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Mountain Resilience: A Systematic Literature Review and Paths to the Future

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Mountains are home to a considerable share of the human population. Around a billion people live in mountainous areas, which harbor rich natural and sociocultural diversity. Today, many people living in mountainous areas worldwide face fundamental changes to their cultural and economic living conditions. At the same time, mountain communities have defied harsh environments in the past by adapting to changing natural conditions and showing remarkable levels of resilience. In this review paper, we provide a comprehensive overview of English-language scientific literature on resilience-related topics in mountain areas based on a systematic review of the Scopus® literature database. We propose a structured starting point for science–practice interactions and concrete action-based activities to support livelihoods and strengthen resilience in mountain areas. We suggest that existing knowledge gaps can be addressed by relying on local knowledge and cocreating solutions with communities. In this way, we can build innovative capacity and actively buffer against the impact of crises while supporting deliberate transformation toward sustainability and regeneration to further enhance resilience.

Keywords: *mountain; resilience; review; Scopus; literature; transformation; sustainability; Alps; Andes; Himalayas.*

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Introduction

Mountain communities have a history of cultural inspiration, pioneering spirit, and self-selected retreat. Harsh and variable mountain environments have throughout time triggered social and technical adaptation. The domestication of the potato in the Andes dates back to 8000 to 5000 BC; the high culture of the Andean Inca reaches as far back as 2500 BC; and the Tibetan Empire rose to territorial and cultural importance between the AD 7th and 9th centuries (Guillet et al 1983; Gade 1999). Visionary infrastructure projects such as passes, tunnels, and cableways have made mountains accessible. In Europe, Splugen Pass road was built in 1822; the Mont Cenis tunnel opened in 1871; and, in 1908, the Wetterhorn lift and the first ski lift in the High Black Forest started operation (Mathieu and Vester 2009; Denning 2014).

Mountains often represent borderlands between regions or countries and have throughout time been the source of conflict over access to natural resources and control of transportation corridors, as well as sites of cultural and linguistic marginalization (Ingalls and Mansfield 2017; Ahmed et al 2019). At the same time, mountain communities have shown remarkable resilience. The challenging environmental surroundings force them to adapt, innovate, and maintain fundamental capacities developed over long periods of time. These capacities help mountain

communities deal with multifaceted stresses such as droughts, flooding, and earthquakes (Brunner and Grêt-Regamey 2016; Choudhry et al 2017).

In recent years, the livelihood resilience of mountain communities has been investigated with respect to various drivers of change, such as climate change (Mathez-Stiefel et al 2019; Vaidya et al 2019), globalization (Mishra et al 2017), and biodiversity mismanagement (Melnykovych et al 2018). In many parts of the world, topography, climate, and remoteness impede access to markets, social services, and basic infrastructure (Wu et al 2014; Saito et al 2018). Above average rates of warming at higher elevations (Pepin et al 2022) and changing precipitation patterns (Palazzi et al 2019) compound major risks to livelihoods and ecosystems in mountain areas. These risks are amplified by the tendency of globally integrated economic value chains to be concentrated (Toscani and Sekot 2017) and by accelerated biodiversity loss (Payne et al 2020). The current coronavirus disease 19 (COVID-19) pandemic has further accelerated such concentration tendencies directly and indirectly, leading to traffic congestion, pollution, further environmental degradation, second-home placebos, and overtourism (Teare 2021; Seraphin and Dosquet 2020).

In this challenging setting, high social and cultural capital are cornerstones of resilience for communities in disaster-prone peripheral mountain areas (Meenawat and Sovacool 2011; Imperiale and Vanclay 2016a; Redshaw et al 2018). Engaging communities as change agents in their specific cultural and geographical contexts can help build long-term resilience by supporting both adaptation to changing environmental conditions and transformation toward sustainability.

In order to strengthen sustainable development in mountain areas, key leverage points (ie points of intervention with high systemic impact) need to be identified to support resilience of mountain communities, which include the stability and adaptability of complex social–ecological systems (SES) upon which livelihoods depend (Altaweel et al 2015). Strengthening proactive community engagement while taking into account potential systemic leverage points can support disaster prevention and response (Hewitt and Mehta 2012), improve capacities and education (Thi and Shaw 2016), and unleash innovative potential. These factors in turn contribute to community wellbeing.

To support these processes, and inspire new approaches, we seek to inform the international mountain research community and international frameworks such as the Sendai Framework for Disaster Risk Reduction and the Alpine Climate Target System 2050.

Based on a mixed-methods approach (Creswell 2003; Baškarada and Koronios 2018), we reviewed the international scientific English-language literature on mountain resilience. In a first step, an international expert panel identified key pillars of the resilience discourse and contextualized their origins, development, and status quo in the broader mountain setting. Next, key topic areas were identified, and papers addressing these issues were picked from the Scopus® database and analyzed by discipline, geographical area, year, and journal of publication. The Scopus database was selected due to its broad coverage of economic, environmental, and social studies. Scopus showed a broader representation of articles among disciplines than Web of Science or Google Scholar (Harzing and Alakangas 2016). Scopus also included more lower impact and more recent papers than Web of Science, providing a broader base of articles for the review, while both databases showed similar overall patterns of coverage (Chadegani et al 2013; Martín-Martín et al 2018).

A complementary qualitative analysis of the broader resilience literature found in Scopus allowed us to relate the results obtained to ongoing discussions concerning the concept of resilience. Finally, we set the findings of our analyses in relation to generic challenges of mountain SES, thereby substantiating suggestions for further research in the field. By doing so, we aimed with our analysis to support science–practice interactions as well as concrete activities in order to strengthen resilience in mountain regions around the world.

The rest of the paper is structured as follows. In the next section, we give an overview of the documented roots of the resilience concept and how the different notions of resilience have manifested themselves in the mountain resilience literature. Based on these definitional foundations, we then present specific subtopics by means of a quantitative Scopus research and analysis of titles, keywords, and abstracts. In the final section, we build on these insights and set them into the overall mountain context, thereby substantiating suggestions for further research in the field.

