ADAPTATION TO CLIMATE CHANGE IN THE ANDES:

Gaps in understanding and opportunities for knowledge management

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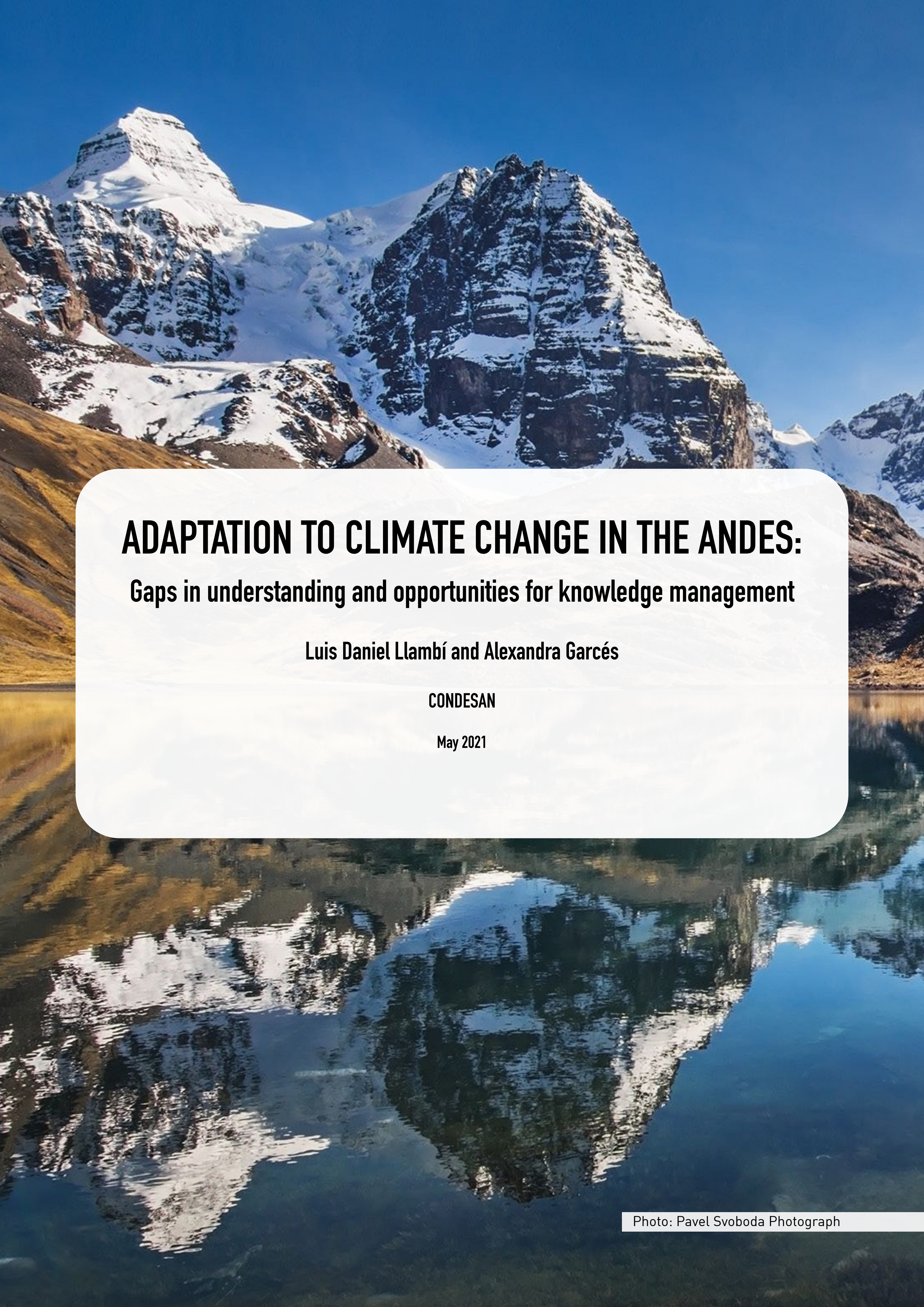

ADAPTATION TO CLIMATE CHANGE IN THE ANDES:

Gaps in understanding and opportunities for knowledge management

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CONDESAN

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Acronyms & Abbreviations

A@A	Adaptation at Altitude
AICCA	Adaptation to the Impacts of Climate Change on Water Resources in the Andes
ACP	African, Caribbean and Pacific Countries
AvHI	Alexander von Humboldt Institute
CAN	Andean Community
CBD	Convention on Biological Diversity
CBI	Caribbean Basin Initiative
CC	Climate change
CCA	Climate change adaptation
CELAC	Community of Latin American and Caribbean States
CIAT	International Center for Tropical Agriculture
CONDESAN	Consortium for the Sustainable Development of the Andean Ecoregion
COPs	Conferences of the Parties
EbA	Ecosystem-based Adaptations
ECLAC	Economic Commission for Latin America and the Caribbean
EMA	Strategy for Integrated Monitoring of Colombia's High Mountain Ecosystems
FAO	United Nations Food and Agriculture Organization
FONAG	Fund for Protection of Water
GAN	Global Adaptation Network
GLOCHAMORE	Global Change in Mountain Regions Research Strategy
IAI	Inter-American Institute for Global Change Research
IAM	Andean Mountain Initiative
ICRAF	International Centre for Agroforestry Research
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies
IMHEA	Hydrological Monitoring Initiative for Andean Ecosystems
INAP	Colombia's Integrated National Adaptation Programme
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
MA	Millennium Ecosystem Assessment
MIREN	Mountain Invasions Research Network
MRI	Mountain Research Initiative
NAPs	National Adaptation Plans
NbS	Nature-based Solutions
NDCs	Nationally Determined Contributions
NGOs	Non-governmental Organizations
OAS	Organization of American States

PACC	Peru's Climate Change Adaptation Programme
PBA	Andean Forests Programme
PIACC	Ibero-American Climate Change Adaptation Programme
PRAA	Project for Adaptation to the Impact of Rapid Glacial Retreat in the Tropical Andes
REDD	Reducing emissions from deforestation and forest degradation
REDD+	Reducing emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks
RIOCC	Ibero-American Network of Climate Change Offices
RISK-MACC	Directorate for Risk Management and Adaptation to Climate Change
SCOPE	Scientific Committee on Problems of the Environment
SDC	Swiss Agency for Development and Cooperation
SDGs	United Nations Sustainable Development Goals
SGCAN	General Secretariat of the Andean Community
UNASUR	Union of South American Nations
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WASP	World Adaptation Science Programme

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Acknowledgements

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Executive Summary

Climate change adaptation (CCA) has become a priority issue on the scientific and management agenda around the relationship between sustainable development and climate change (CC), both globally and in the Andes. However, this is a very broad topic and there is no updated analysis of the knowledge needs regarding CCA in the Andes, which would allow the identification of priority areas of work to face the most urgent challenges imposed by global environmental change. Thus, CONDESAN—within the framework of the A@A and the PBA (financed by the SDC)—proposed to carry out an analysis of the knowledge gaps and work priorities regarding CCA in the And es, as an input to guide knowledge management efforts in this area, and as a contribution to guide decision-making processes, as well as programmes for the implementation of adaptation measures in the region.

The analysis was based on a comprehensive review of the scientific literature, previous analyses of knowledge gaps and research agendas available globally and in the Andes, and a consultation process with more than 40 experts and decision-makers (with an emphasis on stakeholders linked to the IAM). The document first presents a review of the policy and conceptual framework in relation to CCA, including a review of the evolution of the issue globally and in the Andes. This is followed by a synthesis of the state of knowledge and gaps identified around: (1) the knowledge base on CC, vulnerability and impacts on Andean socioecosystems; and, (2) knowledge gaps for the design and implementation of adaptation strategies and policies. Given the wide range of issues related to this topic, we subdivided the analysis into the following areas of work: public policies and institutional framework; water resources and glaciers; ecosystem-based adaptation; production systems; socio-economic, cultural and health aspects; and other sectors (energy, industry, infrastructure).

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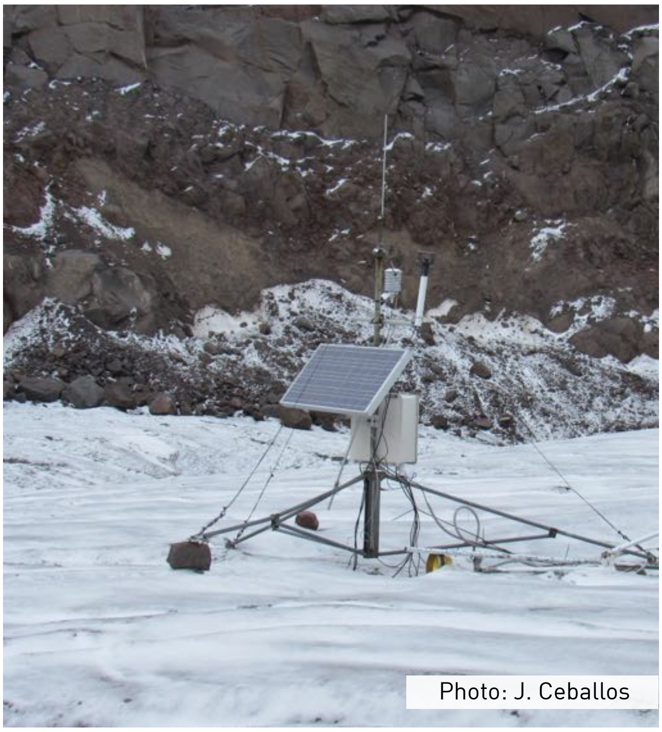

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The results of the study showed a great deal of overlap between the analysis derived from the literature review and the views of the experts and decision-makers consulted. There is broad agreement that, despite significant advances in the last decade, important gaps remain in our knowledge base of spatial-temporal climate patterns and the ecological and social impacts of CC in the Andes. Another key gap emphasised has to do with the need for agreed tools and experiences of systematic monitoring and evaluation of CCA strategies implemented in the region. From a thematic point of view, the need to promote a more holistic or multi-sectoral vision of adaptation strategies was identified, in particular around synergies and contradictions in water resource management, Andean production systems and ecosystem-based adaptations (EbAs). Also, the need for an integrated analysis and comparative synthesis of the impacts on ecosystem functioning and services of different land use, restoration and ecosystem management strategies in the Andes in CC scenarios was emphasised. At the same time, although there is growing recognition of the value of local traditional practices as CCA strategies, there is a need to analyse how these Andean knowledge systems contribute to reducing the vulnerability of communities, especially the poorest or most isolated ones, and how governance contexts at different scales influence social participation, effective adoption and the success of adaptation processes. Finally, there is a need to continue promoting a more effective dialogue between science and policy in the region, so as to ensure that adaptation strategies respond more explicitly to the available scientific evidence on the impact of CC on Andean socioecosystems and their resilience to environmental change scenarios.

Introduction

CCA has become, especially in the last decade, a priority issue in the scientific, policy and management agenda around the relationship between sustainable development and CC globally and in the Andes of South America (Schoolmeester et al. 2016, Klein et al. 2017, Global Commission on Adaptation, 2019). However, there are few initiatives focused on identifying knowledge needs around adaptation, especially at the regional and sub-regional levels (Chatterjee et al. 2014). In turn, CCA is thematically very broad, being a cross-cutting approach that touches on a very large diversity of aspects, from disaster engineering and risk management, climate-smart agriculture to EbA. Thus, it is necessary to identify priority areas of work to focus efforts on an agenda that is viable and that will make it possible to face the most urgent challenges posed by CC in the region. Recognizing this reality, CONDESAN has proposed to conduct an analysis of the gaps in knowledge and work priorities related to CCA in the Andes, as a key input to guide synthesis and knowledge management efforts in this area, and as a contribution to guide the definition of priorities for decision-making processes and policies in the Andean region, as well as programs and actions for the implementation of CCA measures in the region.

This exercise is part of the A@A Programme: taking action in the mountains, in partnership with the SDC. The programme´s global objective is to "increase knowledge on climate change and appropriate adaptation solutions in mountains as inputs for informed decision making by policy dialogue platforms at national, regional and global levels, with the aim of increasing the resilience of mountain ecosystem communities to climate change".

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CONDESAN is the agency responsible for the implementation of Outcome 2 of this programme for the Andes region, which proposes that "adaptation to mountain climate change is integrated into the planning and policy processes of regional bodies / frameworks / platforms / initiatives as a result of the strengthening of science-policy dialogue platforms". In turn, this analysis of knowledge gaps and priorities is carried out in association with the PBA (in its 2nd Phase), financed by the SDC, and whose general objective is to "contribute to improve adaptation and mitigation capacities in the face of climate change through the consolidation and scaling up of successful practical policies, tools and incentives in the Andes relevant to the sustainable management of Andean forests".

The objective of this document is to identify the main knowledge gaps on the different aspects related to CCA in the region, including the analysis of the impacts of CC on Andean ecosystems and societies, as well as knowledge management to guide strategies for the implementation of CCA measures. To meet this objective, we propose to integrate an overview derived from the review of the literature and research agendas available on the subject at the global and Andean levels, the experience accumulated by CONDESAN and other institutions in the region on CCA, and the vision of key actors in the Andes, including decision makers, experts on the subject, and stakeholders involved in the implementation of adaptation projects and solutions.

The document is structured as follows. First, we present the methodology used to identify gaps and priority knowledge issues related to CCA in the Andes. Secondly, a review of the general political and conceptual framework related to CCA is presented, including a brief review of the evolution of this issue in the framework of international CC policies and strategies, as well as the main concepts involved and general guiding principles to be taken into account. Third, a synthesis of the state of knowledge and the gaps and priority issues identified from the review of the available literature and the vision of the actors consulted is presented, organized around: (1) Knowledge base on CC, vulnerability and impacts on Andean socioecosystems; and (2) Knowledge for the identification, design and implementation of CCA policies and strategies. Given the wide range of issues linked to the implementation of CCA strategies, we subdivide this section into the following thematic areas: public policies and institutional framework; water resources and glaciers; EbA (biodiversity and ecosystem services); productive systems (agriculture and livestock); socioeconomic, cultural and health aspects; and, other sectors (energy, industry, infrastructure). Finally, we present conclusions and recommendations, emphasising the main knowledge management products that could be developed in light of the knowledge gaps and work priorities identified.

Methods

The focus of this exercise is the identification of knowledge gaps understood as gaps in our understanding of the impacts, exposure and vulnerability of socioecosystems to CC, as well as limitations or barriers to the implementation and adoption of effective adaptation strategies or solutions (see Klein et al. 2014, Hofstede 2019). In this context, we start from the knowledge gaps perspective of the first United Nations Environment Programme (UNEP) Adaptation Gaps report (Chatterjee et al. 2014) that proposes three types of knowledge gaps: (1) gaps in the current knowledge base, (2) lack of integration of different knowledge areas, and (3) limited transfer and adoption of this knowledge to key stakeholders including decision makers.

Furthermore, from the gaps in knowledge identified, we propose to analyse those that can be considered a priority in the context of the region, in terms of the urgency of addressing the main vulnerabilities of Andean ecosystems and societies. At the same time, we consider as an additional criterion to establish these priority issues, the thematic agenda defined in the space of interrelationships between ecosystems and their diversity, Andean societies, their productive systems/landscapes and livelihood strategies, and ecosystem services, as work space more directly related to the scope of action of the A@A Programme and to the mission and institutional experience of CONDESAN and its partners in the region. Thus, in this exercise we integrated multiple sources of information, following these steps:

2.1. Definition of the general conceptual and policy framework

First, we reviewed the evolution of available conceptual frameworks and views on CCA, taking as a starting point the approaches of different agencies and international agreements related to this topic: the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC), the Caribbean Basin Initiative (CBD), the United Nations Development Programme (UNPD), the United Nations Environment Programme (UNEP), the International Union for Conservation of Nature (IUCN), and the World Bank; as well as conceptual reviews on the subject, especially the syntheses of research priorities on adaptation derived from meetings and interviews with experts and researchers from Adaptation Futures (Klein et al. 2017) and the World Adaptation Science Programme (WASP, Hofstede 2019).

2.2. Review of the Andean adaptation policy framework

The key issues identified by the Action Plan for the Sustainable Development of the Andean Mountains (Plan de Tucumán, 2007) and the Strategic Agenda on Climate Change Adaptation in the Andes Mountains (2018) were analysed, as well as the key antecedents of regional work and integration around CC promoted in spaces such as the Andean Community (CAN – See reviews in Bustamante et al. 2012, Maldonado et al. 2012, Schoolmeester et al. 2016, Bárcena et al. 2020).

2.3. Review of the state of knowledge in the Andes

In order to have an overview of the state of knowledge on CC and adaptation in the Andes, comprehensive publications and meta-analyses available on the subject were reviewed, including those generated by Scientific Committee on Problems of the Environment (SCOPE) and the Inter-American Institute for Global Change Research (Herzog et al. 2011), CONDESAN in the framework of the Andean Panorama on Climate Change initiative (Cuesta et al. 2012), the IPCC in the framework of the 5th Status and Trends Report for South and Central America (Magrin et al. 2014), the UNEP in the framework of the Mountain Adaptation Outlook Series (Schoolmeester et al. 2016), and the Economic Commission for Latin America and the Caribbean (CELAC) in its analysis of CC impacts and adaptation strategies in Latin America and the Caribbean (Bárcena et al. 2020), among others. In turn, recent key publications were reviewed in order to have more updated information on some topics where important advances in knowledge have been generated in the last ten years (e.g., climate and glacier dynamics, monitoring of vegetation response to CC in the framework of the GLORIA-Andes Network and Andean Forest Network, etc.).

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2.4. Review of research agendas and gap analysis

We reviewed proposals for research agendas on global change in mountains generated under the Global Change in Mountain Regions Research Strategy programme (GLOCHAMORE 2005), the Perth Conference series convened by the Mountain Research Initiative (MRI) and other institutions (Gleeson et al. 2016), and the work plan of the GEO-GNOME global monitoring network (Adler et al. 2018). In turn, we reviewed the research agendas generated by the PBA (Mathez-Stiefel et al. 2017), the Alexander von Humboldt Institute's (AvHI) High Mountain Research Agenda (Avella 2019) and the Proposal for the Integrated Monitoring of Colombia's High Mountain Ecosystems (IDEAM et al. 2018, Llambí et al. 2019). Finally, the knowledge gap analysis for adaptation in the Andes promoted by the Global Adaptation Network (GAN, Becerra 2015) constituted a key input, being based on a broad consultation process with decision makers and experts in the region (see also Huggel et al. 2015 and Bárcena et al. 2020).

2.5. Analysis of flagship projects in the Andes

We carried out a first analysis of the priority thematic areas of work, generated the main knowledge synthesis products, and examined the lessons learned from projects in recent years related to CCA in the Andes that were conducted by CONDESAN and other institutions—e.g., PBA, EcoAndes, Project for the Adaptation to the Impacts of Climate Change on Water Resources in the Andes (AICCA), Andean Paramo Project, Paramo Communities Project, etc. Some key reviews in this regard are those conducted by Bustamante et al. (2012), Magrin et al. (2014), Huggel et al. (2015), Schoolmeester et al. (2016), Becerra (2017) and Bárcena et al. (2020).

2.6. Stakeholder consultation

Finally, to explore the vision on the thematic priorities and knowledge gaps on CCA of decision makers, experts on the subject and actors involved in the implementation of adaptation actions in the region, we conducted an online survey and open interviews (see Appendix 2). The online survey was disseminated to a group of 100 people and a total of 44 responses were received; of which, 25 corresponded to researchers, 11 implementers of Adaptation Projects, and 8 decision makers in the area of CC in the Andes (see Appendix 1). The survey was divided into four sections, the first and second focused on specific data of the interviewees and their work topics, the third section focused on the identification of knowledge gaps and priority topics for intervention in the Andes, and the fourth section aimed at gathering information on relevant CCA projects. In this document we focus on the responses obtained from section three, linked to the identification of knowledge gaps on CC impacts and response actions focused on CCA.

