FUNDACIÓN AMBIENTE Y RECURSOS NATURALES

CLIMATE CHANGE AND BIODIVERSITY IN THE TROPICAL ANDES

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Author and editor
Catalina María Gonda (FARN)

Reviewer
Ana Di Pangracio (FARN)

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Design
Lucila Gallegos – info@lucilagallegos.com

Design adaptation
Cucha Estudio – hola@cuchaestudio.com

Editing
Estudio REC – www.estudio-rec.com

Translation
Elisa Predassi Bianchi

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KEY MESSAGES

- **Climate change is a major driver of biodiversity loss and its impacts are expected to increase throughout the century.**
- **The Tropical Andes are one of the most important biodiversity hotspots in the world. Yet, they represent one of the regions most severely threatened by human activities and most vulnerable to climate change. This double pressure makes this area a key priority for global conservation efforts.**
- **Ongoing warming and changes in precipitation patterns are causing many high-Andes biomes to retreat upslope and suffer changes in their composition. The most affected ones are glacier and cryoturbated areas, páramos and high mountain forests.**
- **Climate change is causing many high-montane species to shift their distribution ranges, leading to population declines and increasing local extinction risks.**
- **If global warming is not limited to 1.5 °C the impacts of climate change on Andean biodiversity and, thus, on the key services ecosystems provide to societies will become increasingly severe.**
- **Protecting and restoring Andean natural ecosystems is an urgent priority, not only to halt biodiversity loss, but also because they play a fundamental role in climate change mitigation and adaptation.**

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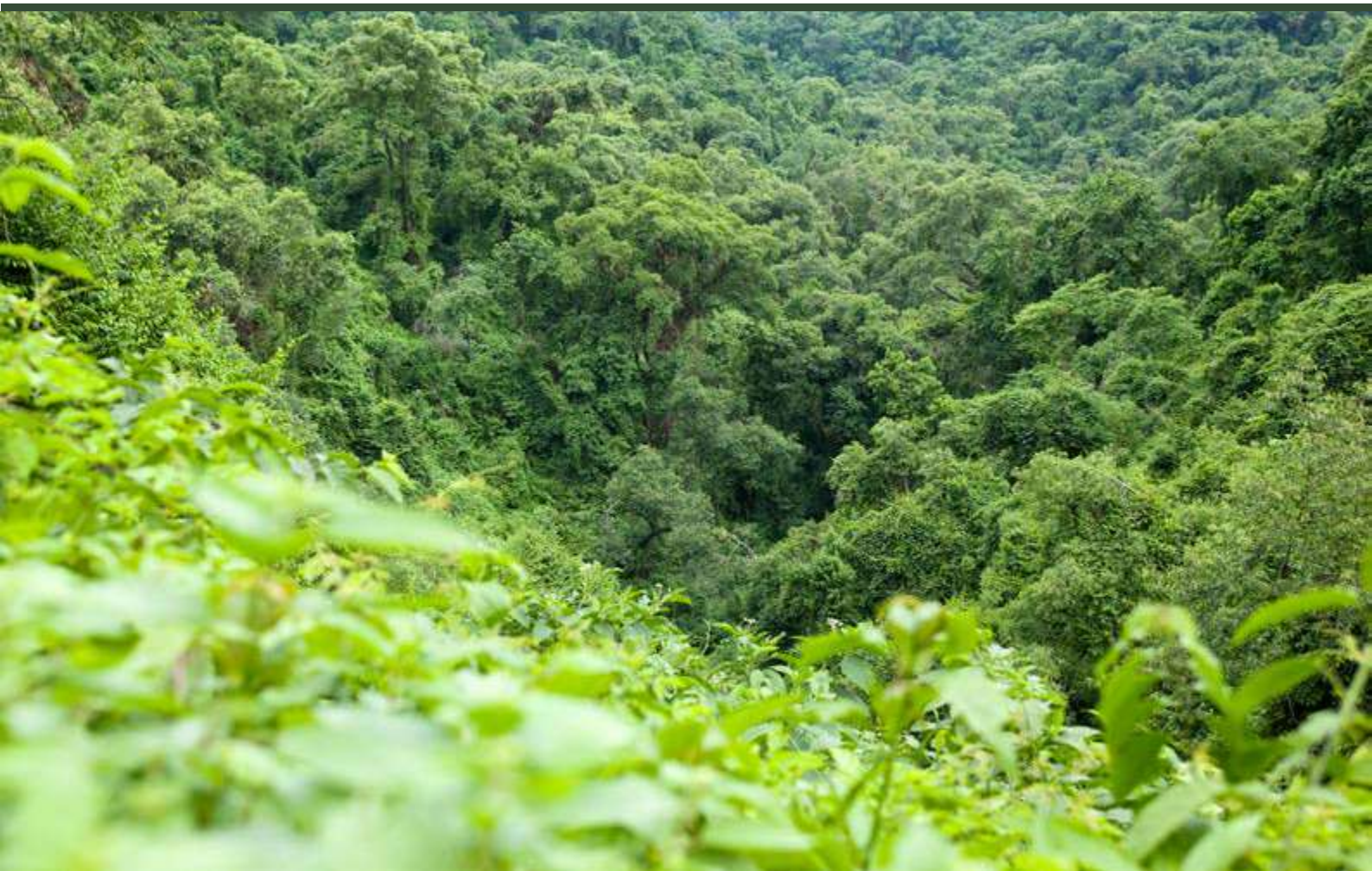


INTRODUCTION

The San Pablo-Catarata Gocta private conservation area, in Peru, preserves representative Andean ecosystems including Peruvian yungas and grasslands.

Two major crises pose severe threats for life on Earth: the climate change crisis and the biodiversity crisis. Major intergovernmental global assessments, including those by the Intergovernmental Panel on Climate Change (IPCC) and by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), have demonstrated that these two crises are deeply connected and stress the urgency to address them in an integrated and ambitious manner.

Biodiversity is the variety of life on Earth, at all levels of biological organization. Not only does it have intrinsic value, but it is also the very basis of human survival and well-being: it supplies all the food, freshwater, most medicines, pollination, construction materials and a vast number of other goods and services. Moreover, it is a source of amazing beauty that enriches people's life providing recreational and cultural assets.