Resilience: origins, development, and current understandings in the mountain context

The origins of the concept

The concept of resilience has different origins. The term first appeared in materials science in 1859 and found a broad reception in psychological and medical contexts from the 1950s on (Alexander 2013). Resilience research gained a foothold in the broader context of mountain development in the 1980s, originating from the adjacent fields of infrastructure engineering (Whiteman 1985, Vander Velde 1989) and (mountain) ecology (Price 1988; Meeus et al 1990). It also entered the mountain policy arena, with the first documents appearing in the middle of the 1980s. The resilience concept came to the social science literature considerably later (Tobin 1999; Olsson et al 2006; Hornborg 2009; Davoudi 2012; Imperiale and Vanclay 2016a). Today, the concept of resilience interests many academic disciplines, but also the general public, for example, in the fields of regional development, disaster risk reduction (DRR), and tourism (eg Filimonau and De Coteau 2020; Katsikopoulos 2020; Parker 2020).

Within the next sections we first elaborate on different approaches and definitions in resilience research by touching upon physical, ecological, psychological, and social resilience. This order is explicitly not meant to be chronological, but conceptually related. Next, we discuss the term resilience against the background of selected contexts and fields of application of central importance for mountain regions, covering SES and sustainability, development, DDR, and governance.

Infrastructure and physical resilience: The physical resilience of infrastructure, such as roads, power grids, water distribution networks, and railways, is the "the ability to reduce the magnitude, impact, or duration of a disruption" from a

potentially catastrophic event (Bertocchi et al 2016: 8). In mountainous terrain, the lack of network alternatives means that any interruption of supply lines has the potential for far-reaching negative consequences, since it may reduce accessibility or provision of crucial goods. Compared to those located in lowlands, infrastructure elements in mountains are exposed to additional natural hazards, such as avalanches, rockfalls, and mudflows, which are likely to become more frequent and more intense due to climate change. Consequently, striving for increased resilience of physical infrastructure means improved accessibility, robustness, and fast response by current infrastructure networks and systems to maintain the desired network performance (D'Este and Taylor 2003; Taylor et al 2006; Yin et al 2016).

Ecological resilience: The concept of ecological resilience has its roots in natural history and ecological research describing the robustness or persistence of different types of ecosystems (Holling 1973). Currently, the resilience of ecological systems is described as the capacity to persist in the face of change, that is, to continue to develop within ever-changing environments (Folke 2016).

Ecological resilience is of great importance. The loss of an ecosystem's ability to recover from a disturbance, whether through natural hazard processes, such as storms and floods, or human influences, such as overfishing and pollution, threatens the ecosystem services on which humanity depends.

The resilience of mountain ecosystems assures the continuation of crucial ecosystem services of all 4 types (provisioning, regulating, cultural, and supporting) to the populations in the adjacent lowlands. While mountains represent hotspots for biodiversity and are the sources of all major rivers worldwide, mountain ecosystems are often fragile and under extreme pressure due to global change processes.

Psychological and social resilience: The resilience concept in psychology originated from research about the qualities of children who thrived despite the devastation of World War II. Later studies aimed to discover the motivational forces within individuals and groups that drive them to grow through adversity and disruption (Richardson 2002).

Psychological resilience predominantly deals with individuals and their ability to learn from adversity and adapt (Fletcher and Sarkar 2013). Various conceptualizations of psychological resilience focus on subjective distress and the consequences thereof (Kaplan 2013). The tendency to experience positive emotions (Tugade and Fredrickson 2004) and emotional intelligence (Armstrong et al 2011) may also be closely related to psychological resilience. Recent conceptualizations of resilience in psychological studies comprise several interdependent levels, including individual, community, and societal (Paton 2008). Kimhi (2016) showed that all 3 levels predict individual wellbeing and successful coping, suggesting that attention needs to be directed at multiple levels to better understand resilience of individuals and groups.

The first understanding of social resilience focused on the capacity to cope with disturbances collectively. Adger's (2000: 361) early definition of social resilience is "the ability of communities to withstand external shocks to their social infrastructure." Further conceptual advances in understanding social resilience have been made both in behavioral sciences and in natural resource management theory.

Broadly speaking, social resilience research scrutinizes the extent to which social entities (eg individuals, communities, and organizations) tolerate, absorb, and adjust to environmental and social threats of various kinds (Keck and Sakdapolrak 2013).

Compared to the many studies on psychological, community, and social resilience in recent years, there have been few investigations into the resilience of mountain communities (Imperiale and Vanclay 2016a, 2016b; Mishra et al 2017; Wilson et al 2018; Pedoth et al 2019). Identification of positive psychological, social, and governance drivers is important to understand how to build resilience of mountain communities.

Established pillars of resilience research

Disaster resilience: In disaster research, the resilience concept bridges theory and practice and emphasizes the importance of community, societal, and governance aspects in reducing the risks and impacts of hazardous processes.

Within the context of the DRR discourse, resilience does not mean bouncing back to a pre-event state. Instead, it denotes the capacity of systems to move forward by modifying their internal dynamics and recombining their structures and processes for positive transformation and change toward enhanced DRR at all levels of society (Manyena 2009; Koontz et al 2015; Pelling et al 2015; Imperiale and Vanclay 2016a).

Efforts to enhance resilience must consider how positive adaptation occurs before, during, and after crises, through individual and collective processes of learning and transformation toward sustainability (Berkes and Ross 2013, 2016; Imperiale and Vanclay 2016a, 2016b).

Mountain communities are highly exposed to multihazard events. For example, earthquakes may trigger secondary cascading hazard processes (such as avalanches, landslides, and rockfalls) that can have strong negative impacts at local levels (Gardner and Dekens 2007). Therefore, it is crucial to understand resilience in order to implement the Sendai Framework and build community sustainability in mountain regions (Wymann von Dach et al 2018).