Below we present the questions analysed and the sequence we have followed for the presentation of the results.

A. Questions about knowledge gaps on the impacts of climate change on different topics:

"In your opinion, what are the main gaps or knowledge gaps in each of the following topics around climate change?"

- Research/scientific evidence on the impacts of climate change in the Andes.
- Vulnerability of socioecosystems in the Andes
- Adaptation of Andean production and livestock systems
- Ecosystem-based adaptation

B. Questions about knowledge gaps for action around climate change adaptation:

- Main gaps in the knowledge basis for the implementation of adaptation projects.
- Priority issues to work on in the implementation of adaptation solutions.
- Priorities for investment of human and financial resources in adaptation.
- Tools or methodologies in terms of their priority for the implementation of climate change adaptation projects in the Andes.

Conceptual and Policy Framework

Evolution of the policy framework related to CCA

Since its signature in 1992 and ratification in 1994, the UNFCCC recognizes the need to generate strategies not only to mitigate CC, but also to respond to its effects through the implementation of adaptation measures. However, in the policy framework of the UNFCCC and other international bodies, an evolutionary process can be observed that emphasises the importance of analysing the impacts of CC, analysing the resulting risks and vulnerabilities, and promoting and evaluating practical adaptation solutions (Bustamante et al. 2012, Magrin et al. 2014, Chong 2014, Huggel et al. 2015, Klein et al. 2017). We can observe this evolution in the emphases and approaches in the work of the UNFCCC and the Conferences of the Parties (COPs, see Maldonado et al. 2012, and www.unfccc.int). Below we list the main decisions that reflect the evolutionary process of the policy framework related to adaptation to CC:

- Impact observation, risk and vulnerability assessment, mitigation and emission reduction (COP2 Geneva 1996, National Communications on Climate Change, COP3, Kyoto Protocol, agreements on emission mitigation and Clean Development Mechanisms).

- Adaptation strategy planning and pilot implementation. Link between adaptation and the development context of countries (COP7 Marrakesh 2001).

- Synthesis of knowledge and first lessons learned on adaptation (COP11 2005, Nairobi Work Program).

- Emphasis on implementation and scaling up of adaptation and mitigation measures. Incentives and policies for reducing emissions from deforestation and forest degradation in developing countries, and REDD and REDD+ programs (COP13 2007, Bali Action Plan).

- Strengthening of the institutional framework for adaptation (COP16, Cancun Adaptation Framework and 2015 Paris Agreement, promotion of National Adaptation Plans – NAPs).

This same process is reflected in the evolution of research and knowledge generation around CC and adaptation, which Klein et al. (2017) divide into four stages:

- **Descriptive stage:** Focused on the measurement and characterization of CC impacts (First and Second IPCC Reports and National Communications).

- **Normative stage:** focused on the need to articulate adaptation strategies, including the formulation of NAPs. From the 3rd IPCC Report onwards, adaptation began to be emphasised as a central axis of work. Key concepts in the context of adaptation to CC such as vulnerability, adaptive capacity and resilience are defined (e.g., Smith et al. 1999).

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• **Governance stage:** Characterized by addressing adaptation at the same level of priority as mitigation. Emphasis on water issues, agricultural production and on the analysis of governance, financing and evaluation of the transparency of adaptation (e.g., Adaptation Watch 2015). Work on estimating the costs of adaptation promoted by institutions such as the World Bank (e.g., World Bank 2010).

• **Implementation stage:** Determined by the inclusion of adaptation measures in the Nationally Determined Contributions (NDCs). The 5th IPCC Report (2014) defines a more comprehensive conceptual framework for the analysis and implementation of adaptation, its incorporation into national planning and transformation towards sustainable development. Information on the effectiveness of implementing adaptation solutions is still limited, but there is increasing emphasis on approaches and data for evaluation at local, regional and global levels.

Key concepts

One of the key advances during this evolutionary process has been the definition of a conceptual framework* that defines the "risks" associated with the impact of CC, understood as the result of the combination of "climate hazards", which correspond to damaging or dangerous events and trends such as sustained increases in extreme temperatures, droughts, floods, etc.

This conceptual framework emphasizes the relationship between the risks to which both ecosystems and human societies are exposed and the adaptation responses to these risks, and recognizes climate hazards as the result of the natural spatiotemporal variability of climate systems and anthropogenic alterations that enhance climate impacts.

The impacts resulting from climate hazards and the level of risk are determined by the degree of exposure and vulnerability of environmental and social systems. Interestingly, however, given the difficulty of documenting these impacts and attributing them to CC, in many cases (e.g., in Peru, Ecuador or Colombia), climate risk is interpreted as a combination of climate hazards, exposure and vulnerability, without directly considering the resulting impacts.

In this framework, adaptation measures should be aimed at reducing the exposure and vulnerability of environmental and social systems, with the objectives of (1) reducing the risk of negative impacts, (2) improving the adaptive capacity of socio-environmental systems, and (3) generating co-benefits of adaptation and mitigation (IPCC 2014, Bárcena et al. 2020, see Figure 1). For example, restoration of high mountain wetlands can reduce the vulnerability of high-altitude livestock systems to droughts and at the same time reduce or prevent greenhouse gas emissions from the degradation of wetland organic soils.

** PCC (2014) is the most widely used conceptual framework at global level.*

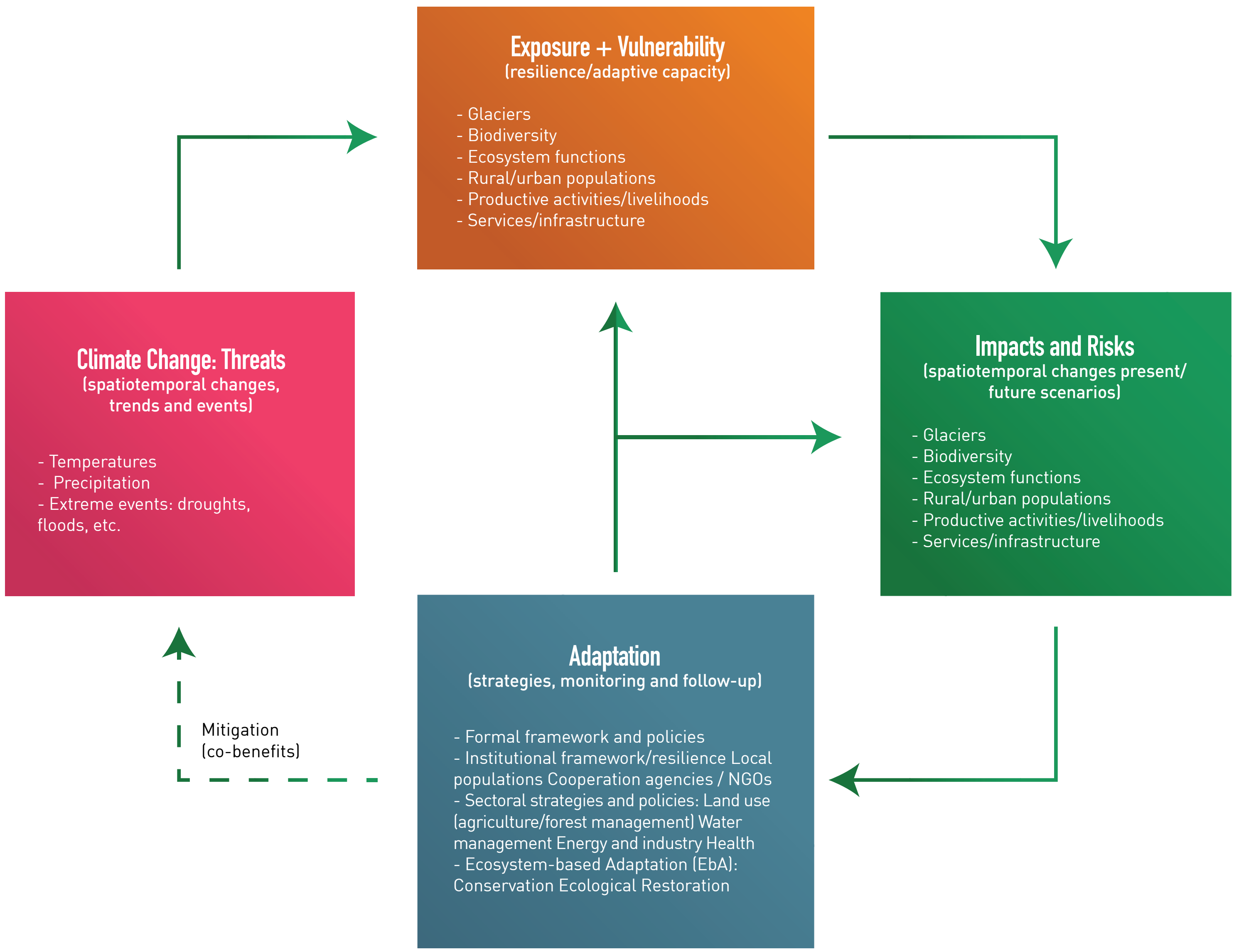

Figure 1. Main concepts associated with CCA. Theoretical relationships between the hazards generated by CC, the vulnerability/exposure of socio-environmental systems, the resulting impacts/risks and the different adaptation measures.

Table 1 presents some of the key concepts related to CCA, which are fundamental for evaluating the current status of knowledge on this subject.

Table 1. Some key concepts and their definitions in the context of CCA literature (adapted from IPCC 2014, Bárcena et al. 2020).

Adaptation	The process of adjusting to the current or expected climate and its effects by reducing the exposure and vulnerability of environmental and social systems. In human systems, adaptation seeks to moderate or avoid impacts and take advantage of opportunities. In some natural systems, human intervention can enhance their resistance or resilience to CC and its impacts.
Threat	Weather-related physical events or trends that may cause injury, death or other health effects as well as damage and loss of property, infrastructure, livelihoods, provision of ecosystem services or natural resources.
Exposure	Presence of people, productive systems, social/cultural capital, infrastructure, species or ecosystems and their services in places or contexts where they may be affected by CC.
Vulnerability	Proneness or predisposition of an environmental or social system to be adversely affected by CC. Vulnerability involves a number of concepts including sensitivity and susceptibility to damage and lack of resistance, resilience and adaptive capacity.
Impact	Effects of extreme events and CC trends on natural or human systems. Impacts are the result of the interaction of the hazards produced by adverse climate events or trends in a given time period and the vulnerability and exposure of the system to these hazards.
Risk	Risks are the combination of the probability of occurrence of hazards and their potential impacts. Risk is usually represented as the probability of occurrence of hazards (events or trends) multiplied by their negative impact. In the context of adaptation monitoring, it can also be defined as the product of climate hazards, exposure and vulnerability.
Resilience	Capacity of a social, economic or environmental system to cope with adverse climatic shocks, events or trends, responding or reorganizing itself in such a way as to maintain its identity, structure and functioning and the capacity to adapt, learn and transform.
Transformation	A change in the fundamental attributes of environmental and social systems. In the context of CCA, transformation reflects the strengthening and alignment of societal paradigms, goals and values toward promoting adaptation to promote sustainable development, emphasising the reduction of poverty and vulnerability.

Adaptation strategy design

The definition of adaptation measures and strategies is based on an adaptive management approach, understood as a cyclical learning process that generally involves (see Figure 2):

- **Definition of goals:** common objectives, assessment of vulnerabilities and risks.

- **Definition of options:** alternative solutions and adjustments to the institutional and organisational policy framework.

- **Implementation of the adaptation strategy:** including monitoring and evaluation, learning and revision of objectives.

For the application of an adaptive management approach in the context of CC, there are two main approaches: (1) top-down, based on the generation of broad CC and vulnerability scenarios as a basis for planning; and, (2) bottom-up, based on generally participatory analyses of vulnerability and adaptive capacity at the local level. However, several authors have emphasised the need for further integration of both approaches (Bhave et al. 2014, Huggel et al. 2015).

In this context, an interesting alternative is "adaptive co-management", in which the integration of local stakeholders, decision-makers and researchers is promoted for the implementation and monitoring of CCA measures and strategies through the adaptive management cycle, but focusing on collective knowledge management and construction (Olsson et al. 2004, Ariza et al. 2017).

Effective information management is the basis of the learning cycle that adaptation requires, so that the process itself contributes to filling critical knowledge gaps. For example, the need to start from agreements on adaptation objectives that harmonise the risk visions/perceptions of local stakeholders, technicians/researchers and decision-makers is repeatedly pointed out in CCA projects (Huggel et al. 2015, Ariza et al. 2017). From this point of view, the very definition of effectiveness or success of adaptation, in terms of its impact on the adaptive capacity and resilience of socio-environmental systems, is an aspect that raises important unresolved methodological challenges (Seddon et al. 2016, Dilling et al. 2019): Whose adaptation? To which risk factors? Who defines success? In which time frame?

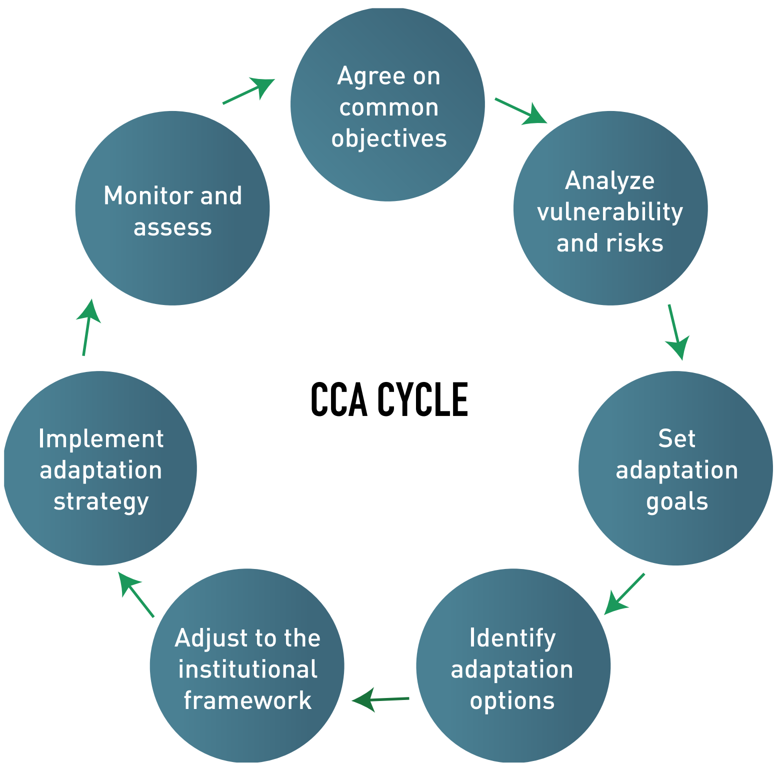

Figure 2. The CCA cycle under the adaptive management approach (adapted from Bustamante et al. 2012, IPCC 2014)

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In terms of defining targets, the 2015 Paris Agreement explicitly set the goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to CC, so as to contribute to sustainable development and ensure an adequate adaptive response in the context of mitigation goals".

In the same vein, UNEP has been producing a series of Adaptation Gap Reports that emphasise the need to establish integrated indicators and metrics, as well as procedures and methodologies to assess the achievement of adaptation goals in local, regional and national projects, and to report on global progress (UNEP 2014, 2017; Hofstede 2019). In this context, this UNEP approach proposes the development of five-yearly assessments, starting in 2023, to report on adaptation progress through the so-called "global stocktake", a component of the Paris Agreement focused on monitoring its implementation and evaluating collective progress towards the agreed achievements. In turn, more than forty countries worldwide are beginning to define concrete adaptation targets and implement or design national programmes to monitor and evaluate the progress and achievements of NAPs (e.g., Colombia and Chile, as it appears in UNEP 2017, Bárcena et al. 2020).

The design of adaptation strategies is conceptualised in the growing recognition of the close links between vulnerability, adaptive capacity in the face of CC, economic development, poverty and exclusion (e.g., gender considerations, indigenous populations), issues that receive particular attention in the 2015 Paris Agreement and that have been particularly emphasised by the UNPD and the World Bank at the global level (e.g., UNPD 2015, World Bank 2017) and by ECLAC, in the case of Latin America (Bárcena et al. 2020). Indeed, the IPCC (2014) emphasises the need to move from vulnerability and exposure reduction strategies towards more ambitious goals of transforming societies and identifying "climate resilient trajectories" for sustainable development.

In the context of the United Nations Sustainable Development Goals (SDGs), the need to focus adaptation efforts on the most vulnerable social groups through actions aimed at strengthening resilience, reducing vulnerability and increasing the adaptive capacity of the poorest social groups in the face of CC and extreme events is recognised (targets 1.5 and 13.1, Wymann et al. 2018). This has been associated with a strong emphasis on the development and conceptualisation of the "community-based adaptation" approach, which builds on the growing evidence accumulated from the greater effectiveness of adaptation strategies that explicitly involve local populations, traditional knowledge and adaptive capacities of social groups—such as women or indigenous communities—from the early stages (Reid 2016, Ariza et al. 2017, Hofstede 2019). For example, the comparative study by Striessnig et al. (2013) shows


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that, of a range of adaptation strategies, training women in the community was the most effective in terms of reducing vulnerability to disasters.

On the other hand, the key role of ecosystems and nature in the adaptive capacity of societies has been conceptualised in "nature-based solutions" (NbS), understood as actions inspired by nature that help address societal challenges in effective and adaptive ways (Cohen-Shacham et al. 2016, Seddon et al. 2020). NbS is an umbrella concept that encompasses several approaches related to ecosystem management in the context of CC, including ecosystem-based adaptation (EbA), ecosystem-based mitigation, ecological disaster risk reduction and green infrastructure (Cohen-Shacham et al. 2016, Seddon et al. 2020). The application of NbSs includes three categories of actions which include the protection, sustainable management and restoration of natural or modified ecosystems (Cohen-Shacham et al. 2016), which are based on characteristics, processes and services provided by natural systems that contribute to disaster risk reduction and increase human and biodiversity well-being (European Commission 2015).

Within this framework, EbA takes as its starting point the concept of ecosystem services, which describes the relationship between natural systems and human well-being (Chong 2014). This approach received a huge boost in terms of empirical documentation and support on the policy agenda with the Millennium Ecosystem Assessment (MA 2005), which categorised services into three broad groups: (1) resource supply (water, wood, fibre, food); (2) regulating services (climate, flood control, etc.), sustaining services (soils, photosynthesis, nutrient cycling, pollination, etc.); and, (3) cultural services (recreation, spiritual values, etc.).

The Convention on Biological Diversity (CBD 2009) defines the EbA to adaptation as: "the use of biodiversity and ecosystem services... to support societies to adapt to the adverse effects of climate change... and may include sustainable management, conservation and restoration of ecosystems as part of an integrated adaptation strategy, which takes into account the multiple social, economic and cultural co-benefits for local communities".

EbA has become a pivotal issue in integrating the SDGs with the objectives of the CBD and those of the United Nations Convention to Combat Desertification (UNCCD). The EbA approach is considered a priority in Latin American countries given the importance of ecosystem integrity for rural and indigenous populations that depend on it (Bárcena et al 2020). EbA has been an approach particularly widely applied by international cooperation through agencies and initiatives such as UNEP, UNPD, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services—IPBES—and IUCN (e.g., Hole et al. 2011, UNPD 2015, Seddon et al. 2016, IPBES 2019), which have advanced the implementation of EbA in multiple projects benefiting poor rural communities in developing countries (Figure 3, Chong 2014).

