

ADAPTATION  
AT ALTITUDE

Leave No Mountain Behind: The Synthesis Series

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# Adapting to transboundary risks in mountain regions



**Adaptation at Altitude**, a collaborative programme launched and co-supported by the Swiss Agency for Development and Cooperation, assists mountain communities and those working with them by improving the knowledge of appropriate climate change adaptation and disaster risk reduction strategies in the mountains, and by transferring that knowledge through science–policy platforms to inform decision-making in national, regional and global policy processes. This synthesis series is an example of that work.

**Authors:**

Kate Williamson (SEI), Rosie Witton (SEI), Estelle Lorang (Edinburgh University)

**Contributor:**

Sara Talebian (SEI)

**Copy-editing:**

Steven Graham

**Graphic design:**

Maria Libert and Carolyne Daniel (Zoï Environment Network)



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## Key messages

- Successful transboundary solutions in mountainous regions require both high-level coordination between national and regional authorities, and collaboration on solutions with Indigenous and local communities.
- Cooperation of regional and national governing bodies is important when coordinating a transboundary solution to ensure an integrated approach. This is key for countries in mountainous regions to both adapt to climate change impacts and manage shared resources that cross national borders.
- Stakeholder engagement and inclusive participatory processes are key to supporting the longevity and long-term sustainability of a transboundary solution in mountainous regions. There is a need to encourage local ownership through collaboration with Indigenous and local communities.
- Capacity building and knowledge sharing are key to support the creation, implementation, and success of transboundary solutions in mountainous regions. Furthermore, sharing best practices between countries and regions can support effective resource management.
- Using available information resources such as regional data platforms can better account for and anticipate transboundary climate risks, and help share information and knowledge of hazards, risks to resources, and risks to ecosystems.

## Introduction

Mountains suffer some of the most visible impacts of climate change: rising temperatures and changing precipitation patterns are melting glaciers, disrupting water flows and affecting ecosystems, creating and worsening natural hazards and threatening livelihoods and communities both within mountain regions and further downstream. These climate impacts and associated risks are not constrained by national borders. With mountain ranges often spanning multiple countries, adaptation to transboundary climate risks is becoming an increasingly complex and urgent challenge in mountain regions.

Here we synthesise knowledge available on the [Adaptation at Altitude Solutions Portal](#) regarding transboundary climate risks, challenges, and solutions. The brief is intended to enhance awareness of these risks and improve preparedness to manage them by sharing examples of solutions available on the portal.

## What are transboundary climate risks?

Transboundary climate risks can be defined as climate risks that cross national borders, encompassing both risks associated with the transboundary impacts of climate change and risks associated with the transboundary effects of adaptation or maladaptation (Hedlund *et al.*, 2018; Harris *et al.*, 2022). In other words, these are risks and/or impacts that result in a region outside of the country of their inception (Carter *et al.*, 2021).

There are different approaches to conceptualising and assessing transboundary climate risks. They can be characterised by:

- **The pathway through which they flow:** risks propagate through pathways or channels that connect different systems and countries. These pathways can be i) biophysical, encompassing transboundary ecosystems; ii) financial, focusing on flows of capital; iii) people-based, representing the movement of people between countries; and iv) trade-based, encapsulating markets and supply chains (Benzie *et al.*, 2016).
- **The geographical nature of transmission:** risks can be transmitted across physical borders and spread to neighbouring countries through for example shared river basins and mountain ranges (Challinor *et al.*, 2017; Bednar-Friedl *et al.*, 2022); and across 'non-contiguous borders' between geographically distant countries via for example trade and supply chains (Benzie *et al.*, 2019; Bednar-Friedl *et al.*, 2022).
- **The sectors through which they propagate and impact:** risks can spread across economic sectors, such as financial, agricultural and social sectors, within or between countries (Talebian *et al.*, 2023).
- **The mode and dynamic of transmission:** risks can transmit across borders through alternative modes. Their transmission dynamics could be simple, complex, or systemic. The initial climate risks can generate knock-on effects that can grow in magnitude or diminish as they cascade across borders, or interact and compound with other non-climate drivers to create new risks. (Talebian *et al.*, 2023; Anisimov *et al.*, 2023)