Resilience and development: Resilience has become an increasingly popular concept in development (Béné et al 2015; Bousquet et al 2016). It offers systemic approaches with which to reduce adverse impacts of natural hazards (eg floods, droughts, and earthquakes); manage political conflicts and social unrest; tackle critical economic conditions based on changes in food prices or the failure of commercial markets; and face stressors like degraded soils or deforestation. All of these aspects need to be considered when designing pathways toward sustainable development and transformation in mountain regions.

Social–ecological resilience and sustainability: Sustainability manifests in many definitions and mental models (Luthe and von Kutzschenbach 2016). As a concept, sustainability has evolved from balancing opposing needs to cocreating a better future by transforming SES (Carpenter et al 2001; Folke et al 2002; Berkes et al 2003; Walker et al 2004; Folke

2006; Olsson et al 2006). The SES approach to resilience recognizes that a crisis or disaster represents an opportunity for social actors to learn and transform, bringing about individual and collective innovations that can improve SES management and resilience (Folke et al 2009; Scheffer 2009; O'Brien 2012; Berkes and Ross 2013, 2016; Imperiale and Vanclay 2016a, 2016b). The SES approach investigates how social systems learn by changing and transforming their internal structures and components to address the negative consequences of disturbances and reduce future risks in their localities (Folke et al 2002; Berkes et al 2003; Folke 2006). The term SES then evolved and incorporated notions of learning and adaptation, taking into consideration the importance of power and politics, and the role of institutions in enhancing SES resilience and sustainability (Folke 2006; Beratan 2007; Davidson 2010; Keck and Sakdapolrak 2013).

In this domain, resilience describes a system's capacity to cope with change and continue to thrive. In relation to sustainability, the resilience concept departs from a closely coupled understanding of social and ecological systems, which need to be understood as a whole (Folke 2006). Resilience develops over time in continuous sets of nested "adaptive cycles," with phases of stable conservation, crisis release, reorganization, and growth (Carpenter et al 2001). The adaptive cycles have been framed as waves, where the social ability for transformation buffers the amplitude of the 4 phases, which may increase resilience in SES (Luthe and Wyss 2015).

Resilience and governance: Governance is understood as the process of decision-making (Bedi et al 2014) and the ability to make and enforce rules and deliver services (Fukuyama 2013). Good governance, understood as being transparent, just, accountable, responsive, and participatory, is a key to resilience (Bedi et al 2014). Resilience thinking has linked the research agenda of governance to the dynamic interactions of SES (Ostrom 2007). Recent studies have focused on (1) the benefits of a complex systems approach to governance; (2) the relevance of new governance models to cope with complex change; and (3) the role of the resilience concept in governance studies. The results show that complexity, change, adaptability, and self-organization are fundamental factors for understanding multilevel governance systems.

As a way to assess and quantify (community) resilience from a governance perspective, growing numbers of studies use social network analysis to interpret collaborative governance structures of communities (eg Luthe and Wyss 2014, 2015; Kelman et al 2016).

Table 1 gives an overview of the main origins, developments, and current understandings related to the mountain resilience discourse and the major relevant scientific references.

The peer-reviewed knowledge of mountain resilience research

In a research approach following a classic combined qualitative–quantitative approach (Creswell 2003; Baškarada and Koronios 2018), 7 key focus areas of the mountain resilience research discourse were identified in an iterative process. First, an explorative search in Scopus was run to understand the development of the research field over time and identify the main topics in the literature. The search was restricted to articles appearing in English in the Scopus database and published in peer-reviewed scientific journals.

Important fields of interest were identified based on the Scopus research and then further aggregated to form the frame for qualitative analysis in the field. The identification of these key research areas within the mountain resilience literature was complemented by a multistage discussion among experts from various research fields, spanning pure natural sciences through social sciences to inter- and transdisciplinary research, all familiar with mountain resilience research. Most of the coauthors are also members of the Mountain Resilience Working Group hosted by the Mountain Research Initiative (MRI n.d.).

This iterative process yielded 7 broad topics, ranging from livelihoods to tourism. Within every topic, a quantitative Scopus analysis was conducted, and key information (authors, journal, year of publication, keywords) for the papers was collected. Based on the broad expertise of the authors, specific groups were formed, and each group worked on individual topics. The results from the quantitative Scopus search based on a keyword search of titles, keywords, and abstracts were triangulated with qualitative information derived from the papers reviewed within the topic areas and reported in the respective tables in Appendix S1 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1.S1). We followed the Reporting standards for Systematic Evidence Syntheses (ROSES) standard for scientific reviews (Haddaway et al 2017) as reported in Appendix S2 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1.S1).

Quantitative overview

The search for English-language articles appearing in the Scopus database published up to the end of 2020 in scientific journals returned 775 peer-reviewed articles referring to "mountain(s)" and "resilience" in the title, abstract, or keywords. Over the years, the number of articles increased significantly, from 3 to 4 articles per year with reference to these 2 keywords at the turn of the century to more than 100 articles per year by the end of 2020. Environmental sciences predominated according to author affiliation in the Scopus database, followed by agricultural and biological sciences. *Forest Ecology and Management* was by far the most prominent journal with respect to articles that refer to the 2 terms (48 articles). *Mountain Research and Development* was second (20 articles), with *Ecology and Society* and *Sustainability* in joint third place at 18 articles each. Figure 1 gives an overview of the development of the publications in the 10 main journal outlets for the period 1994 to 2020.

When investigating the keywords chosen by the authors, "climate change" was the most prominent with 198 references, followed by "ecosystem resilience" and "resilience," with 179 and 164 entries in Scopus, respectively.