Over the last few years there has been considerable progress in research and application of EbA, especially in coastal and mountain ecosystems, including in the Andes (Hole et al. 2011, UNPD 2015, Almeida 2015, Becerra 2017, Cerrón et al. 2017). There are several syntheses of lessons learned, best practices for scaling up and replication, as well as co-benefits for mitigation, such as those conducted in the context of REDD+ forest management or ecosystem restoration projects (Magrin et al. 2014, Seddon et al. 2016, Hofstede 2019). These syntheses highlight how one of the main limitations of the EbA approach relate to the extended timeframe in which many EbA strategies effectively modify ecosystem functioning and services, the complexity involved in monitoring the effectiveness and impacts of measures, as well as in documenting their effectiveness in terms of costs vs. benefits (Seldon et al. 2016).

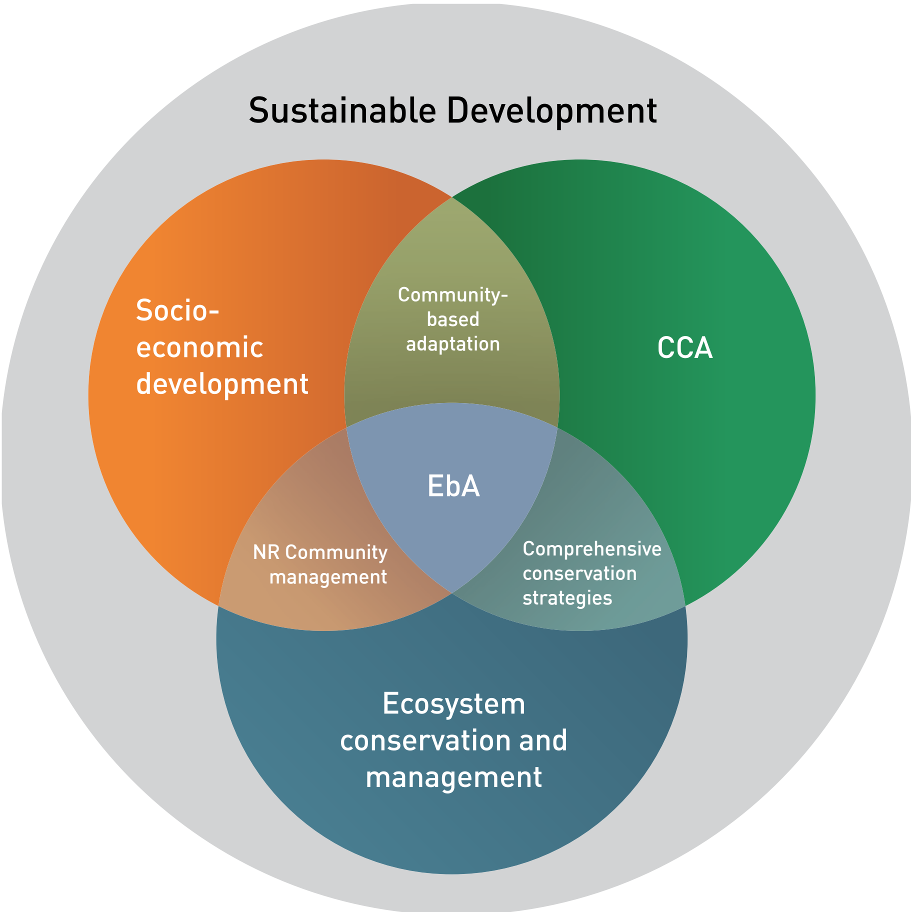


Figure 3. Linkages between EbA and other approaches to work that contribute to sustainable development and natural resource (NR) conservation and management (Adapted from Midgeley et al 2012, Hofstede 2019)

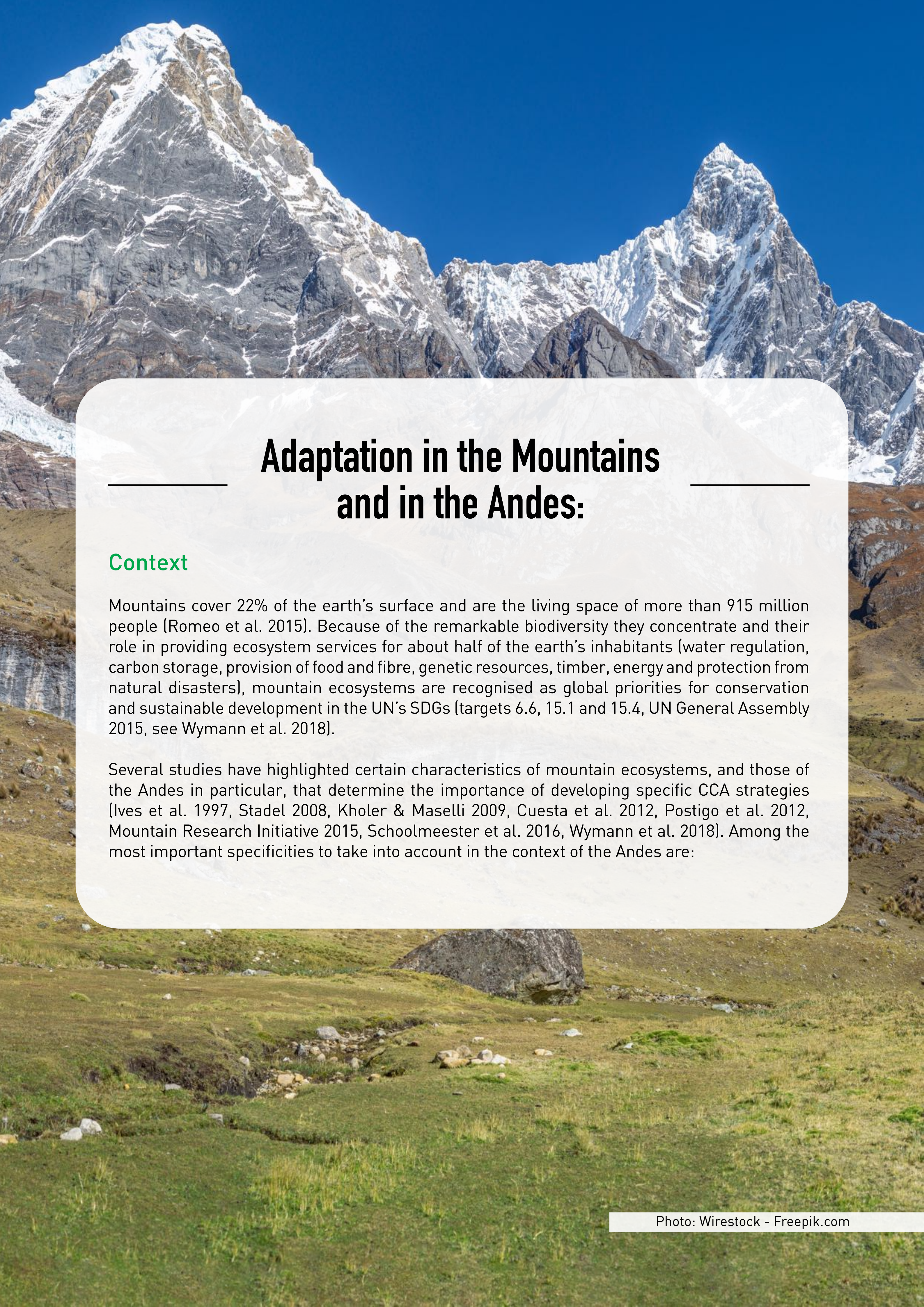
Specifically in the context of mountains, the Global Mountain Programme for Ecosystem-based Adaptation (UNEP 2015) proposes a set of criteria to distinguish EbA measures from more traditional natural resource management approaches or rural development projects that include: (1) measures that effectively reduce the vulnerability of local people to CC; (2) measures that increase the resilience of biodiversity and its ecosystem services; and, (3) measures that harness diversity and ecosystem services in a sustainable manner.

Adaptation in the Mountains and in the Andes:

Context

Mountains cover 22% of the earth's surface and are the living space of more than 915 million people (Romeo et al. 2015). Because of the remarkable biodiversity they concentrate and their role in providing ecosystem services for about half of the earth's inhabitants (water regulation, carbon storage, provision of food and fibre, genetic resources, timber, energy and protection from natural disasters), mountain ecosystems are recognised as global priorities for conservation and sustainable development in the UN's SDGs (targets 6.6, 15.1 and 15.4, UN General Assembly 2015, see Wymann et al. 2018).

Several studies have highlighted certain characteristics of mountain ecosystems, and those of the Andes in particular, that determine the importance of developing specific CCA strategies (Ives et al. 1997, Stadel 2008, Kholer & Maselli 2009, Cuesta et al. 2012, Postigo et al. 2012, Mountain Research Initiative 2015, Schoolmeester et al. 2016, Wymann et al. 2018). Among the most important specificities to take into account in the context of the Andes are:



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• The topographical complexity and the marked variations in climatic regimes over short distances, which create high uncertainty in the generation of present and future climate scenarios, especially in the case of precipitation.

• Rates of temperature increase vary along elevation gradients. The higher the altitude, the greater the increase in temperature values (up to c. 0.2 ºC per decade in areas above 3,000 m asl).

• There are conspicuous transition zones or ecotones between ecosystems, which promote diversity and provide an opportunity to monitor the dynamics of change, given the high sensitivity of species to climate variations (e.g., altitudinal boundary of forests or glaciers, ecotones between wetlands and mountain grasslands).

• High mountains face glacier and permafrost melting processes, which generate important risks (e.g., collapse of dams in high mountain lakes) and modify water regulation and the dynamics of mountain wetland systems (following the so-called peak flow curve).

• Mountainous areas show a high vulnerability of soils to erosion and loss of organic matter as a result of temperature increase and a high exposure to risks linked to droughts, floods and mass movements (landslides).

• Mountains provide freshwater for half the world's population for drinking, domestic use, irrigation, industry and hydropower generation.

• The demand for water in mountain areas for agricultural, domestic or energy uses is increasing, leading to growing conflicts, which will become even more acute in regions where precipitation is expected to decrease.

• Mountains play a role in "long-distance" connectivity between regions (tele-connections), which determines the need to integrate research and management approaches at multiple spatial scales.

• Mountains, particularly in the Andes, are hotspots for biodiversity, and show a high proportion of endemic and specialist species, with a high vulnerability to CC and vertical shifting of thermal floors.

• Mountain people have a high cultural diversity, agrodiversity and crop genetic diversity, including the areas of origin of important crops such as potatoes.

• Agriculture, herding and forestry activities are the main source of income for a significant proportion of the rural population. However, there is a marked process of diversification of the economies and sources of income of rural populations, with the incorporation of many non-traditional activities (tourism, services, etc.).

• CC interacts in complex ways with multiple non-climatic drivers of transformation, including deforestation, degradation of wetlands and high mountain pastures, mining and infrastructure construction, etc.

• In the Andes, there are large urban concentrations that depend directly on the services provided by mountain ecosystems and show complex links of migration, resource demand, etc. with rural areas (e.g., Bogotá, Quito, Santiago de Chile).

• Many mountain areas concentrate particularly poor and CC-vulnerable populations, who may live in areas that are inaccessible and poorly linked to decision-making centres. However, mountain societies, and in particular Andean populations, have evolved in highly dynamic climatic contexts at different time scales and have therefore developed a number of traditional adaptive management and social organisation strategies (e.g., use of different ecological floors, water and erosion management strategies, etc.).

Policy framework

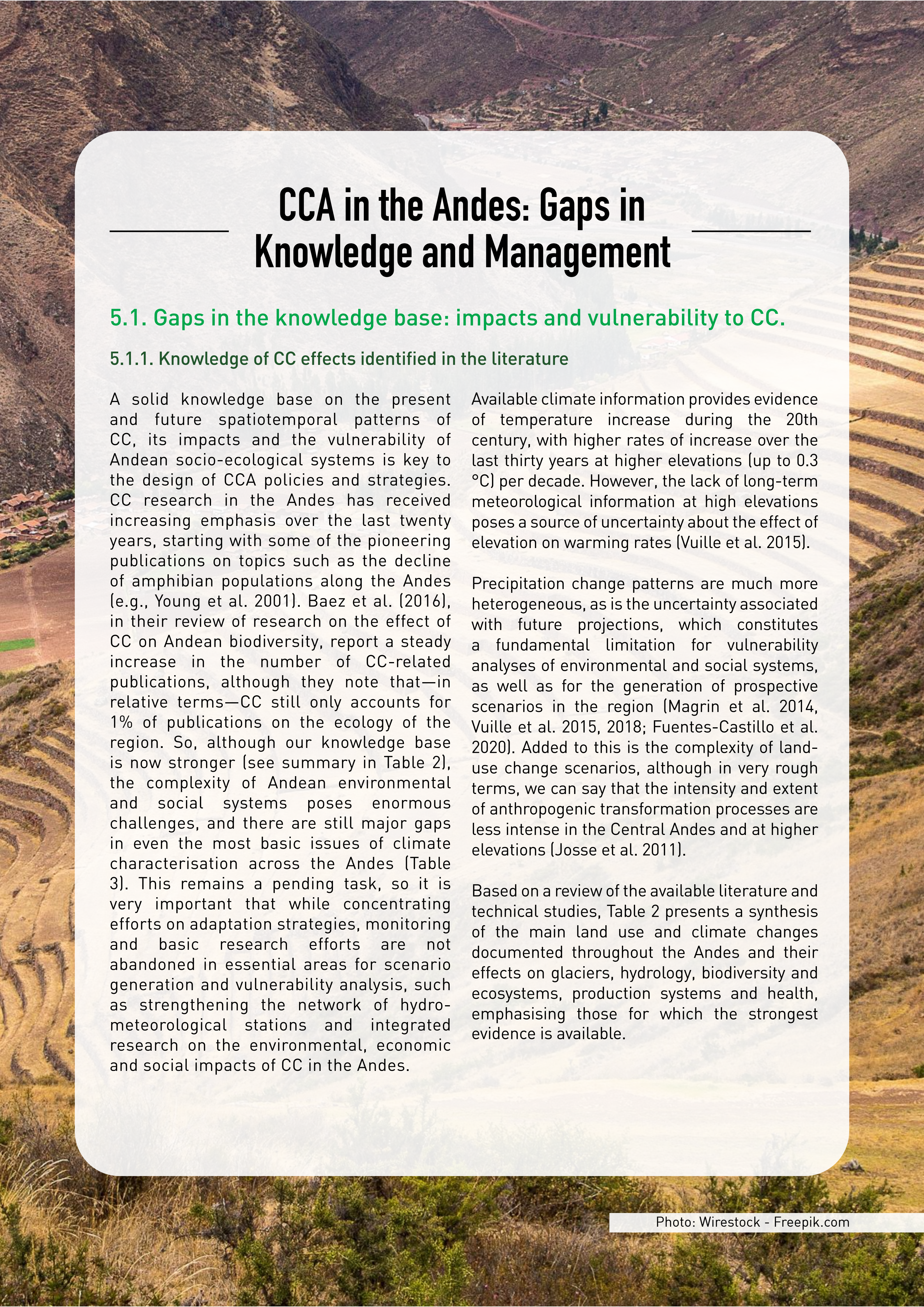
Regarding the CC policy framework in the Andean region, since the ratification of the UNFCCC in 1994 and subsequently of the Kyoto Protocol (1999-2002), the states in the region (see Annex 1) have been strengthening technical and political focal points (including the establishment of CC offices) and developing the necessary efforts to comply with their reporting and regulatory development commitments (national communications, policies and national CC strategies or programmes). In turn, countries in the region have been progressively incorporating CC into their national development plans and promoting the implementation of low-emission development schemes. In particular, given the vulnerability to potential CC impacts, adaptation has been gaining weight and importance and all countries have instruments on the subject, including NAPs or mechanisms and the submission of adaptation measures as part of their NDCs to the UNFCCC (Maldonado et al. 2012, Schoolmeester et al. 2016).

In terms of regional cooperation mechanisms that incorporate the Andean countries, it is worth highlighting the emphasis that the CAN placed on environmental and CC issues. In particular, the Andean Environmental Agenda oriented its actions around the issues of CC, biodiversity and water resource management, and supported multiple exercises to synthesise information on CC in the region. In turn, the CAN supported the implementation of pioneering projects in the area of CCA, such as the Project for Adaptation to the Impacts of Glacial Retreat (PRAA), the ANDESCLIMA programme (with emphasis on EbA approaches from the private sector) and the consolidation of regional monitoring networks such as GLORIA-Andes (Maldonado et al. 2012, Cuesta et al. 2017).

The Andean Mountain Initiative (IAM) has been another key space for the formulation of adaptation policies specifically focused on mountain socioecosystems. During the first meeting of the IAM in 2007 in Tucumán, CC was explicitly incorporated into the "Action Plan for Sustainable Development in the Andean Mountains" (under Axis 4). In turn, the Tucumán Plan points to the need for joint strategies and cooperation in the region for monitoring impacts and adaptation to CC. In response to this need, the IAM member countries with the collaboration of UNEP, CONDESAN and GRIDArendal published in 2018 "The Strategic Agenda on Adaptation to Climate Change in the Andes Mountains", presenting a very broad proposal of objectives and adaptation measures to guide the joint work of the countries of the region. These include objectives linked to the following thematic areas:

- Vulnerability of the most affected social groups.
- Sustainable agriculture, herding and feeding.
- Water resources management and governance.
- Andean ecosystems and biodiversity.
- Health and environmental sanitation systems.
- Natural disaster risk management.
- Reducing impacts of industrial and energy generation activities.
- Strengthening climate, environmental and social research and monitoring.
- Environmental education and capacity building.
- Governance, cooperation and financing mechanisms.

Other regional cooperation spaces such as the Union of South American Nations (UNASUR), the Community of Latin American and Caribbean States (CELAC), and the Pacific Alliance, have been less active on the issue of CCA in general and on the issue of mountains in particular, even when they have generated declarations or treaties that explicitly address CC (Schoolmeester et al. 2016). For example, the Constitutive Treaty of UNASUR (2008) states that one of the objectives of the block is cooperation in disaster prevention and the fight against the causes and effects of CC, while CELAC produced the Sixth Special Declaration on Climate Change in 2014. For its part, the OAS has been supporting important adaptation programmes for risk management through its Directorate for Risk Management and Adaptation to Climate Change (RISK-MACC). At the South and Central American level, another interesting initiative is the Ibero-American Climate Change Adaptation Programme (PIACC), developed by the Ibero-American Network of Climate Change Offices (RIOCC, see Keller et al. 2011).



CCA in the Andes: Gaps in Knowledge and Management

5.1. Gaps in the knowledge base: impacts and vulnerability to CC.

5.1.1. Knowledge of CC effects identified in the literature

A solid knowledge base on the present and future spatiotemporal patterns of CC, its impacts and the vulnerability of Andean socio-ecological systems is key to the design of CCA policies and strategies. CC research in the Andes has received increasing emphasis over the last twenty years, starting with some of the pioneering publications on topics such as the decline of amphibian populations along the Andes (e.g., Young et al. 2001). Baez et al. (2016), in their review of research on the effect of CC on Andean biodiversity, report a steady increase in the number of CC-related publications, although they note that—in relative terms—CC still only accounts for 1% of publications on the ecology of the region. So, although our knowledge base is now stronger (see summary in Table 2), the complexity of Andean environmental and social systems poses enormous challenges, and there are still major gaps in even the most basic issues of climate characterisation across the Andes (Table 3). This remains a pending task, so it is very important that while concentrating efforts on adaptation strategies, monitoring and basic research efforts are not abandoned in essential areas for scenario generation and vulnerability analysis, such as strengthening the network of hydro-meteorological stations and integrated research on the environmental, economic and social impacts of CC in the Andes.