## Why it matters for mountains

Mountainous regions are significantly exposed to transboundary climate risks. Left unchecked, these risks could threaten countries' societies and economies, damaging livelihoods, spurring inequalities, amplifying food and water insecurities, and impeding progress towards many of the Sustainable Development Goals and Sendai Framework for Disaster Risk Reduction Targets. For example, the Hindu Kush Himalaya (HKH) region spans eight countries (Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan) and includes 12 major river basins (seven of them transboundary) that connect upstream and downstream areas through trade, culture, communication and resource management and support the livelihoods of nearly 2 billion people (Molden *et al.*, 2017). The HKH region is vulnerable to transboundary climate risks that originate within the region (e.g. flooding, including from glacial lake outburst floods), and beyond it (e.g. food insecurity as a result of climate events in food-exporting countries outside the region) (Talebian *et al.*, 2023).

However, efforts to integrate transboundary climate impacts and associated risks within adaptation, and understand the impacts of climate change and adaptation responses within mountains more generally are insufficient (Bilbao Barrenetxea and Faria, 2022; Harris *et al.*, 2022). Greater cooperation utilising the diverse pool of knowledge that exists across mountain ranges will help tackle this deficit and accelerate learning opportunities for mountain stakeholders.

## Adapting to transboundary climate risks

The complex nature of transboundary climate risks and their origins means that pre-emptive responses can be fragmented or absent altogether (Harris *et al.*, 2022; Steiner *et al.*, 2023). Effectively tackling these risks and mitigating their further inception and transfer require adaptation approaches that follow a systems perspective (Nadin and Roberts, 2018). Stakeholders involved in adaptation planning and implementation must take a holistic view, addressing interdependencies between different components, such as ecosystems, practices, and economies, that may span and operate across borders.

Designing and implementing cross-border adaptation solutions requires cross-scale collaboration between different actors. This includes national, regional and local governments (public actors), local communities and non-governmental organisations (NGOs) (non-profit private actors), and businesses (for-profit private actors) in multiple countries. Cooperating at transboundary scale provides an opportunity for new types of knowledge exchange, and policy makers can benefit from the breadth of expertise on climate risks and adaptation approaches within their region. Not only will this strengthen countries' own national adaptation plans by enhancing their policy responses to the negative effects of transboundary climate impacts, it will also help share the costs of adaptation measures and mediate potential areas of conflict between countries (Tilleard and Ford, 2016; Nadin and Roberts, 2018).

## Transboundary risks, impacts, and solutions

This brief examines solutions on the A@A Solutions Portal that have been implemented either across borders or in multiple countries with shared borders. These transboundary solutions were then categorised according to the type of risk that they primarily address:

- hazards
- risks to shared resources
- ecosystem risks

The first group addresses hazards such as avalanches and flooding; the second focuses on the management of resources, such as water; and the third group describes solutions where impacts on the environment and ecosystems can affect livelihoods, for instance in agriculture.

Overall, six solutions are discussed within the three main themes. Further information on each of the solutions can be found on the [A@A Solutions Portal](#).

# 1. Hazards

Hazards are potential natural or human-induced physical events that can lead to loss of life or to the loss or damage of infrastructure, property livelihoods, ecosystems and resources.

Hazards in mountains are evolving and complex, with higher elevations experiencing more rapid changes in temperature compared to lower elevations. This warming can impact ecosystems, the cryosphere, hydrology and biodiversity, as well as communities (Pepin *et al.*, 2015). Consequently, there is no shortage of potential transboundary hazards in mountain regions. Common hazards which could have transboundary impacts include flooding, drought, landslides, avalanches and rockfalls as well as disease and health risks. Hazards are often linked and can have cumulative, multi-level effects on a region, including at a transboundary level.

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## The Winter Preparedness and Avalanche Readiness Programme in Afghanistan, Pakistan, and Tajikistan

Avalanches can be transboundary hazards. Large-scale ice avalanches can mobilise solid material in downstream areas and pose risks to lives, livelihoods, and infrastructure. Between 2010 and 2021, 919 avalanche events and 362 fatalities were recorded across Afghanistan, Pakistan and Tajikistan (Gurung *et al.*, 2023). Seasons with heavy avalanche activity generally extend across borders and the associated risks and negative consequences (e.g. for international tourism in the Himalaya, labour migration in the Hindu Kush) are of a transboundary nature (Acharya *et al.*, 2023).



