

Supplemental material for

“Mountain Resilience: A systematic literature review and paths to the future” by Romano Wyss, Tobias Luthe, Lydia Pedoth, Stefan Schneiderbauer, Carolina Adler, Martha Apple, Eduardo Erazo Acosta, Haley Fitzpatrick, Jamila Haider, Gözde Ikizer, Angelo Jonas Imperiale, Nuray Karanci, Eva Posch, Olimjon Saidmamatov, and Thomas Thaler, published in *Mountain Research and Development* 42(2), 2022. (See <https://bioone.org/toc/mred/42/2>)

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Appendix 1 Complementary findings of the literature analysis grouped along the 7 topics

Table S1 Summary of literature analysis, search strings and frequencies together with the main arguments describing livelihoods and resilience and mountains

	Search string	Identified focal sub-themes			References
Livelihoods	<i>Mountains AND Resilience AND Livelihoods</i>	<i>climate change</i>	<i>vulnerability</i>	<i>adaptive management</i>	
No. of articles	43	31	27	17	
	Leveraging local knowledge on resources, particularly insight gained through women and their roles in communities, can help communities systemically adapt to change				Kernecker 2017
	Social innovation within traditional practices such as agriculture, shepherding, hunting and medicine/wellness, cements resiliency efforts across many different socio-economic systems				Gretter 2019; Haron Y 2004; Kassam 2010; Shokirov 2020
	Re-framing the 'impractical nature-culture binarism of nature protection' has been proposed to better evaluate the resilience of mountain social-ecological systems and ecosystem services linked to it, which fosters ecosystem stewardship and resource sharing.				Cambell 2018
	Within the planning and design discourse, reimagining the connection between rural/isolated high-altitude settlements and the regional peri-urban/urban valleys areas below is critical. For example, reframing this linkage as 'landscape societies' could more effectively cultivate information exchange, encourage social innovation and promote shared services and resources.				Carlow 2016
	Generating locally based renewable energy and material/resource economies through both timber and non-timber forest products (NTFPs) through 'climate adaptive design' or 'bioclimatic architecture' strategies can stimulate social capital and community belonging within both the built environment and underlying ecosystems.				Albatici 2006
	At the macro-level, 'social innovations in rural regions remain underrepresented, be it in public discourses or in research'; and the 'diffusion of cross-regional cluster-based cooperation is much-needed'.				Richter 2016; Guetaz 2008
	Commonly seen at the building level is the 'lack of a capacity to read and to reinterpret the environmental characters of the existing architecture.'				Albatici 2006
	Emerging methods within design fields are beginning to suggest potential solutions: 'Conducting live, interactive graphic geography drawing and spatial visualization techniques are conducive to building community trust and collective dynamics.'				Bertoncin 2020

Table S2 Summary of literature analysis, search strings and frequencies together with the main arguments describing disaster and resilience and mountains

	Search string	Identified focal sub-themes			References
Disaster prevention	<i>Mountains AND Resilience AND Disaster prevention</i>	<i>community social resilience</i>	<i>physical-engineering resilience</i>	<i>social-ecological resilience</i>	
No. of articles	69	43	17	15	
Various international declarations have contributed to the evolution of a disaster risk reduction (DRR) and resilience paradigm that should be the basis of any post-disaster and development intervention in all countries.					UNDRO 1982; IDNDR 1994; UNISDR 2005, 2015
A strong link exists between the concepts of resilience and disaster risk reduction, especially within the last two decades.					Fekete et al 2020; Kuhlicke et al 2020
A number of international agreements, such as Sendai Framework for Disaster Risk Reduction, the 2030 Agenda for Sustainable Development, the IPCC reports or the United Nations Human Settlement Programme (UN/HABITAT), provide strong support to discuss and to use the concept of resilience in natural hazard risk management.					SFDRR; United Nations 2015, UN Habitat
Resilience in mountainous regions has less frequently been discussed within the international academic debate.					Gaillard and Kelman 2012; Imperiale and Vanclay 2016a, 2016b
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 and impacts at all levels of social-ecological governance.					Imperiale and Vanclay 2019, 2020
Physical-engineering resilience often understands resilience as the counterpart of vulnerability, which is highly criticised in the current literature, since it has been shown that even within the most vulnerable communities there are extraordinary resources of resilience, especially in times of crises and disasters.					Alexander 2013; Imperiale and Vanclay 2016a, 2016b