Available climate information provides evidence of temperature increase during the 20th century, with higher rates of increase over the last thirty years at higher elevations (up to 0.3 °C) per decade. However, the lack of long-term meteorological information at high elevations poses a source of uncertainty about the effect of elevation on warming rates (Vuille et al. 2015).

Precipitation change patterns are much more heterogeneous, as is the uncertainty associated with future projections, which constitutes a fundamental limitation for vulnerability analyses of environmental and social systems, as well as for the generation of prospective scenarios in the region (Magrin et al. 2014, Vuille et al. 2015, 2018; Fuentes-Castillo et al. 2020). Added to this is the complexity of land-use change scenarios, although in very rough terms, we can say that the intensity and extent of anthropogenic transformation processes are less intense in the Central Andes and at higher elevations (Josse et al. 2011).

Based on a review of the available literature and technical studies, Table 2 presents a synthesis of the main land use and climate changes documented throughout the Andes and their effects on glaciers, hydrology, biodiversity and ecosystems, production systems and health, emphasising those for which the strongest evidence is available.

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Table 2. Summary of some documented or projected major changes due to CC in the Andes.

Topics	Documented or projected changes/effects	Some key references
Climate	Observed average temperature increase of c. 0.10 to 0.13 ºC per decade during the 20th century, with higher rates of increase (0.2 to 0.3 ºC per decade) in the last 30 years, but at higher elevations (above 2,000 m). Most evident trends of increases in minimum temperatures. Projected rise of +4 to 5 ºC above 4,000 m elevation by the 21st century (Representative Concentration Pathway 8.5). Complex patterns of variation in precipitations: areas where increases are observed and projected (e.g., western slopes of the Northern Andes) and others where decreases are projected (e.g., dry subtropical Andes and Patagonia, highlands in the Central Andes, Venezuela). High uncertainty. Increased frequency of extreme weather events (droughts, floods, increased landslides and erosion associated with high regional/ local uncertainty). Changes in air humidity and the frequency, coverage and elevation of cloud and haze.	Ruiz et al. 2008, Urrutia & Vuille 2009, Barros et al. 2014, Magrin et al. 2014, Vuille et al. 2015, Fuentes-Castillo et al. 2020.
Land use	Highly variable degree of anthropogenic transformation across the Andes, generally higher in the Northern Andes (≥50% above 500 m of elevation) than in the Central Andes (<15%). Intensity of anthropogenic transformation processes tends to decrease with elevation. Some Andean countries have lost 50-60% of their cloud forests (550,500 km^2) to deforestation. High variability in the history of land use in the region, from regions with millennia-old transformation processes to areas that remain largely untransformed.	Josse et al. 2011, Mathez-Stiefel et al. 2017, Malizia et al. 2020.
Glaciers	General trend of glacier retreat throughout the Andes, with higher than global average rates in the tropical Andes and an increase in the rate of retreat after 1970 (doubling the previous period). Projected disappearance of tropical glaciers with elevations below 5,400 m by 2050, and reductions of more than 90% by 2100 (Representative Concentration Pathway 8.5) in some regions of the Central Andes (e.g., Vilcanota Range, Peru). Marked retreat of most glaciers in the Southern Andes, including 48 of the 50 glaciers of the "Southern Continental Icefield".	Rabatell et al. 2013, Barros et al. 2014, Vuille et al. 2017, Cuesta et al. 2019, Masiokas et al. 2020, Ramírez et al. 2020.
Hydrology	Glacial retreat associated with initial increase and subsequent decrease in flows in high mountain basins (more important in drier areas of the central and desert Andes). Formation of new glacial lakes, expansion of existing ones and increased risks associated with flooding due to collapse in these high mountain water bodies. Models indicate little net change in water supply at continental level (due to competing effects of precipitation and evapotranspiration). High associated uncertainty.	Buytaert et al. 2010, de Biévre et al. 2012, Mark et al. 2017, Drenkhan et al. 2018, 2019; Masiokas et al. 2020, Correa et al. 2020.

Biodiversity and ecosystems	Models of biome distribution in CC scenarios suggest upward vertical displacement of the lower boundary and contraction of the extent of many biomes, most pronounced in biomes such as paramos, wetlands and evergreen forests. Associated changes in the distribution of studied species (birds and plants) suggest the possibility of extinction of a significant proportion in the most pessimistic scenarios (35-60% of the analysed species). Degradation of wetlands (including edaphic C losses) and decrease in the diversity of benthic aquatic fauna in basins affected by glacial retreat. Reduced population sizes of many tree species in tropical Andean forests and increased relative importance of lower elevation species (thermophilisation). Higher rates of altitudinal displacement of the altitudinal limit of Andean forests in protected areas than in intervened areas. Extinction and/or marked decline in abundance of several Andean amphibian species as a result of the interaction of CC and disease. Vertical displacement to higher elevations and habitat contraction of high Andean plant, amphibian and insect species (e.g., carabid beetles). Narrow thermal niches (increased vulnerability) and high levels of endemism in high Andean plants with increasing elevation and at equatorial latitudes (paramos). Increased colonisation of invasive alien plants in high Andean ecosystems.	Feeley & Silman 2010, Cuesta et al. 2012, Benavides et al. 2013, Lutz et al. 2013, Tovar et al. 2013, Morueta-Holme et al. 2015, Baez et al. 2016, Moret et al., 2016, Dangles et al. 2017, Seimon et al. 2017, Fadrique et al. 2018, Llambí et al. 2019, Cuesta et al. 2020.
Production systems	Crop distribution models in CC scenarios indicate that crops distributed towards the upper end of the elevation range in the Andes would be the most affected in terms of loss of climatic suitability areas (e.g., potato, arracacha, ulluco), while other crops in lower elevations could expand their distribution and altitudinal range (e.g., coffee). Experiments with transplanting maize and potatoes to higher elevations indicate significant decreases in yields (up to 80%) and crop quality, related to the incidence of new pests and soil limitations. Many Andean production systems are highly vulnerable to CC because they occupy marginal production areas, have limited access to infrastructure, financing and services, and high levels of poverty. Changes in precipitation patterns and decreasing rainfall are particularly affecting agricultural and livestock producers in the altiplano region.	Pérez et al. 2010, Postigo et al. 2012, Boillat & Berkes 2013, Schoolmeester et al. 2016, Tito et al. 2017, Bárcena et al. 2020.
Health	Temperature rises and changes associated with El Niño events associated with altitudinal expansion in the prevalence of diseases such as malaria and dengue fever or an increase in the incidence of diarrhoea.	Siraj et al. 2014, Schoolmeester et al. 2016, Bárcena et al. 2020.

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Current studies show that one of the most evident manifestations of CC is the rapid process of glacier retreat throughout the Andes, which has reached unprecedented rates since the 1970s, resulting in the complete disappearance of many glaciers (with faster rates of retreat on glaciers closer to the equator and at lower elevations, see Rabatell et al. 2013, Vuille et al. 2017, Masiokas et al. 2020, Ramírez et al. 2020). In the case of the drier regions of the central and desert Andes, these changes are having important effects on flow dynamics and water availability for local communities (e.g., Barros et al. 2014, Mark et al. 2017, Masiokas et al. 2020). In turn, several recent studies have emphasised the effect of global change and glacial retreat on high Andean landscapes and ecosystems, including the colonisation and emergence of new biotic communities at glacial retreat fronts, the degradation of the structure, soils and water regulation capacity of high Andean wetlands, the formation and expansion of lagoons, and the reduction in the richness and changes in the trophic dynamics of specialist benthic fauna in glacier-fed rivers (see Table 2 and review in Cuesta et al. 2019).

On the other hand, studies based on simulation models of the spatial distribution of biomes and species in the tropical Andes under warming scenarios (e.g., birds, vascular plants) suggest significant shifts to higher elevations and a contraction of their extent (which could even lead to the extinction of many specialist species at higher elevations: Cuesta et al. 2012, Tovar et al. 2013). However, there is high uncertainty associated with these models, due to the lack of empirical long-term monitoring data on species abundance and distribution in the Andes and of knowledge on their autoecology (physiological tolerance), dispersal and migration strategies, phenology and interspecific interactions (Table 3).

In this sense, research over the last ten years and the consolidation of long-term monitoring networks throughout the Andes, such as the Andean Forests Network and the GLORIA-Andes Network, have begun to fill these gaps, providing key information on: (1) latitudinal and altitudinal changes in community structure (e.g., Cuesta et al. 2017, Malizia et al. 2020); (2) dispersal strategies, phenology and thermal niches of paramo and puna plant species and communities (Cuesta et al. 2019, Tovar et al. 2020); (3) the dynamics of change and altitudinal shift of high Andean forest woody species (e.g., Fadrique et al. 2018); and, (4) the role of plant-plant (competition/facilitation) and plant-animal interactions in the assembly of high-mountain communities along the Andes (e.g., Cavieres and Badano 2009, Anthelme et al. 2014, Hupp et al. 2017, Pelayo et al. 2019). In turn, research over the last decade across the Andes, including studies in the framework of the Mountain Invasions Research Network (MIREN), draws attention to the growing importance of invasive alien plants in fragile high Andean ecosystems and their negative effects on native flora, a threat that could become more acute under CC scenarios (Cavieres et al. 2008, León and Vargas-Ríos 2011, Malizia et al. 2017, Sandoya et al. 2017, Llambí et al. 2018, 2020).

Another aspect in which long-term monitoring networks have played an important role is the study of the response of ecosystem services to land use and CC, particularly the hydrological response, which has been the focus of the research network Hydrological Monitoring Initiative for Andean Ecosystems (IMHEA) (Célleri et al. 2011, Correa et al. 2020).


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There are numerous studies in the Andes that analyse the impact of different land-use systems (agriculture, grazing, forestation) on key ecosystem services such as biomass/carbon accumulation in vegetation and soils, and water and nutrient dynamics (e.g., Buytaert et al. 2006, Pérez et al. 2010, Hofstede et al. 2014, Peña et al. 2018, Cerrón et al. 2019, Llambí & Rada 2019, Duchicela et al. 2019, Correa et al. 2020). However, monitoring, research and knowledge synthesis on the impact of CC on these processes at the ecosystem level and their interaction with different management systems is still very limited, this being one of the most important barriers to the design of EbA strategies (Anderson et al. 2011, Schoolmeester et al. 2016, Hofstede 2019) (Tables 3 and 6). In particular, in the context of long-term monitoring systems in the region, there is a great need for the integrated study of biodiversity and ecosystem services (see proposal for the Colombian Andes in Llambí et al. 2019).

At the same time, knowledge about the impacts and vulnerability of production systems and Andean societies to CC continues to be a major challenge. Studies on CC and production systems in the Andes emphasise, on the one hand, the highly vulnerable conditions of many small producers and communities, occupying marginal production areas (poor soils or steep slopes, upper elevation limits for many crops, etc.) and due to limited access to infrastructure, financing and services and high levels of poverty. However, these studies highlight, on the other hand, a high adaptive response capacity of Andean people and indigenous communities, resulting from centuries of developing traditional coping strategies in the face of the marked spatial and temporal variability of the Andean climate (e.g., Dillehay & Kolata 2004, Halloy et al. 2005, Young & Lipton 2006, Stadel 2008, Pérez et al. 2010, Postigo et al. 2012).

As indicated above, climate variability phenomena (e.g., increased frequency and severity of droughts) and overgrazing are generating in some regions processes of degradation of high Andean wetlands and pastures on which depend many communities with livelihoods closely linked to livestock and Andean camelid farming (Buttolph & Coppock 2004, Molinillo & Monasterio 2006, Salvador et al. 2014, Loza-Herrera et al. 2015, López-i-Gelats et al. 2015, Dangles et al. 2017, Morales et al. 2018, Hofstede & Llambí 2019). On the other hand, empirical studies and simulation models of the spatial distribution of crops in the tropical Andes under CC scenarios suggest an upward shift of the boundary of crops from colder areas (e.g., arracacha, potato, ulluco, etc.), and the contraction of their total area of climatic suitability, but with a very heterogeneous response across countries (Halloy et al. 2008, Postigo et al. 2012). In turn, the study by Postigo et al. (2012) shows marked differences between countries in the areas for which greater losses and gains are expected in the projected distribution of crops and the areas where a higher proportion of the population lives in poverty (with more negative consequences for many crops in countries such as Venezuela or Bolivia than in countries like

Ecuador or Peru). Several studies also indicate that CC and the altitudinal displacement of crops can generate negative effects on yields and quality of crops such as maize or potatoes, due to an increase in the incidence of pests (including herbivorous insects), diseases (such as fungi and pathogenic bacteria) and limitations in soil suitability and fertility (Dangles et al. 2008, Pérez et al. 2010, Crespo et al. 2015, Tito et al. 2017).

Finally, regarding the vulnerability of Andean production systems, Schoolmeester et al. (2016) perform an interesting analysis for the Tropical Andes in which they combine the probability of change in climate variables, vulnerability to disasters and food security, illustrating the great variability in the degree of vulnerability of rural societies across the region.

Table 3. Gaps in the knowledge base on CC impacts and vulnerability of Andean socioecosystems.

Knowledge gaps	References
Knowledge base on spatiotemporal variability of temperature and precipitation and hydrological processes (especially in high mountains), including key aspects such as the effect of elevation on the rate of temperature increase.	GLOCHAMORE 2005, Anderson et al. 2011, Hole et al. 2011, de Biévre et al. 2012, Hofstede et al. 2014, Magrin et al. 2014, Salzmann et al. 2014; Becerra 2015, 2017; Schoolmeester et al. 2016, Adler et al. 2018, Vuille et al. 2018, Fuentes-Castillo et al. 2020.
Standardised methodologies and data for vulnerability and resilience analysis of Andean socio-environmental systems, and the generation of future scenarios (including analysis of extreme events) especially at regional-local scales.	Hole et al. 2011, Bustamante et al. 2012; Vuille et al. 2013, 2018; Becerra 2015, Gleeson et al. 2016, Becerra 2017, Wymann et al. 2018, Fuentes-Castillo et al. 2020.
Integrated analyses of the drivers of change in land use, their interactions with CC and their effects on functional diversity and ecosystem services, including hydrological regulation and biomass/carbon accumulation. Need for comparative studies along spatial environmental (e.g., elevation) and land- use-transformation gradients and for models that integrate land-use change and CC. Need for greater emphasis on historical studies (e.g., recovery of early ecological surveys).	GLOCHAMORE 2005, Anderson et al. 2011, Cuesta et al. 2012, Chatterjee et al. 2014, Hofstede et al. 2014, Magrin et al. 2014, Becerra 2015, Huggel et al. 2015, Baez et al. 2016, Gleeson et al. 2016, Becerra 2017, Mathez-Stiefel et al. 2017, Adler et al. 2018, Avella 2019, Hofstede 2019, Llambí et al. 2020, Pauli & Halloy 2020.
Basic knowledge and modelling to analyse the impact of CC on hydrological response in the Andes (including lack of information on water quantity and quality). High uncertainty in the context of climate variability (need for higher spatial resolution and longer time series).	Bustamante et al. 2012, de Biévre et al. 2012, Vuille et al. 2013, Hofstede et al. 2014, Salzmann et al. 2014, Becerra 2015, Schoolmeester et al. 2016.
Need for more locations with empirical data and long-term monitoring of the dynamics and role of glaciers and high Andean wetlands in hydrological regulation and the impact of their degradation on Andean landscapes and ecosystems.	GLOCHAMORE 2005, Anderson et al. 2011, de Biévre et al. 2012; Vuille et al. 2013, 2017; Salzmann et al. 2014, Huggel et al. 2015, Cuesta et al. 2019.

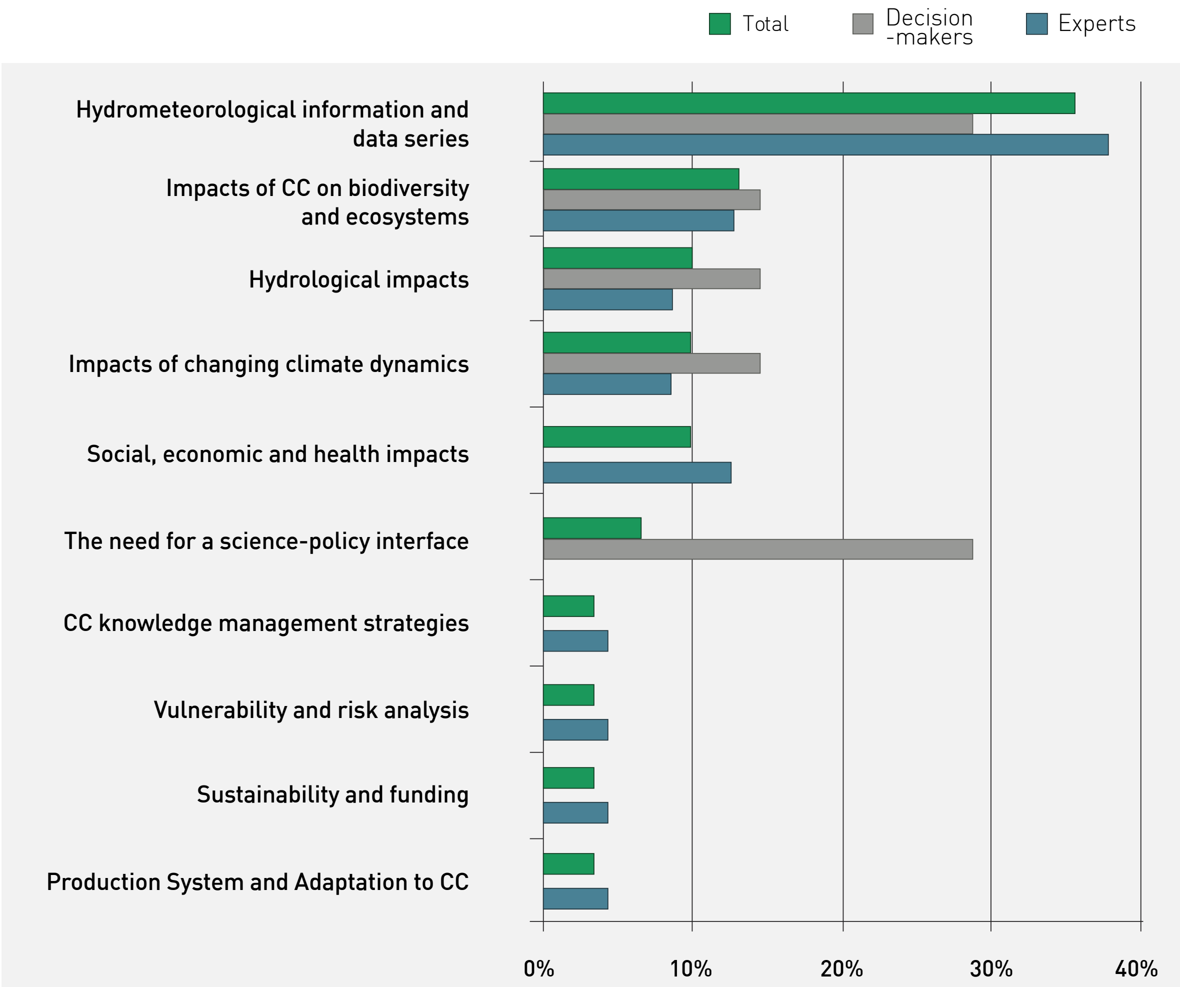
CC effects on carbon accumulation in soils and biomass and nutrient cycling and dynamics.	Anderson et al. 2011, de Biévre et al. 2012, Hofstede et al. 2014, Mathez-Stiefel et al. 2017.
Need to deepen our understanding of autoecology and species interactions, including understanding of spatial distribution, adaptive strategies and functional diversity (tolerance/physiology, thermal and water niches), dispersal and migration strategies and reproductive ecology (e.g., phenology) as a basis for improving our predictive capacity for diversity response in CC scenarios. In turn, there is a need to better understand the role of species interactions in CC scenarios (competition, facilitation and ecosystem engineers, pollinators and dispersers).	Cuesta et al. 2012, Becerra 2015, Baez et al. 2016, Avella 2019, Cuesta et al. 2019, Llambí et al. 2019, Pauli & Halloy 2020.
Studies with a socio-ecological and transdisciplinary approach on the effects of CC on the quality of life of Andean communities and societies and their relationship with the provision of ecosystem services, including socio-economic analyses at multiple scales (local, national, Andean regional).	Chatterjee et al. 2014, Magrin et al. 2014, Becerra 2015, Huggel et al. 2015, Gleeson et al. 2016, Mathez-Stiefel et al. 2017, Adler et al. 2018, Vuille et al. 2018, Avella 2019, Hofstede et al. 2019, Pauli & Halloy 2020.
Strengthening of regional monitoring and comparative research networks in the Andes, (especially on ecosystem service dynamics), development of protocols and indicators and comparative experimental studies (e.g., warming chambers, CO2 or nutrient enrichment, grazing exclusion, etc.). Need to complement permanent monitoring systems with synchronous comparative studies along gradients (e.g., elevation or regeneration, successional gradients).	Hole et al. 2011, Cuesta et al 2012, Becerra 2015, Huggel et al. 2015, Baez et al. 2016, Gleeson et al. 2016, Schoolmeester et al. 2016, Becerra 2017, Adler et al. 2018, Vuille et al. 2018, Avella 2019, Cuesta et al. 2019, Hofstede 2019, Llambí et al. 2019, Pauli & Halloy 2020.
Need for further study of ecotones and their dynamics (forest boundary, glacier boundary, wetland-grassland boundary).	Hole et al. 2011, Cuesta et al. 2012, Hofstede et al. 2014, Young et al. 2017, Cuesta et al. 2019, Hofstede 2019.
Strengthening knowledge co-production approaches, co-learning and co-exploration/analysis of the information generated with the participation of researchers, decision-makers, local communities and civil society actors.	Chatterjee et al. 2014, Huggel et al. 2015, Gleeson et al. 2016, Klein et al. 2017, Mathez-Stiefel et al. 2017, Dilling et al. 2019.
Increased emphasis on the analysis of interactions and interdependence relations between upland and lowland areas (tele-connections).	Gleeson et al. 2016, Hofstede 2019.