An exercise on high altitude Search and Rescue being conducted with the volunteers from the Avalanche Village Preparedness Team of Barchadev, Nishusp and Pish villages in Tajikistan. © AKAH

The Winter Preparedness and Avalanche Readiness Programme plan in Afghanistan, Pakistan, and Tajikistan, funded and implemented by Aga Khan Agency for Habitat (AKAH), **addressed the topic of preparing for snow hazards that may affect infrastructure and livelihoods in each country and on a trans-boundary level. The initiative aimed to improve avalanche preparedness plans including risk assessment, weather monitoring, emergency communication, early warning, risk awareness, building community capacity through volunteers, and stockpiling essentials. The programme is based on a community level hazard, vulnerability and risk assessment to identify villages and people exposed to avalanches.** AKAH prioritised 616 out of 2,496 assessed settlements as high avalanche risk in order to enhance protections for over 40,000 people across programme areas in the three countries (Gurung *et al.*, 2023).

Capacity building is central to the programme, with external experts providing training for volunteers from local communities. For example, awareness sessions have been held and avalanche preparedness teams established in several avalanche-prone villages; trained volunteers are also managing more than 80 weather monitoring posts set up in high-avalanche-risk areas.

A recent study (Gurung *et al.*, 2023) compared avalanche events in AKAH programme areas against those in similar locations. The study found that, despite a nearly six-fold increase in avalanche events in 2021 compared to 2017, recorded fatalities were 12% lower in and around AKAH programme areas. There were also fewer fatalities per avalanche event in the programme area compared to the other locations.

The results indicate that capacity building and preparedness planning for avalanches on a trans-boundary scale can improve resilience and reduce fatalities.

## 2. Risks to shared resources

Resource management can be a complex task when undertaken at local, regional, and national levels. With the impacts of climate change cascading across borders, it is becoming imperative to think about resources and how best to manage them also on a transboundary level. Resource management encompasses a variety of goods, materials, and services whose availability in one location may be reliant on actions or processes in another location. For example, in a river basin, downstream communities may need to engage and cooperate with upstream communities to manage their shared ecosystems and resources. In particular, risks to shared water resources and measures taken to manage water resources can have significant implications for water quantity, quality, and security.

With mountain regions facing increasing risks from climate change, resources may become scarcer, so resource management will become increasingly important to mitigate cascading risks and support transboundary cooperation.

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### Adaptation to the Impacts of Climate Change on Water Resources in [Bolivia](#), [Colombia](#), [Ecuador](#) and [Peru](#)

The 'Adaptation to the Impacts of Climate Change on Water Resources in the Andes' (AICCA) project is a regional initiative to increase climate resilience and manage water resources across Bolivia, Colombia, Ecuador and Peru (CAF, 2016). As the countries are all reliant on effective resource planning, allocation, and management systems to ensure sustainable use of their shared ecosystems and water basins, the project (led by their national environmental authorities) encouraged and supported knowledge exchange, learning and transfer among the countries. Whilst the respective A@A solutions focus on projects undertaken at a country level, lessons can be drawn from the wider AICCA project on regional resource management in a mountainous context.

Traditionally, water management has been governed according to political sub-divisions within countries, despite water basins not being constrained by national or political borders. As climate change makes water cycles less predictable, with impacts felt downstream in sectors including agriculture, sanitation, energy, and basic services, the need for cooperation in the management of shared water resources becomes more pressing. Accounting for shared water challenges while also recognising each country's individual needs, the AICCA project focuses on each of these sectors in a different country, with the aim of generating transferable knowledge and adaptation solutions.