Table S3 Summary of literature analysis, search strings and frequencies together with the main arguments describing community and resilience and mountains

	Search string	Identified focal sub-themes			References
Community engagement	<i>Mountains AND Resilience AND Community engagement</i>	<i>Social science communities</i>	<i>Human communities only</i>	<i>Community engagement</i>	
No. of articles	304	92	66	22	
Critical intervention areas to engage with resilience building and fostering social learning is by leveraging the embedded, collective memory found in the physical landscape.					García-Hernández 2018; Latocha 2019
Collective memory aids in better understanding social patterns in different contexts, such as population shrinking and demographic change in mountain areas.					Feldhoff 2013
Socio-economic and socio-ecological change in alpine areas greatly shapes community identity formation process: 'currently many people continue to identify and associate themselves with a landscape that no longer exists, whilst others identify themselves with a future landscape that as yet does not exist.'					Dossche 2016
In general, traditional ecological knowledge tends to be eroded by the integration of small-scale societies in the market economy. Many communities in the Alps have been integrated into wide economical networks for several centuries and have been deeply influenced by these networks.					Carrer 2020
Within participatory scenario planning strategies, bolstering local knowledge systems can help inspire reflection into innovative pathways towards new mountain futures					Angelstam 2013; Thorn 2020

Table S4 Summary of literature analysis, search strings and frequencies together with the main arguments describing agriculture and resilience and mountains

	Search string	Identified focal sub-themes			References
Agriculture	<i>Mountains AND Resilience AND Agriculture</i>	<i>Crop diversity</i>	<i>Pests and pathogen s</i>	<i>Transhumanc e</i>	
No. of articles	59	29	23	3	
Selection of species and varieties may shift towards those that are physiologically and economically viable under new climatic conditions.					Bottani Claros et al 2019; Lamichhane et al 2020
Diversity of crops and biodiversity in arable land are important factors in mountain agricultural resilience and the likelihood of resilience may be increased with complex, biodiverse, multi-crop systems.					Ponce 2020
Ecosystem stability along elevational gradients is enhanced by diverse vegetation and soil conservation is crucial to mountain agriculture.					Geng et al 2019; Ahmed et al 2019
In forested areas, humans can increase forest resilience by thinning and controlled burning, which can be instrumental in controlling pine bark beetles and reducing the effects of severe wildfires.					Hood et al 2016
Microbial symbioses are important factors in mountain agricultural resilience. For example, wheat crops rotated with N-fixing legumes had higher nitrogen uptake in Andean foothills than in interior drylands, emphasizing the importance of N-fixing symbioses as well as climatic and topographical variations. Mycorrhizal fungi enhance nutrient uptake and can increase resilience in sensitive mountain systems following disturbance.					Espinoza et al 2020; Scandellari 2015

Table S5 Summary of literature analysis, search strings and frequencies together with the main arguments describing tourism and resilience and mountains

	Search string	Identified main focal sub-themes			References
Tourism	<i>Mountains AND Resilience AND Tourism</i>	<i>SES or territorial resilience</i>	<i>Ecosystem and farming</i>	<i>Climate change, natural hazards</i>	
No. of articles	22	17	12	11	
<p>Resilience as an analytical, normative, or planning-oriented concept has been applied to issues as diverse as tourism infrastructure, tourism governance, climate change, disasters risks and skiing.</p>					<p>Barthod-Prothade and Leroux 2020; Bardsley and Bardsley 2014; Luthe et al 2012; Wyss et al 2014; Demiroglu and Hall 2020; Luthe and Wyss 2016; Hewitt and Mehta 2012; Prasad et al 2016; Knowles 2019</p>
<p>The literature has addressed 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 lense.</p>					<p>Maroudas et al 2004; Prager 2010; Rescia et al 2008; Lemelin et al 2012; Shie 2020; Membretti and Iancu 2017</p>
<p>The majority of the studies dealing with tourism and resilience were conducted in Europe (14), 6 in Asia, and 2 each in North America and Australia/New Zealand. Accordingly, most articles deal with the Alps (10 out of 33), with only a minor part explicitly dealing with the Himalayas (3 articles) or the Andes (1 article).</p>					<p>All references included</p>