5.1.2. Knowledge gaps identified by experts and decision-makers in the surveys

The most relevant results of the knowledge gaps on CC impacts identified by the experts and decision-makers consulted in the surveys are presented below.

The main knowledge gap for CC impact research identified was the lack of more hydrometeorological data, monitoring stations and continuous time series of climatological data (Figure 4). The second gap identified was research on impacts of changes in biodiversity and ecosystem functioning, including how ecosystems will respond to changes in precipitation and temperature, the recovery of ecosystems, and variations in ecosystem services such as water availability and carbon storage. The third research need identified was changing climate dynamics and improving scientific evidence on changes in precipitation patterns in mountains, including changes in seasonality (closely related to the first theme mentioned above). Interestingly, for decision-makers, one of the three most frequently mentioned issues included the need to link scientific evidence with policy-making, developing policy-making processes based on research results and spaces that promote such exchange.

With regard to the main gaps in the knowledge of the vulnerability of the Andean socioecosystems (Figure 5), the most significant gap identified refers to the development of validated vulnerability analysis methodologies and the need to define adaptation typologies, calculation methodologies and guide interventions in sites that have been identified as vulnerable to CC. The need for vulnerability analyses that integrate social, economic, political, biophysical and institutional components was also pointed out. It is interesting to note that, for decision-makers, it is very relevant to learn more about comprehensive methodologies for vulnerability analysis linked to climate variables and that respond to indicators that are more focused at the local scale and reflect the specific conditions of the intervention zones—a challenge from the point of view of information availability at these local scales.



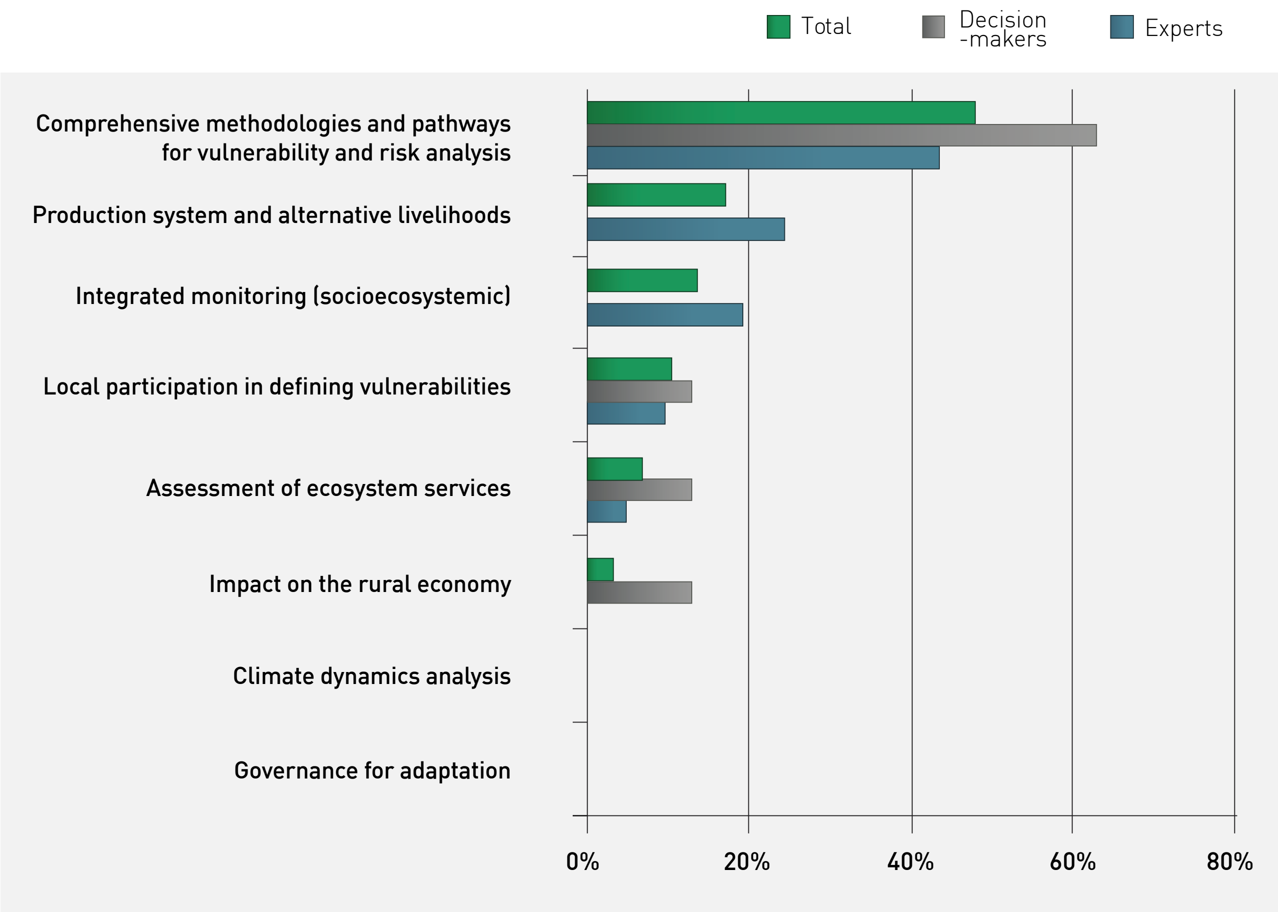
Note: The percentage of respondents who indicated each of the issues identified in the answers (open-ended question) are indicated

Figure 4. Knowledge gaps identified by experts and decision-makers in the Andes around CC impact research.

The second gap that has been pointed out (in this case only by experts), which is closely related to the previous one, is the need for comprehensive monitoring systems for ecosystems and the analysis of variables that allow for understanding and responding to the integral behaviour of socioecosystems. It could be interpreted that for decision-makers, this is indeed related to vulnerability monitoring and improved integrated methodologies. However, it raises the need to focus monitoring systems on being able to answer questions specifically linked to the issue of vulnerability.

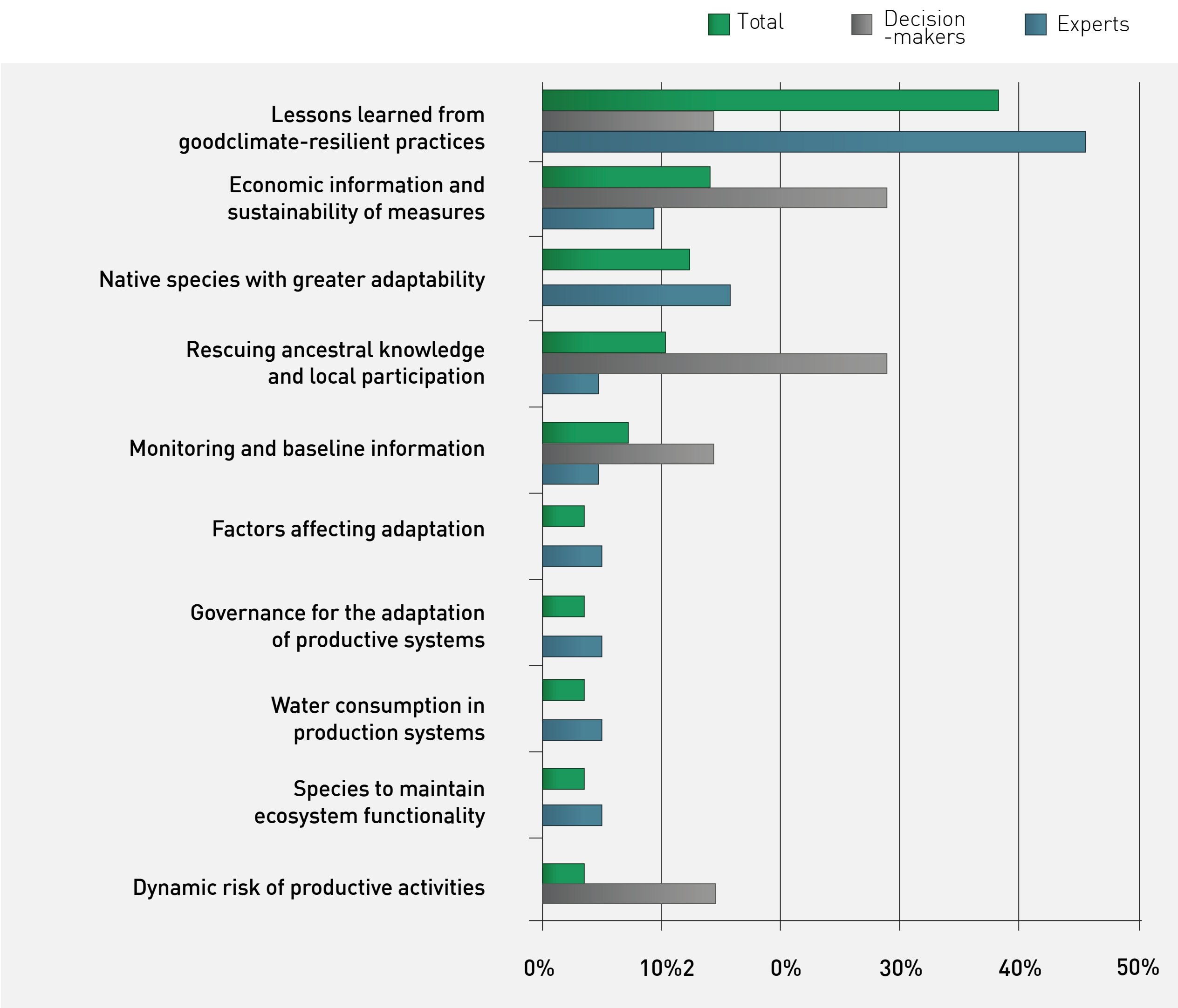
The third knowledge gap prioritised in this theme was related to information and monitoring of the vulnerability of productive systems, mainly associated with understanding the limits to achieving a balance between productive activities and the permanence of ecosystems and their ecosystem services, and the identification of alternative livelihoods that reduce pressure on ecosystems.

In turn, as shown in Figure 5, local participation and the analysis of their social perceptions of vulnerability, the valuation of ecosystem services and the impacts of CC on the economic system are also priority issues for the decision-makers surveyed.



Note: The percentage of respondents who indicated each of the issues identified in the answers (open-ended question) are indicated.
Figure 5. Knowledge gaps identified by experts and decision-makers in the Andes regarding the vulnerability of Andean socioecosystems to CC

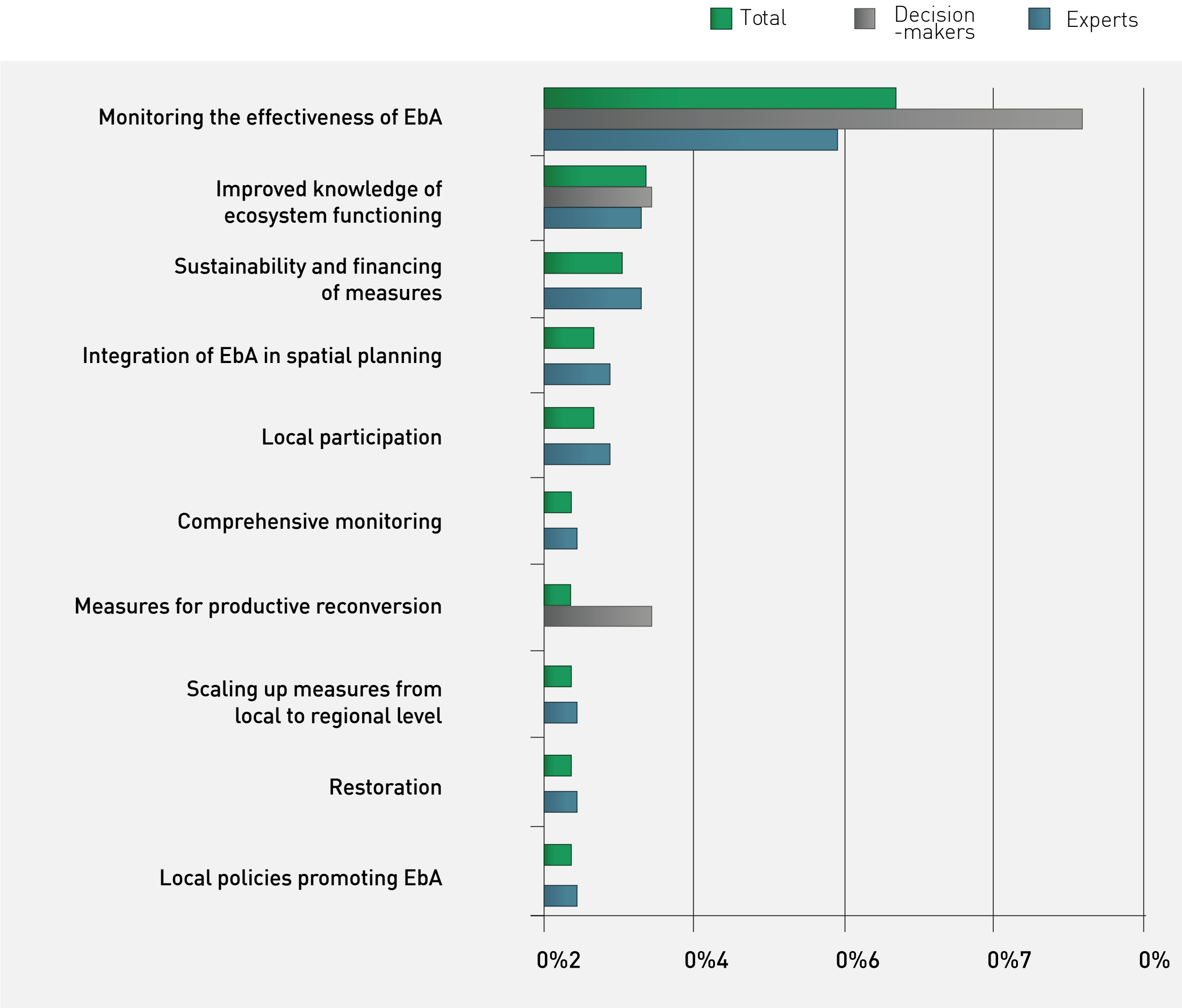
In terms of knowledge gaps in production systems (Figure 6), the main gap identified by the experts surveyed is knowledge about lessons learned from good climate-resilient practices, especially techniques that respond to the particular conditions of high mountains. Also, the need for research or systematisation of experiences of crop response to CC (e.g., altitudinal shifts) is mentioned.



Note: The percentage of respondents who indicated each of the issues identified in the answers (open-ended question) are indicated.
Figure 6. Knowledge gaps identified by experts and decision-makers in the Andes regarding the impacts of CC on Andean production systems.

For decision-makers, the two main knowledge gaps were related to economic information on alternative production practices (costs and benefits of climate-smart agriculture) and the incorporation of traditional local knowledge on sustainable production practices and their participation in the projects. As shown in Figure 6, for the experts interviewed, the third most mentioned gap refers to the need for information on native species with greater adaptability to climate, while for decision-makers, it is relevant to know about experiences of good climate-resilient practices, the monitoring of practices and to know about the climate risk to which productive activities are exposed.

With regard to knowledge gaps on the issue of ecosystem-based adaptation (Figure 7), both groups of respondents agreed that it is a priority to know and monitor the effectiveness of conservation, restoration and other EbA actions and to recognise the contribution of CCA strategies.



Note: The percentage of respondents who indicated each of the issues identified in the answers (open-ended question) are indicated.
Figure 7. Knowledge gaps identified by experts and decision-makers in the Andes on EbA strategies.

There is also agreement among decision-makers and experts on the second priority of improving knowledge of ecosystem functioning, including knowledge of key species and ecosystem processes. In addition, for decision-makers it is also a priority to document and analyse conversion strategies for productive purposes in vulnerable ecosystems. For experts, it is key to deepen information on the sustainability and financing of ecosystem-based options.

Summary of results

The results of the main knowledge gaps in research reflect a great need to establish long-term and more comprehensive monitoring systems in each of the thematic areas. In the four areas analysed, it is evident that there are gaps in information on the monitoring and evaluation of impacts and on improving our knowledge of ecosystems, their dynamics and their responses to changes in climate and how this has repercussions on the services they provide. In the same vein, there is a clear need to improve hydrometeorological information and strengthen monitoring of the effectiveness of ecosystem-based adaptation measures. In turn, this suggests that many of the interventions being implemented as adaptation measures are not based on detailed information on the behaviour of socio-ecosystems under environmental change scenarios (CC and land use change), and there are no monitoring and evaluation systems in place to reflect their effectiveness (i.e., monitoring of alternative management and adaptation strategies). In addition, there is agreement among decision-makers and experts on the need to develop comprehensive CC vulnerability analysis methodologies and indexes that reflect the specific characteristics of each location—i.e., having more detailed information at the local scale. Although there has been significant progress in defining vulnerability and risk methodologies, respondents suggest that there is a need to integrate social, economic, political, biophysical and institutional components into vulnerability analyses. This suggests that traditional vulnerability studies do not see adaptation as part of a broader system of vulnerabilities, and rather focus on narrow criteria that do not reflect the relationships between different social, political, economic and other variables. Finally, an important finding is the need raised by decision-makers to continue to articulate research efforts with policy and decision making.