For example, measures implemented to increase the resilience of agriculture in Ecuador (using greenhouses to conserve water and maintain stable climatic conditions), Peru (strengthening local capacities in Indigenous communities and improving irrigation channels), Bolivia (agroforestry systems and urban flood control) and Colombia (rainwater harvesting and ecological restoration strategies) were documented and shared for other countries in the Andes to learn from, adapt to their specific challenges and opportunities, and implement (Garcés and Benítez, 2022). Similarly, measures to establish sustainable urban drainage in Bolivia were showcased in one of nine 'Andean Knowledge' events coordinated by the AICCA project to promote a regional discussion on building flood resilience through natural and grey infrastructure (AICCA, 2022; Melfo and Sáenz, 2022). Results from across the countries' projects were also collated and stored in a new regional knowledge exchange platform, 'Saber Andino', to make the findings accessible and support the replication of best practices (Melfo and Sáenz, 2022).

**This solution demonstrates how a regional, integrated approach can minimise the risk of country projects being conducted or evaluated in isolation, and instead encourage South-South transboundary learning and collaboration.** There is still room for improvement, with AICCA, like other regional adaptation projects (Browne *et al.*, 2022), largely focusing on common risks – in this case, water vulnerability – rather than risks that transcend national borders and that require more strategic cooperation and planning. A shift towards the latter will help further build resilience in mountain regions.





Buzeyi park reservoir that supplies Muramba subcounty. © Water 4 Virungas

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## Water4Virunga Project

The Virunga area has experienced civil unrest, conflict and instability that has impacts across the Democratic Republic of the Congo (DRC), Rwanda and Uganda, including in the area of water resource management.

The Water for Virunga (W4V) project aims to **promote and facilitate collective action and prevent conflicts through improved delivery of water and integrated water resource management, enhancing household water security and health, and encouraging cross-border collaboration on water resources from local to international levels.** The project was implemented under the Greater Virunga Cross-Border Collaboration programme in 16 villages across the three countries. W4V carried out a detailed situation analysis and mapped the most pressing water-related conflicts. These included conflicts related to access to water including conflicts within communities; conflict between park authorities and local communities; conflicts between herders, farmers, and communities; and conflicts at the transboundary level.

The project provided rainwater harvesting tanks, built 34 public stand posts, implemented an integrated planning approach at the local level to promote sustainable farming and resilient agriculture, and took steps to reduce crop damage by wildlife.

To support long-term maintenance of the gains from the project, stakeholders across scales from local to national were involved and received training. Furthermore, W4V was able to leverage its institutional capacity through collaboration with authorities at different scales and cooperation between consortium partners to support the transboundary dialogue and solutions.

The W4V project has made a positive impact on the lives of vulnerable groups such as women and children by reducing the burden placed on them to collect water. This initiative can therefore serve as a good practice for other regions facing similar conflicts and challenges. Rainwater harvesting could, however, lead to conflicts if it is introduced without stakeholder participation, as has been the case in the past. The W4V project encountered resistance to controlled water pricing in DRC but demonstrated the benefits of formal water management committees to overcome the issue.

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## PROSNOW

**Resource management can better account for and anticipate transboundary climate risks through the use of regional data platforms.** The PROSNOW project brought together 13 academic and industrial partners from across the European Alps (including from France, Italy, Switzerland and Austria) to develop a model to help ski resorts predict and adapt to changes in meteorological and snow conditions. Europe is home to approximately 50% of the world's ski resorts, and ski tourism is a key component of mountainous regions' economies (François *et al.*, 2023). However, increasing climate variability and rising temperatures are causing snow and ice to deplete, further enhancing warming through the reduced albedo effect (Maragno, 2020). To adapt to such climate change impacts in real time, the PROSNOW solution uses models to simulate snow cover changes based on past and/or future meteorological conditions whilst accounting for snow grooming and snowmaking processes that seek to reverse these impacts. This can help to optimise activities to cope with variable and declining snow cover.

As part of the design process, the project intentionally brought together partners and local stakeholders from different countries with different expertise and perspectives on how to approach the challenge of declining snow cover. A survey was conducted across nine ski resorts, involving participants of varying levels of responsibility for resort management. Results showed a strong desire to better manage tourism resources through the use of customised snow and meteorological forecasts. Obtaining this consensus was important to the success of PROSNOW, helping enable effective communication, and raising awareness of the impacts of climate change for a range of stakeholders at each ski resort whose cooperation is required to produce adaptation plans.