The 7 key topics

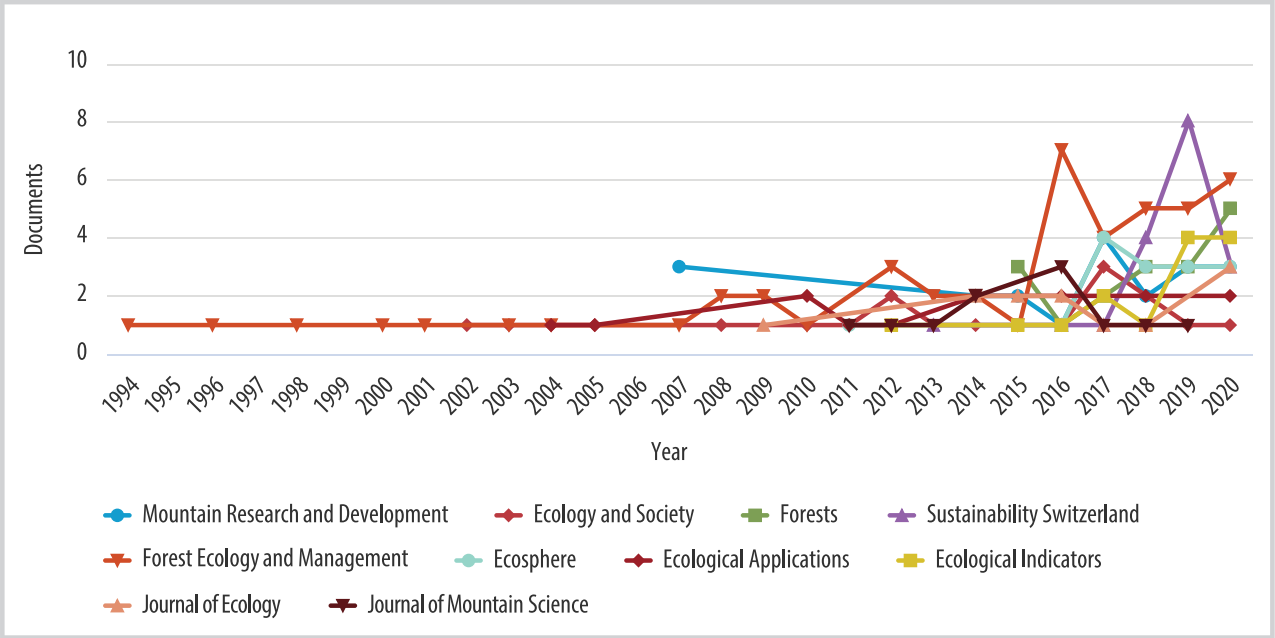
Complementing the quantitative Scopus research, we put together a comprehensive list of topics in the field of mountain resilience. The multistage process included a preselection of topics based on a preliminary literature search by the 4 lead authors and 2 online meetings with all authors to validate the preselection (held during the COVID-

TABLE 1 The origins, development, and status quo of the mountain resilience literature.

Resilience: origins, development, and current understandings related to mountains	References
Early impulse of resilience: The International Symposium on Ecology of the Development of Tropical and Subtropical Mountain Areas and the Himalayan Region Conference apply the topic of resilience to mountains.	Holling (1973); Ives et al (1987)
An engineering variable from AD 1800 in applied mechanics and material science: Resilience of water, transport, energy, and communication networks refers to climate, natural hazards, and human-caused attacks. It is usually measured by quantitative and semiquantitative methods and aims for improved accessibility, robustness, and fast response (bounce-back) of the current infrastructure networks and systems.	D'Este and Taylor (2003); Taylor et al (2006); Yin et al (2016); Eidsvig et al (2017); Gößling-Reisemann et al (2018); Schlögl et al (2019)
Ecological resilience considers the probabilities that systems will undergo critical transitions to alternative states. Species-specific responses to the effects of climate change can limit ecological resilience in mountains. Appropriate management of ecosystems can increase ecological resilience in mountains.	Hirota et al (2011); Brooks et al (2016); Levine et al (2016); Six et al (2018); Bender et al (2019); Chambers et al (2019)
Psychological resilience arises from the multiple processes shaping a person. The assessment is heavily influenced by trait- and process-oriented perspectives. It looks at the nature of a community's strengths and capacities (rather than its deficits or vulnerabilities) and how these capacities contribute within a collective process to facing disasters and developing overall resilience.	Walker et al (2004); Norris et al (2008); Pfefferbaum et al (2008); Cutuli and Masten (2009); Schultze-Lutter et al (2016)
Social resilience is the human capacity to mitigate risks and impacts of disturbances at multiple governance levels. Community resilience is the human capacity in small social subsystems. Both psychological adaptation of residents and individual and collective capacities are needed to learn from vulnerabilities and impacts to transform toward sustainability.	Funnell and Parish (2001); Berkes and Ross (2013, 2016); Imperiale and Vanclay (2016a, 2016b); Kruse et al (2017); Matarrita-Cascante et al (2017)
Disaster resilience is considered an iteration of the rather negatively connotated concept of vulnerability with a crucial role in current international debates on how to address disaster risk reduction in a holistic way, as emphasized by several international agreements (eg DRR Sendai Framework). Most scientific studies neglect mountain regions, even though they are highly exposed to various forms of natural hazards. A significant aspect for their resilience is the limited space for settlements.	Hewitt (1983, 1992, 1997); Tobin and Whiteford (2002); Pelling (2003); Gardner and Dekens (2007); Gaillard and Kelman (2012); Alexander (2013); Zimmermann and Keiler (2015); Fuchs et al (2017); Röthlisberger et al (2017); Deeming (2019); Klein et al (2019); Kuhlicke et al (2020); Posch et al (2020)
Greater awareness is a core concept for development, but it is less known how to apply awareness in practice. There is potential for stronger cross-sectorial approaches beyond monodisciplinary thinking. Coupling awareness with vulnerability narrows down its forward-oriented thinking, but it may disempower marginalized groups.	Arora-Jonsson (2011); Johnson et al (2018); Constas et al (2020)
The social–ecological system (SES) theory is entangled with sustainability. Disturbances, such as crises or disasters, represent a window of opportunity during which social actors can learn and transform, bringing about individual and collective innovative change that can improve SES management and resilience. The resilience of SESs is ultimately enhanced by the ways in which cognitive dimensions shape interactions between human and ecological systems.	Carpenter et al (2001); Folke et al (2002); Berkes et al (2003); Walker et al (2004); Folke (2006); Olsson et al (2006); Folke et al (2009); Scheffer (2009); Westley et al (2011); O'Brien (2012); Berkes and Ross (2013, 2016); Luthe and Wyss (2015); Xu et al (2015); Imperiale and Vanclay (2016a, 2016b)
Governance and resilience are linked by the disaster risk reduction (DRR) discourse, and this link is considered crucial to strengthen resilience, if sustainable. A complex system perspective rethinks governance and required decision-making processes. Governance of and for resilience requires flexibility and stability of institutions. Studies look at dynamics and (inter)actions through which actors steer, develop, sustain, or disrupt institutions.	Folke et al (2005); Duit et al (2010); Gardner (2015); Beunen et al (2017)

19 pandemic and originally planned to be held on site). The authors agreed on 7 central topics for the mountain resilience research field, namely, (1) livelihoods, (2) disaster prevention, (3) community (engagement), (4) agriculture, (5) tourism, (6) economy, and (7) forests. Forestry was added as the seventh topic due to its relative importance in the subsequent comprehensive Scopus database research. Climate change, as another top entry in the quantitative keyword search, was not integrated as an individual and additional topic category due to its universal and cross-

FIGURE 1 Development of the publications for the period 1994 to 2020. (Source: Scopus.com)



sectoral importance in all areas covered, but it appears as a central issue in the qualitative analysis within all selected topic areas. Articles within the individual topic areas were identified within the Scopus database by inserting the subject plus the terms mountain(s) and resilience. In the following subsections, we give an overview of the main insights from the qualitative analysis of the articles with the topic areas. Complementary information and references can be found in Appendix S1 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1.S1).

Livelihoods: In total, 43 articles were identified for the search string "Mountains AND Resilience AND Livelihoods." Climate change (mentioned in 31 articles), vulnerability (mentioned in 27 articles), and adaptive management (mentioned in 17 articles) were identified as focal subtopics. Though shaped by different political and cultural systems, mountain communities around the world share many similarities regarding livelihoods. For centuries, many mountain communities have depended on some form of pastoralism and subsistence agriculture rooted in local climate and traditional knowledge (Huntsinger et al 2010; Imperiale and Vanclay 2016b; Schermer et al 2016). However, the modernization and globalization of mountain regions, coupled with mass tourism, industrialization, population growth, and drastic climate change effects within the last century, have led to increased vulnerability of mountain ecosystems and their surrounding social–ecological networks. Livelihood adaptation is therefore critical in building resilience, especially in the diversification of local economies (Wu et al 2014; Spies 2018; Shahzad et al 2019). Leveraging local knowledge about resources, particularly insights gained through women and their roles in communities, can help communities systemically adapt to change (Kernecker et al 2017).

The issues surrounding climate change and mountain livelihoods are evident within the physical built environments of the communities themselves. Recognition of this feature offers a critical learning environment for local, regional, and national collaboration. Social innovation within traditional practices, such as agriculture, shepherding, hunting, and medicine/wellness, can cement resilience efforts across many different socioeconomic systems (Haron et al 2004; Kassam et al 2010; Gretter et al 2019; Shokirov and Backhaus 2019). Reframing the "impractical nature–culture binarism of nature protection" has been proposed to better evaluate the resilience of mountain SES and their linked ecosystem services, which in turn can foster ecosystem stewardship and resource sharing (Campbell 2018). Furthermore, researchers and practitioners acknowledge the lack of transdisciplinary tools with which to evaluate the relationships between resilient livelihoods and social systems within mountain communities.

Disaster prevention: In total, 69 articles on "Mountains AND Resilience AND Disaster" were found in the Scopus database. Most of the studies took a multihazard perspective, showing how resilience affects the consequences of different types of mountain hazards. The second largest group of studies focused on geohydrological hazards, such as torrential floods, debris flows, and landslides. Some of the papers were country specific, focusing on local hazards, such as bushfires in Australia. Around a third of the articles used hazard events, like the earthquakes in L'Aquila (2009) and Nepal (2015), as starting points to assess the resilience of affected local communities and recovery interventions. A strong link was found between the concepts of resilience and DRR, especially within the last 2 decades (Fekete et al 2020; Kuhlicke et al 2020).

Various international declarations have contributed to the evolution of a DRR and resilience paradigm that should be the basis of any postdisaster and development intervention in all countries (UNDRO 1982; IDNDR 1994; UNISDR 2005, 2015). The DRR and resilience paradigm advocates building community resilience and supporting local communities to reduce local vulnerabilities and

enhance community wellbeing and resilience to better manage disaster risks at all levels of social–ecological governance (Imperiale and Vanclay 2019, 2020).

Community (engagement): In total, 304 articles referred to "Mountains AND Resilience AND Community" in the title, abstract, or keywords in the Scopus database. Social science communities (92 articles), human communities (66 articles), and community engagement (22 articles) were major subtopics. Many mountain communities face complex challenges in achieving resilience, particularly in balancing socioeconomic pressures from global factors such as climate change with traditional livelihoods and societal practices. Socioeconomic and socio–ecological change in mountain areas greatly shapes community identity formation processes: "currently many people continue to identify and associate themselves with a landscape that no longer exists, while others identify themselves with a future landscape that as yet does not exist" (Dossche et al 2016: 1). In general, existing research across disciplines reiterates the importance of codeveloping strategies to build resilience with local communities (Cwik et al 2019). Traditional ecological knowledge tends to be eroded by the integration of small-scale societies into the market economy. Many communities in the European Alps have been integrated into wide economic networks for several centuries and have been deeply influenced by these networks (Carrer et al 2020). Similarly, researchers suggest that adoption of novel sustainability transitions in mountain regions requires multilevel and horizontal engagement throughout the various socioeconomic systems in place (Kratzer 2018). Accordingly, bolstering local knowledge systems can help to inspire reflection into innovative pathways toward new mountain futures (Angelstam et al 2013; Thorn et al 2020).