5.2. Knowledge gaps in design and implementation of adaptation strategies and policies

5.2.1. Knowledge gaps for action as identified in the literature

In the last twenty-five years there have been very significant advances in the implementation of CCA strategies and projects in the Andes. In fact, Bustamante et al. (2012) identified 217 adaptation actions promoted by international cooperation in the tropical Andes after the enforcement of the UNFCCC. However, although there are some general reviews of adaptation strategies and policies implemented in the Andes (McGray et al. 2007, Agrifort Consult 2009, Hole et al. 2011, Bustamante et al. 2012, Huggel et al. 2015, Schoolmeester et al. 2016), the lack of systematic processes for monitoring and evaluating the impacts of these strategies has limited the development of critical comparative analyses and the systematisation of lessons learned (see Table 4).

In thematic terms, Bustamante et al. (2012), Huggel et al. (2015) and Schoolmeester et al. (2016) point out that most of the strategies focus on water resources management, then on the thematic pillars of adaptation based on ecosystems and productive systems, and finally on climate risk management. In turn, most of the strategies analysed by Bustamante et al. (2012), were implemented at the local scale, with an emphasis on community capacity building processes and addressing a single thematic line, while multi-focal projects accounted for only 30% (in many cases combining water management and productive systems actions and emphasising the rescue of traditional management practices, see also—for example—Almeida 2015, Ariza et al. 2017). Another interesting aspect is that most of the projects identify rainfall scarcity or extreme events as the main climate hazards, either through an increase in the frequency of droughts or floods. Although in some cases a technical climate risk analysis was taken as a starting point, the need for more robust prospective climate scenarios (especially at the local scale), and a better integration of inputs from scientific research and local stakeholder perceptions, is repeatedly pointed out (Bustamante et al. 2012, Huggel et al. 2015, Schoolmeester et al. 2016).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5.2.1.1. Policy framework, institutions and adaptation management.

As noted above, countries in the region have been strengthening the policy framework and institutional framework around CC (see reviews in Maldonado et al. 2012, Huggel et al. 2015, Schoolmeester et al. 2016). However, evaluations indicate that there are still limitations in the implementation of national CCA strategies and plans, particularly in terms of the integration, systematisation and coordination of actions at the local and regional level with national and international policies. Table 4 shows the main gaps identified in terms of the policy framework, institutions and management of adaptation in the region. As can be seen, priority issues include the need to consolidate systems for monitoring and evaluation of the impacts of CCA processes and the integrated analysis of multi-sectoral adaptation actions and with a territorial perspective, including possible contradictions between different policies (e.g., infrastructure and agricultural production vs. ecosystem conservation). Another frequently raised issue is the need to analyse the influence of the institutional and governance framework on the adoption of CCA strategies, especially at the local level, and the importance of analysing and strengthening adaptive co-management experiences (see Ariza et al. 2017).

In terms of monitoring the impacts of adaptation and recognising the specificities and challenges posed by mountain ecosystems, the recent experience in Colombia is particularly interesting. The country has had a National Climate Change Adaptation Plan since 2011, which includes monitoring and evaluation of the actions implemented as the fourth and final phase of its implementation. This has led, since 2015, to the development of a National System of Adaptation Indicators. On the other hand, work has been ongoing on the design and consolidation of a Strategy for Integrated Monitoring of Colombia's High Mountain Ecosystems (EMA), which emphasises the need for an integrated approach to monitoring diversity, ecosystem services and the quality of life of the population along the environmental and transformation gradients that characterise the country's Andean ecosystems (IDEAM et al. 2018, Llambí et al. 2019).

Table 4. Knowledge gaps around the policy framework, institutions and management of CCA in the Andes.

Knowledge gaps	References
Need for common definition of goals and objectives in adaptation projects from the early stages and to analyse the adaptation gap against agreed goals. Strengthening of adaptive co-management processes.	Huggel et al. 2015. Gleeson et al. 2016, Ariza et al. 2017, Hofstede 2019.
Need to consolidate monitoring and evaluation systems for adaptation in terms of effectiveness and social impacts (equity, empowerment, adaptive capacity) and environmental impacts (holistic approaches). Definition of measurable and comparable indicators against participatively defined adaptation targets. Reporting and learning from successful solutions and failures (documented examples of "maladaptation"). Incorporate not only quantitative indicators but also qualitative changes (e.g., through the compilation of narratives).	Bustamante et al. 2012, Chatterjee et al. 2014, Magrin et al. 2014, Almeida 2015, Becerra 2015, Huggel et al. 2015, Schoolmeester et al. 2016, Gleeson et al. 2016, Ariza et al. 2017, Klein et al. 2017, Wymann et al. 2018, Dilling et al. 2019, Hofstede 2019, Llambí et al. 2019.
Need for comparative cost-benefit analyses of adaptation alternatives in general, and EbA strategies in particular; and analysis of economic incentives and payment for ecosystem services schemes that contribute to adaptation.	Hole et al. 2011, Chatterjee et al. 2014; Becerra 2015, 2017; Seddon et al. 2016, Vuille et al. 2018, Hofstede 2019.
Need for analysis of the links between instruments for spatial planning and management and the development of adaptation agendas with territorial approaches at multiple scales.	Hole et al. 2011; Becerra 2015, 2017; Ariza et al. 2017, Hofstede 2019, Llambí et al. 2019.
Lack of policy instruments explicitly targeting mountain socioecosystems in Andean countries.	Schoolmeester et al. 2016, Wymann et al. 2018.
Lack of analysis of interaction and complementarity between multiple impacts and risks and between multiple adaptation strategies (water, agriculture, EbA, etc.) and mechanisms to promote comprehensive and cross-cutting (multi-sectoral) adaptation processes. Identification of contradictions and trade-offs between different objectives (e.g., infrastructure or agricultural production and conservation of mountain ecosystems).	Becerra 2015, UNDP 2015, Gleeson et al. 2016, Ariza et al. 2017, Klein et al. 2017, Wymann et al. 2018, Hofstede 2019.
Analysis of the institutional context, actor and conflict networks and decision-making processes and their effects on the effectiveness of CCA processes and the implementation of solutions (identification of barriers and opportunities or factors that promote the successful adoption of adaptation strategies).	GLOCHAMORE 2005, Chatterjee et al. 2014, Becerra 2015, Huggel et al. 2015, Klein et al. 2017, Avella 2019, Hofstede 2019.
Lack of specific information for the mountains and for the Andes to be able to assess progress towards the 2030 Sustainable Development Goals. Need for agreements on the measurement of indicators or proxies to assess targets.	Mathez-Stiefel et al. 2017, Wymann et al. 2019.

Need for development of methodological tools to link climate vulnerability analysis with adaptation options or solutions.	Bustamante et al. 2012, Becerra 2015.
Need to develop methodology and approaches to assess changes in the adaptive capacity of institutions and social organisations.	Bustamante et al. 2012, Dilling et al. 2019.
Development of approaches and knowledge synthesis for scaling up, replication and financial sustainability of adaptation strategies and the need for comprehensive analyses of the factors that favour the scaling up and replication of successful solutions.	Bustamante et al. 2012, Klein et al. 2017, Vuille et al. 2018, Avella 2019, Hofstede 2019.
Analysis of transboundary processes (shared basins, migration, etc.) for the design of adaptation strategies, including analysis of the effect of extreme climate events.	Hole et al. 2011, Becerra 2015, Klein et al. 2017.

5.2.1.2. Water resources and risks

Strategies to address climate risks linked to water resources management have been a major focus of adaptation efforts in the region. These include a wide range of actions, from identifying the degree of exposure and sensitivity of Andean systems, strengthening national hydrological monitoring systems and early warning schemes, to rescuing traditional local approaches and measures for water management (Bustamante et al. 2012, de Biévre et al. 2012, Vuille 2013, Huggel et al. 2015, Schoolmeester et al. 2016). Some of the flagship projects developed around this issue include the Project for Adaptation to the Impact of Rapid Glacial Retreat in the Tropical Andes (PRAA), Peru's Climate Change Adaptation Programme (PACC), Colombia's Integrated National Adaptation Programme (INAP), the "Paramos Communities" project (see Almeida 2015, Huggel et al. 2015) and, more recently, the Adaptation to the Impacts of Climate Change on Water Resources in the Andes (AICCA) project. In terms of the most common adaptation actions or solutions reported around water management in the region, we can mention:

• Strengthening of hydro-meteorological information and early warning systems.

• Integrated watershed management, including management actions at the micro-watershed level, zoning for livestock activities, etc.

• Strengthening water governance, including water boards and working with local or regional governments and aqueducts.

• Conservation, fencing or restoration of springs and wetlands or forestation/reforestation of upper watersheds, with a tendency to emphasise more the use of native species over exotic ones in recent times.

• Control of water demand, including educational campaigns and payment for water services schemes, including emblematic experiences such as the Fund for Protection of Water (FONAG).

• Rescue of traditional water use practices, including water harvesting, canals, reservoirs, terraces, use of drought-resistant crop varieties, etc.

• Technological alternatives for more efficient water management, such as improved irrigation reservoirs, storage and canalisation infrastructures, etc.

Despite much accumulated experience, there are still significant gaps in knowledge for adaptation and sustainable water resources management (Table 2, Table 5). The most reported gaps include the need for information on water use and demand at multiple scales, and knowledge of strategies and technological alternatives for more efficient water management. In turn, the need to integrate traditional knowledge with the use of new technologies and critical analysis of information and early warning systems was identified, especially in high mountain scenarios where glacial lake outburst hazards exist.

Table 5. Knowledge gaps around water resources management for CCA in the Andes.

Knowledge gaps	References
Gaps in information and analysis of access to and demand for water resources. Many of the available assessments and studies emphasise the supply side.	De Biévre et al. 2012; Vuille et al. 2013, 2017; Becerra 2015, Gleeson et al. 2016.
Lack of systematisation of knowledge on technological alternatives for more efficient water management (e.g., irrigation optimisation, water storage infrastructure, groundwater inventories, etc.).	Becerra 2015, Schoolmeester et al. 2016.
Lack of documentation and synthesis of communities' adaptive strategies and traditional knowledge for water management.	De Biévre et al. 2012, Becerra 2015.
Need for integrated methodological designs to address risk management and CC issues and development of early warning systems in the context of mountain ecosystem management (e.g., glacier-related high mountain lake overflow risks).	GLOCHAMORE 2005; Vuille et al. 2013, 2017; Magrin et al. 2014, Becerra 2015, Huggel et al. 2015, Klein et al. 2017, GCA 2019.

Photo: Pakhnyushchyy - Freepik.com

5.2.1.3. Ecosystem-based Adaptation (EbA)

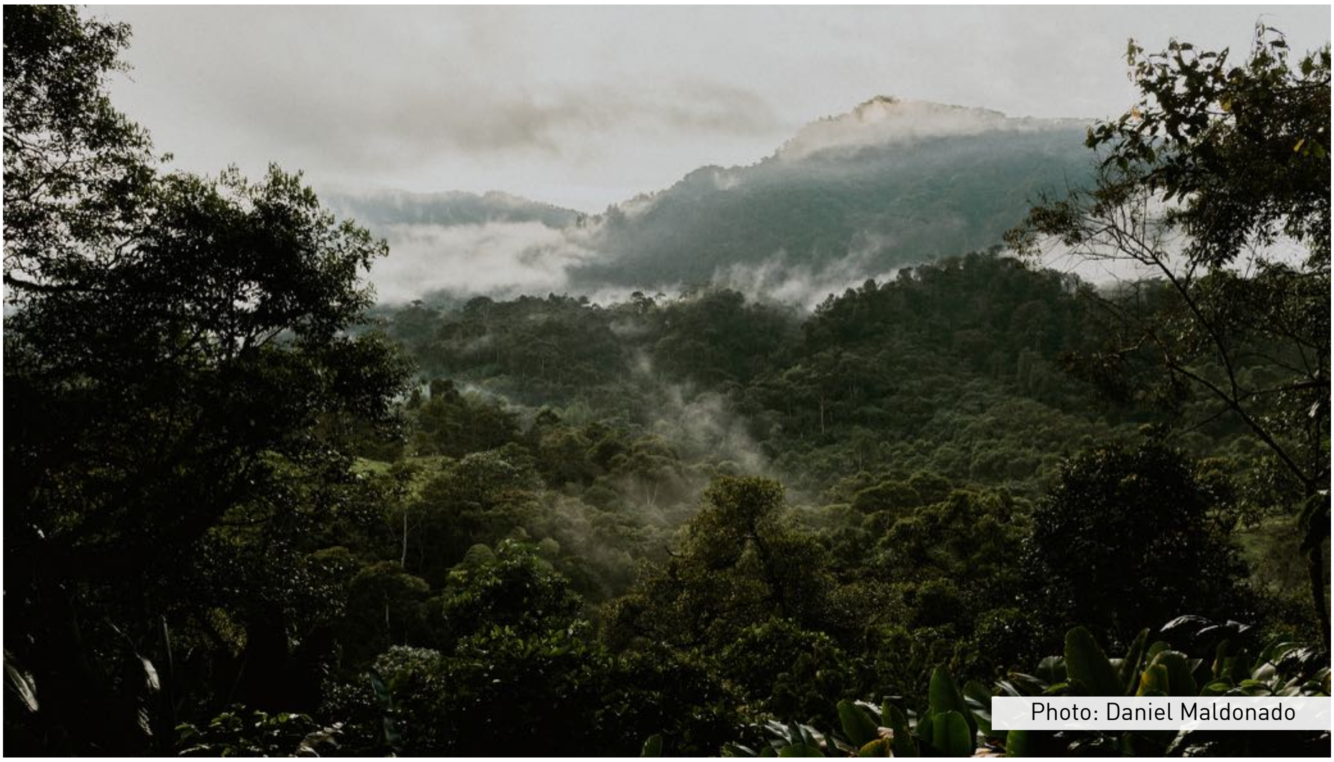


Photo: Daniel Maldonado

Many of the adaptation actions implemented in the region are related to EbA. Most of them involve the implementation of measures traditionally associated with conservation, restoration, ecosystem management and community-based natural resource management (UNEP 2015, Seddon et al. 2016, Hofstede 2019). Examples of EbA actions that have been used include (Heller and Zabaleta 2009, Hole et al. 2011, Cuesta et al. 2012, PPA 2012, Cuesta et al. 2014, Almeida 2015, Becerra 2017, Ariza et al. 2017, Fuentes-Castillo et al. 2020):

- Conservation and management of threatened or emblematic species (in-situ and ex-situ management, translocations, threat reduction, etc.).

- Community agreements: in indigenous reserves, in private areas, or at regional-municipal level for participatory land management and conservation of forests and high Andean ecosystems (paramos, punas).

- Identification of gaps in protected area systems and establishment of protected area corridors (considering climate hazard scenarios).

- Management of rural landscapes (e.g., live fences, shade crops, etc.).

- Ecological restoration strategies using native or exotic species (including monitoring strategies in some cases).

- Agroforestry and silvopastoral systems (e.g., analogue forestry).

- Fencing or protection of springs, livestock stocking control, sustainable pasture management.

- Soil restoration in degraded areas (e.g., by mining or intensive agriculture).

- Management of invasive species that have negative impacts on diversity or ecosystem services (e.g., the thorny shrub *Ulex europaeus*).

- Fire monitoring, early warning and control systems.

Although there is information generated by projects and studies, among the most important knowledge gaps identified is the need to synthesise information on the impact on ecosystem services and the quality of life of different conventional, traditional and alternative management systems (agriculture, livestock, forestry, etc.). At the same time, gaps are identified in the integration of knowledge on the effectiveness and social and environmental impacts of ecological restoration measures, as well as the effectiveness of conservation strategies and the generation of greater connectivity from the landscape to the continental level (e.g., biological corridors, regional systems of protected areas) that have been implemented in the region (Table 6).

Table 6. Knowledge gaps around EbA in the Andes ecosystems.

Knowledge gaps	References
Uncertainty about the impacts of CC and land use on the structure, ecosystem services and resilience of Andean ecosystems remains a fundamental gap in the design of EbA strategies.	Cuesta et al. 2012, Becerra 2015, Schoolmeester et al. 2016, Hofstede 2019.
Lack of studies and monitoring data and a critical review at Andean level of the evidence of ecological restoration experiences, and their impacts on ecosystem services and the quality of life of local populations: identifying potentials, bottlenecks and institutional enabling conditions, limiting factors and opportunities.	Bustamante et al. 2012, Aguilar & Ramírez 2015, Becerra 2015, 2017, Seddon et al. 2016, Klein et al. 2017, Mathez-Stiefel et al. 2017, Avella 2019, Hofstede 2019, Llambí et al. 2019.
Comparative analysis of adaptation practices that reduce impacts on biodiversity and ecosystem services and increase resilience (many are traditional conservation or ecosystem management practices, but their effectiveness in increasing resilience is unknown).	Becerra 2015, UNEP 2015, Seddon et al. 2016, Hofstede 2019.
Effectiveness of EbA in the context of semi-natural or transformed systems (e.g., agro-forestry systems, managed pastures) and along transformation gradients.	Hofstede et al. 2019, Llambí et al. 2019.
Effectiveness of biodiversity conservation measures and their contribution to adaptation. Species and ecosystem conservation measures have been implemented in the region (e.g., protected area systems, biological corridors, ex situ conservation), but there is a lack of evaluation studies on their effectiveness as adaptation tools. Evaluation of the effectiveness of REDD and REDD+ measures in the region.	Hole et al. 2011. Becerra 2015, UNEP 2015, Hofstede 2019, Fuentes-Castillo et al. 2020.
Although there have been advances in research, knowledge of the impact of forestation and reforestation strategies on hydrological functioning is still lacking (e.g., long-term monitoring data, systematic comparative studies, traditional knowledge on species and forest management, effects of managed plantations, impact of exotic species, including *Polylepis racemosa*).	Bustamante et al. 2012, Mathez-Stiefel et al. 2017, Cerrón et al. 2019.
Identification of priority conservation areas in CC scenarios and gaps in conservation areas at the Andean regional scale and coordination of conservation figures (protective forests, regional conservation areas, private reserves, indigenous reserves).	Hole et al. 2011, Cuesta et al. 2012, Fuentes-Castillo et al. 2020, Pauli & Halloy 2020.
Evaluation of the effectiveness of conservation corridors and high Andean ecosystems.	Hole et al. 2011, Cuesta et al. 2012, Baez et al. 2016.
Empirical evaluation of the effectiveness of rural landscape management strategies (e.g., live fences, shade crops, etc.).	Hole et al. 2011, Cuesta et al. 2012, Baez et al. 2016.

5.2.1.4. Production systems and agriculture

This is another thematic area in which much experience has been accumulated in the Andes, and in which many of the adaptation actions are related to more traditional measures of sustainable rural development and community-based development projects. In turn, adaptation projects in production systems have emphasised the rescue and revalorisation of traditional management practices (especially in Bolivia, Peru and Ecuador) and, in some cases, their integration with new technologies (Bustamante et al. 2012, Pérez et al. 2010, Postigo et al. 2012, Hosftede 2019). Examples of adaptation strategies in the area of crop and livestock production systems include (Young and Lipton 2006, Stadel 2008, VanDerwill 2008, Pérez et al. 2010, Surkin et al. 2010, de Biévre et al. 2012, Postigo et al. 2012, Vidaurre et al. 2013, Almeida 2015, Ariza et al. 2017):

- Agroclimatic modelling and analysis of crop distribution, phenology and productivity under CC scenarios for the implementation of adjustments to the agricultural calendar, locations or planting practices, etc.; for example, the International Center for Tropical Agriculture (CIAT) and the Food and Agriculture Organization (FAO).

- Promotion of agroecological management alternatives (e.g., biological pest and disease control, biofertilizers and organic fertilisers, community gardens, etc.).

- Improvement of irrigation systems, infrastructure and water management efficiency.

- Sustainable livestock farming (e.g., pasture improvement, rotation, genetic improvement of herds, wetland conservation, etc.).