**Developing real-time data on a transboundary scale is also important in minimising negative impacts of snowmaking on the environment, which have the potential to cascade into neighbouring regions.** Snowmaking is the artificial production of snow using water and pressurised air, and is highly connected to the local environment (by using water resources and impacting ecosystems) and the local climate (as temperatures need to be sufficiently low for snowmaking to proceed) (François *et al.*, 2023). Means to anticipate demand for artificial snow are often lacking, which can result in overconsumption of energy, increased labour expenses and additional pressure on local water resources. It has the potential to create tension between different sectors and stakeholders who rely on the same water source (e.g. for agriculture, energy, subsistence). Therefore, by optimising the use of snowmaking, PROSNOW will help not only the ski industry adapt to potential impacts from climate change but also reduce risks for additional stakeholders.

An obstacle to PROSNOW realizing its potential is the need for transboundary cooperation in the tourism sectors. While encouraged in the [Alpine Convention](#), this cooperation is not easy to achieve due to competition between ski destinations (Scott and Gössling, 2022). It is too early to determine whether PROSNOW has supported fundamental change in climate change adaptation practices across the European Alps, but its approach will likely help minimise the risk of transboundary climate impacts caused by maladaptive practices.

### 3. Ecosystem risks

Mountain ecosystems are biodiversity-rich and provide a myriad of crucial ecosystem services to people worldwide. Yet, with temperatures in high-altitude regions rising faster than elsewhere, mountain ecosystems are already experiencing rapid biodiversity loss and habitat degradation (Kotru *et al.* 2020). Exacerbating their vulnerability, mountain ecosystems often straddle political borders, which adds to the challenge of anticipating and managing these growing risks.

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#### GLORIA

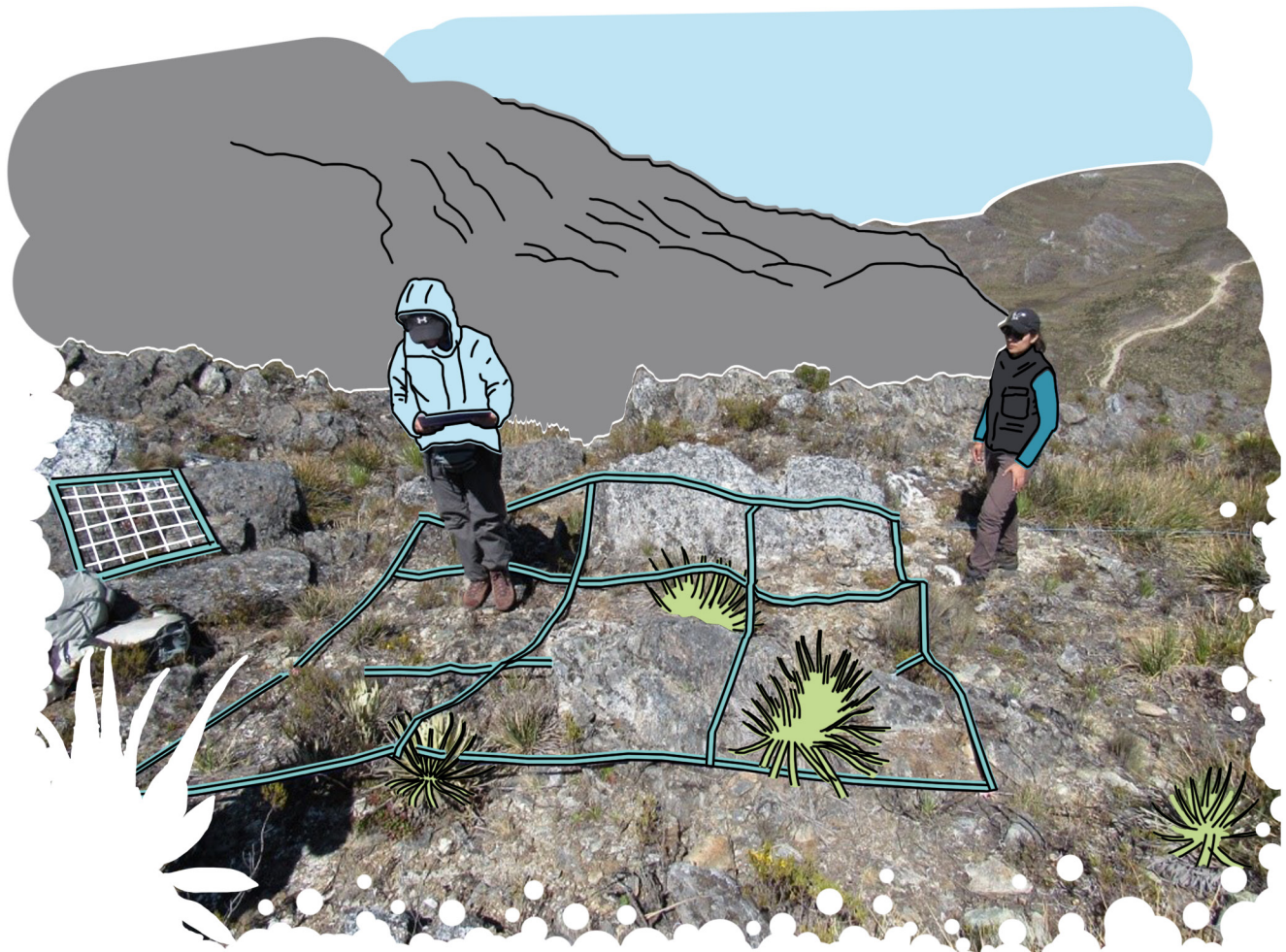
**One way to better understand and adapt to transboundary climate risks that propagate through shared ecosystems is to pool regional resources and expertise.** An example of this is the Global Observation Research Initiative in Alpine Environments (GLORIA)–Andes network, which offers long-term, transboundary monitoring to study the effects of climate change on biodiversity in the High Andes and tackle the information deficit on long-term changes to plant communities. The initiative spans the seven countries that are home to Andean ecosystems: Argentina, Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela (Red GLORIA Andes, 2023).

