EXECUTIVE REPORT

Biodiversity through time

Deep histories and living knowledge systems from the Global South

OCTOBER 2026



Perspectives from the Global South on the Anthropocene

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The Perspectives from the Global South on the Anthropocene Initiative

The *Perspectives from the Global South on the Anthropocene Initiative* was established in 2023 by a team of scholars at the Max Planck Institute of Geoanthropology. The initiative focuses on integrating insights from palaeoecology, archaeology, and traditional knowledge to address the urgent challenges of the Anthropocene.

Together, the group forms ECHOES: *Exploring Climate and Human Observations from the Global South* working group. The group currently has members from across Eurasia, the Americas, and Africa, and continues to expand its network.

The ECHOES working group believes that recognizing the importance of archaeological, historical, and ancestral perspectives from the Global South is essential for developing a truly comprehensive understanding of the Anthropocene crisis. These viewpoints shed light on the long-term dynamics of human–environment interactions and their enduring impacts.

Further information about the initiative is available on our website:
https://gs-anthropocene.org/

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ECHOES team and the members of the Voices of the Global South Conference

Foreword and Acknowledgements

This executive report is part of the initiative *Perspectives from the Global South on the Anthropocene*, developed by researchers from the Max Planck Institute of Geoanthropology (MPI-GEA) in Jena, Germany together with colleagues and partners across the Americas, Africa, and Asia.

The idea for this series of reports took shape after our conference "Voices of the Global South", held at the MPI-GEA in 2024, where participants from different regions of the Global South shared experiences on how archaeological, paleoecological, and historical evidence can inform today's climate and biodiversity agendas. All members of this group share a common commitment to rethink global environmental policies through the lens of long-term, place-based knowledge.

Our first volume, "Regenerative Agriculture and Resilient Food Systems", was launched at the 2025 United Nations Climate Change Conference (COP30) in Brazil.

This second volume turns to biodiversity, and specifically to biodiversity through time. Its central premise is that biodiversity is not a fixed baseline to be restored to some recent, imagined "natural" state, but a dynamic phenomenon with deep histories: shaped over millennia by climatic change and by the many ways in which human communities have related to and lived alongside non-human beings. Reconstructing those histories matters for policy: it reveals how ecosystems have shifted, which baselines are possible and realistic, and how people have sustained diversity in the past. Without this long-term perspective, conservation and restoration targets risk being anchored to a snapshot that is itself the product of recent disturbance.

Much of the research on biodiversity has historically been shaped by institutions from the Global North, often within broader colonial and extractive frameworks, despite the disproportionate impacts of biodiversity loss being felt across the Global South and Indigenous Peoples' territories, which harbour approximately 80% of the world's remaining biodiversity. By centering case studies and perspectives from the Global South, this report helps address this imbalance and elevate voices and knowledge that have often been underrepresented in global biodiversity research and policy. By doing so, this report contributes to the growing acknowledgment that the Global South should not be viewed merely as a site of vulnerability, but rather a source of innovation and leadership.

The report is conceived for presentation at the 17th Conference of the Parties (COP17) to the Convention on Biological Diversity (CBD) in Yerevan, Armenia, and subsequently at the United Nations Climate Change Conference (COP31) in Antalya, Türkiye. We hope it will also reach other arenas of decision-making, encouraging dialogue between science, policy and the communities that care for the world's ecosystems.

In doing so, we acknowledge the inequalities of the Anthropocene: the gap between those who bear the greatest responsibility for environmental change and those who suffer its consequences most acutely. Bringing affected communities into governance means recognising that conservation is inseparable from heritage. The heritages of Indigenous Peoples and Local Communities cross the boundary between nature and culture, and remind us that distinct ontological realities must be taken seriously in any conservation strategy.

The editors wish to express our deep appreciation to all the authors who contributed their research and time to this collective effort, and to the Indigenous Peoples and Local Communities whose knowledge, practices and generosity of dialogue made this work possible. We value these contributions with respect and in alignment with the principles of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) and with the recognition by both the UNFCCC and the CBD of Indigenous Peoples as vital knowledge holders, custodians of biodiversity, and key actors in environmental governance. Their voices are a reminder that biodiversity solutions must be rooted in respect, reciprocity and justice.

This report is also indebted to the institutional and logistical support of the MPI-GEA, particularly directors Prof. Dr. Patrick Roberts, Prof. Dr. Ricarda Winkelmann and Prof. Dr. Jürgen Renn. We are grateful to the ECHOES team, who contributed at different stages of this publication, and to Hans Sell and Michelle O'Reilly of the Outreach, Policy and Sustainability unit at the institute for the invaluable design support and scientific communication input.

We dedicate this volume to all communities working daily to sustain their lands, foods, and ecosystems, and to those striving to ensure that the wisdom of the past becomes a foundation for equitable futures.

Introduction

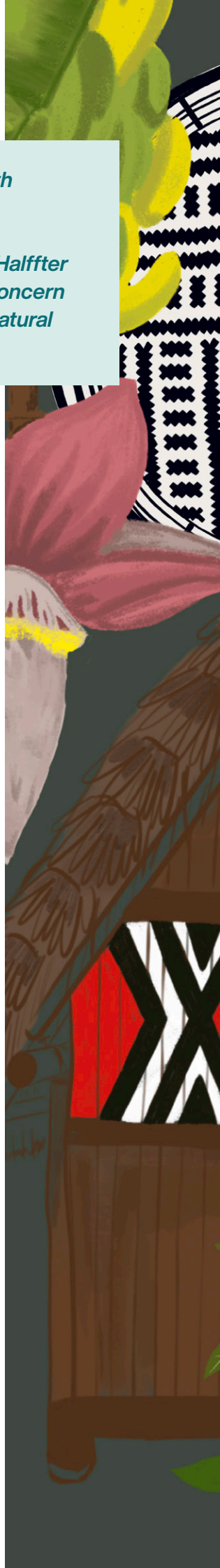
Michael J. Ziegler, Daniela Arango Ruda, Mariya Antonosyan, Patrick Roberts

Contemporary understandings of biodiversity as a field of study have expanded considerably beyond the enumeration of species in a given area to encompass multiple levels of biological variation and their interactions, while increasingly adopting a conservation-oriented perspective shaped by growing concern over the transformation of tropical ecosystems and its implications for economic development, agriculture, natural resources, and governmental decision-making (Núñez et al., 2003; Halffter & Ezcurra, 1992). Compared with disciplines like taxonomy, biogeography, genetics and ecology that have long examined variation across organisms and ecosystems, the emergence of biodiversity as a broader conceptual and policy framework has gradually become fundamental to understanding the organization and functioning of the biological world and its interrelationships (Wilson, 1988). This shift was driven in part by growing recognition that human activities were transforming biological diversity at an unprecedented scale through both direct and indirect destructive activities and environmental change (IPBES, 2019). Recent global evidence reinforces the multidimensional nature of these transformations demonstrating that humans alter local biodiversity and community composition across terrestrial and aquatic ecosystems through five main pressures, including the introduction of invasive species, land-use change, resource exploitation, pollution and climate change (Keck et al., 2025). This expanding evidence base underscores that biodiversity change is not a single process, but a set of interacting ecological transformations unfolding across scales and systems.

... the emergence of biodiversity as a broader conceptual and policy framework has gradually become fundamental to understanding the organization and functioning of the biological world and its interrelationships (Wilson, 1988)

The documentation and understanding of biodiversity change and conservation is embedded in landscapes shaped by long histories of human-environment interactions, particularly in the Global South, where Indigenous Peoples and Local Communities maintain living knowledge systems grounded in sustained relationships with ecosystems. These knowledge systems are dynamic forms of observation and practices. Empirical evidence from 48 sites inhabited by Indigenous Peoples and local communities and covering all climate zones and nature-dependent livelihoods demonstrate that climate change impacts on these sites and occupants are widespread and affect multiple elements of their social-ecological systems including the active monitoring and interpretation of ecological change through place-based knowledge systems (Reyes-García et al., 2024). Moreover, these traditional knowledge systems are vulnerable to disruption as shifts in biodiversity and livelihoods can lead to erosion or ecological knowledge over time. Here, for example, research of traditional knowledge on plant use in the Maasai in Africa shows that documented plant species reduced from 139 to 84 species in a 15-year period, and of those 30 species had experienced loss of uses whereas 18 species had received new uses (Bussmann et al., 2018).

Environmental impacts resulting from human pressures are unevenly distributed and shaped by intersecting vulnerabilities, context-specific responses and geographic disparities.



For example, climate change is predicted to have its strongest negative impacts predominantly in countries in the Global South, despite these countries contributing less to greenhouse gas emissions on a per capita basis when compared to the Global North (Sampson et al., 2011). Within the Global South, the changing climate scenario has both direct and indirect health-related impacts on Indigenous health (Sahu et al., 2023). At the same time, areas of high biodiversity value frequently overlap with zones targeted for agriculture, energy, mining and urban expansion, creating persistent tensions between conservation and development (Neugarten et al., 2024). These hazards are further emphasised through deforestation-induced local warming associated with 28,000 heat-related deaths per year in pan-tropical settings (Reddington et al., 2025). Biodiversity loss transcends ecological concern and is also a health, development and just equality issue.

By the final decade of the twentieth century, biodiversity had become increasingly embedded within a conservation-oriented paradigm (Halffter & Ezcurra, 1992), driven by deep concern over the loss and degradation of natural environments.

These challenges have encouraged international biodiversity governance to move towards a perspective more closely connected to decision-making within the policy arena. The emergence of multiple forums for discussion, knowledge dissemination, and decision-making on biodiversity reflects this transition (Wilson, 1988). Beginning in the late twentieth century, when biodiversity was still emerging as a concept, some of the first spaces aimed at influencing public policy began to take shape. One important example was the National Forum on BioDiversity, held in 1986 and organized by the National Research Council/National Academy of Sciences and the Smithsonian Institution. By the final decade of the twentieth century, biodiversity had become increasingly embedded within a conservation-oriented paradigm (Halffter & Ezcurra, 1992), driven by deep concern over the loss and degradation of natural environments. Consequently, academic institutions and national and international organizations increasingly focused their efforts on identifying actions to address the growing pressures and threats facing the planet's biological diversity (Núñez et al., 2003). Thus, the study of biodiversity evolved from a matter of scientific interest and curiosity into a pressing need for contemporary societies. Biodiversity ceased to be an issue confined exclusively to science and became a prominent component of political agendas worldwide. This growing relevance also fostered the creation of international spaces for knowledge exchange, negotiation, and political action.

Within this context, multilateral institutions and mechanisms such as the Convention on Biological Diversity (CBD) emerged in response to the growing concerns of the 1980s and 1990s and to the recognition of biodiversity loss as an issue requiring international political action. The Convention was adopted in 1992 and established the Conference of the Parties (COP) as its decision-making body. The COP of the Convention on Biological Diversity has since become one of the most prominent multilateral arenas for translating knowledge about biodiversity into international political commitments. Despite its global recognition, however, a substantial gap has persisted between the targets agreed upon within these forums and their achievement in practice. For example, at COP10 in Nagoya in 2010, Parties adopted the 20 Aichi Biodiversity Targets to be achieved during the 2011–2020 period. Yet, after nearly a decade of implementation, the official Global Biodiversity Outlook assessment concluded that none of the 20 targets had been fully achieved at the global level and that only six had been

The chapter on Quilombola perspectives from Brazil further develops this approach by presenting biodiversity not simply as an inventory of species, but as a living relationship between communities, territories, and the wider living world.

partially achieved (Secretariat of the Convention on Biological Diversity [SCBD], 2020).

In response to these shortcomings, COP15, held in Montreal, Canada, in 2022, adopted the Kunming-Montreal Global Biodiversity Framework (KMGBF), establishing four goals for 2050 and 23 targets for 2030. Among its major commitments are placing at least 30% of degraded ecosystems under effective restoration, halving global food waste, reforming or eliminating incentives harmful to biodiversity by at least USD 500 billion annually, and mobilizing at least USD 200 billion per year for biodiversity by 2030 (CBD, 2022). Finally, COP16, held in Cali, Colombia, in 2024, represented an important step toward monitoring and assessing progress in implementing these commitments. Among its major developments was the establishment of the Cali Fund to support the fair and equitable sharing of benefits arising from the use of digital sequence information on genetic resources, alongside measures to strengthen the participation of Indigenous Peoples and local communities and mobilize resources for biodiversity action. COP16 also advanced the implementation and finalization of the KMGBF monitoring framework, establishing common indicators through which progress toward its four goals and 23 targets can be assessed (CBD, 2025). Following COP16 Biodiversity and COP30, Colombia became the first country in the region to protect its entire Amazonian territory (483,000 km2), which makes up 42% of the country's national land and 7% of the South American Amazon, as off-limits to oil and large-scale mining. Time will tell if these governmental measures will hold up to international pressure for resource exploitation and protection of one of the world's most biodiverse regions.

History, palaeoecology, ethnohistory, and archaeology have, for a long time, revealed the legacies left by past populations on contemporary biodiversity and environments, something embodied in the field of historical ecology (Bálee, 2013; Isendahl and Stump, 2018). Meanwhile, Indigenous communities have consistently noted the long-term role of humans in shaping plant and animal distributions, behaviour, and health, both in terms of positive 'care', and ruptures in these systems with historical periods of colonialism and industrialisation (Fletcher et al., 2021). In a policy context, however, these observations have often been marginalized as a result of existing power systems. Meanwhile, biological and ecological research on contemporary ecosystems in the 'Anthropocene' has often integrated historical datasets to a limited extent due to their qualitative, anecdotal, or locally-specific nature (Hamilton, 2016; Malhi, 2017). This can make it hard to understand the tempo, nature, and factors behind contemporary change, given the role of shifting historical baselines and the lack of culture-specific environmental understandings in contemporary discourse. To contribute to this conversation, we are bringing together specialists from diverse backgrounds and methodological traditions. We are especially interested in dialogues among archaeology, history, palaeoecology, oral histories, and Indigenous and local knowledge systems, as these approaches can offer deeper insights into biodiversity dynamics and human–environment relations over time.

The chapter on Quilombola perspectives from Brazil further develops this approach by presenting biodiversity not simply as an inventory of species, but as a living relationship between communities, territories, and the wider living world. Drawing on the concept of

biointeraction, it highlights how Quilombola practices of territorial care, cultivation, fishing, forest management, seed conservation, and the transmission of ancestral knowledge contribute to sustaining biodiversity across generations. It also shows how the defence of biodiversity is inseparable from the defence of Quilombola territories, cultural practices, autonomy, and territorial rights. By bringing together ancestral knowledge, collective memory, historical research, and scientific approaches, the chapter challenges colonial understandings of 'untouched nature' and demonstrates the importance of recognizing traditional communities as active producers of knowledge and stewards of biodiverse landscapes.

This report further highlights the importance of listening to long-marginalized historical and Indigenous knowledge systems when considering contemporary biodiversity assessment and policy, with powerful contributions from Global South Researchers and Indigenous voices (ECHOES et al., 2024).

This report further highlights the importance of listening to long-marginalized historical and Indigenous knowledge systems when considering contemporary biodiversity assessment and policy, with powerful contributions from Global South Researchers and Indigenous voices (ECHOES et al., 2024). This report addresses how biodiversity is understood, studied, and protected and challenges approaches that treat biodiversity primarily as an inventory of species. The contributions highlight biodiversity as a relational and biocultural phenomenon, shaped by cultural values, knowledge systems, foodways, landscapes, and relationships between humans and other forms of life. The report extends this perspective through time and across regions of the Global South through case studies from Africa, Asia and South America. Drawing on archaeological, palaeoecological, historical, and ethnographic evidence, contributions examine long-term interactions between climate, human activities, species, and landscapes, including extinction, species redistribution, ecosystem restructuring, coexistence, and conflict. Case studies demonstrate that biodiversity change has followed diverse regional trajectories and cannot be reduced to a single global narrative. They also reveal how colonialism, extractive economies, changing land-use practices, and other historical processes have shaped present-day biodiversity, while highlighting the importance of Indigenous and local knowledge for understanding these long-term dynamics. The contributions further bring these conceptual and historical perspectives into the present, focusing on pathways for biodiversity conservation, restoration, and governance. Featured case studies highlight Indigenous, community-led, and civil-society initiatives, traditional ecological knowledge, heritage ecology, and locally grounded approaches to caring for biodiverse landscapes (ECHOES et al., 2024).

Together, the chapters argue for conservation approaches that are historically informed, locally grounded, inclusive, and attentive to the rights and knowledge of the communities whose lives and futures are closely connected to biodiversity. The report also showcases latest methods in archaeological and palaeoecological science, as well as environmental history, for recording, monitoring, and tracing biodiversity and how these can improve our understanding of biodiversity change and inform conservation and restoration practice.



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1. Indigenous Perspectives

Biodiversity knowledge is shared and preserved in many forms beyond written texts, including oral histories, stories, songs, and artistic expressions such as paintings, tattoos, sculptures, etc. These forms of knowledge carry understandings of relationships between people, other living beings, and their environments, passed across generations and expressed through diverse cultural practices. This chapter presents two artworks by Indigenous artists, accompanied by their own interpretations.

By including these works, we aim to create space for Indigenous perspectives and forms of knowledge that are often underrepresented in conventional scientific reports, recognising art as a way of communicating knowledge, experience, and relationships with biodiversity.

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Desana and Barâ Woman from the Cucura Indigenous Community

La biodiversidad es la vida que nos rodea y de la cual hacemos parte: nuestros ríos, selvas, animales, plantas, semillas, alimentos, territorios y también nuestros conocimientos, tradicones y saberes. Para nosotras, las mujeres indígenas, la biodiversidad no es solamente la naturaleza, sino un patrimonio que recibimos de nuestros ancestros y que tenemos la responsabilidad de cuidar y transmitir a las nuevas generaciones. Como lideresa, considero que proteger la biodiversidad es defender nuestro territorio, nuestra cultura, nuestra alimentación y nuestra propia vida, promoviendo y conservando el equilibrio entre las necesidades de la comunidad y el respeto a Nuestra ley de origen.



Biodiversity is the life that surrounds us and of which we are a part: our rivers, forests, animals, plants, seeds, food, and territories, as well as our knowledge, traditions, and wisdom. For us Indigenous women, biodiversity is not merely nature; it is a heritage received from our ancestors—one we have a responsibility to safeguard and pass on to future generations. As a leader, I believe that protecting biodiversity means defending our territory, our culture, our food systems, and our very lives, while promoting and maintaining a balance between the community's needs and respect for our Law of Origin.

Brayan Gomez Ayala

Artist – Digital Illustrator

Como artista - ilustrador, puedo contrastar los materiales artísticos que empleo para la realización de mis obras; como la variedad de colores, pinceles, papeles, o texturas; Así mismo existe una gran variedad de fauna, flora, y cultura en nuestros territorios, que hacen de nuestro país aún más rico y diverso; me siento afortunado de ser colombiano y el poder ilustrar lo que mis ojos ven o lugares que mis pies han caminado, como el Mitu - Vaupés; no tengo la necesidad de pedir una descripción o pedir una fotografía o una imagen de referencia para ilustrar mi Colombia o parte de la Amazonia, porque estuve allí, y volvería las veces que fuesen necesarias para recordarme a mi mismo la belleza y diversidad de nuestros territorios.

As an artist and illustrator, I can explore the diverse materials I use to create my work—such as the wide range of colors, brushes, papers, and textures. At the same time, our lands are home to an incredible variety of flora, fauna, and culture, making our country even richer and more diverse. I feel fortunate to be Colombian and to be able to illustrate what my eyes have seen and the places my feet have walked—such as Mitú in Vaupés. I have no need to ask for a description, a photograph, or a reference image to illustrate my homeland of Colombia or parts of the Amazon; I have been there, and I would return as many times as necessary to remind myself of the beauty and diversity of our lands.

Mutaka Orbin

Artist – Digital Illustrator



*Biology means **life**. Diversity means **variety**. When combined, they give us **biodiversity** – the variety of life on earth. The artwork suggests the co-existence of micro-organisms, insects, worms, fish, reptiles and depicts vegetation, wildlife, birds and us humans. We all live together in one environment. We depend on each other to survive. When one part is lost, every other part is affected. This is the harmony of life. We treasure livestock, and nature as a symbol of pride and wealth, and so we do everything to protect them. This is a practice past from one generation to another. While the rest of the world cuts down trees, closes water bodies and destroys animal habitats to pave way for modern structures, our native environment remains natural – a true depiction of biodiversity. We endeavor to protect it and its inhabitants, because it is what sustains life on earth.*

Mutaka Orbin
Lusaka, Zambia, 2026

2. Quilombola Perspectives on Biodiversity

Contemporary Quilombola communities from Brazil embody long-standing practices of collective territorial stewardship, diversified cultivation, seed conservation, care, and protection of forests, waters, and sacred places and territories that became because of the trauma of colonization and slavery, their territories in Brazil. Their practices and knowledge shared here helps to name Local Communities more accurately and show their profound ties with Indigenous Peoples. The Quilombola contribution here also highlights that biodiversity is a historical experience that not merely preserved within territories and lands, but through relationships of deep and unique intergenerational responsibility. Recognising this contribution also requires securing Quilombola territorial rights and treating communities as knowledge authorities and governance partners, as they are for many Indigenous Peoples underscored by Edson Krenak, the indigenous scholar responsible for articulating together the Quilombola different voices from different parts of the country in the article.

Quilombola Communities are Afro-descendant peoples whose territories emerged through resistance to slavery and State violence, and were often sustained through historical alliances, refuge, and exchange with Indigenous Peoples and other forest peoples. Therefore, their struggles and ecological relationships converge or conflate without erasing their distinct histories and rights, especially when a vague, catch-all category of “local communities” sometimes obscure their specificity.

EDITOR



Edson Krenak

Biodiversity: the living territory. Quilombola Perspectives on Biodiversity

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Contribution, organization, and translation from Portuguese by Edson Krenak

This text emerged from our collaborative efforts, from action research conducted in the field and online, through our comings and goings, conversations, generous exchanges, and encounters that we have cultivated in our territories and spaces where we can share, through our relationships, our experiences and insights regarding sociobiodiversity and territory. It was the initiative of an Indigenous son of the Krenak territory that brought together and sparked the conversations presented here. This conversation about biodiversity and territory was inevitable for an Indigenous person inspired-and also provoked-by the life stories of the Quilombola, prompting questions and reflections on what our brothers and sisters-descendants of the *Bantu* Indigenous Peoples of Central and Southern Africa, or the Yoruba, *Jeje*, and so many others from the greater African continent-think: those who were enslaved, massacred, but who resisted side by side with Indigenous peoples and are today the surviving remnants of the colonial violence that still challenges us. Historical and modern colonialism unites us in the struggle for justice and rights.

Even when these taxonomic frameworks recognised a holistic view of territory as a place of life, Alexander von Humboldt did not hesitate to map everything through his utilitarian, Eurocentric, and colonial lens, one marked by economic exploitation and disregard for local forms of land management and care.

And it is the dominant national and international legal and environmental frameworks that impose upon us a concept of territory understood as a delimited cartographic unit-an area of land to be measured, registered, and administered-whose bureaucratic apparatus renders invisible the pains, wounds, and scars that spread across the body, the ground, and the soul. Biodiversity, the second and central term in this discussion, also needs to be operationalised through taxonomic inventories and conservation metrics that reduce living systems to countable and manageable objects of public policy. Even when these taxonomic frameworks recognised a holistic view of territory as a place of life, Alexander von Humboldt did not hesitate to map everything through his utilitarian, Eurocentric, and colonial lens, one marked by economic exploitation and disregard for local forms of land management and care. These approaches, though dominant and present in the sciences that are taught, studied, and applied, have deep colonial roots: they abstract the land and life from the relational webs that produce and sustain them, enabling their conversion into property, resources, and capital, while rendering invisible and destroying the ancestral memories of these places.

Quilombola intellectual traditions, nurtured and imagined within communities, and articulated by renowned thinkers such as Nego Bispo, Beatriz Nascimento, Lélia Gonzalez, and Abdias do Nascimento- and now by new voices- offer a distinct ontological foundation for understanding territory and biodiversity, grounded in Afro-indigenous cosmologies of belonging, reciprocity, and co-constitution between human communities and the living world.

This article links this theoretical framework to a situated account: the experience of the São Sebastião Cipoal Quilombo Territory in Portel, in the Marajoara region of the Amazon; the Cascavel/Pastos Bons Quilombo Community in Maranhão; and the Quilombo de Raiz/ Presidente Kubitschek in Minas Gerais. The authors draw from two distinct experiences: collaborating on territorial stewardship through a partnership with Cultural Survival, a nongovernmental organisation that supports Indigenous and traditional peoples in their self-determination and rights, and participating in a project called Juventude Climática, a partnership between Cultural Survival and IPAM, the Amazon Research Institute.

The text is organized as follows: in the first part, we discuss the concepts that allow us to rethink territory and biodiversity from a Quilombo perspective; in the second part, drawing on community experiences and research conducted by Quilombola professor-researchers within their own territories, we demonstrate how these concepts manifest in traditional land management, the threats faced, and the historical depth of Black settlement in Brazil, particularly in the Amazon, Cerrado, and Caatinga biomes.

TERRITORY AS A LIVED HISTORICAL RELATIONSHIP

For Nego Bispo, the fundamental distinction between colonial and Afro-indigenous ways of inhabiting the world lies in the difference between bio-interaction and monoculture (Nego Bispo, 2015), which embodies a multifaceted way of life in which human beings and their bodies, as well as animals and other beings, are not separated from the land, but are constitutive elements of a living, plural, and interdependent whole.

Biointeraction is “keeping the fish in the waters, where they continue to grow and reproduce”; it is living, coexisting, and learning from the forest, the earth, the waters, the wind, the moon, the sun, people, and animals. It is transforming work into life, art, and poetry. It is transforming differences into diversity. It is removing the heavy burdens of the punishment of labour to allow interaction -biointeraction- to flow and converge. (Rodrigues de Souza, as cited by Nego Bispo, 2015, Afterword).

In an interview, Nego Bispo clarifies that this interaction stems from a concept held by Indigenous Peoples regarding the planet, which is intertwined with our own intrinsic reality: the planet is not “out there,” and we are not “here”: “The earth is not a resource. The earth is a living being with whom we interact. It gives to us, and we give to it.” (Santos, 2025).



Quilombola Women's Music Group celebrating community life. Photo taken by Jaime Malcolm Brown/Cultural Survival Courtesy

From this perspective, territory is not an inert surface, but an active subject engaged in relationships of reciprocity and history. Beatriz Nascimento, another Quilombo thinker, expands this understanding by conceiving the Quilombo as a living and continuously recreated institution—a shared space of memory, practice, and survival. Menezes (2024), commenting on the work of Beatriz Nascimento, highlights the need to view the quilombo—*Quilombola territory*—as an institution originating in pre-diaspora Africa, an autonomous community-based institution. The quilombo was criminalized in colonial and imperial Brazil as a threat to the slave-based order. Later, it was reframed as an ideological principle of cultural resistance and identity affirmation. In the 20th century, this ideology was historicized by the Black movement, consolidating the *quilombola* as a political paradigm active in contemporary agendas of reparations, territoriality, and citizenship.

Therefore, territory and biodiversity are terms that must be examined, discussed, and politically redefined against the backdrop of this history. The relationship between the quilombos and the biodiversity of their territories is deeply linked to the cultural and socioeconomic practices of these communities. As they escaped and fought against slavery in 17th- and 19th-century Brazil, the quilombolas developed forms of self-sufficiency that endure to this day. An emblematic example is the management of everlasting flowers and golden grass by various communities in Brazil's Caatinga and Cerrado biomes, where, for instance, more than 300 species of these plants are known, managed, and used in activities that integrate the biological, social, and economic dimensions of daily life in the quilombo. These flowers represent not only beauty but also food, medicine, and economic sustenance for many communities. Biodiversity takes on a cultural and ceremonial dimension for these communities.

BIODIVERSITY AS A COSMOPOLITICAL RELATIONSHIP

The contemporary scientific notion of biodiversity often treats it as a measurable property of ecosystems, national parks, forest reserves, etc. This has led to jurisdictional conflicts with Indigenous and Quilombola communities, resulting in the loss of territories, the dispersion of peoples, forced removal, violence, and other colonial forms of suppression of territorial plurality and biointeraction. Quilombola cosmologies-*and, incidentally*, those of Indigenous peoples-offer another perspective: plants, animals, waters, and soils are understood as relatives, ancestors, or spiritual presences with which communities maintain permanent, dynamic relationships.

These relationships are not political in the sociological or philosophical sense of the term, but are relationships of *self-management* and self-determination, because "within the animal kingdom, politics exists only among the human species." In other species, there is self-management. There is no group of goats that wants to govern all the herds. Each group of goats forms its own herd. (Nego Bispo, 2015:29). The concept of "politics" as applied to biodiversity, as described by the State and institutions such as the UN and the Convention on Biological Diversity, is deeply anthropocentric[1] . As Nego Bispo explains:

> *We Quilombolas, however, do not have politics; we have ways of life. We do not hold assemblies to resolve our issues; we have discussions in which we argue until we understand one another. Afterward, we drink cachaça to celebrate. Our movement is the movement of transfluence. Through transfluence, we are the beginning, the middle, and the beginning. Because we transfluence, confluence, and transfluence. Confluence, transfluence, and confluence. The order can be any which way. (Nego Bispo, 2023:29)*

[1]Consider, for example, how humans serve as the reference point for this definition: Biological diversity refers to the variety of life on Earth and the natural patterns it forms. It is vital to protect the vast array of species on our planet, but in the pursuit of human development, this often takes a backseat. In fact, according to the United Nations Environment Programme, human activity is pushing one million species of plants and animals toward extinction. Available at https://www.un.org/sustainabledevelopment/blog/2023/08/explainer-what-is-biodiversity/

By offering self-management as a form of policy, Quilombola territorial practices produce and sustain the very biodiversity that conservation science seeks to protect, demonstrating that the defense of biodiversity is inseparable from the defense of Quilombola territories, culture, and the rights of these communities-who did not come to these lands to exploit, extract, and transform the landscape, but rather to *biointeract* with it through their ancestral practices.

TOWARD A QUILOMBOLA CONCEPT OF BIODIVERSITY IN THE CONTEXT OF THE CLIMATE CRISIS

Based on the convergence of biointeraction, cosmopolitical relations, and territorial memory discussed above, it is possible to outline a distinctly Quilombola concept of biodiversity, which differs both from the quantitative and qualitative classification of species in conservation science and from the economistic notion of "natural resource." From this perspective, biodiversity is not a stock to be inventoried or a place on the map to be governed from afar or from the outside, but rather the visible result of a pact of care, renewed generation after generation, between the community, the forest, the rivers, and the nonhuman beings that inhabit them. Biodiversity is a relationship of self-management of the planet, where beings and forms enjoy and celebrate life in such a way that they do not cause harm or the extinction of others.

This preliminary concept articulates three dimensions: a relational dimension, in which plants, animals, and waters are kin rather than objects; a historical dimension, in which biological diversity is the result of management and self-management practices passed down through generations, rather than "untouched nature"; and a political dimension of care, in which the defense of biodiversity is inseparable from the defense of the territory and of Quilombo autonomy and self-determination. In São Sebastião Cipoal, this conception is expressed through rotational farming, agroforestry management, and the oral transmission of knowledge; in the Quilombo de Raiz, it manifests in the relationship with everlasting flowers and their self-managed economies, which are examples of practices that produce biodiversity as much as they conserve it.

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A Quilombo concept of biodiversity, therefore, does not ask "what and how much is conserved," but rather "what relationships sustain life and how these relationships can be nurtured." This theoretical and methodological shift has direct implications for how environmental impact assessments, biological inventories, and conservation policies should address Quilombo territories, as well as for the legal and jurisdictional issues that land and territory raise in democratic countries.

However, the climate crisis challenges these communities and their traditional knowledge to develop forms of management and self-governance that address the crises threatening not only their lives but also the species, flora, and fauna that inhabit their territories.

The Quilombo Cascavel community understands that traditional Quilombo management contributes directly to environmental conservation as a whole because it is based on traditional ecological wisdom-biointeraction passed down orally by elders, the sustainable use of the land, respect for natural cycles, and the transmission of ancestral knowledge about plants, rivers, soils, and forests. For the community, the climate is not something to be controlled, but rather part of a balance with nature.

Quilombola communities employ practices that preserve natural resources and allow ecosystems to regenerate, often serving as barriers to deforestation and environmental destruction and contributing to the conservation of Brazilian biodiversity. Studies by the National Institute for Space Research (INPE) reveal that over the past four decades, the number of dry periods has increased across much of Brazil, particularly in the Central-West, Northeast, Southeast, and Amazon regions, highlighting the country's vulnerability to climate extremes.

The impacts associated with climate change are factors that lead, for example, to food insecurity and trigger risks that affect human health and the economy. Additionally, other social impacts related to floods and droughts, as well as vector-borne diseases such as dengue and malaria, are much greater in highly vulnerable communities such as the Indigenous Peoples and Quilombolas of the Amazon. The knowledge and very survival of these peoples and communities are of central importance for environmental protection and the fight against climate change.

The knowledge and very survival of these peoples and communities are of central importance for environmental protection and the fight against climate change.

In 2014, Indigenous territories, as well as Quilombola communities and other protected areas in the Amazon, accounted for more than 60% of the biome's total carbon stock and had the lowest rates of deforestation (2.1%) and wildfires, demonstrating their effectiveness in protecting natural environments and their ecosystem services (Birkmann et al., 2022).

Protected areas in the Cerrado biome, including indigenous territories, have also contributed to significantly reducing deforestation in the Amazon deforestation arc region (Castellanos et al., 2022). However, the survival of Indigenous communities and the integrity of their territories are threatened by large-scale agribusiness, increased deforestation, controlled burning, the use of pesticides, conflicts and land invasions, the expansion of livestock ranching, mining, and wildfires-all of which exacerbate health problems, violence, and legal uncertainty. These activities can lead to the removal of native vegetation, soil and water contamination, a reduction in biodiversity, and the disappearance of plants and animals traditionally used by the community. The use of chemicals and the aerial application of pesticides can also affect areas closer to farmlands and water sources, posing risks to food production and environmental quality. In addition to environmental impacts, these activities threaten the community's continued presence and autonomy within the territory, as they can reduce the spaces used for agriculture, fruit gathering, animal husbandry, and the preservation of cultural practices.

Therefore, it is essential to strengthen the protection of Quilombola territories, value traditional knowledge, and promote sustainable economic activities that ensure the conservation of ecosystems and the quality of life for future generations. Indigenous communities and other rural communities in the Amazon that depend on natural resources have also been suffering the climatic impacts of extreme droughts. In the Cascavel Quilombola Community, traditional knowledge about plants, water, the climate, and natural cycles is directly linked to the community's history of occupation, resistance, and continued presence on its territory. This knowledge is built up and passed down through the generations via the memories of elders and daily practices, such as the cultivation of rice, beans, corn, and cassava, as well as the observation of rainfall, moon phases, plants, and nature's signs to determine the appropriate times for planting and harvesting.

Accounts from the oldest residents show that, in the past, the agricultural calendar was guided

by observations of nature. The community used its own knowledge to predict the arrival of rains, such as observing a salt stone placed in a bowl, as well as the position of the stars and other natural signs. There were also traditional methods of managing the fields, in which fire was used in a controlled manner, and work was carried out collectively. These practices demonstrate that the Quilombolas developed their own strategies for coexisting with the environment and for the sustainable use of natural resources.

This knowledge aligns with historical, historiographical, and archaeological evidence because it helps us understand that Quilombola territories are not recently occupied spaces, but places built and preserved over generations. Oral history, farming methods, places of traditional use, cultural practices, and knowledge of biodiversity can complement historical and archaeological research, helping to identify the continuity of the presence and relationship of Black communities with their territories. In the case of Cascavel, it is important that new research documents and values these memories and investigates possible material evidence of this occupation, without disregarding the knowledge produced by the community itself.



Picture: Urucom shared between Quilombola and Indigenous communities: Quilombo Mutuca. Photo taken by Jaime Malcolm Brown/Cultural Survival Courtesy

The dialogue between traditional knowledge and science can also contribute to the development of public policies better suited to the reality of the Quilombo communities. In the Cascavel Community, for example, this dialogue can guide actions to protect springs and water sources, implement rainwater harvesting systems, restore degraded areas, preserve native seeds and plants, strengthen traditional and agroecological agriculture, prevent and control wildfires, and protect the territory against deforestation and other activities that threaten biodiversity.

Furthermore, Quilombola knowledge must be recognised as an important contribution to biodiversity conservation policies and to international commitments related to the protection of ecosystems and traditional knowledge. Valuing this knowledge means recognising that Quilombola communities are not merely beneficiaries of environmental policies, but also producers of knowledge and guardians of practices that are fundamental to nature conservation. Thus, in the Cascavel Quilombola Community, bringing together the memories of elders, traditional knowledge, historical and archaeological research, and scientific knowledge can strengthen the defence of the territory, food security, biodiversity conservation, and adaptation to climate change. This dialogue helps shape public policies that respect the community's identity, culture, ways of life, and territorial rights, ensuring that their knowledge is preserved and passed on to future generations.

In the heart of Jalapão National Park, in the state of Tocantins, where crystal-clear natural pools drive tourism in the region, the Mumbuca Quilombo takes pride in the way of life shaped by their ancestors, grandparents, and great-grandparents, who taught them to love the land

and to sustain themselves from it in a respectful manner. Living in Mumbuca means cherishing the nature that surrounds them: it provides food, fruits, and even materials for building homes, such as coconut husks and piassava, as well as the traditional work of making their daily flour.

Their way of caring for the land is based on traditional management practices and self-governance skills they learned from their elders, such as harvesting golden grass to produce handicrafts unique in the world, and caring for the Cerrado without destroying it. This management directly helps conserve biodiversity, as they respect the earth's rhythms, protects water sources, and aids in the regeneration of areas that have suffered from deforestation or improper burning outside the quilombo. Their deep knowledge of plants, water sources, and the natural cycles of the Cerrado is no myth; it has been recognised and confirmed by archaeologists and historians who study the land and find evidence that the Quilombolas have continuously occupied and protected this territory for generations.

This management directly helps conserve biodiversity, as they respect the earth's rhythms, protects water sources, and aids in the regeneration of areas that have suffered from deforestation or improper burning outside the quilombo.

The rich histories of biocultural and bio-interactive practices have survived the test of time thanks to oral tradition-the practice of passing knowledge down from generation to generation through conversation and listening to elders, as well as through songs and rituals related to harvesting and caring for the land. In preserving these stories, Dona Miúda, the grandmother of one of the authors, plays an enormous role. She was the one who preserved and spread the legacy of the golden grass culture and craftsmanship, transforming these shimmering strands into the economic, social, and cultural foundation of the community. Today, to ensure that this entire tradition remains alive, the master artisans-both men and women-are essential, as they apply and teach the lessons of Dona Miúda. Some of these beloved figures-such as "Doutora," "Santinha," and "Arnon"-ensure the culture's survival by teaching the younger generation and visitors how to play the buriti wood viola, sew with golden grass at the right time of harvest, weave baskets, and prepare our traditional foods.

It is from this sustainable way of life that community-based tourism also emerges. Today, activities carried out with visitors are one of the community's largest sources of income, creating a system where everything is done collectively. Tourists come to be part of daily life; they stay at the inns and eat at the restaurants. True immersion occurs when visitors sit with the community around the campfire to listen to stories and conversations, join in traditional songs, and learn through hands-on workshops in crafts and cooking. This rich *experience* unfolds in places steeped in memory and warmth, such as the "Cantinho da Viola de Buriti," the "Oficina de Buriti," and the "Casa da Cultura," along with the Community Association; conversations with the guardians of knowledge and the keepers of memory; and the warm welcome at the "Casa de Santinha" and the "Casa de Doutora." These spaces, like others in the Mumbuca community, invite the world to learn about resistance, the power of socio-bio-cultural preservation, and to value local history.

This dialogue between our ancestral knowledge and modern forms of social engagement is a powerful tool that helps policymakers create better public policies, strengthen local governance, and improve international biodiversity agreements, demonstrating that the best way to protect nature is by guaranteeing the rights of Quilombola peoples to their lands.

BANTU, YORUBA, AND JEJE HERITAGES: OTHER ONTOLOGIES OF NATURE

The Quilombola worldview described here also engages with specific African traditions that crossed the Atlantic with enslaved peoples and remain alive in Afro-Brazilian religions, in artistic practices such as music and dance, and in interactions with the land through food production in the quilombos and Black communities of Brazil.

Among the Bantu peoples of Central and Southern Africa, from whom a large portion of the enslaved population brought to the Brazilian Amazon and other regions of the country originated, the world is described as a network of vital forces that communicate with one another and are strengthened or weakened through the relationships between humans, ancestors, and the natural world (Tempels, 1945). In this ontology, land, water, and forest are not an inert backdrop, but participants in a totality of interrelated forces-a notion structurally close to Nego Bispo's ideas of biointeraction and convergence.

Among the Yoruba and Jeje peoples of West Africa, who were also brought to Brazil and played a role in the historical formation of the quilombos - this relationship with nature is expressed in the worship of the orixás, who are deities associated with natural elements and forces: Oxum with rivers, Iemanjá with waters, Ogum with iron and the cleared forest, and Ossaim, linked to leaves and the healing power of plants. Depending on the tradition and the people, the names change, but the principles remain the same[2]. For example, there is no worship of the orixás without leaves; there is no healing or medicine, ritual, or ceremony without the presence of plants, demonstrating that the sacred depends materially on the integrity of the forest (PRANDI, n.d.). In this sense, environmental destruction is not merely an ecological loss but a spiritual rupture.

... there is no worship of the orixás without leaves; there is no healing or medicine, ritual, or ceremony without the presence of plants, demonstrating that the sacred depends materially on the integrity of the forest.

The specific heritages mentioned here, such as Bantu, Yoruba, and Jeje, do not replace the generic African ancestry evoked in Quilombola discourses; rather, they show that the Quilombola relationship with the territory embodies, in a deeply rooted way, different African cosmologies regarding the relationship with the land, reworked through the Amazonian experience and intertwined with local Indigenous cosmologies. Recognising this plurality of matrices is part of treating Quilombola knowledge as a living territorial science, rather than as a homogeneous block of "tradition." This plurality of matrices is also deeply linked to what is called in Brazil the ancestry of Indigenous Peoples, whom Quilombola thinkers refer to as the guardians of plurality.

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[2]There are other aspects that have changed and evolved with the arrival in the Americas, as Prandi points out: *With the arrival in the Americas, the process of anthropomorphization and the change or diversification of the pantheon was accompanied by the unification of the pantheon, with orixás from different locations coming to be worshiped together in the same places of worship—in the case of Brazil, the candomblé terreiros—leading to a greater specialization in the division of labor among the guardian deities. Thus, Iemanjá, now queen of the sea, is the protector of motherhood and mental balance; Oxum takes on the fresh waters and the prerogative to govern human fertility and love; Ogum governs iron and war, but is also the one who opens all paths and social opportunities; Xangô, the orixá of thunder, is the master of justice.* (*op. cit. 5*)

In the São Sebastião Cipoal Quilombola Territory in the state of Pará, experiences of sociobiodiversity are understood and lived as knowledge produced by the territory itself through the historical relationships between people, waters, forests, plants, animals, memory, and ancestry. The territory is not merely a physical space or an object of conservation: it actively participates in the formation of knowledge, social practices, and Quilombola ways of understanding and sustaining life. Oral memory, sacred sites, ancient river routes, farming, fishing, and healing practices, and knowledge of natural cycles constitute living records of this long-standing relationship.

In this sense, scientific research, historical memory, and ancestral knowledge are not three independent sources used to explain São Sebastião Cipoal. They converge within the territory and through it. Historiography and archaeology help demonstrate the depth of the Quilombola presence; collective memory preserves experiences and relationships passed down through generations; and ancestral knowledge remains present in the interpretation of water patterns, the agricultural calendar, the medicinal use of plants, fishing, and forest management. The text itself characterises this knowledge as a kind of "living territorial science."

Biodiversity is inseparable from the practices of cultivation, circulation, food, spirituality, kinship, and knowledge transmission that keep the territory alive. This perspective directly challenges the colonial narrative of "untouched nature" and recognises that traditional territories are also the result of long histories of management, interaction, and care.

For this reason, São Sebastião Cipoal develops its own conception of sociobiodiversity. The forest is not a natural realm external to society, preserved despite human presence. It is a landscape historically shaped by the relationships between the community and different forms of life. Biodiversity is inseparable from the practices of cultivation, circulation, food, spirituality, kinship, and knowledge transmission that keep the territory alive. This perspective directly challenges the colonial narrative of "untouched nature" and recognises that traditional territories are also the result of long histories of management, interaction, and care.

It is at this point that the experience of São Sebastião Cipoal can be placed in dialogue with Nêgo Bispo's notion of "biointeraction." Biointeraction allows us to understand territory not through the colonial logic of separation between humanity and nature, but through the relationships of coexistence, reciprocity, and continuity among different forms of life. The territory is not a reserve of resources to be exploited. It exists because its relationships continue to circulate and be renewed.

In São Sebastião Cipoal, this takes a very concrete form. The waters guide the rhythms of fishing and agriculture; plants connect the forest, food, health, and memory; the farmlands depend on cycles of regeneration; the forest provides knowledge while simultaneously being transformed by historical management practices; and the wisdom of the elders sustains these relationships across generations. The territory is, therefore, simultaneously a memory, a school, an archive, a place of production, an ecological system, and a spiritual space.

Biointeraction also helps to shift the conventional idea of conservation. In mainstream environmental policy, conservation often means protecting nature from human action. The experience of São Sebastião Cipoal suggests another possibility: biodiversity is maintained precisely because certain human relationships with the territory persist. Preserving the forest also means preserving the knowledge, practices, community ties, and territorial conditions that enable its regeneration. According to Antonio Carlos Diegues, traditional peoples and

communities have developed “historically sustainable ways of relating to nature,” capable of conserving ecosystems through ecological knowledge accumulated over generations (Diegues, 2000, p. 87). This perspective reinforces the idea that the Quilombolas are not obstacles to environmental development, but rather protagonists of biocultural conservation.

This perspective also reshapes the relationship between science and traditional knowledge. The text shows that social maps, community archaeology, participatory cartography, historical research, environmental inventories, and academic studies can strengthen territorial defence. However, these tools should neither replace nor validate from the outside the knowledge produced within the territory. They can engage with it on an equal footing and help make visible what colonial narratives have historically erased.

Thus, São Sebastião Cipoal can be understood not only as a territory where knowledge is produced, but as a territory that produces knowledge. Its waters, forests, paths, memories, and intergenerational relationships constitute a distinct territorial epistemology. From the perspective of Nêgo Bispo’s biointeraction, the territory ceases to be an object of conservation and emerges as a living subject of knowledge, relationship, and the production of futures.

This last dimension is especially important: the articulation between science, memory, and ancestry serves not only to prove historical occupation or claim recognition. It allows São Sebastião Cipoal to assert authority over the present and future of the territory, countering colonial ways of defining, from the outside, what constitutes biodiversity, conservation, and development.

However, in São Sebastião Cipoal, we observe increasingly intense environmental changes: shifts in the rainy season, increased extreme heat, a decline in agricultural productivity, a reduction in traditional fishing, and difficulty accessing drinking water at certain times of the year. These phenomena demonstrate that climate change is already directly affecting the ways of life of the Quilombola communities in the Marajoara Amazon.

Furthermore, Ailton Krenak asserts that the contemporary climate crisis stems from humanity’s rupture with nature, which capitalism has transformed into a mere economic resource (Krenak, 2019, p. 22). In the Amazonian quilombos, by contrast, the forest remains integral to the community’s social, spiritual, and dietary life-a bond that is particularly strong in our quilombo.

Traditional quilombo land management contributes directly to environmental conservation and the fight against climate change because it is based on the sustainable use of the land, respect for natural cycles, and the transmission of ancestral knowledge about plants, rivers, soils, and forests.

Traditional quilombo land management contributes directly to environmental conservation and the fight against climate change because it is based on the sustainable use of the land, respect for natural cycles, and the transmission of ancestral knowledge about plants, rivers, soils, and forests. Quilombo communities employ practices that preserve natural resources and allow ecosystems to regenerate, often acting as barriers against deforestation and environmental destruction and contributing to the conservation of Brazilian biodiversity.

In the São Sebastião Cipoal territory, traditional land-use practices include rotational shifting cultivation (using secondary forests), agroforestry management, protection of springs, sustainable harvesting, medicinal use of plants, and preservation of areas of native forest. These practices directly contribute to the maintenance of ecological cycles and the natural

regeneration of degraded areas, especially in regions under pressure from advancing deforestation and climate change.

Therefore, to ensure that this self-management works, six key points are necessary:

- strengthening definitive land titling for Quilombola territories;
- expand public policies on climate adaptation;
- guarantee direct climate finance for traditional communities;
- encourage community-based agroecological systems;
- legally protect traditional knowledge;
- include Quilombolas in decision-making forums at COP30 and other COPs, as well as at the Convention on Biological Diversity.

As Boaventura de Sousa Santos points out, there can be no environmental justice without social justice and recognition of historically marginalised forms of knowledge (Santos, 2010, p. 56). Therefore, defending the quilombos also means defending Amazonian biodiversity and global climate balance.

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THREATS TO TERRITORY AND BIODIVERSITY: MINING, MONOCULTURE, AND DAMS

Various economic activities threaten quilombo territories and the ecosystems preserved by these communities. Mining causes deforestation and contaminates rivers with mercury and other heavy metals, destroying forms of life in the environment and generating territorial conflicts, violence, and threats to the food and cultural survival of quilombo communities. Monoculture stems from the exploitation, expansion, and impact of agribusiness. Dams and hydroelectric plants cause flooding in traditional territories and force the displacement of entire communities, in addition to altering the natural cycles of rivers, harming fishing, agriculture, and the water supply. Land grabbing and deforestation, illegal land occupation and logging, reduce preserved areas and intensify land disputes. This threatens both the physical and cultural survival of the Quilombola communities and the environmental conservation efforts they undertake. Finally, climate change causes prolonged droughts, floods, and changes in rainfall patterns, directly affecting traditional ways of life and weakening the ecosystems protected by these communities.

The São Sebastião Cipoal Quilombola Territory currently faces multiple threats associated with the spread of predatory economic models in the Amazon. Among these, the following stand out:

- deforestation;
- rising temperatures;
- illegal logging;
- agribusiness expansion;
- wildfires;
- land grabbing;
- river pollution;
- lack of effective public environmental policies.

These processes affect not only the environment but also the physical, cultural, and historical continuity of Quilombola communities in their ancestral territories.

According to Milton Santos, territory cannot be understood merely as physical space, but as a space of life, identity, and social reproduction (Santos, 2006, p. 63). When environmental destruction occurs in Quilombola territories, it is accompanied by cultural destruction and the weakening of the community.

In the Portel region, the impacts of climate change have been exacerbated by environmental degradation. Wildfires intensify the heat and directly affect family farming; rivers exhibit changes in their natural cycles; plant and animal species become less abundant; and communities face growing food insecurity, in addition to respiratory problems caused by smoke from illegal and uncontrolled wildfires.

Researcher Vandana Shiva argues that the economic model based on destructive extractivism promotes a "monoculture of the mind," eliminating local knowledge and sustainable practices (Shiva, 2003, p. 45). This also occurs in the Amazon, where economic projects frequently disregard the traditional ways of life of the Quilombola communities.

Quilombola communities face a lack of infrastructure, social vulnerability, and limited participation in decision-making processes on climate and biodiversity.