Table S6 Summary of literature analysis, search strings and frequencies together with the main arguments describing economy and resilience and mountains

	Search string	Identified focal sub-themes			References
Economy	<i>Mountains AND Resilience AND Economy</i>	<i>disaster exposure and recovery</i>	<i>climate, communities and adaptation</i>	<i>Ecosystem services value</i>	
No. of articles	29	8	9	13	
The discussion is dominated by dealing with post-disaster recovery from earthquakes, climate change and demographic impacts on rural community economies (e.g., abandonment).					Imperiale and Vanclay 2016a; Monge and McDonald 2020; Kizos et al 2014, Feldhoff 2013
A second stream of research relates to discussing how a resilient economy may look: diversification from agriculture, forestry, mining, or tourism.					Wu et al 2014, Dupare et al 2008; Jonsson et al 2019; Yu et al 2013, Rescia et al 2008
Only one study looking into a differently integrated bio-system economy from an agricultural standpoint.					Merson et al 2010
The economic lens is dominated by a. general climate change impacts...					6 studies, e.g., Lega et al 2018
...and b. negative impacts of extreme events on the rural economy, infrastructure and post-disaster recovery, often, e.g., heavy rainfalls, windthrow, and earthquakes.					Schlögl et al 2019; e.g. Bennike 2017, Mishra et al 2017, Zhou et al 2020
A second stream of research looks at rural abandonment with land degradation or ecosystem services loss.					7 studies, e.g., Honrado et al 2017
One article takes a historical approach of understanding economic impacts of landscape change in relation to traditional mountain land-use.					Carrer et al 2020

Table S7 Summary of literature analysis, search strings and frequencies together with the main arguments describing forests and resilience and mountains

	Search string	Identified main focal sub-themes			References
Forests	<i>Mountains AND Resilience AND Forests</i>	<i>climate change</i>	<i>coniferous forests</i>	<i>fire</i>	
No. of articles	318	100	52	44	
Disturbance of forest regimes and forest calamities in relation with climate change, i.e. increasing fire danger, postfire resilience, treeline changes related with fire disturbance, or on insects, i.e. pine beetle.					Rodman et al 2020; Koba and Zhigalova 2019; Naccarella et al 2020; Windmuller-Campione 2018
Tree adaptations to droughts and fire, such as through mycorrhiza, or silviculture and harvesting, or invasive tree species.					Carpenter et al 2020; Crotteau et al 2018; Meigs et al 2017; Bellingham et al 2018
Soil properties such as carbon storage related to climate change and land management buffering.					Bojko and Kabala 2017; Moscatelli et al 2017; Loehman et al 2018
Articles published before 2011 rather look at more general forest stability and management, conservation, protection functions, and nutrient cycling.					Dorren et al 2004; Dinesen et al 2001; Brang 2001; McDonald and Healey 2000
From about the year 2006 on, there are more forest fire and drought related studies published.					Blarquez and Carcaillet 2010; Buhk et al 2006

Appendix S2 ROSES form with author responses

Topic	Author response
Title	Systematic review of mountain resilience literature
Type of review	Systematic review
Authors contacts	All full names, institutional addresses, and email addresses for all authors are provided in the submission interface of MRD and will be published on the final paper.
Structured summary	The review paper looks into the scientific literature on mountain resilience. It thereby takes a broad stance on literature stemming from the natural and social sciences. A major goal is to generate a systematic overview of the knowledge in the field of mountain resilience and give an overview of what subjects, issues, geographical areas have been treated, and where insights are lacking. The review is based on a systematic search of the SCOPUS research data base. In order to allow for comparisons between papers, the review is restricted to English speaking articles which have been published in peer-reviewed journals. A major outcome of the review is to identify topic areas in which research has been lacking up to know and open up avenues to fill these knowledge gaps in the future.
Background	There is a broad literature on various mountain resilience topics which have been published in scientific outlets over the last 20 years. Up to know, a systematic review of the literature is missing, leading to a situation in which there is no clear overview of what has already been achieved, and in what aspects / sub-topics additional research is required.
Stakeholder engagement	Researchers have been integrated all along the review process in defining key-words, refining search strategies and identifying future research avenues. Besides this, an exchange with the Mountain research initiative (MRI) has been held along the review process in order to reach out to the broader community and also integrate insights from practice actors outside academia, specifically policy actors and international conservation specialists.
Objective	The primary research objective is to identify key topical areas of the mountain resilience literature (including aspects such as geographical areas, research traditions, etc.) and derive areas of research which so far have not drawn the required attention.
Search strategy	The search has been executed on the SCOPUS data base, including only English-speaking titles which have been published in peer-reviewed scientific journals. The search sting has always started with Mountain AND Resilience, followed by an additional term of interest (such as e.g. tourism, disaster, economy, etc.).
Search string	The search has been executed on the SCOPUS data base, including only English speaking titles which have been published in peer-reviewed scientific journals. The search sting has always started with Mountain AND Resilience, followed by an additional term of interest such as e.g. tourism, disaster, economy, etc. In order to restrict the search to those titles which have thoroughly dealt with the issues and which have themselves reported to be related to mountain resilience, only titles, key-words and abstracts have been considered for the review.
Languages – bibliographic databases	The review has been restricted to articles written in English.
Languages – grey literature	The grey literature has not been taken into account in the review.
Bibliographic databases	The review was based on the SCOPUS database, the largest database for peer-reviewed literature in the world (https://www.elsevier.com/en-gb/solutions/scopus)

Web – based search engines	No search engine outside SCOPUS has been used for the systematic review part of the paper. Google Scholar has been used for some of the preliminary searches in the preparation of the article, and WebofScience has been used to verify some of the findings.
Organisational websites	No organisation websites have been searched.
Estimating the comprehensiveness of the search	In a first step, the comprehensiveness of the search-strategies was assessed within the group of authors, with several rounds of critique leading to a improvement of the overall search strategy. After the quantitative search has been conducted, a core-group from within the list of actors worked on further refining some of the specific search results from within the individual topic areas.
Search update	The search has been iterated various times along the review process, leading to an update of the numbers of articles feeding into the review. The search has been performed within one year from starting to submitting the paper.
Screening strategy	Articles have been screened within SCOPUS, based on their character as articles which have appeared in the peer-reviewed literature in English language. All the articles that complied with these characteristics have been included in the review.
Consistency checking	All titles and abstracts are subject to a quantitative content analysis in MAXQDA, which includes checking for consistency with the overall goal of the review, as well as compliance with the content aspects of the individual subsections.
Inclusion criteria	An overall search of all articles dealing with the issue of MOUNTAIN AND RESILIENCE has been conducted as a first step. Based on these first results (which are also given in the paper), relevant subtopics / subject(s) have been identified. While a first quantitative search was conducted in the same way for all subtopics / subsections, the main topics within the sections were derived in a qualitative way (including the pre-disposable knowledge of experts in their fields) by a limited number of authors (mostly 2-3), the results of which were then double-checked by the rest of the authors under coordination of the four lead-authors.
Reasons for exclusion	Reasons for exclusion were restricted to language (only English) and publication channel (only peer-reviewed journal articles listed in SCOPUS).
Critical appraisal strategy	Within the study, an in-depth assessment of every paper was not feasible. All articles included in the paper were scanned though, and the quality of the paper had an influence on how it has been reviewed in the qualitative part of the study. For the quantitative text analysis, all texts were treated equally to avoid biases, assuming that papers which had past the original hurdle of being published in a peer-reviews journal dispose of a certain minimal quality level in terms of scientific feasibility and validity.
Critical appraisal used in synthesis	Describe how the information from critical appraisal will be used in synthesis. The critical appraisal of the co-authors were integrated in the study, mainly in the qualitative part and more specifically in section 4 and 5, which discuss the results achieved and show future research paths to new fields of application of the resilience concept in mountain areas.
Consistency checking	All information regarding the articles included in the study, as well as the criteria upon which they have been assessed are clearly stated in the article and the appendix that comes along with it. Researchers therefore dispose of all the necessary information to replicate the study in the future.
Meta-data extraction and coding strategy	All articles were screened automatically using MaxQDA. Specific importance was laid upon the country where the article was published, the mountain ranges within and upon which the study was conducted, as well as the main topics which were treated in the article. A qualitative content analysis based on manual content coding has not been conducted within the scope of the study.
Data extraction strategy	Main information regarding the country of origin, the mountain ranges treated and the main topics have been extracted using the automated search mechanism of the MaxQDA software.

Approaches to missing data	In general, on a meta-level (regarding the number of publications, the key-words and the abstract content), no missing data was detected. When looking into the specific papers, some (minor) information was not available and had to be complemented, i.e. by a sort of approximation using the data from other sources and/or papers. In general, the problem was not virulent in our study since we were not looking for specific means, for example, but were more interested in general topics and the properties of the papers overall (for example with respect to the topics that are treated, and the methods that are applied).
Consistency checking	The repeatability of the meta-data/data extraction was tested throughout the writing process and several sub-samples were extracted at different moments in time. Overall, the data can be retrieved again whenever chosen from the scopus.com homepage.
Potential effect modifiers/reasons for heterogeneity	We thoroughly considered the presence or absence of effect modifiers that would affect the relation of an exposure with the expected results. We developed a list by consulting experts from within and outside our co-author group, as well as by relating to comparable systematic literature reviews. As examples, we checked for publication bias, language bias, availability bias, cost bias, duplication bias, familiarity bias, and citation bias.
Type of synthesis	A combination of narrative, qualitative and quantitative synthesis have been applied in the study. Narrative synthesis were restricted to the individual subsections, whereas a quantitative synthesis has been applied in a systematic manner across the whole paper, and qualitative methods were applied where it was reasonable due to the large size of the overall sample.
Narrative synthesis strategy	We use descriptive statistics to narratively synthesising the evidence base, i.e. the total numbers and relation of articles lists in the SCOPUS database with those matching the different key word searches. We include some tables and flow diagrams to ease visual access to the narratives. We summarize coding results from the automated qualitative content analysis by MAXQDA in absolute and relative numbers.
Quantitative synthesis strategy	No such method has been applied in the scope of the current study.
Qualitative synthesis strategy	The keyword searches on SCOPUS lead to the identification of published peer-reviewed papers on the different sub-fields of Mountain and Resilience topics. The abstracts of these papers were analysed by automated qualitative content analysis with MAXQDA, and then the type, diversity, absolute and relative numbers of codings were orally summarized. In addition, a functional explanation of what these frequencies mean, and how single key words from the automated codings relate with contextual understanding of the paper the abstract was taken from, was added.
Other synthesis strategies	For the paper it has been central to start off with a quantitative review of the literature in a systematic way. Based on this systematic review, the co-authors were asked to look into the quantitative results from their point of view as experts in the field. Based on this appraisal, a review of the search terms as well as the discussion/conclusion were developed. This allowed on the one hand to build the review on the actually published scientific literature and the topics which have been dealt with there, while tying in the knowledge of experts in the subfields. In order to work against biases (and be aware of the biases which occur nevertheless), all choices were discussed in the group of lead-authors over all sections, and within the section contributors on the level of the individual sections.
Assessment of risk of publication bias	Publication bias in the field that we review is not as dominant as in other fields, since most studies are qualitative in nature and deal with both the positive and negative aspects of resilience, both on people, and the environment. Nevertheless, we are aware of the fact that certain topics have a longer tradition within the resilience research community and certain application fields are more prestigious than others, which naturally leads to certain topics being underrepresented. We actively address this problem in section 5 of the paper.

Knowledge gap identification strategy	The main approach was to start off with the key-word based quantitative study, in order to identify areas of interest which were very generally underrepresented in the literature (in comparison to what one would expect). After the key-word based search of the SCOPUS literature base and the quantitative text-analysis of the abstracts (of the articles which have been chosen), a general appraisal of the topics which have gained appraisal in the literature has been compared to what the team of experts which have written the paper would have expected in section 4, and future avenues to balance the representation of different topics has been thematized in section 5.
Demonstrating procedural independence	Within the field of mountain resilience, none of the authors have been part of another, conflicting or concurrent publication. Where conflicts arose of how to proceed and what topics to integrate, issues were first discussed and coordinated between the lead-authors and the individuals involved. If questions could not be solved on this level, the discussion was broadened and the topic addressed in one of the meetings with all the authors of the paper (as e.g. the case for the topic of community resilience).
Competing interests	The lead-authors declare not competing interests. Competing interests of other members of the author team are not known to the group of lead-authors.

Note: Form retrieved from Haddaway et al (2017).

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