- Research, development and field promotion of new varieties, breeding and biotechnological alternatives, including more drought-resistant crop varieties.

- Promotion of agricultural diversification strategies

- Development of rural funds, agricultural insurance and other financing schemes that consider climate risk (especially in the face of extreme events).

- Strengthening local producer organisations and social capital.

Among the most important knowledge gaps identified (Table 7), it is important to highlight the need for more comprehensive analyses of how CCA practices are embedded in the social context, socioecological dynamics, productive sectors, rural livelihoods, and value chains in order to make them more climate resilient and influence the transformation of agriculture towards a "climate-smart" agriculture (see, for example, Chen et al. 2018, Ngoma et al. 2018, Hofstede 2019). In turn, the need for integration of traditional farming practices and agroecological strategies with the use of new technologies (e.g., agroclimatic information technologies) is identified as a priority, particularly in relation to economic costs and social benefits. Table 7 presents the gaps identified in this area.

Table 7. Knowledge gaps around production systems and CCA strategies.

Knowledge gaps	References
Need for agricultural research on plant varieties (e.g., drought resistant varieties) and biotechnological alternatives, breeding and use of molecular markers to identify potential genes for adaptation in medium-term breeding programmes (especially in small-scale agricultural sectors).	Postigo et al. 2012, de Biévre et al. 2012, Becerra 2015, GCA 2019.
Climate information systems for agricultural support and early warning of climate risks.	De Biévre et al. 2012, Hofstede 2019.
Study of the effects of CC and adaptation strategies as a basis for the development of CC-resilient value chains in the agricultural and livestock sector with a territorial approach to production systems.	Ariza et al. 2017, Klein et al. 2017, Mathez-Stiefel et al. 2017, Hofstede 2019, Wymann et al. 2018.

Effects of CC on the spatial distribution of crops and soil erosion and degradation processes and their implications for the adaptation of agricultural production systems.	Pérez et al. 2010, Postigo et al. 2012, Hofstede et al. 2014, Tito et al. 2017.
Effects of CC on pest and disease dynamics for crops and animals and adaptation strategies for pest and disease management (e.g., agricultural diversification).	GLOCHAMORE 2005, Pérez et al. 2010, Postigo et al. 2012, Tito et al. 2017.
Improve knowledge of the social mechanisms that enable different adaptation options in the agricultural sector, based on the approach of access to different types of capital and the adaptive capacities of the rural population.	Pérez et al. 2010, Postigo et al. 2012, Dilling et al. 2019.
Analysis of rural-urban migration processes, how CC interacts with these processes and the impacts on the adaptive capacity of rural populations.	GLOCHAMORE 2005, Klein et al. 2017.
Analysis of the links between changes in water availability due to CC and production alternatives/adaptation strategies.	Pérez et al. 2010, Gleeson et al. 2016.
Analysis of low-cost, climate-smart agroecological strategies for adoption by the poorest sectors.	Hofstede 2019.
Analysis of the social impacts of adaptation strategies in production systems beyond the effects on performance (indicators of quality of life, environment, nutrition, etc.).	Tito et al. 2017, Hofstede 2019..
Ecological, social and productive impacts and analysis of the adaptive value of agricultural diversification strategies.	Pérez et al. 2010, Ariza et al. 2017, Klein et al. 2017.

5.2.1.5. Socio-economic, cultural and health aspects

Consideration of context-related aspects and socio-economic, cultural and health impacts are fundamental cross-cutting issues for the implementation of CCA strategies, and require the adoption of more transdisciplinary approaches. There are several key issues here that constitute gaps for adaptation in the region (Table 8), including the development of indicators for analysing social vulnerability to CC adapted to different contexts (e.g., rural vs. urban), as well as multi-criteria indicators to assess changes in the adaptive capacity of individuals, communities and institutions in relation to changes in livelihoods and human and social capital (see Klein et al. 2017, Wymann et al. 2018, Dilling et al. 2019). This is critical, as many CCA projects tend to have a more overt impact on these issues (e.g., through education, governance and capacity building strategies), which directly impact on the climate exposure and vulnerability of socio-environmental systems.

Photo: Luis Daniel Llambí

In turn, it was identified as relevant to deepen the understanding of the different perceptions of climate risks of local actors vs. technical experts and decision-makers and what constitutes, therefore, successful adaptation for different stakeholders. Thus, the analysis of knowledge systems around CC remains fundamental to identify more effective strategies for knowledge dialogue, social and community participation and adaptive co-management (Huggel et al. 2015, Ariza et al. 2017). Likewise, the gender dimension, and in particular the role of women in the successful implementation of CCA programmes, and the vulnerability/impact of CC on the health and nutrition conditions of the poorest sectors are important gaps for adaptation in the region.

Table 8. Knowledge gaps on cross-cutting socio-economic, cultural and health issues and CCA strategies in the Andes.

Knowledge gaps	References
Need to strengthen effective communication, training and education strategies on CCA with rural communities and decision-makers.	Hole et al. 2011, Becerra 2015, Schoolmeester et al. 2016, Wymann et al. 2018.
Need for comparative studies and analyses of social vulnerability, resilience and change in adaptive capacity of rural communities with the implementation of adaptation strategies. Studies on the impact on the quality of life of CCA strategies, especially of the most vulnerable groups.	GLOCHAMORE 2005, Postigo et al. 2012, Huggel et al. 2015, Schoolmeester et al. 2016, Klein et al. 2017, Vuille et al. 2018, Wymann et al. 2018, Avella 2019, Hofstede 2019.
Lack of processes of systematisation and documentation of traditional knowledge associated with adaptation to CC and of strategies for integration with scientific- technical knowledge (dialogue of knowledge).	GLOCHAMORE 2005, Bustamante et al. 2012, Chatterjee et al. 2014, Magrin et al. 2014, Becerra 2015, Schoolmeester et al. 2016, Ariza et al. 2017, Becerra 2017.
Need for analysis and comparative studies to understand the social and institutional determinants for effective adoption of participatory adaptation strategies: How do local context, cultural, organisational and power relations influence these processes?	Bustamante et al. 2012, Huggel et al. 2015, Vuille et al. 2018, Hofstede 2019.
Need for studies on the perception of climate risks by local actors (vs. technical vulnerability and risk analysis). Analysis of historical changes in perceptions and knowledge systems around CC.	Magrin et al. 2014, Huggel et al. 2015, Becerra 2017, Vuille et al. 2018, Dilling et al. 2019.
Lack of information and comparative or synthesis studies on health conditions and variables associated with the impact of CC on health and disease prevalence in the Andean region.	GLOCHAMORE 2005, Chatterjee et al. 2014, Magrin et al. 2014, Gleeson et al. 2016, Schoolmeester et al. 2016, Klein et al. 2017.
Need for analysis and greater emphasis on the gender dimension of adaptation processes, and in particular what factors promote women's effective participation.	Schoolmeester et al. 2016, Hofstede 2019.

5.2.1.6. Other sectors: energy, industry, infrastructure

Although in this analysis we have emphasised adaptation gaps linked to water management, ecosystems and Andean production systems, CCA policies and strategies involve many other sectors including industrial production, mining, large infrastructure development, and energy generation (see—for example—the Strategic Agenda on CCA in the Andes Mountains, 2018).

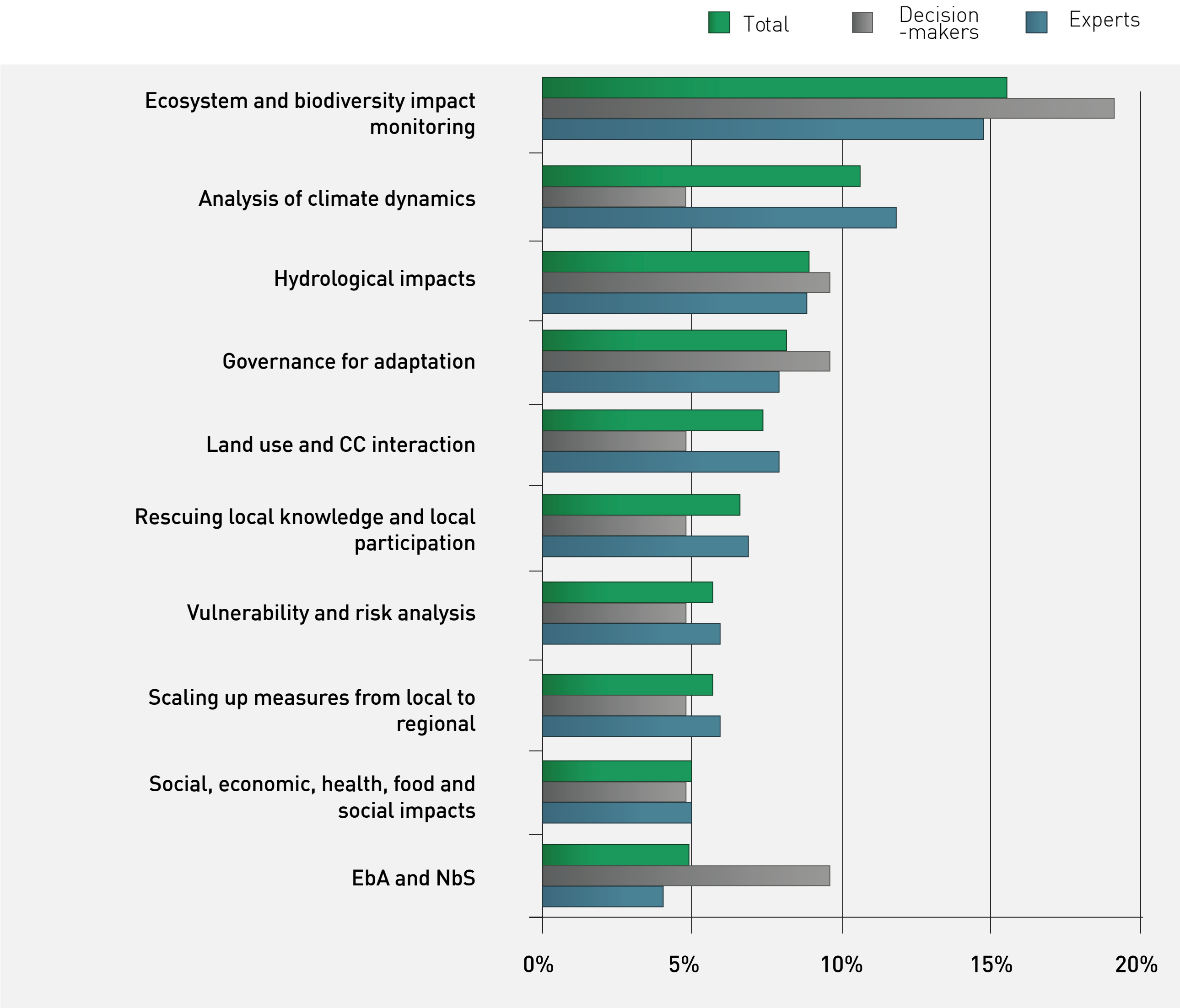
In this context, one of the main gaps identified is precisely the comparative analysis of the adaptation needs of the different sectors of the economy in the Andean countries, and making CC visible as a cross-cutting issue for the design of cross-sectoral policies consistent with the transition towards low-emission, climate-resilient development (see Becerra 2015, Schoolmeester et al. 2016). In the context of the Andes, some key issues to consider here relate to the presence and interdependent relationships between rural spaces and urban populations (e.g., Bogotá, Quito, Santiago de Chile) and the impact of increased demand for renewable energy on mountain socioecosystems (biofuels, hydroelectric generation, etc.). At the same time, an analysis of the opportunities and challenges posed by greater private sector involvement in the implementation and financing of adaptation options is needed (Table 9).

Table 9. Knowledge gaps for CCA in the Andean energy, industry and infrastructure sectors.

Knowledge gaps	References
Comparative analyses of sectoral needs for CCA (e.g., industry, risk and insurance, energy).	Becerra 2015, Schoolmeester et al. 2016, GCA 2019.
Analysis of changes in demand for renewable energy (e.g., biofuels) and its interaction with land use change and ecosystem degradation. Impacts of CC on hydropower generation and shifts to non-renewable sources (e.g., thermoelectric energy).	Hole et al. 2011, Bárcena et al. 2020.
Need for synthesis studies on risks to urban areas (especially poorer populations) and infrastructure linked to CC in mountain areas (e.g., risks for dams, urbanisation in hazardous areas, etc.).	Huggel et al. 2015, Schoolmeester et al. 2016, Klein et al. 2017.
Opportunity to integrate risk management approaches and strategies into climate risk analysis and management in the Andes, including the strengthening of early warning systems, and the development of preventive measures.	Schoolmeester et al. 2016, Bárcena et al. 2020.
Lack of emphasis on exploring and engaging the private sector in adaptation processes. Assessment and analysis of what constitutes "climate resilient investments".	Klein et al. 2017, World Bank 2017, Hofstede 2019,
Need to identify conflicts, trade-offs or contradictions (as well as alternatives and opportunities) between infrastructure development and the conservation of mountain ecosystems (need for integrated social and environmental impact analysis).	Wymann et al. 2018.

5.2.2. Gaps for action identified by experts and decision-makers

The three main gaps identified by respondents regarding the knowledge base for the implementation of CCA projects in the Andes (see Figure 8) were the monitoring of impacts on ecosystems and biodiversity, the analysis of climate dynamics and information on the hydrological impacts of adaptation measures; i.e., mainly ecological and biophysical aspects.

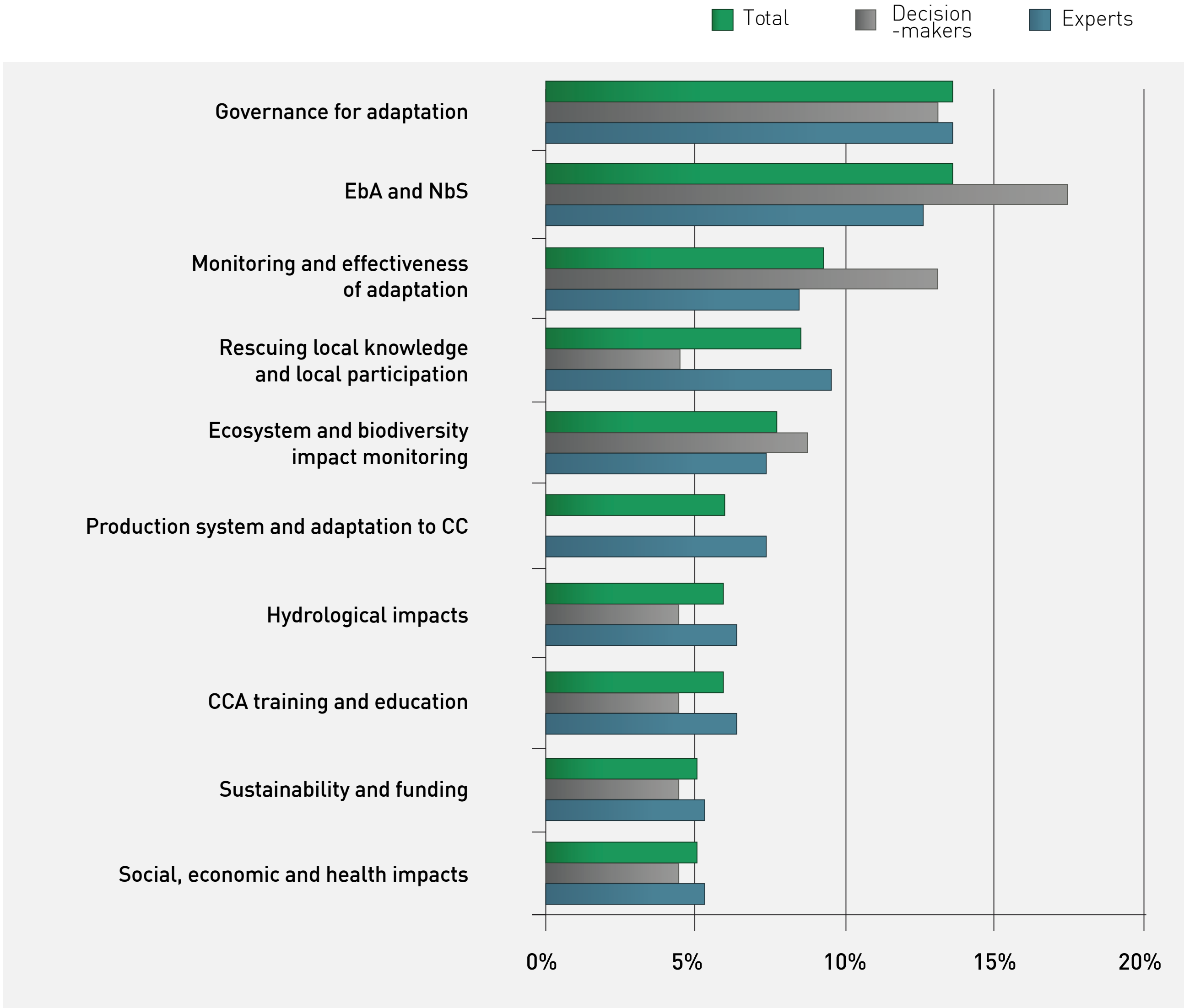


Note: The percentage of respondents who indicated each of the issues identified in the answers (open-ended question) are indicated.

Figure 8. Gaps identified by experts and decision-makers in the Andes in the knowledge base for CCA project implementation.

As shown in Figure 8, there is agreement among experts and decision-makers that the main knowledge base gap for the implementation of adaptation strategies is impact monitoring; i.e., understanding how CC affects the ecological structures of ecosystems and its repercussions on the provision of ecosystem services, which obviously has key implications for the design of CCA projects. For decision-makers, the other issues identified by a significant percentage of respondents were the need for information on hydrological impacts, governance for adaptation, referring to the lack of greater inter-sectoral articulation, and the implementation of ecosystem conservation and restoration strategies or measures. For their part, the experts surveyed pointed to the analysis of climate dynamics; i.e., changes in precipitation patterns and seasonality variation, and hydrological impacts (including present and future changes in hydrology and water availability in watersheds under CC scenarios).

In terms of priority work themes in CCA, respondents most frequently pointed to measures related to governance for adaptation (Figure 9), referring mainly to tools or instruments such as locally adapted management plans, the formation of inter-institutional platforms or working mechanisms, and inter-institutional arrangements for adaptation measures. It is interesting to note that, for IAM decision-makers, the most frequently mentioned topic of work was ecosystem conservation and restoration strategies (EbA and NbS).