Another critical element is environmental racism. According to Carlos Walter Porto-Gonçalves, traditional communities have historically been more exposed to environmental impacts due to the unequal logic of land occupation (Porto-Gonçalves, 2006, p. 289). Quilombola communities face a lack of infrastructure, social vulnerability, and limited participation in decision-making processes on climate and biodiversity.

Given this scenario, I consider it essential to:

- to ensure prior, free, and informed consultation with communities;
- combat territorial invasions;
- create international mechanisms for climate protection for quilombos;
- strengthen community-based and school-based environmental education;
- expand investments in sustainable technologies adapted to the Amazonian context;
- officially recognise quilombo territories as strategic areas for biodiversity conservation.

The continued presence of the Quilombolas in their territories represents a concrete form of environmental protection and resistance to climate collapse, as well as a guarantee of future life.

HISTORICAL DEPTH: A DIALOGUE BETWEEN QUILOMBOLA KNOWLEDGE, HISTORIOGRAPHY, AND ARCHAEOLOGY

The Quilombola knowledge produced in the São Sebastião Cipoal Territory engages deeply with historical, archaeological, and environmental evidence demonstrating the long-standing presence of traditional Black populations in the Amazon. Our ancestry is linked to resistance, sustainable forest management, and the historical development of our own systems of territorial organisation.

Colonial narratives often rendered the quilombos invisible or reduced them to isolated spaces of refuge. However, more recent historiographical and archaeological research demonstrates

that the quilombos constituted complex territories of social interaction, agricultural production, economic exchange, and ecological management.

Historian Beatriz Nascimento asserts that the quilombo represents a historical African continuity in Brazil, structured by territorial resistance and the collective construction of freedom (Nascimento, 1985, p. 41). This understanding broadens the concept of the quilombo beyond resistance to slavery, recognising it as a political, cultural, and ecological territory.

From an archaeological and environmental perspective, contemporary studies demonstrate that traditional Amazonian communities have historically contributed to the formation and maintenance of biodiverse ecosystems. According to William Balée, much of the Amazon rainforest is directly influenced by ancestral human management, especially by traditional peoples (Balée, 1994, p. 12). This understanding dispels the false notion of "untouched nature" and recognises the quilombolas as historical agents of environmental conservation.

In São Sebastião Cipoal, traditional knowledge remains alive:

- in the medicinal use of plants;
- in the observation of water cycles;
- in the agricultural calendar;
- in fishing practices;
- in forest management;
- in the oral transmission of ancestral knowledge (which is very powerful in the territory).

This knowledge must be recognised as living territorial science and incorporated into public environmental policies, universities, and international debates. As bell hooks points out, the knowledge produced by historically marginalised populations possesses a critical capacity for social and political transformation (Hooks, 2013, p. 73).

The Quilombola presence in the São Sebastião Cipoal Territory has a historical depth that extends beyond the formal period of the abolition of slavery in 1888, being linked to complex processes of Black resistance, territorial mobility, and the collective construction of autonomous ways of life in the Amazon. In the region, especially in the Marajó archipelago and the riverine areas of Pará-many quilombo territories were formed through the movement of enslaved Black populations fleeing colonial frontiers and the violent labour relations imposed since the colonial period.

According to Beatriz Nascimento, the quilombo should be understood as a continuous historical system of Black social organisation, constituted not only by escape but also by the development of projects of freedom, territoriality, and historical permanence (Nascimento, 1985, p. 41). This perspective is also reinforced by Clóvis Moura, who asserts that the quilombos were permanent structures of resistance against the slave system and fundamental elements of Brazilian social formation (Moura, 1981, p. 103).

In the São Sebastião Cipoal Territory, the oral history of the elders, the knowledge passed down through generations, the sacred sites, the ancient river routes, and traditional forest management practices constitute living evidence of this long-standing quilombo presence.

In the São Sebastião Cipoal Territory, the oral history of the elders, the knowledge passed down through generations, the sacred sites, the ancient river routes, and traditional forest management practices constitute living evidence of this long-standing quilombo presence. As Kabengele Munanga points out, Quilombo resistance gave rise to distinct territorialities,

sustained by networks of solidarity, kinship, and cultural preservation (Munanga, 2001, p. 52).

Recognising the long history of the Quilombola presence in São Sebastião Cipoal also means recognising:

- the historical legitimacy of the territory;
- the Quilombo contribution to environmental conservation;
- the importance of ancestral knowledge in addressing climate change;
- the right of Quilombola communities to participate in global biodiversity and climate policies.

Historical, archaeological, and collective memory data related to the São Sebastião Cipoal Quilombola Territory constitute important material evidence of traditional Black occupation in the Amazon and serve as fundamental tools for strengthening territorial and environmental claims in national and international forums, especially in debates related to the Convention on Biological Diversity and the UN Climate Conferences.

In international forums on biodiversity and climate, this evidence can strengthen claims related to:

- the legal recognition of Quilombola territories;
- protection against deforestation and mining;
- direct access to climate finance;
- the inclusion of Quilombola communities in international environmental governance mechanisms;
- the recognition of traditional knowledge as a tool for biodiversity conservation.

According to Carlos Walter Porto-Gonçalves, current environmental conflicts are also territorial and epistemological conflicts, as they involve disputes over who has the legitimacy to produce knowledge and decide on the future of nature (Porto-Gonçalves, 2006, p. 287). By presenting this evidence in international forums such as COP30 and the Biodiversity COP, Quilombola communities demonstrate that their territories have historically been protected by sustainable traditional practices, that environmental conservation depends on the continued existence of traditional peoples, and that climate justice requires historical reparations and the guarantee of territorial rights.

... quilombos are not recent or irregular occupations, but territories historically built through continuous processes of resistance, social organisation, environmental conservation, and cultural production.

COUNTERING COLONIAL NARRATIVES: TRADITIONAL KNOWLEDGE AND SCIENTIFIC RESEARCH

Quilombolas can counter the colonial narratives that have historically erased, rendered invisible, or delegitimised their presence in these territories by integrating traditional knowledge, ancestral memory, and critical scientific research. This strategy makes it possible to demonstrate that quilombos are not recent or irregular occupations, but territories historically built through continuous processes of resistance, social organisation, environmental conservation, and cultural production.

In the case of the São Sebastião Cipoal Quilombo Territory, the very fact that the community has persisted across generations constitutes concrete evidence of territorial ancestry. Orally

transmitted knowledge, traditional farming methods, forest management, and knowledge of rivers, medicinal plants, and natural cycles reveal a deep historical relationship between the Quilombo population and Amazonian biodiversity.

Colonial narratives have historically constructed the idea that traditional territories were "empty," "backward," or "unproductive," denying the leading role of Black populations in the formation of Brazilian territory. However, historiographical, anthropological, archaeological, and environmental studies have demonstrated exactly the opposite: the Quilombolas played a fundamental role in preserving ecosystems and in establishing sustainable systems of occupation in the Amazon.

... the Quilombolas played a fundamental role in preserving ecosystems and in establishing sustainable systems of occupation in the Amazon.

Similarly, Kabengele Munanga emphasises that Quilombola identity is linked to collective memory, a sense of territorial belonging, and historical resistance against processes of racial exclusion (Munanga, 2001, p. 56). Thus, strengthening ancestral memory also constitutes a form of epistemological resistance to colonialism.

Furthermore, the Quilombolas can use social maps, oral history, historical records, community archaeology, participatory cartography, collaborative academic research, environmental inventories, and ethnographic studies as technical and political tools to strengthen territorial claims in national and international forums.

According to Boaventura de Sousa Santos, it is necessary to promote an "ecology of knowledge," recognising that traditional knowledge possesses scientific and political legitimacy in the development of solutions to contemporary crises (Santos, 2010, p. 53). In this sense, Quilombola knowledge should engage in a horizontal dialogue with academic science, rather than being subordinated to it.

In São Sebastião Cipoal, this dialogue between science and tradition can directly contribute to strengthening the struggle for land titling, protecting areas threatened by deforestation, ensuring Quilombola participation in the COPs, expanding public policies on climate adaptation, valuing traditional agroecological systems, and recognising the quilombos as strategic territories for the conservation of Amazonian biodiversity.

In this way, by uniting scientific research, historical memory, and ancestral knowledge, the Quilombolas are building a powerful foundation of resistance against the colonial structures that have historically sought to erase their existence. More than simply defending the past, this integration affirms the Quilombola right to actively participate in shaping the environmental, climatic, and political futures of the Amazon and the world.

CONCLUSION

When considering the quilombola narratives as a whole, a conception of sociobiodiversity emerges that is rooted in the territories themselves. The quilombos are not merely spaces where communities live or conserve natural resources, but living territories that produce knowledge, memory, social relations, and their own unique ways of interacting with forests, waters, plants, animals, and ecological cycles. This perspective shifts biodiversity from a purely environmental category to an understanding of it as the result of historical relationships between territory, ancestry, culture, and different ways of life.

In this framework, scientific research, historical memory, and ancestral knowledge do not function as separate spheres. Archaeology, historiography, cartography, environmental

studies, and other forms of research can document the antiquity and territorial continuity of the Quilombola; at the same time, oral traditions, the knowledge of elders, sacred sites, trails, farming practices, fishing, and knowledge of waters and plants constitute living archives produced by the territories themselves. Quilombola knowledge, therefore, does not need to be transformed into science to gain legitimacy; the challenge is to build a horizontal dialogue in which different forms of knowledge production reinforce one another without subordination.

... the challenge is to build a horizontal dialogue in which different forms of knowledge production reinforce one another without subordination.

This interpretation brings Quilombola experiences closer to Nêgo Bispo's concept of biointeraction. In contrast to the colonial logic that separates humanity from nature and reduces territory to a resource, biointeraction allows us to understand existence as the continuous production of relationships of reciprocity, circulation, care, and regeneration. In quilombola territories, conserving biodiversity thus means continuing to interact with it: managing the forest, understanding water cycles, farming, fishing, transmitting knowledge, and allowing these relationships to span generations. The document highlights precisely this continuity in the medicinal use of plants, in the observation of water, in the agricultural calendar, in fishing, in forest management, and in oral transmission.

This perspective also transforms the meaning of "territory." Territory is not merely a demarcable area or natural heritage; it is relationship, memory, identity, autonomy, and the reproduction of life. For this reason, mining, monocultures, dams, land grabbing, wildfires, and climate change do not merely produce environmental impacts: they disrupt social and ecological relationships built up over generations. The destruction of territory is simultaneously the destruction of biodiversity, memory, and the conditions for community continuity.

The diverse experiences of the Quilombola communities also challenge the colonial narrative of "untouched nature." Traditional human presence is not seen as a threat to biodiversity, but rather as one of the historical conditions for its formation and continuity. The long-standing presence of the Quilombolas demonstrates that biodiverse landscapes also result from management, knowledge, and interaction accumulated over generations, recognizing the Quilombolas as historical agents in the creation and conservation of these landscapes.

There is, therefore, an explicitly epistemological and political dimension. Oral history, community archaeology, participatory mapping, historical records, and collaborative research become tools for challenging narratives that have portrayed quilombo territories as "empty," backward, or unproductive. Producing knowledge about the territory also comes to mean producing the authority to decide its future.

In summary, the experiences of the quilombos reveal a socio-biodiversity grounded in biointeraction: territory, community, ancestry, and the living world are produced jointly through relationships accumulated and renewed over generations. Historical memory demonstrates this continuity; ancestral knowledge keeps it alive; and scientific research can strengthen it without replacing it. Thus, quilombo territories are not merely spaces for biodiversity conservation but active agents that produce knowledge, relationships, and futures.

Indigenous contributions-learned, taught, and shared with the Quilombolas-gain depth as biointeraction emerges not only as a historical continuity of the territory but also as forms of resistance and as expressions of reciprocal, responsible, and kinship-based relationships between humans and other beings. As in many Indigenous perspectives, rivers, forests, animals, and plants, mountains, and ancestral sites are not merely external resources to society

but active participants in relationships that guide forms of care, use, circulation, and decision-making regarding the territory. Just as among the Quilombolas, Indigenous knowledge is produced through territorial experience and transmitted across generations, weaving together memory, spirituality, ecological observation, and cosmopolitical practice. The convergence of indigenous and Quilombola perspectives in this text thus broadens the concept of sociobiodiversity as a relational and intercultural construct. Consequently, this convergence also informs public policy not only on how to conserve ecosystems but also as a way to recognise that the continuity of life depends on the continuity of the bonds between peoples, territories, ancestral lineages, and the myriad beings that make up the living world.

... how can we recognise that many of the forms of biodiversity we seek to conserve continue to exist precisely because these territories and their relationships remain alive?

What we need is to shift the debate from "how to include the Quilombolas in conservation" to a deeper question: how can we recognise that many of the forms of biodiversity we seek to conserve continue to exist precisely because these territories and their relationships remain alive?

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3. Rethinking Biodiversity: Concepts, Ontologies and Histories

This section explores how biodiversity is conceptualised and understood across disciplines and knowledge systems. It examines biodiversity as a relational and biocultural system, including through diet and food-web dynamics, and engages with diverse ontologies of human-nature relationships.

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Genetic biodiversity and traditional knowledge in the digital age

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The ability to extract economic value from genetic resources of biodiversity is a relatively recent development in capitalism, enabled by the biotechnology revolution of the 1970s (Bud, 1999). With the rise of technologies like recombinant DNA and conservation sciences in biodiversity hotspots, the concept of biodiversity emerged in the mid-1980s. Since then, life-science industries, scientists, and even governments in the Global South– where most of the world's biodiversity is located – have argued to move beyond destructive development models and generate sustainable economic growth by allowing access to genetic biodiversity. However, a significant issue persists. Technology, financial power, and biodiversity remain unequally distributed along neocolonial lines. Countries in the Global North possess the capabilities to exploit biodiversity, while most global biodiversity is embedded in the knowledge systems, territories and lifeways of Indigenous peoples in the Global South. Biodiversity increasingly becomes commodified by life-science industries through the utilization of genetic information and structures within organisms (Relly, 2024).



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According to the Convention on Biological Diversity (CBD, 1992), genetic biodiversity is understood through the concept of genetic resources and refers to any material of plant, animal, microbial or other origin that contains functional units of heredity with actual or potential value, excluding human beings. Since the biotechnological revolution of the 1970s, it has become a relevant asset for life-science corporations. While Western science captures only part of global biodiversity, biodiversity is deeply embedded in Indigenous knowledge systems. This creates a conflict-ridden global political ecology: the success of the biotech sector relies on access to Indigenous knowledge. Furthermore, the global development of intellectual property instruments like patents has led to exclusionary processes that perpetuate the North-South inequalities (Kloppenburg, 2004).

THE CONVENTION ON BIOLOGICAL DIVERSITY AND THE NAGOYA PROTOCOL

Over time, Indigenous peoples have challenged the idea of biodiversity, arguing either that biodiversity cannot be separated from human beings or that it possesses intrinsic "cultural and spiritual" values beyond mere economic considerations (Posey, 1999). Resistance to the biotech industry's efforts to exploit global genetic biodiversity has been particularly strong in places like the Amazon and India. Given that genetic biodiversity is deeply rooted in traditional knowledge, misappropriation of indigenous cultures has been widespread. This context gave rise to Vandana Shiva's (2004) concept of "biopiracy," which she describes as a form of biotechnological neocolonialism based on the theft of indigenous peoples' and traditional communities'knowledge. Debates surrounding global nature conservation and the developmental inequalities between the Global North and South, especially in the post-Cold War era, led to the establishment of the Convention on Biological Diversity (CBD) in 1992, aiming to regulate biopiracy by finding means of (financial) compensation towards indigenous peoples and local communities and to protect biodiversity on a global scale. To achieve such objectives, the CDB replaced the idea of biodiversity as global commons and established its core principle: the national state sovereignty on biological/genetic resources.

However, the CBD has also been criticized for maintaining an instrumental/western view on nature, as protection of traditional knowledge is tied to the propertization (patenting) of genetic resources (Dutfield, 2004). Subsequently, the Nagoya Protocol (2010), which came into force in 2014, established global regulations for access and benefit-sharing (ABS), ensuring compensation and legal protection for Indigenous peoples from the use of genetic biodiversity and traditional knowledge. Genetic biodiversity is currently regulated on a global scale, and its economic potential is integrated into various bioeconomic strategies and national policies for socioecological transitions across the World.

Global governance of biodiversity, which is mostly provided by the Nagoya Protocol, operates in tandem with national regulations, as the CBD transferred sovereignty over genetic resources to national states. However, implementing the CBD and the Nagoya Protocol is easier said than done. Although the CBD and the Nagoya Protocol aim to end the misappropriation of Indigenous knowledge, debates persist over whether the CBD legalized or legitimized misappropriation. Critics of the CBD's architecture and the Nagoya Protocol argue that indigenous peoples' rights to the protection of their knowledge and culture are treated as a matter of intellectual property rather than from a human rights perspective. Furthermore, the contractual nature of ABS and the unequal balance of power between large corporations, the scientific establishment, and indigenous peoples and traditional communities has not created the conditions for grounded informed consent. In 2024, the World Intellectual Property Organization's Treaty on Intellectual Property, Genetic Resources and Associated Traditional Knowledge amended patent law by requiring mandatory disclosure of the origins of genetic resources associated with traditional knowledge.

DIGITAL SEQUENCE INFORMATION (DSI): A NEW FRONTIER

These regulatory developments are now being challenged by the increasing digitization of research and development. Advances in genomics have made genetic sequencing faster and less expensive, facilitating the widespread circulation of digital sequence information (DSI). DSI consists of digital data derived from the genetic material of organisms and can be accessed and shared without transferring the physical biological material from which it originated.. As can be glimpsed from contemporary discussions within the COPs, DSI

represents a turning point for global biodiversity governance. It may weaken existing access and benefit-sharing mechanisms by allowing genetic information to circulate independently of the organisms, ecosystems and territories from which it originates. The impacts of this on environmental conservation policy and intellectual property are already being felt, since genetic information has been treated less as intellectual property and more as a data asset. Furthermore, the ability of traditional knowledge holders to consent to and regulate access to their traditional knowledge tends to be severely hampered. In this regard, there is a widespread trend among corporations to reclaim the global commons of biodiversity through access to digital genetic information, a move that faces strong opposition from the organized indigenous movement and other organizations (Klüncker; Richter, 2002). Recently, during COP 16, a multilateral fund for ABS specific for DSI known as the Cali Fund was established, which operates alongside the Nagoya Protocol. At COP 17 in October 2026, further discussions will take place on the operationalization of the Cali Fund, with a view to the expected contributions to be paid by companies and scientific institutions. The recent 'Friends of the Cali Fund' initiative, an informal network of countries interested in the running of the new system, seeks to mobilize synergies with industry to channel the payments expected for the use of the DSI. How DSI is governed will shape not only the future of biodiversity conservation but also the recognition of Indigenous rights and equitable benefit-sharing in the decades ahead. Ensuring that digital innovation remains aligned with the original objectives of the Convention on Biological Diversity will be essential for protecting both biodiversity and the traditional knowledge systems that have sustained it over millennia.



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Biodiversity in Khawaja Ghulam Farid's poem: "Where the desert-grasses twist"

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Most of our biodiversity loss stems from the idea that humans and other non-human species are different and cut off from each other. The way we treat our various varieties of life on Earth reflect the value we grant to our mother Earth. This report explores biodiversity in Khawaja Ghulam Farid's poem, "Where The Desert-Grasses Twist". In his poetic expression, all the non-human elements have a vivid presence and challenge anthropocentric bias of contemporary political thought.

In Christopher Shackle's translation of Khawaja Ghulam Farid's poetry, the third section of the book is named as Songs of the desert and the Rains. The first poem in this section named as "Where The Desert-Grasses Twist" is the focus of this report. It discusses how Farid's spatial subjectivity contrasts with the usual representation of biodiversity in literature. It does not only play a metaphorical role, but it becomes a symbol for life, hope and spirituality as well. The biodiversity takes on multiple interpretations because of spatial proximity of the author. This report does not restrict the concept of non-human just to its literal interpretation and its metaphorical use. It will approach biodiversity not just as a metaphor or a theme, but as an active participant in meaning-making and a site where literature, land, and memory intersect. The association Farid shares with the land, animals, sand, soil and desert is defined by its intimate, familial, and spiritually charged nature. In contrast to a utilitarian perspective on nature, which regards the land only for its tangible benefits, the poet perceives non-human entities as source of spiritual enlightenment and a reflection of divine beauty.



Figure 1: Animals and natural environment coexisting in valley of Gabeen Jaba, Pakistan.

> *Where the desert-grasses twist, my love*
> *Ever-shifting shapes exists, my love.*
> *The crickets creak, the pigeons coo*
> *The foxes howl, hyenas new*
> *The geckoes puff, the lizards whoo*
> *The snakes and serpents hiss, my love.*

(Farid 180 Lines 1-6)

In the opening stanza of the poem, the desert is presented as a lively ecosystem in which biodiversity is articulated through presence, movement and voice of various animal species. The first line challenges the typical notion of the desert as barren and hostile wastelands

by characterizing it as a rich ecological landscape. The "twisted-grass" is a symbol of adjustment to the hostile realities of the desert landscape. The poet registers various animal species which belong to different ecological habitats i.e. cricket, pigeons, foxes, hyenas, geckoes, lizards, snakes and serpents. The imagery of the sounds of animals plays a crucial role in the depiction of the desert. It is a symbol of ecological inclusivity where every creature has a voice and all of those voices contribute to harmony of nature. The poet's use of onomatopoeic poetic device creates a strong visual imagery in the minds of the readers enabling them to imagine the desert through auditory senses. The presence of different types of animals also portray ecological interconnectedness in which birds, mammals, reptiles and insects coexist in the ecosystem which underscore the importance of all the species in the ecosystem. The repetition of the word "My Love" portrays the poet's intimacy with the desert landscape and his profound admiration of the natural environment and various species of life because of his spatial proximity. With regard to wider ecological implications, the poet challenges the biased anthropocentric view by giving equal significance to non-human elements of life.



Figure 2: A view of sunset in Cold desert Skardu, Pakistan.

> *In these fair mounds and hills of sand*
> *These graceful stones, this gravel bland,*
> *Ravines and tanks and gullies grand*
> *The rains all grief dismiss, my love.*

(Farid 180 Lines 7-10)

In this stanza, the poet establishes the desert's physical objects as objects of beauty rather than symbols of wasteland. The poet employs a warm and positive tone to urge the readers to view the desert as an aesthetically pleasing and ecologically essential landscape through words like "fair", "graceful" and "grand". He turns ordinary geographical spaces into motifs of beauty of the natural environment. The first three lines classifies various forms of non-human elements of the desert which highlights the geographical variety of mother Earth. The end of the stanza portrays rain as a symbol of hope and renewal. Rain is considered crucial for ecological regeneration, vegetation, and wildlife. Metaphorically, rain is also important in renewing human emotions and feelings highlighting nature's restorative powers beyond the physical environment. In this stanza, poet beautifully weaves human emotion and weather together as they are in sync.

> *Oh, In this desert's blessed sight*
> *I'll die indeed, but not take fright*
> *Though through your cruel heart by night*
> *And day, I'm feverish my love.*

(Farid 180 Lines 19-22)

This stanza shifts from describing biodiversity and natural environment to articulating poet's deep spiritual intimacy with his environment and non-human elements of life. The desert takes on a different interpretation from being a hostile physical landscape to a sacred intimate space which is a source of peace, hope and belonging for the poet. The poet is in favor of one of the central claims of ecocriticism that biodiversity possesses inherent spiritual and emotional significance independent of human beings. He states that harmony with biodiversity provides a deeper sense of belonging, resilience, and peace than human affection alone. He seems to be in agreement with Ecosophy which is a philosophy of ecological harmony, emphasizing the interconnectedness and intrinsic value of all forms of life that humans are emotionally and spiritually interconnected with their natural environment. To conclude, this report suggests that our understanding of the world and biodiversity must transcend the traditional anthropocentric lens and take on a Ecosophical perspective to sustain other forms of life on mother Earth.

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Key insights

- This report reinforces that man's connection and relationship with biodiversity must transcend its material significance.
- It should be viewed and treated as an inherent object instead of just a backdrop or extension of human activities.
- It advocates for ecological justice and a decolonial reading of biodiversity and natural environment by viewing it not as a backdrop and extension for human activities but as a geography that articulates the voices of its inhabitants through their language, rhythm, and cosmology in Farid's majestic poem.

Knowledge that Nourishes the Mountains: Seeds of Identity, Memory and Livelihoods in the Colombian Páramo

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Colombia is home to approximately half of the world's páramo ecosystems. Páramos are high-altitude ecosystems characterized by their cold climate and vegetation adapted to these conditions, such as frailejones, grasslands, and shrublands[1]. In addition to their biological richness, they play a fundamental role in water capture, storage, and regulation, supplying millions of people and supporting a great diversity of species.

To conserve these ecosystems, native and heirloom seeds (varieties preserved and selected by communities over generations) play a fundamental role in their conservation (Figure 1). They enable the regeneration of vegetation, help maintain biodiversity, strengthen livelihoods, and contribute to food security by preserving crop diversity and the knowledge that communities have passed down from generation to generation.

For this purpose, the GEF Páramos para la Vida Project[2] has consolidated essential community-based processes for the stewardship of the páramo, including the safeguarding of native and heirloom seeds from both restoration and nursery perspectives, as well as food security through garden and *chagra* systems (traditional agricultural systems of Indigenous Peoples). These efforts are complemented by spaces for the exchange and commercialization of native seeds through short supply chains, supporting emerging bioenterprises among rural and Indigenous communities across 16 páramos in six regions of Colombia: Boyacá, Cundinamarca, Tolima, Nariño, Santander, and Cauca. These communities maintain a deeply rooted historical, spiritual, and cultural relationship with the páramo and its cycles.

As part of this process, the project promotes spaces for exchanging experiences and sharing knowledge developed around seed conservation. One example was the panel[3]



Figure 1: The custodians of native seeds play a fundamental role in the Páramos of Colombia, as guardians of agrobiodiversity, promoters of food sovereignty and transmitters of ancestral knowledge. The photograph was taken at the 3rd International Meeting of Native Seed Keepers, Regions, Knowledge, and Agrobiodiversity, held in Tunja, Boyacá, Colombia, on June 4 and 5, 2026. It portrays the seed keepers from more than six páramo ecosystems across the country, in collaboration with the Alexander von Humboldt Institute for Biological Resources.

[1] The páramo is a Neotropical biome defined as extensive areas that crown the mountain ranges between the Andean forest and the lower limit of the perpetual snow line. Its natural region is determined by the relationship between soil, climate, biota, and human influence (Rangel-Churio et al., 2000).

[2] This project is funded by the Global Environment Facility (GEF), whose focal point in Colombia is the Ministry of Environment and Sustainable Development; implemented by the United Nations Development Programme (UNDP); and executed by the Alexander von Humboldt Institute for Research on Biological Resources in conjunction with local communities.

[3] 3rd International Meeting of Native Seed Keepers: Regions, Knowledge, and Agrobiodiversity, held in Tunja, Boyacá, Colombia, June 4-5, 2026



The seed will not bloom if knowledge is not passed on.

Lorena Chalapú
Custodia Resguardo Paleterá



If there are no pollinators, there is no life.

Pumamaki Cruz González
Custodia Resguardo Muellamues



Food sovereignty means producing what we eat and knowing how we produce it.

Manuel Calambas
Custodio Resguardo Kokonuko Muellamues



The biggest difficulty we face is the weather.

Pumamaki Cruz González
Custodia Resguardo Muellamues



We went back to find our roots.

Fabio Arias
Custodio de Vetas

"*Rooted Knowledge: Cultivating Native Seeds to Harvest Páramo Stewardship*," which brought together seed custodians[4] from Cauca, Nariño, Santander, and Boyacá (Figure 2).

During this gathering, experiences from distant places with diverse ecological and cultural characteristics found common ground in the conservation of native seeds and the páramo ecosystems that sustain them. This shared purpose contributes to strengthening food sovereignty and keeping the traditional knowledge and practices of communities alive as a tool for addressing environmental challenges. Behind every seed lies a story built by generations of rural and Indigenous families who have kept this heritage alive. Being a seed custodian means much more than storing seeds: it means recovering and selecting varieties, exchanging them, cultivating them, and sharing knowledge and organizational processes. As Carolina Carlosama expressed it: "*In the páramo, every seed is a story of resistance.*"

For the seed custodians from the different regions who took part in the gathering, including members of the Kokonuko and Paletará Indigenous reserves (Cauca), Muellamues (Nariño), as well as rural communities and organizations from the municipalities of Vetas (Santander) and Mongua (Boyacá), conserving native seeds means keeping the history of their communities alive. Recognizing children and young people as "seeds of life," as they do in the Indigenous reserves of Cauca, makes it possible to pass on and ensure the continuity of inherited knowledge about natural cycles and environmental signals for planting, harvesting, and conservation. Likewise, from Mongua, the experience of the *Escuela de Semillas Boyacenses* demonstrates that strengthening local capacities contributes to conserving agricultural diversity and preparing new generations to face the challenges of the region. Sharing knowledge ensures that seeds and traditional wisdom endure. Conserving seeds is a learning process built within the community.

Among these lessons is the seed conservation work carried out by communities in the Páramo of Sierra Nevada del Cocuy. They conduct seed collections following species conservation protocols, using seeds that incorporate plant ecology and genetic diversity as key elements in plants' ability to adapt to environmental changes. The recovery of native species by rural communities is vital for protecting water resources, while the implementation of silvopastoral agroforestry systems demonstrates that it is possible to restore ecosystems while simultaneously strengthening local livelihoods.

Figure 2: The photographs were taken at the 3rd International Meeting of Custodians of Native Seeds, Regions, Knowledge and Agrobiodiversity, held in Tunja, Boyacá, Colombia, June 4 and 5, 2026, portraying the seed custodians from more than 6 Páramo complexes of the country, in the company of the Alexander von Humboldt Institute of Biological Resources.

[4] Seed keepers are individuals and communities who conserve, multiply, and exchange native seeds, keeping alive the knowledge associated with their use and cultivation.

For the Muellamués Indigenous Reserve in Guachucal (Nariño), the *chagra* represents a process of transforming agricultural practices and reconnecting with traditional knowledge. Following the food scarcity crisis of the 1970s, the community was encouraged to adopt machinery and methods that were unfamiliar to its traditional agricultural practices, which led to the abandonment of crops such as quinoa, potatoes, and ullucos (tubers). Over time, families began to notice the emergence of illnesses associated with consuming foods with high levels of agrochemical residues. This situation highlighted the urgent, although complex, need to return to ancestral methods of planting, cultivation, and harvesting (Memories compiled in the Muellamués Indigenous Reserve Life Plan, 2017–2018). In Indigenous territories, traditional knowledge is recognized as one of the foundations for the stewardship and conservation of biodiversity. Although reclaiming these practices has involved complex processes, communities have gradually been restoring, day by day, commitments and forms of stewardship that strengthen their relationship with the land.



Figure 3: The layout shows A) two seed custodians from Nariño, and B) some native seeds exchanged in a short commercial circuit between Tunja and Boyacá in 2026. Although the territories represented by the seed custodians correspond to different regions of the country, there are common concerns, lessons learned, and goals surrounding the conservation of native seeds and páramo ecosystems.

These actions include the care, management, and propagation of native seeds; the production of organic fertilizers; the protection and isolation of conservation areas; the restoration of forests around water sources; the strengthening of community knowledge; the planting of native crops; and the development of livestock practices with an agro-environmental approach. In this way, thanks to collective effort and the ongoing work of seed custodians, ancestral practices are returning and becoming firmly re-established in the territory, revitalizing community life.

One example that gained great importance within the project was how to sustain two processes that revitalized the integrated management of the páramo through native and heirloom seeds. These involved strengthening local economies through bioenterprises led by native and heirloom seed guardians, who identified new opportunities by becoming our main suppliers of native seeds. This, in turn, helped ensure coherence in agricultural transition and productive reconversion efforts among other traditional páramo inhabitants. This opportunity has become a necessity for rural areas, not only in high-mountain regions, but also as a central element of the country's transition toward sustainable agriculture. It is further driven by growing demand from people adopting more conscious food practices. Moreover, although this is a long-term process, future generations are finding a pathway to preserve the legacy of native and heirloom seed guardians within their own contexts. Such is the case of the Talkal Seed House in the Great Cumbal Indigenous Reserve, an Indigenous organization with a longstanding legacy of seed sovereignty and the conservation of native and heirloom seeds.

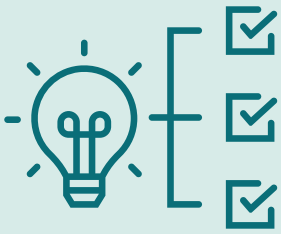
For its part, La Minga de Gualmatán, in the municipality of Pasto, Nariño, operates as a community-based agroecological production organization with a focus on supplying urban areas (Figure 3). This has required maintaining seed conservation and safeguarding processes to sustain its production systems and ensure a product oriented toward healthy food. At the same time, in terms of intergenerational continuity, the organization has a youth *minga* and the *Heirs of the Planet* initiative, which engages children in production and marketing processes. Through knowledge-sharing festivals, the community *minga* promotes rural identity and creates new recipes using products from its local gardens.

When it comes to adding value to native and heirloom seeds in connection with Indigenous women, in particular, there is a direct relationship with food production, the transformation of these resources into artisanal bioproducts, and the stewardship of the territory. Native and heirloom seeds, together with the chagra, are an essential part of transmitting traditional knowledge and wisdom that support bioenterprises based on agroecological production and processed products. One example is the production of artisanal and ancestral ointments and salves, which are only possible by maintaining native and locally conserved seeds of species with medicinal and spiritual uses.

> *Recovering seeds also means recovering traditional knowledge, cultural practices, local economies, and historical relationships with the territory.*

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Key insights

- The shared experiences of the seed custodians show that conserving native seeds also means preserving the history, knowledge, and ways of life of the communities that inhabit the páramos.
- Across all the territories, the same message emerged: seeds are the foundation for protecting water, biodiversity, and family food security.
- The seed custodians demonstrated that through seed exchanges in short supply chains, the restoration of native species, home gardens, chagras, and teaching children and young people, it is possible to strengthen both conservation and community livelihoods.
- The Páramos para la Vida Project has supported these processes by creating spaces to share experiences and strengthen local efforts.
- Looking ahead, one of the main challenges will be to continue recognizing the role of communities in páramo conservation and to incorporate these lessons into future conservation strategies.

From Rural Home Gardens to Urban Markets: Plant Diversity, Non-Timber Forest Products, and Biocultural Heritage in Colombia

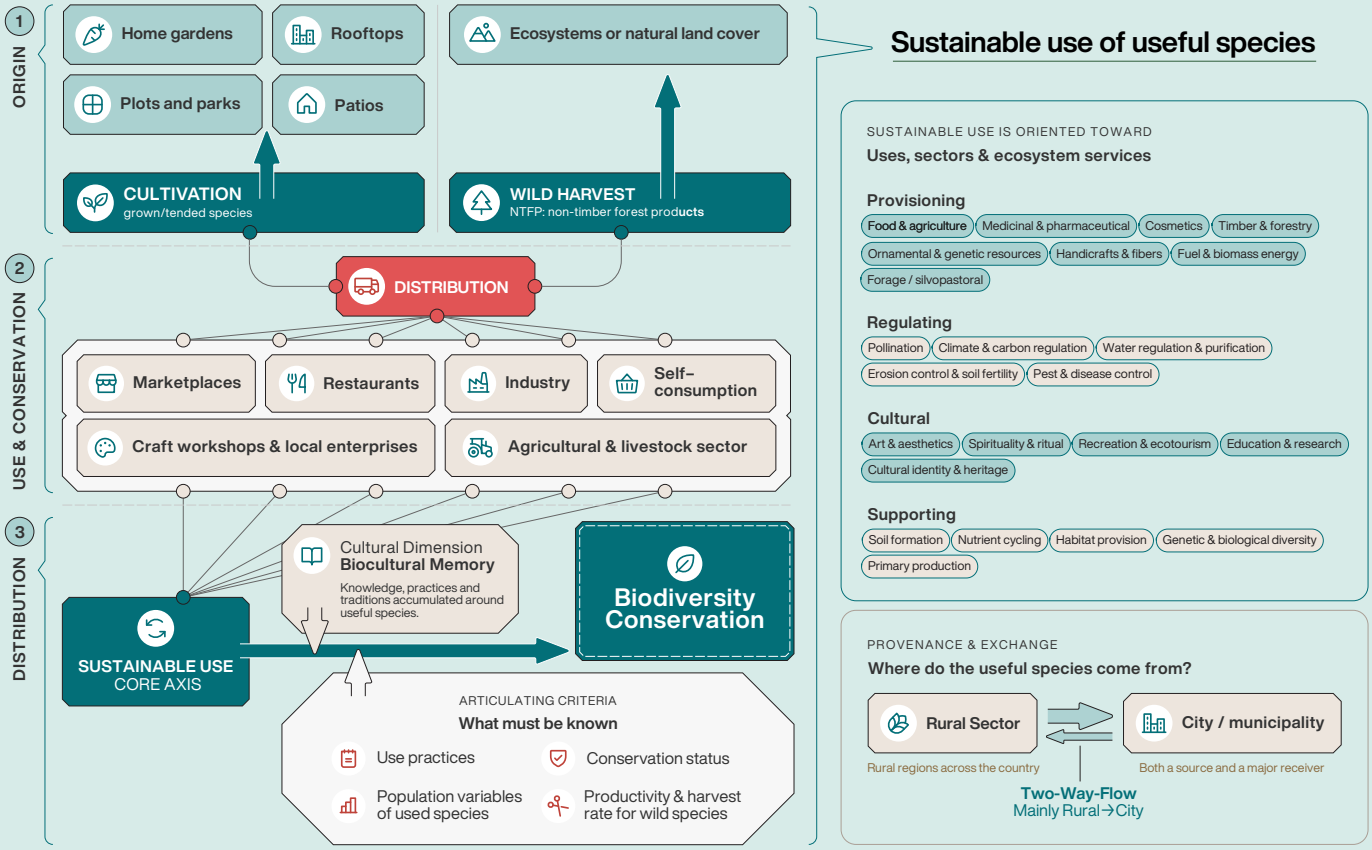
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Sustainable use can take place in both rural and urban settings, and may be either consumptive (extractive) or non-consumptive (non-extractive), encompassing the full range of ecosystem services that species provide to society. In consumptive use, individuals are removed from their natural environment and incorporated into a production, consumption, or subsistence chain (Fromentin et al., 2022). In non-consumptive use, resources are derived from the species or its habitat through non-invasive means that do not require extraction or killing of the organism. For the consumptive use of wild species, an adequate understanding of population ecology, conservation status, the productivity of the harvested resource, and reproductive rates is required to ensure that extraction occurs at sustainable levels (Peters, 1996; Ranta et al., 2005; Novato et al., 2025). Furthermore, sustainable use must entail respect for the traditional knowledge associated with local practices and the biocultural memory of local communities, as well as the fair and equitable distribution of benefits derived from commercial or subsistence use (Tengö et al., 2017).

Sustainable use is therefore not only a means of obtaining products and services from biodiverse origins, it is also a potential pathway for maintaining species, genetic diversity, ecological functions and the knowledge systems associated with them. Its contribution to conservation, however, depends on whether harvesting and management practices maintain the ecological integrity and regenerative capacity of the species and ecosystems involved. In Colombia, the general picture of use is heterogeneous. A large proportion of native species use is for self-consumption purposes and does not represent significant pressure on populations. The other side of the picture is the excessive use of species for commercial purposes, either illegally or legally through formal applications and permissions from environmental authorities.

While sustainable use is most often associated with rural, indigenous, or Campesino (peasant) communities that depend directly on natural resources for their subsistence, this principle is not limited to rural contexts. Cities, as spaces of high population density and consumption, also maintain constant and frequently overlooked relationships with biodiversity through the consumption of food, medicinal plants, materials, or ecosystem services originating from other territories (Camacho Gutiérrez et al., 2025). Understanding sustainable use in urban settings is therefore essential to bridging the gap between those who produce and conserve biodiversity and those who consume it without necessarily being aware of its origin or impact (Beninde et al., 2015). Major capital cities like Bogotá, Colombia depend on the connections with rural areas for the continuous provision of biodiversity-based products, ecosystem services,



and lend from traditional knowledge. The growing emergence of urban agroecological initiatives in Bogotá further illustrates how rural knowledge systems are reinterpreted within the city, strengthening rural–urban linkages while contributing to the decolonization of urban spaces through more balanced relationships between people, food production, and biodiversity (Hoinle, 2025). The rural–urban interface of Bogotá offers an ideal setting to examine how biodiversity, livelihoods, and local knowledge remain interconnected through systems of production, wild harvesting, exchange, and consumption (Quimbayo et al., 2020).

This rural-urban perspective is also relevant to the emerging biodiversity agenda for cities. Biodiversity conservation increasingly requires attention to urban landscapes where gardens, agroecological spaces, urban parks, markets and other forms of green infrastructure can maintain ecological functions, support native and cultivated diversity, and strengthen the populations connection to local flora and fauna. This perspective is closely aligned with the Kunming–Montreal Global Biodiversity Framework, particularly Target 12, which calls for increasing the area, quality, connectivity, accessibility, and benefits of urban green and blue spaces while enhancing native biodiversity, ecological connectivity, ecosystem functions and services, and human well-being. At the same time, the circulation of biodiversity-based products between rural and urban areas connects with Target 15, which emphasizes the assessment and

Figure 1: Conceptual scheme of the sustainable use of useful species along an origin–distribution–use chain. Species are obtained by cultivation (in home gardens, rooftops, plots and patios) or by wild harvest of non-timber forest products (NTFP) from ecosystems and natural land cover; both supply a distribution stage that channels them to marketplaces, restaurants, industry, self-consumption, craft workshops and local enterprises, and the agricultural and livestock sector , and from there into sustainable use. Sustainable use and biodiversity conservation reinforce each other (two-way arrow), articulated by biocultural memory and by the knowledge that must be acquired - use practices, population variables, conservation status, and (for wild species) productivity and harvest rate. Sustainable use is further oriented toward a broad set of provisioning, regulating, cultural and supporting ecosystem services. Useful species originate in rural regions or in the city itself and circulate in both directions between sectors, concentrating in cities through marketplaces and farmers' markets.

disclosure of biodiversity dependencies and impacts across business operations and supply chains, as well as the promotion of more sustainable production and consumption patterns. In this context, understanding the biological and cultural diversity maintained across Bogotá's rural–urban interface can contribute to identifying opportunities for biodiversity-inclusive urban planning and more sustainable relationships between local communities, markets, and biodiversity.

In Bogotá, these rural–urban linkages are rooted in the local landscapes that surround the city. Biodiversity in the rural areas of Bogotá cannot be understood solely through the species that inhabit its landscapes, but also through the knowledge, livelihoods, practices, and ways of life that have enabled its persistence over time (Figure 1). Within these processes, women have played a central role in maintaining and transmitting local ecological knowledge associated with the cultivation, management, exchange, and use of food, medicinal, spiritual, and ornamental plants. By carrying family traditions from rural territories into urban agriculture initiatives, they have contributed to the continuity of biocultural practices across the rural–urban interface (Pantoja Bohórquez et al., 2024). This diversity is reflected in home gardens that form part of rural territories, where cultivated and wild species coexist within management systems that promote the conservation of seeds, knowledge, and ecological functions (Mahecha-Groot & Leichenko, 2025). At the same time, many of these products circulate into the city and become visible in traditional food markets, agroecological fairs, and other exchange spaces, highlighting the close interconnections between rural and urban areas (Consuegra et al., 2021).

Previous research has shown that urban home gardens in Bogotá constitute important reservoirs of plant diversity, harboring 238 plant species in 2017. Species richness varies according to the age of urban settlements and the socioeconomic characteristics of households, with older gardens maintaining a greater number of native species and lower-income households cultivating proportionally more edible and medicinal plants, highlighting their contribution to biodiversity conservation and urban food security (Sierra-Guerrero & Amarillo-Suárez, 2017). In different cases, urban gardens play an important role in biodiversity conservation, depending on how they are managed. In Bogotá, various urban gardens that have been studied show high floristic diversity, complex vegetation structure, heterogeneous spatial distribution, and less intensive management. This characteristic influences the diversity of arthropods each space hosts and the environmental services it provides, and therefore contributes with habitat space for local fauna (Ruíz-Ríos, D. 2018). Likewise, different types of gardens can have different attributes. In areas like the Valle del Sibundoy, in the department of Putumayo, Colombia, urban gardens have been found to contain up to 113 plant species from 45 families (Duarte-Doyes et al., 2019). Although urban gardens can contribute to strengthening ecosystems in the face of climate change like pest control, habitat creation for species and ecosystems and pollination, It should be noted that these benefits can vary depending on different factors, such as the size of the garden, the region, its function, and the type of management (Mayorquín & Orozco, 2023).

However, in most cases, the selection of plant species in Colombian urban gardens is predominantly oriented toward well-known exotic species, with specific choices largely dependent on the thermal belt (*piso térmico*) and local knowledge. This trend is frequently driven by the homogenization of species utilization, alongside a general lack of awareness and the erosion of traditional knowledge regarding native species and their potential applications. Furthermore, only a small proportion of native species have been thoroughly investigated

through scientific studies-many of which are published in English-characterizing their physicochemical properties via clinical trials, toxicity analyses, and side-effect evaluations. In contrast, numerous widely used exotic species have already been subjected to such comprehensive analyses.

In the rural areas of Bogotá, the plant biodiversity documented reveals the remarkable diversity maintained within peasant agrobiodiversity niches. Previous research has shown that, beyond harboring useful plant species, these niches function as multifunctional socioecological systems shaped by the everyday knowledge and management practices of peasant caretakers. Based on participatory analyses, eight agroecological functions were identified, together with 249 useful plant species and a wide range of local knowledge related to plant uses and management (Ortiz et al., 2023). These findings demonstrate that agrobiodiversity niches contribute not only to food production but also to ecological connectivity, biodiversity conservation, and the maintenance of biocultural heritage across the rural landscapes of Bogotá.

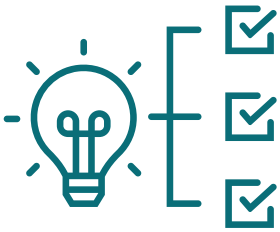
Complementing these findings, an ethnobotanical inventory conducted in peasant home gardens documented 231 useful plant species, corresponding to 320 vernacular names, distributed across 191 genera and 86 botanical families (Pérez & Matiz, 2017). Relative importance analyses identified local varieties of “cubio” (*Tropaeolum tuberosum*) as the most culturally significant cultivated resource, whereas “encenillo” (*Weinmannia tomentosa*), a native tree harvested from surrounding Andean forests, showed the highest number of reported uses. Notably, 58% of the recorded useful species were cultivated in home gardens, whereas 42% corresponded to non-timber forest products (NTFPs) obtained from nearby natural habitats, emphasizing the close relationship between cultivated agrobiodiversity and wild plant resources in sustaining rural livelihoods and maintaining diverse relationships with the surrounding landscape. Nevertheless, in many cases in Colombia, native species subject to wild harvesting lack sustainable utilization protocols, which are of particular importance for endemic species or those listed under some category of threat, such is the case of orchids, bromeliads, timber trees and zamias. To promote an adequate sustainable harvesting of NTFPs, Colombia elaborates the 0219 resolution in 2025, which regulates Decreto 1076 of 2015, which sets legal and technical mechanisms for the sustainable use of wild flora without causing deforestation, with particular emphasis on Non-Timber Forest Products (NTFPs) such as fibers, resins, bark, oils, and fruits (based on the ecology of species and used structures). The regulation applies to all environmental authorities, users, and communities operating in natural forests across the country, and it explicitly involves ethnic, peasant, and local communities in the governance of their natural resources. Any activity carried out under this resolution is barred from negatively altering the ecological attributes of the forest, and harvesting measures must help curb the expansion of the agricultural frontier. The rule also imposes strict documentation and traceability requirements, including identification papers, written consent, NIT registration for associative groups, and precise definition of the species to be managed.

The diversity documented in rural landscapes is reflected in Bogotá's urban markets, where products originating from home gardens, agroecosystems, and surrounding forests converge. Previous inventories have recorded 409 useful plant species traded across Bogotá's traditional markets (Bussmann et al., 2018), while 391 species (201 native and 5 endemic to Colombia) have been documented in the Samper Mendoza Market (Figure 2), one of the largest medicinal and useful plant markets in Latin America, where approximately 200 vendors

- many of whom have been harvesting and trading these species for decades, passing down their knowledge orally across family generations - continue to safeguard this living biocultural heritage.(Torres-Morales et al., 2021). Among the most representative products is “zarzaparrilla”, a common name used locally for several medicinal species of the genus Dioscorea, which are harvested in rural areas surrounding Bogotá and increasingly commercialized in urban markets due to their widespread use in traditional medicine (Pérez & Raz, 2022). These results demonstrate that urban markets are not merely commercial spaces but also repositories of the biological and cultural diversity maintained in rural territories. The movement of plants and plant products between rural and urban markets creates a continuous biocultural network in which local communities contribute to the conservation and utilisation of plant diversity through cultivation, forest management, and traditional ecological knowledge, while urban markets ensure its circulation, visibility, and continued contribution to food security, health, and cultural heritage. Given that sustainable use can be a strategy for biodiversity conservation, plant markets can promote this as long as it happens at rates appropriate to the ecology and biology of the species, without overexploitation of wild populations. In many cases, however, no population analyses exist that would allow a real understanding of the impacts on native species. In the case of the Samper Mendoza market in Bogotá, 5 endemic species have been reported, none of which carry any threat category (Torres-Morales et al., 2021).



Figure 2: Samper Mendoza market in Bogotá D.C, Colombia.



Key insights

- **Sustainable use is not merely an economic activity but a powerful mechanism for biodiversity conservation.** When applied responsibly, it strengthens the connection between rural and urban spaces, fostering interdependence between producers and consumers. Beyond its ecological function, sustainable use safeguards biocultural heritage across the entire value chain, from harvesting practices rooted in traditional knowledge to the products and services that reach urban markets. In Bogotá, plant markets and home gardens demonstrate how species diversity, agricultural diversity, ecological traditional knowledge and biocultural memories can remain connected across rural and urban landscapes. This dual role positions sustainable use as both a conservation strategy and a vehicle for cultural continuity. Achieving this requires developing protocols grounded in species ecology and conservation status, alongside outreach strategies that strengthen societal awareness of biodiversity and rural cultures. Equally essential are policies that preserve biocultural heritage, prevent the gentrification of urban marketplaces, recover threatened species and traditions, sustainable use and promote diversified sustainable livelihoods.
- **These approaches are consistent with existing biodiversity policies in Bogotá and Colombia.** Bogotá's Policy for the Management of Biodiversity Conservation, updated through CONPES D.C. 22 of 2022, explicitly integrates urban and rural biodiversity, promotes sustainable use, knowledge generation, citizen participation, and the equitable distribution of benefits derived from biodiversity. At the national level, Colombia's Biodiversity Action Plan 2030 aligns its conservation and sustainable-use actions with the Kunming–Montreal Global Biodiversity Framework, including efforts to integrate biodiversity into territorial planning, transform production systems toward sustainability, and strengthen collective and biocultural governance. These policy commitments provide an enabling framework for recognizing rural–urban biodiversity linkages and for translating knowledge about plant diversity, sustainable use, and local livelihoods into conservation and territorial planning.
- **For Bogotá and other rapidly growing cities, the challenge is therefore to ensure that growing demand for biodiversity-based products strengthens, rather than undermines, biodiversity and the local communities that sustain it.** Sustainable use can contribute to this goal when ecological sustainability, species biology and ecology, cultural continuity, equitable benefits and long-term stewardship are considered in policy-making. Connecting these principles with urban green-space planning, sustainable production and consumption, and the recognition of local and rural communities can help translate global biodiversity commitments into place-based actions.