Agriculture: In total, 59 articles in the Scopus database dealt with "Mountain AND Resilience AND Agriculture" in the title, abstract, or keywords. Crop diversity (29 articles), pests and pathogens (23 articles), and transhumance (3 articles) were major subtopics. Mountain agricultural sites vary from cultivated valleys to high mountain pastures. Therefore, mountain agricultural land encompasses a range of habitats and ecosystems, including those that support trees grown for food, timber, and fuel. The articles in the Scopus database reflect this diversity with respect to place, habitat, risk exposure, and agricultural practices. Diversity of crops and biodiversity in arable land are important factors in mountain agricultural resilience and the likelihood that resilience may be increased with complex, biodiverse, multicrop systems (Ponce 2020). Though a human endeavor by definition, agriculture relies on natural processes and factors such as arable soil, climate, topography, and the animals and plants themselves. Under climate change, mountain crops and agricultural animals must not only survive, but also be productive. Ecosystem stability along elevational gradients is enhanced by diverse vegetation, and soil conservation is crucial to mountain agriculture (Ahmed et al 2019; Geng et al 2019). Although novel crops may provide new avenues for crop biodiversity, they may not be as nutritionally valuable as traditional food crops (TFCs). TFCs may be "future smart foods" that play strong roles in sustainability. For example, the novel crops of mustard and cardamom in Nepal and fruits and coffee in Bangladesh lack the nutritional value and economically sustainable cultivation of TFCs. At the same time, policies and societal attitudes must be in place to favor the cultivation of TFCs over novel crops (Adhikari et al 2019). In this case, TFCs can increase social resilience, for example, for typhoon-displaced mountain people who traditionally grew and consumed red quinoa (Taibin et al 2020).

Tourism: In total, 22 articles were found using the search string "Mountain AND Resilience AND Tourism." The main identified subtopics were social–ecological or territorial resilience (17 articles), ecosystem and farming (12 articles), and climate change (11 articles). Resilience as an analytical, normative, or planning-oriented concept has been applied to issues as diverse as tourism infrastructure, tourism governance, climate change, disaster risks, and skiing (Hewitt and Mehta 2012; Luthe et al 2012; Bardsley and Bardsley 2014; Wyss et al 2014; Luthe and Wyss 2016; Prasad et al 2016; Knowles 2019; Barthod-Prothade and Leroux 2020; Demiroglu and Hall 2020).

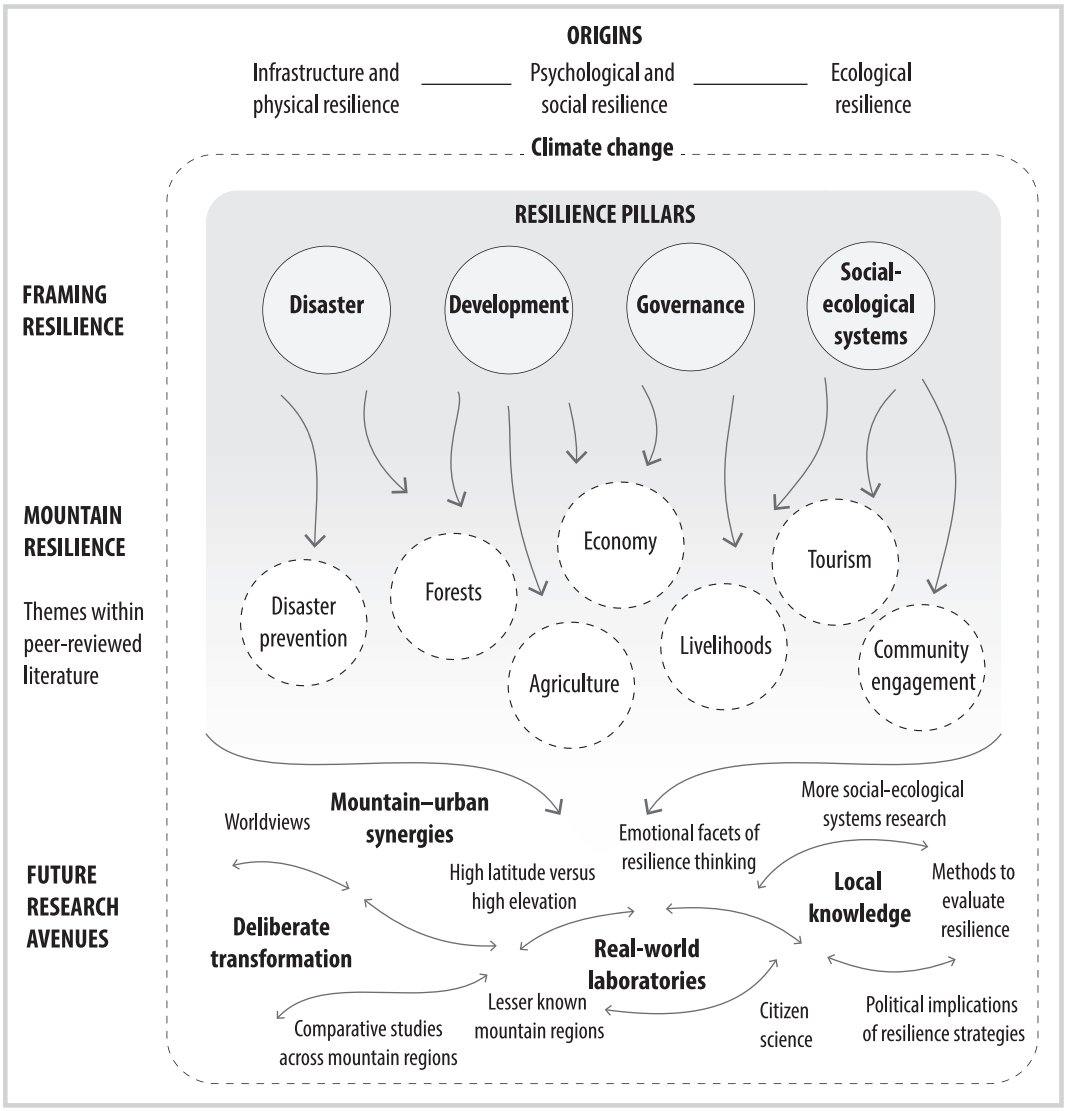
Resilience in the tourism context is often poorly conceptualized or used in an overly general manner. Even though resilience first appeared in the tourism literature in the early 1980s, when Holder (1980) studied the role of tourism activities in strengthening the economic wellbeing of communities in the Caribbean, almost no empirical investigations into resilience in mountain regions appeared in English scientific literature up to the early 2000s.