However, nature's capacity to contribute to people's quality of life is rapidly declining, putting livelihoods, food security, economies and the well-being of humanity at risk.

> Today, millions of people depend on Andean ecosystems as a source of freshwater, food and many other goods and services including their cultural value.

Even though many human activities leading to habitat loss and degradation, over-exploitation and the introduction of invasive species are important drivers responsible for recent biodiversity loss, climate change is expected to be a major cause of species extinctions in the 21st century (Beaumont *et al.*, 2011; IPBES, 2019).

The Tropical Andes is considered to be the world's most biodiverse hotspot, hosting an outstanding variety of species-rich ecosystems. At the same time, it is one of the natural areas most severely disturbed by human activities and most vulnerable to climate change. Therefore, understanding potential impacts of climate change on these ecosystems is critical as current biodiversity loss is likely to become exacerbated by changes in the climate system in the next few decades (IPCC, 2007; Knutti and Sedláček, 2013).

The well-being of human populations in the Tropical Andes has been associated with the health and integrity of these ecosystems for at least 13,000-19,000 years (Fuselli, 2003). Today, millions of people depend on them as a source of freshwater, food, medicine and many other goods and services, including their cultural value (Josse *et al.*, 2009).

This report aims to provide a comprehensive scientific overview of climate change impacts on Tropical Andean biodiversity, while highlighting the key role that Andean ecosystems play in both climate change mitigation and adaptation.

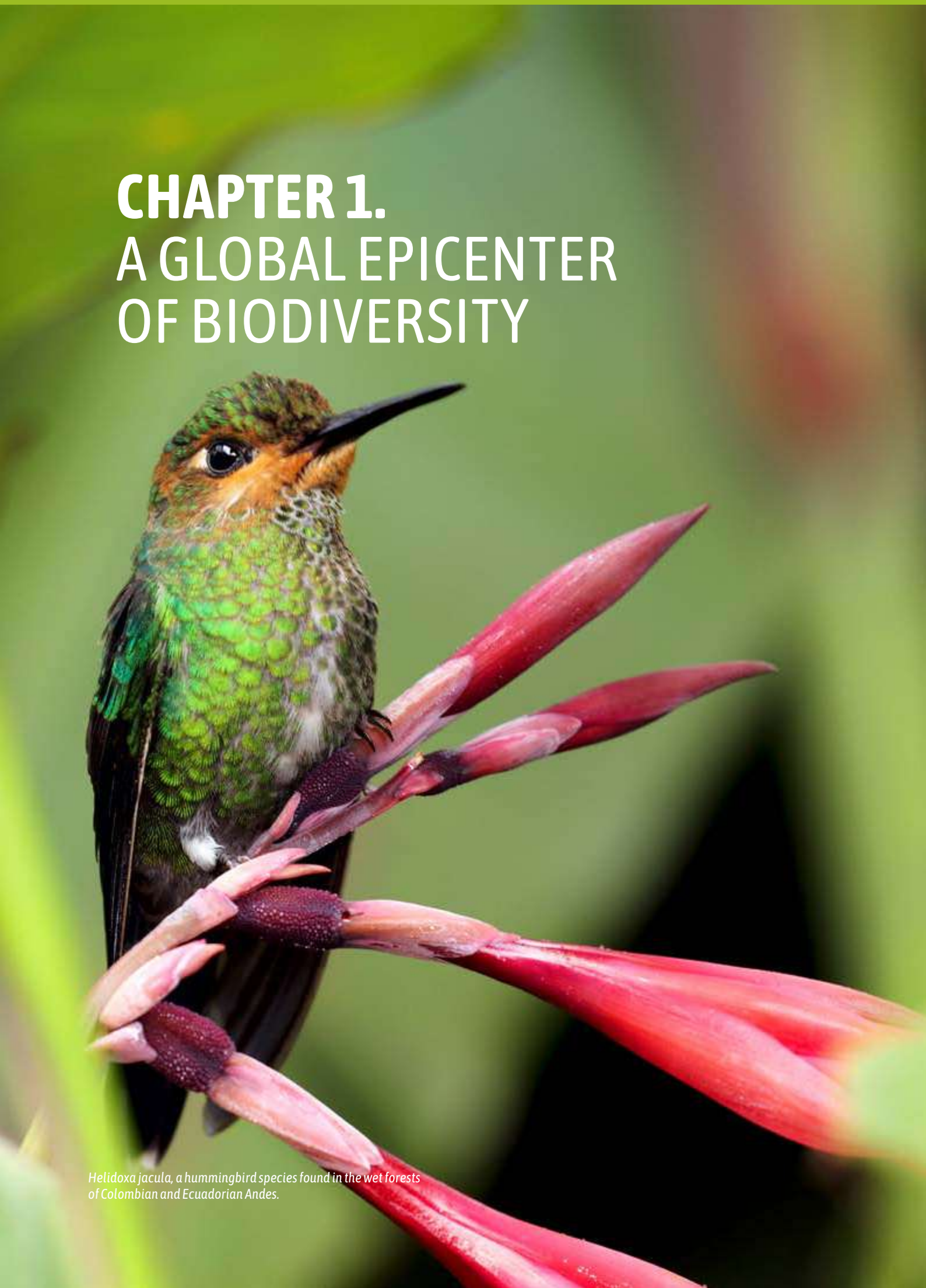
A SIXTH MASS EXTINCTION IS UNDERWAY

Just now, we face a sixth mass extinction: biological diversity is declining globally at an unprecedented rate in the history of mankind and human activities are increasingly putting species under threat of disappearing (IPBES, 2019). Although extinction is a natural phenomenon –it occurs at a natural background rate– science estimates that today species are **disappearing tens to hundreds of times faster than the average rates in the absence of humans, and that about one million species are at risk of vanishing forever** (Ceballos *et al.*, 2015; IPBES, 2019).

We can no longer afford to continue destroying the ecosystems that support life on Earth in order to satisfy our short-term needs: biodiversity is so essential for sustaining societies that destroying it means destroying ourselves.

The San Pablo-Catarata Gocta private conservation area, in Peru, preserves representative Andean ecosystems including Peruvian yungas and grasslands.

CHAPTER 1.
A GLOBAL EPICENTER OF BIODIVERSITY



Helidoxa jacula, a hummingbird species found in the wet forests of Colombian and Ecuadorian Andes.