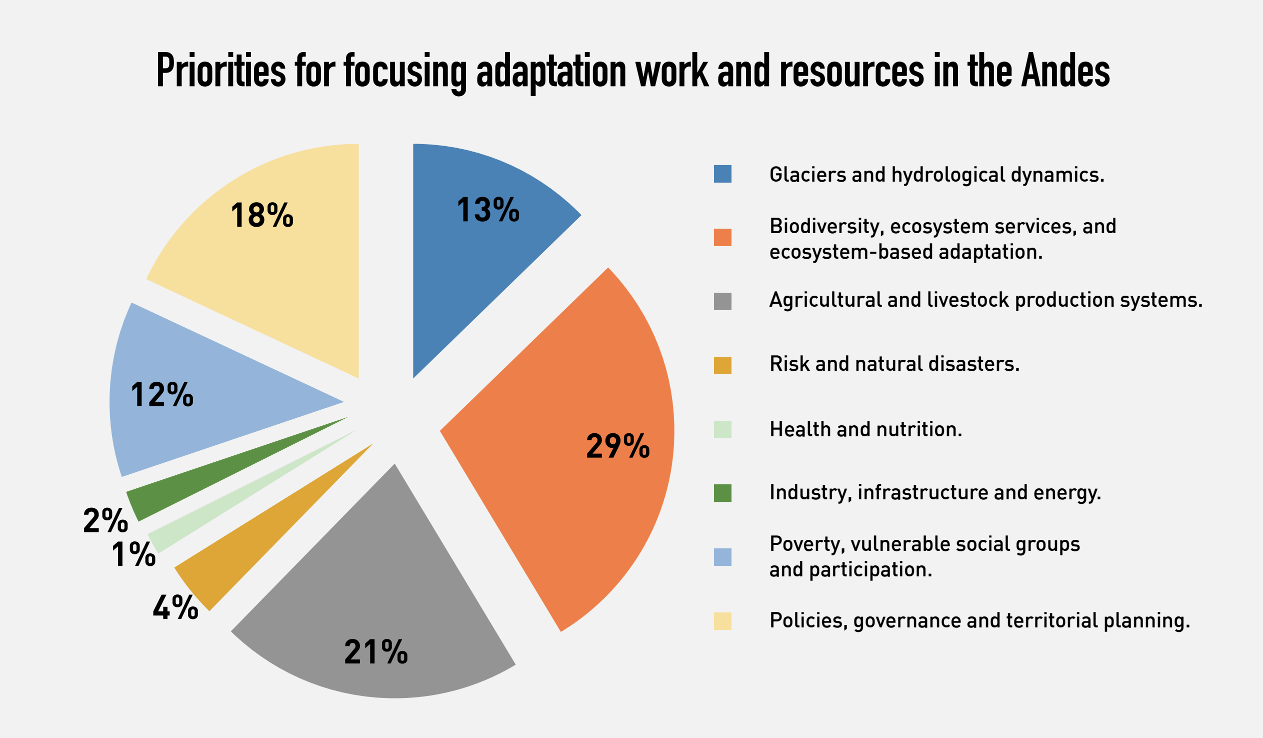


Note: The percentage of respondents who indicated each of the issues identified in the answers (open-ended question) are indicated.

Figure 9. Knowledge gaps identified by experts and decision-makers in the Andes regarding priority issues for work on CCA.

In Figure 9, we observe that the second and third priority work themes identified were conservation and restoration strategies, and monitoring the effectiveness of adaptation, respectively. We can see that, regarding the latter, decision-makers agree that it is one of the main issues and that there is a need to evaluate and compare the effectiveness of different strategies and their results in terms of adaptation to CC. Finally, the rescue of ancestral knowledge and social participation in the design, implementation and development of adaptation measures and strategies were also among the most mentioned topics.

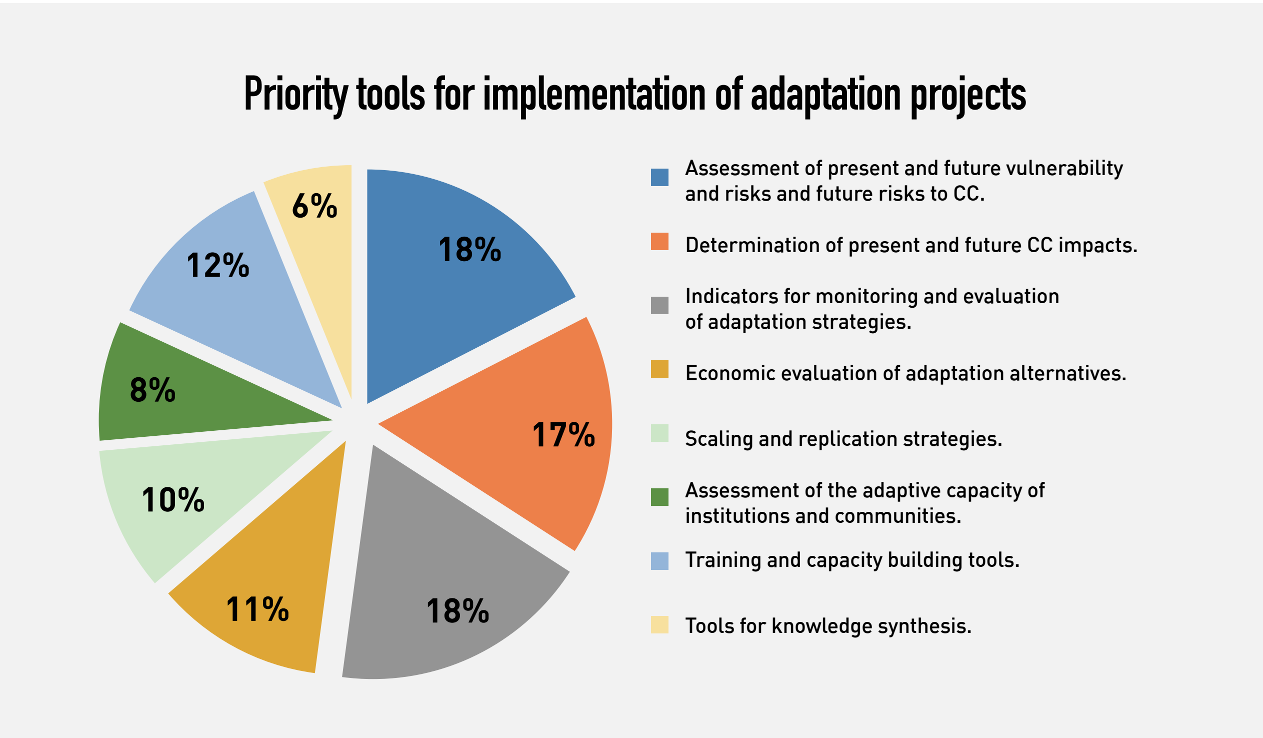
When respondents were asked to rank their priority for investing human and financial resources in different thematic areas linked to CCA (Figure 10), almost a third of respondents identified biodiversity, ecosystem services and ecosystem-based adaptation as the highest priority, followed by crop and livestock production systems, land policy, governance and planning, and glacial retreat and hydrological dynamics (largely in line with the priorities identified in the previous open-ended question on priority themes for work).



Note: The percentage of the top priority issues identified by respondents is indicated (closed question).

Figure 10. Thematic areas prioritised by experts and decision-makers in the Andes to focus work and financial resources on CCA.

Finally, Figure 11 presents the percentage of respondents who considered different tools for the implementation of adaptation projects as priorities. The three prioritised tools were the development of adaptation effectiveness monitoring indicators, CC vulnerability and risk indicators and the determination of CC impacts.



Note: The percentage of the top-priority tools collected by the respondents are indicated (closed question).

Figure 11. Tools prioritised by experts and decision-makers in the Andes for the implementation of CCA strategies.

Summary of results

An interesting finding is that, in the gaps for action and implementation of adaptation strategies, respondents also emphasised the need to strengthen processes for monitoring impacts, vulnerability and effectiveness of adaptation. On the one hand, the need to improve hydrometeorological stations and data series was emphasised, and on the other hand, the use of this information for monitoring the impact of CC on ecosystem services. At the same time, decision-makers and experts agree on the lack of information on the effectiveness of adaptation measures, and the development of indicators to determine whether an action improves adaptive capacity or, on the contrary, it is a maladaptation. Thus, it is evident that there are still gaps in knowledge about the impacts of CC (emphasising impacts on biodiversity, ecosystem services and hydrological regulation) and how management actions contribute to adaptation (tools to assess changes in adaptive capacity for monitoring and evaluation purposes). Joint science-policy work therefore appears to be a priority for knowledge management on adaptation in the region.

It can be observed that, for experts and decision-makers, it is also a priority to strengthen knowledge on EbA strategies, the development of sustainable productive reconversion alternatives and the establishment of resilient production systems. Likewise, both groups agree that it is a priority to work on governance, so that CCA functions as a transversal axis that incorporates multiple institutions, sectors and scales.

Conclusions: Gaps and opportunities for knowledge management

Based on the analysis of the conceptual, policy and management framework for CCA in the global context and in the Andes, as well as the main advances and gaps in knowledge on the subject in the region, we can conclude that the region has made significant progress in the development of a policy and institutional framework for CCA. At the same time, the results of the study show that the knowledge generated on the impacts and vulnerability of Andean socioecosystems to CC has advanced considerably in the last 20 years, with the consolidation of long-term continental monitoring networks being a fundamental contribution (e.g., the Andean Ice and Snow Working Group, Gloria-Andes, IMHEA and the Andean Forests Network).

However, there are still important knowledge gaps that limit the effective implementation of CCA policies and strategies in the region and therefore constitute opportunities for the generation of knowledge management tools and products and for the strengthening of ongoing initiatives. The following are the main needs to respond to these gaps, prioritised in light of the analysis carried out and the responses of the experts and decision-makers consulted:

- There are important gaps in basic knowledge about climate, CC and its ecological and social impacts in the Andes. This raises the need to continue strengthening hydro-meteorological monitoring systems in the Andes, as well as long-term monitoring networks and comparative research. Regarding the generation of knowledge synthesis studies, it would be important to analyse the lessons learned in terms of the functioning and sustainability of these networks, as well as to continue supporting the dissemination of information derived from them (web page, synthesis publications, etc.).

- It is necessary to analyse how different adaptation actions or solutions generate changes in the vulnerability, resilience and adaptive capacity of individuals, communities and Andean socioecosystems. The absence of agreed tools and the lack of experiences that evaluate CCA policies and strategies have limited the processes of generating syntheses and comparative studies on the impacts of these strategies and CCA actions. This raises the need to propose tools and indicators (toolkits) for monitoring CCA projects or strategies.

- Comparative analyses of approaches, impacts and lessons learned from adaptation projects and strategies are required. It is important to understand how institutional and governance contexts have influenced the success or failure of adopted adaptation strategies, as well as the factors that have influenced the integration of different visions and knowledge systems on CC, (traditional vs. technical/scientific) and the incidence of effective participation of local actors and the most vulnerable social groups. In turn, it is important to evaluate the strategies that have been implemented for the replication and scaling up of experiences and the promotion of institutional and financial sustainability schemes (obstacles and opportunities).

- It is necessary to promote a more comprehensive or multisectoral vision of adaptation strategies. An interesting opportunity is the generation of synthesis or meta-analysis studies in which projects

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and strategies linked to the management of water resources, production systems and EbA in the region are jointly analysed (including the analysis of synergies and contradictions). For this, it is important to start from a transdisciplinary approach that analyses socioecosystems considering the environmental and ecological dimensions of adaptation strategies, as well as the opportunities for insertion and potential impacts in the social, economic and cultural context.

• Integrated analyses and comparative syntheses of the impacts of CC on ecosystem functioning and the ecosystem services they provide (e.g., water regulation, biomass and carbon accumulation, fertility regulation, etc.), the effects of different land-use strategies, and the benefits of ecosystem restoration and management in the Andes under CC scenarios are a priority. These analyses are relevant to identify different adaptation options, especially those linked to agricultural and livestock production alternatives and assisted restoration, forestation/reforestation and management strategies (e.g., agroforestry systems, pasture management, rural landscape management, etc.).

• It is necessary to promote processes of systematisation and comparison of different CCA strategies based on traditional management strategies and their integration with new technological options, especially considering the costs and benefits of different alternatives, and their value in strengthening the adaptive capacities of local populations (especially the most vulnerable) and the institutional framework.

• It is important to generate and disseminate (e.g., through INFOANDINA or other platforms) analysis documents and synthesis indicators of the state of health, impact and vulnerability of Andean ecosystems to CC at different scales (including downscaling methodologies, integration of multiple sources of information, etc.). In this regard, it is necessary to promote the discussion of tools and alternatives for the generation of CC vulnerability scenarios, as well as approaches and methodologies for linking vulnerability and risk analyses with the proposal of portfolios of adaptation solutions.

• Another priority is the development of vulnerability analyses that integrate social, economic, political, biophysical and institutional components and the generation of indicators to assess the adaptive capacity of local communities, Andean production systems and society in general, with comprehensive approaches that reflect the complexity of adaptation and the context in which they develop.

• Work on analysing the most effective models of governance and the structural changes needed in governmental and non-governmental institutions for adaptation remains a priority issue despite the institutional and regulatory advances stemming from the UNFCCC and its implementation at the national level in the region. Understanding adaptation as a transversal axis in all development activities and not as an environmental problem is reflected in the need to articulate adaptation policies intersectorally, at different scales and among diverse actors.

• There is a need to focus efforts on understanding how and how much ancestral and local practices contribute as adaptation measures to reduce the vulnerability of communities. In the same sense, the sustainability of adaptation measures will depend on the appropriation of these practices by local communities, which in turn affects the opportunities for participation in CCA strategies, from the conceptualisation of the climate problem to the implementation of measures. This is where there is an opportunity to revalue ancestral knowledge, integrate it with innovative technological options and evaluate its effectiveness vis-à-vis other alternatives.

• Not enough effort has been devoted to communicating information on the impacts of CC on Andean socioecosystems, so it is a priority to have the appropriate mechanisms in place to make the available information readily accessible to the public and, above all, to ensure that it reaches decision-makers in an effective way. Thus, it is still a pending task to promote a more effective dialogue between science and policy and to ensure that adaptation strategies respond more clearly to the scientific evidence on the impact of CC on socioecosystems and their responses.

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Annexes

ANNEX 1
List of respondents
Specificities and Policies

	Nombre y Apellido	Institución	País
1	Ana María Benavides	Jardín Botánico de Medellín	Colombia
2	Eulogio Chacón Moreno	Instituto de Ciencias Ambientales y Ecológicas (ICAE), Universidad de Los Andes (ULA)	Venezuela
3	Esteban Suárez	Universidad San Francisco de Quito	Ecuador
4	Francisco Clavijo	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
5	Verónica Quitigiüiña	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
6	Jessica Calle	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
7	Jorge Luis Ceballos	Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)	Colombia
8	Nikolay Aguirre	Universidad Nacional de Loja	Ecuador
9	Fabian Drenkhan	Universidad de Zúrich	Suiza
10	Martin Baruffol	Kew Royal Botanic Gardens	Reino Unido
11	Olivier Dangles	Instituto Francés de Investigación y Desarrollo (IRD)	Francia
12	Diego Quishpe	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
13	Javier Yépez	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
14	Johnny Mena	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
15	Héctor Peñaherrera	Proyecto Adaptación a los Impactos del Cambio Climático en los Recursos Hídricos de los Andes (AICCA) – CONDESAN	Ecuador
16	Natalia Norden	Instituto de Investigación en Recursos Biológicos Alexander von Humboldt	Colombia
17	Cristiana Leucci	Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña (INAIGEM)	Perú
18	Vivien BONNESOEUR	Consorcio para el Desarrollo Sostenible de la Ecorregión Andina (CONDESAN)	Perú
19	Bert De Bievre	Fondo para la Protección del Agua (FONAG)	Ecuador
20	Antonio Tovar	Centro de Datos para la Conservación-Universidad Nacional Agraria La Molina	Perú
21	Aracely Salazar-Antón	Cooperación Técnica Alemana (GIZ)	Ecuador
22	Rossi Taboada	Centro de Competencias del Agua	Perú

23	Julio Postigo	Indiana University	Estado s Unidos
24	Marcela Galvis	Instituto de Investigación en Recursos Biológicos Alexander von Humboldt	Colombia
25	Enrique Michaud	Illa Biodiversidad y Desarrollo (Illariy)	Perú
26	Pere Ariza Montobbio	Inspira Red y Facultad Latinoamericana de Ciencias Sociales (FLACSO)	Ecuador
27	Francisco Román	Consorcio para el Desarrollo Sostenible de la Ecorregión Andina (CONDESAN)	Perú
28	Stef de Haan	Centro Internacional de la Papa (Iniciativa Andina)	Perú
29	Lermis Lara	Ministerio del Poder Popular para la Pesca y Acuicultura	Venezuela
30	Camilo Rodríguez	Consultor Independiente	
31	Raúl Córdova	Universidad de Helsinki	Finlandia
32	Carlos Enrique Sarmiento Pinzón	Programa Páramos y Bosques USAID	Colombia
33	Rolando Célleri	Universidad de Cuenca	Ecuador
34	Daniel Wiegant Crespo	Universidad de Wageningen	Holanda
35	Julieta Carilla	Instituto de Ecología Regional (IER)	Argentina
36	Patricia Velasco	Fundación Fututo Latinoamericano (FFLA)	Ecuador
37	Mirella Gallardo	Instituto de Montaña	Perú
38	Cecilia Turin	Instituto de Montaña	Perú
39	Andrés Felipe Carvajal Vanegas	Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)	Colombia
40	Vanessa Cortés	Ministerio de Ambiente y Desarrollo Sostenible	Colombia
41	María José Galarza Vásconez	Ministerio del Ambiente y Agua	Ecuador
42	Gladys Santis	Ministerio del Medio Ambiente	Chile
43	Jaime Rovira	Ministerio del Medio Ambiente	Chile
44	Lucas Di Pietro Paolo	Ministerio de Ambiente y Desarrollo Sostenible	Argentina

ANNEX 2
Online survey of knowledge gaps on climate change adaptation in the Andes

Link to the online survey: https://docs.google.com/forms/d/e/1FAIpQLSfePU2O1TiwEQyGtWePmYYmemmw1YZuzPaL6ob87AW_o1-qMg/viewform

Section III. IDENTIFICATION OF KNOWLEDGE GAPS AND PRIORITY ISSUES

7. In your opinion, what are the three main knowledge gaps for the implementation of climate change adaptation projects in the Andes?

Option 1. Your answer:

Option 2. Your answer:

Option 3. Your answer:

8. In your opinion, what are the three priority areas of work in terms of implementing climate change adaptation strategies in the Andes?

Option 1. Your answer:

Option 2. Your answer:

Option 3. Your answer:

9. What do you consider to be the three thematic areas where there is the greatest need for capacity building for climate change adaptation in the Andes?

Option 1. Your answer:

Option 2. Your answer:

Option 3. Your answer:

10. On which three topics do you think it is most important to generate knowledge synthesis at the Andean regional level and why?

Option 1. Your answer:

Option 2. Your answer:

Option 3. Your answer:

11. Choose three of the following thematic areas according to their level of priority to focus work and financial resources on climate change adaptation in the Andes (Choose the top three highest priority).

- Glaciers and hydrological dynamics.

- Biodiversity, ecosystem services and ecosystem-based adaptation.

- Agricultural and livestock production systems.

- Risk and natural disasters.

- Health and nutrition.

- Industry, infrastructure and energy.

- Poverty, vulnerable social groups and participation.

- Policy, governance and spatial planning.

12. Choose three of the following tools or methodologies in terms of their priority for the implementation of climate change adaptation projects in the Andes (Choose the 3 with the highest priority).

- Tools for assessing current and future climate change vulnerability and risks.

- Tools for the determination of current and future climate change impacts.

- Tools and indicators for monitoring and evaluation of adaptation strategies.

- Tools for economic assessment of adaptation alternatives.

- Scaling-up and replication strategies.

- Tools for assessing adaptive capacity of institutions and communities.

- Training and capacity building tools.

- Knowledge synthesis tools.

13. In your opinion, what key elements should be incorporated in a climate change adaptation project, beyond what is usual in environmental management and/or development projects?

Element 1. Your answer:

Element 2. Your answer:

Element 3. Your answer:

14. In your opinion, what is the main gap or knowledge gap in each of the following climate change issues (mention one, the most relevant). Example: hydrometeorological information, vulnerability calculation methodologies, risk indicators, etc.

1. Research/scientific evidence on climate change impacts in the Andes. Your answer:

2. Vulnerability of socioecosystems in the Andes. Your answer:

3. Adaptation of Andean production and livestock systems. Your answer:

4. Ecosystem-based adaptation. Your answer:

5. Ancestral/traditional practices as adaptation measures. Your answer:

6. Water resources in the Andes. Your answer:

7. Policies, institutions and social participation. Your answer: