efforts and effectiveness, there are considerable gaps in adequate monitoring and appropriate evaluation of successful implementation of diverse adaptation measures. • Across mountain areas, integrated monitoring of key environmental and socio-economic variables, including international efforts for the acquisition and sharing of data, offers prospects for supporting the tracking of impacts and adaptation responses, including community-based monitoring initiatives (Shahgedanova et al., 2021; Thornton et al., 2021).	Section 17.5; CCP5.4.2
Feasibility and suitability of adaptation options for managing climate risks	• The feasibility of adaptation options for managing risks, for example those that could facilitate systems transitions with respect to energy, remains largely unexplored in the literature, with *limited evidence* on how projected climate change could impact prospects to develop wind, solar or biomass energy production and use in mountain contexts. • Given assessments on observed adaptation (Section CCP5.2) and adaptation responses (Section CCP5.4), few studies report a 'systems approach' to the study and evaluation of adaptations that combine all relevant aspects of the risk framework (i.e. hazards, exposure, and vulnerabilities), including how synergies and trade-offs are considered in context for managing risks. • There is *limited evidence* of the feasibility and long-term effectiveness of adaptation measures to address climate-related impacts and related losses and damages in cities and settlements experiencing changing demographics.	CCP5.2.2.2; CCP5.4.2; CCP5.4.3

[START FAQ CCP5.1 HERE]

FAQ CCP5.1: How is freshwater from mountain regions affected by climate change, and what are the consequences for people and ecosystems?

Sources of freshwater from mountains such as rainfall, snow and glacier melt, and groundwater are all strongly affected by climate change, leading to important changes in water supply in terms of quantity, and *partly quality, and timing (e.g. shifts and changes in seasonality). In many cases, the effects on ecosystems and people are negative, e.g. creating or exacerbating ecosystem degradation, water scarcity, or competition or conflict over water.*

River flow is a main source of freshwater both in mountain regions and downstream areas. Various sources contribute to it, including rainfall, snow and glacier melt, and groundwater. Climate change affects these different sources in different ways. Climate change affects rainfall patterns such as long-term increase or decrease, seasonal shifts or changes in rainfall intensity. Rising temperatures strongly influence snow and glacier melt generated river discharge; the snowmelt season starts earlier, less snow mass is available for melt, and snowmelt contribution to river flow thus decreases over the year. Whether rising temperatures produce meltwater from glaciers depends on the state and characteristics of the glaciers and the catchment basin. The concept of 'peak water' implies that first, as glaciers shrink in response to a warmer climate, more meltwater is released until a turning point (peak water) after which glaciers melt and thus its contribution to river flow decreases. In many mountain regions worldwide, glaciers and their basins have already passed peak water, and the runoff contribution of glaciers is on the decline. Glacier shrinkage not only influences river discharge but also water quality. In the Andes of Peru, for instance, it has been observed that retreating glaciers expose bedrock, resulting in more acid water because of minerals that dissolve from the rock. Mountain ecosystems are also affected by changing freshwater availability. For instance, high-elevation wetlands in the tropical Andes critically depend on glacier meltwater during the dry season and the disappearance of this freshwater source results in ecosystem degradation.

The effect of climate change on groundwater in mountains is insufficiently understood. Infiltrating water from glaciers and snowmelt plays an important role in groundwater recharge. Groundwater recharge is expected to decrease with continued climate change in several mountain regions. In the Himalaya many springs have already been observed to decline.

The availability of freshwater is a function of water supply and water demand, with the latter being determined by sectors such as agriculture, energy, industry, or domestic use, as well as by competition between these sectors. Formal and informal water extraction and use prevail, and competition includes issues of inequalities, and power relations and asymmetry. Consequently, the effects of climate change on water resources, people and ecosystems are strongly modulated and often exacerbated by socio-economic development and related water resource management. For example, increasing frequency and intensity of droughts in the European Alps, combined with decline and seasonal shifts of river runoff from snow and glacier melt, is expected to result in growing competition between different sectors, such as hydropower, agriculture, and tourism. Similar developments are projected or have already been observed in many other mountain regions. This situation calls for strengthening and improving negotiation formats for water management that are transparent, equal, and socially and environmentally just. Management of water demand and strategies that entail multiple uses of water will become increasingly important in this context.

[END FAQ CCP5.1 HERE]

[START FAQ CCP5.2 HERE]

FAQ CCP5.2: Are people in mountain regions, and further downstream, facing more severe risks to water-related disasters due to climate change, and how are they coping?

Mountain regions have always been affected by either too much or too little water. Because of climate change, hazards are changing rapidly and becoming even more unpredictable. Whether or not these changes will result in more disasters locally and further downstream depends on several factors, not least the fact that more people are settling in exposed locations. People in mountains have a history of developing skills to live in a dangerous and dynamic environment, which will be invaluable in the future when combined with inclusive and long-term disaster risk reduction measures.

Water-related hazards in mountains include rainfall (pluvial) and river (fluvial) floods, extreme rainfall-induced landslides, debris flows, ice and snow avalanches and droughts. When people are exposed and vulnerable to these hazards, there is potential for them to result in disasters. Floods and landslides in mountains contribute to, and count amongst the most devastating disasters globally, often resulting in significant losses such as high numbers of fatalities and damages. Climate change may change rainfall frequency/intensity distributions, potentially leading to floods and droughts. Climate change may also lead to shifts in precipitation type, with more precipitation falling as rain than snow in the future., which further impacts both short- and long-term water storage, and therefore impacts downstream ecosystems and cities.

Although climate change directly affects water-related hazards, studies indicate that above and beyond natural hazards, disaster risk and disasters are influenced to a major extent by vulnerability and exposure. This is of relevance in mountains, where disaster risk is influenced by population growth, induced displacements, land-use changes and inefficient water distribution systems. For example, current trends suggest that more people are settling in exposed locations, with more infrastructure being built and activities such as tourism and recreation being promoted, exacerbating this exposure.

Experiences in dealing with water-related disasters provide a basis from which to build adequate responses to increasing risks in the future. For example, upgrading infrastructure such as dams and embankments can help address water shortages, but diversification of income-generating activities, such as subsistence farming moving away from certain drought-sensitive crops, can also help.

The risk perceptions of people also shape their behaviours in coping with disaster risks. For example, based on their longstanding observations and local knowledge, communities in the southern part of the Peruvian Andes identified the shrinking of glaciers, more frequent and intense extreme weather events, more extreme temperatures, and shortened rainy seasons as key challenges. The recognition of local knowledge is key to address these challenges, as well as provide a basis for the transformation of current systems. A lack of community involvement and participation in decision making on how to addresses disaster risk can contribute to a mismatch between perceptions and behaviours towards those risks, and the actions needed to reduce losses. Therefore, measures which are flexible, address the objectives and needs of all those affected by disasters and bring long term benefits have more chances of being successful in dealing with future disaster risks.

[END FAQ CCP5.2 HERE]

[START FAQ CCP5.3 HERE]

FAQ CCP5.3: Is climate change a risk to mountain species and ecosystems, and will this affect people?

Treeline position, bioclimatic zones and species ranges move up in elevation as the climate warms, increasing the risk of extinction for species isolated on mountaintops as a result of exceeding their physiological limits, loss of habitat or competition from colonising species. Additionally, climate change may alter the quality and quantity of food and natural products on which the livelihood of many mountain communities depends.

Mountain regions cover about a quarter of the Earth's land surface, scattered around the globe and may support a wide range of climates within short horizontal distances. Mountains have experienced above-average warming, and this trend is expected to continue. Mountains provide a variety of goods for people, are home to many Indigenous Peoples and are attractive for tourism and recreational activities. Mountain regions support many different ecosystems and some are very species rich. Mountain regions can be vast and diverse, and climate change and impacts on ecosystems vary greatly depending on location.

With increasing average global temperature, the climatic conditions under which plants and animals can thrive are shifting to higher elevations. Movement of some plant taxa toward mountaintops, has been observed in the past decades. However, for species restricted to the highest elevations, there is nowhere to move to, meaning they are increasingly at risk of extinction. Climatic conditions may exceed the physiological limits for species and the habitat may become unsuitable for others. There is also a risk from competition with colonizing native species and invading non-native species, spreading to higher elevations and some species cannot move quickly enough to keep pace with the change in climate. The most vulnerable species are those that reproduce and disperse slowly and those that are isolated on the mountaintops, including endemic species, which may face global extinction. In other cases species will be lost from some parts of their current range. Mountains can however allow other species to survive in areas where they would not otherwise do so, because of small scale variations in climate with elevation or different aspects of slopes.

Changes in snow cover and snow duration are related to changes in temperature and precipitation and are also critical for plants and animals. In particular, glacier retreat and changing snow patterns affect both streamflow dynamics (including extremes) and soil moisture conditions and can cause moisture shortages during the growing season. Change of snow patterns can critically affect animal movements in mountains. Other processes creating stresses on mountain ecosystems are direct human impacts, such as the influence of grazing, tourism, air pollution and nitrogen deposition on alpine vegetation. In some cases, these impacts can be so large on the goods and services provided by alpine ecosystems, that they can overshadow the effects of climate change or exacerbate its effects.

In many mountain regions, multiple sources of evidence point to tree expansions into treeless area above (and in some cases below) the forest belt. This may increase forest productivity at the upper treeline. Treelines have moved up in the last 30-100 years in many mountain regions, including e.g. Andes, Urals and Altai. At the same time, since the 1990s, treelines responses in different parts of the Himalaya have been highly variable, in some places advancing upslope, in others demonstrating little change, and in others moving downward. This can be explained by site-specific complex interactions of the positive effect of warming on tree growth, drought stress, change in snow precipitation, land-use change, especially grazing, and other factors. Treelines are affected by land use and management around the globe and changing land-use practices can supersede climate change effects in some mountain regions. An upward shift in elevation of bioclimatic zones, decreases in area of the highest elevation zones, and an expansion of the lower zones can be expected by mid-century, for examples in regions such as the Himalaya.

In some regions, the livelihoods of many local mountain communities depend on access to firewood, pastures, edible plants and mushrooms, medicinal and aromatic plants. Climate change can alter the quality and quantity of these ecosystem services; however, the degree and direction of change are context specific. The appeal and feasibility of mountains for tourism and recreation activities are also affected by climate change.

[END FAQ CCP5.3 HERE]

[START FAQ CCP5.4 HERE]

FAQ CCP5.4: What type of adaptation options are feasible to address the impacts of climate change in mountain regions under different levels of warming, and what are their limits?

The feasibility of adaptation to address risks in mountain regions is influenced by numerous factors, many of which are unique to mountain people and their environment. Adaptation efforts in mountains are mainly made of small steps and largely autonomous. Robust and flexible adaptation measures have a better chance to address risks, but eventually large systemic transformation will be needed for higher levels of warming. Empirical evidence on "what works and what does not work" is largely absent, but urgently needed.

The term feasibility refers to climate goals and adaptation options that are possible and desirable. Feasibility is influenced by factors such as economic viability, availability of technical resources, institutional support, social capital, ecological and adaptive capacity, and biophysical conditions. Establishing the feasibility of options under changing climatic and socio-economic conditions is not an easy task – mostly because even present feasibility is difficult to assess in mountains, due to a lack of systematic information on opportunities and challenges of adaptation in practice.

Underlying environmental conditions such as limited space, shallow soils, exposure to numerous hazards, climate-sensitive ecosystems and isolation make it particularly difficult to implement adaptation at scales relevant for implementation. Common adaptation options are often implemented at the individual, household or community scale. These options are incremental and have generated observable results and outcomes. Adaptation actions that involve partial changes that do not dramatically alter established practices and behaviours seem to have better chances of being implemented than systemic or structural changes. Formal or planned adaptation efforts which are more institutionally driven are only a small proportion of observed adaptation in mountains regions. Where adaptation options are implemented, they are often not only targeting climate change, but an array of other issues, priorities, and pressures experienced by and in those communities (e.g. livelihood diversification in farming practices).

Whether or not adaptation options are feasible does not say much about their effectiveness, i.e. the degree to which adaptation has been or will be successful in reducing the risks of negative impacts. Adaptation is difficult to disentangle from other factors that contribute to both increasing and decreasing risks. Since adaptation in mountains is often autonomous and unplanned, measuring its effectiveness is complex and missed by more conventional, formal, or structured monitoring and evaluation frameworks.

Evidence suggests that promising measures being taken in mountains are those that are robust under uncertain futures, allow for adaptive planning and management, and respond to multiple interests and purposes. For example, multi-purpose water reservoirs can alleviate multiple stressors and address several risks such as those from natural hazards and water shortages. Capacity building and awareness-raising can go a long way to ensure that these measures are also socially acceptable if combined with more structural and systemic changes. Indeed, transformations are happening slowly in mountains and it is unlikely that small steps and incremental measures will be able to cope with more severe and pervasive risks.

Overall, empirical evidence on the effectiveness of adaptation to reducing risk is largely missing but is urgently needed to better understand what works and what does not work under certain circumstances.

[END FAQ CCP5.4 HERE]

[START FAQ CCP5.5 HERE]

FAQ CCP5.5: Why regional cooperation and transboundary governance is needed for sustainable mountain development?

Regional cooperation and transboundary governance are key to managing our vast mountain resources because they do not necessarily share political boundaries. Mountain countries need to come together, share data and information, form joint management committees, bring in policies and take decisions that benefit all countries equitably. Lack of cooperation may lead to missing important opportunities to address climate risks and adequately manage mountain resources, which can cause potential social unrest and spark conflict within and between countries.

Mountains are climate change hotspots that are highly susceptible to climate change. Due to rapidly changing climatic conditions, climate change is one of the major issues that would benefit from regional cooperation. The transboundary management of mountains means shared legal and institutional frameworks for sharing the benefits and costs of managing the mountain ranges across boundaries, be it local or district jurisdictions within countries or indeed across national boundaries.

The IPCC's Special Report on Oceans and Cryosphere refers to governance as an "effort to establish, reaffirm or change formal and informal institutions at all scales to negotiate relationships, resolve social conflicts and realise mutual gains". Governance is an act of governments, NGOs, private sectors, and civil society in establishing rules and norms for restricting the use of common goods. "Institutions can guide, constrain, and shape human interaction through direct control, incentives, and processes of socialisation". How do we apply the definitions of governance and institutions in the context of mountains? Since governance not only refers to government, which is a formal arm of the state, it also talks about other agencies such as community organizations, non-profit or businesses that play a vital role in society and influences individual or collective decisions and help in preventing the overexploitation of its resources.

To comprehend the processes of governance in mountain areas, we need to recognize how each of these agencies add to the enduring task of enabling and managing change at the system level but also to preserving social structure and reconciling disputes. For the sustainable and resilient development of mountain regions, governance mechanisms may be different than those applied for managing other resources such as coastal zones or rivers. This is also because mountains are mostly transboundary and do not necessarily follow political boundaries. Mountain governance, therefore, is about managing the resources across political boundaries for the benefit of all countries. This includes downstream countries that also rely on these resources such as water, silt, and other resources from these mountain regions. These include high rangelands, biodiversity hotspots, forests, glaciers etc.

There are several examples of regional cooperation around the governance of shared resources in mountains. Some examples come from the Arctic (bottom-up and science-based evolution of Arctic cooperation), South-East Europe (regionalisation of environmental benefits) and the Hindu Kush Himalaya region (inter-governmental scientific institution for research and data sharing). Mountains share resources and therefore, their management will benefit from cooperation between countries. Transboundary cooperation is not only needed to address transboundary climate risks and regional adaptation to climate change in mountains, but also to work across countries to reduce greenhouse gas emissions.

[END FAQ CCP5.5 HERE]

References

Abatzoglou, J. T., A. P. Williams and R. Barbero, 2019: Global Emergence of Anthropogenic Climate Change in Fire Weather Indices. *Geophysical Research Letters*, **46**(1), doi:10.1029/2018GL080959.

Abram, N. J. et al., 2021: Connections of climate change and vari-ability to large and extreme forest fires in southeast Australia. *Communications Earth and Environment*, **2**, doi:10.1038/s43247-020-00065-8.

Adams, H., 2016: Why populations persist: mobility, place attachment and climate change. *Population and Environment*, **37**, 429–448, doi:10.1007/s11111-015-0246-3.

Adhikari, L., S. Tuladhar, A. Hussain and K. Aryal, 2019: Are Traditional Food Crops Really 'Future Smart Foods?'A Sustainability Perspective. *Sustainability*, **11**(19), 5236, doi:10.3390/su11195236.

Adler, C., C. Huggel, B. Orlove and A. Nolin, 2019: Climate change in the mountain cryosphere: impacts and responses. *Regional Environmental Change*, **19**(5), 1225-1228, doi:10.1007/s10113-019-01507-6.

Aggarwal, A. et al., 2021: Adaptation to climate change induced water stress in major glacierized mountain regions. *Climate and Development*, 1-13, doi:10.1080/17565529.2021.1971059.

Ahlers, R. et al., 2015: Framing hydropower as green energy: assessing drivers, risks and tensions in the Eastern Himalayas. *Earth System Dynamics*, **6**(1), 195–204, doi:10.5194/esd-6-195-2015.

Al-Gabbiesh, A., M. Kleinwächter and D. Selmar, 2015: Influencing the contents of secondary metabolites in spice and medicinal plants by deliberately applying drought stress during their cultivation. *Jordan Journal of Biological Sciences*, **147**(3379), 1-10.

Albrich, K., W. Rammer and R. Seidl, 2020: Climate change causes critical transitions and irreversible alterations of mountain forests. *Global Change Biology*, **26**(7), 4013-4027, doi:10.1111/gcb.15118.

Alcántara-Ayala, I., V. Murray, P. Daniels and G. McBean, 2017: International Council for Science (ICSU)—On the Future Challenges for the Integration of Science into International Policy Development for Landslide Disaster Risk Reduction. In: *Advancing Culture of Living with Landslide* [Sassa, K., M. Mikoš and Y. Yin (eds.)]. Springer, Cham, Switzerland, pp. 143-154. ISBN 9783319594699.

Alfthan, B. et al., 2018: *Mountain Adaptation Outlook Series – Synthesis Report*. United Nations Environment Programme, and GRID-Arendal, Nairobi, Kenya, Vienna, Austria, and Arenda, Norway, 51 pp. ISBN 9788277011806.

Alfthan, B. et al., 2016: *Waste Management Outlook for Mountain Regions – Sources and Solutions*. United Nations Environment Programme, GRID-Arendal and ISWA, Nairobi, Kenya, Vienna, Austria, and Arenda, Norway, 51 pp. ISBN 9788277011585.

Allen, S. et al., 2020: *Building Transformative Institutional Adaptive Capacity: Assessing The Potential Contribution of PPCR to Build a Climate Resilient Water Governance Framework in The Plurinational State of Bolivia*. Inter-American Development Bank Available at: https://publications.iadb.org/en/building-transformative-institutional-adaptive-capacity-assessing-potential-contribution-ppcr-build (accessed 30/08/2021).

Allen, S. K. et al., 2018: Translating the concept of climate risk into an assessment framework to inform adaptation planning: Insights from a pilot study of flood risk in Himachal Pradesh, Northern India. *Environmental Science & Policy*, **87**, 1-10, doi:10.1016/j.envsci.2018.05.013.

Allen, S. K. et al., 2016: Glacial lake outburst flood risk in Himachal Pradesh, India: an integrative and anticipatory approach considering current and future threats. *Natural Hazards*, **84**(3), 1741-1763, doi:10.1007/s11069-016-2511-x.

Allison, E. A., 2015: The spiritual significance of glaciers in an age of climate change. *WIREs Climate Change*, **6**(5), 493-508, doi:10.1002/wcc.354.

AlpineConvention, 2021: *CLIMATE ACTION PLAN 2.0*. Permanent Secretariat of the Alpine Convention, Innsbruck, Austria. Available at: https://www.alpconv.org/en/home/news-publications/publications-multimedia/detail/climate-action-plan-20/.

Amadu, F. O., D. C. Miller and P. E. McNamara, 2020: Agroforestry as a pathway to agricultural yield impacts in climate-smart agriculture investments: Evidence from southern Malawi. *Ecological Economics*, **167**(C), 106443, doi:10.1016/j.ecolecon.2019.106443.

Anderson, E. P. et al., 2018: Fragmentation of Andes-to-Amazon connectivity by hydropower dams. *Science Advances*, **4**(1), eaao1642, doi:10.1126/sciadv.aao1642.

Applequist, W. L. et al., 2020: Scientists' warning on climate change and medicinal plants. *Planta medica*, **86**(01), 10-18.

Archibald, S. et al., 2018: Biological and geophysical feedbacks with fire in the Earth system. *Environmental Research Letters*, **13**(3), 033003, doi:10.1088/1748-9326/aa9ead.

Arnell, N. W. and S. N. Gosling, 2016: The impacts of climate change on river flood risk at the global scale. *Climatic Change*, **134**(3), 387-401, doi:10.1007/s10584-014-1084-5.

Artemov, I. A., 2018: Changes in the Altitudinal Distribution of Alpine Plants in Katunskiy Biosphere Reserve (Central Altai) Revealed on the Basis of Multiyear Monitoring Data. *Contemporary Problems of Ecology*, **11**(1), 1-12, doi:10.1134/S1995425518010018.

Ashraf, M., J. K. Routray and M. Saeed, 2014: Determinants of farmers' choice of coping and adaptation measures to the drought hazard in northwest Balochistan, Pakistan. *Natural hazards*, **73**(3), 1451-1473, doi:10.1007/s11069-014-1149-9.

Ashrafzadeh, M. R., A. A. Naghipour, M. Haidarian and I. Khorozyan, 2019: Modeling the response of an endangered flagship predator to climate change in Iran. *Mammal Research*, **64**, 39-51, doi:10.1007/s13364-018-0384-y.
Báez, S., L. Jaramillo, F. Cuesta and D. A. Donoso, 2016: Effects of climate change on Andean biodiversity: a synthesis of studies published until 2015. *Neotropical Biodiversity*, **2**(1), 181-194, doi:10.1080/23766808.2016.1248710.
Baiker, J. R. et al., 2020: How the COVID-19 pandemic is teaching us to tackle the climate crisis, PLOS Collections. Available at: https://collectionsblog.plos.org/how-the-covid-19-pandemic-is-teaching-us-to-tackle-the-climate-crisis/.
Balderas Torres, A., S. Angón Rodríguez, A. Sudmant and G. A., 2021: *Adapting to climate change in mountain cities: Lessons from Xalapa, Mexico*. Coalition for Urban Transitions, London and Washington, DC. Available at: https://urbantransitions.global/publications.
Balsiger, J., E. Dupuits and A. Scolobig, 2020: *International Experience in Transboundary Mountain Governance: Insights for Andean Cooperation*. Institute for Environmental Governance and Territorial Development, University of Geneva, Geneva, Switzerland, 124 pp. Available at: https://archive-ouverte.unige.ch/unige:145756 (accessed 10/12/2020).
Banerjee, S., R. Black, A. Mishra and D. Kniveton, 2018: Assessing vulnerability of remittance-recipient and non-recipient households in rural communities affected by extreme weather events: Case studies from south-west China and north-east India. *Population, Space and Place*, **25**(2), e2157, doi:10.1002/psp.2157.
Banerjee, S., A. Hussain, S. Tuladhar and A. Mishra, 2019: Building capacities of women for climate change adaptation: Insights from migrant-sending households in Nepal'. *Climatic Change*, **157**, 587-609, doi:10.1007/s10584-019-02572-w.
Bani, L. et al., 2019: Winners and losers: How the elevational range of breeding birds on Alps has varied over the past four decades due to climate and habitat changes. *Ecology and Evolution*, **9**(3), 1289-1305, doi:10.1002/ece3.4838.
Baraer, M. et al., 2015: Contribution of groundwater to the outflow from ungauged glacierized catchments: a multi-site study in the tropical Cordillera Blanca, Peru. *Hydrological Processes*, **29**(11), 2561-2581, doi:10.1002/hyp.10386.
Barberán, R. M. et al., 2019: Vulnerability to climate change of smallholder cocoa producers in the province of Manabí, Ecuador. *Revista Facultad Nacional de Agronomía Medellín*, **72**(1), 8707-8716, doi:10.15446/rfnam.v72n1.72564.
Barnett, T. P., J. C. Adam and D. P. Lettenmaier, 2005: Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, **438**(7066), 303–309, doi:10.1038/nature04141.
Batima, P., L. Natsagdorj and N. Batnasan, 2013: Vulnerability of Mongolia's pastoralists to climate extremes and changes. In: *Climate Change and Vulnerability and Adaptation* [Leary, N., C. Conde, J. Kulkarni, A. Nyong, J. Adejuwon, V. Barros, I. Burton, R. Lasco and J. Pulhin (eds.)]. Routledge, London, United Kingdom, pp. 67-87. ISBN 9781315067179.
Baul, T. and M. A. McDonald, 2015: Integration of Indigenous knowledge in addressing climate change. *Indian journal of traditional knowledge*, **1**, 20-27.
Baur, B. and A. Baur, 2013: Snails keep the pace: shift in upper elevation limit on mountain slopes as a response to climate warming. *Canadian journal of zoology*, **91**(8), 596-599, doi:10.1139/cjz-2013-0036.
Beeton, T. A. and K. A. Galvin, 2017: Wood-based bioenergy in western Montana: the importance of understanding path dependence and local context for resilience. *Ecology Society*, **22**(2), 9, doi:10.5751/ES-09157-220209.
Bekchanov, M. and J. P. A. Lamers, 2016: Economic costs of reduced irrigation water availability in Uzbekistan (Central Asia). *Regional Environmental Change*, **16**(8), 2369-2387, doi:10.1007/s10113-016-0961-z.
Beltrán-Tolosa, L. M. et al., 2020: Action needed for staple crops in the Andean-Amazon foothills because of climate change. *Mitigation and Adaptation Strategies for Global Change*, **25**(6), 1103-1127, doi:10.1007/s11027-020-09923-4.
Benedetti, Y., E. Kapsalis, F. Morelli and V. Kati, 2021: Sacred oak woods increase bird diversity and specialization: Links with the European Biodiversity Strategy for 2030. *Journal of Environmental Management*, **294**, 112982, doi:10.1016/j.jenvman.2021.112982.
Beniston, M. et al., 2018: The European mountain cryosphere: a review of its current state, trends, and future challenges. *The Cryosphere*, **12**(2), 759-794, doi:10.5194/tc-12-759-2018.
Beniston, M. et al., 1996: Impacts of climate change on mountain regions. In: *Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* [Watson, R. T., M. C. Zinyowera and R. H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom, pp. 191-213. ISBN 052156431X.
Beniston, M., M. Rebetez, F. Giorgi and M. R. Marinucci, 1994: An analysis of regional climate change in Switzerland. *Theoretical and Applied Climatology*, **49**, 135–159, doi:10.1007/BF00865530.
Beniston, M. and M. Stoffel, 2014: Assessing the impacts of climatic change on mountain water resources. *Science of The Total Environment*, **493**, 1129-1137, doi:10.1016/j.scitotenv.2013.11.122.
Berkey, J. K., R. T. Belote, C. T. Maher and A. Larson, 2021: Structural diversity and development in active fire regime mixed-conifer forests. *Forest Ecology Management*, **479**, 118548, doi:10.1016/j.foreco.2020.118548.
Berrang-Ford, L. et al., 2021: A systematic global stocktake of evidence on human adaptation to climate change. *Nature Climate Change*, In press, doi:10.21203/rs.3.rs-100873/v1.

Bharti, N. et al., 2020: Dynamics of urban water supply management of two Himalayan towns in India. *Water Policy*, **22**(s1), 65-89, doi:10.2166/wp.2019.203.

Bhatta, K. P., J.-A. Grytnes and O. R. Vetaas, 2018: Downhill shift of alpine plant assemblages under contemporary climate and land-use changes. *Ecosphere*, **9**(1), e02084, doi:10.1002/ecs2.2084.

Biemans, H. et al., 2019: Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nature Sustainability*, **2**(7), 594-601, doi:10.1038/s41893-019-0305-3.

Bissenbayeva, S., J. Abuduwaili, A. Saparova and T. Ahmed, 2021: Long-term variations in runoff of the Syr Darya River Basin under climate change and human activities. *Journal of Arid Land*, **13**(1), 56-70, doi:10.1007/s40333-021-0050-0.

Bitencourt, C., A. Rapini, L. Santos Damascena and P. De Marco Junior, 2016: The worrying future of the endemic flora of a tropical mountain range under climate change. *Flora - Morphology, Distribution, Functional Ecology of Plants*, **218**, 1-10, doi:10.1016/j.flora.2015.11.001.

Bocchiola, D., M. G. Pelosi and A. Soncini, 2017: Effects of hydrological changes on cooperation in transnational catchments: the case of the Syr Darya. *Water International*, **42**(7), 852-873, doi:10.1080/02508060.2017.1376568.

Boelens, R., 2014: Cultural politics and the hydrosocial cycle: Water, power and identity in the Andean highlands. *Geoforum*, **57**, 234-247, doi:10.1016/j.geoforum.2013.02.008.

Bondé, L. et al., 2019: Variability and estimating in fruiting of shea tree (Vitellaria paradoxa CF Gaertn) associated to climatic conditions in West Africa: implications for sustainable management and development. *Plant Production Science*, **22**(2), 143-158.

Bosson, J. B., M. Huss and E. Osipova, 2019: Disappearing World Heritage Glaciers as a Keystone of Nature Conservation in a Changing Climate. *Earth's Future*, **7**(4), 469-479, doi:10.1029/2018EF001139.

Bowman, D. M. J. S., A. Bliss, C. J. W. Bowman and L. D. Prior, 2019: Fire caused demographic attrition of the Tasmanian palaeoendemic conifer Athrotaxis cupressoides. *Austral Ecology*, **44**(8), 1322-1339, doi:10.1111/aec.12789.

Bowman, D. M. J. S. et al., 2014: Abrupt fire regime change may cause landscape-wide loss of mature obligate seeder forests. *Global Change Biology*, **20**(3), 1008-1015, doi:10.1111/gcb.12433.

Bowman, D. M. J. S., G. J. Williamson, L. D. Prior and B. P. Murphy, 2016: The relative importance of intrinsic and extrinsic factors in the decline of obligate seeder forests. *Global Ecology and Biogeography*, **25**(10), 1166-1172, doi:10.1111/geb.12484.

Bradstock, R. et al., 2014: Divergent responses of fire to recent warming and drying across south-eastern Australia. *Global Change Biology*, **20**(5), 1412-1428, doi:10.1111/gcb.12449.

Bradstock, R. A., 2010: A biogeographic model of fire regimes in Australia: current and future implications. *Global Ecology and Biogeography*, **19**(2), 145-158, doi:10.1111/j.1466-8238.2009.00512.x.

Bramer, I. et al., 2018: Advances in monitoring and modelling climate at ecologically relevant scales. In: *Advances in Ecological Research* [Bohan, D. A., A. J. Dumbrell, G. Woodward and M. Jackson (eds.)]. Elsevier, San Diego, California, USA, pp. 101-161. ISBN 9780128139493.

Brandt, R., R. Kaenzig and S. Lachmuth, 2016: Migration as a Risk Management Strategy in the Context of Climate Change: Evidence from the Bolivian Andes. In: *Migration, Risk Management and Climate Change: Evidence and Policy Responses* [Milan, A., B. Schraven, K. Warner and N. Cascone (eds.)]. Springer, Cham, Switzerland, pp. 43-61. ISBN 9783319429229.

Bråthen, K. A., V. T. González and N. G. Yoccoz, 2018: Gatekeepers to the effects of climate warming? Niche construction restricts plant community changes along a temperature gradient. *Perspectives in Plant Ecology, Evolution and Systematics*, **30**, 71-81, doi:10.1016/j.ppees.2017.06.005Get.

Bremer, S. and S. Meisch, 2017: Co-production in climate change research: reviewing different perspectives. *Wiley Interdisciplinary Reviews: Climate Change*, **8**(6), e482, doi:10.1002/wcc.482.

Briner, S., C. Elkin and R. Huber, 2013: Evaluating the relative impact of climate and economic changes on forest and agricultural ecosystem services in mountain regions. *Journal of Environmental Management*, **129**, 414-422, doi:10.1016/j.jenvman.2013.07.018.

Britton, A. J. et al., 2016: Climate, pollution and grazing drive long-term change in moorland habitats. *Applied Vegetation Science*, **20**(2), 194-203, doi:10.1111/avsc.12260.

Brunette, M., R. Bourke, M. Hanewinkel and R. Yousefpour, 2018: Adaptation to climate change in forestry: A multiple correspondence analysis (MCA). *Forests*, **9**(1), 20, doi:ff10.3390/f9010020.

Brunetti, M. et al., 2019: Phylogeography and species distribution modelling of Cryptocephalus barii (Coleoptera: Chrysomelidae): is this alpine endemic species close to extinction? *ZooKeys*, **856**, 3-25, doi:10.3897/zookeys.856.32462.

Brunner, M. I. et al., 2019: Present and future water scarcity in Switzerland: Potential for alleviation through reservoirs and lakes. *Science of The Total Environment*, **666**, 1033-1047, doi:10.1016/j.scitotenv.2019.02.169.

Buerkert, A., E. Fernandez, B. Tietjen and E. Luedeling, 2020: Revisiting climate change effects on winter chill in mountain oases of northern Oman. *Climatic Change*, **162**(3), 1399-1417, doi:10.1007/s10584-020-02862-8.

Burke, M. et al., 2021: The changing risk and burden of wildfire in the United States. *Proceedings of the National Academy of Sciences of united States of America, PNAS*, **118**(2), e2011048118, doi:10.1073/pnas.2011048118.

Buytaert, W. et al., 2014: Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*, **2**, 1-21, doi:10.3389/feart.2014.00026.
Camac, J. S. et al., 2021: Predicting species and community responses to global change using struc-tured expert judgement: An Australian mountain ecosystems case study. *Global Change Biology*, 1-15, doi:10.1111/gcb.15750.
Camac, J. S. et al., 2017: Climatic warming strengthens a positive feedback between alpine shrubs and fire. *Global Change Biology*, **23**(8), doi:10.1111/gcb.13614.
Camac, J. S. et al., 2013: Post-fire regeneration in alpine heathland: Does fire severity matter? *Austral Ecology*, **38**(2), 199-207, doi:10.1111/j.1442-9993.2012.02392.x.
Capitani, C. et al., 2019: Views from two mountains: Exploring climate change impacts on traditional farming communities of Eastern Africa highlands through participatory scenarios. *Sustainability Science*, **14**(1), 191-203, doi:10.1007/s11625-018-0622-x.
Carboni, M. et al., 2018: Simulating plant invasion dynamics in mountain ecosystems under global change scenarios. *Global change biology*, **24**(1), 289-302, doi:10.1111/gcb.13879.
Carey, M. et al., 2014: Toward hydro-social modeling: Merging human variables and the social sciences with climate-glacier runoff models (Santa River, Peru). *Journal of Hydrology*, **518, Part A**, 60-70, doi:10.1016/j.jhydrol.2013.11.006.
Carey, M. et al., 2017: Impacts of Glacier Recession and Declining Meltwater on Mountain Societies. *Annals of the American Association of Geographers*, **107**(2), 350-359, doi:10.1080/24694452.2016.1243039.
CarpathianConvention, 2020: *Long-term Vision 2030 towards combating climate change in the Carpathians*. Carpathian Convention Working Group on Climate Change. Sixth Meeting of the Conference of the Parties to the Framework Convention on the Protection and Sustainable Development of the Carpathians. Available at: http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/03%20Meetings%20and%20Events/COP/2020_COP6_Online/official%20documents/CC%20COP6%20DOC10_Long_Term_Vision_2030_FINAL%20DRAFT.pdf.
Caruso, B., S. Newton, R. King and C. Zammit, 2017a: Modelling climate change impacts on hydropower lake inflows and braided rivers in a mountain basin. *Hydrological sciences journal*, **62**(6), 928-946, doi:10.1080/02626667.2016.1267860.
Caruso, B. S., R. King, S. Newton and C. Zammit, 2017b: Simulation of Climate Change Effects on Hydropower Operations in Mountain Headwater Lakes, New Zealand. *River Research and Applications*, **33**(1), 147-161, doi:10.1002/rra.3056.
Catford, J. A., R. Jansson and C. Nilsson, 2009: Reducing redundancy in invasion ecol-ogy by integrating hypotheses into a single theoretical framework. *Diversity and Distributions*, **15**, 22-40, doi:10.1111/j.1472-4642.2008.00521.x.
Cattaneo, C. et al., 2019: Human Migration in the Era of Climate Change. *Review of Environmental Economics and Policy*, **13**, 2, doi:10.1093/reep/rez008.
Ceruti, M. C., 2019: Practical Spirituality and Journey with Sacred Mountains. In: *Practical Spirituality and Human Development*. Springer, pp. 495-509.
Chakraborty, A., P. K. Joshi and K. Sachdeva, 2016: Predicting distribution of major forest tree species to potential impacts of climate change in the central Himalayan region. *Ecological engineering*, **97**, 593-609, doi:10.1016/j.ecoleng.2016.10.006.
Chakraborty, R. and P. Y. Sherpa, 2021: From climate adaptation to climate justice: Critical reflections on the IPCC and Himalayan climate knowledges. *Climatic Change*, **167**(3), 49, doi:10.1007/s10584-021-03158-1.
Chanapathi, T. and S. Thatikonda, 2020: Evaluation of sustainability of river Krishna under present and future climate scenarios. *Science of The Total Environment*, **738**, 140322, doi:10.1016/j.scitotenv.2020.140322.
Chang, J. D. et al., 2016: Effects of elevated CO2 and temperature on Gynostemma pentaphyllum physiology and bioactive compounds. *Journal of Plant Physiology*, **196**, 41-52, doi:10.1016/j.jplph.2016.02.020.
Chaudhary, P. et al., 2020: Threats, Drivers, and Conservation Imperative of Agrobiodiversity. *The Journal of Agriculture and Environment*, **21**, 44-61.
Chelleri, L., G. Minucci and E. Skrimizea, 2016: Does community resilience decrease social–ecological vulnerability? Adaptation pathways trade-off in the Bolivian Altiplano. *Regional Environmental Change*, **16**, 2229-2241, doi:10.1007/s10113-016-1046-8.
Chen, M. et al., 2021: Climatic, land cover, and anthropogenic controls on dissolved organic matter quantity and quality from major alpine rivers across the Himalayan-Tibetan Plateau. *Science of The Total Environment*, **754**, 142411, doi:10.1016/j.scitotenv.2020.142411.
Chevallier, P., B. Pouyaud, W. Suarez and T. Condom, 2011: Climate change threats to environment in the tropical Andes: glaciers and water resources. *Regional Environmental Change*, **11**, 179-187, doi:10.1007/s10113-010-0177-6.
Chhetri, P. K. and D. M. Cairns, 2018: Low recruitment above treeline indicates treeline stability under changing climate in Dhorpatan Hunting Reserve, Western Nepal. *Physical Geography*, **39**(4), 329-342, doi:10.1080/02723646.2018.1428266.

Chirwa, P. W., L. Mahamane and G. Kowero, 2017: Forests, people and environment: some African perspectives. *Southern Forests: a Journal of Forest Science*, **79**(2), 79-85, doi:10.2989/20702620.2017.1295347.
Chitale, V., R. Silwal and M. Matin, 2018: Assessing the Impacts of Climate Change on Distribution of Major Non-Timber Forest Plants in Chitwan Annapurna Landscape, Nepal. *Resources*, **7**(4), 66, doi:10.3390/resources7040066.
Clayton, S., 2020: Climate anxiety: Psychological responses to climate change. *Journal of Anxiety Disorders*, **74**, 102263, doi:10.1016/j.janxdis.2020.102263.
Coals, P. et al., 2018: Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high-mountain flora. *Journal of vegetation science*, **29**(2), 255-264, doi:10.1111/jvs.12618.
Crimmins, S. M. et al., 2011: Changes in climatic water balance drive downhill shifts in plant species' optimum elevations. *Science*, **331**(6015), 324-327, doi:10.1126/science.1199040.
Cuesta, F. et al., 2019: New land in the Neotropics: a review of biotic community, ecosystem, and landscape transformations in the face of climate and glacier change. *Regional Environmental Change*, **19**(6), 1623-1642, doi:10.1007/s10113-019-01499-3.
Cuesta, F. et al., 2020: Thermal niche traits of high alpine plant species and communities across the tropical Andes and their vulnerability to global warming. *Journal of Biogeography*, **47**(2), 408-420.
Cui, P. and Y. Jia, 2015: Mountain hazards in the Tibetan Plateau: research status and prospects. *National Science Review*, **2**(4), 397-399, doi:10.1093/nsr/nwv061.
Cunsolo, A. and N. R. Ellis, 2018: Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change*, **8**(4), 275-281, doi:10.1038/s41558-018-0092-2.
Dainese, M. et al., 2017: Human disturbance and upward expansion of plants in a warming climate. *Nature Climate Change*, **7**(8), 577-580, doi:0.1038/nclimate3337.
Dandy, J. et al., 2019: Leaving home: place attachment and decisions to move in the face of environmental change. *Regional Environmental Change* **19**, 615-620, doi:10.1007/s10113-019-01463-1.
Dangles, O. et al., 2017: Ecosystem sentinels for climate change? Evidence of wetland cover changes over the last 30 years in the tropical Andes. *PLoS One*, **12**(5), e0175814, doi:10.1371/journal.pone.0175814.
Dantés, H. G., J. A. Farfán-Ale and E. Sarti, 2014: Epidemiological Trends of Dengue Disease in Mexico (2000–2011): A Systematic Literature Search and Analysis. *PLOS Neglected Tropical Diseases*, **8**(11), e3158, doi:10.1371/journal.pntd.0003158.
Das, M., V. Jain and S. Malhotra, 2016: Impact of climate change on medicinal and aromatic plants: Review. *Indian Journal of Agricultural* **86**(11), 1375-1382.
Das, P. V., 2021: People's climate knowledge versus scientists' climate knowledge: a study of apple farming communities in Western Himalayas, India. *GeoJournal*, 1-12.
Davies, K. T. et al., 2019: Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. *Proceedings of the National Academy of Sciences*, **116**(13), 6193-6198, doi:10.1073/pnas.1815107116.
de la Barrera, F. et al., 2018: Megafires in Chile 2017: Monitoring multiscale environmental impacts of burned ecosystems. *Sci Total Environ*, **637-638**, 1526-1536, doi:10.1016/j.scitotenv.2018.05.119.
de la Riva, M. V. d. l., A. Lindner and J. Pretzsch, 2013: Assessing adaptation – Climate change and indigenous livelihood in the Andes of Bolivia. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, **114**(2), 109-122.
De Roos, S., D. Turner, A. Lucieer and D. M. J. S. Bowman, 2018: Using Digital Surface Models from UAS Imagery of Fire Damaged Sphagnum Peatlands for Monitoring and Hydrological Restoration. *Drones*, **2**(4), 45, doi:10.3390/drones2040045.
Demiroglu, O. C., L. Lundmark, J. Saarinen and D. K. Müller, 2019: The last resort? Ski tourism and climate change in Arctic Sweden. *Journal of Tourism Futures*, **6**(1), 91-101, doi:10.1108/JTF-05-2019-0046.
Dhakal, S. et al., 2019: Meeting Future Energy Needs in the Hindu Kush Himalaya. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A. B. Shrestha (eds.)]. Springer, Cham, Switzerland, pp. 167-207. ISBN 9783319922881.
Dhimal, M., B. Ahrens and U. Kuch, 2015: Climate Change and Spatiotemporal Distributions of Vector-Borne Diseases in Nepal – A Systematic Synthesis of Literature. *PLOS ONE*, **10**(6), e0129869, doi:10.1371/journal.pone.0129869.
Di Baldassarre, G. et al., 2018: Water shortages worsened by reservoir effects. *Nature Sustainability*, **1**, 617-622, doi:10.1038/s41893-018-0159-0.
Di Virgilio, G. et al., 2020: Climate Change Significantly Alters Future Wildfire Mitigation Opportunities in Southeastern Australia. *Geophysical Research Letters*, **47**(15), e2020GL088893, doi:10.1029/2020GL088893.
Díaz, P., C. Adler and A. Patt, 2017: Do stakeholders' perspectives on renewable energy infrastructure pose a risk to energy policy implementation? A case of a hydropower plant in Switzerland. *Energy Policy*, **108**, 21-28, doi:10.1016/j.enpol.2017.05.033.
Dickerson-Lange, S. et al., 2016: Challenges and successes in engaging citizen scientists to observe snow cover: from public engagement to an educational collaboration. *Journal of Science Communication*, **15**(1), 1-14, doi:10.22323/2.15010201.

Diemberger, H., A. Hovden and E. T. Yeh, 2015: The honour of the snow-mountains is the snow: Tibetan livelihoods in a changing climate. In: *The High-Mountain Cryosphere: Environmental Changes and Human Risks* [Huggel, C., M. Carey, J. Clague and A. Kääb (eds.)]. Cambridge University Press, pp. 249-271. ISBN 9781107588653.
Dong, Z. et al., 2015: New insights into trace elements deposition in the snow packs at remote alpine glaciers in the northern Tibetan Plateau, China. *Science of The Total Environment*, **529**, 101-113, doi:10.1016/j.scitotenv.2015.05.065.
Drenkhan, F. et al., 2015: The changing water cycle: climatic and socioeconomic drivers of water-related changes in the Andes of Peru. *Wiley Interdisciplinary Reviews: Water*, **2**(6), 715-733, doi:10.1002/wat2.1105.
Drenkhan, F., C. Huggel, L. Guardamino and W. Haeberli, 2019: Managing risks and future options from new lakes in the deglaciating Andes of Peru: The example of the Vilcanota-Urubamba basin. *Science of the Total Environment*, **665**, 465-483, doi:10.1016/j.scitotenv.2019.02.070.
Dumont, B. et al., 2015: A meta-analysis of climate change effects on forage quality in grasslands: specificities of mountain and M editerranean areas. *Grass and Forage Science*, **70**(2), 239-254, doi:10.1111/gfs.12169.
Dupire, S., T. Curt and S. Bigot, 2017: Spatio-temporal trends in fire weather in the French Alps. *Science of the Total Environment*, **595**, 801-817, doi:10.1016/j.scitotenv.2017.04.027.
Duque, A., P. R. Stevenson and K. J. Feeley, 2015: Thermophilization of adult and juvenile tree communities in the northern tropical Andes. *Proceedings of the National Academy of Sciences*, **112**(34), 10744-10749, doi:10.1073/pnas.1506570112.
Dwire, K. A., S. Mellmann-Brown and J. T. Gurrieri, 2018: Potential effects of climate change on riparian areas, wetlands, and groundwater-dependent ecosystems in the Blue Mountains, Oregon, USA. *Climate Services*, **10**, 44-52, doi:10.1016/j.cliser.2017.10.002.
Ebi, K. L. et al., 2021: Extreme weather and climate change: population health and health system implications. *Annual Review of Public Health Volume*, **42**, 293-315, doi:10.1146/annurev-publhealth-012420-105026.
Ehrlich, D., M. Melchiorri and C. Capitani, 2021: Population Trends and Urbanisation in Mountain Ranges of the World. *Land*, **10**(3), 255, doi:10.3390/land10030255.
Elliott, G. P. and C. M. Cowell, 2015: Slope aspect mediates fine-scale tree establishment patterns at upper treeline during wet and dry periods of the 20th century. *Arctic, Antarctic, and Alpine Research*, **47**(4), 681-692, doi:10.1657/AAAR0014-025.
Elsen, P. R., W. B. Monahan and A. M. Merenlender, 2018: Global patterns of protection of elevational gradients in mountain ranges. *Proceedings of the National Academy of Sciences*, **115**(23), 6004-6009, doi:10.1073/pnas.1720141115.
Encalada, A. C. et al., 2019: A global perspective on tropical montane rivers. *Science*, **365**(6458), 1124-1129, doi:10.1126/science.aax1682.
Enright, N. J., 2014: Introduction to the special virtual issue on climate change. *Plant Ecology*, **215**, 1-2, doi:10.1007/s11258-013-0284-9.
Enright, N. J. et al., 2015: Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes. *Frontiers in Ecology and the Environment*, **13**(5), 265-272, doi:10.1890/140231.
Equihua, M. et al., 2017: Establishment of Aedes aegypti (L.) in mountainous regions in Mexico: Increasing number of population at risk of mosquito-borne disease and future climate conditions. *Acta Tropica*, **166**, 316-327, doi:10.1016/j.actatropica.2016.11.014.
Eriksen, S. et al., 2021: Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Development*, **141**, 105383, doi:10.1016/j.worlddev.2020.105383.
Escobar, L. E. et al., 2016: Declining prevalence of disease vectors under climate change. *Scientific reports*, **6**, 39150, doi:10.1038/srep39150.
Fadrique, B. et al., 2018: Widespread but heterogeneous responses of Andean forests to climate change. *Nature*, **564**(7735), 207-212, doi:10.1038/s41586-018-0715-9.
Fairman, T. A., L. T. Bennett, S. Tupper and C. R. Nitschke, 2017: Frequent wildfires erode tree persistence and alter stand structure and initial composition of a fire-tolerant sub-alpine forest. *Journal of Vegetation Science* **28**(6), 1151-1165, doi:10.1111/jvs.12575.
Fang, Y., D. Scott and R. Steiger, 2019: The impact of climate change on ski resorts in China. *International Journal of Biometeorology*, doi:10.1007/s00484-019-01822-x.
FAO, 2015: *Mapping the vulnerability of mountain peoples to food insecurity* [Romeo, R., A. Vita, R. Testolin and T. Hofer (eds.)]. Food and Agriculture Organization of the United Nations, Rome, Italy, 66 pp. ISBN 9789251089934.
FAO, 2019: *Mountain agriculture: Opportunities for harnessing Zero Hunger in Asia* [Li, X., M. El Solh and K. H. M. Siddique (eds.)]. Food and Agricultural Organization of the United Nations, Bangkok, Thailand, 278 pp. ISBN 9789251316801.
Farinotti, D. et al., 2019: Large hydropower and water-storage potential in future glacier-free basins. *Nature*, **575**(7782), 341-344, doi:10.1038/s41586-019-1740-z.
Fassio, G., L. M. Battaglini, V. Porcellana and P. P. Viazzo, 2014: The Role of the Family in Mountain Pastoralism—Change and Continuity. *Mountain Research and Development*, **34**(4), 336-343, doi:10.1659/MRD-JOURNAL-D-14-00019.1.

Feeley, K. J. et al., 2013: Compositional shifts in Costa Rican forests due to climate-driven species migrations. *Global Change Biology*, **19**(11), 3472-3480, doi:10.1111/gcb.12300.
Felder, G. et al., 2018: From global circulation to local flood loss: Coupling models across the scales. *Science of the Total Environment*, **635**, 1225-1239, doi:10.1016/j.scitotenv.2018.04.170.
Fill, J. M., C. N. Davis and R. M. Crandall, 2019: Climate change lengthens southeastern USA light-ning-ignited fire seasons. *Global Change Bioloiy*, **25**(10), 3562– 3569, doi:10.1111/gcb.14727.
Ford, J. D. et al., 2020: The Resilience of Indigenous Peoples to Environmental Change. *One Earth*, **2**(6), 532-543, doi:10.1016/j.oneear.2020.05.014.
François, B., K. E. Schlef, S. Wi and C. M. Brown, 2019: Design considerations for riverine floods in a changing climate – A review. *Journal of Hydrology*, **574**, 557-573, doi:10.1016/j.jhydrol.2019.04.068.
Freeman, B. G., M. N. Scholer, V. Ruiz-Gutierrez and J. W. Fitzpatrick, 2018: Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. *Proceedings of the National Academy of Sciences*, **115**(47), 11982-11987, doi:10.1073/pnas.1804224115.
French, A., J. Barandiarán and C. Rampini, 2015: Contextualizing conflict. Vital water and competing values in glaciated environments. In: *The High-Mountain Cryosphere. Environmental Changes and Human Risk* [Huggel, C., M. Carey, J. J. Clague and A. Kääb (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 315-336. ISBN 9781107588653.
French, M., A. Trundle, I. Korte and C. Koto, 2021: Climate Resilience in Urban Informal Settlements: Towards a Transformative Upgrading Agenda. *Climate Resilient Urban Areas*, 129-153, doi:10.1007/978-3-030-57537-3_7.
Frisbee, M. D. et al., 2011: Streamflow generation in a large, alpine watershed in the southern Rocky Mountains of Colorado: Is streamflow generation simply the aggregation of hillslope runoff responses? *Water Resources Research*, **47**(6), doi:10.1029/2010WR009391.
Froude, M. J. and D. N. Petley, 2018: Global fatal landslide occurrence from 2004 to 2016. *Natural Hazards and Earth System Science*, **18**(8), 2161-2181, doi:10.5194/nhess-18-2161-2018.
Fuhrer, J., P. Smith and A. Gobiet, 2014: Implications of climate change scenarios for agriculture in alpine regions - A case study in the Swiss Rhone catchment. *Science of the Total Environment*, **493**, 1232-1241, doi:10.1016/j.scitotenv.2013.06.038.
Furberg, M., B. Evengard and M. Nilsson, 2011: Facing the limit of resilience: perceptions of climate change among reindeer herding Sami in Sweden. *Global Health Action*, **4**(1), 8417, doi:10.3402/gha.v4i0.8417.
Furian, W., D. Loibl and C. Schneider, 2021: Future glacial lakes in High Mountain Asia: an inventory and assessment of hazard potential from surrounding slopes. *Journal of Glaciology*, **67**(264), 653-670, doi:10.1017/jog.2021.18.
Furu, P. and D. K. Van, 2013: Health Impacts of Climate and Environmental Change: Awareness and Challenges to Adaptation. In: *On the Frontiers of Climate and Environmental Change* [Bruun, O. and T. Casse (eds.)]. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 195-217. ISBN 978-3-642-35803-6 978-3-642-35804-3.
Gaira, K. S., R. S. Rawal, B. Rawat and I. D. Bhatt, 2014: Impact of climate change on the flowering of Rhododendron arboreum in central Himalaya, India. *Current Science*, 1735-1738.
Gaire, N. P., 2016: Climate Trend and Treeline Dynamics in Nepal Himalaya. Ph.D. thesis. Tribhuvan University, Institute of Science and Technology, Kirtipur , Nepal.
Gairola, S., N. M. Shariff and A. Bhatt, 2010: Influence of climate change on production of secondary chemicals in high altitude medicinal plants: issues needs immediate attention. *Journal of Medicinal Plants Research*, **4**(18), 1825-1829.
Gariano, S. L. and F. Guzzetti, 2016: Landslides in a changing climate. *Earth-Science Reviews*, **162**, 227-252, doi:10.1016/j.earscirev.2016.08.011.
Gaudard, L. et al., 2014: Climate change impacts on hydropower in the Swiss and Italian Alps. *Science of The Total Environment*, **493**, 1211-1221, doi:10.1016/j.scitotenv.2013.10.012.
Gautam, Y., 2017: Seasonal migration and livelihood resilience in the face of climate change in Nepal. *Mountain Research and Development*, **37**(4), 436-445, doi:10.1659/MRD-JOURNAL-D-17-00035.1.
Gentle, P. and R. Thwaites, 2016: Transhumant Pastoralism in the Context of Socioeconomic and Climate Change in the Mountains of Nepal. *Mountain Research and Development*, **36**(2), 173-182, doi:10.1659/MRD-JOURNAL-D-15-00011.1.
Gerbaux, M. et al., 2020: Snow reliability and water availability for snowmaking in the ski resorts of the Isère département (French Alps), under current and future climate conditions. *Journal of Alpine Research*, **108**, 1, doi:10.4000/rga.6724.
Gergel, D. R. et al., 2017: Effects of climate change on snowpack and fire potential in the western USA. *Climatic Change*, **141**, 287–299, doi:10.1007/s10584-017-1899-y.
Gibson, R. K., L. Broome and M. F. Hutchinson, 2018: Susceptibility to climate change via effects on food resources: the feeding ecology of the endangered mountain pygmy-possum (Burramys parvus). *Wildlife Research*, **45**(6), 539-550, doi:10.1071/WR17186.
Gidey, T., T. S. Oliveira, J. Crous-Duran and J. H. Palma, 2020: Using the yield-SAFE model to assess the impacts of climate change on yield of coffee (Coffea arabica L.) under agroforestry and monoculture systems. *Agroforestry Systems*, **94**(1), 57-70, doi:10.1007/s10457-019-00369-5.

Gilgel, A. W., T. Terefe and M. Asfaw, 2019: Assessment and Projection of Climate Change Impacts on Malaria Distribution in Ethiopia: Case of Combolcha and Debark Districts. *International Journal of Research in Environmental Science*, **5**(4), 20-42, doi:10.20431/2454-9444.0504003.
Gioli, G., T. Khan, S. Bisht and J. Scheffran, 2014: Migration as an Adaptation Strategy and its Gendered Implications: A Case Study From the Upper Indus Basin. *Mountain Research and Development*, **34**(3), 255-265, doi:10.1659/MRD-JOURNAL-D-13-00089.1.
Gioli, G. et al., 2019: Understanding and Tackling Poverty and Vulnerability in Mountain Livelihoods in the Hindu Kush Himalaya. In: *The Hindu Kush Himalaya Assessment* [Wester, P., A. Mishra, A. Mukherji and A. Shrestha (eds.)]. Springer, Cham, Switzerland, pp. 421-455. ISBN 9783319922881.
Godde, C. M. et al., 2021: Impacts of climate change on the livestock food supply chain; a review of the evidence. *Global Food Security*, **28**, 100488, doi:10.1016/j.gfs.2020.100488.
Gonzales-Valero, W., 2018: Hazards to food caloric availability and coverage per capita due to climate change in the Puno region, Peruvian Altiplano: Challenges in food security and sovereignty. *Food and Energy Security*, **7**(2), e00134, doi:10.1002/fes3.134.
Goodrich, C. G., A. Prakash and P. B. Udas, 2019: Gendered vulnerability and adaptation in Hindu-Kush Himalayas: Research insights. *Environmental Development*, **31**, 1-8, doi:10.1016/j.envdev.2019.01.001.
Gordon, R. P. et al., 2015: Sources and pathways of stream generation in tropical proglacial valleys of the Cordillera Blanca, Peru. *Journal of Hydrology*, **522**, 628-644, doi:10.1016/j.jhydrol.2015.01.013.
Gottfried, M. et al., 2012: Continent-wide response of mountain vegetation to climate change. *Nature Climate Change*, **2**(2), 111-115, doi:10.1038/nclimate1329.
Grêt-Regamey, A. and B. Weibel, 2020: Global assessment of mountain ecosystem services using earth observation data. *Ecosystem Services*, **46**, doi:10.1016/j.ecoser.2020.101213.
Grigorieva, A. V. and P. A. Moiseev, 2018: Peculiarities and Determinants of Regeneration of Siberian Larch on the Upper Limit of Its Growth in the Urals. *Contemporary Problems of Ecology*, **11**, 13-25, doi:10.1134/S1995425518010031.
Grüneis, H. et al., 2018: Why do we not pick the low-hanging fruit? Governing adaptation to climate change and resilience in Tyrolean mountain agriculture. *Land Use Policy*, **79**, 386-396, doi:10.1016/j.landusepol.2018.08.025.
Guisan, A., W. Thuiller and N. E. Zimmermann, 2017: *Habitat suitability and distribution model with applications in R*. Cambridge University Press, 462 pp. ISBN 9781139028271.
Guisan, A. A. et al., 2019: Climate change impacts on mountain biodiversity. In: *Biodiversity and Climate ChangeTransforming the Biosphere* [Lovejoy, T. E. and L. Hannah (eds.)]. Yale University Press, pp. 221-233. ISBN 9780300206111.
Guo, F., J. Lenoir and T. C. Bonebrake, 2018: Land-use change interacts with climate to determine elevational species redistribution. *Nature communications*, **9**, 1315, doi:10.1038/s41467-018-03786-9.
Gurung, A. B. et al., 2016: Rethinking pumped storage hydropower in the European Alps. *Mountain Research and Development*, **36**(2), 222–232, doi:10.1659/MRD-JOURNAL-D-15-00069.1.
Haasnoot, M. et al., 2020: Defining the solution space to accelerate climate change adaptation. *Regional Environmental Change*, **20**, 37, doi:10.1007/s10113-020-01623-8.
Haeberli, W. and M. Beniston, 2021: Icy mountains in a warming world: Revisiting science from the end of the 1990s in the early 2020s. *Ambio*, **50**, 1130–1132, doi:10.1007/s13280-021-01513-1.
Haeberli, W. et al., 2016a: New lakes in deglaciating high-mountain regions – Opportunities and risks. *Climatic Change*, **139**(2), 201-214, doi:10.1007/s10584-016-1771-5.
Haeberli, W., Y. Schaub and C. Huggel, 2016b: Increasing risks related to landslides from degrading permafrost into new lakes in de-glaciating mountain ranges. *Geomorphology*, **293**(Part B), 405-417, doi:10.1016/j.geomorph.2016.02.009.
Hagedorn, F., K. Gavazov and J. M. Alexander, 2019: Above- And belowground linkages shape responses of mountain vegetation to climate change. *Science*, **365**, 1119-1123., doi:10.1126/science.aax4737.
Halofsky, J. E., D. L. Peterson and B. J. Harvey, 2020: Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, **16**, 4, doi:10.1186/s42408-019-0062-8.
Hansson, A., P. Dargusch and J. Shulmeister, 2021: A review of modern tree-line migration, the factors controlling it and the implications for carbon storage. *Journal of Mountain Science*, **18**(2), 291-306, doi:10.1007/s11629-020-6221-1.
Haque, U. et al., 2019: The human cost of global warming: Deadly landslides and their triggers (1995–2014). *Science of The Total Environment*, **682**, 673-684, doi:10.1016/j.scitotenv.2019.03.415.
Harish, B. S., S. B. Dandin, K. Umesha and H. M. Pallavi, 2012: Impact of climate change on Medicinal Plants - A review. *Ancient Science of life*, **32**(5), 23, doi:10.4103/0257-7941.111986.
Helmer, E. H. et al., 2019: Neotropical cloud forests and páramo to contract and dry from declines in cloud immersion and frost. *PloS ONE*, **14**(4), e0213155, doi:10.1371/journal.pone.0213155.
Hemp, A., 2005: Climate change-driven forest fires marginalize the impact of ice cap wasting on Kilimanjaro. *Global Change Biology*, **11**(7), 1013-1023, doi:10.1111/j.1365-2486.2005.00968.x.

Herman-Mercer, N. M., R. A. Loehman, R. C. Toohey and C. Paniyak, 2020: Climate-and disturbance-driven changes in subsistence berries in coastal Alaska: Indigenous knowledge to inform ecological inference. *Human Ecology*, **48**(1), 85-99.
Hill, M., 2013: Adaptive Capacity of Water Governance: Cases From the Alps and the Andes. *Mountain Research and Development*, **33**(3), 248, doi:10.1659/MRD-JOURNAL-D-12-00106.1.
Hirabayashi, Y. et al., 2013: Global flood risk under climate change. *Nature Climate Change*, **3**(9), 816-821, doi:10.1038/nclimate1911.
Hock, R. et al., 2019: High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [Pörtner, H. O., D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama and N. M. Weyer (eds.)], pp. 133-202.
Hoffmann, D., M. F. de Vasconcelos and G. Wilson Fernandes, 2020: The fate of endemic birds of eastern Brazilian mountaintops in the face of climate change. *Perspectives in Ecology and Conservation*, **18**(4), 257-266, doi:10.1016/j.pecon.2020.10.005.
Honda, E. A. and G. Durigan, 2016: Woody encroachment and its consequences on hydrological processes in the savannah. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **371**(1703), 20150313, doi:10.1098/rstb.2015.0313.
Hopping, K. A., S. M. Chignell and E. F. Lambin, 2018: The demise of caterpillar fungus in the Himalayan region due to climate change and overharvesting. *Proceedings of the National Academy of Sciences*, **115**(45), 11489-11494, doi:10.1073/pnas.1811591115.
Horvath, P. et al., 2021: Improving the representation of high-latitude vegetation distribution in dynamic global vegetation models. *Biogeosciences*, **18**(1), 95-112, doi:10.5194/bg-18-95-2021.
Hovelsrud, G. K., M. Karlsson and J. Olsen, 2018: Prepared and flexible: Local adaptation strategies for avalanche risk. *Cogent Social Sciences*, **4**(1), 1460899, doi:10.1080/23311886.2018.1460899.
Howarth, C. and I. Monasterolo, 2016: Understanding barriers to decision making in the UK energy-food-water nexus: The added value of interdisciplinary approaches. *Environmental Science & Policy*, **61**, 53-60, doi:10.1016/j.envsci.2016.03.014.
Huang, J. and H. Hao, 2020: Effects of climate change and crop planting structure on the abundance of cotton bollworm, Helicoverpa armigera (Hübner)(Lepidoptera: Noctuidae). *Ecology and Evolution*, **10**(3), 1324-1338, doi:10.1002/ece3.5986.
Huang, Z. et al., 2021: Global assessment of future sectoral water scarcity under adaptive inner-basin water allocation measures. *Science of The Total Environment*, **783**, 146973, doi:10.1016/j.scitotenv.2021.146973.
Huggel, C. et al., 2020a: Anthropogenic climate change and glacier lake outburst flood risk: local and global drivers and responsibilities for the case of lake Palcacocha, Peru. *Natural Hazards and Earth System Sciences*, **20**(8), 2175-2193, doi:10.5194/nhess-20-2175-2020.
Huggel, C. et al., 2020b: Glacier Lake 513, Peru: Lessons for early warning service development. *World Meterological Organization (WMO) Bulletin*, **69**(1), 45-52.
Huggel, C. et al., 2019: Loss and Damage in the mountain cryosphere. *Regional Environmental Change*, **19**, 1387–1399, doi:10.1007/s10113-018-1385-8.
Huggel, C. et al., 2015: A framework for the science contribution in climate adaptation: Experiences from science-policy processes in the Andes. *Environmental Science & Policy*, **47**, 80-94, doi:10.1016/j.envsci.2014.11.007.
Hugonnet, R. et al., 2021: Accelerated global glacier mass loss in the early twenty-first century. *Nature*, **592**(7856), 726-731, doi:10.1038/s41586-021-03436-z.
Hunt, J. D. et al., 2020: Mountain Gravity Energy Storage: A new solution for closing the gap between existing short- and long-term storage technologies. *Energy*, **190**, 116419, doi:10.1016/j.energy.2019.116419.
Hunter, L. M., J. K. Luna and R. M. Norton, 2015: The Environmental Dimensions of Migration. *Annual Review of Sociology*, **41**, 377-397, doi:10.1146/annurev-soc-073014-112223.
Hupp, J., M. Brubaker, K. Wilkinson and J. Williamson, 2015: How are your berries? Perspectives of Alaska's environmental managers on trends in wild berry abundance. *International journal of circumpolar health*, **74**(1), 28704.
Huss, M., 2011: Present and future contribution of glacier storage change to runoff from macroscale drainage basins in Europe. *Water Resources Research*, **47**(7), W07511, doi:10.1029/2010WR010299.
Huss, M. et al., 2017: Toward mountains without permanent snow and ice. *Earth's Future*, **5**(5), 418-435, doi:10.1002/2016EF000514.
Huss, M. and R. Hock, 2018: Global-scale hydrological response to future glacier mass loss. *Nature Climate Change*, **8**(2), 135-140, doi:10.1038/s41558-017-0049-x.
Hussain, A., N. K. Agrawal and I. Leikanger, 2016a: Action for Adaptation: Bringing climate change science to policy makers - a synthesis report of a conference held in Islamabad on 23–25 July 2015. *Food Security*, **8**, 285-289, doi:10.1007/s12571-015-0529-7.
Hussain, A. et al., 2019: Climate Change Perspective in Mountain Area: Impacts and Adaptations in Naltar Valley, Western Himalaya, Pakistan. *Fresenius Environmental Bulletin*, **28**(9), 312-320.
Hussain, A. and F. M. Qamar, 2020: Dual challenge of climate change and agrobiodiversity loss in mountain food systems in the Hindu-Kush Himalaya. *One Earth*, doi:10.1016/j.oneear.2020.10.016.

Hussain, A., G. Rasul, B. Mahapatra and S. Tuladhar, 2016b: Household food security in the face of climate change in the Hindu-Kush Himalayan region. *Food Security*, **8**(5), 921-937, doi:10.1007/s12571-016-0607-5.
Hussain, A. et al., 2018: Climate change-induced hazards and local adaptations in agriculture: a study from Koshi River Basin, Nepal. *Natural Hazards*, **91**(3), 1365-1383, doi:10.1007/s11069-018-3187-1.
IDMC, 2020: *Internal displacement index 2020 report*. Internal Displacement Monitoring Centre, Geneva, Switzerland. Available at: https://www.internal-displacement.org/global-report/grid2020/.
Ilyashuk, B. P. et al., 2018: Rock glaciers in crystalline catchments: Hidden permafrost-related threats to alpine headwater lakes. *Global Change Biology*, **24**(4), 1548-1562, doi:10.1111/gcb.13985.
Immerzeel, W. W. et al., 2020: Importance and vulnerability of the world's water towers. *Nature*, **577**, 364-369, doi:10.1038/s41586-019-1822-y.
Ingxay, P., S. Yokoyama and I. Hirota, 2015: Livelihood factors and household strategies for an unexpected climate event in upland northern Laos. *Journal of Mountain Science*, **12**(2), 483-500, doi:10.1007/s11629-013-2879-y.
IPCC, 2018: *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, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor and T. Waterfield (eds.)]. Intergovernmental Panel on Climate Change, Geneva, Switserland.
Iribarren Anacona, P., A. Mackintosh and K. Norton, 2015: Reconstruction of a glacial lake outburst flood (GLOF) in the Engaño Valley, Chilean Patagonia: Lessons for GLOF risk management. *Science of The Total Environment*, **527-528**, 1-11, doi:10.1016/j.scitotenv.2015.04.096.
Isaak, D. J. et al., 2016: Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. *Proceedings of the National Academy of Sciences*, **113**(16), 4374-4379, doi:10.1073/pnas.1522429113.
Islam, R., S. Schech and U. Saikia, 2020: Climate change events in the Bengali migration to the Chittagong Hill Tracts (CHT) in Bangladesh. *Climate and Development*, 1-11, doi:10.1080/17565529.2020.1780191.
Jalilov, S.-M., S. A. Amer and F. A. Ward, 2018: Managing the water-energy-food nexus: Opportunities in Central Asia. *Journal of Hydrology*, **557**, 407-425, doi:10.1016/j.jhydrol.2017.12.040.
Jurt, C. et al., 2015: Cultural values of glaciers. In: *The High Mountain Cryosphere: Environmental Changes and Human Risks* [Huggel, C., M. Carey, J. J. Clague and A. Kääb (eds.)]. Cambridge University Press, pp. 90-106. ISBN 9781107588653.
Juschten, M. et al., 2019a: Out of the City Heat—Way to Less or More Sustainable Futures? *Sustainability*, **11**, 214, doi:10.3390/su11010214.
Juschten, M., A. Jiricka-Pürrer, W. Unbehaun and R. Hössinger, 2019b: The Mountains Are Calling! An Extended Tpb Model for Understanding Metropolitan Residents' Intentions to Visit Nearby Alpine Destinations in Summer. *Tourism Management*, **75**, 293-306, doi:10.1016/j.tourman.2019.05.014.
Kaboosi, K. and M. Kordjazi, 2017: The effect of climate change on meteorological parameters and drought in Golestan province. *Iran-Water Resources Research*, **13**(3), 205-213.
Kadetz, P. and N. B. Mock, 2018: Chapter 9 - Problematizing vulnerability: Unpacking gender, intersectionality, and the normative disaster paradigm. In: *Creating Katrina, Rebuilding Resilience* [Zakour, M. J., N. B. Mock and P. Kadetz (eds.)]. Butterworth-Heinemann, pp. 215-230. ISBN 978-0-12-809557-7.
Kalbali, E., S. Ziaee, M. Mardani Najafabadi and M. Zakerinia, 2019: Assessment of Climate Change Impacts on Optimum Cropping Pattern: A Case Study of Ghareso Basin in Golestan Province. *Iran-Water Resources Research*, **15**(3), 251-271.
Kapos, V. et al., 2000: Developing a map of the world's mountain forests. In: *Forests in sustainable mountain development: a state of knowledge report for 2000. Task Force on Forests in Sustainable Mountain Development* [Price, M. F. and N. Butt (eds.)]. CABI, Wallingford, United Kingdom, pp. 4-18. ISBN 9780851994468.
Karavani, A. et al., 2018: Effect of climatic and soil moisture conditions on mushroom productivity and related ecosystem services in Mediterranean pine stands facing climate change. *Agricultural and Forest Meteorology*, **248**, 432-440, doi:10.1016/j.agrformet.2017.10.024.
Käser, D. and D. Hunkeler, 2016: Contribution of alluvial groundwater to the outflow of mountainous catchments. *Water Resources Research*, **52**(2), 680-697, doi:10.1002/2014WR016730.
Kaul, V. and T. F. Thornton, 2014: Resilience and adaptation to extremes in a changing Himalayan environment. *Regional Environmental Change*, **14**(2), 683-698, doi:10.1007/s10113-013-0526-3.
Khanian, M., B. Serpoush and N. Gheitarani, 2019: Balance between place attachment and migration based on subjective adaptive capacity in response to climate change: the case of Famenin County in Western Iran. *Climate and Development*, **11**(1), 69-82, doi:10.1080/17565529.2017.1374238.
Kidane, Y. O., M. J. Steinbauer and C. Beierkuhnlein, 2019: Dead end for endemic plant species? A biodiversity hotspot under pressure. *Global Ecology and Conservation*, **19**, e00670-e00670, doi:10.1016/j.gecco.2019.e00670.
Kimaro, E. G., S. M. Mor and J.-A. L. M. L. Toribio, 2018: Climate change perception and impacts on cattle production in pastoral communities of northern Tanzania. *Pastoralism*, **8**(1), 19, doi:10.1186/s13570-018-0125-5.

Kinouchi, T. et al., 2019: Water security in high mountain cities of the Andes under a growing population and climate change: A case study of La Paz and El Alto, Bolivia. *Water Security*, **6**, 100025, doi:10.1016/j.wasec.2019.100025.
Kirschbaum, D., S. B. Kapnick, T. Stanley and S. Pascale, 2020: Changes in Extreme Precipitation and Landslides Over High Mountain Asia. *Geophysical Research Letters*, **47**(4), 1-9, doi:10.1029/2019GL085347.
Kirschbaum, D. et al., 2019: The State of Remote Sensing Capabilities of Cascading Hazards Over High Mountain Asia. *Frontiers in Earth Science*, **7**, 197, doi:10.3389/feart.2019.00197.
Kiseleva, N. V., 2020: Long-term Population Dynamics of the Bank Vole in the Ilmen Nature Reserve. *Russian Journal of Ecology*, **51**(2), 188-194, doi:10.1134/S1067413620020071.
Klein, J. A. et al., 2019a: Catalyzing Transformations to Sustainability in the World's Mountains. *Earth's Future*, **7**(5), 547-557, doi:10.1029/2018EF001024.
Klein, J. A. et al., 2019b: An integrated community and ecosystem-based approach to disaster risk reduction in mountain systems. *Environmental Science & Policy*, **94**, 143-152, doi:10.1016/j.envsci.2018.12.034.
Klepp, S. and L. Chavez-Rodriguez (eds.), 2018: *A Critical Approach to Climate Change Adaptation. Discourses, Policies and Practices*, Routledge, 302 pp.
Kmoch, L., T. Pagella, M. Palm and F. Sinclair, 2018: Using local agroecological knowledge in climate change adaptation: a study of tree-based options in Northern Morocco. *Sustainability*, **10**(10), 3719.
Köberl, J. et al., 2021: The demand side of climate services for real-time snow management in Alpine ski resorts: Some empirical insights and implications for climate services development. *Climate Services*, **22**, 100238, doi:10.1016/j.cliser.2021.100238.
Koide, D., K. Yoshida, C. C. Daehler and D. Mueller-Dombois, 2017: An upward elevation shift of native and non-native vascular plants over 40 years on the island of Hawai'i. *Journal of vegetation science*, **28**(5), 939-950, doi:10.1111/jvs.12549.
Körner, C., 2003: *Alpine Plant Life: Functional Plant Ecology of High Mountain Ecosystems*. Springer, Berlin, Germany, 349 pp. ISBN 9783642189708.
Körner, C., 2020: Climatic Controls of the Global High Elevation Treelines. In: *Encyclopedia of the World's Biomes* [Goldstein, M. I. and D. A. DellaSala (eds.)]. Elsevier, USA, pp. 275-281. ISBN 9780128160978.
Körner, C. and E. Spehn, 2016: Alpine Ökosysteme. In: *Brennpunkt Klima Schweiz. Grundlagen, Folgen und Perspektiven.* [Mittler, M. and S. Hosi (eds.)]. Akademien der Wissenschaften Schweiz, Bern, Switzerland, pp. 96-99.
Kueffer, C. et al., 2013: Plant Invasions into Mountain Protected Areas: Assessment, Prevention and Control at Multiple Spatial Scales. In: *Plant Invasions in Protected Areas* [Foxcroft, L., P. Pyšek, D. Richardson and P. Genovesi (eds.)]. Springer, Dordrecht, pp. 89-113. ISBN 9789400777507.
Kumar, R. et al., 2020: Elevated CO2 and temperature influence key proteins and metabolites associated with photosynthesis, antioxidant and carbon metabolism in Picrorhiza kurroa. *Journal of Proteomics*, **219**, 103755, doi:10.1016/j.jprot.2020.103755.
Kummu, M. et al., 2016: The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. *Scientific Reports*, **6**, 38495, doi:10.1038/srep38495.
Laha, A., R. Badola and S. A. Hussain, 2018: Earning a Livelihood from Himalayan Caterpillar Fungus in Kumaon Himalaya: Opportunities, Uncertainties, and Implications. *Mountain Research and Development*, **38**, 323, doi:10.1659/MRD-JOURNAL-D-17-00063.1.
Lamborn, C. C. and J. W. Smith, 2019: Human perceptions of, and adaptations to, shifting runoff cycles: A case-study of the Yellowstone River (Montana, USA). *Fisheries Research*, **216**, 96-108, doi:10.1016/j.fishres.2019.04.005.
Landeros-Mugica, K., J. Urbina-Soria and I. Alcántara-Ayala, 2016: The good, the bad and the ugly: on the interactions among experience, exposure and commitment with reference to landslide risk perception in México. *Natural Hazards*, **80**(3), 1515-1537, doi:10.1007/s11069-015-2037-7.
Lane, S. N. et al., 2019: Making stratigraphy in the Anthropocene: climate change impacts and economic conditions controlling the supply of sediment to Lake Geneva. *Scientific Reports*, **9**, 8904, doi:10.1038/s41598-019-44914-9.
Lavorel, S. et al., 2019: Mustering the power of ecosystems for adaptation to climate change. *Environmental Science & Policy*, **92**, 87-97, doi:10.1016/j.envsci.2018.11.010.
Lehikoinen, A. et al., 2019: Declining population trends of European mountain birds. *Global Change Biology*, **25**(2), 577-588, doi:10.1111/gcb.14522.
Lepcha, P. T., P. K. Pandey and P. Ranjan, 2021: Hydrological significance of Himalayan surface water and its management considering anthropogenic and climate change aspects. *IOP Conference Series: Materials Science and Engineering*, **1020**, 012013, doi:10.1088/1757-899X/1020/1/012013.
Li, D., Z. Li, Y. Zhou and X. Lu, 2020: Substantial Increases in the Water and Sediment Fluxes in the Headwater Region of the Tibetan Plateau in Response to Global Warming. *Geophysical Research Letters*, **47**(11), e2020GL087745, doi:10.1029/2020GL087745.
Li, J. et al., 2017: Assessing vulnerability of giant pandas to climate change in the Qinling Mountains of China. *Ecology and Evolution*, **7**(11), 4003-4015, doi:10.1002/ece3.2981.
Liang, E. et al., 2016: Species interactions slow warming-induced upward shifts of treelines on the Tibetan Plateau. *Proceedings of the National Academy of Sciences*, **113**(16), 4380, doi:10.1073/pnas.1520582113.

Littell, J. S., D. McKenzie, H. Y. Wan and S. A. Cushman, 2018: Climate change and fu-ture wildfire in the western United States: An ecological approach to nonstationarity. *Earth's Future*, **6**(8), 1097-1111, doi:10.1029/2018EF000878.
Liu, H. et al., 2011: Predicting the wetland distributions under climate warming in the Great Xing'an Mountains, northeastern China. *Ecological Research*, **26**(3), 605–613, doi:10.1007/s11284-011-0819-2.
López, S., J.-K. Jung and M. F. López, 2017: A hybrid-epistemological approach to climate change research: Linking scientific and smallholder knowledge systems in the Ecuadorian Andes. *Anthropocene*, **17**, 30-45, doi:10.1016/j.ancene.2017.01.001.
Lu, X. et al., 2021: Mountain treelines climb slowly despite rapid climate warming. *Global Ecology and Biogeography*, **30**, 305–315, doi:10.1111/geb.13214.
Lucas, J. and R. M. B. Harris, 2021: Changing Climate Suitability for Dominant Eucalyptus Species May Affect Future Fuel Loads and Flammability in Tasmania. *Fire*, **4**(1), 1, doi:10.3390/fire4010001.
Lutz, A. F., W. W. Immerzeel, A. B. Shrestha and M. F. P. Bierkens, 2014: Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature Climate Change*, **4**(7), 587-592, doi:10.1038/nclimate2237.
Lynch, B. D., 2012: Vulnerabilities, competition and rights in a context of climate change toward equitable water governance in Peru's Rio Santa Valley. *Global Environmental Change*, **22**(2), 364-373, doi:10.1016/j.gloenvcha.2012.02.002.
Mach, K. J., M. D. Mastrandrea, P. T. Freeman and C. B. Field, 2017: Unleashing expert judgment in assessment. *Global Environmental Change*, **44**, 1-14, doi:10.1016/j.gloenvcha.2017.02.005.
Maharjan, A. et al., 2020: Migration and Household Adaptation in Climate-Sensitive Hotspots in South Asia. *Current Climate Change Reports*, **6**, 1-16, doi:10.1007/s40641-020-00153-z.
Maharjan, A. et al., 2021: Can labour migration help households adapt to climate change? Evidence from four river basins in South Asia. *Climate and Development*, doi:10.1080/17565529.2020.1867044.
Maikhuri, R. K. et al., 2018: Assessment of climate change impacts and its implications on medicinal plants-based traditional healthcare system in Central Himalaya, India. *Iranian Journal of Science and Technology, Transactions A: Science*, **42**(4), 1827-1835.
Majone, B., F. Villa, R. Deidda and A. Bellin, 2016: Impact of climate change and water use policies on hydropower potential in the south-eastern Alpine region. *Science of the Total Environment*, **543**, 965-980, doi:10.1016/j.scitotenv.2015.05.009.
Manes, S. et al., 2021: Endemism increases species' climate change risk in areas of global biodiversity importance. *Biological Conservation*, **257**, 109070, doi:10.1016/j.biocon.2021.109070.
Manton, M. J. and L. A. Stevenson, 2014: Future Directions for Climate Research in Asia and the Pacific. In: *Climate in Asia and the Pacific* [Manton, M. J. and L. A. Stevenson (eds.)]. Springer, Netherlands, pp. 289-307. ISBN 9789400773387.
Marazziti, D. et al., 2021: Climate change, environment pollution, COVID-19 pandemic and mental health. *Science of The Total Environment*, **773**, 145182, doi:10.1016/j.scitotenv.2021.145182.
March, H., D. Saurí and J. C. Llurdés, 2014: Perception of the effects of climate change in winter and summer tourist areas: the Pyrenees and the Catalan and Balearic coasts, Spain. *Regional Environmental Change*, **14**(3), 1189-1201, doi:10.1007/s10113-013-0561-0.
Marjanac, S., L. Patton and J. Thornton, 2017: Acts of God, human influence and litigation. *Nature Geoscience*, **10**(9), 616-619, doi:10.1038/ngeo3019.
Marzeion, B., G. Kaser, F. Maussion and N. Champollion, 2018: Limited influence of climate change mitigation on short-term glacier mass loss. . *Nature Climate Change*, **8**, 305–308, doi:10.1038/s41558-018-0093-1.
Mastrorillo, M. et al., 2016: The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, **39**, 155-169, doi:10.1016/j.gloenvcha.2016.04.014.
Matasci, C., S. Kruse, N. Barawid and P. Thalmann, 2014: Exploring barriers to climate change adaptation in the Swiss tourism sector. *Mitigation and Adaptation Strategies for Global Change*, **19**(8), 1239-1254, doi:10.1007/s11027-013-9471-1.
Mbow, C., M. van Noordwijk, R. Prabhu and T. Simons, 2014: Knowledge gaps and research needs concerning agroforestry's contribution to sustainable development goals in Africa. *Current Opinion in Environmental Sustainability*, **6**, 162-170, doi:10.1016/j.cosust.2013.11.030.
McCormick, S. et al., 2017: Science in litigation, the third branch of U.S. climate policy. *Science*, **357**(6355), 979-980, doi:10.1126/science.aao0412.
McDougall, K. L. et al., 2011: Plant Invasions in Mountains: Global Les-sons for Better Management. *Mountain Research and Development*, **31**(4), 380-387, doi:10.1659/MRD-JOURNAL·D-11.QOOS2.1.
McDowell, G. et al., 2020: From needs to actions: prospects for planned adaptations in high mountain communities. *Climatic Change*, **16**, 953-972, doi:10.1007/s10584-020-02920-1.
McDowell, G. et al., 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, doi:10.1016/j.gloenvcha.2018.10.012.
McDowell, G. et al., 2021a: Lived experiences of "peak water" in the high mountains of Nepal and Peru. *Climate and Development*, 1–14, doi:10.1080/17565529.2021.1913085.

McDowell, G., E. Stephenson and J. Ford, 2014: Adaptation to climate change in glaciated mountain regions. *Climatic Change*, **126**(1), 77-91, doi:10.1007/s10584-014-1215-z.
McDowell, G. et al., 2021b: Closing the adaptation gap in mountains. *Mountain Research and Development*, In Press, doi:10.1659/MRD-JOURNAL-D-21-00033.1.
McDowell, J. Z. and J. J. Hess, 2012: Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. *Global Environmental Change*, **22**(2), 342-352, doi:10.1016/j.gloenvcha.2011.11.002.
Mekuyie, M., A. Jordaan and Y. Melka, 2018: Understanding resilience of pastoralists to climate change and variability in the Southern Afar Region, Ethiopia. *Climate Risk Management*, **20**, 64-77, doi:10.1016/j.crm.2018.02.004.
Merino, V. M., D. Sietz, F. Jost and U. Berger, 2019: Archetypes of climate vulnerability: a mixed-method approach applied in the Peruvian Andes. *Climate and Development*, **11**(5), 418-434, doi:10.1080/17565529.2018.1442804.
Mętrak, M. et al., 2017: Nature's patchwork: How water sources and soil salinity determine the distribution and structure of halophytic plant communities in arid environments of the Eastern Pamir. *PLOS ONE*, **12**(3), e0174496, doi:10.1371/journal.pone.0174496.
Mills-Novoa, M. et al., 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**(2), 393–402, doi:10.1080/24694452.2016.1232618.
Milner, A. M. et al., 2017: Glacier shrinkage driving global changes in downstream systems. *Proceedings of the National Academy of Sciences*, **114**(37), 9770-9778, doi:10.1073/pnas.1619807114.
Min, S., J. Huang, J. Bai and H. Waibel, 2017: Adoption of intercropping among smallholder rubber farmers in Xishuangbanna, China. *International Journal of Agricultural Sustainability*, **15**(3), 223-237, doi:10.1080/14735903.2017.1315234.
Mina, M. et al., 2017: Future ecosystem services from European mountain forests under climate change. *Journal of Applied Ecology*, **54**(2), 389-401, doi:10.1111/1365-2664.12772.
Minta, M. et al., 2018: Land use and land cover dynamics in Dendi-Jeldu hilly-mountainous areas in the central Ethiopian highlands. *Geoderma*, **314**, 27-36, doi:10.1016/j.geoderma.2017.10.035.
Mishra, A. et al., 2019: Adaptation to Climate Change in the Hindu Kush Himalaya: Stronger Action Urgently Needed. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A. B. Shrestha (eds.)]. Springer, Cham, Switzerland, pp. 457-490. ISBN 9783319922881.
Mishra, S. K. et al., 2020: Differential Impact of Climate Change on the Hydropower Economics of Two River Basins in High Mountain Asia. *Frontiers in Environmental Science*, **8**, 26, doi:10.3389/fenvs.2020.00026.
Mitter, H., C. Heumesser and E. Schmid, 2015: Spatial modeling of robust crop production portfolios to assess agricultural vulnerability and adaptation to climate change. *Land Use Policy*, **46**, 75-90, doi:10.1016/j.landusepol.2015.01.010.
Mod, H. K., P. C. le Roux, A. Guisan and M. Luoto, 2015: Biotic interactions boost spatial models of species richness. *Ecography*, **38**(9), 913-921, doi:10.1111/ecog.01129.
Molden, D. et al., 2017: Advancing regional and transboundary cooperation in the conflict-prone Hindu Kush-Himalaya. *Mountain Research and Development*, **37**(4), 502-508, doi:10.1659/MRD-JOURNAL-D-17-00108.1.
Montanari, A. and D. Koutsoyiannis, 2014: Modeling and mitigating natural hazards: Stationarity is immortal! *Water Resources Research*, **50**(12), 9748-9756, doi:10.1002/2014wr016092.
Morin, S. et al., 2021: Pan-European meteorological and snow indicators of climate change impact on ski tourism. *Climate Services*, **22**, 100215, doi:10.1016/j.cliser.2021.100215.
Morrison, C. and C. M. Pickering, 2013: Perceptions of climate change impacts, adaptation and limits to adaption in the Australian Alps: the ski-tourism industry and key stakeholders. *Journal of Sustainable Tourism*, **21**(2), 173-191, doi:10.1080/09669582.2012.681789.
Morueta-Holme, N. et al., 2015: Strong upslope shifts in Chimborazo's vegetation over two centuries since Humboldt. *Proceedings of the National Academy of Sciences*, **112**(41), 12741-12745, doi:10.1073/pnas.1509938112.
Moser, D. J. and C. Baulcomb, 2020: Social Perspectives on Climate Change Adaptation, Sustainable Development, and Artificial Snow Production: A Swiss Case Study Using Q Methodology. *Environmental Science & Policy*, **104**, 98-106, doi:10.1016/j.envsci.2019.10.001.
Motschmann, A. et al., 2020a: Losses and damages connected to glacier retreat in the Cordillera Blanca, Peru. *Climatic Change*, **162**(2), 1-22, doi:10.1007/s10584-020-02770-x.
Motschmann, A., C. Huggel, R. Muñoz and A. Thür, 2020b: Towards integrated assessments of water risks in deglaciating mountain areas: water scarcity and GLOF risk in the Peruvian Andes. *Geoenvironmental Disasters*, **7**(26), 1–18, doi:10.1186/s40677-020-00159-7.
Mourey, J., C. Perrin-Malterre and L. Ravanel, 2020: Strategies Used by French Alpine Guides to Adapt to the Effects of Climate Change. *Journal of Outdoor Recreation and Tourism*, **29**, 100278, doi:10.1016/j.jort.2020.100278.
Mourey, J. et al., 2019: Access Routes to High Mountain Huts Facing Climate-Induced Environmental Changes and Adaptive Strategies in the Western Alps since the 1990s. *Norwegian Journal of Geography*, **73**(4), 215-228, doi:10.1080/00291951.2019.1689163.
Muccione, V. and B. Daley, 2016: The Role of Ecosystem-based Adaptation in the Swiss Mountains. In: *Climate Change Adaptation Strategies – An Upstream-downstream Perspective* [Salzmann, N., C. Huggel, S. U. Nussbaumer and G. Ziervogel (eds.)]. Springer, Cham, Switzerland, pp. 161-177. ISBN 9783319407739.

Muccione, V., N. Salzmann and C. Huggel, 2016: Scientific Knowledge and Knowledge Needs in Climate Adaptation Policy: A Case Study of Diverse Mountain Regions. *Mountain Research and Development*, **36**(3), 364-375, doi:10.1659/MRD-JOURNAL-D-15-00016.1.
Mueller, V., C. Gray and K. Kosec, 2014: Heat stress increases long-term human migration in rural Pakistan. *Nature Climate Change*, **4**, 182-185, doi:10.1038/nclimate2103.
Muhlfeld, C. C. et al., 2020: Specialized meltwater biodiversity persists despite widespread deglaciation. *Proceedings of the National Academy of Sciences*, **117**(22), 12208-12214, doi:10.1073/pnas.2001697117.
Mukherji, A. et al., 2019: Contributions of the cryosphere to mountain communities in the Hindu Kush Himalaya: a review. *Regional Environmental Change*, **19**, 1311-1326, doi:10.1007/s10113-019-01484-w.
Munia, H. A. et al., 2020: Future transboundary water stress and its drivers under climate change: A global study. *Earth's Future*, **8**(7), e2019EF001321, doi:10.1029/2019EF001321.
Muñoz-Torrero Manchado, A. et al., 2021: Three decades of landslide activity in western Nepal: Unique insights into trends and climate drivers.
Munt, D. D., P. Muñoz-Rodríguez, I. Marques and J. C. M. Saiz, 2016: Effects of climate change on threatened Spanish medicinal and aromatic species: predicting future trends and defining conservation guidelines. *Israel Journal of Plant Sciences*, **63**(4), 309-319, doi:10.1080/07929978.2016.1258257.
Musakwa, W., E. Mpofu and N. A. Nyathi, 2020: Local community perceptions on landscape change, ecosystem services, climate change, and livelihoods in Gonarezhou National Park, Zimbabwe. *Sustainability*, **12**(11), 4610.
Nagel, L. M. et al., 2017: Adaptive Silviculture for Climate Change: A National Experiment in Manager-Scientist Partnerships to Apply an Adaptation Framework. *Journal of Forestry*, **115**(3), 167-178, doi:10.5849/jof.16-039.
Nair, K. P., 2019: Utilizing crop wild relatives to combat global warming. *Advances in Agronomy*, **153**, 175-258.
Nawrotzki, R. J. and J. DeWaard, 2016: Climate shocks and the timing of migration from Mexico. *Population and Environment*, **38**, 72-100, doi:10.1007/s11111-016-0255-x.
Nepal, M. et al., 2018: Valuing Cultural Services of the Kailash Sacred Landscape for Sustainable Management. *Sustainability*, **10**(10), 3638, doi:10.3390/su10103638.
Ngwenya, S. J., E. Torquebiau and J. W. H. Ferguson, 2019: Mountains as a critical source of ecosystem services: the case of the Drakensberg, South Africa. *Environment, Development and Sustainability*, **21**(2), 1035-1052, doi:10.1007/s10668-017-0071-1.
Niemeyer, R. J., K. D. Bladon and R. D. Woodsmith, 2020: Long-term hydrologic recovery after wildfire and post-fire forest management in the interior Pacific North-west. *Hydrological Processes*, **34**, 1182– 1197, doi:10.1002/hyp.13665.
Nischalke, S. M. et al., 2017: Forgotten Forests? Food Potential of Ancient Coffee Forests and Agroforestry Systems in the Southwestern Ethiopian Mountains, Seen Through a Gender Lens. *Mountain Research and Development*, **37**(3), 254-262, doi:10.1659/MRD-JOURNAL-D-16-00096.1.
Njue, N. et al., 2019: Citizen science in hydrological monitoring and ecosystem services management: State of the art and future prospects. *Science of The Total Environment*, **693**, 133531, doi:10.1016/j.scitotenv.2019.07.337.
Nkuba, M. R. et al., 2020: Influence of Indigenous Knowledge and Scientific Climate Forecasts on Arable Farmers' Climate Adaptation Methods in the Rwenzori region, Western Uganda. *Environmental Management*, **65**, 500-516, doi:10.1007/s00267-020-01264-x.
Nogués-Bravo, D., 2009: Predicting the past distribution of species climatic niches. *Global Ecology and Biogeography*, **18**(5), 521-531, doi:10.1111/j.1466-8238.2009.00476.x.
Nones, M. and G. Pescaroli, 2016: Implications of cascading effects for the EU Floods Directive. *International Journal of River Basin Management*, **14**(2), 195-204, doi:10.1080/15715124.2016.1149074.
O'Neel, S. et al., 2015: Icefield-to-Ocean Linkages across the Northern Pacific Coastal Temperate Rainforest Ecosystem. *BioScience*, **65**(5), 499-512, doi:10.1093/biosci/biv027.
Ojha, H. et al., 2020: Scarcity Amidst Plenty: Lower Himalayan Cities Struggling for Water Security. *Water*, **12**(2), 567, doi:10.3390/w12020567.
Ojha, H. R. et al., 2016: Policy without politics: technocratic control of climate change adaptation policy making in Nepal. *Climate Policy*, **16**(4), 415-433, doi:10.1080/14693062.2014.1003775.
Oliver-Smith, A., 2014: Climate change adaptation and disaster risk reduction in Highland Peru. In: *Adapting to Climate Change* [Glavovic, B. and G. Smith (eds.)]. Springer, Dordrecht, Netherlands, pp. 77-100. ISBN 9789401786317.
Oliveras, I., L. O. Anderson and Y. Malhi, 2014: Application of remote sensing to understanding fire regimes and biomass burning emissions of the tropical Andes. *Global Biogeochemical Cycles*, **28**(4), 480-496.
Oliveras, I. et al., 2018: Fire effects and ecological recovery pathways of tropical montane cloud forests along a time chronosequence. *Global change biology*, **24**(2), 758-772.
Otto, F. E. L. et al., 2017: Assigning historic responsibility for extreme weather events. *Nature Climate Change*, **7**, 757–759, doi:10.1038/nclimate3419.
Palomo, I., 2017: Climate Change Impacts on Ecosystem Services in High Mountain Areas: A Literature Review. *Mountain Research and Development*, **37**(2), 179-187, doi:10.1659/MRD-JOURNAL-D-16-00110.1.
Palomo, I. et al., 2021: Assessing nature-based solutions for transformative change. *One Earth*, **4**(5), 730-741, doi:10.1016/j.oneear.2021.04.013.

Pandey, A., A. Prakash and S. E. Werners, 2021: Matches, mismatches and priorities of pathways from a climate-resilient development perspective in the mountains of Nepal. *Environmental Science and Policy*, **125**, 135-145, doi:10.1016/j.envsci.2021.08.013.
Patro, E. R., C. De Michele and F. Avanzi, 2018: Future perspectives of run-of-the-river hydropower and the impact of glaciers? shrinkage: The case of Italian Alps. *Applied Energy*, **231**, 699-713, doi:10.1016/j.apenergy.2018.09.063.
Patton, A. I., S. L. Rathburn and D. M. Capps, 2019: Landslide response to climate change in permafrost regions. *Geomorphology*, **340**, 116-128, doi:10.1016/j.geomorph.2019.04.029.
Paulsen, J. and C. Körner, 2014: A climate-based model to predict potential treeline position around the globe. *Alpine Botany*, **124**(1), 1-12.
Payne, D. et al., 2020: Nature and People in the Andes, East African Mountains,European Alps, and Hindu Kush Himalaya: CurrentResearch and Future Directions. *Mountain Research and Development*, **40**(2), A1-A14, doi:10.1659/MRD-JOURNAL-D-19-00075.1.
Phillips, J. et al., 2017: Climate change and national crop wild relative conservation planning. *Ambio*, **46**(6), 630-643.
Picarelli, L., S. Lacasse and K. K. S. Ho, 2021: The Impact of Climate Change on Landslide Hazard and Risk. In: *Understanding and Reducing Landslide Disaster Risk* [Sassa, K., M. Mikoš, S. Sassa, P. T. Bobrowsky, K. Takara and K. Dang (eds.)]. Springer, Cham, pp. 131-141. ISBN 9783030601966.
Polato, N. R. et al., 2018: Narrow thermal tolerance and low dispersal drive higher speciation in tropical mountains. *Proceedings of the National Academy of Sciences*, **115**(49), 12471-12476, doi:10.1073/pnas.1809326115.
Porter, J. R. et al., 2014: Food security and food production systems. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, 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 and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533.
Pospelova, E. B., I. N. Pospelov and M. V. Orlov, 2017: Climate Change in Eastern Taimyr over the Last 80 Years and the Warming Impact on Biodiversity and Ecosystem Processes in Its Territory. *Nature Conservation Research*, **2**(3), 48-60, doi:10.24189/ncr.2017.040.
Prakash, A. and D. Molden (eds.), 2020: *Water in Himalayan Towns: Lessons for Adaptive Water Governance*, IWA, London, United Kingdom, 204 pp. ISBN 9781789061901.
Prasain, S., 2018: Climate change adaptation measure on agricultural communities of Dhye in Upper Mustang, Nepal. *Climatic Change*, **148**(1), 279-291, doi:10.1007/s10584-018-2187-1.
Pretzsch, H. et al., 2018: Wood density reduced while wood volume growth accelerated in Central European forests since 1870. *Forest Ecology and Management*, **429**, 589-616, doi:10.1016/j.foreco.2018.07.045.
Prevéy, J. S. et al., 2020: Climate change shifts in habitat suitability and phenology of huckleberry (Vaccinium membranaceum). *Agricultural and forest meteorology*, **280**, 107803.
Price, M. F., T. Schaaf and M. R. Cárdenas Tomažič, Accepted/In press: Mountain research in UNESCO's Man and the Biosphere Programme: The first five decades. *eco.mont*, **13**, 90-98, doi:10.1553/eco.mont-13-sis90.
Prichard, S. J., C. S. Stevens-Rumann and P. F. Hessburg, 2017: Tamm Review: Shift-ing global fire regimes: Lessons from reburns and research needs. *Forest Ecology and Management*, **395**, 217-233, doi:10.1016/j.foreco.2017.03.035.
Pröbstl-Haider, U., W. Haider, V. Wirth and B. Beardmore, 2015: Will Climate Change Increase the Attractiveness of Summer Destinations in the European Alps? A Survey of German Tourists. *Journal of Outdoor Recreation and Tourism*, **11**, 44-57, doi:10.1016/j.jort.2015.07.003.
Pullanikkatil, D. et al., 2020: Unsustainable trade-offs: provisioning ecosystem services in rapidly changing Likangala River catchment in southern Malawi. *Environment, Development and Sustainability*, **22**(2), 1145-1164, doi:10.1007/s10668-018-0240-x.
Quincey, D. et al., 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), e1258, doi:10.1002/wat2.1258.
Rakhmatullaev, S. et al., 2009: Groundwater resources use and management in the Amu Darya River Basin (Central Asia). *Environ Earth Science*, **59**, 1183, doi:10.1007/s12665-009-0107-4.
Ramirez-Villegas, J. et al., 2014: Using species distributions models for designing conservation strategies of Tropical Andean biodiversity under climate change. *Journal for Nature Conservation*, **22**(5), 391-404, doi:10.1016/j.jnc.2014.03.007.
Ramsar Convention on Wetlands, 2018: *Global Wetland Outlook: State of the World's Wetlands and their Services to People*. Ramsar Convention Secretariat, Gland, Switzerland, 84 pp. Available at: https://medwet.org/publications/ramsar-global-wetland-outlook-2018/ (accessed 03/11/2020).
Rangecroft, S. et al., 2013: Climate Change and Water Resources in Arid Mountains: An Example from the Bolivian Andes. *AMBIO*, **42**(7), 852-863, doi:10.1007/s13280-013-0430-6.
Rashid, I. et al., 2015: Projected climate change impacts on vegetation distribution over Kashmir Himalayas. *Climatic Change*, **132**(4), 601-613, doi:10.1007/s10584-015-1456-5.
Rasul, G. and A. Hussain, 2015: Sustainable food security in the mountains of Pakistan: Towards a policy framework. *Ecology of food and nutrition*, **54**(6), 625-643, doi:10.1080/03670244.2015.1052426.

Rasul, G. et al., 2014: *Towards a framework for achieving food security in the mountains of Pakistan*. International Centre for Integrated Mountain Development, Kathmandu, Nepal, 22 pp. ISBN 9789291153305.
Rasul, G. and D. Molden, 2019: The Global Social and Economic Consequences of Mountain Cryospheric Change. *Frontiers in Environmental Science*, **7**(91), doi:10.3389/fenvs.2019.00091.
Rasul, G., B. Pasakhala, A. Mishra and S. Pant, 2020: Adaptation to mountain cryosphere change: issues and challenges. *Climate and Development*, **12**(4), 297-309, doi:10.1080/17565529.2019.1617099.
Ravera, F. et al., 2016: Gender perspectives in resilience, vulnerability and adaptation to global environmental change. *Ambio*, **45**(3), 235-247, doi:10.1007/s13280-016-0842-1.
Rehm, E. M. and K. J. Feeley, 2015: The inability of tropical cloud forest species to invade grasslands above treeline during climate change: potential explanations and consequences. *Ecography*, **38**(12), 1167-1175, doi:10.1111/ecog.01050.
Rehnus, M. et al., 2018: Alpine glacial relict species losing out to climate change: the case of the fragmented mountain hare population (Lepus timidus) in the Alps. *Global Change Biology*, **24**(7), 3236-3253.
Reid, H., 2016: Ecosystem-and community-based adaptation: learning from community-based natural resource management. *Climate and Development*, **8**(1), 4-9, doi:10.1080/17565529.2015.1034233.
Renaud, F. G., U. Nehren, K. Sudmeier-Rieux and M. Estrella, 2016: Developments and Opportunities for Ecosystem-Based Disaster Risk Reduction and Climate Change Adaptation. In: *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice* [Renaud, F. G., K. Sudmeier-Rieux, M. Estrella and U. Nehren (eds.)]. Springer International Publishing, Cham, pp. 1-20. ISBN 978-3-319-43633-3.
Ribot, J., 2014: Cause and response: vulnerability and climate in the Anthropocene. *The Journal of Peasant Studies*, **41**(5), 667-705, doi:10.1080/03066150.2014.894911.
Rocca, M. E., P. M. Brown, L. H. MacDonald and C. M. Carrico, 2014: Climate change impacts on fire regimes and key ecosystem services in Rocky Mountain forests. *Forest Ecology and Management*, **327**, 290-305, doi:10.1016/j.foreco.2014.04.005.
Rodman, K. C. et al., 2020: A changing climate is snuffing out post-fire recovery in montane forests. *Global Ecology and Biogeography*, **29**(11), 2039-2051, doi:10.1111/geb.13174.
Rojas-Downing, M. M., A. P. Nejadhashemi, T. Harrigan and S. A. Woznicki, 2017: Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, **16**, 145-163, doi:10.1016/j.crm.2017.02.001.
Román-Cuesta, R. M. et al., 2014: Synchronous fire activity in the tropical high An-des: an indication of regional climate forcing. *Global Change Biology*, **20**(6), 1929-1942, doi:10.1111/gcb.12538.
Roth, T., M. Plattner and V. Amrhein, 2014: Plants, Birds and Butterflies: Short-Term Responses of Species Communities to Climate Warming Vary by Taxon and with Altitude. *PLoS ONE* **9**(1), e82490, doi:10.1371/journal.pone.0082490.
Rumpf, S. B. et al., 2018: Range dynamics of mountain plants decrease with elevation. *Proceedings of the National Academy of Sciences*, **115**(8), 1848, doi:10.1073/pnas.1713936115.
Rust, A. J., T. S. Hogue, S. Saxe and J. McCray, 2018: Post-fire water-quality response in the western United States. *International Journal of Wildland Fire*, **27**(3), 203-216, doi:10.1071/WF17115.
Ryan, D. and E. Bustos, 2019: Knowledge gaps and climate adaptation policy: a comparative analysis of six Latin American countries. *Climate Policy*, **19**(10), 1297-1309, doi:10.1080/14693062.2019.1661819.
Sagynbekova, L., 2017: Environment, rural livelihoods and labour migration. A case study in central Kyrgyzstan. *Mountain Research and Development*, **37**(4), 456-463, doi:10.1659/MRD-JOURNAL-D-17-00029.1.
Said, M., H. C. Komakech, L. K. Munishi and A. N. N. Muzuka, 2019: Evidence of climate change impacts on water, food and energy resources around Kilimanjaro, Tanzania. *Regional Environmental Change*, **19**, 2521–2534, doi:10.1007/s10113-019-01568-7.
Salim, E. and L. Ravanel, 2020: Last chance to see the ice: visitor motivation at Montenvers-Mer-de-Glace, French Alps. *Tourism Geographies*, doi:10.1080/14616688.2020.1833971.
Salzmann, N., C. Huggel, S. U. Nussbaumer and G. Ziervogel (eds.), 2016: *Climate Change Adaptation Strategies – An Upstream-downstream Perspective*, Springer, Cham, Switzerland, 292 pp. ISBN 9783319407715.
Salzmann, N., C. Huggel, M. Rohrer and M. Stoffel, 2014: Data and knowledge gaps in glacier, snow and related runoff research – A climate change adaptation perspective. *Journal of Hydrology*, **518**, 225-234, doi:10.1016/j.jhydrol.2014.05.058.
Sannikov, S. N., N. V. Tantsyrev and I. V. Petrova, 2018: Invasion of Siberian Pine Populations in Mountain Tundra in the Northern Urals. *Contemporary Problems of Ecology*, **11**(4), 396-405, doi:10.1134/S1995425518040078.
Sansilvestri, R., N. Frascaria-Lacoste and J. Fernández-Manjarrés, 2016: One option, two countries, several strategies: subjacent mechanisms of assisted migration implementation in Canada and France: Implementation issues of assisted migration. *Restoration Ecology*, **24**(4), 489-498, doi:10.1111/rec.12343.
Satyal, P. et al., 2017: A new Himalayan crisis? Exploring transformative resilience pathways. *Environmental Development*, **23**, 47-56, doi:10.1016/j.envdev.2017.02.010.
Sauri, D. and J. C. Llurdés, 2020: Climate Change and Adaptation Strategies of Spanish Catalan Alpine Ski Resorts. *Journal of Alpine Research*, **108**, 1, doi:10.4000/rga.6796.
Schaefli, B., 2015: Projecting hydropower production under future climates: a guide for decision-makers and modelers to interpret and design climate change impact assessments. *WIREs Water*, **2**(4), 271-289, doi:10.1002/wat2.1083.

Schaefli, B. et al., 2019: The role of glacier retreat for Swiss hydropower production. *Renewable Energy*, **132**, 615-627, doi:10.1016/j.renene.2018.07.104.
Schauwecker, S. et al., 2019: Anticipating cascading effects of extreme precipitation with pathway schemes - Three case studies from Europe. *Environment International*, **127**, 291-304, doi:10.1016/j.envint.2019.02.072.
Schauwecker, S. et al., 2017: The freezing level in the tropical Andes, Peru: an indicator for present and future glacier extents. *Journal of Geophysical Research: Atmospheres*, **122**(10), 5172-5189, doi:10.1002/2016JD025943.
Scheidl, C. et al., 2020: The influence of climate change and canopy disturbances on landslide susceptibility in headwater catchments. *Science of The Total Environment*, **742**, 140588, doi:10.1016/j.scitotenv.2020.140588.
Scherrer, D., S. Schmid and C. Körner, 2011: Elevational species shifts in a warmer climate are overestimated when based on weather station data. *International Journal of Biometeorology*, **55**(4), 645-654, doi:10.1007/s00484-010-0364-7.
Scherrer, D. et al., 2020: Competition and demography rather than dispersal limitation slow down upward shifts of trees' upper elevation limits in the Alps. *Journal of Ecology*, **108**(6), 2416-2430, doi:10.1111/1365-2745.13451
Schipper, E. L. F. et al., 2020: Turbulent transformation: abrupt societal disruption and climate resilient development. *Climate and Development*, 1-8, doi:10.1080/17565529.2020.1799738.
Schneiderbauer, S. et al., 2021: Risk perception of climate change and natural hazards in global mountain regions: A critical review. *Science of The Total Environment*, **784**, 146957, doi:10.1016/j.scitotenv.2021.146957.
Schoolmeester, T. and K. Verbist (eds.), 2018: *The Andean Glacier and Water Atlas - The Impact of Glacier Retreat on Water Resources*, UNESCO and GRID-Arendal, Paris, France and Arendal, Norway, 77 pp. ISBN 9789231002861.
Schwanghart, W. et al., 2016: Uncertainty in the Himalayan energy–water nexus: estimating regional exposure to glacial lake outburst floods. *Environmental Research Letters*, **11**, 074005, doi:10.1088/1748-9326/11/7/074005.
Scott, C. A. et al., 2019: Water in the Hindu Kush Himalaya. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A. B. Shrestha (eds.)]. Springer, Cham, Switzerland, pp. 257-299. ISBN 9783319922881.
Sebald, J. et al., 2019: The effects of forest cover and disturbance on torrential hazards: large-scale evidence from the Eastern Alps. *Environmental Research Letters*, **14**, 11, doi:10.6084/m9.figshare.9758891.v1.
Seddon, N. et al., 2020: Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **375**(1794), 20190120, doi:10.1098/rstb.2019.0120.
Selmar, D. and M. Kleinwächter, 2013: Influencing the product quality by deliberately applying drought stress during the cultivation of medicinal plants. *Industrial Crops and Products*, **42**, 558-566, doi:10.1016/j.indcrop.2012.06.020.
Serquet, G. and M. Rebetez, 2011: Relationship between Tourism Demand in the Swiss Alps and Hot Summer Air Temperatures Associated with Climate Change. *Climatic Change*, **108**(1), 291-300, doi:10.1007/s10584-010-0012-6.
Setzer, J. and L. C. Vanhala, 2019: Climate change litigation: a review of research on courts and litigants in climate government. *WIREs Climate Change*, **10**(3), e580, doi:10.1002/wcc.580.
Shah, S. and A. Tewari, 2016: Limited impact of climate change on seed maturation time in Myrica esculenta Buch-Ham. Ex. D. Don in Himalayan region. *International Journal of Environment, Agriculture and Biotechnology*, **1**(4), 713-717, doi:10.22161/ijeab/1.4.13.
Shahgedanova, M. et al., 2021: Mountain Observatories: Status and Prospects for Enhancing and Connecting a Global Community. *Mountain Research and Development*, **41**(2), doi:10.1659/MRD-JOURNAL-D-20-00054.1.
Sharma, G. et al., 2020: Water management systems of two towns in the Eastern Himalaya: case studies of Singtam in Sikkim and Kalimpong in West Bengal states of India. *Water Policy*, **22**, 107-129, doi:10.2166/wp.2019.229.
Sherry, J., A. Curtis, E. Mendham and E. Toman, 2018: Cultural landscapes at risk: Exploring the meaning of place in a sacred valley of Nepal. *Global Environmental Change*, **52**(July), 190-200, doi:10.1016/j.gloenvcha.2018.07.007.
Shijin, W. and Q. Dahe, 2015: Mountain inhabitants' perspectives on climate change, and its impacts and adaptation based on temporal and spatial characteristics analysis: a case study of Mt. Yulong Snow, Southeastern Tibetan Plateau. *Environmental Hazards*, **14**(2), 122-136, doi:10.1080/17477891.2014.1003776.
Shikuku, K. M. et al., 2017: Smallholder farmers' attitudes and determinants of adaptation to climate risks in East Africa. *Climate Risk Management*, **16**, 234-245, doi:10.1016/j.crm.2017.03.001.
Shiyatov, S. G. and V. S. Mazepa, 2015: Contemporary expansion of Siberian larch into the mountain tundra of the Polar Urals. *Russian Journal of Ecology*, **46**(6), 495-502, doi:10.1134/S1067413615060168.
Shrestha, A. B. et al., 2015: The Himalayan Climate and Water Atlas: impact of climate change on water resources in five of Asia's major river basins. *The Himalayan Climate and Water Atlas: impact of climate change on water resources in five of Asia's major river basins.*
Shrestha, U. B. and K. S. Bawa, 2014: Economic contribution of Chinese caterpillar fungus to the livelihoods of mountain communities in Nepal. *Biological Conservation*, **177**, 194-202, doi:10.1016/j.biocon.2014.06.019.
Shrestha, U. B., K. R. Dhital and A. P. Gautam, 2019: Economic dependence of mountain communities on Chinese caterpillar fungus Ophiocordyceps sinensis (yarsagumba): a case from western Nepal. *Oryx*, **53**(2), 256-264, doi:10.1017/S0030605317000461.

Shrestha, U. B. et al., 2018: Potential impact of climate change on the distribution of six invasive alien plants in Nepal. *Ecological Indicators*, **95**, 99-107, doi:10.1016/j.ecolind.2018.07.009.
Shugar, D. H. et al., 2021: A massive rock and ice avalanche caused the 2021 disaster at Chamoli, Indian Himalaya. *Science*, **373**(6552), 300-306, doi:10.1126/science.abh4455.
Shukla, R., K. Sachdeva and P. K. Joshi, 2018: Demystifying vulnerability assessment of agriculture communities in the Himalayas: a systematic review. *Natural Hazards*, **91**(1), 409-429, doi:10.1007/s11069-017-3120-z.
Siddiqui, T. et al., 2019: Migration in the Hindu Kush Himalaya: Drivers, Consequences, and Governance. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A. B. Shrestha (eds.)]. Springer, Cham, Switzerland, pp. 517-544. ISBN 9783319922881.
Sideris, L. H., 2020: Grave Reminders: Grief and Vulnerability in the Anthropocene. *Religions*, **11**(6), 293, doi:10.3390/rel11060293.
Sigdel, S. R. et al., 2020: Tree-to-tree interactions slow down Himalayan treeline shifts as inferred from tree spatial patterns. *Journal of Biogeography*, **47**, 1816-1826, doi:10.1111/jbi.13840.
Sigdel, S. R. et al., 2018: Moisture-mediated responsiveness of treeline shifts to global warming in the Himalayas. *Global change biology*, **24**(11), 5549-5559, doi:10.1111/gcb.14428.
Simane, B. and N. Bird, 2017: Enhancing Adaptation and Mitigation Activities Through Effective Climate Change Financing Policy in Ethiopia. In: *Climate Change Adaptation in Africa* [Leal Filho, W., S. Belay, J. Kalangu, W. Menas, P. Munishi and K. Musiyiwa (eds.)]. Springer, Cham, Switzerland, pp. 435-445. ISBN 9783319495200.
Singh, D. et al., 2021: Ensuring Domestic Water Security for Cities Under Rapid Urbanisation and Climate Change Risks. In: *Exploring Synergies and Trade-offs between Climate Change and the Sustainable Development Goals* [Venkatramanan, V., S. Shah and R. Prasad (eds.)]. Springer, Singapore, pp. 213-229. ISBN 9789811573019.
Singh, N., J. Ram, A. Tewari and R. P. Yadav, 2015: Phenological events along the elevation gradient and effect of climate change on Rhododendron arboreum Sm. in Kumaun Himalaya. *Current Science*, **108**(1), 106-110.
Singh, S., K. Shrestha, M. Hamal and A. Prakash, 2020: Perform or wither: role of water users' associations in municipalities of Nepal. *Water Policy*, **22**(s1), 90-106, doi:10.2166/wp.2019.051.
Siraj, A. S. et al., 2014: Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia. *Science*, **343**(6175), 1154-1158, doi:10.1126/science.1244325.
Skarbø, K. and K. VanderMolen, 2016: Maize migration: key crop expands to higher altitudes under climate change in the Andes. *Climate and Development*, **8**(3), 245-255, doi:10.1080/17565529.2015.1034234.
Somers, L. D. and J. M. McKenzie, 2020: A review of groundwater in high mountain environments. *WIREs Water*, **7**(6), e1475, doi:10.1002/wat2.1475.
Somers, L. D. et al., 2019: Groundwater Buffers Decreasing Glacier Melt in an Andean Watershed—But Not Forever. *Geophysical Research Letters*, **46**(22), 13016-13026, doi:10.1029/2019GL084730.
Stäubli, A. et al., 2018: Analysis of weather- and climate-related disasters in mountain regions using different disaster databases. In: *Climate Change, Extreme Events and Disaster Risk Reduction* [Mal, S., R. Singh and C. Huggel (eds.)]. Springer, Cham, Switzerland, pp. 17-41. ISBN 9783319564692.
Steiger, R., B. Abegg and L. Jänicke, 2016: Rain, Rain, Go Away, Come Again Another Day. Weather Preferences of Summer Tourists in Mountain Environments. *Atmosphere*, **7**(5), 63, doi:10.3390/atmos7050063.
Steiger, R., A. Damm, F. Prettenthaler and U. Pröbstl-Haider, 2020a: Climate change and winter outdoor activities in Austria. *Journal of Outdoor Recreation and Tourism*, **100330**, In Press, doi:10.1016/j.jort.2020.100330.
Steiger, R., E. Posch, G. Tappeiner and J. Walde, 2020b: The impact of climate change on demand of ski tourism - a simulation study based on stated preferences. *Ecological Economics*, **170**, 106589, doi:10.1016/j.ecolecon.2019.106589.
Steiger, R. and D. Scott, 2020: Ski tourism in a warmer world: Increased adaptation and regional economic impacts in Austria. *Tourism Management*, **77**, 104032, doi:10.1016/j.tourman.2019.104032.
Steinbauer, M. J. et al., 2018: Accelerated increase in plant species richness on mountain summits is linked to warming. *Nature*, **556**, 231-234, doi:10.1038/s41586-018-0005-6.
Strouth, A. and S. McDougall, 2021: Historical Landslide Fatalities in British Columbia, Canada: Trends and Implications for Risk Management. *Frontiers in Earth Science* **9**, 22, doi:10.3389/feart.2021.606854.
Su, Y. et al., 2017: Gendered Responses to Drought in Yunnan Province, China. *Mountain Research and Development*, **37**(1), 24-34, doi:10.1659/MRD-JOURNAL-D-15-00041.1.
Sujakhu, N. M. et al., 2019: Assessing the livelihood vulnerability of rural indigenous households to climate changes in central Nepal, Himalaya. *Sustainability*, **11**(10), 2977, doi:10.3390/su11102977.
Sultan, B., D. Defrance and T. Iizumi, 2019: Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Scientific reports*, **9**, 12834, doi:10.1038/s41598-019-49167-0.
Sunderland, T. C. and W. Vasquez, 2020: Forest conservation, rights, and diets: Untangling the issues. *Frontiers in Forests and Global Change*, **3**, 29.
Suwal, M. K. et al., 2016: Land-use change under a warming climate facilitated upslope expansion of Himalayan silver fir (Abies spectabilis (D. Don) Spach). *Plant Ecology*, **217**, 993-1002, doi:10.1007/s11258-016-0624-7.
Takano, K. T. et al., 2017: Detecting latitudinal and altitudinal expansion of invasive bamboo Phyllostachys edulis and Phyllostachys bambusoides (Poaceae) in Japan to project potential habitats under 1.5°C–4.0°C global warming. *Ecology and Evolution*, **7**(23), 9848–9859, doi:10.1002/ece3.3471.

Tangjitman, K. et al., 2015: Potential impact of climatic change on medicinal plants used in the Karen women's health care in northern Thailand. *Songklanakarin Journal of Science and Technology*, **37**(3), 369-379.
Tellman, B., J. E. Saiers and O. A. R. Cruz, 2016: Quantifying the impacts of land use change on flooding in data-poor watersheds in El Salvador with community-based model calibration. *Regional Environmental Change*, **16**(4), 1183-1196, doi:10.1007/s10113-015-0841-y.
Telwala, Y., B. W. Brook, K. Manish and M. K. Pandit, 2013: Climate-Induced Elevational Range Shifts and Increase in Plant Species Richness in a Himalayan Biodiversity Epicentre. *PLoS ONE*, **8**(2), e57103, doi:10.1371/journal.pone.0057103.
Tepley, A. J. et al., 2018: Influences of fire–vegetation feedbacks and post-fire recovery rates on forest landscape vulnerability to altered fire regimes. *Journal of Ecology*, **106**(5), 1925-1940, doi:10.1111/1365-2745.12950.
Terzi, S. et al., 2019: Multi-risk assessment in mountain regions: A review of modelling approaches for climate change adaptation. *Journal of Environmental Management*, **232**, 759-771, doi:10.1016/j.jenvman.2018.11.100.
Thapa, S. et al., 2018: Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PloS one*, **13**(4), e0195752, doi:10.1371/journal.pone.0195752.
Thapa, S. and A. Hussain, 2020: Climate change and high-altitude food security: a small-scale study from the Karnali region in Nepal. *Climate and Development*, 1-12.
Thornton, J. M. et al., 2021: Toward a definition of Essential Mountain Climate Variables. *One Earth*, **4**, 805-827, doi:10.1016/j.oneear.2021.05.005.
Tian, X.-r., F.-j. Zhao, L.-f. Shu and M.-y. Wang, 2014: Changes in forest fire danger for south-western China in the 21st century. *International Journal of Wildland Fire*, **23**, 185-195, doi:10.1071/WF13014.
Tiwari, K. R. et al., 2020: Vulnerability of Pastoralism: A Case Study from the High Mountainsof Nepal. *Sustainability*, **12**(7), 2737, doi:10.3390/su12072737.
Tiwari, P. C. and B. Joshi, 2012: Natural and socio-economic factors affecting food security in the Himalayas. *Food Security*, **4**(2), 195-207, doi:10.1007/s12571-012-0178-z.
Tiwari, P. C. and B. Joshi, 2015: Climate Change and Rural Out-migration in Himalaya. *Change and Adaptation in Socio-Ecological Systems*, **2**(1), 8-25, doi:10.1515/cass-2015-0002.
Tiwari, P. C., A. Tiwari and B. Joshi, 2018: Urban growth in Himalaya: understanding the process and options for sustainable development. *Journal of Urban and Regional Studies on Contemporary India*, **4**(2), 15–27.
Tonjer, L. R. et al., 2021: Expanding forests in alpine regions: space-for-time indicates a corresponding shift in belowground fungal communities. *Authorea*, doi:10.22541/au.161065834.45838723/v1.
Torres-Batlló, J. and B. Martí-Cardona, 2020: Precipitation trends over the southern Andean Altiplano from 1981 to 2018. *Journal of Hydrology*, **590**, 125485.
Trabacchi, C. and M. Stadelmann, 2016: Making Climate Resilience a Private Sector Business: Insights from the Agricultural Sector in Nepal. In: *Climate Change Adaptation Strategies - An Upstream-downstream Perspective* [Salzmann, N., C. Huggel, S. Nussbaumer and G. Ziervogel (eds.)]. Springer, Cham, Switzerland, pp. 213-238. ISBN 9783319407739.
Trant, A., E. Higgs and B. M. Starzomski, 2020: A century of high elevation ecosystem change in the Canadian Rocky Mountains. *Scientific Reports*, 9698, doi:10.1038/s41598-020-66277-2.
Trombley, J., S. Chalupka and L. Anderko, 2017: Climate change and mental health. *American Journal of Nursing*, **117**(4), 44-52, doi:10.1097/01.NAJ.0000515232.51795.fa.
Tsai, C.-F. et al., 2015: Species turnover in tropical montane forest avifauna links to climatic correlates. *Global Ecology and Conservation*, **3**, 541-552, doi:10.1016/j.gecco.2015.01.008.
Tschakert, P. et al., 2019: One thousand ways to experience loss: A systematic analysis of climate-related intangible harm from around the world. *Global Environmental Change*, **55**, 58-72, doi:10.1016/j.gloenvcha.2018.11.006.
Turner, M. G., W. H. Romme and D. B. Tinker, 2003: Surprises and lessons from the 1988 Yellowstone fires. *Frontiers in Ecology and the Environment*, **1**(7), 351-358, doi:10.1890/1540-9295(2003)001[0351:SALFTY]2.0.CO;2.
Udas, P. B., A. Prakash and C. G. Goodrich, 2018: Gendered Vulnerabilities in Diaras. Struggling with Floods in the Gandak River Basin *Review of Women's Studies*, **53**(17), 46-54.
UN, 2015: *Transforming our world: the 2030 agenda for sustainable development*, **A/RES/70/1**, United Nations, New York, NY, USA, 35 pp. Available at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf (accessed 31/10/2020).
UN (ed.), 2017: New Urban Agenda - Habitat III. Housing and Sustainable Urban Development (Habitat III), Quito, Ecuador, United Nations, 52 pp. ISBN 9789211327311.
UNEP, 2017: *The Status of Climate Change Litigation – A Global Review*. United Nations Environment Programme, Nairobi, Kenya, 41 pp. ISBN 9789280736564.
UNEP, 2021: *Adaptation Gap Report 2020*. United Nations Environment Programme, Nairobi, Kenya. Available at: https://www.unep.org/resources/adaptation-gap-report-2020.
UNFCCC, 2015: *Adoption of the Paris agreement, COP 21, Paris, France*. Available at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.
UNFCCC, 2020: National Adaptation Plans, United Nations Framework Convention on Climate Change. Available at: https://www4.unfccc.int/sites/NAPC/News/Pages/national_adaptation_plans.aspx.

UNFCCC, 2020: NDC Registry (interim), United Nations Framework Convention on Climate Change. Available at: https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx.

UNFCCC, 2020: Submitted NAPAs, United Nations Framework Convention on Climate Change. Available at: https://unfccc.int/topics/resilience/workstreams/national-adaptation-programmes-of-action/napas-received.

UNISDR, 2015: *Disaster Risk reduction and resilience in the 2030 agenda for sustainable development*. Geneva, Switzerland. Available at: https://www.undrr.org/publication/disaster-risk-reduction-and-resilience-2030-agenda-sustainable-development.

Upgupta, S. et al., 2015: Climate change impact and vulnerability assessment of forests in the Indian Western Himalayan region: A case study of Himachal Pradesh, India. *Climate Risk Management*, **10**, 63-76, doi:10.1016/j.crm.2015.08.002.

Vaidya, R. A. et al., 2021: The role of hydropower in South Asia's energy future. *International Journal of Water Resources Development*, **37**(3), 367-391, doi:10.1080/07900627.2021.1875809.

Vaidya, R. A. et al., 2019: Disaster Risk Reduction and Building Resilience in the Hindu Kush Himalaya. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A. B. Shrestha (eds.)]. Springer, Cham, Switzerland, pp. 389-419. ISBN 9783319922881.

Vander Naald, B., 2020: Examining tourist preferences to slow glacier loss: evidence from Alaska. *Tourism Recreation Research*, **45**(1), 107-117, doi:10.1080/02508281.2019.1606978.

Verrall, B. and C. M. Pickering, 2019: Recovery of subalpine grasslands 15 years after landscape level fires. *Australian Journal of Botany*, **67**(5), 425-436, doi:10.1071/BT19020.

Vitali, A. et al., 2019: Pine recolonization dynamics in Mediterranean human-disturbed treeline ecotones. *Forest Ecology and Management*, **435**, 28-37, doi:10.1016/j.foreco.2018.12.039.

Vitasse, Y. et al., 2012: Tree recruitment of European tree species at their current upper elevational limits in the Swiss Alps. *Journal of Biogeography*, **39**(8), 1439-1449, doi:10.1111/j.1365-2699.2012.02697.x.

Viviroli, D. et al., 2020: Increasing dependence of lowland populations on mountain water resources. *Nature Sustainability*, doi:10.1038/s41893-020-0559-9.

Vuille, M. et al., 2018: Rapid decline of snow and ice in the tropical Andes – Impacts, uncertainties and challenges ahead. *Earth-Science Reviews*, **176**, 195-213, doi:10.1016/j.earscirev.2017.09.019.

Wang, C., B. Gao, Z. Weng and Y. Tian, 2020: Primary causes of total hamlet abandonment for different types of hamlets in remote mountain areas of China. A case study of Shouning country, Fujian province. *Land Use Policy*, **95**, 104627, doi:10.1016/j.landusepol.2020.104627.

Wang, S. and D. Qin, 2015: Mountain inhabitants' perspectives on climate change, and its impacts and adaptation based on temporal and spatial characteristics analysis: a case study of Mt. Yulong Snow, Southeastern Tibetan Plateau. *Environmental Hazards*, **14**(2), 122-136, doi:10.1080/17477891.2014.1003776.

Wang, Z. and C. Lu, 2018: Urban land expansion and its driving factors of mountain cities in China during 1990–2015. *Journal of Geographical Sciences*, **28**(8), 1152-1166, doi:10.1007/s11442-018-1547-0.

Ward, M. et al., 2020: Impact of 2019–2020 mega-fires on Australian fauna habitat. *Nature Ecology and Evolution*, **4**(10), 1321-1326, doi:10.1038/s41559-020-1251-1.

Warner, K. and T. Afifi, 2014: Where the rain falls: Evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Climate and Development*, **6**(1), 1-17.

Wester, P., A. Mishra, A. Mukherji and A. B. Shrestha (eds.), 2019: *The Hindu Kush Himalaya assessment: mountains, climate change, sustainability and people*, Springer Nature, Cham, Switzerland, 627 pp. ISBN 9783319922881.

Westerling, A. L., 2016: Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. *Philosophical Transactions Roral Society B*, **371**, 20150178, doi:10.1098/rstb.2015.0178.

Wijngaard, R. R. et al., 2018: Climate change vs. socio-economic development: understanding the future South Asian water gap. *Hydrology and Earth System Sciences*, **22**(12), 6297-6321, doi:10.5194/hess-22-6297-2018.

Williams, R. J. et al., 2008: Large fires in Australian alpine landscapes: their part in the historical fire regime and their impacts on alpine biodiversity. *International Journal of Wildland Fire*, **17**, 793-808, doi:10.1071/WF07154.

Winkler, D. E. et al., 2016: Seasonal dry-down rates and high stress tolerance promote bamboo invasion above and below treeline. *Plant ecology*, **217**(10), 1219-1234, doi:10.1007/s11258-016-0649-y.

Wirz, V., M. Geertsema, S. Gruber and R. S. Purves, 2016: Temporal variability of diverse mountain permafrost slope movements derived from multi-year daily GPS data, Mattertal, Switzerland. *Landslides*, **13**(1), 67-83, doi:10.1007/s10346-014-0544-3.

Wrathall, D. J. et al., 2014: Migration Amidst Climate Rigidity Traps: Resource Politics and Social–Ecological Possibilism in Honduras and Peru. *Annals of the Association of American Geographers*, **104**(2), 292-304, doi:10.1080/00045608.2013.873326.

Wu, X. et al., 2016: Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment international*, **86**, 14-23, doi:10.1016/j.envint.2015.09.007.

Wyborn, C., L. Yung, D. Murphy and D. R. Williams, 2015: Situating adaptation: how governance challenges and perceptions of uncertainty influence adaptation in the Rocky Mountains. *Regional Environmental Change*, **15**, 669-682, doi:10.1007/s10113-014-0663-3.

Xenarios, S. et al., 2019: Climate change and adaptation of mountain societies in Central Asia: uncertainties, knowledge gaps, and data constraints. *Regional Environmental Change*, **19**(5), 1339-1352, doi:10.1007/s10113-018-1384-9.

Yadav, P. K. et al., 2019: Yartsagunbu: transforming people's livelihoods in the Western Himalaya. *Oryx*, **53**(2), 247-255, doi:10.1017/S0030605318000674.
Yadava, A. K. et al., 2017: Altitudinal treeline dynamics of Himalayan pine in western Himalaya, India. *Quaternary International*, **444**, 44-52, doi:10.1016/j.quaint.2016.07.032.
Yan, Y. et al., 2017: Range shifts in response to climate change of Ophiocordyceps sinensis, a fungus endemic to the Tibetan Plateau. *Biological Conservation*, **206**, 143-150, doi:10.1016/j.biocon.2016.12.023.
Yang, H. et al., 2016: Land-use response to drought scenarios and water policy intervention in Lijiang, SW China. *Land Use Policy*, **57**, 377-387, doi:10.1016/j.landusepol.2016.05.027.
Yapiyev, V. et al., 2017: Essentials of Endorheic Basins and Lakes: A Review in the Context of Current and Future Water Resource Management and Mitigation Activities in Central Asia. *Water*, **9**(10), 798, doi:10.3390/w9100798.
Yohannes, Z., M. Teshome and M. Belay, 2020: Adaptive capacity of mountain community to climate change: case study in the Semien Mountains of Ethiopia. *Environment, Development and Sustainability*, **22**(4), 3051-3077, doi:10.1007/s10668-019-00334-3.
Zekollari, H., M. Huss and D. Farinotti, 2020: On the Imbalance and Response Time of Glaciers in the European Alps. *Geophysical Research Letters*, **47**, e2019GL085578, doi:10.1029/2019GL085578.
Zhang, C. et al., 2019a: Climatic factors control the geospatial distribution of active ingredients in Salvia miltiorrhiza Bunge in China. *Scientific Reports*, **9**, 904, doi:10.1038/s41598-018-36729-x.
Zhang, Y. et al., 2019b: Identifying refugia and corridors under climate change conditions for the Sichuan snub-nosed monkey (Rhinopithecus roxellana) in Hubei Province, China. *Ecology and Evolution*, **9**(4), 1680-1690, doi:10.1002/ece3.4815.
Zhao, Q. et al., 2018: Modeling impacts of climate change on the geographic distribution of medicinal plant Fritillaria cirrhosa D. Don. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, **152**(3), 349-355, doi:10.1080/11263504.2017.1289273.
Zheng, G. et al., 2021: Increasing risk of glacial lake outburst floods from future Third Pole deglaciation. *Nature Climate Change*, **11**, 411–417, doi:10.1038/s41558-021-01028-3.
Zimmermann, M. and M. Keiler, 2015: International Frameworks for Disaster Risk Reduction: Useful Guidance for Sustainable Mountain Development? *Mountain Research and Development*, **35**(2), 195-202, doi:10.1659/MRD-JOURNAL-D-15-00006.1.
Zkhiri, W. et al., 2019: Spatiotemporal characterization of current and future droughts in the High Atlas basins (Morocco). *Theoretical and Applied Climatology*, **135**(1), 593-605.
Zolotareva, N. V. and M. P. Zolotarev, 2017: The phenomenon of forest invasion to steppe areas in the Middle Urals and its probable causes. *Russian Journal of Ecology*, **48**(1), 21-31, doi:10.1134/S106741361606014X.
Zomer, R. J. et al., 2014a: Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India, Nepal. *Climatic change*, **125**(3-4), 445-460, doi:10.1007/s10584-014-1176-2.
Zomer, R. J. et al., 2014b: Environmental stratification to model climate change impacts on biodiversity and rubber production in Xishuangbanna, Yunnan, China. *Biological Conservation*, **170**, 264-273, doi:10.1016/j.biocon.2013.11.028.
Zylstra, P. J., 2018: Flammability dynamics in the Australian Alps. *Austral Ecology*, **43**(5), 578-591, doi:10.1111/aec.12594.