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Culinary Ecosystems: A Biocultural Framework for Biodiversity Conservation in Colombia

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Among the contemporary challenges facing food systems, the loss of agrobiodiversity driven by the cultural homogenization of diets and the rapid transformation of agroecosystems has renewed interest in understanding the interdependence between nature and culture and its importance for resilient and sustainable food systems (Khoury et al., 2014). Beyond ensuring the subsistence of human groups, food mobilizes practices, values, and symbols that sustain community life and are essential for achieving food security and food sovereignty (Medina, 2017). Eating, therefore, is not limited to merely food consumption, it also entails the accumulation of experiences and the construction of memories, identities, and social relationships that constitute the biocultural heritage of these communities. This heritage is increasingly under threat, even as it provides an important foundation for the stewardship, management and governance of territories (FAO, 2009).

The relationships and interactions that communities establish with nature are fundamental for strengthening traditional knowledge systems associated with food systems. In turn, these relationships contribute to adaptation, resilience, and conservation and sustainable management of biodiversity in contexts of environmental and livelihood vulnerability. Through territorial knowledge, seed management, the protection of water sources, species domestication, and the transmission of knowledge, these communities have historically contributed to the stewardship, utilisation, management and conservation of biodiversity (Olesen et al., 2022). Because Indigenous Peoples and Local Communities have typically played custodial roles in relation to nature (Forest Peoples Programme, 2011; Garnett et al., 2018), activities that extend beyond eating, including caring, teaching, sharing, performing rituals and celebrating, are closely connected to the ways ecosystems are conserved, used, managed, and transformation.



Figure 1: Coexistence of agricultural systems with patches of Tropical Dry Forest in the Montes de María. Source: Darío Pérez, personal archive.

It is within this close relationship between biodiversity and culture, and through the contributions of ecosystem services to human well-being, that the complexity of food systems and the concept of Culinary Ecosystems (CE) become particularly relevant. In this report, we propose CEs as a framework to understand terrestrial or aquatic macrohabitats that reflect the ways in which communities shape and manage biodiversity through decisions regarding what they produce, cultivate, process, and consume as food, as well as the goods and services derived from these relationships. They provide a framework for understand how

food-related practices contribute to biodiversity conservation across multiple levels. At the genetic level, the management and exchange of local seeds maintain crop diversity and agrobiodiversity; at the species level, the use and conservation of food, medicinal, and other useful species sustain biological diversity beyond cultivated crops. At the ecosystem level, home gardens, agroforestry systems, agricultural fields, and surrounding forests maintain landscape heterogeneity and ecological connectivity. These practices also sustain ecological functions such as pollination, soil fertility, pest regulation, and water regulation, linking biodiversity conservation to food production and local well-being. Here, agrobiodiversity is understood broadly, encompassing not only cultivated species and varieties, but also wild species, genetic resources, associated organisms, habitats, ecological functions, and the knowledge and practices that sustain their management and use. Furthermore, they enable the recognition, engagement, and conservation of biocultural heritage, ecosystems, and key species, while strengthening local resilience to socio-environmental pressures through the revitalization of traditional knowledge and biodiversity management practices (Cárdenas-Botero et al., 2023).



Figure 2: Management of chagras and local farming systems in the Colombian Amazon. Source: Klaudia Cárdenas Botero, Personal archive.

In a context of erosion of the knowledge associated with rural culinary practices, driven by the industrialization of food systems and cultural homogenization (Leyva Trinidad & Pérez Vásquez, 2015; Contreras, 2019), the CE framework highlights kitchens as social spaces for integration and the intergenerational knowledge transmission. This concept goes beyond agricultural production by integrating previous approaches that describe both the material and immaterial flows surrounding food and the exchanges between nature and people, including seed conservation, biocultural memory, the socioeconomic dimensions of food systems, cultural and festive practices, as well as the symbolic meanings of food and its consumption.

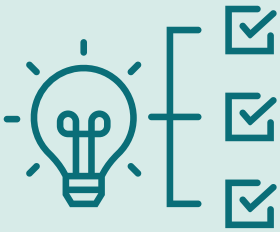
By broadening the notion of the "culinary" beyond the application of techniques, resourcefulness, and the cultural dimensions surrounding food, CEs recognize the creative, innovative, and resourceful ways in which communities relate to, adapt to, and transform the landscapes where food is produced, cared for, and processed—not only to nourish themselves, but also to strengthen social, spiritual, and cultural ties. In this way, CEs constitute cultural landscapes that embody the memory and heritage of peoples, where collective decisions about seeds, crops, harvesting, forest, and food production shape how biodiversity is used and maintained. Through customary rules, seed exchange networks, collective practices, and community stewardship, local knowledge becomes embedded in decisions about access to and management of biological resources, influencing ecosystem services (Caro-Caro & Torres-Mora, 2015) and the community governance of territory. In this regard, this report demonstrates that Culinary Ecosystems constitute an emerging conceptual and practical contribution to biodiversity conservation by making visible the interdependence among cultivated and wild species, genetic resources, habitats, ecological functions, biological diversity, cultural practices, and sustainable livelihoods, while highlighting how nature's contributions to people are interwoven with local aspirations for well-being (Gudynas, 2003; IPBES, 2019).

In this regard, this report demonstrates that Culinary Ecosystems constitute an emerging conceptual and practical contribution to biodiversity conservation by making visible the interdependence among cultivated and wild species, genetic resources, habitats, ecological functions, cultural practices, and sustainable livelihoods, while highlighting how nature's contributions to people are interwoven with local aspirations for well-being (Gudynas, 2003; IPBES, 2019).

Table 1: this table presents a series of case studies from Colombia illustrating how Culinary Ecosystems emerge in practice. These experiences provide empirical evidence supporting the concept and highlight the ecological, cultural, and governance dimensions that make CEs a valuable approach to biodiversity conservation.

Location	CE Description	References
Montes de María region, Bolívar and Sucre	In the Montes de María region, food extends beyond agricultural production and expresses a network of relationships among biodiversity, local knowledge, cultural practices, and livelihoods. The high diversity of food species documented, the coexistence of multiple production arrangements (monocultures, intercropping systems, silvopastoral systems, agroforestry systems, and home gardens), the conservation and management of local varieties, and the close relationship between kitchens, agroecosystems, and the Tropical Dry Forest demonstrate that decisions regarding what to cultivate, gather, process, and consume are the result of historical processes of adaptation and biocultural management of the territory. Montes de María represents a landscape in which biodiversity sustains food practices, identities, memories, and forms of local governance that simultaneously contribute to nature conservation, socioecological resilience, and the continuity of food systems (Figure 1).	MinCultura, 2014 Cárdenas Botero et al., 2016 Pérez et al., 2022 Garzón Ramos et al., 2023 Cárdenas Botero et al., 2023 Cárdenas Botero et al., 2026
Cañamomo Lomaprieta Indigenous Reserve, Caldas	The Cañamomo Lomaprieta Indigenous Reserve constitutes a clear example of a Culinary Ecosystem, understood as a network of relationships among biodiversity, cultural practices, traditional knowledge, and forms of community organization that make the production, processing, exchange, and consumption of food possible. In this territory, the kitchen extends beyond the domestic sphere to become the meeting point between home gardens, native seeds, pancoger farming systems, traditional occupations, medicinal plants, and collective celebrations. The diversity of cultivated species, the agroecological management of crops, the conservation and exchange of seeds, the preparation of food over wood-fired stoves, and the use of utensils made from locally available materials reflect a dynamic relationship between culture and nature that strengthens food sovereignty and collective identity. Thus, rather than simply being an agricultural production area, Cañamomo Lomaprieta represents a biocultural system in which food brings together knowledge, livelihoods, governance, and heritage, making diversity the foundation of its continuity and territorial resilience.	Cárdenas Botero & Galán, 2004 Rey-Lema & Peña-Galindo, 2024 Cardona Iglesias et al., 2025 Obando-Enríquez et al., 2025
Rural Bogotá, Cundinamarca	The agrobiodiversity niches of rural Bogotá can be understood as Culinary Ecosystems because they integrate, within a single territorial network, biological diversity, local knowledge, and food practices that underpin the relationship between farming communities and their environment. These spaces encompass home gardens, forested areas, productive systems, and water sources that provide cultivated plants and non-timber forest products used in everyday diets, traditional medicine, and other cultural practices. The conservation and exchange of seeds, the management of native and cultivated species, the intergenerational transmission of knowledge, and the preparation of traditional foods are all processes that directly connect biodiversity with local culinary culture. In addition, these products circulate through farmers' markets, agroecological fairs, and other marketing channels in Bogotá, where they continue to generate cultural, economic, and social value. Consequently, agrobiodiversity niches transcend their role as agricultural production spaces to become dynamic biocultural systems that sustain food diversity, strengthen rural livelihoods, and maintain the ecological and cultural connections between rural areas and the city.	Pérez & Matiz, 2017 Quimbayo et al., 2020 Consuegra et al., 2021 Ortíz et al., 2021 Torres-Morales et al., 2021 Ortíz et al., 2023 Pantoja et al., 2024 Mahecha-Groot & Leichenko, 2025
Colombian Amazon	Amazonian chagras constitute an emblematic example of a Culinary Ecosystem by integrating biodiversity, food production, traditional knowledge, and cultural practices within a single system that sustains the livelihoods of Amazonian Indigenous peoples. More than simply cultivated plots, chagras are biocultural spaces where the conservation of high levels of agrobiodiversity, the continuous experimentation and selection of genetic resources, the intergenerational transmission of knowledge, and the social and spiritual organization of communities converge. Their management, based on polycultures, long ecological succession cycles, and a close relationship with the surrounding forest, promotes the continuous provision of food, the regulation of ecological processes, natural pest control, and resilience to environmental variability. Furthermore, the chagra integrates crop production with fishing, hunting, gathering, and the use of medicinal plants, forming a comprehensive food system that is closely regulated by ecological, climatic, and ritual calendars. The central role of women in managing the chagra and processing food, together with the function of the maloka as a space for the transmission of knowledge, demonstrates that food extends beyond its productive dimension to become a cornerstone of identity, memory, and social cohesion. From this perspective, the chagra represents a Culinary Ecosystem in which landscapes, species, food practices, and cultural relationships coevolve, simultaneously ensuring food security, biodiversity conservation, and the continuity of Indigenous knowledge systems (Figure 2).	Van der Hammen, 1992 Vélez & Vélez, 1999 Tejada, 2004 Acosta et al., 2011 Sierra & Raz, 2014 Fajardo-Cano et al., 2023

Colombian Pacific	In the Colombian Pacific, Culinary Ecosystems reflect the historical and dynamic relationships between Afro-descendant and Indigenous communities and one of the most biodiverse regions in the world, where mangroves, rivers, estuaries, tropical rainforests, the sea, family farms, home gardens, and raised gardens provide a wide diversity of fish, mollusks, fruits, tubers, cereals, medicinal plants, and cultivated and wild species that sustain both food systems and biocultural diversity. This socioecological system is supported by traditional and ecological knowledge accumulated over generations, which guides fishing, gathering, agriculture, and forest use through an understanding of tidal cycles, rainfall patterns, lunar phases, seasonality, and species phenology, promoting productive diversification, the complementary use of different territorial spaces, and resilience to environmental variability. Each landscape performs specific functions: mangroves provide mollusks, crustaceans, firewood, and nursery habitats for fish; the sea and rivers supply fisheries while facilitating connectivity and exchange among communities; tropical forests provide wild fruits, fibers, medicinal plants, construction materials, and wildlife; and family farms, home gardens, and raised gardens conserve a high diversity of food, condiment, and medicinal crops that ensure a continuous supply of fresh ingredients and reduce dependence on markets. This Culinary Ecosystem demonstrates that food extends far beyond agricultural production, constituting a process through which communities shape their territories, generate and transmit knowledge, conserve biodiversity, strengthen cultural identity, and develop adaptive capacities, thereby positioning the kitchen as a strategic space for integrating biodiversity conservation, biocultural heritage, community well-being, and socioecological restoration.	Fundación ACUA; 2016 Sánchez, Enrique & Cárdenas Botero, Klaudia. 2007



Key insights

- Culinary Ecosystems (CEs) are an emerging socioecological and biocultural framework that explains how biodiversity, culture, and food are interconnected from the perspectives of Indigenous peoples and local communities, transforming the kitchen into a living laboratory for biodiversity conservation, restoration, and sustainable livelihoods.
- Food reflects ecological knowledge and biocultural heritage. Decisions about what to cultivate, gather, fish, process, and consume embody generations of ecological knowledge, management practices, cultural values, and memories, revealing how communities know, use, manage, and conserve biodiversity.
- CEs strengthen resilience and socioecological restoration. By promoting the diversification of species, production systems, and food practices, they can contribute to local resilience in the face of environmental and socioeconomic change while supporting ecological functions, livelihoods, traditional knowledge, and food cultures.
- CEs link biodiversity with health, well-being, and governance. Conserving biodiversity supports nutrition, health, cultural identity, and quality of life, while strengthening local stewardship and informed decision-making. Recognizing and reinforcing Culinary Ecosystems provides a framework for integrating biodiversity conservation, sustainable food systems, biocultural heritage and community livelihoods in Colombia.

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4. Deep Histories of Biodiversity Change

This section examines long-term human-environment interactions and their impacts on biodiversity across different temporal and geographical scales. It explores prehistoric transformations driven by climate change and human agency, along with historical and early modern impacts, including the effects of colonialism, the Columbian Exchange, industrialisation and extractive economies. Finally, it examines long-term human-wildlife coexistence, adaptation, and conflict through millennial-scale case studies.

4.1 Africa



Photo by Jonah Brown on Unsplash

This chapter brings together diverse perspectives on biodiversity and environmental change across Africa, highlighting the value of looking beyond recent ecological records to understand the long-term relationships between people, climate and landscapes. Drawing on archaeological, palaeoecological, and ethnobotanical research, the contributions explore megafaunal extinctions in Madagascar, long-term ecosystem change in South Africa, and traditional ecological and plant knowledge in Tanzania and Kenya. Together, they demonstrate how evidence from the deep past and knowledge held within communities can provide important insights into ecosystem resilience, sustainable resource management, biodiversity conservation, and the development of policies for a changing future.

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Insights from the archaeological sciences into megafaunal extinctions in Madagascar

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The main causes of megafaunal extinctions in Madagascar over the past 2,000 years, as well as contemporary biodiversity loss trends in the country, are subjects of interest to scholars and policymakers in the fields of conservation and the sustainable management of natural resources (Figure 1) (Crowley, 2010; Virah-Sawmy et al., 2010; Douglass et al., 2019; Godfrey et al., 2019; Crowley et al., 2021; Faina et al., 2021; Hixon et al., 2021a; Antonelli et al., 2022; Michielsen et al., 2023; Everson et al., 2025; Godfrey et al., 2025). While the main cause of megafaunal extinctions in Madagascar has been attributed to increase in aridity, marked by extreme climate fluctuations during the late Holocene (past 5,000 years) (Mahe and Sourdat, 1972; Crowley et al., 2021; Faina et al., 2021). It has also been argued that the transition to agropastoralism was the primary trigger (Godfrey et al., 2025). The increasing use of archaeological sciences, such as radiocarbon dating, in the study of human–environment interactions and megafaunal extinctions in Madagascar has provided valuable new insights that were previously unavailable (Figure 1) (Hixon et al., 2024; Iminjili et al., 2025a;). These insights suggest that the transition to agropastoralism around 600–1200 CE (800-1400 years ago), driven by population migration from mainland Africa and the expansion of Indian Ocean trade was the primary factor behind the megafaunal extinctions in Madagascar. In this article, I provide an overview of megafaunal extinctions in Madagascar, followed by the major insights revealed by archaeological sciences that suggest the transition to agropastoralism was the main cause of these extinctions. I conclude by presenting the need to promote archaeological sciences in Africa, and for their inclusion in global policymaking discussions, in order to inform present policies on biodiversity conservation and sustainable management of natural and cultural resources.

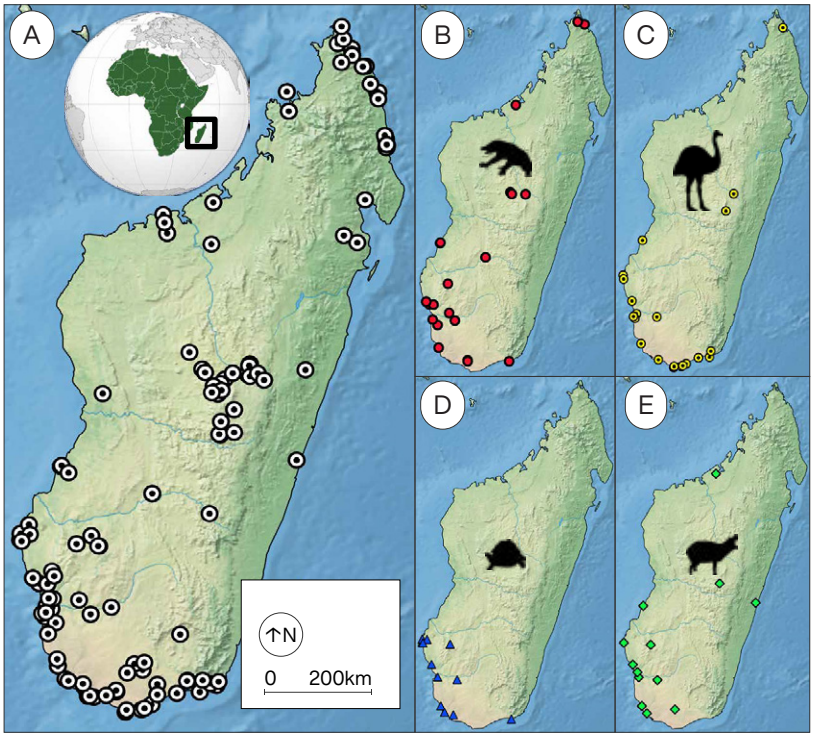


Figure 1: Map of Madagascar showing: (A) the distribution of 677 scientific dates from research sites across Madagascar (mostly radiocarbon dates); (B) the distribution of direct dates acquired from lemurs (186); (C) ratites (43); (D) tortoises (32); and (E) hippopotamuses (91) (Iminjili et al., 2025a; Iminjili et al., 2025b).

AN OVERVIEW ON MEGAFAUNAL EXTINCTIONS IN MADAGASCAR AND CLIMATE CHANGE

Today, 90% of Madagascar's unique endemic species, including the stunning primates known as lemurs, are under threat of extinction (Everson et al., 2025). There are more than 100 species and subspecies of lemur that include ring tailed lemur (*Lemur catta*), indri (*Indri indri*), aye aye (*Daubentonia madagascariensis*), and coquerel's sifaka (*Propithecus coquereli*) (Baden et al., 2019). The island is also home to over 100 species of birds, numerous carnivores resembling big cats, such as the fossa (*Cryptoprocta ferox*), and unique reptiles, including chameleons, snakes and tortoises (Antonelli et al., 2022). Lemurs are the most threatened vertebrate taxon in the world today, with 98% of species facing imminent extinction (IUCN, 2020). Many of Madagascar's other endemic animals are also classified as threatened or critically endangered by the IUCN (2020). Prior to 600 CE (before 1400 years ago), Madagascar was home to an even more astonishing array of unique giant mammals, birds, and reptiles (Figure 2) (MacPhee and Burney, 1991; Simons et al., 1995; Burney et al., 2004; Pearson et al., 2010). The populations of these animals collapsed abruptly and became extinct between 601 and 1800 CE (1400-200 years ago) (Figure 2B) (Hixon et al., 2021b). These extinct megafauna species included 17 species of giant lemur. These included the giant aye-aye, which was three to five times larger than current species; three species resembling orangutans; and eight species of giant sloth lemur, including a species the size of a chimpanzee and a species weighing over 200 kg and resembling a gorilla, which was larger than a silverback gorilla. There were also elephant birds: enormous ratites which were among the largest birds ever to live, with a height of about 3 metres and weighed between 300 and 1,000 kilograms. Other unique mammals included the giant fossa, as well as at least two species of giant tortoise and three species of pygmy hippopotamus.

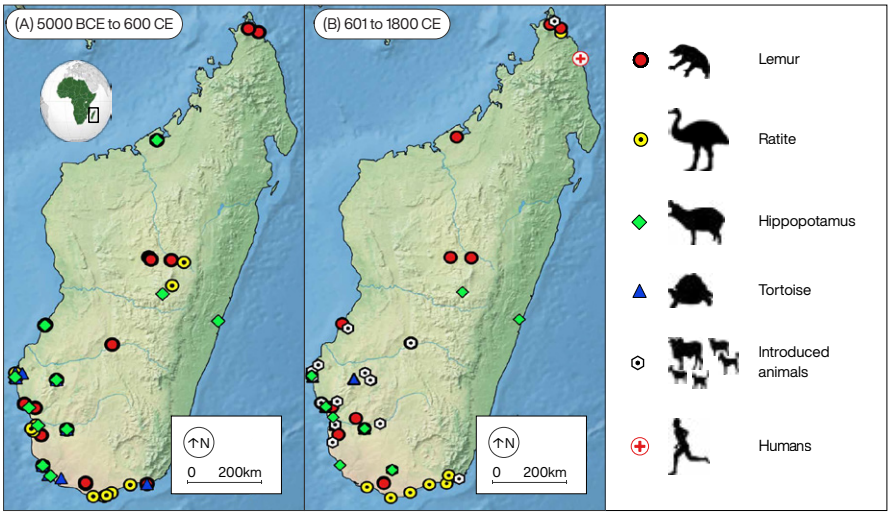


Figure 2: Map of Madagascar highlighting the occurrence and distribution of megafauna species, indicating: (A) their presence from 5000 BCE to 600 CE (6000-1400 years ago) and (B) their persistence and coexistence with agropastoralism, and their subsequent extinction, from 601 to 1800 CE (1400-200 years ago) (Iminjili et al., 2025a; Iminjili et al., 2025b).

INSIGHTS FROM ARCHAEOLOGICAL SCIENCES ON MEGAFAUNAL EXTINCTIONS

The increased application of archaeological sciences to research projects studying megafaunal extinctions in Madagascar during the late Holocene has unlocked new insights on the occurrence and distribution of megafaunal species during the past 6000 years (Figure 2) (Perez et al., 2005; Vasey and Godfrey, 2022; Godfrey et al., 2025; Iminjili et al., 2025b). Systematic excavations and context-specific recording, as well as assemblage analyses, of multiple sites across Madagascar's arid and wet bioclimatic regions have revealed evidence of major anthropogenically-instigated changes in species assemblage and composition beginning around 600 CE (Pearson et al., 2010). This includes an increase in the presence of megafaunal skeletal remains and fragmented eggshells, some of which are modified and found in close association with livestock skeletal remains, ceramics, iron objects and anthropogenic ashes. State-of-the-art zooarchaeological analysis has been used to identify

skeletal remains at species level (Kistler et al., 2015). These analyses have been key to highlight the early persistence and coexistence of megafauna with foraging populations, as well as their later coexistence with agropastoral populations and introduced species, including livestock, commensals, and wild animals. Furthermore, microscopic examination has revealed evidence of cut marks on megafauna bones, which were associated with stone tools in earlier periods and iron implements in later ones (Lawler, 2018). Preliminary archaeobotanical and ceramics analyses have unearthed rice remains, suggesting interaction between Asia and Madagascar as early as 900–1200 CE (Wright et al., 1996; Crowther et al., 2016b).

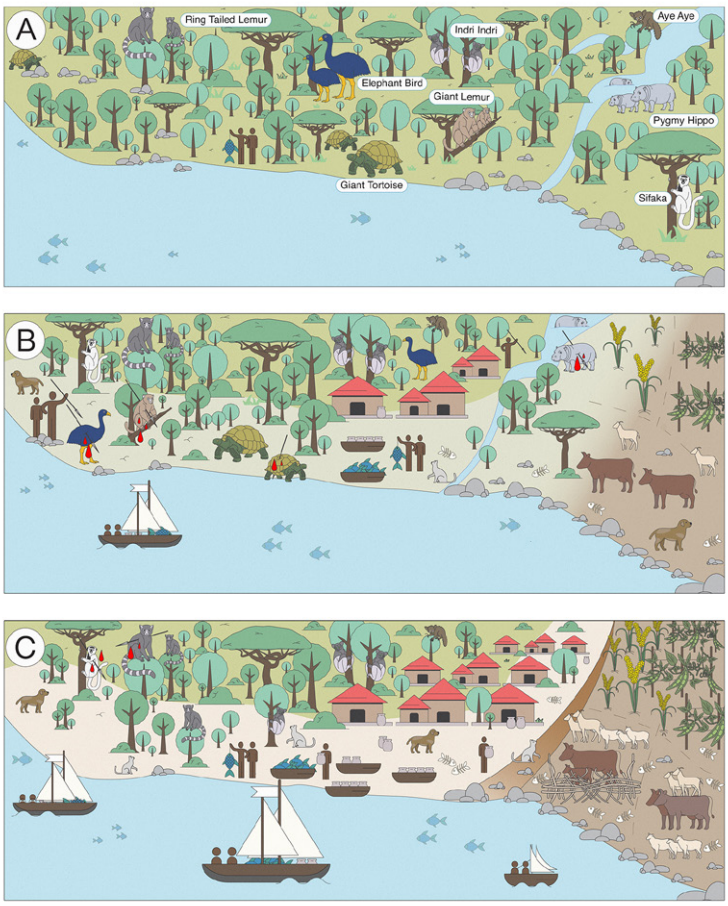


Figure 3: A visual representation of Madagascar depicting the following: (A) the existence and thriving of megafauna between 5000 BCE and 600 CE; (B) the persistence of megafauna alongside agropastoralism, rampant hunting and deforestation, and subsequent extinctions between 601 and 1800 CE; (C) the dominance of human populations, deforestation, and the endangerment of Madagascar's modern endemic species between 1800 and the present day.

Furthermore, isotope ecology, which involves studying chemical variations in faunal skeletal remains, such as bones, in order to reconstruct past environments, was used to analyze nitrogen isotope ratios from lemurs in south-western sites in Madagascar. The results suggested that lemurs did not live in increasingly arid habitats and did not change their trophic level between 5000 BCE and 600 CE (Hixon et al., 2018). This indicates that the extinction of Madagascar's megafauna was not triggered by aridification. In fact, most of the giant lemurs survived extreme aridity and climatic fluctuations during earlier glacial and interglacial cycles, only becoming extinct during a relatively less arid period (601–1800 CE) (Hixon, 2025). This long-term reconstruction of environmental dynamics and species occurrence has been aided by the mass production of AMS radiocarbon dates, as well as the direct dating of zooarchaeological and archaeobotanical remains identified at the species level, which has provided valuable chronological insights (Figure 1-3).

Overall, these insights from the archaeological sciences lend support to the subsistence shift hypothesis, which posits that the transition from foraging to agropastoralism was the primary catalyst for the collapse and subsequent extinction of Madagascar's megafauna between 600 and 1800 CE (Figure 3) (Godfrey et al., 2025).

ROLE OF ARCHAEOLOGICAL SCIENCES IN BIODIVERSITY CONSERVATION IN AFRICA

These insights into agropastoralism and megafaunal extinctions in Madagascar provide a prime example of the enormous, as yet unexploited, potential of archaeological sciences to unearth in-depth insights into the interactions between humans and the environment in Africa. Though still in its infancy, the application of archaeological sciences has also improved our understanding on the emergence and dispersal of food production and food-producing communities during the late Holocene in the interior of eastern Africa and its offshore islands. Overall, these findings offer valuable long-term background information on environmental and biodiversity dynamics, sustainable management of natural and cultural resources, and food security, which policymakers in government and international organizations should take into account when formulating policies for future generations.

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Long-term perspectives of biodiversity changes and policy implications in South Africa

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Africa's linked climate and biodiversity crises threaten to undermine socio-economic development, human wellbeing, and ecosystem health. At global scale, policy agendas are set by the Kunming-Montreal Global Biodiversity Framework and Paris Agreements and in the local scale the South Africa's Climate Change Act and Biodiversity Act provide legal scaffolding, alongside a National Biodiversity Strategy for guiding adaptation plans. But a critical weakness persists: the country's biodiversity management strategy is overly reliant on just 80 years of data from field studies, long-term earth observatories, and satellite records, and earth system models (Gillson & Marchant, 2014). These baselines may still fail to capture long-term environmental shifts, diverse ecosystem responses, and human impacts. Meanwhile, studies of past climate, land-use, and ecosystem changes spanning decades to millennia remain untapped. Including these long-term perspectives could transform how we interpret and measure ecosystem responses and resilience to create a robust foundation for adaptive ecosystem management. To achieve global and national obligations, South Africa must bridge the temporal data gap to ensure biodiversity and climate strategies are informed not only by recent observations, but also an appreciation of diverse environmental histories over different timescales.

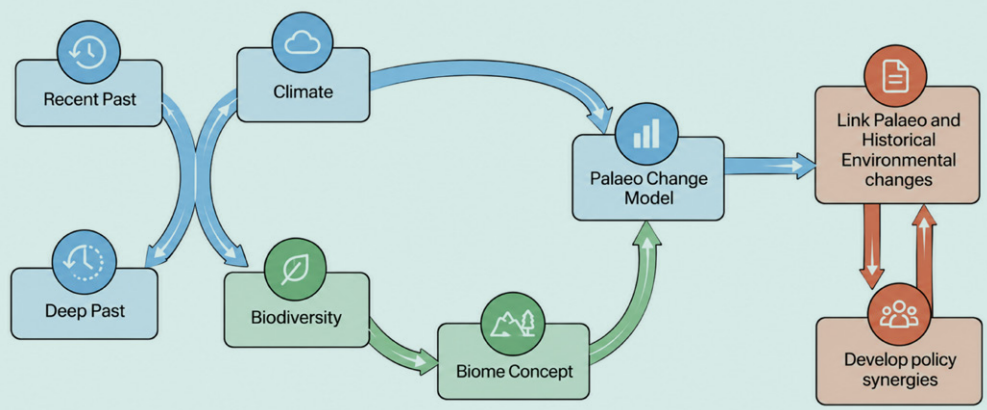


Figure 1. A conceptual framework of how climate and biodiversity changes from the recent to deep past from palaeo-proxy records are interpreted based on relevant models of environmental change from the biome concept, and how these datasets may be used alongside historical records to inform future climate and biodiversity policies.

A critical obstacle in linking short-term ecological data with long-term palaeo-environmental archives is the difficulty of establishing a consistent metric for tracking and comparing changes across vastly different timescales. Biomes, defined by their climate, vegetation, and adapted organisms, are typically delimited at continental or national scales, yet they are routinely treated as behaving analogously to much smaller, local ecosystems (Bond, 2005). This conceptual leap is large when we consider that microscopic biological remains are sampled from sedimentary sequences which are normally the diameter of a soda can. Palaeoecology has shortcomings: the primary vegetation proxy, fossil pollen, is identifiable

mainly to genus, while grass silica bodies that deposit in plant tissue are resolved to tribes (Lejju et al, 2005). Furthermore, deterministic climate-vegetation models often fail in disturbance-prone systems shaped by fire and large herbivores (Bond, 2005). As a result, ecosystem trajectories and vegetation resilience cannot be reliably extrapolated across scales; they can shift less predictably along environmental gradients, contingent upon interactions between species environment tolerance traits and disturbance regimes. Despite these obstacles, palaeoecology's key strength lies in bringing together multiple proxies, e.g., for vegetation, fire, herbivore density, local moisture, and climate, to produce comprehensive narratives about sequences of biodiversity change. In the next section, we demonstrate how deep-time perspectives in South Africa provide contexts for understanding environmental trends, creating a dialectic between the present and deep past to inform robust biodiversity conservation narratives.

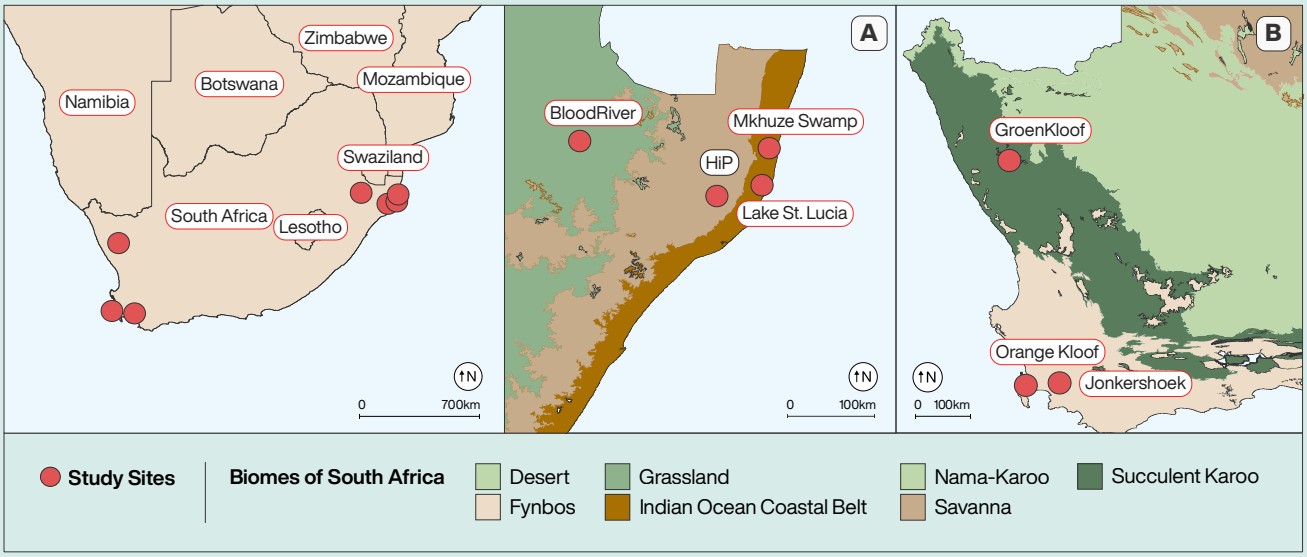


Figure 2. Location of palaeoecological studies of vegetation transitions within the Mucina & Rutherford (2006) biomes of South Africa. A) Forest-Savanna transitions and B) Fynbos-Nama Karoo transitions.

Case studies

1. FYNBOS-NAMA KAROO TRANSITIONS

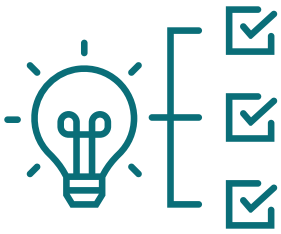
Vegetation changes in the speciose Cape Floristic Region (CFR), which includes fynbos biome, vary along local environmental gradients. Fossil pollen studies tracking vegetation shifts suggest millennial-scale resilience of the fynbos driven by fire, topography, and climate. The drivers control local-scale vegetation transitions near boundaries with forest and karoo biomes (MacPherson et al., 2018). Frequent fire promoted fynbos, which displaced fire-sensitive forest species in wet climatic conditions, but increased aridity favoured karoo expansion. For example, Jonkershoek, at the mesic end of the fynbos gradient, was buffered from vegetation change from climate and land use in the last 8000 years (Oden, 2026). Intra-biome reorganisation between fynbos species was mediated by fires, with frequent or intense fires resulting in fynbos expansion, but less frequent fires increased grassier fynbos (e.g., renosterveld type in sandy areas). However, invasions by alien plant species (e.g., *Pinus* spp.) in the last ~400 years introduced by European settlers caused a novel fire regime, i.e., high fire frequency and intensity that degraded fynbos resilience (Oden, 2026). In drier and climatically variable Groenkloof, fynbos ecotypes switched with Nama karoo shrubs (Figure 2; MacPherson et al., 2018). Increased aridity limited biomass accumulation and fire, which

facilitated the establishment of aridity-adapted karoo species. However, fynbos reestablishment during wet climatic periods indicated long-term resilience. Palynological analysis therefore indicated valuable prehistorical baselines, signal of European settlement, local scale species tolerance traits associated with fire and aridity that play important roles in maintaining resilience.

2. FOREST-SAVANNA-GRASSLAND TRANSITIONS

Lake St. Lucia, the country's largest estuary, is situated in the Indian Ocean Coastal Belt Biome (IOCB) (Figure 2) and forms part of the iSimangaliso Wetland Park, a UNESCO World Heritage Site. This wetland ecosystem contains ~45% of the country's estuarine biodiversity (Perissinotto et al., 2013). Regrettably, Lake St. Lucia is swiftly diminishing in its estuarine performance due to salinity alterations induced by climate change (wet-dry precipitation cycles). Long-term investigations of vegetation changes in this region from fossil pollen indicate a transition from a forested ecosystem to open savanna woodland (Neumann et al., 2008, 2010). Palynological studies from the region indicate changes in vegetation composition and structure that were mainly influenced by climate, which transitioned from humid, high-precipitation, and elevated sea level to warm and dry conditions in the last ~2000 years BP (Effiom et al., 2026). For example, Mkhuze Swamp experienced two phases of fire in the last ~2000 years, which changed vegetation and likely affected animal populations. The first fire period (c. 950-850 years BP) likely resulted from human activities like deforestation for livestock, and the later fire phase (c. 280-200 BP) was worsened by a prolonged dry climatic phase. Changes in species composition over time in the IOCB were mostly influenced by climate, but recent accelerated land-use transformations from pastoralism, colonial settlement patterns, and large-scale agricultural production suggest an uncertain future.

The savanna and grassland biomes, dominated by shade-intolerant grasses and forbs, cover more that 60% of the country (Mucina and Rutherford, 2006). These open ecosystems include the country's arable land and rangelands. Open ecosystems were initially considered a product of increased biomass burning by Iron Age farmers in the last 2000 years (Acocks, 1953), but palaeoecological studies indicate wildfires predated farmers and *Homo sapiens* (Bowman et al., 2009). Moreover, frequent fire and herbivory are key drivers of vegetation openness by



Key insights

- Long-term palaeoecological archives provide essential baselines for evaluating biodiversity changes, but interpretations of ecosystem responses are context dependent. In the examined South African ecosystems, biodiversity responses to environmental changes were shaped by climate, fire, large herbivores, soils, and humans across multiple spatiotemporal scales. Longer timescales revealed the conditions determining ecosystem resilience, reorganisation, and evidence of crossed thresholds.
- Despite the uniqueness and biodiversity importance of studied ecosystems, fire and climate emerged as key drivers of vegetation changes. While fire is considered beneficial for biodiversity and ecosystem persistence in fynbos, savanna, and grassland systems, it is detrimental to forests and other fire-sensitive habitats. Therefore, fire regime baselines and assisted migration of plants threatened by climate and disturbance are concrete policy areas where palaeoecological evidence could be incorporated, possibly extending to key biodiversity area planning, biodiversity assessments, setting of restoration targets in South Africa, similarly, across Africa.

limiting woodland and forest tree cover (Beerling & Osborne, 2006; Bond, 2005). This new insight proposing the likelihood of alternative forest, savanna, and grassland states in similar climates driven by vegetation tolerances traits to disturbances is hotly debated. Yet, evidence at long timescales is mounting from sedimentary charcoal, dung fungal spores, and grass phytolith data at Hluhluwe-iMfolozi Park savanna and Blood River grassland near Vryheid (Dabengwa, 2022; Figure 2). In grassland, for example, the local vegetation transition from short grasses dependent on frequent heavy grazing by large-bodied grazers after c. 700 BP, to fire-dependent tall grasses, coincided with drier conditions and upland settlement by agro-pastoralists. Taken together, these studies demonstrate the utility of alternative stable states theory and the role of historical contingency.

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Traditional Ecological Knowledge and Land Use Management Practices of Magubike Communities, Iringa, Tanzania.

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Traditional ecological knowledge (TEK) refers to the cumulative body of knowledge, practices, beliefs, and innovations developed by Indigenous and local communities through long-term interactions with their environment (Jessen et al., 2022). Long before the emergence of formal scientific systems, indigenous communities relied on observation, experimentation, and intergenerational learning to identify and classify various ethnobotanical plant-uses (edible, medicinal), and sustainable methods for managing landscapes and ecosystems (Ingold, 2000; Jessen et al., 2022). Today, TEK continues to play a vital role in biodiversity conservation, climate adaptation, food security, and the sustainable use of plant resources (Jessen et al., 2022).

Across the globe, indigenous communities have developed sophisticated ecological knowledge systems that guide land management, resource use, and environmental stewardship. These systems are not only practical but are also embedded with cultural values, social institutions, and community identities (Jessen et al., 2022; Tang & Gavin, 2016). Consequently, TEK represents both an important cultural heritage and a valuable resource for addressing contemporary environmental challenges (Jessen et al., 2022; Tang & Gavin, 2016).

Unfortunately, TEK is increasingly threatened by biodiversity loss, climate change, deforestation, urbanisation, and shifting socio-economic practices. In Tanzania, which is home to more than 120 ethnic groups with diverse cultural traditions and knowledge systems, these pressures have been exacerbated by historical factors, including colonial policies that undermined traditional practices while promoting foreign formal education that have often marginalised indigenous knowledge (see also Bigambo, 2020). As a result, many forms of TEK are at risk of disappearing. Despite these challenges, traditional ecological knowledge remains resilient in many parts of Tanzania.

THE CASE OF MAGUBIKE VILLAGE

This paper presents a notable example found among the Hehe communities of Magubike Village in the Iringa Region. Magubike is particularly important case study for three reasons:

First, Muguke has a rich cultural and environmental history. Archaeological evidence indicating continuous human occupation for approximately 50,000 years (Bushozi, 2011; Miller et al., 2020; Willoughby et al., 2018). Second, the area experienced major land-use transformations,









Figure 1 A. Deliberate retention of Azanza garkeana (Mtowo) in a farm; B. Preservation of Azanza garkeana (Mtowo) near homesteads; C-D. Mtowo fruit, with D. showing ripe Mtowo fruit with sugar syrup dripping from it. Photo by Author, 2025

intensive iron production from approximately 2,000 years ago until the last three centuries likely drove extensive woodland clearance for charcoal and fuel (Bushozi, 2011; Katto, 2024). Third, local Hehe and Bena communities continue to maintain extensive ecological knowledge and conservation and sustainable resource management.

TRADITIONAL ECOLOGICAL KNOWLEDGE IN CONTEMPORARY LAND MANAGEMENT AT MAGUBIKE

Field observations made in 2025, during archaeological and environmental research at Magubike, indicate that Traditional Ecological Knowledge (TEK) still influences land-use decisions. Woodland areas are frequently cleared for agricultural production, but local farmers deliberately retain selected tree species within cultivated landscapes. These trees provide multiple benefits, including farm boundary markers, shade, food resources, medicinal products, and ecological services. The deliberate preservation of these species reflects a long-standing system of environment knowledge and sustainable land management.

One example is *Azanza garkeana* locally known as Mtowo, a tree widely valued for its edible fruits, medicinal uses, economic values, and importance as food source during periods of scarcity (see Ruffo et al., 2002). The species is often conserved near and within agricultural fields despite broader vegetation clearance (see Figure 1).

Likewise, *Kigelia africana* locally known as *Mfumbi* is intentionally retained because of its medicinal value, especially in supporting maternal health and lactation. The ongoing preservation of these species demonstrates how ecological knowledge is embedded in daily land-use practices, benefiting both household well-being and the conservation of biological diversity.

The above two examples illustrate that TEK functions as an informal but effective conservation mechanism. Indigenous communities have developed and sustained practices that conserve culturally significant plant species and support the sustainable use of natural resources across generations of observation of environmental change.

RELEVANCE TO FOOD SYSTEMS AND ENVIRONMENTAL RESILIENCE

Traditional management practices that conserve wild edible and medicinal plants directly support resilient food systems. These plant species provide affordable nutrition, support health, improve the ecosystem services, and serve as safety nets during periods of food shortage or environmental stress.

At the same time, these practices preserve biological diversity and maintain cultural knowledge associated with the identification, use, and management of local plant resources (Ruffo et al., 2002). Such knowledge can inform ongoing practices for sustainable agriculture, ecosystem restoration, and climate adaptation (see Ruffo et al., 2002).

KEY CHALLENGES

Traditional ecological knowledge in Magubike and across Tanzania remains poorly documented and increasingly threatened by (i) deforestation and landscape transformation, (ii) climate change and environmental degradation, (iii) changing livelihoods, (iv) limited recognition of TEK in formal education systems, (v) rural-urban migration, and, (vi) declining

intergenerational knowledge transmission (Bigambo, 2020; Ruffo et al., 2002). The loss of natural habitats and wild edible and medicinal plant species reduces opportunities to maintain and pass on ecological knowledge weakening cultural heritage, food security and environment resilience.

RECOMMENDATIONS

- Document and safeguard traditional ecological knowledge through systematic ethnobotanical, cultural heritage, and community-based research initiatives.
- Integrate Indigenous knowledge into environmental and agricultural policies, especially those related to biodiversity conservation, climate adaptation, and sustainable land management
- Support community-led conservation initiatives that protect culturally significant species and their habitats.
- Strengthen intergenerational knowledge transmission through local education programmes, cultural heritage initiatives, and community engagement activities.
- Recognize traditional ecological knowledge as intangible cultural heritage and develop national strategies for its safeguarding in line with the principles of the UNESCO 2003 Convention for the Safeguarding of Intangible Cultural Heritage (UNESCO, 2003).
- Promote interdisciplinary research linking archaeology, ecology, ethnobotany, and heritage studies to better understand long-term human-environment interactions and their relevance for contemporary sustainability challenges.



Figure 2. A. Deliberate retention of Kigelia africana (Mfumbi) in a farm; B-C. A closer look at Mfumbi fruit. Photo by Author, 2025.

Key insights

- The Hehe communities of Magubike village illustrate that traditional ecological knowledge serves as a critical foundation for sustainable land management, biodiversity conservation, and resilient food systems. Through the protection of culturally significant plant species, they continue to apply knowledge accumulated over generations, strengthening both ecological and social resilience.
- As Tanzania confronts climate change, biodiversity loss, and food insecurity, traditional ecological knowledge provides practical insights for sustainable development. Thus, safeguarding and promoting such knowledge is not only about cultural preservation, but also an investment in environmental sustainability, community resilience and future food security.

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Gender, Age and Ethnobotanical Knowledge among the Daasanach community of Ileret, Kenya

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Ileret region is part of the Koobi Fora basin located in northern Kenya which has preserved evidence for the earliest domestication of livestock for the last 4000 years presents a unique opportunity to understand the relationship between pastoralists and plants (. This article presents ethnobotanical knowledge among the Daasanach community living in the Ileret area of northern Kenya. The study investigates which plants are known and used locally by community members, how this knowledge is acquired and transmitted and whether plant use varies according to age, gender and settlement types. We highlight the relationship between demographic class and plant-use knowledge for food, medicine, livestock care, construction, fuel, and tools.

Ethnobotanical studies can be used to document relationships between people, plants, and their environment, including traditional plant knowledge, uses, harvesting practices, and knowledge transmission. Here, we conducted an ethnobotanical study in the Ileret area on the east shore of Lake Turkana (Figure 1) across 12 sites, representing temporary, semi-permanent and permanent settlements. We collected ethnobotanical data through 28 oral interviews involving 37 participants including men and women, with the assistance of Daasanach translators and plant walks. Interviews addressed demographic information (age, gender, and residence type), plant uses, harvesting practices, knowledge acquisition and transmission, and perception of environmental change. Participants were grouped into three age categories: 1st Gen (10-20 yrs), 2nd Gen (21-45 yrs) and 3rd Gen (over 45 yrs). All plant specimens were identified using photographs and regional botanical field guides (Blundell, 1987; Dharani, 2002).

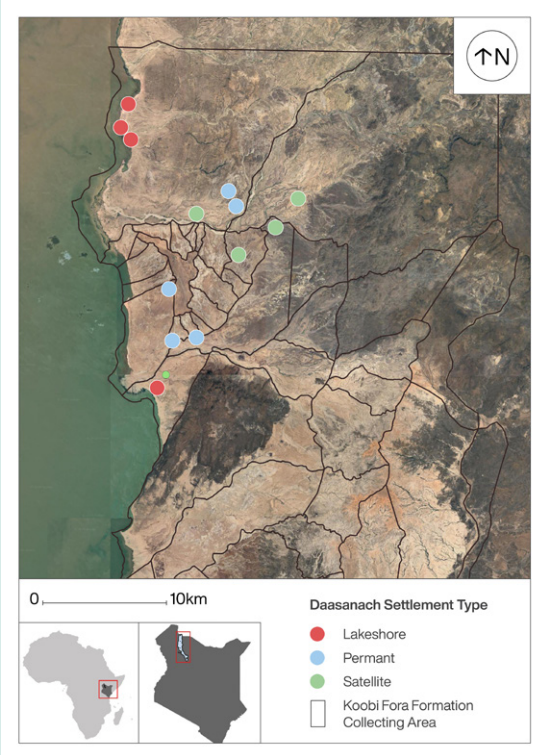


Figure 1. Map showing the study area and location of settlements surveyed.

KEY FINDINGS

The Daasanach retain extensive knowledge of plants

The study demonstrated that the Daasanach community retains extensive ethnobotanical knowledge. Participants identified 115 plant taxa using Daasanach local names (Figure 2). Of these, 30 were identified to species level and 31 to genus level, while the remaining taxa require further botanical identification. This diversity of locally recognised plants highlights the depth of plant knowledge maintained within the community.

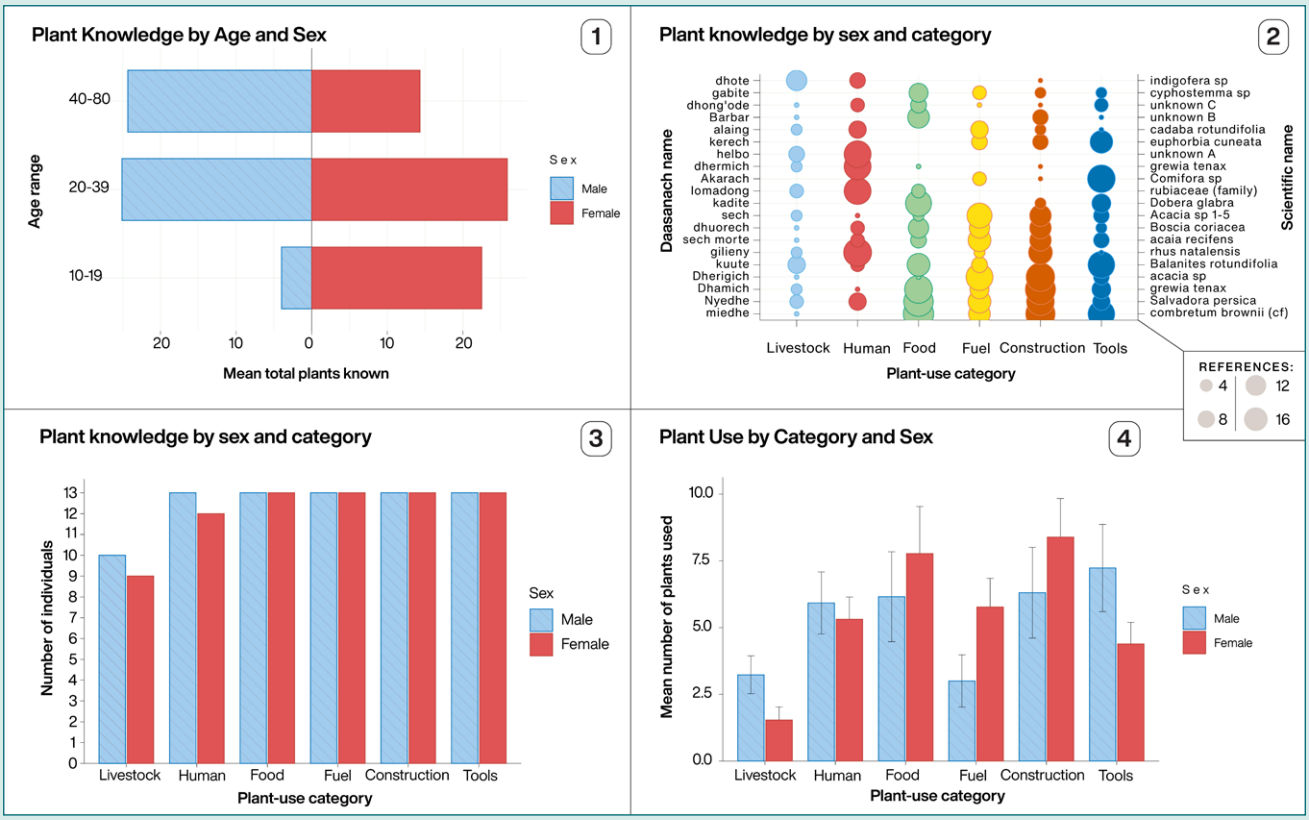


Figure 2. Top 20 plant species used for different purposes. Green- livestock fodder and medicinal, blue – human medicinal, yellow- wild food, orange- fuel, red- for construction and black for tools

Plant knowledge is learned early and transmitted within families

We observe that ethnobotanical knowledge is acquired early in life and is primarily transmitted within families. All respondents reported learning plant use before the age of 10, while 89% identified parents as their main source of knowledge. Respondents with children also reported passing this knowledge to younger generations through observation and practical learning. This indicates that ethnobotanical knowledge is closely embedded in everyday livelihood activities rather than being transmitted only through formal teaching.

Men and women know similar numbers of plants, but use them differently

Plants were broadly similar between men and women, with men reporting knowledge of 24 species compared to 23 species among women. (Figure 3a). However, the plant-use frequency varies significantly between gender ($p=0.032$), indicating that gender influences how plants are used more than the number of plants are known (Figure 3b). Significant differences were also observed across several use categories, especially between human and livestock medicinal plants and among fuel, tool, and construction uses ($p=0.002$), while construction and fuel uses did not differ significantly ($p=0.395$). Women were more involved in household activities, which corresponds with greater reported use of plants for food, fuel, and construction (Mwamidi, 2018), while men's pastoral responsibilities correspond with greater use of plants for livestock-related purposes (Mwamidi, 2018; Ayantunde, 2008).

Environmental knowledge indicates perceived stability, but drought is a concern

Most participants reported restrained harvesting practices, with 96% indicating that they generally collect only what they need, while overharvesting was described as socially discouraged. These practices suggest the presence of community norms that may contribute resource conservation, although ecological monitoring would be required to demonstrate long-term sustainability. On the other hand, drought remains an important environmental concern and may influence the availability and use of plant resources in the future.

Policy discussion and recommendations

- The findings demonstrate that ethnobotanical knowledge remains an important component of the Daasanach livelihood and cultural practice, with knowledge acquired early in life and transmitted primarily through families and practical experience. This knowledge is closely linked to gendered livelihood roles and provides communities with locally adapted strategies for food, medicine, livestock management, fuel, tools and construction products (Schiniter at al., 2021). In addition, participants generally perceive plant resources as stable and report restrained harvesting practices. However, environmental pressures, particularly drought, may contribute to declining plant resource availability and continuity of associated knowledge. Therefore, there is a need for policies that recognize both cultural practices and environmental change when assessing the resilience of ethnobotanical knowledge.
- Policy interventions should prioritize the documentation and intergenerational transmission of ethnobotanical knowledge, particularly knowledge held by older community members. Such initiatives should be community-led and ensure that the communities retain ownership and control over their knowledge (Tamou et al., 2017). Local schools and community programs could support intergenerational learning by creating opportunities for elders, parents, and young people to share knowledge through practical activities such as plant identification, harvesting, and plant-use demonstrations.
- There is also a need to strengthen botanical documentation and research. Many locally named plant taxa remain unidentified to species level, limiting their recognition within conservation and biodiversity-management frameworks. Collaborative research involving community knowledge holders, botanists, and local institutions should therefore be supported to improve plant identification and establish community-accessible records of local plant diversity.
- Finally, reported restrained harvesting practices provide a foundation for community-based resource management, but their effectiveness should be assessed through long-term monitoring of plant populations and harvesting pressures. Attention should be given to the effects of recurrent drought on plant availability and ecosystem resilience. Strengthening community participation in natural-resource governance, alongside drought-resilience measures, can help ensure that both plant resources and the ethnobotanical knowledge associated with them are maintained for future generations.

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4.2 Asia



Photo by Akkash Shah on Unsplash

This chapter explores the long and complex relationships between people, biodiversity, and environmental change across Asia, drawing on archaeological and palaeoecological evidence from the Caucasus, India, and Sri Lanka, as well as the cultural history of human–animal relationships in the ancient Near East. The contributions examine how changing climates, human adaptation, land use, and cultural practices have shaped ecosystems and biodiversity over thousands of years, while also questioning whose knowledge and which regions have shaped dominant global narratives. Together, they highlight the importance of deep-time perspectives and geographically diverse evidence for understanding biodiversity change, human–environment interactions, and the challenges of developing more inclusive and effective approaches to conservation.

EDITORS



Mariya Antonosyan



Gopesh Jha

The Geography of Scientific Attention: How Research Bias Shapes Global Narratives of Late Quaternary Megafaunal Extinctions

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Few questions in Quaternary archaeology have attracted as much attention as the extinction of Late Pleistocene megafauna. For decades, the debate has focused on a familiar set of regions: the Americas, Australia, and Europe (e.g. Meltzer 2020; Fariña and Vizcaíno 2024; Davoli et al. 2024; Adesanya Adeleye et al. 2023). These regions have become the canonical case studies through which competing hypotheses, including climate-driven extinction, human overkill, and other potential impacts, remain fiercely debated. Yet, this geographical emphasis raises an important question. Are these regions central because they genuinely represent the most informative records of megafaunal extinction, or because they have received disproportionate scientific attention? The answer has important implications for how extinction hypotheses are formulated, evaluated, and ultimately accepted.



Figure 1: Steppe Mammoth (Mammuthus armeniacus / Mammuthus trogontherii) exhibit in the Geological Museum after H. Karapetyan of Institute of Geological Sciences of the National Academy of Sciences of Armenia

This position paper argues that the current debate is shaped not only by the available evidence but also by a persistent geographical imbalance in research effort. As a result, regions such as Mainland Africa or Central and West Asia, which preserve rich records of both megafauna and long-term hominin occupation, remain understudied and underrepresented in global syntheses (Stewart et al. 2025). At the same time, South-East Asia (Roberts et al. 2014; Lubeek and Westaway 2020; Louys and Roberts 2020) and islands like Madagascar (e.g., Hansford et al. 2021; Hixon et al. 2021) and New Zealand (Allentoft et al. 2014; Collins et al. 2014) are notably well represented.

This imbalance matters because conclusions drawn primarily from a limited number of well-studied regions risk being interpreted as globally representative, when in reality they may reflect regional historical trajectories. Consequently, these generalised theories and models are often applied elsewhere, despite the diversity of ecological, climatic, and human histories that challenge simplified “one-size-fits-all” approaches to understanding extinction dynamics.

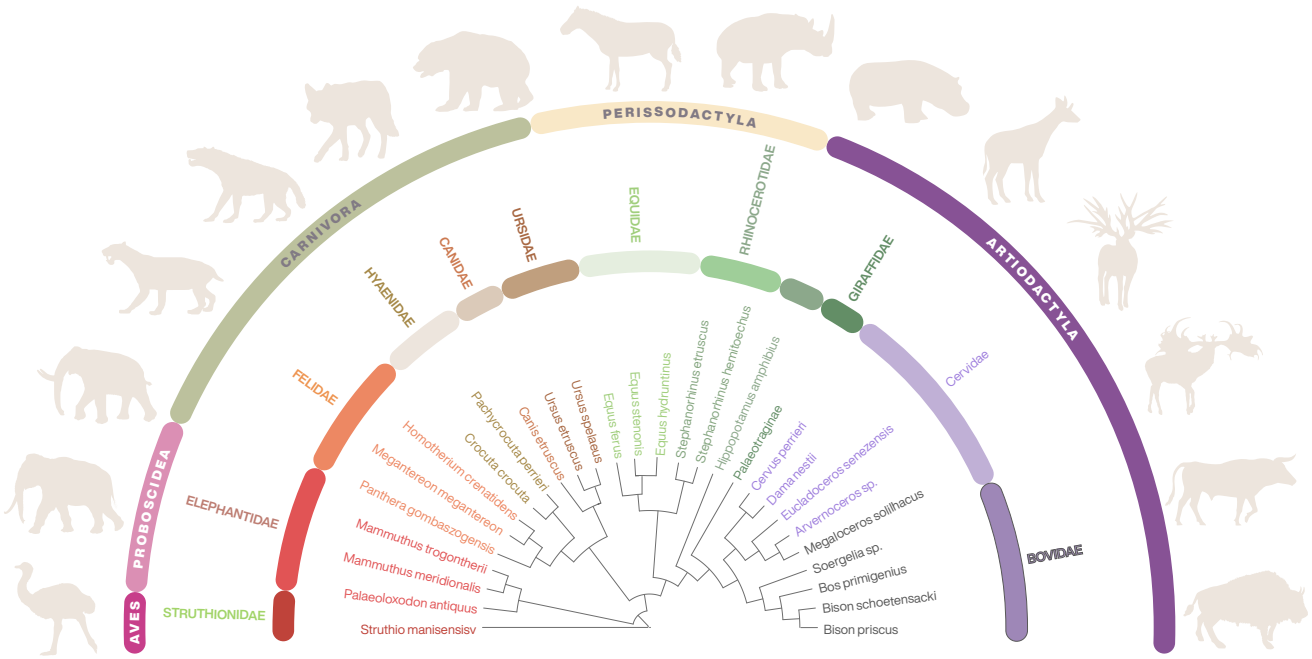


Figure 2: Pleistocene megafauna of the Caucasus (Tesakov et al. 2019; Van der Made et al. 2016; Gabunia et al. 2000; Antonosyan et al. 2019; Pushkina 2007)

It has already been highlighted that large-scale "big data" analyses, which are largely built on evidence from a relatively small number of well-studied regions, have come to dominate discussions of Late Quaternary megafaunal extinctions and their drivers. Critiques of these approaches have emphasised the need for species-by-species and region-specific analyses rather than broad global syntheses (Price et al. 2018).

The dominance of North America, for instance, in the megafaunal extinction literature is understandable. The continent experienced great losses of mammals (38 mammalian genera) near the end of the Pleistocene, and the timing broadly overlaps with the arrival and expansion of modern humans (Meltzer 2020). These records have therefore become the principal testing grounds for evaluating the relative roles of climate change and human impacts. The wealth of archaeological, palaeontological, and chronological data generated over several decades has therefore justifiably placed North America at the centre of this debate (Stewart et al. 2025). What is more difficult to explain, however, is why other regions that experienced comparable faunal turnovers have remained largely peripheral to these discussions.

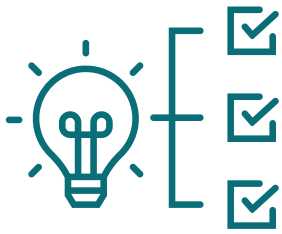
The Caucasus region illustrates this problem particularly well.

During the Pleistocene, the Caucasus supported many iconic extinct megafaunal taxa that dominate global discussions of megafaunal extinctions, including Narrow-nosed rhinoceros, Giant deer, Steppe bison, Steppe mammoth, Scimitar-toothed cat, giant ostrich, and many others (Figure 2) (Tesakov et al. 2019; Van der Made et al. 2016; Gabunia et al. 2000; Antonosyan et al. 2019; Pushkina 2007). Rather than representing a landscape newly colonised by humans during the Late Pleistocene, the Caucasus provides records of extraordinarily long-term coexistence between hominins and megafauna. Dmanisi site documents hominin occupation since 1.8 m.a. (*Homo erectus*) (Lordkipanidze et al. 2007), while Azokh cave reveals evidence of *Homo heidelbergensis* and *Homo neanderthalensis* starting from 300 kya (King et al. 2016). Furthermore, a handful of sites indicate that groups producing Upper Paleolithic (UP) material culture (generally accepted to be Anatomically Modern Humans) arrived in the region after the local disappearance of bearers of late Middle Paleolithic (MP) technology (associated with Neanderthals) (Pinhasi et al. 2011). The Caucasus has also been proposed as a temperate

refugium, where species survived the cold and aridity of the glacial periods of the Middle to Late Pleistocene (Van der Made et al. 2016; Antonosyan et al. 2024).

These characteristics make the region particularly valuable for addressing key questions on the relative contributions of climate change and human impacts on megafaunal population dynamics. If humans and megafauna coexisted successfully in the Caucasus for such extended periods, why did many species ultimately disappear near the end of the Pleistocene? Conversely, if climate change explains extinction, why did species disappear from regions considered climatic refugia? These questions become considerably more informative when investigated outside the traditional study regions.

If the objective is to understand one of Earth's most significant biological transformations, then the evidence base must become genuinely global. This does not require abandoning the well-established records of the Global North. Rather, it requires integrating regions that have thus far occupied the margins of the debate despite their exceptional scientific value.



Key insights

- The underrepresentation of the Caucasus reflects a broader issue within scientific practice. Research attention is not distributed evenly across the globe. Instead, it tends to concentrate on regions with long-established research traditions, extensive funding, and large collaborative networks (Stewart et al. 2025).
- This pattern is not unique to megafaunal research. Across archaeology, paleoecology, and conservation science, knowledge production remains geographically uneven. Consequently, some regions become canonical examples that define theoretical debates, whereas equally informative regions receive comparatively little attention. This imbalance also reflects broader inequalities in the production of scientific knowledge.
- For decades, research agendas, funding priorities, publication opportunities, and theoretical frameworks have been disproportionately shaped by institutions in the Global North. As a consequence, evidence generated by institutions in the Global North often comes to define global narratives, while data from other regions remain peripheral, regardless of their scientific relevance. This reflects a form of epistemic colonialism that has permeated into research, as unequal structures of knowledge production influence not only who produces scientific knowledge, but also which questions are considered important and which regions become central to scientific debate.
- Importantly, this imbalance cannot simply be attributed to inaccessible data or language barriers (Bampi et al. 2024). A substantial body of archaeological, palaeontological, and palaeoenvironmental research from the Caucasus and West Asia, in general, has

been published in English and is readily available internationally. Nevertheless, these datasets are seldom incorporated into global reviews, meta-analyses, or conceptual syntheses that shape current thinking about Late Quaternary extinctions.

- Understanding Late Quaternary faunal dynamics not only offers important perspectives on past biodiversity patterns and human-animal interactions but also supports more informed conservation strategies by providing long-term ecological baselines (Meltzer 2020; Smith et al. 2022). Yet policies and theories based predominantly on evidence from a limited set of regions risk overlooking the diversity of historical human-environment relationships that shaped biodiversity trajectories. Effective environmental policy, therefore, requires an equally deep historical understanding that reflects regional variability rather than assuming universal patterns.
- Ultimately, addressing the geographical imbalance in research requires more than expanding datasets or incorporating additional study regions. It demands a fundamental shift away from colonial models of scientific practice and extractivist approaches in which the Global South is often viewed as a source of data while research agendas, interpretations, and theoretical frameworks are developed elsewhere. Moreover, widening the dialogue to other knowledge systems (e.g. Indigenous knowledge, traditional knowledge) is crucial when aiming for more inclusivity/epistemic justice. Science must be built on equitable and reciprocal partnerships that recognise local researchers, Indigenous peoples and local communities as intellectual partners and rights holders rather than passive consultants or providers of access. Their perspectives should help shape research questions, methodologies, interpretations and applications (Smith et al. 2025). Widening the community to include Indigenous and local knowledge holders is not a courtesy but a necessary correction: to fill the gaps that a narrow group cannot even see, and to produce a fuller, more accurate understanding of life on Earth. Equally important is ensuring that the benefits of research are returned to the communities and regions where it is conducted through accessible science communication, capacity building, training opportunities for local students and early-career researchers, collaborative infrastructure development, and open sharing of knowledge and resources.

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Deep Histories of Biodiversity Change in Mirzapur and Sonbhadra Districts, Uttar Pradesh, India: An Archaeologist's Perspective

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It is said that if we do not stop climate change, climate change will stop us. In the long run, however, especially in India, climates have in fact changed earlier than the Anthropocene, with negative consequences for biodiversity, in which three separate floral and faunal regimes were replaced successively. In the Vindhyan context, particularly along the middle Sone Valley (in Mirzapur and Sonbhadra Districts, Uttar Pradesh) and its neighbouring hilly and elevated landscape, geological, sedimentological, palaeontological, faunal, climatic, as well as archaeological parameters are consistent with the fact that there has been tremendous ecological change, leading to several succeeding 'regimes' of flora and fauna. The earliest natural histories point to Meso-Proterozoic origins of the basin, with sedimentary activity leading to deposition of sandstones characterising the entire Middle India. Remnants from the period are 1.6 by old Stromatolite fossils from an existing marine formation at Salkhan Fossil Park in Sonbhadra. As five extremely wet and dry weather cycles, marking the birth of the Indian summer monsoons, prevailed, the shift from moist tropical deciduous forests to open savannah and grasslands, followed by semi-arid dry deciduous forests, took place. Whereas Pleistocene megafauna, at several places in middle India, including the Narmada Valley, were replaced by more recent subspecies, in the Post-Pleistocene semi-arid conditions, only small game and dry climate plants survived. Excavated data over a large range suggest that prehistoric human cultures adapted to ecological change and evolved their symbolic and material cultures, settlement systems, and hunting-herding strategies in tandem with climate and ecosystem changes. The faunal diversity in the region's rock art gives us pointers to the symbolic construction of changing climates over ten thousand years.



Figure 1 A UAV view of the hydrological landscape of the Belan Upriver tracts that have several rock art sites, at the Mukkha Dari Waterfalls, which were inhabited during the early Holocene as a recourse to increasing aridity of the Sone River Valley. Photo Courtesy: Author

Biodiversity changes seem to follow a three-tier pattern with mainly the replacement of Pleistocene megafauna, followed by the replacement of terminal Pleistocene fauna like elephants, rhinos, buffalo, and cattle, by Holocene fauna adapted better to semi-aridity. Thus, given that most of the rock art here is Holocene, antelopes and deer dominate the rock art as excavated faunal profiles from the highland Vindhyas sites like Raja Nal ka Tila, Raipura, Lekhahia, Bagahi Khor and Morhana Pahar. Hunting activities followed by animal and plant domestication are reflected in several sites, accentuated greatly during the terminal-to-post-Pleistocene periods, when dramatic changes in rainfall engendered the disappearance of large canopied forests of the moist deciduous type. These were in the Holocene, overtaken by grasslands dominated by *acacia* and *anogeissus* scrub and bush forests containing medium to small fauna as the new basis for hunting and pastoral pursuits. Human groups of the middle to late Holocene adapted remarkably by keeping goat/sheep flocks and buffalo/cattle herds that could subsist on semi-arid vegetation.



Fig. 2. Human-animal relationships of the Mesolithic, roughly 10,000 – 6000 ya, depicted at MKD 1 (Mukkha Dari Waterfalls) Site, inside the Kaimur Wildlife Sanctuary, Sonbhadra District, Uttar Pradesh. Here, Terminal Pleistocene calcite deposits on vertical rock surfaces have multi-period rock paintings and storied panels depicting fish, turtles, deer, and wild cattle, painted in red ochre. The calcites attracted prehistoric artists as they act as mordants, binding the ochreous paint/pigment to the rock. Photo and DStretch Courtesy: Author

BACKGROUND

Overpopulation and excessive exploitation of trees, soil, land and water resources are the causes of ecosystem transformation and decline in the Vindhyas from the beginning of the Anthropocene around 12,600 years ago. The process of ecosystem change was as follows: 1. River valleys of the Vindhyan region, like the Sone and Belan, were inhabited first by early Stone Age populations around 1,00,000 years ago. Environmental changes after the Last Glacial Maximum alternated between very dry and very wet, leading to Dry Deciduous

Forests where moister vegetation regimes had existed. Early to mid-Pleistocene environments were complete with high rainfall and swamps that harboured such species as the Rhino and the Hippo. During the Anthropocene (the Holocene), the vagaries of the summer monsoons caused human (and faunal) populations to spread out from locations like river valleys to the (well-watered) plateau regions of the Vindhyas. 2. Human habitations grew on the highland Vindhyas with the first Mesolithic hunting-gathering camps in rock shelters and caves around 10,000 years ago. Caves and shelters were heavily painted with scenes of human social life in prehistoric times, which form a secure basis of information on subsistence patterns. 3. However, forest clearances became more frequent during the Neolithic period to create pasturage for domesticated animals. Although wild food like tubers, nuts, fibre and wild cereal grasses were exploited for human diets earlier, plant domestication involving millets, lentils, peas, barley, rice and wheat began during the Neolithic. 4. The rise of agro-pastoralism and full scale agriculture put the two systems of land use on Vindhyan scarps in competition, while precipitating the selection of plant and animal species, and altering their genetics and distribution. 5. Pastoralism and agriculture were complementary during the Neolithic, when characteristic corralling compounds and homesteads were established in the highlands, but in the Iron Age and early historical times, human conflicts over the sharing of water and vegetation resources (or the landscape) started. Pastoralists required access to pasture, water and mobility spaces, while agriculture required permanent control over all these.



Take away

- With temperatures slated to rise 1.5 degrees celsius by 2040, major changes are predicted and already happening due to anthropogenic intervention in the plant, animal and environmental contexts, which have weakened natural ecosystem cycles reducing livelihood sustainability through agriculture and pastoralism in the inner and highland Vindhyas.
- Denudation of tree cover exceeds reforestation and has already resulted in tremendous soil erosion, flash floods, and insufficient irrigation during dry seasons. Despite the existence of check dams on highland drainages, the supply of water for the irrigation of lowland farms is reduced. Monsoons are delayed, insufficient, and hot winds during the summer also scour denuded landscapes, contributing further to desiccation.
- Freakish weather patterns are becoming more frequent and will worsen with cyclones and typhoons increasing. These disastrous changes must be mitigated by suitable technologies to provide equitable livelihoods and resource utilisation patterns that step up the adaptive fitness of humans, animals, plants and the ecosystems towards sustainable productivity.

From coexistence to conflict: A deep-time perspective on human agency in shaping biodiversity of Sri Lanka

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AN ISLAND OF EXCEPTIONAL BIODIVERSITY

Sri Lanka (Figure 1), together with India's Western Ghats, is one of the world's most species-rich biodiversity hotspots, distinguished by exceptionally high endemism (Bossuyt et al., 2004), yet also has one of the highest human population densities of any hotspot (S. J. Perera & Suranjan Fernando, 2024), often framed as a paradox given its long human habitation. With half the global population predicted to live in the tropics by 2050 (Roberts, Hunt, et al., 2017; State of the Tropics Project, 2014), we argue instead that at least some elements of Sri Lanka's biodiversity, particularly its ecosystem heterogeneity, cannot be understood apart from this history of habitation, encompassing both active landscape shaping and sustained reliance on, and coexistence with, faunal and floral communities.

PREHISTORIC TRANSFORMATIONS- SELECTIVE HUNTING, FORAGING AND HUMAN-INDUCED VEGETATIONAL CHANGES

Human agency has occurred within Sri Lanka's ecosystems for at least 48,000 years. Evidence from Fa-Hien Lena, Batadomba-lena, and Kitulgala Beli-lena (Figure 1) demonstrates *Homo sapiens* occupying tropical rainforests from the Late Pleistocene (Wedage et al., 2019) developed specialised strategies for exploiting rainforest resources, including hunting arboreal mammals such

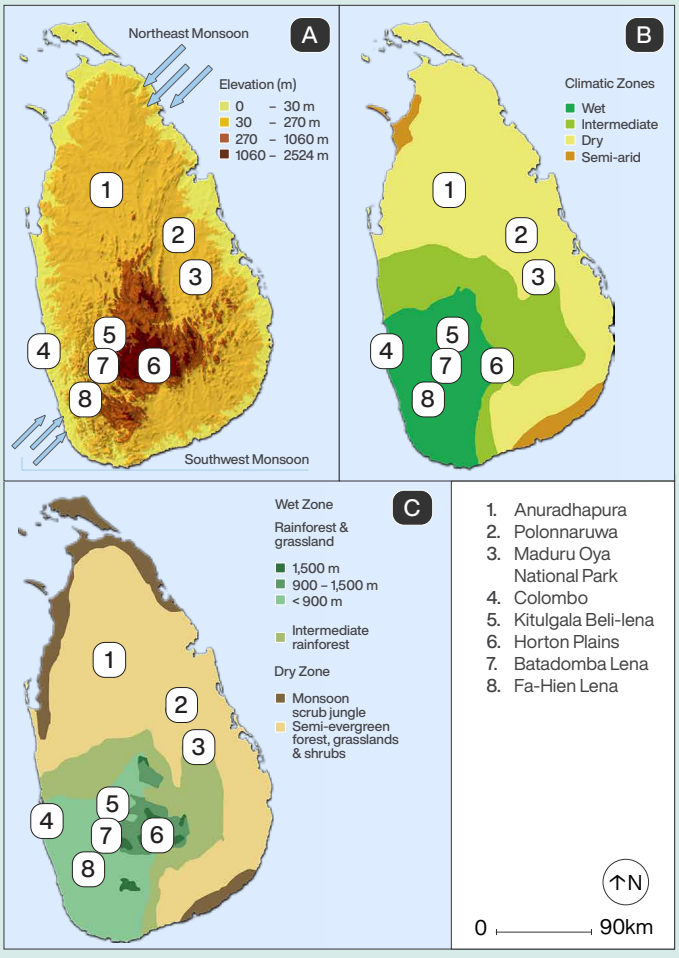
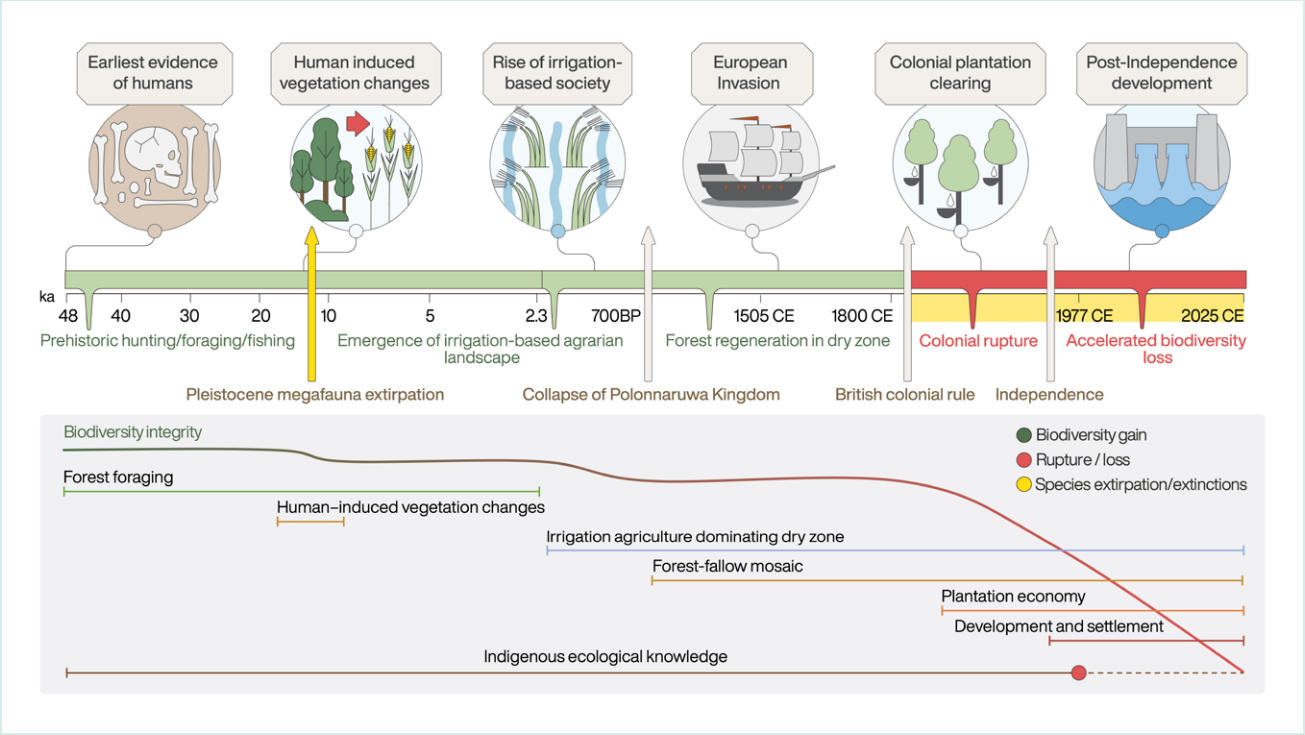


Figure 1: Environmental setting of Sri Lanka and locations referenced in the text. (a) Topographic map showing elevation classes and the dominant directions of the northeast and southwest monsoon systems, (b) major climatic zones and (c) distribution of principal vegetation formations across climatic and elevational gradients [redrawn from Erdelen (1988) and Gunatilleke et al. (2005)] of Sri Lanka. Numbered circles indicate key prehistoric and historic locations mentioned in the text.



as monkeys (Cercopithecidae) and giant squirrels (Ratufa macroura), and foraging freshwater resources (Wedage et al., 2019, 2020). In addition, macro- and microbotanical evidence for wild breadfruit (*Artocarpus nobilis*), nuts, and wild rice (*Oryza rufipogon*) indicates that the plant resources were a vital component of subsistence (Premathilake & Hunt, 2018; Wedage et al., 2020), while isotope data confirm year-round forest reliance (Roberts, Perera, et al., 2015, 2017). Coastal populations similarly intensified estuarine and marine exploitation into the Holocene, at times focusing on a single taxon (Amano et al., 2024).

Despite specialised extraction over tens of thousands of years, none of the targeted species was driven to extinction, suggesting a sustainable relationship with prey populations. Several large-bodied Pleistocene mammals of the Ratnapura Fauna disappeared, though causes remain contested. Remains of tiger (*Panthera tigris*), rhinoceros (*Rhinoceros unicornis*), and gaur (*Bos gaurus*) in cultural deposits do not exclude human predation (Manamendra-Arachchi et al., 2005; Sumangala et al., 2026; Wedage et al., 2019), but current balance evidence favours climatic change and habitat transformation and perhaps indirect anthropogenic forcing over overexploitation (Manamendra-Arachchi et al., 2005; Roberts, Boivin, et al., 2015).

Evidence from Horton Plains (Figure 1) offers insight into potentially early, indirect human environmental modification. Pollen records indicate anthropogenic disturbances from approximately 18,000 cal. BP, including recurring biomass burning and forest clearance, intensifying around 13,800 cal. BP (Premathilake, 2006, 2012), and linked to increased wild rice (*Oryza nivara*) pollen (Premathilake, 2006, 2012). Recent zinc isotope analysis from Wet and Intermediate Zone rock shelter sites shows increasing plant

Figure 2: Conceptual timeline of human–environment interactions and biodiversity change in Sri Lanka from the Late Pleistocene to the present. The schematic diagram summarises major phases of socio-ecological transformation, including the earliest evidence of human occupation (~48 ka BP), initial anthropogenic vegetation modifications, the emergence and expansion of the irrigation-based agrarian landscape, European colonial incursions, plantation-based land-use conversion, and post-independence development. Colored bars indicate periods associated with biodiversity gains (green), ecological rupture and biodiversity loss (red), and documented species extirpations or extinctions (yellow). Brown arrows indicate major historical events. The biodiversity integrity curve tracks the trajectory of biodiversity changes over time. Horizontal bands represent dominant land-use and socio-ecological systems through time. Indigenous ecological knowledge is shown to persist as a cultural influence throughout the entire sequence. The figure is intended as a conceptual synthesis rather than a quantitative reconstruction.

reliance from the Last Glacial Maximum through the early Holocene, long prior to the arrival of agriculture (Bourgon et al., 2026). Ultimately though, any modification of resource landscapes at this time is not associated with obvious irreversible biodiversity loss.

IRRIGATION-BASED SOCIETY AND MANAGED LANDSCAPES

The most transformative phase of Sri Lanka's pre-colonial history was the emergence of an irrigation-based agrarian landscape in the dry zone. From around the third century BCE, polities built extensive networks of interconnected reservoirs centred on Anuradhapura and Polonnaruwa (Dharmasena, 2011). Rather than simplifying ecosystems, this infrastructure created a heterogeneous landscape of paddy fields, catchment forests, orchards, and ecologically sensitive buffer zones (*Kattakaduwa*) (Bambaradeniya et al., 2004; Dharmasena, 2020). Thousands of artificial water bodies expanded aquatic habitats and facilitated species redistribution, including the Asian elephant (*Elephas maximus*), thriving in mixed landscapes around tank villages (Marambe et al., 2012).

After the collapse of the Polonnaruwa Kingdom in the thirteenth century CE, political centres relocated to the wet zone. Much of the dry zone's closed-canopy forest is believed to have a secondary origin, linked at least in part to abandonment of the irrigation landscape after this collapse (Pemadasa, 1984; G. A. D. Perera, 2001). Communities remaining in the dry zone increasingly practised chena, or fallow cultivation, clearing land before multi-year fallows regenerated secondary forests (G. A. D. Perera, 2001), creating a mosaic that fostered elephants while informal spatial arrangements regulated human–wildlife interactions (Anuradha et al., 2019). Such land-use practices often sustained ecological relationships or at least allowed large urban populations to coexist with Dry Zone biodiversity.

COLONIAL DISRUPTION AND POST-INDEPENDENCE PRESSURES

Portuguese, Dutch, and later British colonial rule introduced a fundamentally different mode of human-environment interaction. Under the British after 1815, forest clearance accelerated for timber and plantation agriculture, namely coffee, tea, rubber, and coconut (Wickramagamage, 1998). Forest cover declined from approximately 84% in 1881 to around 50% at independence in 1948 (S. Fernando et al., 2015). Colonial game and sport hunting reduced elephant and leopard populations, while plantations facilitated invasive species introductions (Marambe et al., 2011; Wickramagamage, 1998).

After independence, population growth, infrastructure development, river diversion, deforestation, and overexploitation of coastal and marine resources intensified ecological pressures in the Wet Zone (S. J. Perera & Suranjanfernando, 2024). Large state projects, including the Accelerated Mahaweli Development Programme, diverted rivers and resettled populations into forested areas inhabited by the Vedda People (Wanniyalaeto), Sri Lanka's Indigenous community. In 1983, their remaining forest refuge became Maduru Oya National Park (Figure 1), restricting their hunting and access to ancestral lands (Stegeborn, 2004).

Government subsidy schemes from the 1970s encouraged a shift from rotational chena farming to fixed-plot cash-crop agriculture, reducing the fallow-forest mosaic elephants depended on and forcing them into permanent croplands (Anuradha et al., 2019). Sri Lanka's contemporary human–elephant conflict is thus not recent but intensified by the abandonment of traditional agricultural systems (P. Fernando et al., 2005); current mitigation strategies rarely

engage with the landscape histories from which it emerged (Gunawansa et al., 2023).

This long-term perspective matters for conservation. Conservation practice often assumes "pristine" landscapes independent of human management, an assumption increasingly challenged by archaeological and palaeoecological evidence across the Global South (Ellis et al., 2021; Roberts et al., 2024). Sri Lanka's archaeological and palaeoenvironmental records indicate that nearly all surviving ecosystems bear the imprint of human activity extending back tens of millennia. Fortress conservation, excluding people from protected landscapes, risks displacing both practices and communities, such as the Vedda People, whose long-term presence sustained these habitats, replicating a dispossessory logic already proven catastrophic.

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Take-home message

- Sri Lanka's biodiversity has been substantially shaped by 48,000 years of human presence, from sustainable prehistoric foraging to the constructed ecologies of irrigation-based agrarian society and the elephant-human coexistence fostered by long-rotation swidden farming. Colonial plantation expansion and post-independence development are comparatively recent disruptions to this longer trajectory.
- Many present-day conservation challenges, including intensified human-elephant conflict, are rooted in these recent shifts, not any deeper incompatibility between people and wildlife.
- Conservation policies that treat Sri Lankan landscapes as pristine, excluding deep-time evidence and the living knowledge of communities such as the Vedda People, risk repeating displacement without addressing actual drivers of biodiversity deterioration.

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From Apex Predator to Royal Symbol: The Biography of Lion Bodies in Antiquity

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HUNTING LIONS - BUT WHAT HAPPENED AFTERWARDS?

Today, lions (*Panthera leo*) survive only in scattered populations across sub-Saharan Africa and in the Gir Forest National Park in India. In antiquity, however, these apex predators occupied a vastly larger territory extending across Southwest Asia, North Africa, and parts of southeastern Europe (Schnitzler, Herrmann 2019: 340-353).

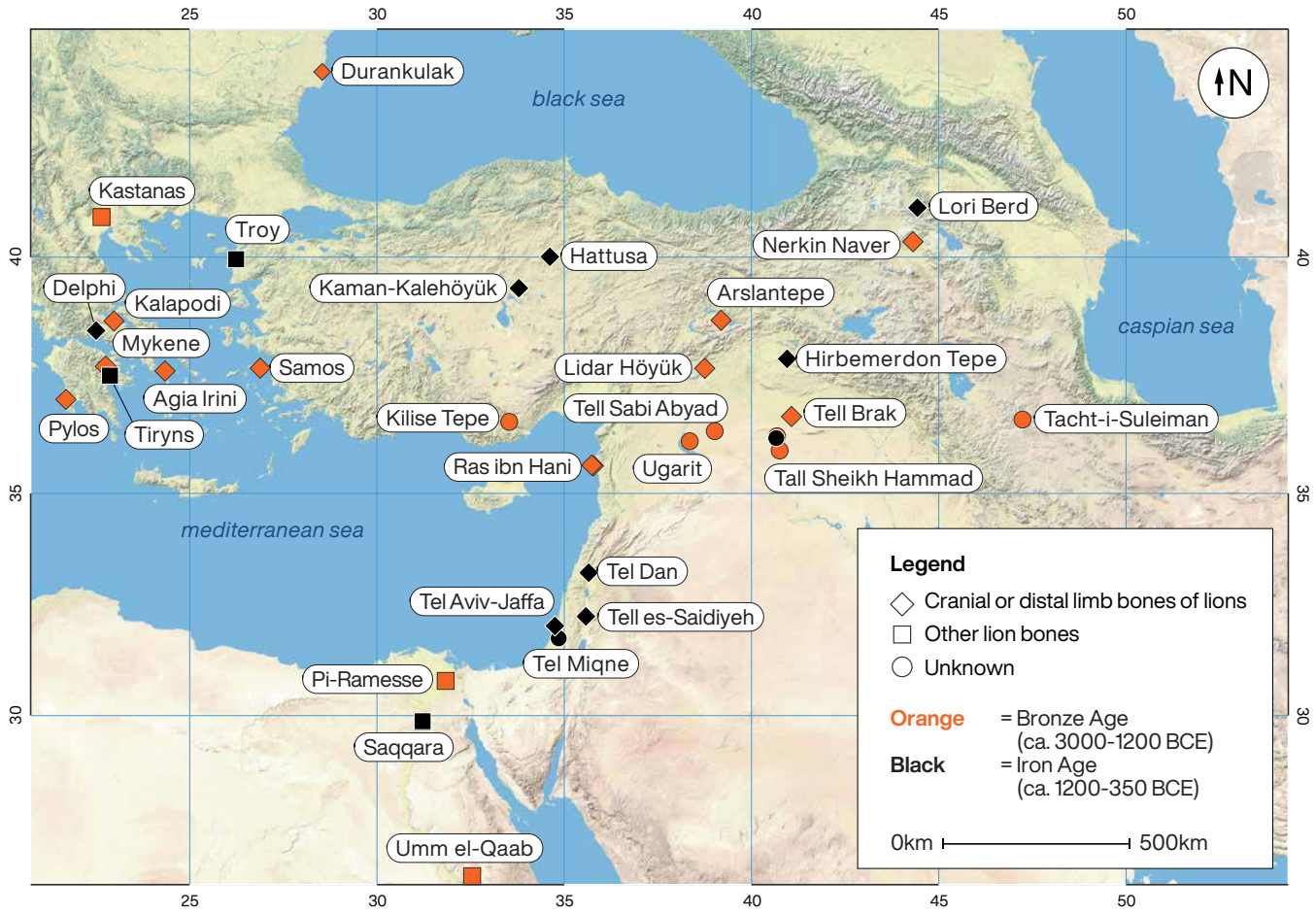
One of the principal reasons for their disappearance from these regions was intensive hunting. Across ancient Western Asia and Egypt, the killing of a lion symbolized the ruler's ability to impose order over both the natural world and political chaos (Watanabe 1998: 439–450; Collins 2014: 629-630). Monumental reliefs, stelae, and other works of art repeatedly depict lion hunts, suggesting that the symbolic value of killing the animal often outweighed any practical value of the carcass itself (Figure 1).



Figure 1. Gypsum wall relief from the North Palace at Nineveh, dated c. 645–635 BCE, depicting a lion being released from a cage by a small attendant (possibly a child), who stands beside a second cage. This scene marks the beginning of the royal lion hunt. British Museum, BM 124869. (Courtesy of the British Museum)

While conducting research on the archaeology of ancient Western Asia, I repeatedly found myself asking a surprisingly simple question that has received little scholarly attention: what happened to the lion after it had been killed? Surely such an extraordinary animal was not simply discarded. This paper, therefore, explores the archaeological evidence to reconstruct how lion carcasses and skeletal remains were treated after the hunt.

To answer this question, I compiled evidence from the ancient Middle East, Egypt, and Greece dating to the Bronze and Iron Ages (Figure 2). These periods were chosen because, beginning in the late Chalcolithic (Copper Age), the emergence of increasingly hierarchical societies, urban centres, and early states fundamentally transformed human relationships with animals. Around the late fourth millennium BCE, representations of lion hunting became increasingly common, for example, on the lion-hunt stele from Uruk (Ornan 2023: 28).



WHICH SKELETAL ELEMENTS ARE DISCOVERED?

Unlike many other large mammals, lions do not appear to have been hunted for food.

Lion mandibles, isolated teeth, phalanges, and claws have been recovered from settlements, palaces, temples, and funerary contexts across the Ancient World. In many cases, these remains have been interpreted as by-products of skinning or hide preparation. Their meaning, however, depended on archaeological context. The lion remains from Ras Shamra and Ras Ibn Hani (important Bronze Age settlements on the Syrian coast) have been interpreted as hunting trophies, whereas finds from cultic contexts in the southern Levant, particularly Jaffa, have led scholars to suggest that lions also possessed ritual significance (Vila 2008). At Hattusha (the capital city of the Hittite empire), by contrast, lion remains appear to have functioned primarily as prestige objects.

Figure 2. Map illustrating the skeletal elements of a lion. In Bronze and Iron Age archaeological contexts, isolated cranial and distal limb elements are frequently interpreted as possible evidence for the deposition of a lion pelt, particularly when recovered without the remainder of the skeleton. (R. Davtyan)

The predominance of mandibles, teeth, and distal limb bones raises an intriguing question. Although differential preservation undoubtedly contributes to this pattern, especially because teeth are exceptionally resistant to decay, it cannot fully explain the archaeological evidence. Robust long bones, such as femora, should also survive well under similar conditions. It is therefore possible that particular skeletal elements were deliberately selected because they possessed symbolic, ritual, or practical significance. This might be the case at Lori Berd (a long-standing Bronze and Iron Age necropolis in northern Armenia), where excavations yielded a mandible of a three- to four-year-old female lion together with an



Figure 3. Photograph of the lower mandible of a female lion recovered from a niche in Tomb 56 at Lori Berd (northern Armenia), dated to the seventh–sixth centuries BCE. (R. Davtyan)

incisor from a second, younger individual (Figure 3). While these isolated cranial remains could be consistent with the deposition of lion pelts, such interpretation remains tentative. In particular, the younger lion is less likely to have been represented by a curated pelt, as its smaller size would have made its skin considerably less valuable as a prestige object.

In this sense, it is worth mentioning that throughout the Ancient Eastern Mediterranean, human skulls and mandibles often received special ritual treatment. Whether similar practices extended to lions remains uncertain. Nevertheless, the archaeological contexts of lion mandibles from sites such as Tel Dan and Jaffa suggest that these elements occasionally carried meanings beyond their anatomical function (Borowski 1998). Rather than proposing a distinct "lion skull cult," it seems more appropriate to suggest that selected parts of lion skeletons could have participated in ritual practices comparable to those known for human remains.

At present, however, the distal limb bones provide the strongest evidence for the use of lion skins as ceremonial rugs or prestigious pelts. It is equally plausible that the skull or mandible sometimes remained attached to the hide, increasing its visual impact. Iconographic evidence clearly demonstrates that lion skins were nevertheless used throughout the Bronze and Iron Ages in Egypt and the ancient Near East. One of the best-known examples is the lion- and leopard-skin garment depicted in Egyptian iconography from around 3000 BCE onwards (Williams 1997: 483).

TURNING THE TABLE BETWEEN PREDATORS AND PREY

The available evidence demonstrates that the value of a lion did not end with its death. On the contrary, the carcass was transformed into a variety of culturally meaningful objects, such as pelts, which became symbols of prestige and authority

Among non-human animals, the lion was more frequently subjected to these processes than most other species. As the most formidable predator of the ancient landscape, it occupied the highest position in the hierarchy of wild animals. Ironically, it was precisely this elevated status that made it the preferred quarry of kings and princes. The greater the symbolic value of the animal, the greater the prestige attached to killing it. Royal lion hunts were therefore



Main takeaway

- As with human–animal relationships more generally, lion hunting cannot be understood solely through the lens of subsistence. Rather, it was a complex and multifaceted practice that extended beyond economic necessity or the acquisition of pelts. While lion skins, claws, and teeth were clearly valued, the archaeological contexts suggest that the act of killing, displaying, or possessing a lion carried deeper political and symbolic meanings. Hunting lions legitimised elite masculinity, kingship, military strength, and ritual authority.
- After lions' hunt, their bodies were transformed into a lasting material expression of power and thus lions acquired a second cultural life after death, a transformation of this very feared predator into a prestigious political resource, which humans appeared to be more interested in.

not simply demonstrations of physical courage but carefully staged performances of political authority, immortalised in reliefs, murals, and monumental sculpture.

Through the selection, modification, and display of its remains, the lion was transformed into a lasting material expression of power. Its body embodied qualities that rulers wished to appropriate-strength, courage, sovereignty, and dominion over the forces of nature. In this sense, the lion (definitely against its own will) acquired a second cultural life after death

Seen from a broader anthropological perspective, this process also reveals a paradox. Lions were driven to extinction across much of their ancient range not because people depended on them for food or raw materials, but because they had become powerful political and ideological symbols. Perhaps the greatest irony is that the lion outlived its physical presence through its symbolism. Lions continue to appear on royal insignia, coats of arms, national emblems, and civic heraldry across the world, while their biological presence has almost faded.

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4.3 South America



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This chapter explores the deep and diverse relationships between people, biodiversity, and landscapes across South America, from more than 12,000 years of Indigenous stewardship in the Cerrado and Amazonia to contemporary challenges of invasive species and marine conservation in the Caribbean. The contributions reveal how Indigenous management, cultivation, fire use, and landscape practices have shaped and maintained biodiversity over millennia, while also examining the consequences of colonialism, agricultural expansion, dam construction, and other forms of environmental change. Together, these perspectives demonstrate the importance of combining archaeological, ecological, and Indigenous knowledge with the experiences and priorities of local communities when addressing biodiversity conservation in a transformed world.

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Conserving the Cerrado Means Preserving More Than 13,000 Years of Historical Ecology

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The Cerrado is a biome that has been inhabited by humans for more than 12,000 years, during which its landscape has been transformed by their cultural practices for millennia through processes of environmental management, plant use and domestication (Ferreira et al., 2022). These long-term interactions have contributed to shaping the biodiversity of present-day Cerrado landscapes, and archaeology and historical ecology provide important evidence for understanding these processes over time. Historical ecology recognises these cultural dynamics as integral components of the biome itself (Clement et al., 2021). The Cerrado is one of the world's most important biodiversity hotspots and one of its most threatened biomes, where rates of native vegetation loss have exceeded those of the Amazon over the last three years (Klink & Machado, 2005; MapBiomas Alerta, 2026). Its degradation threatens not only biodiversity but also archaeological sites and remains as well as botanical evidence of long-term biome management practices carried out by ancestral Indigenous communities.

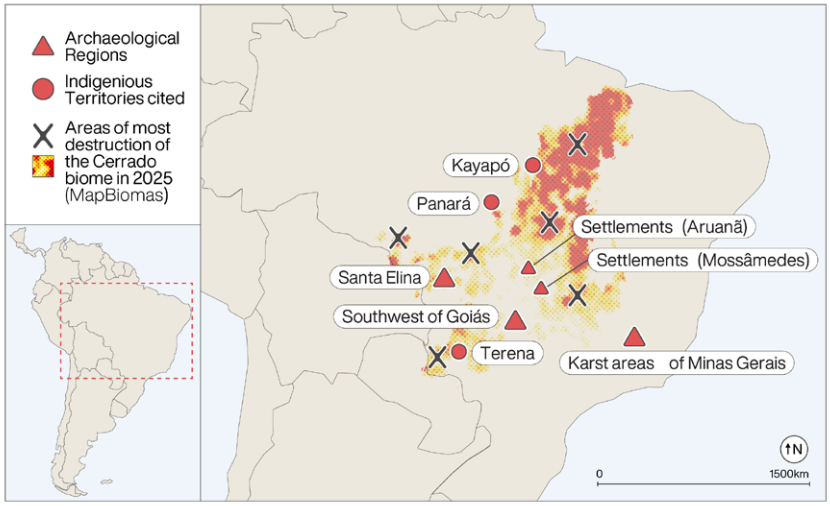


Figure 1. Archaeological sites, Indigenous territories, and areas of Cerrado degradation discussed in the text. The map shows the archaeological regions and Indigenous territories cited in this article in relation to the areas of greatest native vegetation loss in the Cerrado biome in 2025. Deforestation data are based on MapBiomas Alerta (2026).

The Cerrado covers approximately 25% of Brazil's territory and extends into Bolivia and Paraguay. Its vegetation formations are adapted to fire and seasonality and possess deep root systems that help sustain aquifers and major river basins, playing an important role in the continent's climate regulation (Strassburg et al., 2017) (Figure 1).

Although earlier regional occupations like the Santa Elina rock shelter have been documented, human presence became widespread across Central Brazil from approximately 13,000 years

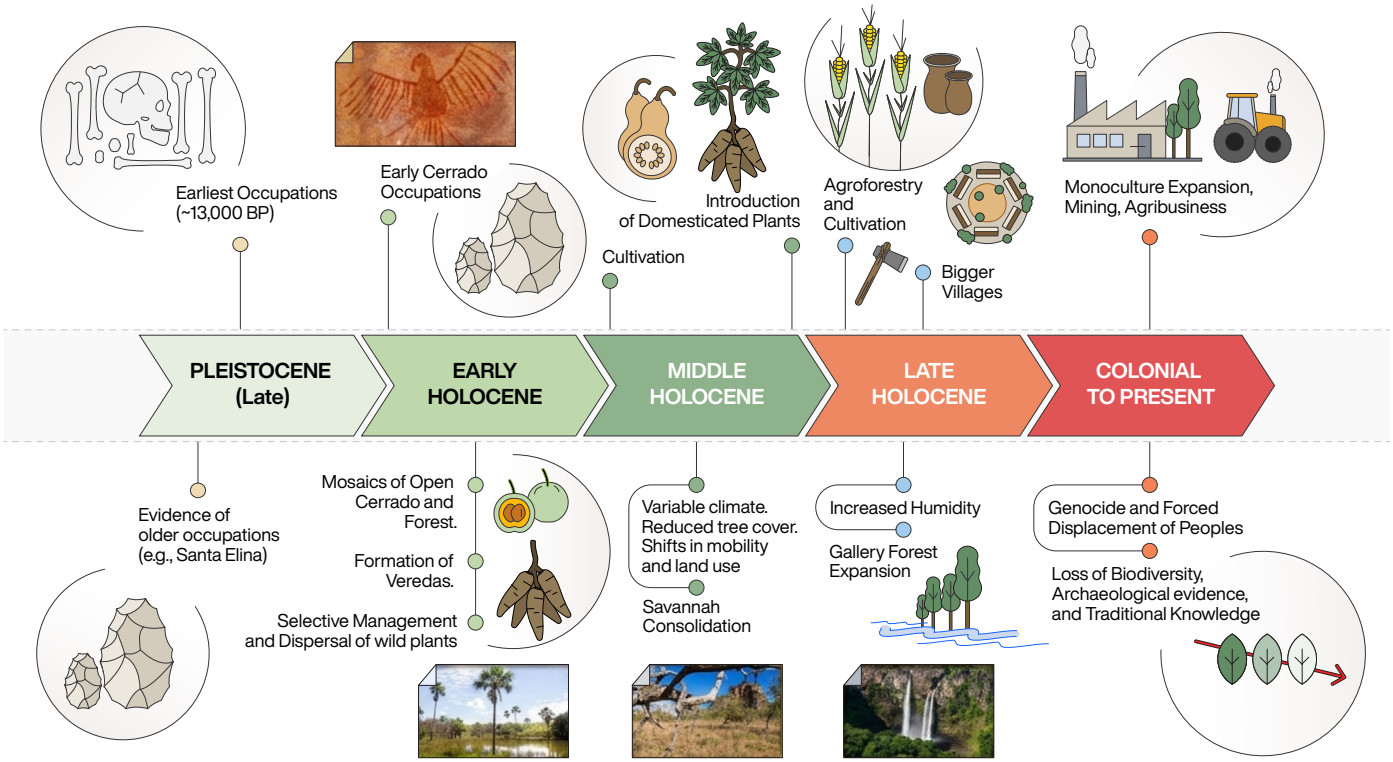
ago onwards, with evidence from southwestern Goiás and the karst areas of Minas Gerais, notably Lagoa Santa and the Peruaçu Valley (Schmitz et al., 2004; Viana et al., 2016; Isnardis et al., 2019; Strauss et al., 2020).

During the Early Holocene (12,000–8,000 BP), the climate was warmer and wetter, with mosaics of open Cerrado and forests, the formation of lakes and buriti palm swamps (*Mauritia flexuosa*), and greater biodiversity (Ledru et al., 1998; Hubbe et al., 2013). Early human inhabitants managed a range of wild resources, including pequi (*Caryocar brasiliense*), jatobá (*Hymenaea spp.*), and other palms, as well as yams (*Dioscorea spp.*), cassavas (*Manihot spp.*), arrowroot (*Maranta arundinacea*), and peppers (*Capsicum spp.*) (Resende & Prous, 1991; Clement et al., 2021; Scheel-Ybert & Bachelet, 2020; Angeles Flores, 2021; Ortega, 2025), likely through practices such as selective gathering, seed dispersal, vegetative propagation or transplantation of viable plants around occupied areas and settlements.

During the Middle Holocene (8,000–4,000 BP), greater climatic variability and a reduction in tree cover favoured the consolidation of the savanna formations typical of the present-day Cerrado (Ledru et al., 1998; Barberi, 2001). Human populations responded to these environmental changes by altering patterns in mobility, territorial occupation, and landscape use practices (Araujo et al., 2025). They continued to use native species and began to occupy areas more suitable for cultivation (Wüst, 1990; Ortega et al., 2023). Domesticated plants from the Amazon also arrived at the end of this period and in the Late Holocene, initially cassava (*Manihot sp.*), bottle gourd (*Lagenaria sp.*), and lima bean (*Phaseolus lunatus*) (Shock et al., 2023).

During the Late Holocene (4,000 BP–present), increased humidity favored the expansion of gallery forests and semideciduous forests (Ledru et al., 1998). Villages grew larger in size, pottery production expanded and systems of agroforestry became increasingly important alongside the cultivation of maize (*Zea mays*), cassava, peanut (*Arachis hypogaea*), common

Figure 2: Long-term human-environment interactions and landscape transformations in the Cerrado. Timeline summarizing and generalizing major archaeological, environmental, and plant-management developments discussed in the text, from the earliest human occupations to the present.



bean (*Phaseolus vulgaris*), squash (*Cucurbita spp.*), and sweet potato (*Ipomoea batatas*), while the use of native Cerrado resources remained important (Bird et al., 1991; Robrahn-González, 1996; Freitas, 2003; Shock et al., 2013; Gardiman et al., 2014; Gardiman et al., 2016; Cassino et al., 2021; Costa et al., 2024; Ortega, 2025) (Figure 2).

Cerrado management included the recurrent use of fire, the selection of useful species, soil modification, and vegetation enrichment (Ferreira et al., 2022). Species such as *Caryocar brasiliense* (pequi), *Mauritia flexuosa* (buriti), and *Himatanthus drasticus* (janaguba) provide evidence of long-term management and domestication processes carried out by Indigenous peoples in this biome (Ferreira et al., 2022; Baldauf & Santos, 2013; Smith & Fausto, 2016; Clement et al., 2021).

From the colonial period onwards, the invasion of Indigenous territories in Central Brazil was marked by violence and episodes of genocide, dispossession of Indigenous lands and forced displacement. These crimes continue today as agricultural frontiers increasingly advance into territories traditionally occupied by Indigenous peoples. At the gateways to the Brazilian Central Plateau, the Paiaguá, Guaicurú, and Southern Kayapó were the Indigenous groups that most strongly resisted attacks by invaders on their territories (Palacín & Moraes, 1994; Kopenawa & Albert, 2015). Extractive activities, mining, and the expansion of agribusiness intensified the conversion of native vegetation into soybean and maize monocultures and pasturelands (Krenak, 2022). These changes have driven ecological simplification, biodiversity loss (Colli et al., 2020), and the destruction of archaeological sites and vegetation managed by Indigenous peoples. In response to these pressures, the Brazilian government has implemented conservation initiatives such as the PPCerrado, whose current phase (2023–2027) aims to reduce deforestation and fires while promoting sustainable development in the Cerrado (MMA, 2023).

Integrating archaeology, paleoecology, and Indigenous knowledge systems is essential for understanding the long-term socioecological histories of the Cerrado and for informing future conservation policies.

At the same time, Indigenous territories play a critical role for environmental conservation and the promotion of biodiversity throughout South America. For example, among the Terena, agroforestry systems and restoration practices combine native species and food crops, promoting ecosystem regeneration, food security, and cultural continuity (Novais, 2013). These practices express forms of knowledge integrated with ecological dynamics. It was through their interaction with the environment, and the way they adapted their economy and way of life to the natural flood cycles of the Pantanal–Cerrado transition zone, that the Terena developed a balanced socioecological relationship with this landscape. In recent years, this balance has been affected by deforestation, illegal fishing, soybean monoculture, and unsustainable tourism (Novais, 2013).

Similarly, the Kayapó (Mebêngôkre and Panará), who belong to the Macro-Jê language family, have developed complex landscape management systems for both the Cerrado and the Amazon. These systems include forest islands, the controlled use of fire, hunting, the enrichment of useful species, and the spatial organization of cultivated areas and forests (Anderson et al., 1985). The importance of Indigenous knowledge and practices for biodiversity conservation was further reinforced at COP16 through Decisions 16/4 and 16/5,

which strengthened the role and participation of Indigenous peoples and local communities in implementing the Convention on Biological Diversity (CBD, 2024a, 2024b).

When the vegetation surrounding archaeological sites has been extensively altered (Rubin et al., 2022), it becomes more difficult to identify cultural modifications made by Indigenous peoples. This substantially limits historical ecology research in the Cerrado, which integrates multiple lines of evidence such as phytoliths, starch grains, geochemical analyses, charcoal and other botanical macro remains, and floristic studies. Therefore, conserving both the Cerrado and the ecotones surrounding archaeological sites becomes essential, as these areas preserve evidence of long-term human-environment interactions (Shock, 2021). Conserving the Cerrado also means preserving its history as recorded in archaeological sites, which should also be understood as broader areas that include the surroundings of past settlements.

The continuity of traditional Cerrado management practices demonstrates that biodiversity, landscape, and traditional knowledge are inseparable (see Levis et al., 2024; Cassino et al., 2025). Archaeology and historical ecology provide a long-term record of the human-environment interactions that contributed to shaping present-day Cerrado biodiversity, while contemporary Indigenous knowledge and practices reflect, in many ways, the persistence and transformation of long-term relationships between people and these landscapes. The destruction of the Cerrado results in the simultaneous loss of ecological, historical, and archaeological heritage. Conserving the biome requires integrating biodiversity, archaeological evidence, and Indigenous territorial rights (Colli et al., 2020; Krenak, 2022). Integrating archaeology, paleoecology, and Indigenous knowledge systems is essential for understanding the long-term socioecological histories of the Cerrado and for informing future conservation policies.



Key Insights

- Conserving the Cerrado requires recognising that its extraordinary modern biodiversity is inseparable from more than 12,000 years of interactions between early human societies and ecological landscapes.
- Protecting the biome therefore requires conserving not only its ecosystem, but also its archaeological heritage guarded by Indigenous territories and the knowledge systems that have shaped it and continue to sustain its ecological resilience.

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Multicultural Landscapes and Ecological Legacies: 9,000 Years of Indigenous Forest Stewardship in Southwestern Amazonia

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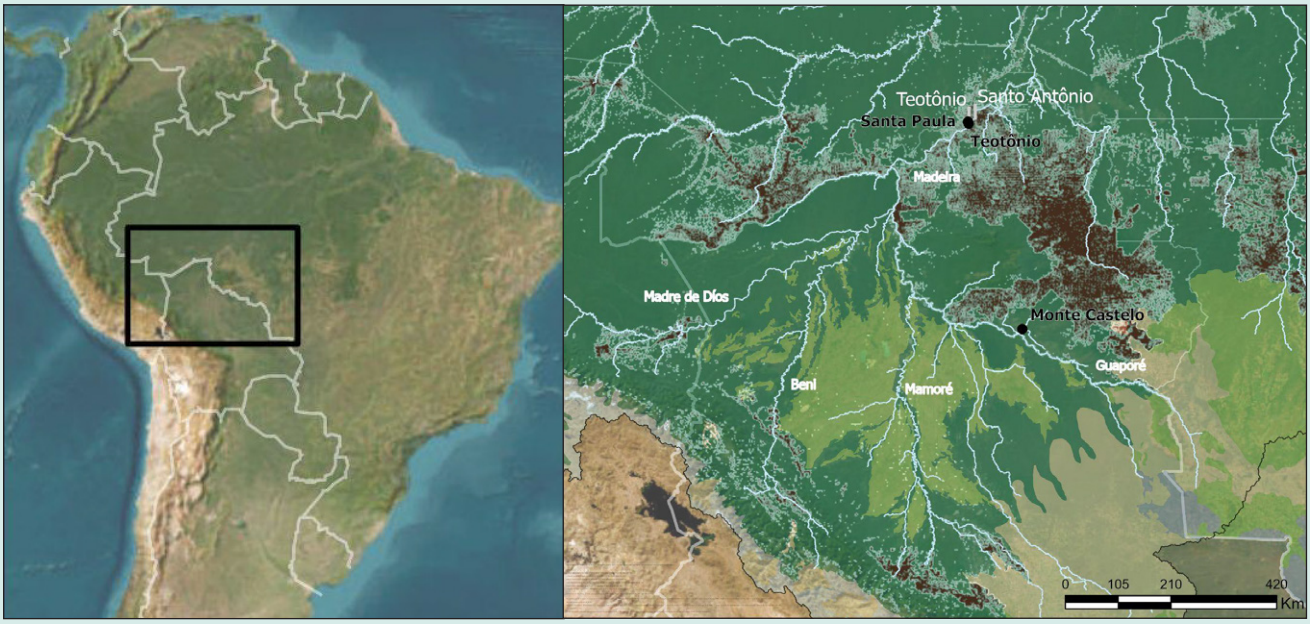


Figure 1: The ancient anthropogenic forests of the southwestern Amazon

The history of the Amazonian Forest is deeply connected with the human populations that have inhabited its territories since at least the Late Pleistocene (ca. 13,000 BP). For decades, tropical forests were often portrayed as pristine environments, where biodiversity levels and species conservation are more successful in the absence of human populations. However, the historical trajectories of the forest and Indigenous peoples-their transformations, contradictions, and futures-are fundamentally inseparable. In Amazonian studies, a growing body of evidence indicates that the forest's ecological richness is, to a large extent, a legacy

of Indigenous land management and cultivation practices developed over millennia (Erikson, 2008; Clement et al., 2015; Fausto & Neves, 2018).

These legacies are particularly visible in the forest's plant composition. For instance, among the hyperdominant tree species identified in Amazonia, many are useful to human communities as sources of food and raw materials (Levis et al., 2017; Ter-Steege et al., 2013). This reflects long-term processes of plant selection by human communities, which culminated in the emergence of independent centers of domestication across Central and South America (Piperno, 2011). Some crops still important today were selected and domesticated within these contexts (Clement et al., 2011). Evidence of plant management and selection has been identified at Pedra Pintada Cave (Pará, Brazil), dated to ca. 13,500–7,000 BP. These remains include palm species such as bacaba (*Oenocarpus sp.*), tucumã (*Astrocaryum sp.*), and moriche palm (*Mauritia flexuosa*), as well as Brazil nut (*Bertholletia excelsa*) (Shock & Moraes, 2019). At Cerro Montoya 1, in the Guaviare region of Colombia, occupations dated between approximately 12,600-400 cal BP reveal the continuous presence of palm remains, including the Syagrus orinocensis and Attalea maripa, throughout the Holocene (Morcote-Ríos et al., 2026). These species continue to be actively managed by Amazonian communities today.



Figure 2: Teotônio Waterfall (Porto Velho, Rondônia, Brazil) before the construction of hydroelectric dams. Photograph by Luiz Claudio Marigo, n.d.

In recent years, the past and present of the Amazon Forest, as well as its deep connection with Indigenous history since before the European Conquest, have been explored through multidisciplinary approaches. Based on a wide range of materials, including archaeological evidence, historical sources, paleoecological data, ethnographic records, and oral narratives, researchers have focused on understanding the multifaceted relationships between Indigenous territories, the maintenance of forest cover, and the enhancement of biodiversity. In this context, Southwestern Amazonia (SWA) has emerged as a key region for such studies. Its deep archaeological record, particularly in the Upper Madeira and Middle Guaporé basins (Rondônia, Brazil), together with the cultural diversity that remains visible in the region today, provides a fruitful framework for analyzing historical variability and long-term relationships between Indigenous communities and ecological dynamics.

The Upper Madeira River is formed by the confluence of the Beni and Mamoré rivers along the Bolivia–Brazil border. This region encompasses the Santo Antônio and Teotônio rapids, an area identified by archaeological research as an important center of human occupation throughout the Holocene, where successive Indigenous communities developed enduring relationships with local environments. The construction of the Santo Antônio and Jirau hydroelectric dams in the 2010s resulted in the permanent inundation of the waterfall and rapids, which are no longer visible today. During the Early and Middle Holocene, climatic changes resulted in drier conditions that favored the expansion of savanna vegetation across the region (Mayle et al., 2006). In the Late Holocene, in turn, increasing humidity promoted forest expansion, giving rise to a landscape more similar to that observed today (Mayle, 2004).

Evidence of long-term human–environment relationships, including indicators of plant management and domestication, has been identified in the archaeological record at sites in the Upper Madeira and Middle Guaporé Basin (Hilbert et al., 2017; Watling et al., 2018, 2020; Furquim et al., 2021). These findings include evidence for the consumption of ariá (Calathea sp.) and guava (*Psidium sp.*) going back to 9,000 cal BP- one of the earliest records of guava use in South America. Archaeological, historical, and genetic evidence suggests that the process of guava selection and domestication may have originated in southwestern Amazonia (Arévalo-Marín et al., 2021, 2024). In this context, the pre-Columbian occupations of this region may have played a role in the management and dispersals of the species. From SWA, guava is thought to have spread through the Andean corridors, reaching northern South America and, subsequently, Mesoamerica. These findings, along with the oldest Amazonian Dark Earth (ADE) deposits identified in the region, support the hypothesis that SWA constitutes one of the earliest and most important centers of early food production in South America, although cultivation practices did not necessarily culminate in irreversible processes of domestication or the loss of plant diversity (Neves, 2016). In fact, the formation of ADE deposits, which enhanced soil fertility, together with the expansion of intercultural networks likely facilitated the cultivation of plant species not native to the region, including common bean (*Phaseolus sp.*) and squash (*Cucurbita sp.*) (Watling et al., 2018).

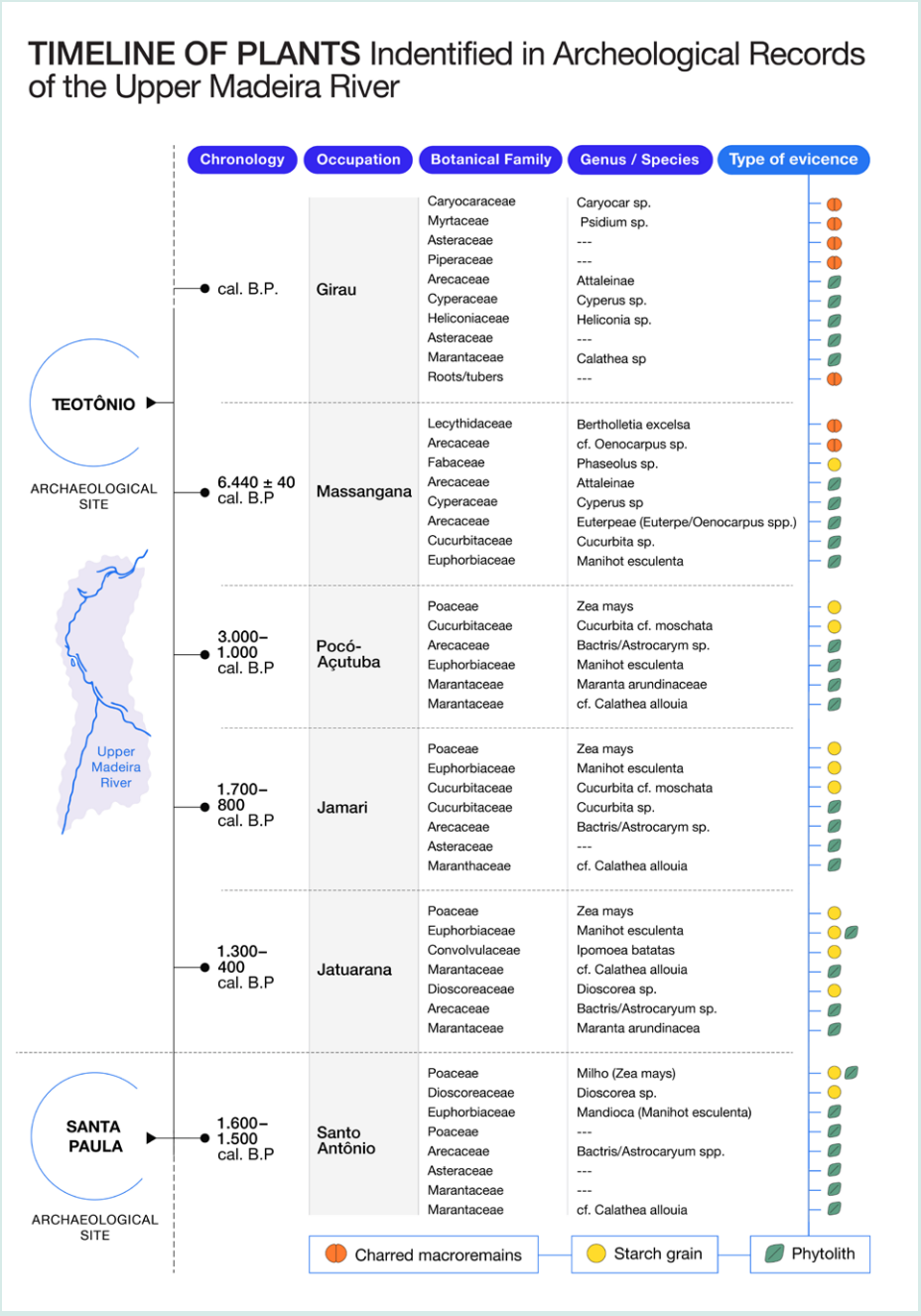


Figure 3: Archaeological plants from the Upper Madeira Basin and Indigenous occupations at the Teotônio and Santa Paula sites (9,400-400 cal. BP). Produced based on Watling et al (2018) and Watling et al. (2020).

In addition, the archaeological record reveals a high degree of cultural diversity reflected in the stratigraphic sequences of sites located along the Upper Madeira River. Different ceramic traditions associated with Arawak-, Tupi- and Pano-speaking populations suggest the coexistence and/or succession of multiple cultural occupations (Zuse, 2014; Kater, 2018;

Costa, 2023; Pessoa, 2015). Archaeobotanical evidence further indicates differences in spatial organization and settlement and food production patterns among these populations. The producers of Pocó-Açutuba ceramics, whose cultural affiliation might be linked partially to the Arawak linguistic family (Kater et al., 2026), show evidence of maize and squash consumption (Watling et al., 2020). In contrast, Tupi-associated occupations, represented by the Jamari and Jatuarana ceramic traditions, appear to have relied on a more diverse range of cultivated plants, including manioc, maize, squash, and ariá. Maize becomes markedly more abundant in the Jamari tradition, whereas it declines in the subsequent Jatuarana tradition. Palms, meanwhile, are consistently represented throughout the archaeobotanical record, indicating their continuous use since the beginning of the Holocene (Watling et al., 2018).

Together, the integration of these archaeobotanical data suggests the initial exploitation of palms, fruit trees and tuberous roots whose management may have contributed to the development of anthropogenic landscapes prior to the gradual incorporation of domesticated plants. Throughout the chronological sequence, the archaeobotanical record reveals a gradual increase in the diversity of cultivated species, while the continued use of palms and other economically important arboreal species is maintained. This pattern points to changes in the composition of plant assemblages used through time, suggesting that cultivation practices and the management of perennial species coexisted in different configurations across occupations. Together, these strategies are consistent with diversified and resilient agroforestry systems, as proposed in models of Indigenous landscape management in Amazonia (Anderson & Posey, 1985; Balée & Gely, 1989).

INDIGENOUS LEGACIES IN AMAZONIAN LANDSCAPES

In the forests of the Southwestern Amazon, the legacies of past Indigenous lifeways, as evidenced by archaeobotanical records, intertwine with the contemporary dynamics of Indigenous territories to shape the landscape's cultural and historical contours. Thus, this region's landscapes can be understood as a biocultural mosaic, continuously formed through successive generations of human occupation and environmental engagement (Kater et al., 2020; Mongeló, 2020; Zuse et al., 2020; Neves et al., 2020; Watling et al., 2018, 2020). During the first centuries of colonization, violence, epidemics, and the subjugation of Indigenous populations caused a drastic demographic decline, resulting in the loss of diversity of managed plants and partial reversion of anthropogenic forests to unmanaged forest conditions (Clement, 1999). Nevertheless, contemporary Indigenous peoples have demonstrated resilience in the face of climate crises and recent conflicts associated with environmentally destructive activities, such as gold mining, hydroelectric dam construction, and deforestation linked to monoculture expansion.

It is therefore crucial that Amazonian history, as well as public policies for forest conservation and the protection of Indigenous territories, be developed in ways that take into account the complex web of relationships between Indigenous peoples and their environments. Over millennia, Indigenous agency has been central to the maintenance and reinvention of management practices that have contributed to the conservation and enrichment of Amazonian forest landscapes (Levis et al., 2018; Balée et al., 2020; Watling et al., 2024). Recognizing these ecological legacies not only expands our understanding of Amazonia's past but also highlights possible ways to value Indigenous environmental knowledge and the biocultural heritage that these peoples have shaped over time.

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The Hippopotamus Invasion of Amphibious Communities in the Middle Magdalena Region of Colombia

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In the Global South, the Anthropocene is manifested through complex socioecological histories where human intervention has reconfigured ecosystems. In Colombia, one of the most profound, striking, and paradoxical examples of biodiversity change is the biological invasion of the common hippopotamus (*Hippopotamus amphibius*). Illegally introduced in the 1980s as part of the private zoo of drug trafficker Pablo Escobar at Hacienda Nápoles, these African megaherbivores grew from a founder population of just four individuals into a wild population estimated at 181 specimens by December 2022 (Minambiente et al., 2022). (Figure 1).

Far from the seasonal droughts and natural predators of their native African habitats, these hippos encountered ideal ecological conditions within the Magdalena River basin, characterized by a constant abundance of water and forage. These favorable conditions have facilitated early maturation and low mortality rates. Consequently, population models project that the wild population could exceed 434 individuals by 2030 in Colombia if effective management measures are not implemented (Minambiente et al., 2022).

Colombia's public policy instruments, such as the National Policy for the Integral Management of Biodiversity and its Ecosystem Services (PNGIBSE) and the National Plan for the Prevention and Management of Introduced, Transplanted, and Invasive Species (Minambiente, 2011), designate biological invasions as the second leading global driver of

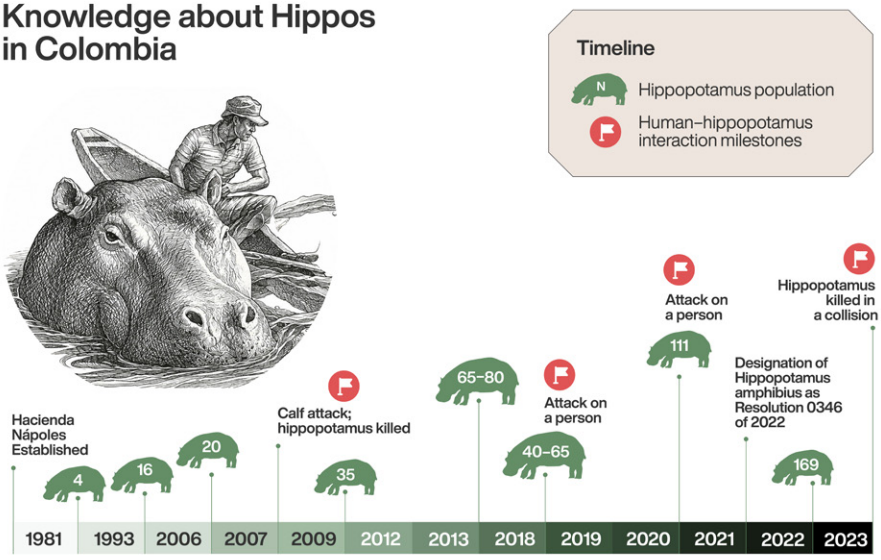
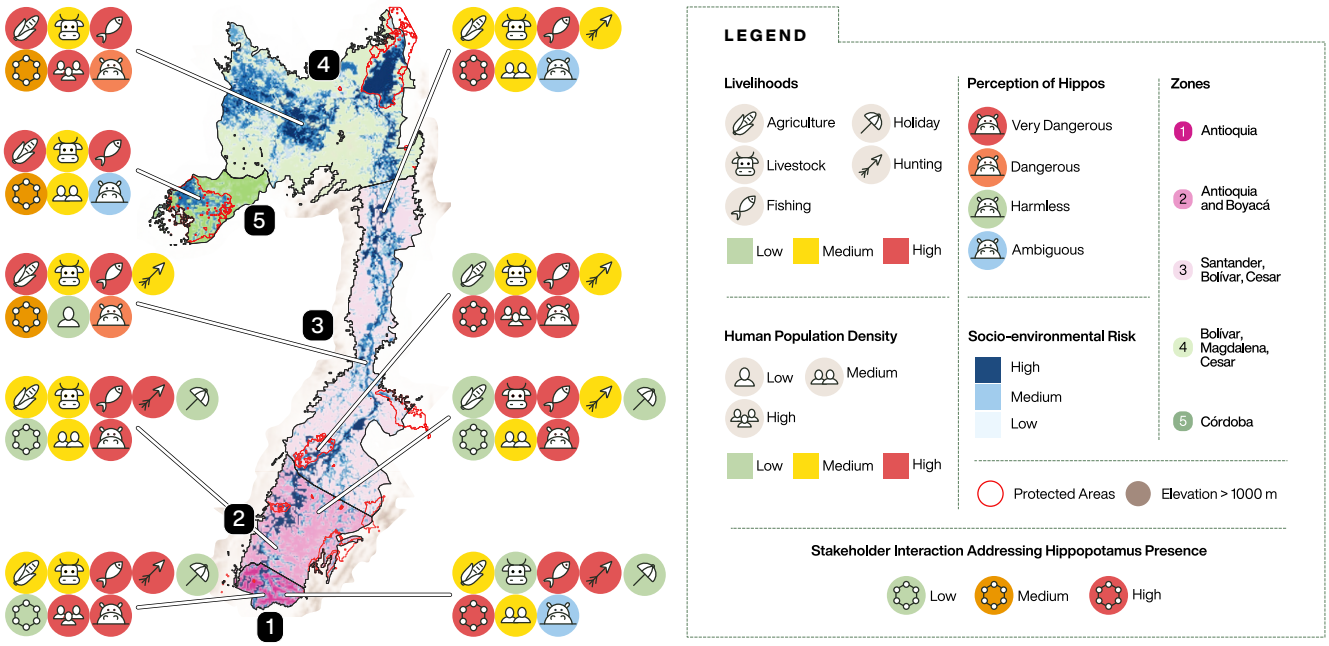


Figure 1: Timeline of the population dynamics of hippos in Colombia, 1981-2023 - Moreno et al 2019 and Alexander von Humboldt Institute (2022).

Social and environmental risk map regarding hippopotamus presence within their suitable distribution range (Middle Magdalena River Valley and Momposina Depression)



biodiversity loss. Globally, the 2019 Global Assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) ranks invasive alien species as one of the five primary direct drivers of global biodiversity loss, with impacts comparable to those of climate change. Furthermore, Target 6 of the Convention on Biological Diversity (CBD) global biodiversity framework calls for the reduction of biological invasions and their associated impacts (SCBD, n.d.).

Figure 2: Map of social and environmental risk due to the presence of the hippopotamus in a suitable distribution area. Humboldt Institute, 2022.

ECOSYSTEM ENGINEERS AND THE PROFOUND ALTERATION OF BIODIVERSITY

The hippopotamus acts as an 'ecosystem engineer' capable of altering the physical and biological environment across multiple scales. The hippopotamus acts as an 'ecosystem engineer' capable of altering the physical and biological environment on multiple scales. Given their immense size, up to 3 metric tons, and their movement patterns, these animals carve alternative channels that can modify natural hydrological dynamics, accelerate riverbank erosion, and cause severe soil compaction and denudation in tropical humid forests.

Beyond physical disturbances, their presence may have broader implications for ecosystem functioning. Hippos graze on terrestrial vegetation (grasses; consuming up to 50 kg per day) and defecate in aquatic systems. This substantial transfer of nutrients (e.g., carbon, organic matter, ammonia) can increase nutrient loading, promoting eutrophication of lentic water bodies and lead to anoxic conditions disrupting phytoplankton communities and reducing native fish and macroinvertebrate populations. Additionally, their highly territorial behavior can lead to competitive exclusion (via both interference and exploitation competition) of native species of immense ecological value, such as the Caribbean manatee *(Trichechus manatus*), the neotropical river otter (*Lontra longicaudis*), and the capybara (*Hydrochoerus isthmius*).

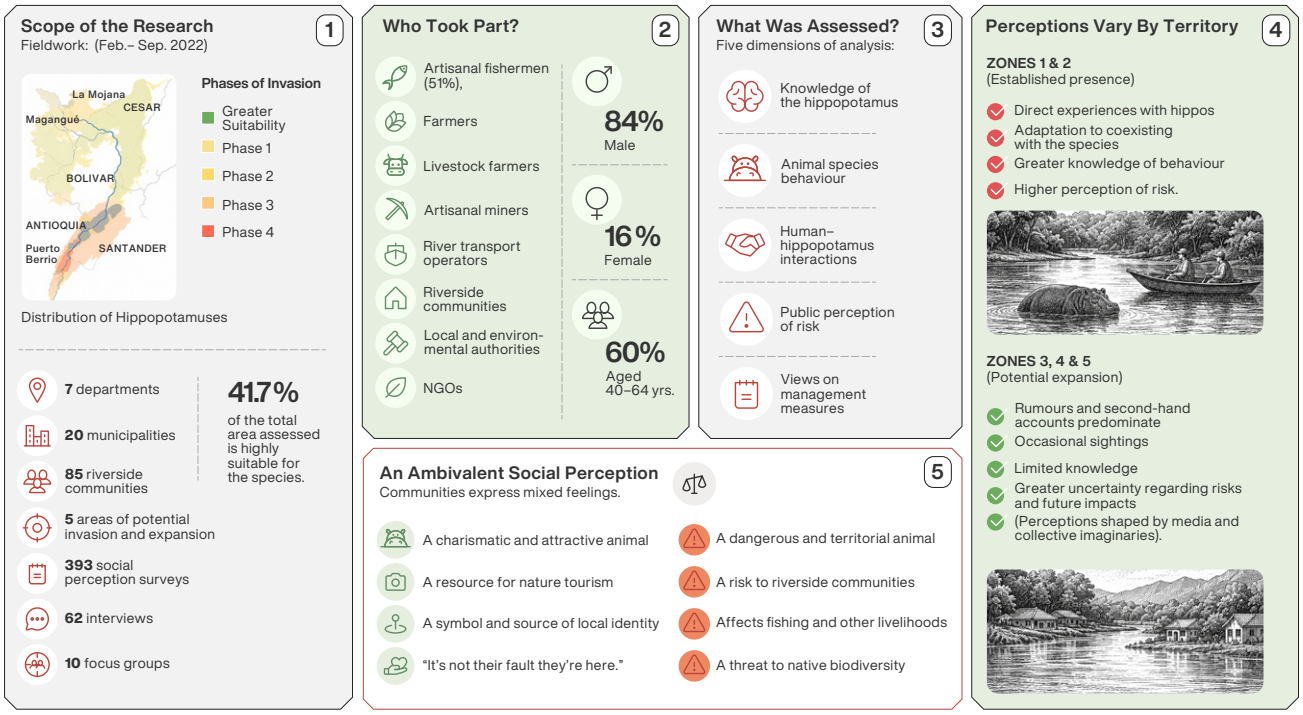


Figure 3: Social perceptions of hippos and management measures. Humboldt Institute (2022).

THE CLASH WITH AMPHIBIOUS COMMUNITIES

The impact of these hippopotamuses transcends purely ecological dimensions, disrupting deep socioecological dynamics in the Middle Magdalena region, which is home to rural campesino (peasant) and local fishing communities with deep-rooted riparian and 'amphibious' livelihoods. Among the local residents surveyed during the social perception component of the research, more than 50% identify as artisanal fishermen who supplement their income with the extraction of riverbed materials (gravel and sand quarrying). For these communities, the presence of hippopotamuses has become a direct threat to food security, local livelihoods, and physical safety (Figure 2).

Fishermen report violent encounters involving chases, attacks on watercraft, and significant damage to fishing gear inflicted by highly territorial individuals. By 2022, at least 17 high-risk interactions between hippopotamuses and local residents had been officially recorded (Minambiente et al., 2022). Consequently, entire communities have altered their daily routines, actively avoiding hippo-frequented zones after five in the afternoon to minimize the risk of encounters with individuals navigating rural paths, pastures, and even public streets in urban centers such as Doradal.

A DIVIDED PERCEPTION: BETWEEN FASCINATION AND RISK

The narrative surrounding this invasion is characterised by a complex web of social perceptions. Despite documented risks, including attacks on humans and livestock, as well as widespread fear regarding their presence, the species continues to enjoy considerable public sympathy in certain regions of Colombia.

In municipalities such as Puerto Triunfo, the hippopotamus has been adopted as a symbol of local identity and a cornerstone of the local tourism industry. Hippo-spotting safaris, alongside themed sculptures and souvenirs, contrast with social resistance to their rejection, given that they are a charismatic species, while in other areas there is a latent fear of the negative impacts on

livelihoods, physical safety and the quality of the ecosystem (Figure 2). This socioecological and emotional bond fosters public resistance to lethal control measures, driving a preference for non-lethal population control methods such as sterilization and national or international translocation (Figure 3). However, these non-lethal alternatives are largely ineffective for controlling the invasion scale and mitigating its environmental impacts. This situation raises profound ethical dilemmas regarding coexistence and territorial rights, encapsulated by a poignant question raised by the community: "Both the animal and we live in the water. So, who has the greater right to it?"

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Key Insights: Conservation Challenges in a Transformed World

- While declaring the hippopotamus an invasive alien species (Resolution 0346 of 2022) was a policy milestone, managing this biological invasion must transcend species control. Effectively addressing invasive alien species as a key driver of biodiversity loss requires a biocultural framework that integrates scientific evidence with the social perceptions, practices, and relationships built by local communities. This approach provides a comprehensive understanding of local realities, identifying factors that facilitate or limit management actions.
- In the Middle Magdalena, restoring socioecological balance entails controlling hippopotamus populations, protecting native species, and safeguarding the rights, safety, and traditions of amphibious communities.
- Future conservation strategies must synthesize ecological and demographic data with inclusive community participation, transforming public curiosity about an invasive species into a collective responsibility for ecosystem resilience and native biodiversity conservation.

Shark Biodiversity of the Southern Caribbean: Threats and Future Perspectives

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Sharks, together with rays, belong taxonomically to the subclass Elasmobranchii, a group commonly referred to as cartilaginous fishes (Figure 1). They differ from bony fishes primarily by having a cartilaginous skeleton, skin covered with placoid scales, multiple pairs of exposed gill slits, internal fertilization, and paired male reproductive organs known as claspers (Compagno et al., 2005). Sharks are a diverse and highly adaptable group of fishes that inhabit a wide range of aquatic environments, including the open ocean, coastal waters, deep-sea habitats, bays, coral reefs, lagoons, estuaries, trenches, and even freshwater systems such as rivers and lakes. Furthermore, sharks play an important role in marine ecosystems because many species function as apex predators that regulate prey populations and maintain trophic balance. At the same time, these groups of fishes also have considerable economic value in fisheries and provide a variety of products, including meat for human consumption, liver oil, leather derived from their skin, and, most importantly, fins, which are highly valued in Asian markets. Increasing fishing pressure has been one of the major threats disrupting the ecological balance and population health of sharks. Today, several shark populations worldwide have declined in abundance by 60-90%, and assessments conducted by the IUCN Red List of Threatened Species indicate that 38% of the approximately 546 shark species currently recognised globally are classified as threatened with extinction (IUCN, 2026).

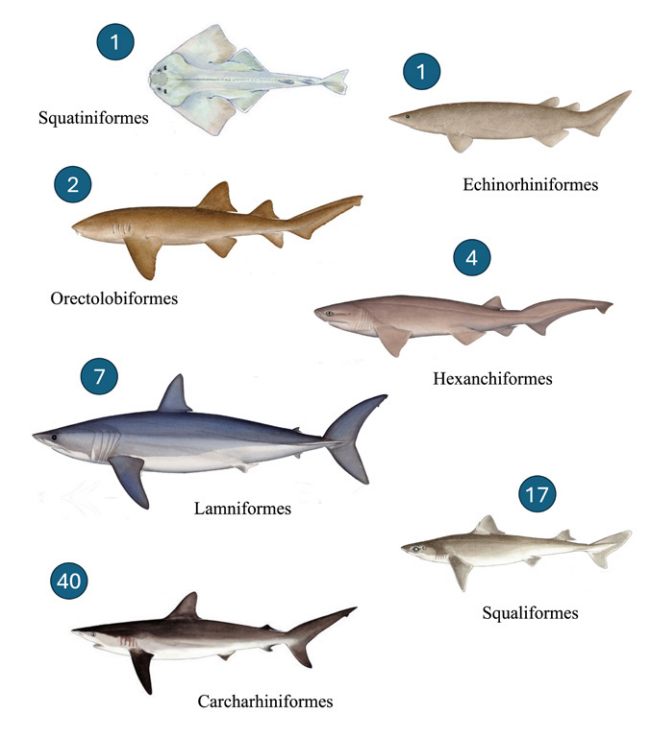


Figure 1. Number of shark species (indicated within the circles) by order recorded in the Southern Caribbean. Shark illustrations represent a member of each order.

The Greater Caribbean, defined herein as comprising four main subregions (Table 1), represents a major biodiversity hotspot within the Tropical Western Atlantic. It consists of a mosaic of complex marine ecosystems that provide essential habitat for a wide variety of marine organisms, supporting feeding, reproduction, ontogenetic development, and migration. The Gulf of Mexico is excluded from the definition of the Greater Caribbean because it is not strictly part of the Caribbean region and exhibits ecological characteristics that differ from those of Caribbean marine environments. Furthermore, despite the geographic proximity of these areas, oceanographic barriers (e.g., the Florida Current-

Greater Caribbean/Subregion	Territories	Number of Species	Source
Southern Caribbean	Colombia, Venezuela, and Trinidad & Tobago. Also includes the Dutch islands of Aruba, Curacao and Bonaire	72	Mejía-Falla & Navia (2019); Tavares (2019)
Western Caribbean	Central America coast, from the eastern Yucatan Peninsula to Panama	50	Ebert *et al*. (2021)
Eastern Caribbean	Islands of the Lesser Antilles	42	Ebert *et al*. (2021); Beaufort (2025)
Northern Caribbean	Islands of the Greater Antilles and Bahamian platform (the Bahamas and Turks & Caicos)	51	Ebert *et al*. (2021)
Gulf of Mexico	Mexican and US territories	69	Ebert *et al*. (2021)

Table 1: Number of shark species recorded in the four subregions of the Greater Caribbean. The Gulf of Mexico is also included for comparative purposes.

Gulf Stream system) can restrict gene flow and dispersal, thereby influencing the spatial distribution and population structure of marine fauna, particularly small- to medium-sized coastal shark species exhibiting philopatric behaviour and limited dispersal capabilities.

The Southern Caribbean encompasses the northern coasts, jurisdictional territories, and associated islands of Colombia and Venezuela, as well as Trinidad and Tobago and the Dutch Caribbean islands of Aruba, Curaçao, and Bonaire. This subregion is strongly influenced by seasonal upwelling systems and the freshwater input of several major rivers, particularly the Magdalena, Orinoco, and Amazon rivers (Muller-Karger & Varela, 1990; Rueda-Roa et al., 2018; Alonso del Rosario et al., 2019), which contribute to high biological productivity and the abundance of marine resources. These processes also generate a mosaic of eutrophic, mesotrophic, and oligotrophic environments that shape the distribution and abundance of marine organisms, including sharks. This environmental heterogeneity likely contributes to the exceptionally high shark diversity documented in the Southern Caribbean, where 72 species have been recorded, the highest number among the subregions of the Greater Caribbean (Table 1). Despite the ecological importance of sharks in tropical marine ecosystems, nearly half of the shark species occurring in the Southern Caribbean have been assessed as threatened with extinction by the IUCN Red List (IUCN, 2026). Overfishing, often under inadequate or ineffective management, represents the principal threat to these species. However, the capture of large numbers of immature individuals, the degradation of essential habitats like nursery areas, and marine pollution have also significantly contributed to their decline.

Over the last two decades, numerous conservation and management measures have been implemented in the Southern Caribbean, as well as throughout the whole Caribbean region, to mitigate the threats facing shark populations. These measures include the establishment of marine protected areas, bans on shark fishing and shark finning (i.e., the removal of fins followed by the discard of the carcass at sea), the implementation of catch quotas, modifications to fishing gear and practices, and other fisheries management regulations. One of the management strategies increasingly applied in recent years is the protection of shark nursery areas because of their conservation value. Tropical shark nurseries are usually located in areas characterised by high marine biodiversity, such as coastal lagoons, bays, and coral reefs. In the context of shark conservation, the most important ecological function of these essential habitats, however, is to serve as recruitment grounds, producing new individuals

that contribute to replacing individuals removed from the adult population. A relevant case of this management measure is the Los Roques Archipelago in Venezuela, an insular platform recognised as a biodiversity hotspot, where shark fishing has been banned to protect shark nurseries and other essential habitats. Furthermore, educational and conservation programmes targeting students at different educational levels, as well as local communities and fishers, have been developed in coastal areas to promote public awareness and encourage community participation in shark conservation initiatives. A notable example is the whale shark conservation programme also developed in Venezuela by the Centre of Shark Research, which successfully brought together fishers, students, volunteers, divers, professional photographers, and other stakeholders around a common goal, reducing the incidental capture of whale sharks and promoting sustainable economic benefits through non-extractive activities such as ecotourism and wildlife observation (Figure 2). These experiences demonstrate the potential of combining biodiversity conservation, sustainable livelihoods and community participation. Many of the conservation achievements in the region have resulted from collaboration with local communities and stakeholders; yet, these efforts have not been sufficient, and shark populations continue to face significant threats.



Figure 2: The iconic whale shark (Rhincodon typus) photographed off the central coast of Venezuela, Southern Caribbean. Photograph by Humberto Ramírez.

Shark fishing, conducted predominantly by artisanal operations, provides a source of income and subsistence for many fishing communities across the Caribbean. In recognition of the importance of these subsistence and commercial activities, fishing regulations often take the needs of fishing communities into account. In cases where shark fishing is banned, regulations may allow local quotas or the retention of incidental catches to support these communities, as occurs under some management frameworks in Colombia and Venezuela. Temporal fishing closures also aim to protect essential habitats during critical periods while allowing fishing activities to continue during the remainder of the year. In any case, it is important to recognise that effective shark conservation requires a combination of several components: responsible use of fishery resources, full utilisation of landed sharks, biodiversity protection, long-term resource sustainability, and community participation. On the other hand, because artisanal fishing activities are often carried out informally and with limited monitoring, collecting the biological and fisheries data needed for stock assessments (i.e., species-specific catch records, biological parameters, and effort data) can be extremely difficult. In this context, educational and conservation programmes have emerged as one of the most effective strategies for building awareness and supporting conservation action; however, sustained long-term implementation is necessary to achieve the greatest conservation benefits. Additionally, because sharks move across political and jurisdictional boundaries, greater international cooperation and regional integration are also essential to improve the effectiveness of conservation and management efforts. Given the ecological importance of the Southern Caribbean, conserving shark diversity, maintaining healthy marine ecosystems and supporting the sustainable use of marine resources should remain regional priorities, underpinned by international cooperation, scientific collaboration, and adequate funding.

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Take-home message

- Continue research and monitoring of shark biodiversity in the Southern Caribbean to improve knowledge of species diversity, distribution, ecology, and population status, while incorporating emerging approaches such as environmental DNA (eDNA) surveys and DNA barcoding.
- Develop and strengthen fisheries monitoring programmes to collect the biological, ecological, and fisheries data required for stock assessments, population evaluations, and evidence-based fishery management and conservation strategies.
- Implement educational and outreach programmes that actively engage local communities, fishers, students, and the general public in shark conservation, data collection, and the management of ecologically important and iconic species.
- Promote regional and international cooperation to coordinate research, conservation, and management initiatives, identify strengths and weaknesses in current strategies, and enhance the effectiveness of shark conservation throughout the Caribbean region.

5. Conservation, Restoration, and Biocultural Futures

This section bridges past and present to explore pathways towards more inclusive and sustainable biodiversity futures. It brings together case studies of Indigenous, community-led and civil society conservation practices, heritage ecology, and the role of communities in caring for biocultural landscapes. Contributions inform contemporary conservation strategies and policy recommendations for more inclusive, just, and effective biodiversity governance.



5.1 Africa



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This chapter discusses the complex relationships between people, biodiversity, and conservation across Africa, with contributions from Zambia, Kenya, and Tanzania. The chapters examine how Indigenous knowledge, customary practices, and community stewardship have shaped relationships with wildlife, forests, and plant resources, alongside the impacts of settlement expansion, colonial conservation policies, land-use change, and environmental degradation. From the Kafue Flats and the medicinal plant traditions of Western Kenya to the Serengeti Basin and the forests of Tanzania's Usambara Mountains, these perspectives highlight both the pressures facing African ecosystems and the knowledge and practices that can support their conservation. Together, they emphasise the importance of inclusive governance, community participation, and traditional ecological knowledge in developing sustainable approaches to conservation.

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Human Settlement and the Increased Risk of Biosphere Depletion: The Role of Indigenous Knowledge Systems in Faunal Conservation

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Zambia is exceptionally rich in biodiversity, supporting approximately 3,543 flowering plant species, 242 mammals, 757 birds, 74 amphibians, 156 reptiles, and 490 fish species. To conserve this natural heritage, the country has established a protected area network comprising over 480 forest reserves, 20 national parks, and 40 Game Management Areas (GMAs), covering approximately 286,161 km^2 (37.8%) of the national territory (Chilembo 2023). These ecosystems provide essential ecological services while underpinning livelihoods, tourism, and national socio-economic development.

Despite this significant conservation network, Zambia's biodiversity is increasingly threatened by human activities. Agricultural expansion, illegal charcoal production and timber extraction, mining, unplanned settlement growth, pollution, invasive alien species, climate change, and overexploitation of wildlife are the main causes of biodiversity loss (Rafferty 2010, Kumari, Deepali et al. 2021). Human settlement via agricultural expansion is the dominant cause of forest loss, accounting for approximately 90% of deforestation and rural settlement expansion and subsistence farming, which support around 60% of the population, increasingly encroach into protected areas, contributing to ecosystem degradation across approximately 25% of national parks and 48% of GMAs while intensifying human-wildlife conflict (Theobald, Oakleaf et al. 2025)(NBSAP-III).

The expansion of permanent human settlements has been a major driver of biosphere depletion from the Holocene into the Anthropocene. As populations shifted from forager-hunter-gatherer societies to permanent Bantu agricultural communities (via agro-transformation- Chitemene), the increasing demand for land, food, water, and natural resources accelerated environmental change; habitat conversion, deforestation, infrastructure development, and resource extraction (mining especially copper on the Copperbelt) (Watson, Becker et al. 2015, Mabeta, Mweemba et al. 2018, Kasaro, Phiri et al. 2019, Tripathi, Mzumara et al. 2019, Yu, Li et al. 2025, Musenge, Phiri et al. 2026). These land-use changes have fragmented ecosystems, reduced species richness, disrupted ecological processes, and degraded both terrestrial and freshwater habitats. Globally, rapid population growth, urbanisation, industrial agriculture, mining, and infrastructure expansion have further intensified biodiversity loss, with an estimated one million species now threatened with extinction due to anthropogenic pressures (IPBES 2019, Yu, Li et al. 2025).

Habitat fragmentation is one of the most significant ecological consequences of settlement expansion. Roads, agricultural fields, fences, and urban development divide continuous habitats into isolated patches, restricting wildlife movement, reducing genetic diversity, and increasing local extinctions (Cushman 2006, Bennett 2017, Mulenga, Phiri et al. 2026, Okello, Nguvulu et al. 2026). Large mammals are particularly vulnerable because they depend on extensive home ranges and migration corridors. Fragmentation also increases exposure to poaching, road mortality, and human-wildlife conflict, while altering predator-prey relationships and ecosystem functioning. Freshwater ecosystems are similarly affected through dam construction, irrigation, pollution, sedimentation, and wetland drainage, which reduce fish diversity and degrade aquatic habitats.



Figure 1: Overview photos of the Kafue flats landscape and some fauna in it. The Kafue Flats is also internationally recognised for its biodiversity, including the endemic Kafue lechwe and important bird populations.

Human settlements also increase pressure through the overexploitation of wildlife. Commercial hunting, bushmeat harvesting, overfishing, and illegal wildlife trade have caused substantial declines in vertebrate populations, with extraction rates often exceeding natural population recovery(Van Velden, Wilson et al. 2020, Zyambo, Mwitwa et al. 2024). These pressures are further compounded by climate change, which alters rainfall patterns, increases drought frequency, and reduces the availability of natural resources within wildlife habitats (Kaonga 2020). As a result, animals increasingly move into agricultural landscapes and settlements in search of food and water, intensifying conflicts with local communities.

Human-wildlife conflict has become a growing conservation and development challenge in Zambia, particularly in regions where settlement expansion overlaps with wildlife habitats, as analyzed in the Maamba, Kasako, and Handula Camps. Competition for land, water, and food has resulted in crop destruction, livestock losses, injuries, and fatalities affecting both people and wildlife. Addressing these challenges requires integrated management strategies, including improved land-use planning, creation and promotion of private game ranches, creation of Game Management Areas, community-based conservation groups in certain areas, area conservation community cooperatives, community-based early warning systems, enhanced water management within protected areas, livelihood diversification through initiatives like ecotourism, and stronger community participation in conservation efforts. A good example is the Kafue Flats, internationally recognized for its biodiversity, including the endemic Kafue lechwe and important bird populations. Communities (for instance, the Maamba, Kasako, and Hundula (Kafue Flats) depend on fishing, agriculture, and livestock, while conservation authorities seek to maintain biodiversity and sustainable resource use. Such approaches aim to reduce conflict while promoting sustainable coexistence between people and wildlife.

INDIGENOUS KNOWLEDGE SYSTEMS AND BIODIVERSITY CONSERVATION

Historically, Indigenous Knowledge Systems (IKS) played an important role in promoting sustainable natural resource management through locally adapted conservation practices developed over generations. Integrating indigenous knowledge with contemporary conservation strategies offers valuable opportunities to strengthen biodiversity management, improve community engagement, and enhance the long-term sustainability of Zambia's ecosystems amid increasing human and environmental pressures.



Figure 2: Photos depicting fish and fishing activities on the Kafue River in the Maamba fishing Camps, Kafue flats.

IKS comprises ecological knowledge accumulated over generations through close interaction with local environments. Rooted in principles of stewardship, reciprocity, and intergenerational responsibility, IKS have traditionally promoted the sustainable use and conservation of biodiversity. Indigenous communities regulate wildlife use through customary laws, spiritual beliefs, seasonal restrictions, and social institutions that limit overexploitation and support long-term ecosystem health.

Traditional conservation practices, including taboos, totems, the protection of sacred forests, rivers, wetlands, and culturally significant species, have historically served as effective biodiversity refugia by reducing human disturbance and safeguarding critical habitats. Seasonal hunting restrictions, rotational harvesting, and customary resource management practices further contribute to maintaining wildlife populations, ecological balance, and habitat diversity.



Figure 3: Highlights livelihoods in the Kafue Flats, where communities depend mainly on fishing, agriculture, ilegal hunting and livestock. The ecosystem also supports wildlife and biodiversity, although settlement expansion and human activities are increasing pressure on natural resources and habitats. The three settlements have an estimated combined population of 6,500 people, with Hundula being the largest, then Kasako and least is Maamba Fish Camps and therefore the highest priority for monitoring settlement-related pressures.

Indigenous fire management is another important conservation practice. Controlled, low-intensity burning creates diverse habitat mosaics, reduces fuel loads, minimises the risk of catastrophic wildfires, and improves grazing conditions for both wildlife and livestock. Increasing scientific evidence recognises these traditional fire regimes as valuable tools for enhancing ecosystem resilience and biodiversity conservation.

Community-based natural resource management systems reinforce conservation by involving local communities directly in wildlife stewardship. Through shared governance, customary institutions, and cultural norms including taboos protecting totemic or spiritually significant species communities have strong incentives to conserve natural resources while ensuring their sustainable use. Such participatory approaches often produce more durable conservation outcomes than externally imposed management systems that exclude local stakeholders.

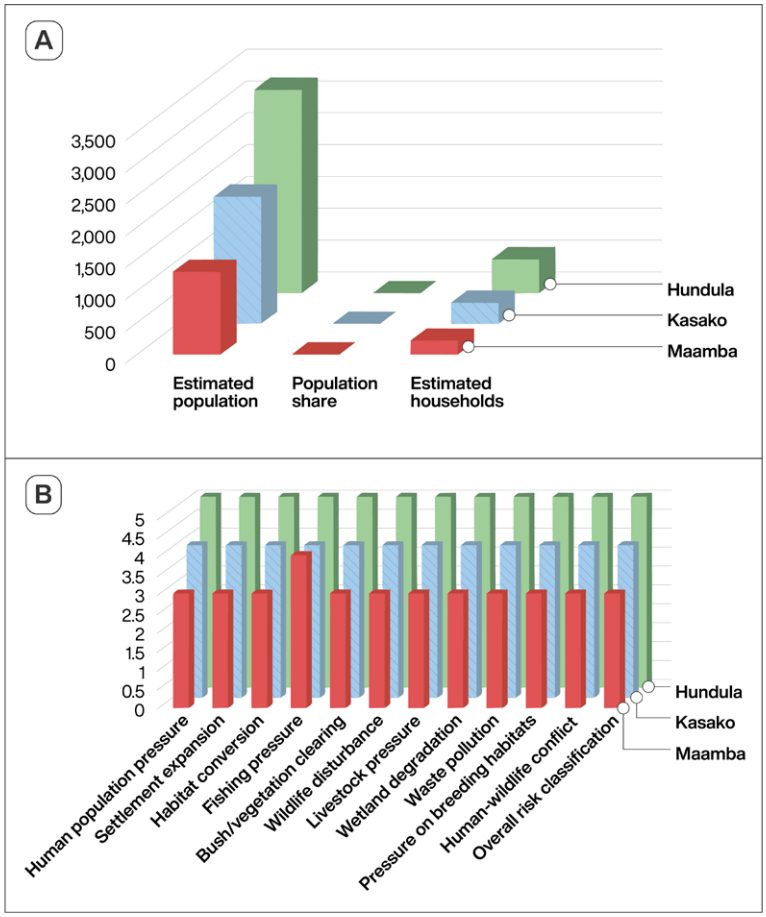


Figure 4 a: Human settlement baseline database of the 3 fish camps studied in this research. b: Proposed faunal conservation risk database; ranging from 1 = Very Low to 5 = Very High, thus indicating how indangered the biodiversity of the Kafue flats are at high risks of endangerment due to unplanned settlements in Fishing Camps.

Importantly, the integration of Indigenous Knowledge Systems with contemporary ecological science is increasingly recognised as an effective approach to biodiversity conservation. Indigenous ecological observations complement scientific monitoring by providing long-term environmental knowledge, particularly in data-poor regions. Collaborative approaches that combine traditional knowledge with modern conservation tools, including geographic information systems, wildlife monitoring, and adaptive management, are consistent with international frameworks such as the Convention on Biological Diversity, which recognises Indigenous peoples and local communities as essential partners in achieving global biodiversity targets.

In Zambia, these principles align closely with the objectives of the Third National Biodiversity Strategy and Action Plan (NBSAP III, 2026-2035), which prioritizes safeguarding natural ecosystems and habitats, strengthening climate resilience and adaptation, enhancing food security and sustainable economic growth, and promoting community engagement and public awareness.

Overall, while the expansion of human settlement continues to drive habitat loss, ecosystem degradation, and biodiversity decline, Indigenous Knowledge Systems demonstrate that sustainable human-environment relationships are achievable. Integrating indigenous conservation practices with scientific approaches offers a practical and inclusive pathway for protecting biodiversity, restoring ecosystem integrity, and strengthening resilience to climate change and other environmental pressures.

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Traditional indigenous knowledge and practices in the conservation of plant resources in rural Western Kenya

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The medicinal plant resources used by rural communities of Kenya have not been exhaustively documented due to complex sociocultural issues and unchecked exploitation. The conspicuous decline in traditional medical knowledge has been largely attributed to the increase in use of modern medicine, access to western education, overexploitation, population pressure and human settlement, deforestation and urbanization. The ever-widening gap in indigenous knowledge is exacerbated by vast undocumented indigenous knowledge base (Kipkore et al., 2014).

Citizen-based elderly approaches and interviews with local community experts help fill the existing information and knowledge gap and enable reconstruction of the past. Regarding sustainable extraction of plant resources by the local communities, practitioners tend to overharvest some plant parts depending on their common uses. Roots, leaves and barks are the commonly harvested plant parts, whereas the fruits and flowers are the least sought plant materials (Wanjohi et al., 2020). Research findings have recorded climbers and woody lianas as the least harvested plant resources. Traditional vegetables and common weeds have also been useful in the treatment of both human and veterinary diseases.

Traditional knowledge acquired through interviews with herbalists from the Marakwet and Pokot communities cited overextraction of Mimosaceae, Euphorbiaceae, and Asteraceae plant families. With *Warburgia ugandensis*, *Zanthoxylum chalybeum*, *Prunus africana*, *Trichilia emetica*, *Azadirachta indica*, *Dregea schimperi*, and *Carissa spinarum* have been reported to be the commonly harvested plant species (Mbuni et al., 2020; Chebii et al. 2022a). These species are mostly native and indigenous to the Cherangani Hills except the naturalized *A. indica* and should be prioritized for conservation (Chebii et al., 2023). Most of these commonly utilized plant resources are exploited for the treatment and management of stomach ailments, reproductive health, chest infections and sexually transmitted infections. Traditionally, stomach ailments are considered the root of all diseases of mankind. *Z. chalybeum* is the leading herbal tea used by the Marakwet and Pokot communities. The use of indigenous knowledge systems (IKS), unlike the use of modern therapies, are also invaluable in the treatment of sociocultural syndromes like bad luck, bad eyes, and bad dreams (Chebii et al., 2022b). The Marakwet and Pokot communities largely extract their plant resources from the Cherangani Forest Ecosystem within the Cherangani Hills in the Elgeyo Marakwet County in the Western part of Kenya.

Community-led conservation efforts have been considered one of the most efficacious conservation approaches that is characteristically all-inclusive, participatory and not elitist (Chebii et al., 2023). The inclusion of local and indigenous communities in conservation

efforts boosts local cooperation, eliminates sabotage and heightens conservation and protection of local biodiversity. All stakeholders must strike a balance between nature conservation and economic gains (Chebii et al., 2023). This efficacious bottom-up approach enables sustainable use of plant resources and bolsters conservation of biodiversity. Integrating diverse traditional and modern conservation practices ensures a somewhat delicate balance of ecosystems. However, the decline in the indigenous ecological knowledge base poses a huge challenge in designing efficacious and community friendly conservation strategies. For so many years, traditional governance practices have been largely ignored. These informal and vastly undocumented regulations are silent and powerful regulators of who and when should sustainably extract plant resources. On the same breadth, the power of vastly undocumented sociocultural beliefs of the local and indigenous communities cannot be underestimated.

IKS is critical in the conservation of biodiversity at all spatial and temporal scales. The use of totems by the Teso people of Western Kenya in their indigenous environmental practices have been useful in the conservation of sacred environments (Ayaa & Waswa, 2016). The Marakwet and Pokot communities also use totems alongside culturally enforced taboos, rituals and norms. These local strategies combined with local community protection approaches alongside age and gender restrictions are effective in the grassroot conservation agenda. Local conservation approaches also have gender roles and responsibilities, where women are considered the major custodians of IKS in a patriarchal society. The amplification of women voices in the conservation agenda is critical and must be considered at all levels. Although the handling of IKS is considered largely esoteric, most indigenous information is disseminated orally to close relatives from generation to generation and the female gender is mostly favoured in this transmission than the male gender (Chebii et al., 2020; Chebii et al., 2022b). Secrecy and limited disclosure of plant resource use and identity is the undocumented patent rights of the local communities. Even the local healers and practitioners intentionally destroy visible taxonomic characters (both floral and vegetative traits) that may allow easy identification. Other local conservation strategies practiced by the Marakwet and Pokot traditional practitioners collect plant resources at odd times like late in the night or at dawn. These measures are designed to check the harvesting of commonly used plant resources. The products at the markets are largely unlabelled and wittingly mixed to avoid easy identification by the buyers (figure 1 A& B). Tight sociocultural tightening rules that support efficacious socio-conservation strategies include stringent family restrictive measures that bar practitioners from extracting plant resources, mandatory covering of exposed plant roots, and preventing excessive debarking. For instance, female practitioners may be barred from extracting plant resources during menstruation and male practitioners may be barred from engaging in sexual activities.



Figure 1: (A) A mixed display of medicinal plant resources in the Kitale open air market of Kitale in Western Kenya. (B) A traditional medical practitioner in the Yala Market, Western Kenya, demonstrating experience, secrecy and limited disclosure of plant's identity.

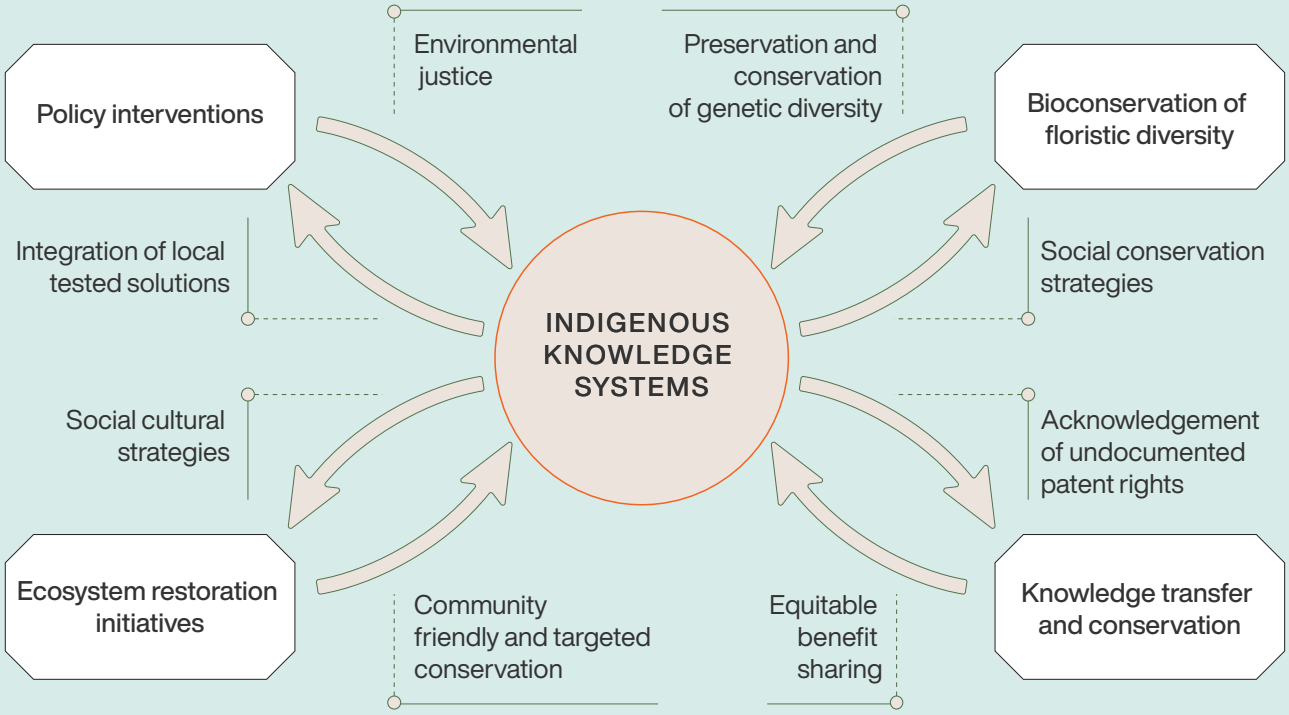


Figure 2. Integration of IKS in ecosystem and biodiversity conservation and policy formulations.

POLICY IMPLICATION

Generally speaking, regulators must find a common ground between indigenous knowledge systems and modern cutting edge knowledge systems. There is no better alternative than to harmonize traditional governance practices and modern governance practices. This underscores the need for co-management of plant resources where communities play a significant role in the management of their own resources. As much as most of the local communities have no land certification, access to land rights, environmental justice and fairness can be easily accessed from the environmental and land courts (Constitution of Kenya, 2010). Kenya has sufficient laws and the challenge remains in strict enforcement. There is need to harmonize potent indigenous conservation strategies with the current modern conservation approaches.Finally, we must always find a place for traditional conservative strategies and implement an all-inclusive bottom-up approaches that injects a sense of ownership and pride in the conservation of plant resources.

ACKNOWLEDGEMENT

I acknowledge all the interviewed traditional health practitioners of Western Kenya for their contribution on indigenous medical knowledge. I also register a lot of appreciation to all the key informants drawn from local institutions and organizations.

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Cultural and historical dimensions of conservation policies in the Serengeti Basin, Tanzania

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The Serengeti Basin in northern Tanzania is one of the world's most iconic ecosystems, celebrated for its biodiversity and the annual migration of wildebeest and other herbivores (Figure 1). Conservation efforts and policy governing the ecosystems in the region have evolved significantly over the centuries, shaped by a complex interplay of historical, political, socioeconomic, and cultural factors (Weldemichel, 2021). This review traces the evolution of conservation policies from pre-colonial times through colonial rule to post-independence reforms. By centering cultural dimensions that have shaped and often been excluded from mainstream conservation practice, we explore the historical trajectory of these policies, from Indigenous conservation practices rooted in spiritual and customary laws, through colonial-era exclusionary frameworks, to modern community-based conservation strategies. In addition, we examine the socio-political, ecological, legal, and cultural transformations that have shaped conservation in the Serengeti, highlighting the importance of integrating traditional knowledge, scientific research, and equitable governance for sustainable wildlife management. While ecological dimensions of Serengeti conservation are well-documented, cultural and historical perspectives remain under-analysed; this review addresses that gap.

PRE-COLONIAL CONSERVATION PRACTICES

Indigenous communities in the Serengeti Basin practised conservation through spiritual beliefs and customary laws. For approximately 10,000 years, Tanzanian societies coexisted with wildlife, using cultural practices such as worship of natural elements to conserve ecosystems (Sirima, 2015). Taboos, rituals, and the authority of elders-maintained biodiversity and ecosystem integrity. For instance, the Maasai indigenous community, who have inhabited the Serengeti region for at least four centuries, developed communal property systems and seasonal rotation of grazing lands (Weldemichel, 2021). This seasonal movement of herds protected pastures from overgrazing, aligning with wildlife migration patterns (Sirima, 2015).

COLONIAL ERA CONSERVATION POLICIES

The period during colonial rule marked a rupture in conservation practice. German colonisation began in 1885, and by 1905 the first game reserve was established (Gissibl, 2016). These reserves excluded Africans from fertile lands and wild meat (The Oakland Institute, n.d.). By 1911, 5% of the colony was designated as protected areas (Gissibl, 2016). Under British colonial rule, the Serengeti National Park was established in 1951. Following this, in 1959, the

Maasai were forcibly evicted from the park (Urquhart, 2021), since colonial conservation policies and narratives emphasised separation between humans and nature, creating exclusionary protected areas (Weldemichel, 2021).

POST-COLONIAL CONSERVATION REFORMS

After independence in 1961, Tanzania inherited colonial policies largely uncritically (Makupa, 2013). The Wildlife Conservation Act of 1974 reinforced state control, excluding communities from decision-making (United Republic of Tanzania, 1974). Community-based conservation (CBC) strategies emerged in the late 1980s and 1990s, through the Serengeti Regional Conservation Strategy (1985) integrated conservation and development (Makupa, 2013; Kaaya & Chapman, 2017) and the wildlife Management Areas (WMAs), which empowered communities to manage and benefit from wildlife, as exemplified by Ikona WMA (480.1 km^2, jointly managed by five villages). Moreover, the Wildlife Policy of 1998 and subsequent legislation supported community participation and sustainable use (Makupa, 2013). These reforms aligned legal frameworks with CBC principles, promoting equitable benefit-sharing and ecological sustainability (Kaaya & Chapman, 2017).

INTEGRATED CONSERVATION AND DEVELOPMENT PROJECTS

Integrated Conservation and Development Projects (ICDPs) link biodiversity conservation with socio-economic development. In the Serengeti, ICDPs promote ecotourism, sustainable agriculture, and alternative livelihoods such as beekeeping and fish farming (Kaaya & Chapman, 2017; Makupa, 2013). However, local people often seek individual-level benefits, as they bear most conservation costs (Kaaya & Chapman, 2017).

CULTURAL DIMENSIONS OF CONSERVATION

Indigenous groups such as the Maasai, Ikoma, and Kurya practiced environmental stewardship rooted in spiritual beliefs and oral traditions (Sirima, 2015). Sacred groves, totemic species, and seasonal hunting restrictions served as informal conservation mechanisms. Although colonial and post-colonial policies often disregarded these systems, eroding traditional knowledge (Weldemichel, 2021). Recent CBC initiatives aim to reintegrate cultural values, promoting cultural tourism and Traditional Ecological Knowledge (Sirima, 2015) in biodiversity conservation. These initiatives recognise that cultural identities are essential for inclusive and resilient conservation frameworks (Weldemichel, 2021).

ONGOING CHALLENGES AND FUTURE DIRECTIONS

Conservation faces challenges including human-wildlife conflicts, resource constraints, climate change, and governance issues (Weldemichel & Lein, 2019). Authorities have used violence to expand protected spaces into buffer zones and corridors (Weldemichel, 2021). Mitigation strategies, adaptive management, and institutional strengthening remain critical (Kaaya & Chapman, 2017).

ACKNOWLEDGEMENT OF INDIGENOUS KNOWLEDGE HOLDERS

This work has been informed by the traditional ecological knowledge of Maasai pastoralists in the Serengeti Basin. Their oral traditions and stewardship practices are foundational to understanding cultural dimensions of conservation. Maasai elders and community representatives should be formally credited as co-authors of this contribution.

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Key Insights

- The evolution of conservation policies in the Serengeti Basin reflects a complex interplay of ecological, political, and cultural forces (Weldemichel, 2021). From Indigenous stewardship to colonial exclusion and modern participatory models, the region's history underscores the need for inclusive, adaptive, and equitable strategies.
- Sustainable conservation depends on balancing ecological integrity with community rights, drawing on both traditional knowledge and scientific expertise (Sirima, 2015; Weldemichel, 2021).

Ecosystem Restoration and Conservation of the Amani-Nilo Forest Corridor and benefits to the East Usambara Mountains Landscape, Tanzania

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The Afromontane Forest ecosystem of the Usambara Mountains of Tanzania hosts remarkably rich and biologically diverse plant and animal communities and ranks among the most important areas in the world for the conservation of endemic species (Burgess et al., 2007; Hamilton & Bensted-Smith, 1989; Mittermeier et al., 2004). Under the direct climatic influence of the Indian Ocean Monsoon (Lovett, 2008), the Usambara Mountains possess an exceptionally stable, warm and humid climate regime and serve as an ecological refugium for formerly widespread flora that once stretched from western through eastern Africa.

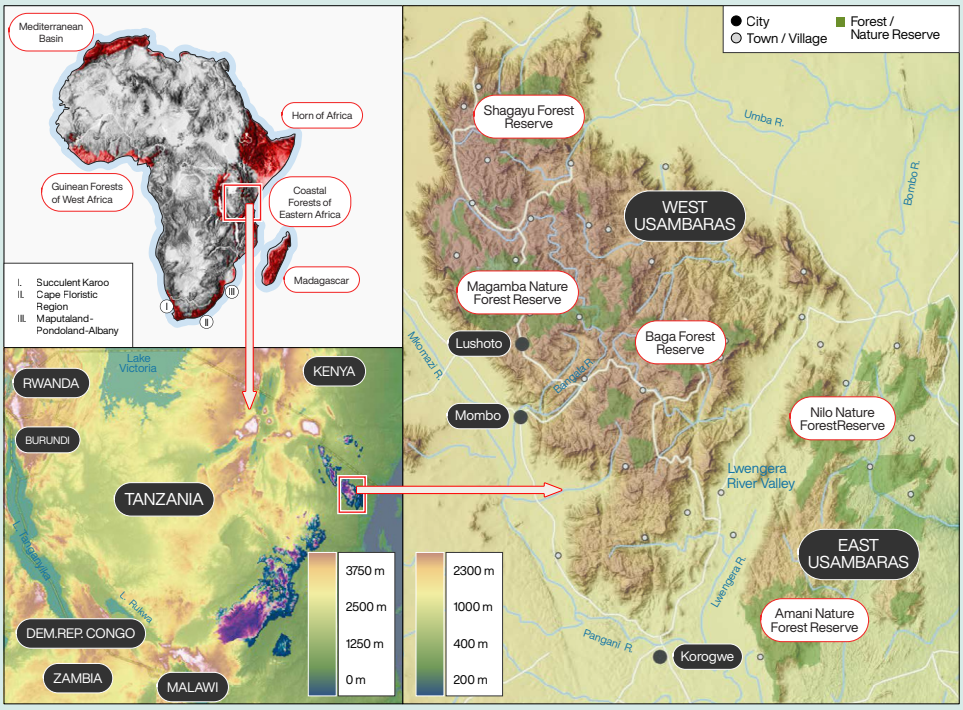


Figure 1. The vin northeastern Tanzania. 1A. Africa's biodiversity hotspots. (Note that the Eastern Afromontane hotspot is not labeled.) 1B. Location of the Eastern Arc Mountains in Tanzania and southern Kenya. 1C. The East and West Usambara Mountains, separated by the Lwengera River Valley.

Located in the Tanga Region of northeastern Tanzania (Figure 1), these mountains only cover an area slightly greater than 4,000 km2 but are home to four endemic primates and are one of Africa's key localities for the conservation of globally threatened birds (Burgess et al., 2007; Davenport et al., 2006; Stewart et al., 2010).

Separated into East and West by the Lwengera River Valley, the Usambaras are part of the Eastern Arc Mountains tropical moist forest ecoregion. As one of the smallest mountain ranges in Tanzania, the East Usambaras cover an area of about 1,145 km2, but of this, only 388 km2 are protected as forest reserves with the two largest being the Amani Nature Forest Reserve (83.8 km2) and the Nilo Nature Forest Reserve (60.3 km2) (Doggart et al., 2017). The West Usambaras are larger at around 3,000 km2 but only about 375 km2 of this area is classified as protected forest like the Magamba Nature Forest Reserve (92.8 km2) (Luswaga & Nuppenau, 2021), the largest forest remaining in the Usambaras. This mountain block is highly populated and has over 215 villages, with most of the land outside of government forest reserves having been converted into farmland.

A HOTSPOT AT RISK

The Eastern Arc Mountains hold the UNESCO World Heritage Convention criteria for "Outstanding Universal Value." Being identified by UNESCO as one of the 36 global biodiversity hotspots, they have high species richness with 211 endemic animal species and 550 endemic plant species (Munishi, 2025). Of these, 57 vertebrate species are exclusively endemic to the Usambara forests, and some of the highest number of endemic or near endemic trees are seen in the East (40 species) and West (27 species) Usambaras.

Today, however, the Usambara Mountains are threatened by environmental degradation and biodiversity loss. Anthropogenic burning, logging, and cash crop farming that began during German colonial rule and persisted through the British colonial period and into the present, have transformed the Usambara Afromontane Forest ecosystem and removed most of the mature, native forests. This, alongside higher demands for irrigation, has altered surface water hydrology to such an extent that many mountain streams are now intermittent or non-existent. We also know, through personal communication and colonial era records (BDA, 1935), that the Lwengera River Valley was once home to some of Africa's most famous animals (e.g., lion, elephant, buffalo, rhinoceros), but these were forced from the area nearly 100 years ago following agricultural intensification during British colonial rule.

The impact of climate change on eastern Africa is manifesting in more intense and longer dry seasons punctuated by severe tropical storms and flooding.

In eastern Africa, traditional agricultural practices have been implicated in the degradation of montane forest over the past two-thousand-years (Newmark, 1998; Uisso & Njoghomi, 2024). Across the Usambara Mountains, roughly 80% of forest coverage has been lost, but the majority of this occurred because of colonial era practices (Newmark, 2002). Since the colonial period of the late 19th Century, the Usambaras have been subjected to detrimental forest and agricultural policies, which subsequently degraded the unique forest ecosystems as well as the community livelihoods of its people (Gaworek-Michalczenia, Sallu, & Di Gregorio, 2019).

Degraded ecosystems are limited in their ability to respond or adapt to climate or environmental shocks (e.g., periods of extreme drought punctuated by periods of extreme

rainfall). The impact of climate change on eastern Africa is manifesting in more intense and longer dry seasons punctuated by severe tropical storms and flooding. Climate change is expected to significantly alter African biodiversity as species struggle to adapt to rapidly changing temperature and precipitation regimes. This also has impacts on local communities as climate shocks leave farmers struggling to produce crops, which subsequently weakens their income and broader livelihoods (Gaworek-Michalczenia et al., 2019).

NATURE-BASED SOLUTIONS (NBS)

Nature-based Solutions (NbS) are those that use ecosystem services to address societal challenges such as climate change, food and water insecurity, or environmental degradation and biodiversity loss. Promoting the conservation, restoration, and sustainable management of ecosystems, while acknowledging the increasing demands placed on ecosystem services, is a major goal of NbS (Figure 2). Wildlife corridors are one NbS that have been shown to promote biodiversity and resilience by allowing species to migrate between forest reserves, safeguard genetic flow between populations, and disperse seeds to ensure survival of native plants.

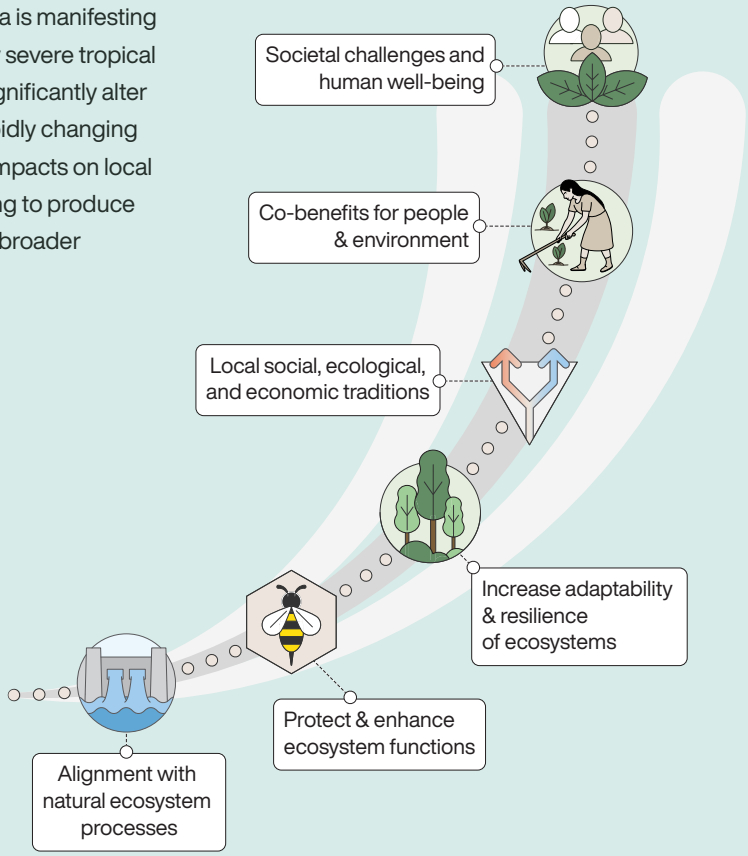


Figure 2. The goals of Nature Based Solutions. In the Usambaras, these goals are often grouped into four categories; 1) provisioning (e.g., water sources, firewood, income), 2) regulation (attracting e.g., climate regulation, protecting the environment), 3) services (e.g., pollination, habitat), and 4) cultural (e.g., ritual practices and tourism).

In the East Usambara Mountains, the 201 km2 Amani-Nilo Forest Corridor (ANFC) connects the Amani and Nilo Nature Forest Reserves (Figure 1) with the Kambai and Semdoe/Msige Forest Reserves, as well as patches of Village Land Forest Reserves. Although one of the smallest corridors in all of Tanzania, this reserve provides habitat to almost 800 species of plants and 100 species of birds and acts as a refuge for 89 species categorized in the IUCN Red List as vulnerable, endangered, or critically endangered (Uisso & Njoghomi, 2024).

Beyond the benefits of safeguarding biodiversity, the ANFC is highly valued by local villagers and farmers as it plays a critical role as a rain catchment area and reduces some of the impacts of climate change in the Tanga region. It also offers eco-tourism opportunities and provides ecosystem goods and services to the livelihoods of local people such as honey, medicinal plants, wild fruits and vegetables, timber, pollination, water, and carbon sequestration. In fact, both the remaining East and West Usambara forest reserves act as carbon sinks and store roughly 31 million and 45 million tons of carbon dioxide, respectively (EAMCEF, 2021).

Recent progress on the success of the ANFC (Uisso et al., 2026) shows strong local awareness and stewardship of forest management plans, laying the foundation for sustainable forest conservation. Reliable rainfall, microclimate regulation, supporting biodiversity, medicinal plants, firewood availability, and regulating and protecting water sources have all been recognized by the communities living in and around the corridor as essential benefits resulting from the restoration and protection of the ANFC's biocapacity.

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Recommendations

- The Amani-Nilo Forest Corridor should act as a template for a wider strategy to connect forest reserves across the Usambara Mountains. Identifying prioritized corridors and key points across both the East and West Usambaras will improve connectivity and benefit all species, especially those listed on the IUCN Red List.
- These corridors, however, are not only inclusive, just, and effective for biodiversity governance, but also address the diverse needs and aspirations of local people and their wellbeing.
- There have been inadequate platforms for co-developing impact-oriented research and sharing of the vast knowledge on socio-economic, ecological, and cultural experiences among researchers, academics, conservationists, and traditional landowners.
- Communicating the hidden wealth of conservation information is crucial to develop inclusive sustainable landscape initiatives, such as promoting agricultural yields, ecotourism potentials, and mitigating climate change impacts.
- Given the unusually large numbers of threatened and endemic species that occur in the Usambara Mountains, opportunities to enhance species' persistence through habitat restoration should be explored in and between other forest reserves.

5.2 Asia



Photo by Bhavesh Joshi on Unsplash

Contributions from India and Armenia consider how traditional practices and long-term human–environment interactions have shaped biodiversity, from the forests of the Maikal Hills and Aravallis to the Armenian Highlands. The chapter also considers the role of geodiversity in sustaining ecosystems, highlighting the dynamic connections between geological processes, biodiversity, and human societies in the Rajmahal–Ganga landscape. Together, these perspectives demonstrate the value of combining Indigenous knowledge, scientific approaches, and long-term environmental histories to better understand and conserve Asia's diverse landscapes.

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The Wisdom of the Wild: Baiga Indigenous Knowledge and The Preservation of Biodiversity in Central India

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In the central Indian region, the Baiga community is considered the 'children of the forest' for whom the forest is an extended part of their life. Mainly concentrated in the forested landscape of the Maikal Hills, they have inhabited the region since time immemorial. Consequently, the forests of the Maikal Hills are not only the home of diverse flora and fauna, but have also developed into a cultural landscape through their long-standing interaction with it. Having a strong bond with the natural entities, they nestled in the remote areas and forested tracts, suggesting that biodiversity is not merely a collection of plant and animal species. Rather, it is understood as a living network of relationships connecting humans, forests, animals, spirits, ancestors and food resources. While conducting fieldwork among them, it became clear that their understanding of biodiversity extends beyond scientific classifications of species and habitats. What they perceive is a living web of a matrix that connects humans with their land and what it produces in a meaningful way. This apprehension shapes their indigenous ecological wisdom, whose role is significant in preserving biodiversity and sustaining ecological balance in the region.



Figure 1. A Baiga woman collecting mushrooms from the forest of the Maikal Hills

Baigas possesses an extraordinary knowledge of forest ecosystems through generations of observation, experience and interaction with nature. Once an elderly Baiga man uttered that "I know very clearly which tubers and berries are found at which place in this entire jungle of Amarkantak, and I know very well which of them among so many contain the medicinal property." This wisdom, which is encoded in everyday mobilisation and reflects a sense of belonging, shows that the Baiga are not aware of the local biodiversity; it is a part of their dwelling. Men and women alike could distinguish edible tubers, leafy vegetables, mushrooms, fruits and medicinal herbs growing in different ecological niches. Such knowledge is not merely descriptive but practical, enabling sustainable use of forest resources without ecological degradation.

As biological conservation is not only a matter of resource management but is deeply embedded with their cosmology, beliefs and rituals. One traditional observance that is associated with wild honey bees was recorded by me. Wherein specific forest areas or bee colonies are left undisturbed for extended periods, sometimes for up to twelve years. During

that period, the collection of honey is either strictly prohibited or heavily restricted. The underlying rationale is not simply religious or devotion to the forest deity, but an ecological understanding that the bee population requires time and protection to multiply. Some community members explained that bees are regarded as indispensable forest beings because they facilitate the reproduction of flowering plants through pollination. By allowing bee colonies to flourish without disturbance, the Baiga ensure the regeneration of numerous forest species that provide fruits, seeds, fodder, medicines and habitat for wildlife. This practice reflects a sophisticated ecological awareness in which the well-being of humans is inseparable from the well-being of the forests.



Figure 2. A group of Baiga women involved in bare-hand fishing by stopping the flow of a stream

The Baiga's relationship with biodiversity is fundamentally shaped by a worldview that regards nature as a living entity rather than a collection of exploitable resources. Another significant example of the indigenous conservation is associated with rivers, streams and aquatic life. During some particular period of the year, certain stretches of rivers, springs and deep pools are restricted to fish and remain undisturbed. Especially during the breeding seasons of fish and other aquatic organisms, they do not go to the river bodies, which allows fish populations to reproduce and replenish themselves. Some elderly Baigas said that disturbing rivers during these times would anger the resident spirits and disrupt the natural balance of life sustained by water. That is why there was never any such case of rivers dying in the region inhabited by indigenous communities. It hints that sacred restrictions transform rivers from exploitable resources into respected kin, fostering attitudes of care and restraint.

What the ecological wisdom of Baigas of the Maikal Hills reminds us is that biodiversity survives not only through protected areas and legal regulations but also through everyday practices of care, respect and reciprocity. Their intimate knowledge of plants, animals, landscapes and ecological processes represents a living archive of environmental understanding. Hence, in an age marked by biological loss and ecological uncertainty, the Baiga's indigenous ecological knowledge offers valuable insights for envisioning more sustainable and inclusive conservation approaches. The forests of the Maikal hills are therefore not only repositories of biological diversity but also reservoirs of cultural wisdom that continue to illuminate alternative ways of living with nature.

Reviving the Nagpahar Landscape Through Traditional Knowledge and Eco-Regeneration

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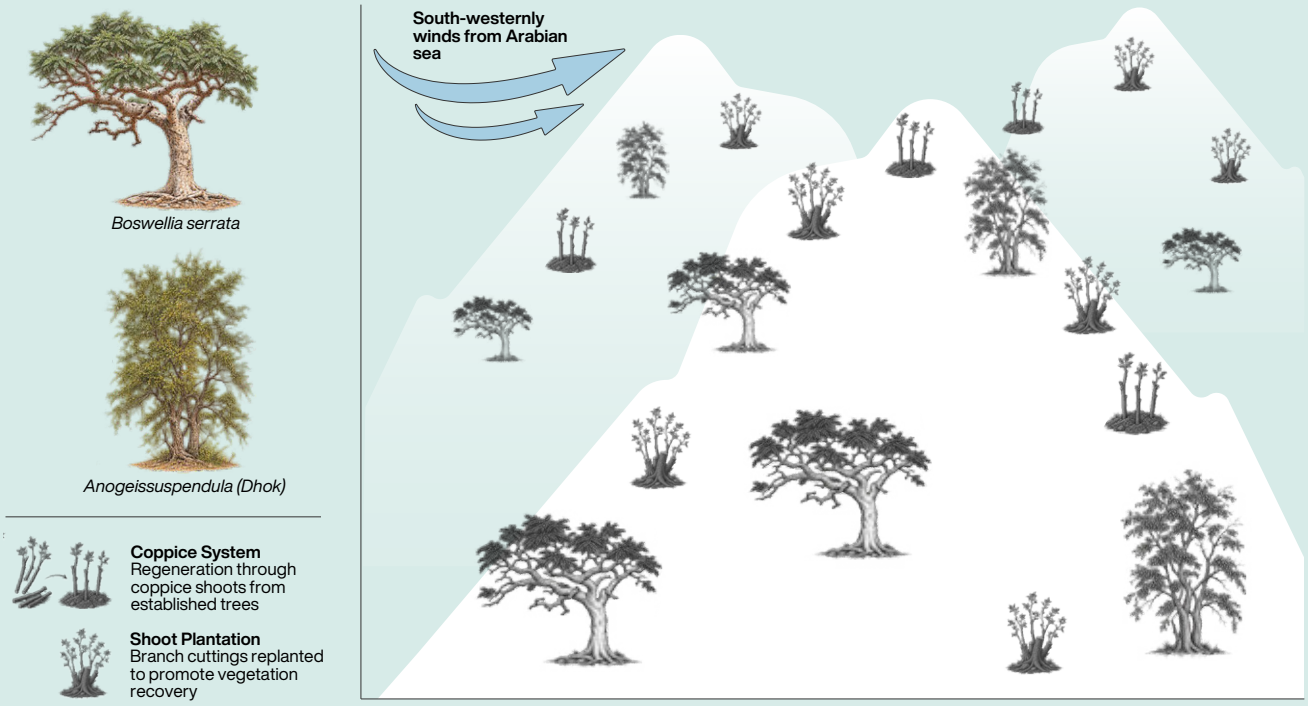
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The Aravallis are among the oldest fold mountain ranges in India, and the Nagpahar hill tract is situated in the heart of the Aravalli Ranges in Pushkar City, located in Ajmer, Rajasthan, India. This hill tract thereby becomes a very pivotal terrain as it stands at the confluence of the dry northwest and the comparatively humid southeast regions. The inhabitants of this tract largely depend on its forest products and, therefore, this study was inspired by the very basic but very apt observations provided by a local tribal woman who was chopping an exotic tree for firewood. The native observations were so time-tested that even forest work plans dated as early as 1915 contained similar details on the phenology and climatic responses of forest species growing here. Tribal observations and forest work plans of more than a century indicate that the forest of this belt is represented by two dominant tree species, *Anogeissus pendula* (Edgew.) and *Boswellia serrata* (Roxb.). These species are highly adaptive to this terrain, and their local names are Dhok and Salar, respectively.

... the vegetation of this region is subjected to continuous degradation from soil erosion and human disturbances leading to a gradual loss of vegetation cover.

The Nagpahar hill tract is located along the eastern fringes of the Thar Desert, and there is no “wind gap” at either the southwestern or north-western ends of the region. Strong south-westerly summer winds during past harsher climatic periods transported sand particles from the western plains and deposited them in the region, leading to the formation of sand dunes. The location of the zone along the desert, combined with the large diurnal temperature range, promotes soil erosion and accelerates desertification processes. Consequently, the vegetation of this region is subjected to continuous degradation from soil erosion and human disturbances leading to a gradual loss of vegetation cover.

To conserve and restore the forest ecosystem of this tract, there is a pressing need to promote regeneration of forest vegetation through silvicultural techniques. The selection of an appropriate technique for a particular ecosystem requires prior evaluation using system ecological methods. The creation of forest vegetation is called regeneration. However, as it was coupled with system ecological assessment, it was agreed to be called eco-regeneration.



According to British Commonwealth Forest Terminology, eco-regeneration is defined as the renewal of forest vegetation through natural and artificial means. The selection of an appropriate regeneration method for this terrain, which displays diverse ecological conditions across the landscape, requires an approach capable of assessing the combined effects of biotic, abiotic, and climatic factors, both individually and collectively. This enables the identification of key ecological drivers and facilitates the application of suitable regeneration techniques to different terrain compartments.

In this process, the experience of the native inhabitants played a crucial role. The tribal communities, who depend on forest vegetation for food, fuel, and fodder, possess extensive knowledge of the conservation and management of this sensitive ecosystem. Through long-term observations, they identified that temperature was a key factor influencing regeneration under clear-felling systems, while shade emerged as the most important factor under shelterwood plantations. However, due to the scarcity of mature shade-providing trees and the prevailing semi-arid conditions, shelterwood plantations could not be widely adopted

*Figure 1. Conceptual illustration of eco-regeneration in the Nagpahar hill tract, showing the restoration of Salar (*Boswellia serrata *(Roxb.)) and Dhok (*Anogeissus pendula (Edgew.)*) through coppice regeneration and shoot plantation following landscape degradation caused by soil erosion.* Anogeissus pendula *photograph by Sonu Kumar.*



Figure 2. Views of the Nagpahar hill tract, Pushkar, Rajasthan. The upper photographs were taken in 1993 and the lower photographs in 2020, illustrating the landscape and vegetation of the tract across time. The photographs represent different locations within the Nagpahar hill tract and were taken during different seasons; therefore, they are intended to provide a general visual representation of the landscape rather than a direct site-to-site comparison. Photographs from 1993 by Vishwas Saxena and photographs from 2020 by Srijna Saxena.

as a main regeneration strategy. Further, as *Anogeissus pendula* and *Boswellia serrata* are slow-growing species, a regeneration approach based on the coppice system was adopted to accelerate ecosystem recovery across the tract. Champion and Seth (1968) suggested that in areas where seed germination is poor, coppice shoots can effectively support eco-regeneration efforts. The coppice system is based on the cutting of branches from trees bearing adventitious buds, from which fresh shoots subsequently emerge. Accordingly, in 1993, a shelterwood system coupled with coppice regeneration was implemented. Within two years, substantial vegetation recovery was observed, leading to the re-establishment of conditions characteristic of a tropical semi-humid ecosystem.

The reclamation of the Nagpahar hill tract represents a notable example of the synergy between traditional afforestation practices of local and tribal communities and established scientific forest regeneration techniques. Collaborative efforts between local inhabitants and the Forest Department proved highly effective in restoring the degraded landscape. As a result, a significant improvement in forest cover and ecosystem condition has been observed across the tract. The Nagpahar experience demonstrates that integrating traditional ecological knowledge with scientific restoration practices can provide an effective pathway for conserving biodiversity and restoring degraded dryland ecosystems.

CONCLUSION

In conclusion, when climate change affects the whole population, the response must be reciprocated by the whole population. As a result, an equilibrium can be established between resources and consumers. Such a balance can be achieved when the use of natural resources and their regeneration go hand in hand, creating conditions conducive to the protection of living organisms across all ecosystems.

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Take-home message

The study has significant policy relevance in the current context, where climate change is a global concern. The findings and lessons learned from the study reveal the following:

1. A native who sustains on the produce of trees of this terrain can also play a significant role in regenerating it. This leads to the creation of a concept called “one square foot ownership,” which is linked to the principle of linking population growth with the spread of forests. If each native undertakes the responsibility of growing a tree in a one-square-foot area, then the whole terrain can be viewed as divided into one-square-foot quadrats. The regeneration of forest vegetation and the consumption of forest produce should go hand in hand. If adopted as a policy, it could result in balanced resource use and contribute to sustainable development.
2. Currently, the responsibility for regenerating forest vegetation rests largely with the State Forest Department. However, native involvement can reinforce these efforts, and through a participatory approach, restoration can evolve into a form of citizen ownership, yielding an appropriate socio-ecological response to climate change.

Human–Wildlife Interactions in Armenia through the Holocene: Deep History, Conflict and Conservation

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The Armenian Highlands, situated at the crossroads of Western Asia, the Caucasus, and the Near East, constitute one of the key regions for understanding the long-term evolution of human–animal interactions throughout the Holocene. Their exceptional environmental diversity, strategic geographical position, and rich archaeological record preserve evidence of how climatic change, environmental dynamics, and human societies have continuously influenced one another over the past 11,700 years (Badalyan et al., 2022; Avetisyan & Bobokhyan, 2012). Archaeological, archaeozoological, and palaeoenvironmental research demonstrates that the relationships between humans and animals have never been static but have evolved alongside major transitions in subsistence, land use, and ecosystem transformation (Manaseryan, 2008; Manaseryan & Gyonjyan, 2018). From the first hunter-gatherer communities to modern conservation practice, these interactions have shaped both Armenia's biodiversity and its cultural development, providing an essential framework for understanding contemporary human–wildlife coexistence and conflict.

Throughout the Holocene, relationships between humans and animals were shaped by continuous reciprocal interactions. Animals provided essential resources, including food, clothing, raw materials, transport, labour, and military support, and became deeply embedded in religious beliefs, mythology, art, and cultural traditions (Avetisyan & Bobokhyan, 2012; Piotrovsky, 1969; Antonosyan et al., 2025). At the same time, human activities, including hunting, animal husbandry, agriculture, and landscape modification, progressively altered wildlife populations, habitats, and ecosystem processes (Manaseryan, 2008; Manaseryan & Gyonjyan, 2018; Gyonjyan, 2022). These reciprocal relationships not only shaped the development of human societies but also transformed the composition and distribution of Armenia's fauna, establishing ecological patterns that continue to influence biodiversity conservation and human–wildlife coexistence today.

HUMAN–ANIMAL RELATIONSHIPS THROUGH HOLOCENE

During the early Holocene, human–animal relationships were primarily shaped by hunting, fishing, and gathering. Archaeozoological evidence indicates that communities exploited a wide range of wild mammals, birds, and aquatic resources, with wild goat (*Capra aegagrus*), wild sheep (*Ovis orientalis*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), and hares (*Lepus* spp.) among the principal game species (Manaseryan, 2008; Mirzoyan & Manaseryan, 2008; Manaseryan & Gyonjyan, 2018). Successful hunting

required detailed ecological knowledge of animal behaviour, seasonal movements, and habitat use, reflecting a close relationship between early human communities and the natural environment that laid the foundation for subsequent domestication and pastoralism.



Figure 1: Representative skulls of predatory mammals preserved in the scientific collections of the SCZH.

A fundamental transformation in human–animal relationships occurred during the Neolithic with the emergence of agriculture and animal husbandry across the South Caucasus. Owing to its strategic location between the Fertile Crescent and the Caucasus, the Armenian Highlands became one of the earliest regions in which food production gradually replaced an exclusive reliance on hunting and gathering (Badalyan et al., 2022; Chataigner, 2007; Hovsepyan et al., 2022). Archaeological and archaeozoological evidence from sites such as Aknashen, Areni-1, Shengavit, and other Neolithic and Chalcolithic settlements demonstrates the domestication and management of sheep (*Ovis aries*), goats (*Capra hircus*), cattle (*Bos taurus*), and pigs (*Sus scrofa domesticus*), marking a fundamental shift from exploiting wild animal populations to managing domestic herds (Badalyan et al., 2022; Manaseryan, 2019; Zeder, 2008; Zeder, 2012).

Domestic animals provided reliable sources of meat, milk, hides, wool, bones, and manure while also supplying traction for cultivation and transportation. The development of livestock husbandry substantially improved food security but also required organised grazing systems, seasonal pasture management, and permanent access to water resources and the seasonal management of pastures, fundamentally reshaping patterns of land use and human interaction with the environment.

Armenia's mountainous terrain favoured the development of transhumant pastoralism, whereby herds were seasonally moved between lowland winter pastures and high-altitude summer grazing areas. This adaptive strategy enabled the efficient use of vegetation across diverse ecological zones and became a defining feature of pastoral lifeways in the Armenian Highlands for millennia (Avetisyan & Bobokhyan, 2012; Hovsepyan et al., 2022). By the Bronze Age, livestock husbandry had become a cornerstone of the regional economy, as demonstrated by archaeological and archaeozoological evidence from numerous settlements throughout Armenia (Manaseryan, 2019; Avetisyan & Bobokhyan, 2012). Sheep and goats predominated in livestock assemblages because of their adaptation to mountainous and semi-arid environments, whereas cattle were valued for meat, dairy production, and draft power. Horses gradually assumed greater importance in transportation, warfare, and social prestige, while the size and composition of livestock herds became key indicators of wealth and social status (Badalyan et al., 2022; Piotrovsky, 1969).

Although animal husbandry became the cornerstone of subsistence, hunting remained economically and culturally important throughout prehistory. Wild animals supplied meat, furs, antlers, horns, bones, and other valuable raw materials, while their symbolic significance is reflected in Armenian rock art, ritual objects, ceramics, metalwork, and decorative motifs depicting deer, wild goats (ibex), bulls, horses, birds of prey, and large carnivores (Avetisyan

& Bobokhyan, 2012; Piotrovsky, 1969; Chataigner, 2007). These representations demonstrate that wildlife was valued not only for its practical importance but also for its symbolic, spiritual, and cultural significance, reflecting the close relationship between prehistoric societies and the natural world.

During the Iron Age and the Kingdom of Urartu, the expansion of agriculture, irrigation systems, and permanent settlements increased the demand for domestic animals used in cultivation, transportation, and military activities (Piotrovsky, 1969; Avetisyan & Bobokhyan, 2012). Throughout the Classical and Medieval periods, sheep, goats, cattle, water buffalo, horses, donkeys, and mules formed the foundation of rural livelihoods, while dogs and cats played important roles in livestock protection, hunting, and pest control. Domestic animals became deeply integrated into Armenian folklore, religious beliefs, and traditional practices, symbolizing fertility, loyalty, strength, and prosperity. At the same time, large carnivores such as wolves and bears inspired both respect and fear because of the threats they posed to people and livestock, reflecting the long-standing coexistence and conflict between humans and wildlife in the Armenian Highlands (Manaseryan, 2008; Manaseryan & Gyonjyan, 2018).

LONG-TERM TRANSFORMATION OF WILDLIFE COMMUNITIES

Archaeozoological, historical, and palaeoenvironmental evidence indicates that increasing human activities progressively transformed the composition and distribution of Armenia's wildlife communities. Agricultural expansion, livestock grazing, deforestation, and habitat modification progressively reduced the extent of natural ecosystems and contributed to the decline of numerous wild species. Several large mammals that once inhabited the Armenian Highlands, including the kulan (*Equus hemionus*) and the goitered gazelle (*Gazella subgutturosa*), disappeared from the territory of present-day Armenia, while populations of the Armenian mouflon (*Ovis gmelini gmelini*) and red deer (*Cervus elaphus*) declined substantially. Archaeological discoveries and historical sources further document the regional disappearance of species such as the Asiatic lion (*Panthera leo persica*), Caspian tiger (*Panthera tigris virgata*), aurochs (*Bos primigenius*), and European bison (*Bison bonasus*) (Piotrovsky, 1969; Manaseryan, 2008; Manaseryan & Gyonjyan, 2018; Gyonjyan 2022). Palaeoecological and archaeological evidence also suggests that forests and forest-steppe habitats formerly occupied a much greater extent than they do today, reflecting the cumulative impacts of long-term human land use and environmental change (Hovsepyan et al., 2022; Manaseryan & Gyonjyan, 2018).

Palaeoecological and archaeological evidence also suggests that forests and forest-steppe habitats formerly occupied a much greater extent than they do today, reflecting the cumulative impacts of long-term human land use and environmental change.

The twentieth century, and particularly the socio-economic changes following the energy crisis of the 1990s, profoundly transformed Armenia's natural landscapes through industrialisation, urban expansion, infrastructure development, mining, agricultural intensification, and widespread deforestation. Habitat fragmentation, river regulation, and pollution accelerated biodiversity loss and disrupted ecological processes across many ecosystems. The extensive logging that occurred during the 1990s substantially reduced Armenia's forest cover, including natural stands of wild fruit trees that constitute important food resources for brown bears (*Ursus arctos*) and numerous other wildlife species (FAO, 2020).

CONTEMPORARY HUMAN–WILDLIFE COEXISTENCE AND CONSERVATION

These long-term environmental changes continue to shape contemporary human-wildlife interactions. In Vayots Dzor Province, particularly within the Yeghegis River basin, habitat degradation, forest loss, hydrological alterations, and the decline of natural food resources have increased interactions between brown bears and rural communities (FPWC, unpublished monitoring data, 2023–2026). As natural habitats have become increasingly fragmented, bears more frequently forage in orchards, apiaries, agricultural fields, and villages, resulting in growing economic losses and safety concerns. Recognising the growing importance of this issue, the Ministry of Environment of the Republic of Armenia established an interagency Working Group on Human–Wildlife Conflict in 2023 to develop scientifically grounded mechanisms for conflict prevention and mitigation. The Working Group brings together governmental institutions, research organisations, environmental non-governmental organisations, and independent experts to promote coordinated, evidence-based approaches to conflict management while ensuring the conservation of protected wildlife species.



Figure 2: A brown bear damaging beehives (Photo: A. Gyonjyan / FPWC).

Within this framework, researchers from the Scientific Center of Zoology and Hydroecology of Armenia are investigating the ecological and anthropogenic drivers of human–brown bear conflict in Vayots Dzor Province. The findings indicate that the recent increase in bear incursions is primarily the result of long-term anthropogenic transformation of natural ecosystems rather than changes in bear behaviour alone. Extensive logging during the energy crisis of the 1990s, particularly the destruction of native wild fruit tree stands dominated by wild apple (Malus orientalis), willow-leaved pear (Pyrus salicifolia), and Caucasian pear (Pyrus caucasica), substantially reduced important seasonal food resources for brown bears. Habitat degradation has been further intensified by hydrological alterations associated with intensive small hydropower development, while unmanaged household waste and other anthropogenic food sources increasingly attract bears into agricultural landscapes and rural settlements. Camera-trap monitoring, field surveys, spatial analyses, and interviews with local communities have enabled the identification of conflict hotspots and informed the implementation of evidence-based mitigation measures, including electric fencing, habitat restoration through native fruit-tree planting, experimental supplementary feeding, and carefully assessed translocation of problem individuals. Social surveys further indicate that concerns regarding human safety often exceed concerns about economic losses, emphasising the importance of integrated management approaches that address both the ecological and social dimensions of conflict (Gyonjyan, et al, unpublished data). Together, these findings demonstrate that effective human–wildlife conflict mitigation relies on engagement with local communities that help address the underlying drivers of conflict

while balancing biodiversity conservation with the safety and livelihoods of local communities. More broadly, the long-term history of human–animal interactions in the Armenian Highlands demonstrates that coexistence is not a static condition but a dynamic process of adaptation between people, wildlife, and changing environments. Understanding this shared history provides an essential scientific foundation for developing evidence-based conservation strategies that promote the sustainable coexistence of people and wildlife in the future.

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Beyond Biodiversity: Geodiversity as a Foundation for Conservation in the Rajmahal-Ganga Ecosystem, India

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The River Ganga originates in the high-relief Himalaya, a young fold mountain belt formed by the collision of the Indian and Eurasian tectonic plates during the Eocene (~55 Ma). Along its ~2,500 km course, the river has shaped extensive floodplains that have supported human settlement and civilization since the Paleolithic phase (Jha et al., 2025), before culminating in the world's largest delta and contiguous mangrove forest, a transboundary UNESCO World Heritage Site shared by India and Bangladesh (IUCN, 2025).

In Northern India, the Ganga River system encompasses a complex mosaic of fluvial landscapes, geomorphic features, hydrological regimes, soils, and riparian habitats that sustain rich biodiversity. These ecosystems support threatened species such as the Gangetic dolphin (*Platanista gangetica*), gharial (*Gavialis gangeticus*), Ganges shark (*Glyphis gangeticus*), and golden mahseer (*Tor putitora*), etc. (Kelkar et al., 2022). Although changes in hydroclimatic and physicochemical regimes are recognized as major threats to downstream ecosystems, particularly the Sundarbans mangroves (IUCN, 2025), conservation efforts within the Ganga basin have largely centred on biological diversity and water quality. Comparatively less attention has been given to the basin's geodiversity, which is the outcome of long-term co-evolution between geological processes, fluvial dynamics, and human land use histories operating across deep time and historical time.

This imbalance is exemplified by the Rajmahal–Ganga geosystem (RGG), a freshwater riverine ecosystem

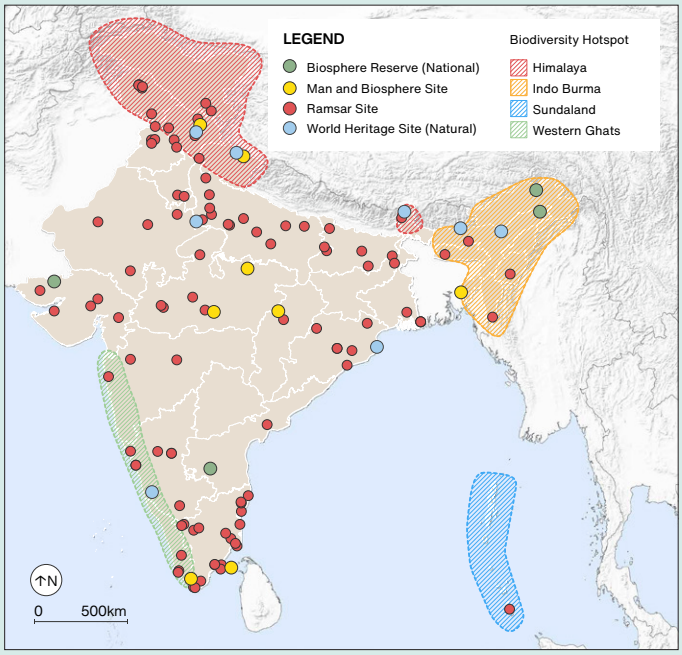
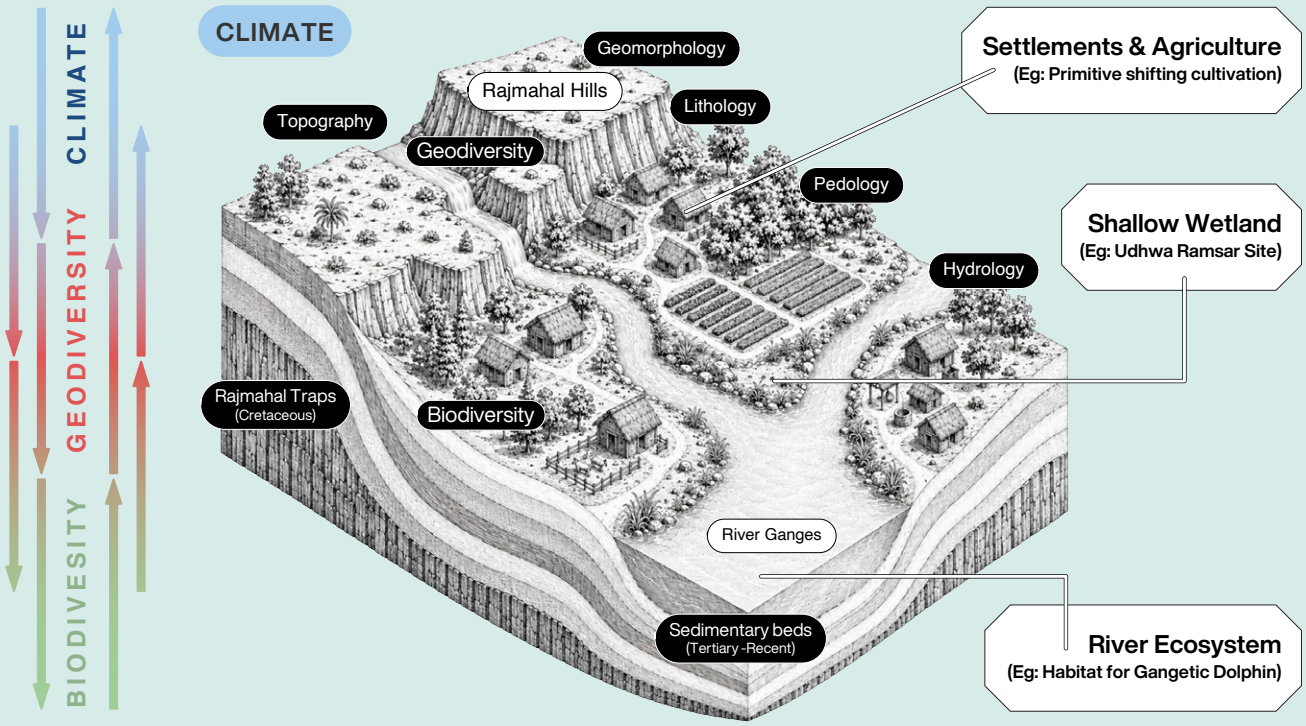


Fig.1: Maps showing a. The distribution of sites with significant biodiversity (biosphere reserves, RAMSAR Wetlands, World Heritage Site – natural, and biodiversity hotspots) in India; and b. False-colour composite (FCC) image illustrating channel migration of the Ganga River between Vikramshila Wildlife Sanctuary (west) and the Udhwa RAMSAR Site and Bird Sanctuary (east) over a decade (June 2016 to May 2026). Data source: USGC EarthExplorer.



within the tropical moist deciduous forest biome, comprising riparian vegetation, floodplain wetlands, and alluvial habitats. It includes the Barhel and Pataura lakes, a RAMSAR site within the Udhwa Bird Sanctuary, Sahibganj District, Jharkhand (Fig.1a). The RGG represents a time-stratified landscape shaped by the legacy of the Rajmahal Large Igneous Province (deep time; ~118-115 Ma; Kent et al., 2002) and the ongoing Quaternary evolution of the Ganga fluvial system (recent geological time), producing contemporary ecological configurations.

Situated along the Central Asian Flyway, the sanctuary supports rich aquatic vegetation, about 80 waterbird species, including 39 migratory and 29 resident species, and 14 bird species (e.g., Asian Woolly-necked Stork, Lesser Adjutant Stork, Common Pochard, Palas's Fish Eagle, Black-headed Ibis, Black-necked Stork, Ferruginous Duck, Pallid Harrier, Greater Spotted Eagle, River tern, Oriental Darter, Eurasian Curlew, Rufous-vented Grass-babbler, Alexandrine Parakeet) and 45 fish species (e.g., *Wallago attu*, High fin Glassy Perchlet, etc.) listed as threatened or vulnerable on the IUCN Red List (RAMSAR, 2025). Beyond its biodiversity value, the wetland provides freshwater, hydrological regulation, nutrient cycling, climate moderation and hazard mitigation. However, conservation and management commonly treat these shallow (~1.5-2 m), small (~9.5 km^2) lakes as static ecosystems rather than products of active fluvial processes driven by sediment transport, channel migration, and seasonal hydrological variability.

The broader significance of the RGG is also reflected in ongoing conservation initiatives along the Ganga River. Two of the six ecologically sensitive zones identified by the National Mission for Clean Ganga and the Wildlife Institute of India for implementing community-based micro-plans are located within its zone of influence at Sahibganj and Bhagalpur (Microplan | Wildlife Institute of India, an Autonomous Institute of MoEF, Govt. of India). The microplan combines biodiversity conservation with livelihoods, sanitation, renewable energy, agriculture, fisheries and community awareness. Mukimpur, Masaklaiya, and Ghat Jamni villages in Sahibganj lie on geomorphically sensitive point bars, terraces and floodplains adjoining the Udhwa wetlands, underscoring the importance of integrating conservation with dynamic landscape processes. Upstream, the Vikramshila Gangetic Dolphin Sanctuary at Bhagalpur protects India's only

Fig. 2: The block diagram illustrates the dynamic relationships among climate, geodiversity, and biodiversity. The left axis highlights their interactions, both directly and through intermediary processes. In the Rajmahal-Ganga landscape, the Cretaceous Rajmahal Traps and active Paleogene-Quaternary fluvial dynamics together shape topography and hydrology. These geodiverse features determine ecosystem distribution (e.g., wetlands and river channels) and influence human land use, including shifting cultivation and settlements. They also generate geosystem services by supporting habitats such as the Udhwa Ramsar wetland and Gangetic Dolphin sanctuary, regulating biogeochemical cycles, and sustaining socio-ecological adaptation through local cultural and knowledge systems.

designated sanctuary for the endangered Ganga Dolphin (*Platanista gangetica*) (Kelkar et al., 2022). The Sahibganj–Bhagalpur stretch supports deep pools, eddies and sediment-rich river confluences that maintain suitable habitat for the species. These examples illustrate that effective conservation is closely linked to geomorphic processes (Fig. 1b), although this connection is rarely made explicit in management strategies.

The RGG illustrates how geodiversity forms the physical foundation for ecological processes. Geological substrates, landforms, hydrological connectivity and sediment dynamics shape nutrient availability, habitat diversity, and ecosystem functioning (Gray, 2013). However, these abiotic controls remain largely overlooked in conservation policy, reflecting a bias that prioritizes biological components while treating geological and geomorphic processes as passive background conditions. This also limits recognition of geosystem services, which support not only biodiversity but also provisioning, regulating, cultural, educational, and knowledge values (Fig. 2; Gray, 2018; Scammacca & Bétard, 2026). Incorporating geodiversity into conservation planning would provide a more complete understanding of ecosystem function and resilience by recognizing that biodiversity depends on the physical environment that sustains it.

The RGG also shows how interactions between the geosphere and human societies have changed through historical land use practices. Before colonial expansion, the indigenous Paharia community relied on low-intensity forest-based livelihoods, including shifting cultivation (Pratap, 2000). During the nineteenth century, colonial land policies promoted settlement in the plains and foothills and introduced formal land tenure systems that reshaped land ownership and resource use. Agricultural expansion and forest loss increased pressure on riverbanks and wetlands, disrupting sediment transport, riverbank stability and floodplain dynamics. These changes demonstrate that biodiversity has been shaped not only by geological processes but also by successive socio-political regimes that transformed land, water and sediment systems over time.

At the national scale, the role of geodiversity in shaping natural and human-induced environmental change remains poorly quantified and is rarely integrated into conservation policy. This reflects a continued emphasis on biological components, often overlooking the abiotic and cultural foundations of ecosystems.

As a result, the interactions among geodiversity, biodiversity and human societies across spatial and temporal scales remain underrepresented in conservation planning.

As a result, the interactions among geodiversity, biodiversity and human societies across spatial and temporal scales remain underrepresented in conservation planning (Scammacca & Bétard, 2026). Without accounting for site-specific geological processes, conservation efforts may address ecological symptoms rather than the processes that sustain ecosystem integrity. Although geological and climatic change is inevitable, its ecological impacts can be reduced through informed and adaptive management (Brilha et al., 2018; IUCN, 2020). The RGG demonstrates that biodiversity is a product of interacting geophysical, ecological and socio-cultural processes evolving through time. Recognising this requires integrating geodiversity, ecosystem dynamics and human history within an Earth system perspective.

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Key Insights

- The RGG shows that biodiversity cannot be understood or effectively conserved without considering the geodiversity that underpins it. A deep-time perspective reveals that geological, hydrological, climatic, and biological processes have co-evolved to shape the landscapes and habitats that support biodiversity today.
- Although geological processes regulate habitat formation, sediment dynamics, hydrological connectivity, and ecosystem resilience, they remain only weakly represented in conservation policy.
- Recognising geodiversity as an integral part of conservation would provide a more complete understanding of ecosystem change and improve the management of landscapes facing increasing environmental pressures.
- Rather than treating geology as a static backdrop, conservation should acknowledge it as a dynamic component of ecosystem evolution. Such a shift provides a stronger scientific basis for resilient landscapes and more adaptive conservation in the Anthropocene.

5.3 South America



Photo by Backroad Packers on Unsplash

This chapter looks at diverse approaches to biodiversity conservation across South America, highlighting the challenges of protecting nature amid social, economic, and environmental pressures. Contributions from Colombia and Brazil consider context-specific conservation strategies, the role of Indigenous and local knowledge, community-based biodiversity monitoring, and the restoration of landscapes shaped by fire and mining. Together, they emphasise the importance of recognising local knowledge, community participation, and the complex relationships between people and their environments in developing more equitable and effective approaches to conservation.

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Conserving Biodiversity from the Global South: Conservation Goals Amid Uncertainty and Inequality

German Corzo[1], Susana Rodríguez Buriticá[1], Elkin Alexi Noguera Urbano[1], and Nicolas Corral-Gómez[1]

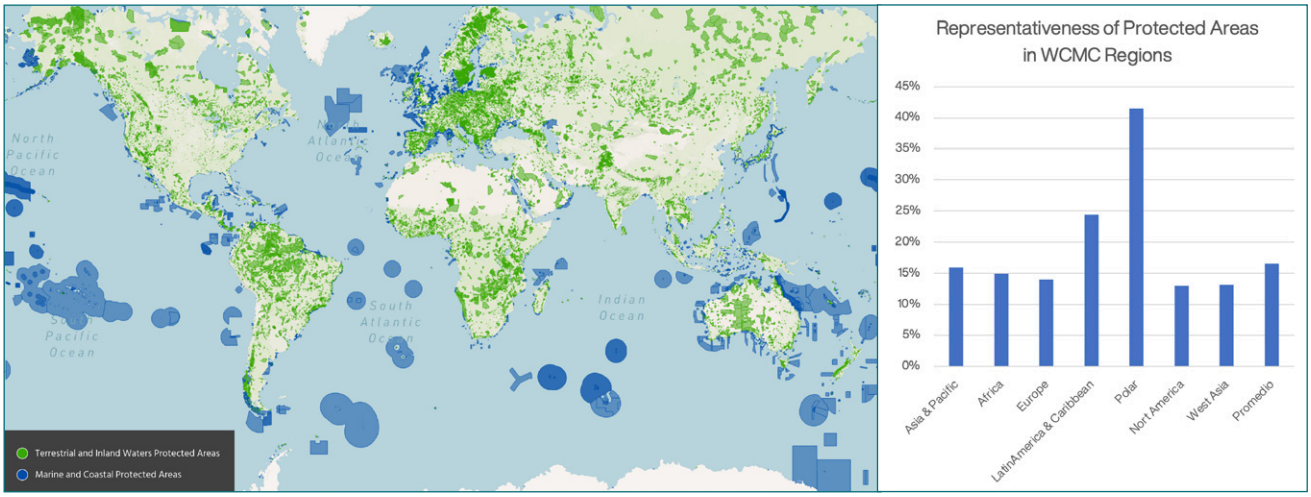
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Global biodiversity is not homogeneous. Specifically, countries with the highest rates of biodiversity are deemed as 'megadiverse' with the majority of these locals concentrated in the intertropical region (Jung et al., 2021; Pollock et al., 2017; Shen et al., 2023) and within the Global South. These megadiverse countries of the Global South (Colombia, Ecuador, Venezuela, Brazil, Peru, Mexico, Kenya, South Africa, the Dominican Republic Congo, Indonesia, Papua New Guinea, Tanzania, Thailand, Myanmar, Vietnam) share many common characteristics, including significant proportions of land remaining undisturbed, parts of which are incorporated into Protected Area (PA) systems and part of governments with moderate economies, social inequality and, in some cases, relatively low human population densities.

The database of terrestrial and marine protected areas (UNEP-WCMC) shows that Latin America and the Caribbean is the only populated region on the planet that met the Aichi target and is closer to meeting the Kunming-Montreal target.

The conservation of global biodiversity has been closely linked to the designation and management of PAs, which are considered one of the most cost-effective measures for maintaining viable populations of flora and fauna, as well as the ecological processes that sustain them and provide benefits to human populations. In this regard, international organisations such as UNEP, the CBD, IPBES and IUCN have been setting Conservation Targets (CTs), defined as the proportion of terrestrial and marine areas within national jurisdictions subject to active conservation measures. These targets have steadily increased

Figure 1: The database of terrestrial and marine protected areas (UNEP-WCMC) shows that Latin America and the Caribbean is the only populated region on the planet that met the Aichi target by 2020.



since the end of the last century, from 10% according to the IUCN, to 30 per cent by 2030 (GFB Kunming Montreal, 2022). This includes the Aichi Targets that aim for 17% terrestrial and 10% marine conservation by 2020 and even more ambitious recommendations such as 50% by 2050 (Wilson, 2016).

However, despite the increase in MCs, the rate of biodiversity loss remains at critical levels. The global Living Planet Index (LPI) stands at -73%, with freshwater ecosystems experiencing the greatest loss (-85%), followed by terrestrial ecosystems (-69%) and marine ecosystems (-56%), as reported in the Living Planet Report (WWF, 2024). In contrast, UNEP-WCMC-IUCN (2024), as part of the 'Protected Planet' initiative, reports that the only inhabited region on the planet to have achieved the Aichi Target in 2020 was Latin America and the Caribbean (LAC). Yet this is precisely the region that the WWF assessment identifies as experiencing the fastest rate of biodiversity loss globally (-95%), followed by Africa (-76%), with both regions exceeding the global average rate of biodiversity loss recorded by the IPV.

These planetary conservation frameworks are defined from a global geopolitical perspective and must be considered against the ecological, social and economic realities of the territories at different levels (i.e., local, regional, national), and in relation to the spatiotemporal scales of the best available information. Global conservation frameworks must therefore be translated into technical and scientific targets that reflect the specific contexts of the territories they seek to conserve.

The ecological representativeness of PAs has been a one-size-fits-all approach to biodiversity conservation from landscapes, ecosystems, populations and communities to genetic diversity. The concept of ecological representativeness assumes that placing a significant part of the whole under protection, whether these be ecoregions, biomes, species ranges, or populations of fauna, flora and biocultural landscapes, helps ensure the maintenance of ecological processes and, consequently, the flow of matter, energy and information between PAs and surrounding areas, thereby contributing to the conservation of biodiversity. However, reasonable doubts remain as to what proportion is sufficient, given that there are no universal answers. For example, zonal and azonal ecosystems exhibit different responses, as do the ranges of widely distributed species and those considered endemic and geographically restricted. Conservation measures must therefore be tailored to these different ecological contexts.

Furthermore, the 2022 Kunming–Montreal Global Biodiversity Framework incorporates useful concepts, such as distinguishing between and integrating managed conservation areas (MCAs) and PAs. The former are understood as areas that have been designated, demarcated and managed with a long-term vision, whilst the latter are those which, although not officially designated, maintain natural cover and make definite contributions to biodiversity conservation. These include, but are not limited to, 'Other Site-based Effective Conservation Measures (OMEC)'. There are also numerous territories that, while not designated for PAs or OMECs, make considerable contributions to biodiversity conservation by maintaining natural cover and ecological functionality, even though conservation is not their primary objective. These include Indigenous reserves, collective territories of Afro-descendant communities, Campesino (peasant) rural reserves, and even 'montes' and water sources on private agricultural land, which land owners consider essential to their production processes.

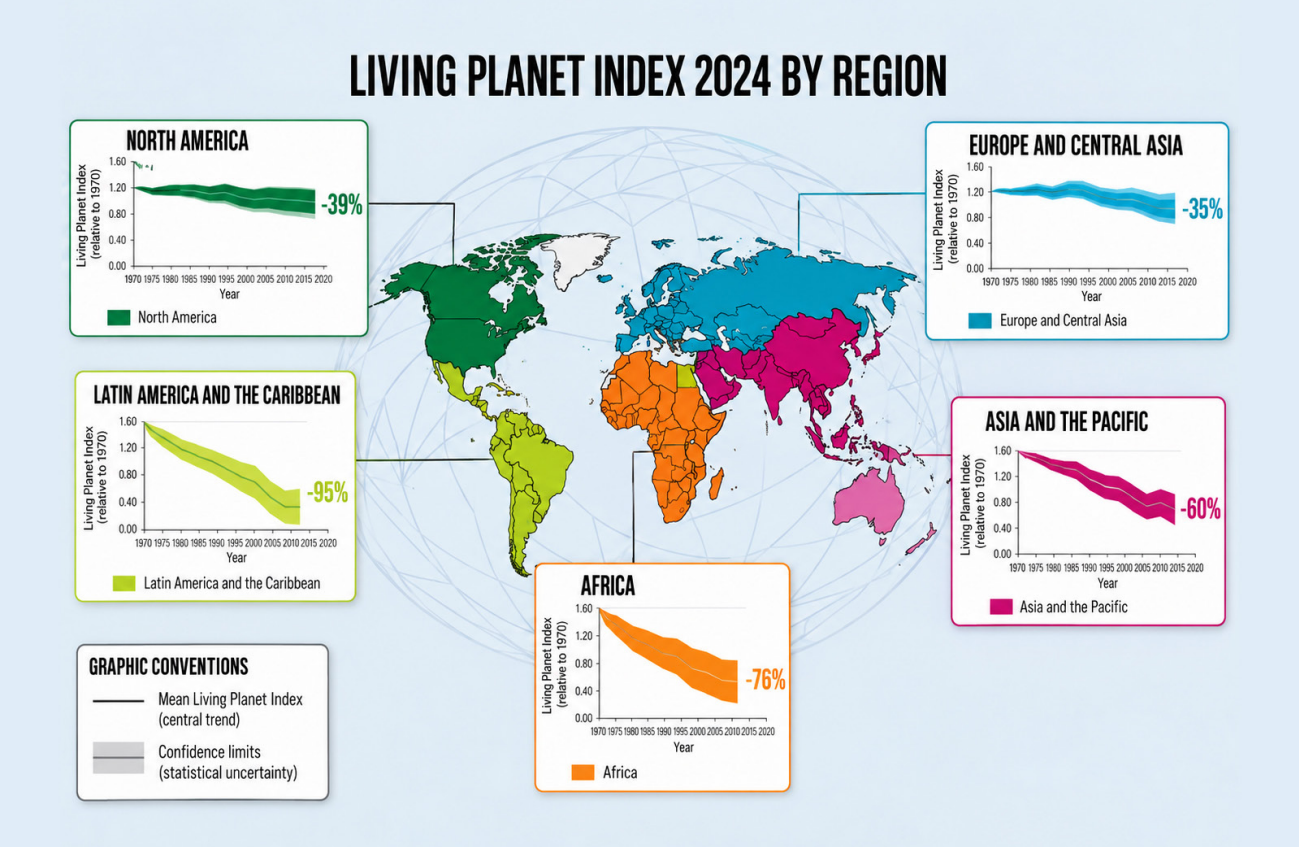
Countries that are megadiverse in terms of species numbers owe this status to their high diversity of landscapes, biomes and ecoregions, but even within these units, conservation

management requires a context-specific approach. This is essential to prevent averages from masking gaps in conservation. For example, in páramo ecosystems where nearly 52% of the entire Colombian Spectacled Bear (*Tremarctos ornatus*) population are located within the 3,000,000 hectares designated as National Parks and other protected areas. Even so, a significant portion of their natural páramos habitat still lacks legal protection.

Similarly, the Colombian Amazon biome maintains natural cover of approximately 99%, largely due to a 26% of the biome being composed of PAs and complemented by other forms of land management, including Indigenous reserves (63%). Despite this, major regions within the biogeographical boundaries of the Colombian Amazon like Florencia–Cagüan have very low remaining natural coverage and essentially no representation within PAs.

In Colombia, the 'mona difícil syndrome' (Corzo et al, 2023) is emerging, which describes a law of diminishing returns in conservation where new PA add less and less new ecological value because the most critical areas were already protected. This situation may be linked to the fact that large areas of high ecological integrity have already been designated as PAs or allocated as collective territories, while more recent addition of PAs consists mainly of small areas with a high edge effect, medium to low ecological integrity, and relatively low contributions to ecological representativeness and connectivity. Although around 17% of terrestrial ecosystem types remain to be represented, these account for barely 2.6% of the country's land area (Corzo et al., 2020). This situation has not been reversed despite the passage of time and the increase in the number of PAs within the National System of Protected Areas (SINAP), which rose from 130 in 2000 to 1,162 in 2019 (Corzo et al., 2020) and is projected to reach 1,710 by 2025 according to the Single Register of Protected Areas (RUNAP).

Figure 2: Regional trends in the Living Planet Index, 1970–2020. The Living Planet Index is shown for five global regions, with values relative to the 1970 baseline.



These trends have raised global concerns about the potential limitations of this conservation mechanism, or at least about the excessive reliance placed on area-based biodiversity conservation strategies which are commonly the primary focus of MCs. In the case of megadiverse countries in the Global South, additional challenges arise related to the effectiveness of management with insufficient funding as well as potential land conflicts with Indigenous and local communities. Furthermore, some authors question the mechanism's effectiveness in limiting the risks of biodiversity loss associated with the uncertainty of the Anthropocene, particularly given the synergistic effects of multiple drivers of biodiversity loss, including climate change, ecological fragmentation from land-use change, introduction of invasive alien species and pollution. PAs may therefore prove insufficient on their own to address these interacting pressures.

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Key Insights

- The megadiverse countries of the Global South have historically seen their prospects for development and well-being constrained by the prevailing economic model of perpetual growth and unbridled consumption; in many cases, this has not been the result of deliberate public policy, but rather a consequence of trade deficits and international geopolitical dynamics. However, this asymmetry means that these countries now harbour an extraordinary proportion of the planet's biodiversity, such that 70% of all existing life forms are sustained within just 10% of the world's land area. This has many implications, but the one we wish to emphasise is that although biodiversity conservation is a global responsibility, its costs and burdens fall primarily on the megadiverse countries of the Global South.
- To maintain natural capital and its functionality, local communities and governments must be able to share in the benefits and development rather than being excluded from them.

Restoring Pyrodiversity: Fire histories, Quilombola knowledge, and biocultural futures in the Brazilian Cerrado

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In the Brazilian Cerrado biome, the most biodiverse savanna on the planet, biodiversity conservation requires relearning how to live with fire. For decades, suppression-based environmental policies classified local burning practices as threats to nature, criminalizing agroextractive practices and disrupting traditional ways of life. This model produced unintended consequences. By disrupting homogenizing fire regimes and encouraging the accumulation of vegetal fuel, it created conditions for late-season fires that are larger, more intense, and harder to control.

Fire ecology has shown that tropical savannas and other pyrophytic ecosystems have been shaped by long histories of combustion, climatic variability, and human action (Bond, Woodward & Midgley 2005; Scott et al. 2014; He, Lamont & Pausas 2019). In the Cerrado, prolonged fire exclusion can profoundly alter these historical fire regimes (Durigan & Ratter 2016). By promoting the accumulation of fine fuels, it can increase the occurrence of large and intense late-dry-season wildfires. When fire is suppressed over longer periods, it can also favour woody encroachment and the replacement of open grassland and savanna ecosystems denser vegetation (De Souza et al. 2022; Souza et. al., 2019). Both trajectories can reduce habitat heterogeneity and threaten species and ecological processes associated with fire-maintained Cerrado landscapes (Fidelis & Pivello 2011 and 2020). Cerrado biodiversity, therefore, must to be understood as emerging from historical relationships among climate, soils, plants, animals, territories, human practices, and diverse fire regimes. Maintaining and restoring this ecological heterogeneity is consistent with Target 2 of the Kunming-Montreal Global Biodiversity Framework, which calls for effective restoration that enhances biodiversity, ecosystem functions and services, ecological integrity, and connectivity. In Brazil, this approach has recently gained a concrete policy framework through the 2024 National Policy for Integrated Fire Management (Schmidt et al. 2018), which recognizes the ecological role of fire while explicitly respecting traditional knowledge and practices of fire use (Fagundes, 2019a,

Fire ecology has shown that tropical savannas and other pyrophytic ecosystems have been shaped by long histories of combustion, climatic variability, and human action.

2019b, 2021). Together, these developments point toward an understanding of Cerrado restoration in which biodiversity conservation depends not only on vegetation recovery, but also on restoring and governing the diverse ecological and social relations through which fire regimes are produced.



Figure 1: Fire landscapes in Jalapão, Brazilian Cerrado. In Quilombola territories and conservation units, fire is part of agroextractive calendars, territorial care practices, and historical processes of biodiversity formation. Crédits: Guilherme Moura Fagundes

The RESPIRO project — Restoring Pyrodiversity in the Cerrado — begins from this premise. Inspired by the hypothesis that pyrodiversity can promote biodiversity (Martin & Sapsis 1992), while taking seriously critiques of generic and unidirectional uses of this paradigm (Parr & Andersen 2006; Bowman et al. 2016; Jones & Tingley 2022), the project investigates pyrodiversity as a biocultural and sociotechnical phenomenon. It focuses on three Cerrado pyrodiversity heritages: golden grass (*Syngonanthus nitens*) in Jalapão, the *sempre-vivas* flowers of the Serra do Espinhaço, and traditional cheese from the Serra da Canastra. In these systems, fire is woven into operational sequences, productive calendars, territorial regimes, and local ecological knowledge (Figure 1).

Jalapão, in the state of Tocantins, offers a particularly important case. Quilombola communities have historically managed fire through practices such as golden grass harvesting, hyper-extensive cattle raising in a free-range regime known as *solta*, slash-and-burn agriculture, fire-assisted hunting, territorial mobility, and the renewal of native pastures (Fagundes 2019a, 2019b, 2021; Eloy et al. 2019). Parts of these territories were later included within or overlapped by strict-protection conservation units, including the Serra Geral do Tocantins Ecological Station (Fagundes and Barradas 2025). The conflict over fire thus became a dispute not only over territory, but also over who has the authority to define which practices and forms of knowledge are legitimate in shaping and sustaining regional biodiversity. Since 2014, the implementation of Integrated Fire Management in the Cerrado has marked an important shift by recognizing the ecological and cultural role of fire and bringing fire ecology, environmental management, and community participation into closer relation (Mistry et al. 2019; Falleiro et al. 2016; Schmidt et al. 2018; Steil et al. 2019).

Restoring pyrodiversity however, cannot be reduced to the standardized application of prescribed burns. The challenge is to identify which fire regimes, in which seasons, scales, intensities, and social relations, can maintain habitat heterogeneity, and ecological resilience, while simultaneously maintaining culturally just landscapes. Studies on Indigenous and community burning have shown that local practices can create pyrodiverse mosaics, reduce the risk of catastrophic wildfires, and sustain complex forms of territorial management (Kimmerer & Lake 2001; Bird et al. 2008; Welch et al. 2013; Trauernicht et al. 2015; Roos et al. 2018). Their significance for biodiversity conservation extends beyond calls for greater participation in environmental policymaking. Traditional fire practices are embedded in territorial institutions and collective decisions about where, when, why, and by whom fire should be used. Recognising them therefore requires not only incorporating local knowledge into fire-management programmes, but also ensuring that traditional peoples and communities participate in decisions about fire regimes, and biodiversity governance (Bilbao et al. 2019). In the Cerrado, this shift has already begun to take institutional form.

During the implementation of an Integrated Fire Management in Jalapão, community meetings were used to define management objectives and develop local burning calendars (Fagundes, 2019b), while formal agreements between protected areas and local communities incorporated traditional fire uses into management arrangements (Barradas and Torres, 2021). At the national level, Brazil's 2024 National Policy for Integrated Fire Management further institutionalised this approach by establishing participatory and shared governance, recognising traditional and adaptive fire use, and requiring the participation of Indigenous peoples, Quilombola communities, and other traditional communities in fire-management planning within their territories (Law No. 14,944/2024).

The international and interdisciplinary collaboration deepens this agenda by embedding RESPIRO within a long-term perspective, building on research that integrates ethnography, palaeoecology, and archaeology to reconstruct historical interactions among humans, climate, vegetation, and fire, while revealing the ecological legacies of Indigenous land management practices in Amazonia (Watling et al. 2017, 2023; Maezumi et al. 2018, 2022, 2023). Adapted to the Cerrado, this collaborative approach will make it possible to investigate historical fire regimes in areas of ecological and cultural relevance to Quilombola communities, especially in Jalapão. Sediment cores from lakes and wetlands, combined with charcoal, pollen, phytolith, stable isotope, and radiocarbon analyses, can help distinguish vegetation change, climatic variability, and signs of anthropogenic burning through time (Whitlock & Larsen 2002; Leys et al. 2015; Belcher et al. 2018; Gosling et al. 2019; Maezumi et al. 2021; Watling et al. 2017).



Figure 2: RESPIRO investigates pyrodiversity as a biocultural heritage of the Cerrado. Ethnography, palaeoecology, archaeology, remote sensing, and knowledge co-production connect deep fire histories to futures of conservation and restoration. Crédits: Guilherme Moura Fagundes

A long-term approach helps unsettle two recurrent assumptions. The first links restoration to the return of a nature without fire and without human presence, an assumption already challenged by conservation anthropology and historical ecology (Diegues 1996; Cronon 1996; Balée 2006; Erickson 2008; Fagundes and Barradas 2026). The second treats pyrodiversity as the direct result of conscious cultural intention. RESPIRO proposes a different path. Pyrodiversity may emerge as a systemic effect of ways of life, technical practices, multispecies interactions, and territorial histories. This hypothesis resonates with Gregory Bateson's critique of purposive reason and with Anna Tsing's notion of "unintentional design" in anthropogenic landscapes (Bateson 1972; Tsing 2015, 2023).

The project's methodology combines temporal scales and distinct forms of evidence. At the synchronic level, RESPIRO documents the "operational sequences" (*chaînes opératoires*) of agroextractive practices (Mauss 2003; Leroi-Gourhan 1984; Lemonnier 1992; Coupaye 2017), follows community and prescribed burns, and conducts interviews, participatory workshops, and audiovisual documentation with Quilombola residents, firefighters, farmers, extractivists, and environmental managers (Figure 2). At the diachronic level, it reconstructs historical fire regimes through palaeoecological and archaeological data, as well as remote-sensing time series, including burned-area datasets and Landsat imagery (Alencar et al. 2022, 2024). Looking toward the future, the project organizes these materials in PiroAtlas, a bilingual,

hypermedia, georeferenced digital platform dedicated to Brazil's on-farm pyrodiversity heritage.

PiroAtlas was conceived as an infrastructure for environmental justice and mediation among science, communities, and public policy. By bringing together fire-scar maps, local burning calendars, territorial narratives, audiovisual records, historical series, and palaeoecological baselines, the platform will make visible relations that conventional conservation instruments rarely capture. Its aim is to support forms of knowledge coproduction that connect ecological restoration and historical reparation through biocultural memory and fire governance. Restoring pyrodiversity in the Cerrado means recognizing that some biodiverse landscapes are living archives of historical relations among humans and non-humans. Conservation and restoration policies that recognize these relationships can strengthen ecological integrity while respecting the knowledge, territories and practices of the communities that have shaped and cared for these landscapes. Projects such as RESPIRO, together with the community-based and public fire-management initiatives discussed throughout this report, are already working to translate these principles into practice by documenting traditional fire regimes, developing participatory maps and burning calendars, and creating spaces in which communities, scientists, and environmental agencies can negotiate restoration priorities. Their work shows that effective conservation depends on learning from these ecological archives and knowledge systems while strengthening the participation and authority of the communities that sustain them in decisions about fire and biodiversity.

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Key Insights

- Cerrado biodiversity results from a long history of interaction among fire, climate, soils, life forms, and human management practices. Policies based solely on fire suppression tend to impoverish this complexity and may increase the risk of severe wildfires.
- The challenge for public policy is not to replace fire exclusion with uniform prescribed burning, but to build a participatory, historically informed, and socially just approach to the biocultural governance of fire.
- Restoring pyrodiversity requires recognizing local knowledge and distinguishing fires that destroy landscapes from those that sustain biodiversity, habitat mosaics, and socioecological resilience. Thus, conserving the future of Cerrado biodiversity depends on understanding fire's many pasts.

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Safeguarding Biodiversity in Post-Mining Landscapes: Lessons from Serra do Navio, Brazilian Amazon

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MINING ENVIRONMENTAL IMPACTS IN SERRA DO NAVIO

Post-mining landscapes are increasingly common across the Global South, yet they remain largely absent from biodiversity discussions. Serra do Navio is a municipality in the Brazilian Amazonian, located in the State of Amapá, in the Guyana Shield. The city was first founded as a company town for the Indústria e Comércio de Minérios S.A. (ICOMI) manganese mining enterprise, a joint venture between the CAEMI group and Bethlehem Steel Corporation, which became the first industrial mining project in the Brazilian Amazon. The mining activities lasted almost half a century, from 1957 until 1997, when the company halted mining operations, plunging the town into an economic crisis and leaving a legacy of environmental degradation. The company town and open-pit mines were settled in an area of upland "terra firme" forest, connected to the port company town of Vila do Amazonas by a 194km railroad, which crossed Amazonian Savannas until reaching the densely forested area where Serra do Navio was located.

Serra do Navio illustrates both the long-term ecological legacies of extraction and the opportunities for biodiversity conservation during environmental restoration. Despite the environmental damages of ICOMI's enterprise expanding beyond Serra do Navio, notably by prompting deforestation of Amazonian Savannas along the railway and opening a new commodity frontier (Moore, 2000) within the Amazon, this contribution focuses on the local impacts of mining. In Serra do Navio, an estimated area of 1350 hectares was deforested, directly impacting local biodiversity through habitat loss and forest fragmentation (REVECOM, 1998a). Under ICOMI administration, there were at least three recorded



Figure 1: Map of Serra do Navio, showing the company town, the mines and the tailings dams. Source: ICOMI, n.d. In: FAUUSP Archives.

environmental accidents, affecting both human and non-human communities. The first accident was recorded in 1979, when one of the company's tailings dams failed, damaging infrastructure and polluting the Amapari River (ICOMI, 1979). The second accident involved the rupture of Baixinho's tailings dam in 1987, affecting riverine life along the Amapari River and compromising the water supply of at least three municipalities (ALAP, 1999). Finally, in 1988, the poor management of the mining rejects piles resulted in the collapse of one of them into the Amapari River (ALAP, 1999). [JS1] The results of this accident are still visible in the area with the reduction of the river's bed. The impact of all three accidents on the local biodiversity remains undocumented.

Since the 1988 Brazilian Constitution, mining companies have been obliged to restore mined areas through a Plan for the Restoration of Degraded Areas (PRAD). In 1989, ICOMI was required by the state to restore the mined and industrial areas, manage the tailings dams and assess pollution levels in the Amapari River and affected Igarapés. This restoration project was run until 2004, when the company's assets were sold to Alto Tocantins Mineração, which discontinued the restoration process (TJAP, 2009). In 2009, the noncompliance with Brazilian environmental law led the Public Prosecution Office, together with the Municipality of Serra do Navio, to file a lawsuit against the Alto Tocantins Mineração and Ecometals Manganês do Amapá, which owned the remaining manganese stockpiled in the city. The long-lasting litigation came to an end this year, ultimately granting 50% of the profits of half of the stocked manganese to the municipality, so they could continue environmental restoration.

ENVIRONMENTAL RESTORATION AND CONSERVATION IN SERRA DO NAVIO

Serra do Navio's unresolved restoration plan only partially restored the mine caves, and some still suffer from erosion. However, beyond the bare slopes, the most striking legacy from the plan is the introduction of the exotic plant *Acacia mangium* Willd, which was extensively used for the reforestation of the area (REVECOM, 1998a, 1998b). This tree, native to Australia, Indonesia and Papua New Guinea, was able to thrive in Serra do Navio's nutrient-scarce mined landscapes, offering an opportunity for environmental restoration. However, *Acacia mangium* has also been identified as a potentially invasive species, and its presence in non-native environments might be associated with biodiversity loss (Koutika and Richardson, 2019). Another striking aspect of the town's unfinished environmental restoration plan is the abandoned tailings dams, which are classified as high risk by the Brazilian Federal Mining Authority and are by far the most degraded areas (ANM, 2026). The resources obtained through the environmental lawsuit offers hope that restoration measures will restart, perhaps this time guided by scientific research aligned with the preservation of local biodiversity, avoiding pitfalls such as the introduction of exotic species without follow-up.



Figure 2: Acacia mangium Willd grows close to one of ICOMI's tailings dams. Source: Authors (2025).

Despite the difficulties, Serra do Navio's community demonstrated socioenvironmental resilience amidst these socioenvironmental injustices, common to mining enclave communities that work as capitalism's sacrifice zones. Nowadays, the city, also listed as a National Heritage by the Brazilian National Heritage institution, mostly on account of its modernist architecture, works to become a hotspot for sustainable ecological tourism. As one of the main gateways to Tumucumaque National Park, the biggest rainforest conservation reserve in the world, and a pioneer in establishing a municipal natural reserve in the state of Amapá, the town receives biodiversity enthusiasts, photographers and researchers who advance the knowledge of unknown Amazonian species.



Figure 3: Trail to enter the Cancão Natural Park. Source: Authors (2025).

The Municipal Natural Park of Cancão, a remaining 370-hectare fragment of primary rainforest turned into a natural park in 2007, was the stage of a few scientific discoveries on local biodiversity. Research conducted at the park has identified at least 110 Bryophyte species, among those, 63 of which were never recorded in the Amapá state, and 3 which were never recorded in the whole of the northern Brazilian region (Oliveira-Da-Silva and Ilkiu-Borges, 2020). Another study by Silva e Silva and Costa-Campos (2018) recorded 49 species of Anuran Amphibians, including 3 endemic species. Finally, another study has provided the first reptile record of the natural park, in which 57 species are recorded, a number considered relatively high by the scientists (Costa-Campos et al., 2021). As more studies are conducted, the rich biodiversity of this small stretch of land amidst a degraded post-mining landscape becomes evident. These studies illustrate how even relatively small protected areas can play a disproportionate role in safeguarding biodiversity within heavily modified landscapes.

If initiatives such as the creation of the Cancão Natural Park point the way forward, others are a threat to conservation in the region. In 2026, Tucano Gold Inc. restarted gold mining in the neighbouring town of Pedra Branca do Amapari, a project expected to also impact Serra do Navio. The Tucano gold mine was formerly owned by the Canadian Great Panther Group, which was fined US$9 million for contaminating water bodies with cyanide (Vidigal, 2021). Regardless of the historical precedent of environmental degradation by mining companies in the state of Amapá, the government granted the new company a license to operate. Despite the advertisement for new jobs, local history reveals that another boom-and-bust cycle with negative socioenvironmental consequences might have begun.