The Tropical Andes are one of the most important and critically endangered biodiversity hotspots in the world. They stretch along 1.5 million km2, from northern Chile and Argentina, running through Bolivia, Peru, Ecuador, Colombia to Venezuela (Map 1). The heterogeneity of landscapes, soils, elevations, rainfall patterns and temperature gradients has led to the emergence of an exceptional array of habitats and species (Mittermeier & Goettsch Mittermeier, 1997; K. R. Young *et al.*, 2002).

Although the most extensive descriptions recognize over 113 different ecosystems in this natural area (Josse *et al.* 2009), ecosystem diversity of the Tropical Andes can be simplified into the following ecoregions: evergreen montane forests, dry montane forests, other types of forests, forests and grasslands of the yungas, puna grasslands, páramo, shrublands, deserts and arid regions, glaciers and cryoturbated areas, and freshwater ecosystems (Map 2).

These remarkable ecosystems are home to over:

- **45,000 plant species (20,000 endemic)**

- **570 mammal species (75 endemic)**

- **724 bird species (579 endemic)**

- **610 reptile species (275 endemic)**

- **981 amphibian species (673 endemic)**

- **80 freshwater fish species (131 endemic)**

This figures represent about 15% of all known plant species and 12% of all vertebrate species known to date, in a region covering only 1% of Earth's terrestrial area (Mittermeier, 2004; Myers *et al.*, 2000).

> About 15% of the plant species and 12% of the vertebrate species known to date are found in the Tropical Andes.

THE CLIMATE CRISIS AND BIODIVERSITY CRISIS ARE DEEPLY CONNECTED

In the last century, human activities have increased the concentrations of carbon dioxide and other greenhouse gases (GHGs) in the atmosphere. These human-emitted gases are intensifying Earth's natural greenhouse effect by trapping extra heat from solar radiation, causing our planet to warm at an unprecedented rate.

Although burning fossil fuels is the largest source of human GHG emissions, ecosystems destruction and degradation (through deforestation, land cover change, fires and climate change) releases massive amounts of GHGs into the atmosphere. Biodiversity loss also affects resilience and the adaptive capacity of societies and natural systems to respond to future stressors.

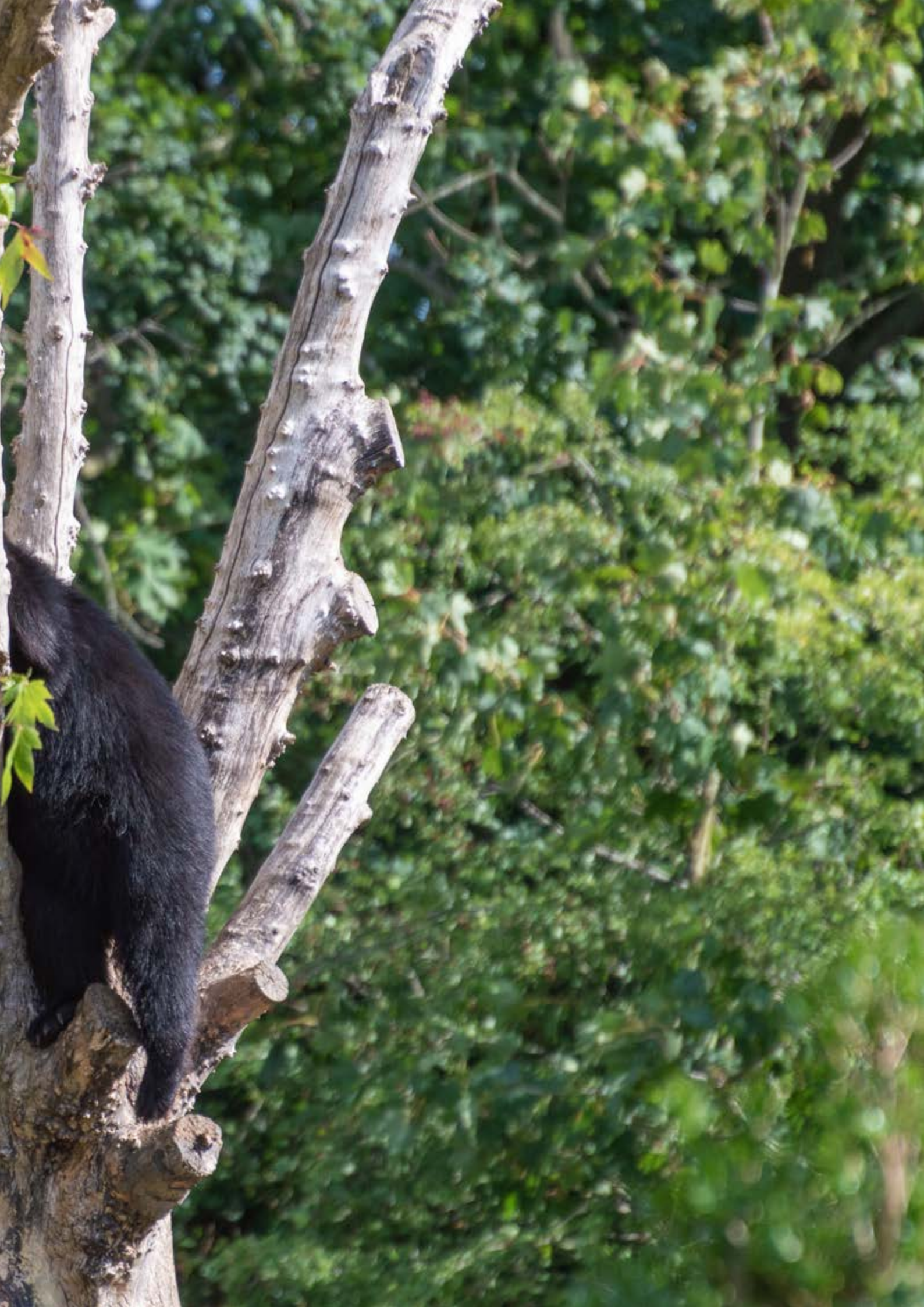
Biological diversity is therefore not only severely affected by climate change but also plays a key role in climate change mitigation and adaptation through the ecosystem services it supports. In short, biodiversity loss and ecosystem decline exacerbate climate change and its adverse impacts.

Map 1. The Tropical Andes biodiversity hotspot. *Source: (Base map) Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, (Biodiversity Hotpots 2016, Feature Layer) Critical Ecosystem Partnership Fund, Conservation International.*

Whilst being one of the most biodiverse places in the world, this area is severely threatened by human activities and climate change, making the Tropical Andes region a major priority for global conservation efforts (Brooks *et al.*, 2002; Mittermeier *et al.*, 2011; Myers *et al.*, 2000).

Map 2. Main ecoregions of the Tropical Andes. *Source: Adapted from "The Tropical Andes ecoregions" by GRID-Arendal and Cartografare il Presente/Riccardo Pravettoni (Link: http://www.grida.no/resources/8097).*

The spectacled bear (Tremarctos ornatus) lives mainly in the Andean cloud forests.



CHAPTER 2.
CLIMATE CHANGE IMPACTS ON TROPICAL ANDEAN BIODIVERSITY

Páramo conservation and protection is critical as these ecosystems provide multiple services and are important carbon sinks.

Ongoing changes in temperature and rainfall patterns in the Tropical Andes are disrupting a wide range of natural processes, putting biodiversity and the vital ecosystem services it supports at risk. However, these impacts differ both at a species and ecosystem level based on their degree of exposure, sensitivity and adaptive capacity to climate change.

It is important to point out that the rate of warming is amplified with elevation. That means that the highest areas of the Andes are warming faster than lowland areas (Mountain Research Initiative EDW Working Group, 2015).

Moreover, future climate change projections for this region are often challenging and highly uncertain given its complex topography and climate (Garreaud, 2009; Vuille *et al.*, 2008).

	Observations	Projections
	Temperatures raised on average 0.13 °C per decade between 1950 and 2010.	Temperature is projected to increase by 1 to 5 °C by 2100, depending on the emissions scenario.
	Precipitation has been increasing in the inner tropics and decreasing in the outer tropical Andes, although detailed trends are hard to identify.	Precipitation and cloud cover patterns are expected to shift, but changes will vary across the region.

Table 1. Climate trends in the Tropical Andes. *Sources: Vuille et al., 2015, 2018.*

Yungas near the province of Salta, Argentina.

CHANGES IN MAIN ANDEAN BIOMES

Montane forests

Tropical and subtropical Andean forests are migrating to higher elevations and suffering changes in their composition due to global warming. This phenomenon, known as "thermophilization", occurs when lowland plant species start migrating to higher altitudes in search of more optimal conditions in response to rising temperatures. Highland tree species adapted to lower temperatures start dying because they are unable to colonise new habitats in higher (hence cooler) areas. Consequently, the relative abundance of heat-tolerant lowland species is increasing (Duque *et al.*, 2015; Fadrique *et al.*, 2018; Feeley *et al.*, 2011).

However, forests' range shift dynamics in response to climate change is a complex matter and treeline displacement to higher areas occupied by páramos and high-Andean puna can be limited by many factors, including high radiation levels, freezing events and human disturbances (Rehm and Feeley, 2015). This poses a major threat to forest biodiversity as it may increase extinction risks.

> Many Tropical Andean biomes are retreating to higher elevations and suffering changes in their composition, with the most vulnerable areas being páramos, cloud forests and glaciers.

Páramo

The páramos are unique and fragile high Andean ecosystems that feature extraordinary plant diversity. They capture, store and supply water for tens of millions of people in the northern Andes (Hofstede *et al.*, 2014). In the last decades they have experienced striking alterations leading to biodiversity loss, including glacier retreat, disappearance of water bodies and less foggy days (Ruiz *et al.*, 2008). These biomes are among the most vulnerable to climate change, and according to some projections they could lose about 31% of their current extent by 2050 (Tovar *et al.*, 2013).

High Andean wetland in Bolivia.

Glaciers and cryoturbated areas

The Tropical Andes host more than 99% of all tropical glaciers. However, they are melting at alarming rates in response to climate change. In the last 50 years, they have shrunk between 20 and 50% and some of them have even completely disappeared. Given the projected changes in climate, glaciers are expected to continue retreating and many will vanish within decades (Dussaillant *et al.*, 2019; Morán-Tejeda *et al.*, 2018; Rabatel *et al.*, 2013).

> The combined effects of climate change and human disturbances put Andean ecosystems are under double pressure.

As glaciers retreat, dramatic changes take place in the landscape: new lakes form, less water is supplied to high-Andean wetlands and the hydrology of glacier-fed river basins and lakes is altered. These changes can have strong impacts on biodiversity, affecting community composition and increasing the risk of wetland and alpine vegetation loss (Cuesta *et al.*, 2019).

Yungas

These premontane cloud forests in southern Bolivia and northern Argentina, are highly sensitive to drying and contracting in response to changes in humidity and cloud immersion declines (Helmer *et al.*, 2019). Modelling studies indicate that Argentine yungas could retract up to 50% and migrate to higher altitudes according to different climate change scenarios (Pacheco *et al.*, 2010).

Puna, shrublands and dry forests

Dry biomes (dry puna, seasonal dry forests and shrublands) are the only ones which lower boundaries are projected to expand downslope in response to higher temperatures and water scarcity (Tovar *et al.*, 2013). While wet puna habitats are quite resilient to climate change, they are also vulnerable to colonisation by lower elevation plant species migrating upslope (Herzog *et al.*, 2011).

Freshwater ecosystems

There are few studies regarding climate change impacts on the aquatic systems of this region, but glacier- and páramo-fed lakes and rivers could become seriously affected as warming impacts water-flow patterns, leading to a local biodiversity loss.

Projections suggest that, for the rest of this century, between 75 to 80% of the Tropical Andes region will remain stable, while wet biomes will continue retreating upslope and dry biomes will expand downslope (Tovar *et al.*, 2013). Importantly, a significant part of the area expected to suffer changes is already being seriously affected by land use changes.

CHANGES IN SPECIES ABUNDANCE AND DISTRIBUTION

As mentioned before, Tropical Andes biodiversity is particularly vulnerable to climate change because many of the species are adapted to very specific (often extreme) conditions and encounter physical barriers to migrate to other habitats in this highly heterogeneous and fragmented landscape. Furthermore, variations in physiological and ecological traits means that different animal and plant species will respond to climate change in different ways (Cuesta *et al.*, 2012).

> Climate change has differentiated impacts on tropical Andean species, causing many of them to move uphill, increasing the spread of invasive species and infectious diseases and accelerating local extinction risk.

The climate-suitable ranges for many species are projected to change as their habitats shift, shrink, or expand due to rising global temperatures. Many species are heading uphill to keep the pace with warming temperatures and humidity changes, seeking optimal conditions to which they are adapted. Shifts in species' distribution and new environmental conditions are altering the ecological processes that result from species interactions and may, in turn, facilitate the spread of invasive species and diseases into new areas. These changes can ultimately lead to population declines and local extinctions.

Local extinction risk is higher for mountaintop species. As temperature increases, many species' suitable habitat shifts upslope and gradually starts shrinking. When cool-adapted summit species cannot shift further, as they have nowhere left to go, mountaintop extinctions can occur.

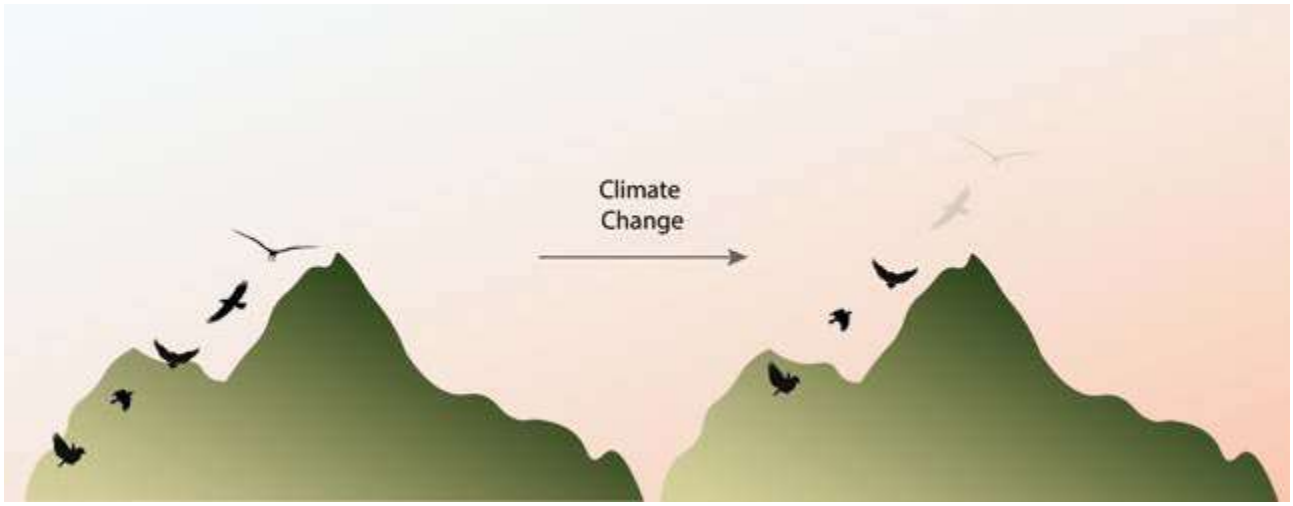


Figure 1. The effects of climate change on mountain species. *Source: Adapted from Freeman et al., 2018.*

When compared to other regions, very few studies have examined how tropical mountain species are being affected by ongoing climate change. Yet, some studies provide some evidence of this in the Tropical Andes (Báez *et al.*, 2016).

Plants

Global warming is strongly reshaping plant distributions and the upper boundaries of many species' ranges are being pushed to higher altitudes. This is affecting vegetation composition and can even lead to changes in ecosystem functioning. In the last two hundred years, many plant species on the Chimborazo volcano in Ecuador have migrated more than 500 metres upslope, colonising areas that were previously covered by glaciers (Morueta-Holme *et al.*, 2015).

Birds

In Peru, warmer temperatures are pushing mountain bird species upslope. Ranges have shifted upwards 68 meters on average in the last three decades and mountaintop species have seen their habitat greatly reduced. Nearly all of them declined in abundance and some even disappeared from the ridgetops (Freeman *et al.*, 2018).

Amphibians

Although drastic amphibian declines in the slopes of the Andes are being reported, temperature rise does not seem to be the main driver (Catenazzi *et al.*, 2014). While ongoing deglaciation is allowing some species to colonize newly formed ponds at higher altitudes, it presents amphibians with rapidly changing habitats, including wetland desiccation, that could result in population declines in the future (Seimon *et al.*, 2017).

Insects

The elevational ranges of Andean paramo ground beetles in Ecuador have changed significantly in the last decades. Some species have moved upslope at least 400 metres in 28 years, warning about the possibility of future local extinctions (Moret *et al.*, 2016).

Modelling studies show that more than half of the bird and plant species of this region risk losing at least 45% of their climatic niche by 2050, while most of endemic species could lose up to 50% (Ramirez-Villegas *et al.*, 2014).

The russet-crowned warbler (Myiothlypis coronata) is a bird endemic to the Tropical Andes, and its distribution range is currently being affected by climate change.

CHAPTER 3.
CHALLENGES AND OPPORTUNITIES

Cotacachi-Cayapas Ecologic Reserve, in Ecuador, comprises several ecosystems including evergreen foothills forests and páramos.

STEPPING UP CLIMATE ACTION

Challenges

Current government pledges are far from being enough to avoid dangerous climate change. Even if all current commitments are implemented, temperatures can be expected to rise 3.2°C above pre-industrial levels by 2100. This figure vastly exceeds the 1.5°C temperature goal of the Paris Agreement, that markedly reduces the negative impacts of climate change (UNEP, 2019). Failing to meet the Paris Agreement goals would have devastating and irreversible consequences for biodiversity and natural systems worldwide.

At the same time, failing to halt biodiversity loss may compromise the world's ability to reduce emissions and successfully prevent dangerous warming. Improving the health and resilience of biodiversity and ecosystems on land and water is crucial to prevent further emissions and sequestering carbon. The land and the ocean act as important sinks removing almost half of annual global emissions from the atmosphere (Friedlingstein *et al.*, 2019). However, the degradation or loss of these ecosystems can turn them from sinks to sources of GHGs, further exacerbating climate change (IPCC, 2019). This is particularly relevant for Andean páramos, wetlands and forests, which represent major carbon stocks in this region.

Opportunities

- Scaling up and accelerating climate action in order to limit global warming to 1.5 °C to prevent further biodiversity loss. This should be done by maximizing climate and biodiversity synergies and through emission reduction pathways compatible with nature conservation and food sovereignty.
- Protecting and restoring Andean natural ecosystems to avoid turning them from sinks into GHG sources. Improving their stability not only provides great mitigation potential, but also entails a range of other benefits, such as maintaining ecological functions, life support services and increasing the resilience of people and their livelihoods.

PROTECTED AREAS AND CONSERVATION STRATEGIES

Challenges

Tropical Andean ecosystems will not respond to climate change in the same way. For this reason, conservation and adaptation measures should be designed accordingly (Tovar *et al.*, 2013).

Currently, many of the protected areas in this region coincide with locations that have no priority for conservation action, and most threatened endemic species are not adequately represented by these systems (Bax and Francesconi, 2019; Tognelli, 2016). Furthermore, these areas are not connected, jeopardizing the persistence of biodiversity and ecosystem service delivery in the long term.

As Tropical Andean biodiversity is already being severely affected by land use changes and climate change will likely exacerbate the losses, establishing new protected areas is a necessary, though difficult, task. Several factors –such as land tenure and ownership, the increasing demand for natural resources, extractive activities, and the lack of resources to create and manage protected areas– compromise the expansion of these zones in the Andes.

Opportunities

- Formulating public policies and developing regional plans aimed at improving landscape connectivity. This represents a much more effective conservation strategy under a changing climate than establishing isolated protected areas surrounded by highly perturbed landscapes (Cuesta *et al.*, 2012; Ramirez-Villegas *et al.* 2014). In this sense, and to strengthen connectivity conservation management across the landscape, it is important to recognize and promote other effective area-based conservation measures (OECM), articulating national reserves with other subsystems such as territories conserved by indigenous peoples and local communities (TICCA), protecting forests and vegetation, and civil society natural reserves.
- Identifying and prioritizing areas where biodiversity protection is most urgently needed, accounting for important factors such as endemic or threatened species, irreplaceability, and vulnerability to the combined impacts of land use and climate change.
- Developing conservation policies and strategies that guarantee self-determination, free, prior, and informed consent of local communities and indigenous peoples in decisions regarding their territories, which currently account for over 82 million hectares (over 52% of the hotspot surface) (Young *et al.*, 2015).

> Currently, most threatened species and priority sites in this hotspot are not covered by protected areas.

KNOWLEDGE GAPS

Challenges

Although the Tropical Andes tops the list of global hotspots for species diversity and endemism, it has historically been very little studied. Existing knowledge on Tropical Andes biodiversity (species inventories, distribution ranges, ecological interactions) and climate (historical data and modelling) is still scarce.

> Even though the Tropical Andes tops the list of global biodiversity hotspots, this region remains poorly studied.

Several studies offer in-depth analysis on the knowledge gaps and research priority-areas for this region (Antonelli *et al.*, 2018; Báez *et al.*, 2011, 2016; Cuesta *et al.*, 2012; Pitman *et al.*, 2011). For instance, it is imperative to reduce taxonomic and spatial biases at the species level and to increase spatial resolution in climate studies. Furthermore, it is essential to carry out large-scale and long-term studies and to develop models that integrate both land use change and climate change scenarios.

Opportunities

- Financing and promoting basic and applied academic research in the Tropical Andes countries to address current knowledge gaps regarding climate change impacts on ecosystems.
- Supporting experts and institutions to carry out fieldwork and facilitate free access to biological collections and data bases as well as encouraging cross-disciplinary research.
- Enhancing and strengthening ecological monitoring networks in the long-term and at a regional level.

REFERENCES

1. Antonelli, A., Ariza, M., Albert, J., Andermann, T., Azevedo, J., Bacon, C., Faurby, S., Guedes, T., Hoorn, C., Lohmann, L. G., Matos-Maraví, P., Ritter, C. D., Sanmartín, I., Silvestro, D., Tejedor, M., ter Steege, H., Tuomisto, H., Werneck, F. P., Zizka, A., & Edwards, S. V. (2018). Conceptual and empirical advances in Neotropical biodiversity research. PeerJ, 6, e5644. https://doi.org/10.7717/peerj.5644
2. Báez, S., Cuesta, F., Cáceres, Y., Arnillas, C. A., & Vázquez, R. (2011). Síntesis del conocimiento de los efectos del Cambio Climático en la biodiversidad de los Andes Tropicales (Serie Panorama Andino sobre Cambio Climático). CONDESAN, SGCAN.
3. Báez, S., Jaramillo, L., Cuesta, F., & Donoso, D. A. (2016). Effects of climate change on Andean biodiversity: A synthesis of studies published until 2015. Neotropical Biodiversity, 2(1), 181-194. https://doi.org/10.1080/23766808.2016.1248710
4. Bax, V., & Francesconi, W. (2019). Conservation gaps and priorities in the Tropical Andes biodiversity hotspot: Implications for the expansion of protected areas. Journal of Environmental Management, 232, 387-396. https://doi.org/10.1016/j.jenvman.2018.11.086
5. Beaumont, L. J., Pitman, A., Perkins, S., Zimmermann, N. E., Yoccoz, N. G., & Thuiller, W. (2011). Impacts of climate change on the world's most exceptional ecoregions. Proceedings of the National Academy of Sciences, 108(6), 2306-2311. https://doi.org/10.1073/pnas.1007217108
6. Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., Rylands, A. B., Konstant, W. R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., & Hilton-Taylor, C. (2002). Habitat Loss and Extinction in the Hotspots of Biodiversity. Conservation Biology, 16(4), 909-923. https://doi.org/10.1046/j.1523-1739.2002.00530.x
7. Catenazzi, A., Lehr, E., & Vredenburg, V. T. (2014). Thermal physiology, disease, and amphibian declines on the eastern slopes of the Andes: Frog Declines in the Tropical Andes. Conservation Biology, 28(2), 509-517. https://doi.org/10.1111/cobi.12194
8. Ceballos G, Ehrlich PR, Barnosky AD, García A, Pringle RM, Palmer TM. 2015. Accelerated modern human-induced species losses: entering the sixth mass extinction. Science Advances 1: e1400253
9. Chivian, E., Bernstein, A., Secretariat of the Convention on Biological Diversity, United Nations Development Programme, United Nations Environment Programme, & IUCN--The World Conservation Union (Eds.). (2008). Sustaining life: How human health depends on biodiversity. Oxford University Press.
10. Cuesta, F., Bustamante, M., Becerra, M. T., Postigo, J., & Peralvo, J. (2012). Panorama andino de cambio climático: Vulnerabilidad y adaptación en los Andes Tropicales. CONDESAN, SGCAN.
11. Cuesta, F., Llambí, L. D., Huggel, C., Drenkhan, F., Gosling, W. D., Muriel, P., Jaramillo, R., & Tovar, C. (2019). New land in the Neotropics: A review of biotic community, ecosystem, and landscape transformations in the face of climate and glacier change. Regional Environmental Change, 19(6), 1623-1642. https://doi.org/10.1007/s10113-019-01499-3
12. Duque, A., Stevenson, P. R., & Feeley, K. J. (2015). Thermophilization of adult and juvenile tree communities in the northern tropical Andes. Proceedings of the National Academy of Sciences, 112(34), 10744-10749. https://doi.org/10.1073/pnas.1506570112
13. Dussaillant, I., Berthier, E., Brun, F., Masiokas, M., Hugonnet, R., Favier, V., Rabatel, A., Pitte, P., & Ruiz, L. (2019). Two decades of glacier mass loss along the Andes. Nature Geoscience. https://doi.org/10.1038/s41561-019-0432-5
14. Fadrique, B., Báez, S., Duque, Á., Malizia, A., Blundo, C., Carilla, J., Osinaga-Acosta, O., Malizia, L., Silman, M., Farfán-Ríos, W., Malhi, Y., Young, K. R., Cuesta C., F., Homeier, J., Peralvo, M., Pinto, E., Jadan, O., Aguirre, N., Aguirre, Z., & Feeley, K. J. (2018). Widespread but heterogeneous responses of Andean forests to climate change. Nature, 564(7735), 207-212. https://doi.org/10.1038/s41586-018-0715-9
15. Feeley, K. J., Silman, M. R., Bush, M. B., Farfan, W., Cabrera, K. G., Malhi, Y., Meir, P., Revilla, N. S., Quisiyupanqui, M. N. R., & Saatchi, S. (2011). Upslope migration of Andean trees: Andean trees migrate upslope. Journal of Biogeography, 38(4), 783-791. https://doi.org/10.1111/j.1365-2699.2010.02444.x
16. Freeman, B. G., Scholer, M. N., Ruiz-Gutierrez, V., & Fitzpatrick, J. W. (2018). Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. Proceedings of the National Academy of Sciences, 115(47), 11982-11987. https://doi.org/10.1073/pnas.1804224115

17. Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Bakker, D. C. E., Canadell, J. G., Ciais, P., Jackson, R. B., Anthoni, P., Barbero, L., Bastos, A., Bastrikov, V., Becker, M., Bopp, L., Buitenhuis, E., Chandra, N., Chevallier, F., Chini, L. P., Currie, K. I., Feely, R. A., Gehlen, M., Gilfillan, D., Gkritzalis, T., Goll, D. S., Gruber, N., Gutekunst, S., Harris, I., Haverd, V., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Joetzjer, E., Kaplan, J. O., Kato, E., Klein Goldewijk, K., Korsbakken, J. I., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Marland, G., McGuire, P. C., Melton, J. R., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Neill, C., Omar, A. M., Ono, T., Peregon, A., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Séférian, R., Schwinger, J., Smith, N., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Werf, G. R., Wiltshire, A. J., and Zaehle, S.: Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783-1838. https://doi.org/10.5194/essd-11-1783-2019
18. Fuselli, S. (2003). Mitochondrial DNA Diversity in South America and the Genetic History of Andean Highlanders. Molecular Biology and Evolution, 20(10), 1682-1691. https://doi.org/10.1093/molbev/msg188
19. Garreaud, R. D. (2009). The Andes climate and weather. Advances in Geosciences, 22, 3-11. https://doi.org/10.5194/adgeo-22-3-2009
20. Helmer, E. H., Gerson, E. A., Baggett, L. S., Bird, B. J., Ruzycki, T. S., & Voggesser, S. M. (2019). Neotropical cloud forests and páramo to contract and dry from declines in cloud immersion and frost. PLOS ONE, 14(4), e0213155. https://doi.org/10.1371/journal.pone.0213155
21. Herzog, S. K., R. Martínez, P.M. Jørgensen, & H. Tiessen. (2011). Climate change and biodiversity in the tropical Andes. Unpublished. https://doi.org/10.13140/2.1.3718.4969
22. Hofstede, R., Calles, J., López, V., Polanco, R., Torres, F., Ulloa, J., Vásquez, A., & Cerra, M. (2014). Los Páramos Andinos ¿Qué sabemos? Estado de conocimiento sobre elimpacto del cambio climático en el ecosistema páram. UICN.
23. IPBES, 2019: Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pp.
24. IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.
25. IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.
26. Josse, C., Cuesta, F., Navarro, G., Barrena, V., Cabrera, E., Chacón-Moreno, E., Ferreira, W., Peralvo, M., Saito, J., & Tovar, A. (2009). Ecosistemas de los Andes del norte y centro. Secretaría General de la Comunidad Andina, Programa regional ECOBONA-INtercooperation, CONDESAN-Proyecto Páramo Andino, Programa BioAndes, EcoCiencia, NatureServe, IAvH, LTA-UNALM, ICAE-ULA, CDC-UNALM, RUMBOL SRL.
27. Knutti, R., & Sedláček, J. (2013). Robustness and uncertainties in the new CMIP5 climate model projections. Nature Climate Change, 3(4), 369-373. https://doi.org/10.1038/nclimate1716
28. Mittermeier, R. A. (Ed.). (2004). Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions (1. engl. ed). CEMEX.
29. Mittermeier, R. A., & Goettsch Mittermeier, C. (1997). Megadiversity: Earth's biologically wealthiest nations (1st English ed). CEMEX.
30. Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M., & Gascon, C. (2011). Global Biodiversity Conservation: The Critical Role of Hotspots. En F. E. Zachos & J. C. Habel (Eds.), Biodiversity Hotspots (pp. 3-22). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-20992-5_1
31. Morán-Tejeda, E., Ceballos, J. L., Peña, K., Lorenzo-Lacruz, J., & López-Moreno, J. I. (2018). Recent evolution and associated hydrological dynamics of a vanishing tropical Andean glacier: Glaciar de Conejeras, Colombia. Hydrology and Earth System Sciences, 22(10), 5445-5461. https://doi.org/10.5194/hess-22-5445-2018
32. Moret, P., Aráuz, M. de los Á., Gobbi, M., & Barragán, Á. (2016). Climate warming effects in the tropical Andes: First evidence for upslope shifts of Carabidae (Coleoptera) in Ecuador. Insect Conservation and Diversity, 9(4), 342-350. https://doi.org/10.1111/icad.12173

33. Morueta-Holme, N., Engemann, K., Sandoval-Acuña, P., Jonas, J. D., Segnitz, R. M., & Svenning, J.-C. (2015). Strong upslope shifts in Chimborazo's vegetation over two centuries since Humboldt. Proceedings of the National Academy of Sciences, 112(41), 12741-12745. https://doi.org/10.1073/pnas.1509938112
34. Mountain Research Initiative EDW Working Group. (2015). Elevation-dependent warming in mountain regions of the world. Nature Climate Change, 5(5), 424-430. https://doi.org/10.1038/nclimate2563
35. Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), 853-858. https://doi.org/10.1038/35002501
36. Pacheco, S., Malizia, L. R., & Cayuela, L. (2010). Effects of Climate Change on Subtropical Forests of South America. Tropical Conservation Science, 3(4), 423-437. https://doi.org/10.1177/194008291000300407
37. Pitman, N. C. A., Widmer, J., Jenkins, C. N., Stocks, G., Seales, L., Paniagua, F., & Bruna, E. M. (2011). Volume and Geographical Distribution of Ecological Research in the Andes and the Amazon, 1995-2008. Tropical Conservation Science, 4(1), 64-81. https://doi.org/10.1177/194008291100400107
38. Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., Ceballos, J. L., Basantes, R., Vuille, M., Sicart, J.-E., Huggel, C., Scheel, M., Lejeune, Y., Arnaud, Y., Collet, M., Condom, T., Consoli, G., Favier, V., Jomelli, V., Galarraga, R., … Wagnon, P. (2013). Current state of glaciers in the tropical Andes: A multi-century perspective on glacier evolution and climate change. The Cryosphere, 7(1), 81-102. https://doi.org/10.5194/tc-7-81-2013
39. Ramirez-Villegas, J., Cuesta, F., Devenish, C., Peralvo, M., Jarvis, A., & Arnillas, C. A. (2014). Using species distributions models for designing conservation strategies of Tropical Andean biodiversity under climate change. Journal for Nature Conservation, 22(5), 391-404. https://doi.org/10.1016/j.jnc.2014.03.007
40. Rehm, E. M., & Feeley, K. J. (2015). The inability of tropical cloud forest species to invade grasslands above treeline during climate change: Potential explanations and consequences. Ecography, 38(12), 1167-1175. https://doi.org/10.1111/ecog.01050
41. Ruiz, D., Moreno, H. A., Gutiérrez, M. E., & Zapata, P. A. (2008). Changing climate and endangered high mountain ecosystems in Colombia. Science of The upTotal Environment, 398(1-3), 122-132. https://doi.org/10.1016/j.scitotenv.2008.02.038
42. Seimon, T. A., Seimon, A., Yager, K., Reider, K., Delgado, A., Sowell, P., Tupayachi, A., Konecky, B., McAloose, D., & Halloy, S. (2017). Long-term monitoring of tropical alpine habitat change, Andean anurans, and chytrid fungus in the Cordillera Vilcanota, Peru: Results from a decade of study. Ecology and Evolution, 7(5), 1527-1540. https://doi.org/10.1002/ece3.2779
43. Tognelli, M. (2016). Estado de conservación y distribución de la biodiversidad de agua dulce en los Andes tropicales. UICN.
44. Tovar, C., Arnillas, C. A., Cuesta, F., & Buytaert, W. (2013). Diverging Responses of Tropical Andean Biomes under Future Climate Conditions. PLoS ONE, 8(5), e63634. https://doi.org/10.1371/journal.pone.0063634
45. United Nations Environment Programme (2019). Emissions Gap Report 2019. UNEP, Nairobi.
46. Vuille, M., Carey, M., Huggel, C., Buytaert, W., Rabatel, A., Jacobsen, D., Soruco, A., Villacis, M., Yarleque, C., Elison Timm, O., Condom, T., Salzmann, N., & Sicart, J.-E. (2018). Rapid decline of snow and ice in the tropical Andes - Impacts, uncertainties and challenges ahead. Earth-Science Reviews, 176, 195-213. https://doi.org/10.1016/j.earscirev.2017.09.019
47. Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B., & Bradley, R. (2008). Climate change and tropical Andean glaciers: Past, present and future. Earth-Science Reviews, 89, 79-96. https://doi.org/10.1016/j.earscirev.2008.04.002
48. Vuille, M., Franquist, E., Garreaud, R., Lavado Casimiro, W. S., & Cáceres, B. (2015). Impact of the global warming hiatus on Andean temperature: Global warming hiatus in the Andes. Journal of Geophysical Research: Atmospheres, 120(9), 3745-3757. https://doi.org/10.1002/2015JD023126
49. Young, B., Josse, C., Stern, M., Vasconez, S., Olander, J., Sanchez de Lozada, A., Zador, M., Smyth, R., Comer, P. J., Moull, K., Echavarría, M., & Hak, J. (2015). Hotspot de biodiversidad de los Andes Tropicales. NatureServe y EcoDecisión, CEPF.
50. Young, K. R., Ulloa, C. U., Luteyn, J. L., & Knapp, S. (2002). Plant Evolution and Endemism in Andean South America: An Introduction. The Botanical Review, 68(1), 4-21. https://doi.org/10.1663/0006-8101(2002)068[0004:PEAEIA]2.0.CO;2

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