In general, resilience as an analytical lens has helped tourism scholars bridge the gap among social, ecological, cultural, and physical aspects of tourism development in mountain areas. The literature addresses issues such as the impact of tourism on mountain communities, on Indigenous Peoples, and on migration in mountainous areas of the world through a distinct resilience lens (Membretti and Iancu 2017; Shie 2020), though with a bias toward tourism in the European Alps and in Europe, more generally.

Economy: In total, 29 articles were identified in Scopus using the search string "Mountains AND Resilience AND Economy," with ecosystem services values (13 articles), climate, communities, and adaptation (9 articles), and disaster exposure and recovery representing major subtopics. The identified studies addressed resilience in the context of mountain economies from a diverse set of interdisciplinary topics, with no clear unifying direction. The literature is dominated by postdisaster recovery from earthquakes, climate change, and demographic impacts on rural community economies (Kizos et al 2014; Monge and McDonald 2020). Most studies described mountain resilience cases in Asia (ie China and India), followed by the European Alps and the Iberian Peninsula. Overall, most of the studies originated from mountainous countries where the rural economy depends on 2 single economic sectors: agriculture (8 studies; eg Grüneis et al 2018) and tourism (4 studies; eg Allan et al 2015).

Most studies took a socioeconomic perspective on resilience, meaning they integrated economics with social aspects, such as community issues and livelihoods. A second stream of research was related to the ways in which a resilient economy may look, including diversification from agriculture, forestry, mining, or tourism (Yu et al 2013; Jonsson et al 2019). Eight studies focused on ecological conservation and intact ecosystem services. Six studies discussed an economy that would benefit from a more

FIGURE 2 The narrative of this paper is shown here. Based on the origins of the resilience concept, we started the literature keyword search from 4 main resilience pillars. In the literature, we identified 7 topical themes, with climate change encompassing them all. We discuss the gaps in the literature and offer 4 main inter- and transdisciplinary avenues as the focal areas for future research on mountain resilience. These 4 avenues are further described by additional keywords. They were either mentioned as such or as gaps in the literature, and they are discussed here as analytical propositions according to the expertise of the author team.



diversified inclusion of other sectors, such as educational components and the arts, to build resilience. Only 1 study looked at the circularity of resource use specifically (Merson et al 2010).

Forests: In total, 318 articles in the Scopus database dealt with "Mountains AND Resilience AND Forests." Climate change was the main subtopic (100 references), with coniferous forests (52 references) and fire (44 references) following. The overall discussion in more recent studies centered on disturbances by fire, beetles, and droughts; forest management and climate change; and carbon storage in soils. Studies on the disturbance of forest regimes and forest calamities in relation to climate change focused on increasing fire danger, postfire resilience, tree line changes related to fire disturbance, or insects, such as the pine beetle (Windmuller-Campione 2018; Koba and Zhigalova 2019; Naccarella et al 2020; Rodman et al 2020). Earlier studies took a more silvicultural approach by considering single tree species, nutrients, conservation and protection, and broader land management perspectives. Articles published before 2011 also looked at more general forest stability and management, conservation, protection functions, and nutrient cycling (McDonald and Healey 2000; Brang 2001; Dinesen et al 2001; Dorren et al 2004). Even when limiting the search to subject areas, including arts and humanities (8 articles), decision sciences (5), social sciences (4), and economics (3), actual direct sociocultural or community impact analysis of forest resilience was largely underrepresented. Two notable exceptions are Ocak (2016) and Haider et al (2019).

Discussion and future research avenues

Overall, there has been a strong increase in publications on mountain resilience research over the last 15 years, with an acceleration over the last 5 years. Figure 2 shows and summarizes the 4 pillars and 7 main themes discussed herein, and the ways in which these relate to the future research

avenues elaborated here. Climate change is a concurrent overarching theme, and it is either directly or indirectly embedded and addressed in many of the identified main themes. It is thus not listed as a pillar, but it should be considered as an inclusive frame, indicating its relation within and across the specific themes.

As for the thematic span, the assessed literature was clustered into 7 main themes. Research on social science aspects of mountain resilience, such as on livelihoods or tourism, has been gaining relevance but is still published less frequently. Yet, themes such as local identity-building through culture and the historical evolution of practices and knowledge are central to strengthening resilience of mountain livelihoods and the ecosystems on which they depend (eg Richter 2016; Bersier and Keller 2019).

Research gaps and opportunities on mountain resilience

In terms of the geographical areas covered by the papers under review, a few well-studied mountain ranges stand out (European Alps, Rocky Mountains, Himalayas, Pamir, Andes), while other, mainly lower-lying and lesser-known or lesser-populated, mountain areas are significantly less studied. Most articles are based on case studies of geographically delimited areas, and there are almost no meta-analyses or intercomparable analyses among different regions or mountain ranges in the sample.