A benefit of a transboundary approach is that the data gathered can provide insights into how climate risks trigger cascading impacts throughout mountain ecosystems. The GLORIA-Andes network has highlighted shifts in species composition and vegetation cover, with warmer soil temperatures increasing species richness (Cuesta *et al.*, 2023). Furthermore, half of Andean mountain summits are becoming increasingly dominated by species able to better adapt to a locally warming climate (*ibid.*), exacerbating the risk of specialist species becoming extinct and competitive displacement which will have knock-on effects elsewhere, including for local communities who rely on mountain ecosystems for their livelihoods.

Additionally, producing more knowledge on how climate change is affecting shared mountain ecosystems and on the drivers of such changes can help actors to respond more effectively (Milman *et al.*, 2020). The GLORIA-Andes network seeks to collect, share, and communicate data in a systematic way by promoting South-South cooperation between 40 researchers and 16 institutions. By gathering landscape-wide data on biodiversity richness and vegetation composition, the initiative aims to help inform continental-scale conservation strategies and, in turn, generate adaptation benefits for local communities, such as protection against flooding and erosion. The extent to which such transboundary knowledge production will equate to more integrated and cooperative climate adaptation and action in the Andes is still to be assessed.

While the transboundary, collaborative approach is key to the success of the GLORIA-Andes network, it also poses a challenge to its long-term sustainability. The network relies on engagement and robust communication between partners from each of the seven countries, the lead monitoring institutions, national environmental authorities, and regional political platforms, such as the Andean Community. Each actor needs to maintain sufficient financial support and demonstrate clear institutional commitment to coordinate with other partners. Thus far, financial support has been obtained from local research institutions responsible for each monitoring site and international cooperation agencies. Yet the network's long-term activities have been threatened by slow progress at some sites, resource constraints, and lack of funding for the selection and resampling of data.

The solution highlights the importance of **having dedicated strategies for information management and data sharing to ensure continuous and long-term adaptation measures and partnerships between institutions.**



Gloria-Andes permanent plot in the Gavidia-Sierra Nevada site (Venezuela). © Luis D. Llambí

## Conservation of Queuñas Forests

**The impacts of transboundary climate risks on shared mountain ecosystems can be ameliorated through regional networks of local communities and on-the-ground adaptation approaches.** While the A@A solution was focused primarily on Peru, a wider programme known as Acción Andina aims to unite mountain communities across the seven Andean countries to protect and preserve Queuñas forests (*Polylepis spp.*). These native forest ecosystems, together with wetlands, are crucial in storing and regulating water in the landscape. This is vital for the supply of water to local populations and helps maintain the humid conditions required to buffer temperature changes in high-altitude environments. However, less than 10% of native High Andean forests remain due to the impacts of climate change, deforestation, mining, and

animal grazing. These changes are threatening water supplies, which are also at risk from the shrinking of glaciers, and farmland productivity (Acción Andina, 2023). In this light, the restoration and conservation of Queuñas forests is imperative to meet local needs and counter cascading climate-related risks such as erosion, glacial melt, and forest fires.

The threat posed by climate change has motivated local communities to act and collaborate with authorities to restore native forests, establish private conservation areas, preserve cultural heritage and build climate resilience. A total of 21 communities were involved in the Acción Andina project, all of whom are from the Quechua ethnic group and follow the traditional and ancestral Andean practice of working together for the common good. The goal is to restore 1 million hectares of native forest ecosystems by 2045 (Acción Andina, 2023). As of 2018, local communities have helped plant almost 10 million native trees to restore over 4,000 hectares of Andean

Forest ecosystems across five countries (ibid.). Private conservation areas not only bolster climate resilience and regional biodiversity but also provide ecotourism opportunities, helping to diversify the incomes of local communities who largely rely on their traditional agricultural livelihoods.

Transboundary cooperation and coordination are key to restoring the Queuñas forests at a sufficient scale for the stabilization of the local effects of climate change; and thus, mitigating the risks of cross-border climate impacts. To upscale the community restoration project beyond its initial reach in Peru, the American Bird Conservancy and Global Forest Generation joined forces with the Asociación Ecosistemas Andinos (ECOAN) and experienced community leaders to manage the programme across the Andes as part of Acción Andina. The long-term sustainability of the programme is further facilitated by i) an online platform which identifies areas for potential intervention and monitors conditions of areas pre- and post-planting across the Andes; ii) agreements between local community leaders and ECOAN for restoration of the forests; and iii) the coordination role of ECOAN, linking communities, businesses and governmental agencies to ensure technical knowledge is effectively and strategically communicated.

The transboundary reforestation and conservation of Queuñas forests provides a pathway to adapt to and mitigate the effects of climate change on the local environment. The success of this solution illustrates both the **importance of regional and national governing bodies coordinating at a continental scale to ensure a systematized approach, and the need to encourage local ownership through collaboration with Indigenous communities from across the Andes**. This combination of community-based and transboundary adaptation is a good example of the landscape approach needed to effectively anticipate and adapt to climate risks and impacts, offering inspiration to mountain regions elsewhere.

## Conclusion

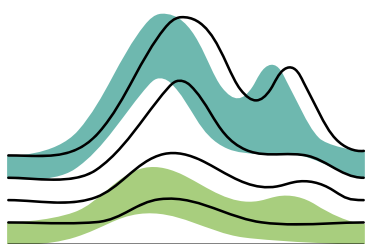
While there are many transboundary challenges and risks in mountain areas, there are also an increasing number of transboundary solutions. These solutions may not explicitly label climate risks as transboundary nor the impacts as cascading; yet they clearly demonstrate why regional collaboration and cooperation are key in mitigating and adapting to the impacts of climate change in mountain regions and more widely. Research continues to emphasise the multiple benefits that regional cooperation, in the context of climate change adaptation, can bring, including reducing the cost of climate action, helping to overcome national-level resource constraints and enhancing climate diplomacy (Talebian *et al.*, 2023). It is vital that transboundary cooperation in mountains continues to develop and that adaptation solutions are designed and implemented at a transboundary scale.

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Mountains suffer some of the most visible impacts of climate change: rising temperatures and changing precipitation patterns are melting glaciers, disrupting water flows and affecting ecosystems, creating and worsening natural hazards and threatening livelihoods and communities both within mountain regions and further downstream. These climate impacts and associated risks are not constrained by national borders. With mountain ranges often spanning multiple countries, adaptation to transboundary climate risks is becoming an increasingly complex and urgent challenge in mountain regions.



ADAPTATION  
AT ALTITUDE