Interdisciplinary integration among the social and natural sciences is lacking. Most papers focus either on social or natural science phenomena, with small numbers of papers looking at social–ecological issues in a more integrated way. While purely ecological or social approaches to resilience are valuable, there is a clear need for more interdisciplinary work in crosscutting resilience topics, such as economic wellbeing of mountain livelihoods, future agricultural systems, or climate change. The understanding of and responses to climate change, for example, are based both in the physical and in the social sciences and, in a transformation context, even involve aspects of design (eg for cocreating visions of resilient futures). Resilience to climate change can therefore only be understood in an inter- and transdisciplinary way.

Critical studies of the political implications of mountain resilience strategies and their associated agendas are also rare. In the infrastructure and economics fields, mechanisms for bouncing back to former points of equilibrium prevail. In fields such as disaster prevention and community development, more complex understandings of multiple equilibria and constant evolution, learning, and transformation are more present. Future-oriented, evolutionary, and societal learning topics are not yet sufficiently discussed in the screened literature, despite their relevance for what the resilience concept offers as an explanatory framework. This is not surprising, since mountain resilience measures and strategies imposed on local populations or such efforts originating from inclusive, organic social cogovernance processes have not been integrated sufficiently in policy processes. This has parallels in other fields such as agronomy or development studies (Rasmussen et al 2018, Colding and Barthel 2019). Additionally, many papers still conceptualize resilience as a bounce-back concept, suggesting technical solutions to reduce vulnerability to disasters. Instead, a more holistic understanding of resilience should be focused on a social–ecological framing of resilience, since innovative and transformative capacities (both of which also describe resilience) are clearly underrepresented in the literature, as shown in the previous section.

Another underrepresented aspect is the emotional facet of resilience thinking, for instance, the notion of ecological grief. There are many examples of grieving for a mountain landscape that vanishes quickly or no longer exists, such as glacier funerals in Iceland and Switzerland. Grief may lead to compassion and enable resilience or hinder deliberate action. The concurrent lack of a debate on transformative innovation in mountain areas mirrors an attachment to a past that has no future under current conditions and projections of global change. More research on cognitive topics like grief and compassion would benefit a contemporary, holistic understanding of mountain resilience (Cunsolo and Ellis 2018).

This review further identified a lack of research on methods with which to evaluate resilience, including the criteria needed to do so. Some methods to assess resilience need a specific mountain focus. Of the few mountain resilience assessment studies found during the literature review, guiding examples include assessments of mountain community resilience by comparative quantitative and qualitative analysis of social network governance structures, looking at both adaptive and innovative capacities (eg Luthe et al 2012; Kelman et al 2016; Luthe and Wyss 2016; Blanco et al 2022). Future research may look more into mixed-methods assessment approaches, quantification and qualitative assessment of mountain resilience, and citizen science (eg by mountain guides and mountaineering tourists).

Future research avenues

Figure 2 summarizes 4 main inter- and transdisciplinary avenues as focal areas for future research on mountain resilience. These 4 avenues are further described by additional keywords that relate and specify them and are derived from gaps in the literature. We discuss them here as analytical propositions through the expertise of the author team.

Deliberate transformation: Our rapidly changing world is marked by grand challenges such as climate change, globalization, migration, and biodiversity loss. Digitalization and innovative design thinking and doing will be instrumental in further strengthening the resilience of mountain communities around the world. These avenues form the basis for full access to information and political participation, for remote working as part of new work, and for new business models in mountain communities that connect across different economic sectors. The innovative and transformative aspects of resilience, built on deliberate transformation through social learning from experience, foresight, intuition, and backcasting, should be analyzed in greater depth (Luthe and Wyss 2015). The deliberate, conscious process of redesigning mountain systems should be based on the understanding of the existence and plurality of worldviews that steer our ways of reasoning and thus require further research.

Mountain–urban synergies: An understanding of current resilience challenges in mountains around the world through

geographical comparison is central to designing strategies for resilient mountain regions and communities. For this purpose, interdependencies among lowlands and mountain regions must be better understood ("new alpine–urbanism"), as well as the complex interconnections and similarities among cultural regions, for example, the similarities and differences among high-latitude and high-elevation SES. Lesser-known mountain regions should also be included.

Real-world laboratories: The dominant academic disciplinary compartmentalization generally does not equip researchers well enough to understand the real-life culture of mountain inhabitants, unless scientists live (at least temporarily) with and as a mountain community member, to gain understanding from a local and a practitioner view, and to build trust and connections. Often, the motivations and time frames of scientists (and of project finances) are totally different from those of mountain livelihoods. Making local knowledge accessible to scientific analysis and feeding back scientific output to practice through real-world laboratories, citizen-science schemes, data-collection endeavors by mountain professionals (such as mountain guides), and the like will promote transdisciplinary and nonexpert dialogues. It will also facilitate the design of governance models and policies derived from such dialogues. Designing resilient regenerative mountain systems through real-world laboratory research as part of a social–ecological mountain observatory network is one example of how such emerging research could be framed.

Local knowledge: To design effective long-term future measures and strategies, it is crucial to make use of local knowledge, for example, to uncover early warning signs linked to greater perils, such as permafrost thawing or rain-induced landslides. Mountain guides can, for example, be motivated and enabled to report their impressions from glacier environments, while laypeople can be asked to take photos of environmental hazards and share these documentations with others via online platforms. These are forms of citizen science.

Observations of social and ecological change by connecting scientists, practitioners, inhabitants, and visitors will increase the impact of mountain resilience research initiatives. This would allow the scientific community to consider local knowledge, values, and identity, and, in general, the emotional facets of resilience thinking. These have often been neglected in the past and are undervalued, as is evident from the research conducted on mountain resilience to date. A broader understanding of resilience in mountains with more SES research would support innovative interventions, strengthen capacity to face future challenges, and develop lasting resilience strategies for mountain areas around the world. It would also help to develop further methods to adequately evaluate systemic resilience and thus support political implications of resilience strategies.

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OPEN PEER REVIEW

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Supplemental material

APPENDIX S1 Complementary findings of the literature analysis grouped along the 7 topics.
APPENDIX S2 ROSES form with author responses.

Found at: https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1.S1.