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Take-home message

- The impact of mining on local biodiversity can hardly be fully reversed, but Serra do Navio's case stresses the importance of pursuing lawsuits to ensure environmental accountability.
- The Serra do Navio Municipality Initiative of creating the Cancão Natural Park stresses the importance of new conservation areas and protecting fragments of the rainforest, even in environments considered degraded.
- The future of rainforest ecosystems will remain at risk while governments continue to grant mining concessions in key regions for climate change mitigation.
- If stakeholders remain unable to shape a sustainable transition of post-mining towns, vulnerable communities will continue to see in mining a frustrated hope of improvement in their social condition.

Biodiversity Monitoring as part of a Fabric: Collaborative Networks in the Colombian Amazon

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"Monitoring is a means, not an end. It adds value by dignifying what we do as rural farmers and demonstrates the value of what we are doing." Campesino (peasant) Leader and member of the Community Biodiversity Monitoring Network for the Amazon (REMBA).

From the perspective of the Humboldt Institute, knowledge networks are dynamic social configurations that foster the collaboration of actors, knowledge systems, and experiences to address shared challenges through collective action. Their functioning is based on horizontal relationships, self-management processes, and principles of trust, solidarity, and reciprocity, making them spaces for the collective construction of knowledge and the strengthening of territories.

Biodiversity monitoring, within this context of collaborative work, is valuable because it responds to the questions and interests of local territories. At the same time, monitoring benefits from the power of networks to address one of its greatest challenges: long-term sustainability through community ownership. With the aim of consolidating monitoring as a methodological approach to guide the socio-environmental changes required by the territory, the Humboldt Institute developed the *Community Monitoring*

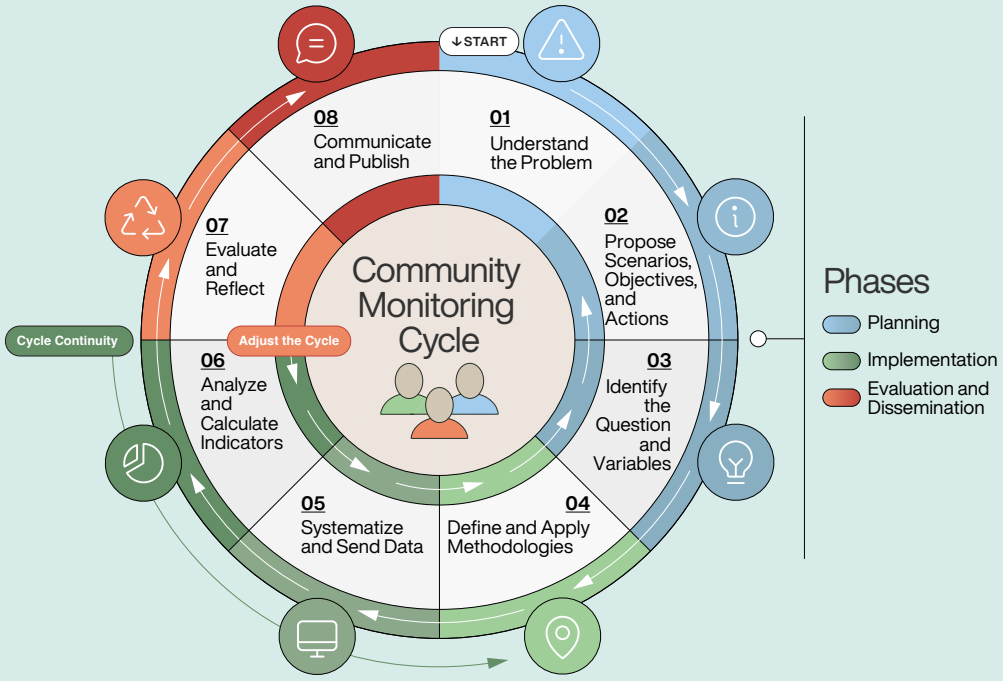


Figure 1: Biodiversity Monitoring Cycle, a tool proposed by the Humboldt Institute to facilitate the planning and implementation of community-based biodiversity monitoring strategies, to produce useful information on biodiversity status and trends based on the needs and interests of the stakeholders involved. The cycle consists of three main phases (i.e., planning, implementation, evaluation and dissemination) with seven steps that begin with contextualizing the territory where the methodology is applied, as well as identifying the problems or questions that the monitoring seeks to address or answer. The cycle also includes the identification of methodologies, systematization of information, and development of indicators, and culminates in the publication of data that can support decision-making (Arce-Plata et al., 2020; Sánchez Clavijo et al., 2024).

Cycle (Figure 1; Arce-Plata et al., 2020; Sánchez et al., 2024). This is a tool designed to facilitate the planning and implementation of biodiversity monitoring strategies based on the needs of the actors involved, bringing together diverse objectives to consolidate data and calculate indicators at the required scales.

The methodology was refined and first implemented by the Institute in 2020 with three associations of conflict victims in the Montes de María region of Bolívar, in the Colombian Caribbean. Since then, this approach has been adapted to different contexts across Colombia, including Río Claro in Antioquia, where the community developed expertise in bird monitoring; the páramo ecosystems, where different plants, birds, and mammals are monitored; and Yaguará in the Amazon, where camera traps have been installed, among other initiatives. Below, two active community-based monitoring initiatives have been selected. These initiatives are funded by the Fondo para la Vida (Fund for Life), using public resources derived from carbon taxes, national and international operations, and other donations.

REMBA: WEAVING KNOWLEDGE FROM THE COLOMBIAN AMAZON

The Colombian Amazon represents 42.3% of its land area and 6.8% of the Greater Amazon (Instituto Amazónico de Investigaciones Científicas SINCHI, 2026). The region is home to 17,933 recorded species, equivalent to 21.4% of the national total (SiB Colombia, 2025). This vast territory is inhabited also by Indigenous peoples, ethnic groups, rural communities, and others, who sustain their cultures and livelihoods there (Ministerio de Ambiente y Desarrollo Sostenible, 2026; Ministerio del Interior, 2026).



Figure 2: REMBA gathering at the Selva Vides Natural Tourism and Research Reserve in Villagarzón, Putumayo. Photo by María Camila Parra, researcher at the Humboldt Institute, 2026.

Despite its remarkable ecological and cultural diversity, the region faces critical pressures, including the loss of natural ecosystems, armed conflict, limited state presence, and inadequate biodiversity information management, among others (Murillo et al., 2021, 2022, 2023; FCDS, 2025). These threats also put biocultural diversity at risk, a fundamental factor in the territory's resilience. Although various organizations have been monitoring biodiversity for years, many of these efforts have remained fragmented or have been difficult to sustain over time.

It was against this backdrop that the REMBA network was created. REMBA is a living network woven from the Colombian Amazon that builds trust by connecting communities and knowledge around community-based biodiversity monitoring. Its purpose is to contribute to the governance, well-being, autonomy, and stewardship of territories and their inhabitants.

The network brings together local communities and ethnic groups that monitor their territories, as well as organizations that accompany these processes, such as the Humboldt Institute. During its first year and a half of operation, 33 initiatives joined the network, enabling

members to collectively develop its objectives, governance agreements, working groups, and identity.

REMBA has also succeeded in mobilizing resources, making it possible to organize in-person gatherings in different territories (Figure 2). These meetings have promoted the exchange of local experiences and dialogue with international initiatives, such as Mexico's Community-based Bird Monitoring Network.

The future of the network can be summed up in the voices of its members:

"The knowledge we generate as a Network should inform decision-making, not only to be limited to the practice of monitoring biodiversity." Local researcher and REMBA member. Monitoring processes must start from the concrete needs of communities. For example, if we are working on bird monitoring, before thinking about the number or diversity of species, we need to ensure families' food security, because without that, it is difficult to sustain the effort." Local researcher and REMBA member.

CESAR LIFE CORRIDOR: A LOOK AT THE TROPICAL DRY FOREST

In parallel, the biodiversity monitoring network within the Cesar Life Corridor (CVC) project is taking shape in a region of the country historically dedicated to coal mining and home to remnants of tropical dry forest. This is a critically threatened ecosystem, of which it is estimated that less than 2% remains in Colombia (Arce et al., 2025). Yet it supports essential ecosystem services such as fisheries, raw materials, climate regulation, and others (Calvo et al., 2017).

The CVC network was established in 2025 and currently consists of 13 women and 12 men from 19 associations engaged in alternatives to coal mining, including tourism, coffee and cacao production, guáimaro production, cattle ranching, and tropical dry forest conservation and restoration. Over a year and a half of work, and with the support of the Humboldt Institute, the network has focused its efforts on building capacities in: (i) bird observation, (ii) the installation of camera traps for mammals, and (iii) monitoring the phenology of native plant species.

One of the network's main objectives is to generate biodiversity indicators. In this context, biological data have become an opportunity for communities to empower themselves as ambassadors for the biodiversity of their territories, with the goal of publishing and becoming authors of information that demonstrates the richness of their natural heritage.

"If I share the data, it has the power to transform realities." CVC network member involved in tourism in La Jagua, Cesar, Colombia.

Monitoring also adds value to community members' productive activities. For example, camera-trap records of wild cats such as ocelots, pumas, and jaguars on their properties can provide evidence supporting their good practices. One of the network's most remarkable cases is that of Professor Julio, whose lifelong dream is to teach through music. Julio is from the municipality of Chiriguaná and is a victim of the armed conflict. He received recognition through the Visibles 2026 initiative of Colombia's Unit for Victims for his musical composition "*Yo soy campesino*" ("I Am a Campesino (peasant)"), in which he tells his story of resilience.

Professor Julio joined the network after standing out as an environmental leader in rural

schools in his region. Through this network, the knowledge Professor Julio has acquired has since been shared with children in different municipalities. He currently visits schools throughout Cesar, sharing his musical compositions about environmental stewardship, all through his own resources and efforts (Figure 3). He also contributes data from camera traps, bird point counts, and observations of native plants as part of the CVC project.

"*We cannot conserve what we do not know*." CVC network member involved in environmental education in rural schools in Chiriguaná, Cesar, Colombia.



Figure 3: Visit to a rural school in the municipality of Chiriguaná as part of visits to properties for the implementation of biodiversity monitoring in the Cesar Life Corridor. The students are taught by Professor Julio, a member of the network. Photo by Juan David León Ariza, researcher at the Humboldt Institute, 2026.

The impact of this community-based monitoring initiative has also reached the National Learning Service (Servicio Nacional de Aprendizaje, SENA), which works to strengthen technical capacities in rural areas of the country where access to higher education is limited. SENA developed a learning module focused on biodiversity knowledge as part of its academic offering, inspired by the training provided through the CVC monitoring network. The course is currently awaiting activation so that it can be officially offered in the region.

By the end of 2026, the CVC project will have biodiversity figures, indicators and publish these records in Colombia's Biodiversity Information System (SiB), where the members of the network are listed as primary authors. The SiB is a node of the global GBIF network, which aims to provide free and open access to information on the planet's biodiversity. All this data is generated through the efforts of women and men who have generously dedicated hours of their work in the field to contributing to the country's biodiversity inventory.

Take-home message

- Among the greatest achievements of working through networks is the promotion of alternative economic activities that are closely linked to biodiversity conservation.
- At the beginning of the process, members of these networks faced the isolation of regions where environmental issues are often given little priority.
- Today, community gatherings organized through these networks have transformed that sense of isolation into spaces for dialogue and a strong community fabric united around a shared territory and its biodiversity.
- Beyond technical rigor, fieldwork and visits to individual properties have become ideal spaces for mutual recognition and the exchange of local knowledge. "*No one weaves alone: we are all a thread in this great tapestry*."

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Beyond Conflict: Identity, Savannas, and Socio-ecological Resilience in the Cinaruco Region

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Located in the Colombian Orinoquia, specifically in the department of Arauca, the Cinaruco River basin encompasses a hydrographic subzone of 747,027.9 hectares distributed across the municipalities of Arauca, Arauquita, and Cravo Norte. At the heart of this territory lies the Cinaruco National Integrated Management District (DNMI), a 324,573-hectare protected area declared in 2018 under the supervision of Colombia's National Natural Parks to preserve the natural dynamics of its floodplain savannas and wetlands.

The history of the micro-basin associated with the main drainage channel of this river, which covers 83,726.4 hectares shared between Arauca and Cravo Norte and lies within this larger conservation area, goes far beyond the outdated notion that human progress is always at odds with nature conservation[1]. Through participatory workshops, surveys, and direct dialogue in the territory, local residents and experts shared their perspectives on what 'good living' or holistic well-being means, a concept closely linked to biodiversity conservation (Castellanos et al., 2024), as well as their traditional knowledge. The qualitative information gathered was systematized and cross-referenced with spatial assessments to create an analytical framework capable of translating the reality of the landscape into a relational and structural map of the territory.

By examining this territory through the resulting model, the '*Being, Doing, and Having*' model, the analysis made it possible to identify historical processes of coexistence and adaptation (Figure 1). This framework draws directly on the conceptualization of well-being presented by Castellanos et al. (2024), which defines well-being as a multidimensional state closely linked to Being, Doing, and Having, governed by reciprocal relationships with biodiversity, meaningful community participation, and dialogue among different knowledge systems.

This model was developed in close collaboration with local communities. The process included virtual surveys with local experts, discussions in rural communities, and, above all, two validation workshops held in the territory in June 2025: one in Cravo Norte (with 15 participants) and one in Arauca (with 10 participants). These co-creative meetings actively involved traditional Llanero cattle ranchers, leaders of local Community Action Boards, representatives of trade and producer associations, and municipal public administration officials.

[1] The analyses and findings presented in this document are derived directly from the landscape sustainability assessments of the Orinoquia developed within the GEF Project "Integrated Sustainable Landscapes of the Orinoquia" – GEF Orinoquia, an initiative designed to harmonize the well-being of local communities with the conservation of biodiversity and ecosystem services.

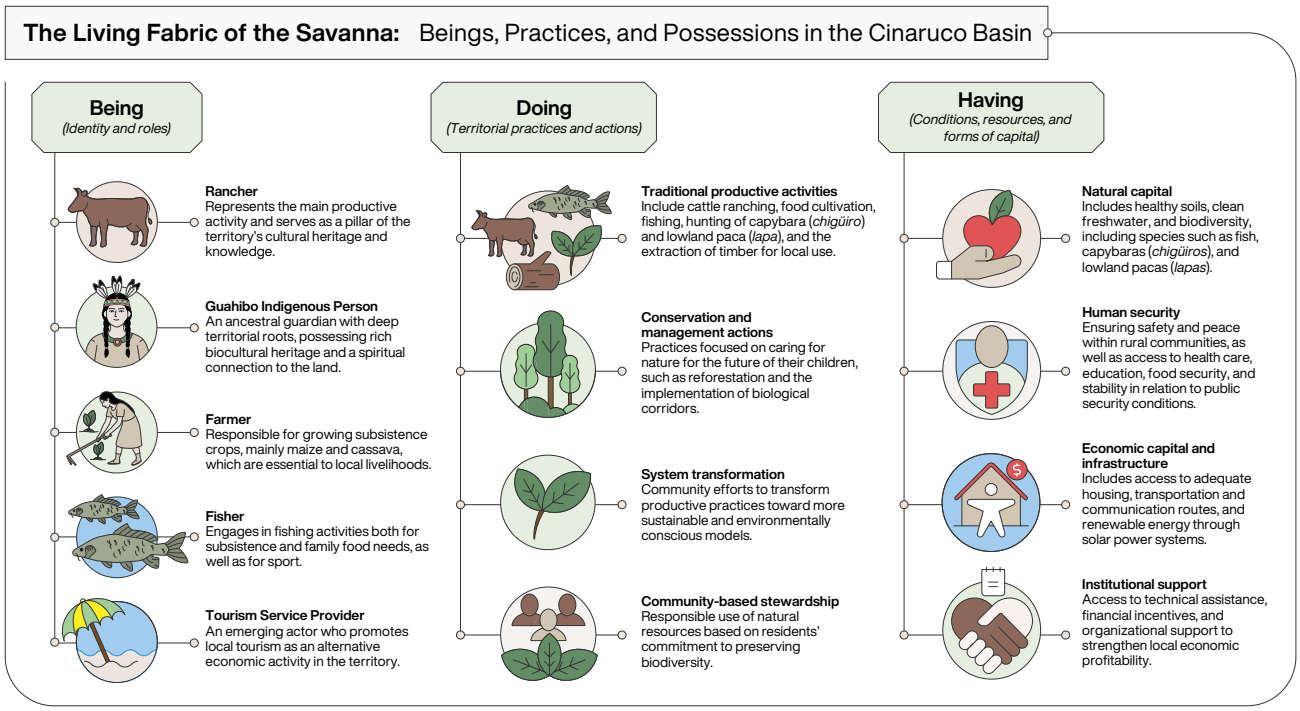


Figure 1: The fabric of local life. Dimensions of well-being in the Cinaruco basin. Table that consolidates the most frequent variables of well-being identified in the Cravo Norte and Arauca workshops. The 'Being' column details the roles of the territory. The 'Doing' column classifies the daily activities of land management and use. The 'Having' column organizes the physical, infrastructure and human security resources of the basin.

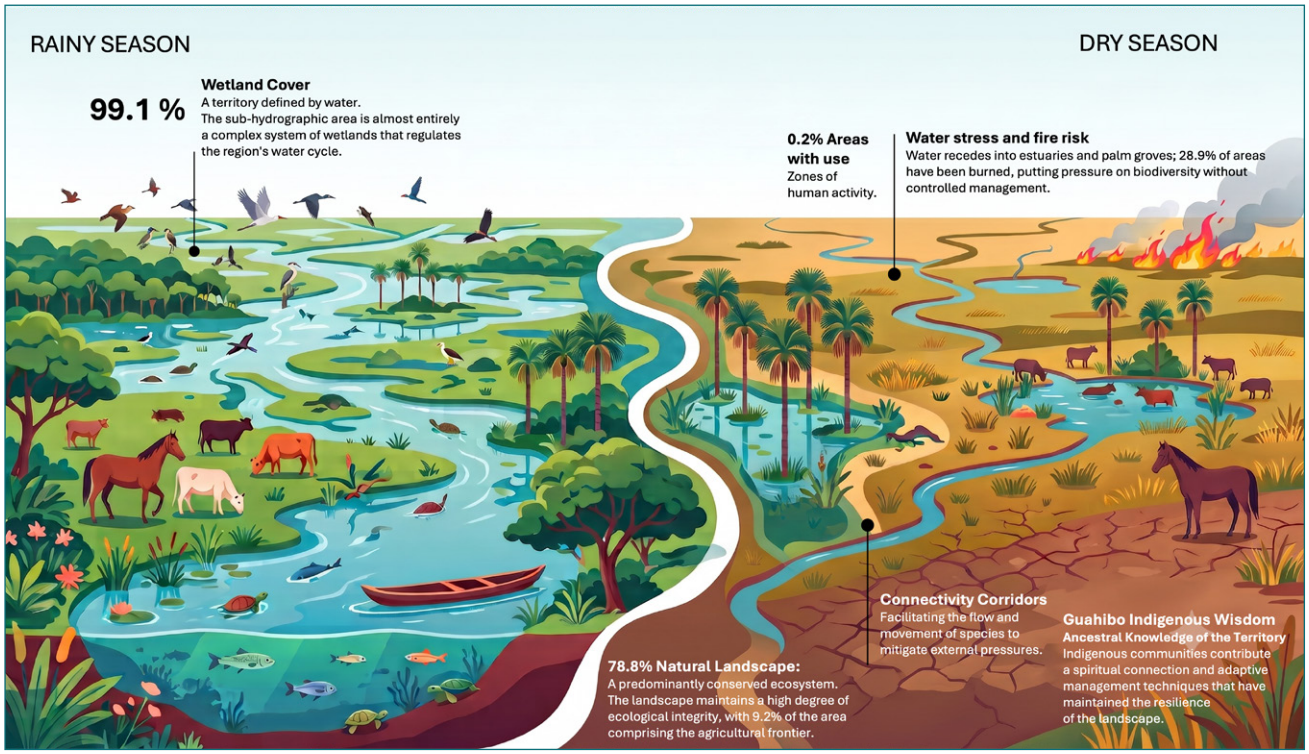
Based on this dialogue and collaborative process, the relational diagram that now underpins this research was developed. In this effort, territorial representation was key to ensuring that the model reflected the diversity of experiences and ways of understanding of those who inhabit the territory. By engaging residents from rural communities in Arauca and Cravo Norte, it was possible to understand community well-being directly through the beings, practices, and resources that define and connect its people. This mapping, presented schematically in Figure 2, made it possible to connect the richness and limitations of nature with the aspirations, perceptions, and everyday lives of these communities.

Through this perspective, it became possible to understand that well-being in the basin is neither a single nor homogeneous concept. On the contrary, it emerges from a living fabric in which the different ways of being, doing, and having of each inhabitant are dynamically interwoven. From this network of local knowledge, it can be concluded that the community and nature form an indivisible system, where the territory itself is at the heart of their knowledge and ways of life (Berkes, 2000).

To understand the magnitude of this co-adaptive relationship, it is first essential to consider the living infrastructure of the landscape[2]. That is, its material 'Having'. The Cinaruco is dominated by immense floodplain savannas, ecosystems that are not static but pulse to the rhythm of climatic extremes marked by severe cyclical fluctuations, whose dynamics have been extensively documented in regional ecological research (Mora-Fernández & Peñuela-Recio, 2015). During the rainy season, these plains transform into complex wetlands that are vital for aquifer recharge and for sustaining vast functional biodiversity[3]. In addition, extensive portions of this basin have been mapped and categorized as *Essential Life Support Areas* (ELSAs),

[2] Geomorphology, climate, and extreme soils (Material HAVING): The Cinaruco River Hydrographic Subzone (SZH) covers 334,200 hectares. From a soil science perspective, the dominant soils are sandy loams with very high levels of aluminum saturation and a strongly acidic chemical reaction. These limitations explain why extensive adaptive practices are the most appropriate long-term response.

[3] Biodiversity richness and helobiomes: Despite its edaphic constraints, the basin is a biological refuge, classified in the Map of Continental, Coastal, and Marine Ecosystems of Colombia (IDEAM et al., 2024). Approximately 99.1% of the total area of the SZH is covered by seasonal wetland ecosystems that function as critically important climate refuges.



which are critical for maintaining ecological processes and mitigating the effects of climate change (Corzo et al., 2021). However, the arrival of the dry season imposes an extreme water deficit that transforms the landscape into a harsh environment. These conditions place clear limits on large-scale industrial agriculture[4], but they also create an ideal setting for local life and practices to adapt to the natural pulse of the savanna.

In response to the challenges posed by such a highly variable environment, the people of the region have developed an unbreakable sense of belonging, giving rise to different ways of 'Being' and identifying with the territory. In this landscape, community and productive life revolves fundamentally around institutions of enormous value, such as cattle ranches (*hatos ganaderos*) and Indigenous reserves. The Llanero *hato* is much more than a productive farm: it simultaneously constitutes a productive unit, a place of residence, and a setting for the transmission of knowledge. It is a meeting point where "Being a rancher" coexists, interacts, and has historically become intertwined with the legacy of "Being Indigenous" in the territory[5].

While the rancher identity is understood as that of a person who works the savanna, the Indigenous identity is understood as that of an ancestral guardian. The perspectives of these local actors, documented through principles of knowledge co-production that ensure the legitimacy of this knowledge, reveal that these populations proudly assume roles as "guardians of the future" and define themselves as "bearers of traditional knowledge." Their greatest aspiration is not the irrational maximization of income, but peaceful coexistence and conservation.

Figure 2: Dynamics of the floodplains. Graphic representation of the open savannas in the Cinaruco River basin. It shows the environment of the traditional cattle ranch and the distribution of its main land cover. The graphic contrasts the changes between the abundance of water during the rainy season and the effects of drought and fires during the dry season.

[4] Suitability constraints: Nearly 70% of the territory presents severe restrictions or legal exclusions for intensive commercial agricultural and livestock development, structural limitations evidenced in the national land-use suitability zoning (UPRA, 2023). In this environment, forced transitions to monocultures would irreversibly degrade the savanna.

[5] SThe Social Fabric and Identity-based "BEING": Important Indigenous Reserves coexist in this region and have been duly mapped (Universidad Externado de Colombia, 2025). They contribute profound ancestral knowledge of the savanna's hydrological rhythms, enriching the community BEING alongside the identity of the Llanero peasant.

This deep connection to their land guides their everyday actions, giving rise to a highly specialized and diversified 'Doing'. Unlike the imposed agro-industrial logics that have historically been among the main drivers of landscape transformation in Colombia (Etter et al., 2008), traditional practices in Cinaruco operate in synchrony with the ecosystem. The rancher identity develops a form of 'Doing' based on open-range, extensive cattle ranching, strategically moving livestock according to an expert reading of hydrological cycles. The Indigenous identity, in turn, engages in 'Doing' centered on artisanal fishing, subsistence hunting, and gathering which are activities regulated by water rhythms and the availability of wildlife (Figure 3).

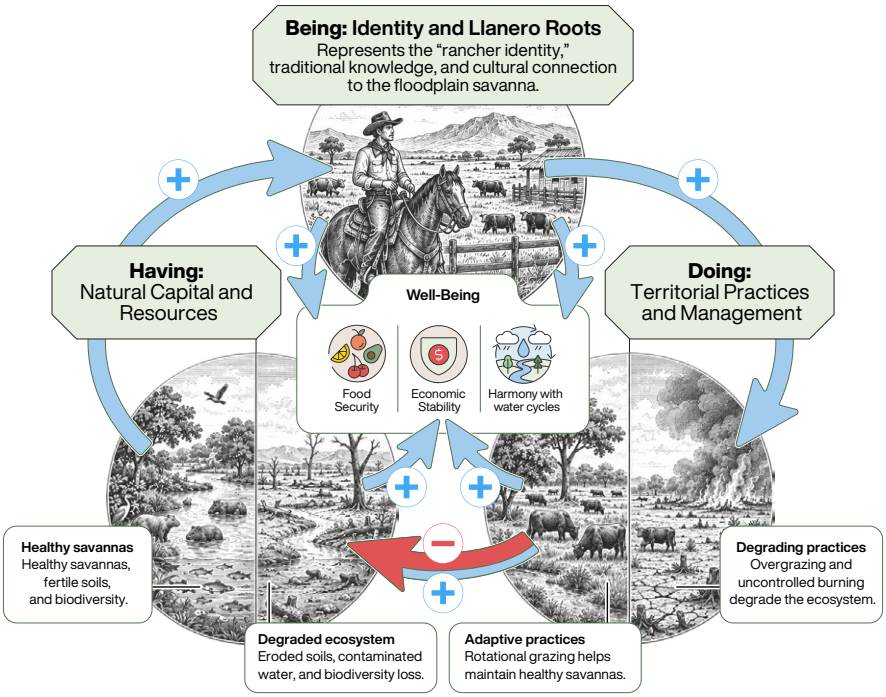


Figure 3: Model of interdependence and feedback loops in the Cinaruco region. Triangular structure diagram representing the relationship between identity, management practices, and resources of traditional livestock farming in the watershed, with community well-being at the center. The Being node illustrates knowledge of the savanna; the Doing node distinguishes adaptive management from overgrazing; and the Having node reflects the state of the soils and water. Blue arrows (+) indicate favorable relationships, and the red arrow (-) shows the degradation cycle.

Within this interconnected system, a shared management technology emerges that has frequently been stigmatized by external policies: the use of fire. Participants describe controlled burning as a territorial management tool. When applied according to precise seasonal calendars, it prevents catastrophic wildfires and stimulates the nutritious regrowth of native grasses. Spatial analyses of land-cover dynamics empirically confirm that these savannas possess an intrinsic resilience to managed fire (Romero-Ruiz et al., 2012).

Despite this demonstrated historical resilience, there are warnings of an imminent risk of collapse if extractive market-driven logics are allowed to penetrate the territory. If extreme economic pressures force local inhabitants to abandon their adaptive 'Doing', pushing them toward overgrazing or erratic fire use, the 'Having' of the savanna rapidly deteriorates. When market pressures demand greater productivity, millennia-old practices such as the use of fire can become uncontrolled, directly threatening the *morichales* (palm wetlands) and gallery forests that land-use policies themselves require to be strictly protected. This irreversibly erodes the valuable social fabric of the *hatos* and cultural pride, sacrificing their natural capital, the 'Having' of their territory, in exchange for immediate economic relief.

To ensure the long-awaited goal of climate justice and the viability of the productive landscape, a scenario of "Governance for Sustainability" may provide a pathway forward, confirming that the most consequential intervention should target the system's true leverage points. The future of this territory requires moving away from vertical, regulatory approaches that restrict and criminalize traditional livelihoods. Instead, territorial planning should protect

open-range cattle ranching based on the universal principles of sustainable governance of common-pool resources (Ostrom, 2009). Only by recognizing and validating these dynamic systems of place-based knowledge can we ensure that the hybrid Llanero and Indigenous identity continues to function as the primary protective shield for floodplain ecosystems.

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Take-home message

- Cinaruco offers a lesson in political ecology in which rural communities and biodiversity are not inherently opposing forces. However, a systemic understanding reveals serious contrasts: there is a tension between conservation and market pressures that drive the overexploitation of the savanna, sacrificing natural capital 'Having' for immediate economic relief through uncontrolled burning and overgrazing.
- To ensure territorial viability, climate-smart land-use planning is required, with the Principal Ecological Structure (PES) serving as the guiding framework to curb agricultural expansion and prevent decontextualized solutions such as reforesting natural savannas.
- The mandate is to consolidate inclusive governance. Only through genuine financing (e.g., Payments for Ecosystem Services), and bioeconomy initiatives can the communities' 'Doing' enhance their livelihoods without degrading their environment, protecting the immense richness of the floodplain savannas in the Anthropocene.

6. Methods for Recording Biodiversity Through Time

This section specifically examines the latest state-of-the-art methods in archaeological and palaeoecological science, as well as environmental history, for recording, monitoring, and tracing biodiversity across different temporal scales and how these can improve our understanding of biodiversity change and inform conservation and restoration practice. Such approaches are beginning to reveal large-scale human impacts on contemporary biodiversity, through both millennia of management and dramatic socioeconomic ruptures.

These methods are not to be seen as 'tests' of or 'pre-eminent' to Indigenous knowledge, but rather complementary sources of quantitative, comparable datasets that are often sought by policy decision makers and can be utililized by communities. The contributions to this section notably highlight that the power of these methods in documenting the role of past legacies in contemporary biodiversity has in fact emerged in contexts in the Global South. Potentially applicable systematically on local, regional and global scales, these approaches are best thought of as part of a toolkit that can be mobilised by communities, stakeholders, and policy makers when asking and addressing questions about the role of historical processes in the presentation, vulnerability, and future dynamics of biodiversity in the 21st century.

The following is the product of collaborative research from within the Max Planck Institute of Geoanthropology's *Jour fixe* on the 'Anthropocene Biosphere', showing what is possible when different researchers, disciplines, and backgrounds come together to explore a particular theme from different viewpoints.

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Ancient DNA and ZooMS: Reconstruction of the Late Pleistocene faunal diversity in the Lesser Caucasus

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Fossil bones have always been a window into the deep past, telling us which animals lived where and how ecosystems shifted over thousands of years. But there's a catch: most of what palaeontologists dig up isn't a neat, complete skull or jaw, it's a scatter of small, broken fragments that are almost impossible to identify by eye. For decades, this meant that a huge amount of potential information about past biodiversity, migration and extinction was essentially unreadable, simply because nobody could say which species a given bone chip belonged to.

That's now changing, thanks to molecular biology.

Over the past twenty years, ancient DNA (aDNA) analysis has moved from a niche technique to a mainstream tool in archaeology and palaeontology. It has helped researchers identify species from scraps too damaged for visual classification, and has opened up new questions about species identification (e.g., Seersholm et al., 2021), evolutionary history (e.g., Barlow et al., 2021), origins (e.g.,Bergström et al., 2020), population history (Vershinina et al., 2021), influence of climate changes (e.g., Ababaikeri et al., 2020), and extinction (e.g., Torres-Roig et al., 2021). Remarkably, DNA has now been recovered from sources once considered impossible: fossilised faeces (e.g., Witt et al., 2021), eggshells (e.g., Grealy et al., 2021), mollusc shells (e.g., Ferreira et al., 2020), ancient wood (e.g., Lendvay et al., 2018), and insects trapped in resin (e.g., Peris et al., 2020), as well as, human-made objects such as leather (e.g., Bastian et al., 2018), parchment (e.g., Díez-del-Molino & Dalén, 2020), drinking horns (e.g., Bro-Jørgensen et al., 2018), pottery (e.g., Foley et al., 2012), and birch-tar adhesives (e.g., Jensen et al., 2019).

A parallel line of research focuses on ancient proteins. Because proteins often survive in conditions where DNA does not, they can offer their own clues: helping refine chronology (e.g., Dickinson et al., 2019), revealing ancient diets (e.g., Bleasdale et al., 2021), identifying species and reconstructing phylogeny (e.g., Cappellini et al., 2019), tracing evolution (e.g., Welker, 2018), and even detecting disease in ancient populations (e.g., Sawafuji et al., 2017).

Powerful as they are, DNA and protein analyses are also expensive and time-consuming, a real problem when an excavation yields thousands of anonymous bone fragments. This has driven researchers to develop cheaper, faster screening methods that can still deliver useful taxonomic information at scale.

One of the most promising is a technique called ZooMS: zooarchaeology by mass spectrometry. ZooMS identifies bones by analysing collagen, the structural protein that makes

up most of bone. Collagen changes only slightly between species, but those small differences are enough to act like a molecular barcode allowing scientists to work out which family, genus, or sometimes even species a bone came from (Buckley et al., 2009).

Applying these tools requires bones with well-preserved biomolecules, and not every site is up to the task. Karin Tak cave, in the Lesser Caucasus mountains, turned out to be an exceptional candidate. Its sediments preserve a window onto the local environment between roughly 48,000 and 24,000 years ago, spanning the transition from the relatively mild Marine Isotope Stage 3 into the cold, dry depths of the Last Glacial Maximum (Antonosyan et al., 2019, 2024).

Researchers combined traditional morphological identification with two molecular approaches: ZooMS and genetic bulk bone metabarcoding. Preservation at Karin Tak proved excellent, allowing molecular identification of numerous bones that would otherwise have stayed unseen.

The results paint a detailed picture of a region in ecological flux, yet remarkably stable in terms of faunal composition through time. Between roughly 42,000 and 25,000 years ago, the cave's surroundings supported at least 29 animal groups, including eleven mammal families and three bird families still found in the area today, alongside several species that have not been previously described from the Late Pleistocene sites of the region or went extinct (badger, spotted hyena, goitered gazelle and Asiatic black bear).

The findings reveal a rich diversity of species at Karin Tak, showing that the same biological community persisted from the late MIS 3 period into the early glacial maximum. Animals typical of broadleaved forest lived alongside those adapted to arid steppe, pointing to a landscape that held onto this ecological diversity even as the last glaciation began. Rather than triggering dramatic upheaval, the onset of the Ice Age's coldest phase appears to have left the region's environment largely intact: suggesting the Lesser Caucasus remained a climatically and ecologically stable refuge even as the rest of the world underwent major climatic change (Antonosyan et al., 2019, 2024).

This case study underscores the value of molecular screening for fossil bones: it offers far greater taxonomic precision, unlocks information that was previously out of reach, and gives a clearer picture of past biodiversity and environmental change. Such efforts do more than deepen our understanding of past environments. By reconstructing species' historical distributions and long-term biodiversity trends, they offer a valuable ecological baseline that can inform present-day conservation and restoration strategies.

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Stable Isotope Analyses: Tracing Biodiversity and Ecological Change Through Time

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Biodiversity change is not only about which species are present or absent, but also about how species live, respond, and persist under changing ecological conditions. Stable isotope analysis offers a powerful means of addressing these questions because it records ecological information directly in biological tissues. Rather than relying only on present-day observations, isotope methods can trace diet, trophic position, habitat use, and environmental conditions across time, including in archaeological and fossil material. This makes them especially valuable for linking modern biodiversity monitoring with longer-term records of ecological change.

Stable isotopes are naturally occurring forms of elements that differ in atomic mass. Biological and environmental processes produce small variations in the ratios of heavier and lighter isotopes in food, water, and ecosystems, and these differences are incorporated into animal tissues. As a result, tissue isotope compositions can provide information about an organism's ecology. Commonly used isotope systems in ecology include carbon, nitrogen, oxygen, and, more recently, zinc. Carbon isotopes can help distinguish between different plant types and, in tropical environments, between forested and more open habitats (Lee-Thorp et al., 1989). Oxygen isotopes can reflect water sources, hydrological conditions, humidity, aridity, and aspects of plant consumption (Pederzani & Britton, 2019). Nitrogen isotopes are widely used to assess trophic level (Deniro & Epstein, 1981), while zinc isotopes, especially in tooth enamel, provide an additional proxy for trophic relationships and are particularly useful where collagen is poorly preserved, as is often the case in tropical fossil contexts (Bourgon et al., 2020). Together, these isotope systems allow researchers to reconstruct multiple complementary aspects of animal ecology.

The study by Bourgon and colleagues (Bourgon et al., 2025) provides a clear example of how stable isotopes can be used to investigate changes in biodiversity over long timescales. The authors analysed fossil mammal teeth from Pleistocene sites in Vietnam, including Coc Muoi and Duoi U'Oi, and combined these new data with previously published isotope records from Laos. Their dataset included enamel-bound zinc and nitrogen isotopes, alongside carbon and oxygen isotope values, from a wide range of mammalian taxa, including primates, carnivores, rodents, ungulates, proboscideans, and perissodactyls. These fossils span key climatic intervals of the Late Pleistocene, a period marked by changing precipitation, seasonality, and habitat structure in mainland Southeast Asia (Wang et al., 2008).

The strength of the approach lies in its multi-isotope design. A single isotope system can be informative, but different ecological processes can sometimes produce similar values. By combining carbon and oxygen isotopes with zinc and nitrogen isotopes, the study could more effectively distinguish habitat use, trophic behaviour, and dietary breadth. This approach made it possible to evaluate whether taxa that survived locally into the present differed ecologically from those that became extinct or regionally extirpated. A key result was that species with extant counterparts in the region generally showed greater isotopic variability than extinct or extirpated taxa. This variability suggests that some surviving lineages were able to use a wider range of habitats or food resources, which may have contributed to their resilience during periods of environmental change. Importantly, the study does not simply show that "flexible" species survived and "specialized" species disappeared, but rather highlights that resilience can take different ecological forms. Some animals may cope with change by moving between habitat types, while others may remain within similar habitats but broaden the resources they exploit. Stable isotope records can therefore help identify the ecological strategies that allowed some species to persist, and the conditions under which others became more vulnerable.

This long-term perspective is especially valuable for conservation since modern assessments often focus on current distributions, population sizes, and threats. However, these are shaped by recent, often intense, human impacts, including deforestation, hunting, fragmentation, and land-use change (IPBES, 2019). Stable isotope analysis can thus help reconstruct the ecology of species prior to when these pressures reached modern levels (Koch et al., 2009). For endangered animals, this can provide a clearer picture of their historical dietary breadth, habitat use, and ecological requirements, rather than relying solely on observations within already degraded, fragmented, or restricted landscapes. Isotope records can therefore provide a baseline for understanding not only where species occur today, but also how their ecological niches and behaviours may have changed over time.

For policy, the implications are important as stable isotope analysis can provide evidence for the ecological conditions under which species persisted, adapted, or disappeared. When combined with modern ecological, demographic, and genetic data, this information can contribute to habitat protection, restoration, rewilding, and translocation planning by identifying not only where species lived, but also how they used landscapes and resources (Dietl et al., 2015). In Southeast Asia, where biodiversity is exceptionally high but increasingly threatened by deforestation and land-use change, such long-term ecological baselines are particularly valuable. They demonstrate that conserving biodiversity is not only a matter of protecting species lists, but also of maintaining habitat mosaics, resource diversity, and the ecological options that may enable species to withstand future environmental change.

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Molecular Traces of Biodiversity: Metabolomics traces the deep history of plants, ecosystems, and human knowledge systems

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Metabolomics studies biodiversity through the small molecules – metabolites – produced, transformed, and preserved from living organisms (Fiehn 2002). These metabolites can survive in sediments, plant remains, archaeological residues, ceramics, dental calculus, bones, coprolites and other archives (Badillo-Sanchez et al. 2023; Huber, Hausleiter, et al. 2025; Velsko et al. 2017). Because many metabolites are linked to particular plants, plant products, ecological stress responses, decay, burning, or processing practices (Patti et al. 2012), they can provide evidence for past biodiversity and human interactions with biodiversity. Metabolites include alkaloids, terpenoids, phenolics, organic acids, sugars, and many other small molecules (Abegaz and Kinfe 2019). In environmental and archaeological contexts, these compounds may be preserved alongside transformation products formed through ageing, heating, decay, or human processing (Badillo-Sanchez et al. 2023). They are commonly analysed using gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-mass spectrometry (LC-MS), including tandem MS/MS and high-resolution MS approaches (Dunn et al. 2005; Fiehn 2016; Rakusanova and Cajka 2024). Volatile organic compounds can be targeted through headspace techniques such as headspace solid-phase microextraction GC-MS (HS-SPME-GC-MS) or thermal desorption GC-MS (TD-GC-MS) (Schmidt et al. 2024). These approaches can identify diagnostic molecular markers and metabolic profiles that point to particular plants, plant products, ecological resources, or transformation processes.

The value of this approach lies not only in identifying plants, but also in reconstructing relationships between biodiversity and knowledge. Plants become medicines, aromatics, foods, dyes, preservatives, fumigants, intoxicants, or ritual substances through practices of selection, preparation, and transformation. These practices form part of biocultural diversity: the intertwined relationships between biological diversity and the cultural knowledge systems through which people understand, use, and transmit knowledge about living resources (Bridgewater and Rotherham 2019; Maffi 2005). Metabolomics can therefore shift biodiversity research from the question of which organisms were present to how organisms were recognised, valued, and incorporated into everyday, medicinal, sensory, or ritual life (Pascual et al. 2023).

A recent example comes from an Iron Age oasis settlement in northwestern Arabia. Huber et

al. (2025) analysed residues preserved in fumigation devices and identified the β-carboline alkaloids harmine and harmane, molecular markers associated with the medicinal and psychoactive plant *Peganum harmala* (Fig. 1). The study provides early radiometrically dated material evidence for the use of this plant in fumigation practices and shows how metabolomics can identify plant materials that are unlikely to preserve as visible botanical remains. In this case, the molecular evidence points not only to the use of a specific dryland plant, but also to knowledge of its properties and applications in therapeutic contexts. Because *Peganum harmala* continues to be used in parts of the Middle East and Central Asia in medicinal, fumigant, and protective practices, the case illustrates how metabolomics can connect ancient residues with longer histories of plant use and living knowledge systems.

Metabolomics can also trace how biological resources were transformed into culturally meaningful materials. A second example comes from the identification of cedar tar in archaeological materials. Cedar wood, resin, essential oil, and tar may all derive from the same plant source, but they represent different ecological materials and technological choices. Huber et al. (2026) developed an archaeo-metabolomics approach to distinguish cedar tar from cedar resin and essential oil by identifying molecular markers formed through dry distillation (Fig. 2). When applied to ancient Egyptian mummification balms dating to 664–332 BCE, these markers provided direct evidence for cedar tar use. The case shows that metabolomics can reconstruct not only a plant source, but also the technical process through which people transformed plant biodiversity into durable, preservative, and culturally significant substances.

Together, these examples show how metabolomics contributes to the study of biodiversity through time. It can reveal plants and plant products that are poorly represented in conventional archaeobotanical records; it can identify ecological resources and it can reconstruct the practices through which these resources were transformed and given meaning. In this sense, metabolomics provides evidence not only for biological diversity, but also for the cultural histories of biodiversity use. This perspective is particularly relevant for the Global South, where many regions are both centres of biodiversity and centres of long-standing medicinal, ritual, agricultural, and ecological knowledge. At the same time, metabolomic research in these contexts must be carried out carefully and collaboratively. Molecular evidence should not be used to extract or appropriate traditional knowledge, but rather to support locally grounded histories of biodiversity, heritage, and environmental stewardship. When combined with archaeology, palaeoecology, ethnobotany, historical sources, and Indigenous and local knowledge, metabolomics can help reconstruct deeper baselines for human-environment relations.

For policy, metabolomics can broaden what counts as biodiversity evidence. It can identify culturally important plants and ecological resources and show how communities have sustained knowledge of biodiversity over centuries or millennia. This aligns with the UNESCO/IPBES framing of biocultural diversity as the interconnections between biological and cultural diversity, including Indigenous and local knowledge systems (UNESCO LINKS/IPBES, 2024). Such evidence can support conservation, restoration, heritage management, and sustainable-use policies that recognise biodiversity as both biological and cultural.

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Dendrochronology and Historical Ecology: Reading Biodiversity Change in Tree Rings

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Dendrochronology, the study of tree rings, allows researchers to read environmental history from living and dead wood. In seasonal environments, many trees form annual growth rings. Their width, density, chemistry, scars, and age patterns can reveal past droughts, fires, forest openings, pollution, and human disturbance. In tropical regions, tree-ring work is often more challenging because seasonality can be subtle and ring boundaries are not always easy to identify. Yet decades of research have shown that many tropical species do form annual rings and can be used to reconstruct ecological and social histories that matter for biodiversity today (Worbes, 2002; Caetano-Andrade et al., 2020).

What makes dendrochronology especially useful is that it links individual trees to landscapes and time. A tree does not only record climate. It also records changing light conditions, competition, canopy openings, and episodes of damage or management. In historical ecology, this means that trees can help distinguish between changes driven mainly by climate and those driven by people. When combined with archaeology, palaeoecology, archives, and oral history, tree rings become a powerful way to trace how biodiversity has been shaped over centuries rather than only in the last few decades (Brienen & Zuidema, 2006; Caetano-Andrade et al., 2020).

One well-known example comes from mainland Southeast Asia. By analysing tree-ring records from southern Vietnam, Buckley and colleagues reconstructed severe and prolonged droughts during the fourteenth and fifteenth centuries and showed that climate stress likely contributed to the decline of Greater Angkor in Cambodia. This study is often cited as a classic case of dendrochronology revealing the broader social consequences of hydroclimatic change. It also shows why biodiversity histories cannot be separated from water, governance, and infrastructure (Buckley et al., 2010).

A second example comes from Mexico, where the Mexican Drought Atlas used a large network of tree-ring chronologies to reconstruct soil moisture over the late pre-Hispanic, colonial, and modern periods. These records revealed repeated severe droughts and helped place major historical crises into a longer environmental context. In biodiversity terms, this kind of reconstruction is crucial because drought shapes fire regimes, forest composition, productivity, and habitat availability. It can also help identify whether recent ecological stress is unprecedented or part of longer regional variability (Stahle et al., 2016).

Dendrochronology can also be used more directly to study forest management and biodiversity in tropical forests. In Central Africa, Morin-Rivat and colleagues combined tree-ring evidence with palaeoecological, archaeological, and historical data to show that present-day forest structure still carries the legacy of nineteenth-century human history. This is an important lesson for conservation: many forests that appear "natural" are in fact historical landscapes, shaped by people, mobility, trade, and land-use change over long periods (Morin-Rivat et al., 2017).

My own work with Brazil nut trees in Amazonia points in the same direction. Brazil nut is a light-demanding, culturally important tree that has long been associated with human occupation and management. By studying recruitment ages, growth releases and suppressions, scars, and the relation between tree growth and archaeological or historical contexts, it is possible to show that many Brazil nut stands are living records of forest use. In central Amazonia, establishment patterns and growth changes in Brazil nut trees were linked to human disturbance and management over the last four centuries, including periods associated with colonial disruption and later extractive economies. Tree rings therefore help reveal not only ecological change, but also the persistence and transformation of managed forest landscapes (Caetano Andrade et al., 2019).

These methods matter for policy because they provide long-term baselines. Conservation and restoration often rely on recent observations, yet recent ecosystems may already reflect colonial disruption, industrial extraction, or biodiversity loss. Dendrochronology helps identify the conditions under which forests developed, the disturbance regimes they experienced, and the forms of human stewardship with which they coexisted. This can improve restoration targets, fire and drought planning, and the recognition of Indigenous and local management practices in biodiversity policy. In the Global South especially, where many of the world's most biodiverse forests are also historical cultural landscapes, tree-ring research can help move policy beyond the false choice between "pristine nature" and human use. It shows that biodiversity is often the product of long relationships among climate, forests, and people (Stahle et al., 2016; Morin-Rivat et al., 2017; Caetano-Andrade et al., 2020).

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Sedimentary Charcoal Analysis: Revealing the Long-Term Role of Fire in Shaping Biodiversity

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Fire has shaped biodiversity for millions of years by influencing vegetation composition, habitat heterogeneity, nutrient cycling, species distributions, and ecosystem resilience across many of the world's most biodiverse regions (Bowman et al., 2020; Kelly et al., 2020; Kobziar et al., 2024). Yet modern fire records typically extend back only a few decades, limiting our understanding of the long–term role of fire in ecosystem dynamics and biodiversity change (McLauchlan et al., 2020; Shuman et al., 2022). Sedimentary charcoal analysis overcomes this limitation by reconstructing fire activity over centuries to millennia, which far exceeds the temporal reach of historical observations and satellite records (Brown and Power, 2013; Whitlock and Larsen, 2002). These records provide critical insights into how fire regimes have responded to climatic variability, human land use, and environmental change, offering valuable perspectives for biodiversity conservation, ecosystem restoration, and climate adaptation planning (Dietl et al., 2015; United Nations Environment Programme, 2022).

Sedimentary charcoal records are derived from charcoal particles produced during vegetation burning and deposited in lakes, wetlands, peatlands, lagoons, and other sedimentary environments (Whitlock and Larsen, 2001). Because these deposits can be dated using radiocarbon, lead 210, and other chronological techniques, charcoal records provide temporally resolved reconstructions of past fire activity (Conedera et al., 2009; Whitlock et al., 2010). Variations in charcoal abundance through time can be used to infer changes in fire frequency, magnitude, and biomass burning (Higuera et al., 2011; Power et al., 2008). When combined with other palaeoecological and archaeological evidence, including pollen, phytoliths, biomarkers, and settlement data, charcoal records provide a powerful tool for investigating the coevolution of fire, biodiversity, and human societies (McMichael et al., 2026; Whitlock et al., 2010).

Amazonia provides an excellent example of the value of long–term fire records. For decades, Amazonian forests were assumed to be largely fire–free ecosystems in which burning occurred only during exceptional droughts (Cochrane, 2003; Laurance, 2003). However, charcoal syntheses from across the basin show that fire activity increased substantially during the middle and late Holocene in association with expanding Indigenous land use, cultivation, and landscape management (Gosling et al., 2021; Maezumi et al., 2018; McMichael et al., 2026). Rather than indicating widespread deforestation, these records reveal diverse

fire management practices that left enduring legacies on forest composition, structure, and biodiversity.

Long–term charcoal records demonstrate that many Amazonian ecosystems experienced recurrent anthropogenic burning for millennia while maintaining forest cover and high biodiversity (Bush et al., 2015; Carson et al., 2014; Maezumi et al., 2018; Urrego et al., 2005). In some regions, fire was used to maintain productive forest–savanna mosaics and enhance landscape heterogeneity (Carson et al., 2014), whereas in others fire activity remained low despite intensive human occupation, highlighting substantial regional variation in Indigenous land use and fire management strategies (Bush et al., 2008; Iriarte et al., 2012; Whitney et al., 2024). Across many parts of Amazonia, charcoal accumulation declined following European colonisation, coinciding with demographic collapse and the abandonment of managed landscapes (Koch et al., 2019). Together, these findings demonstrate that many contemporary forests are products not only of natural ecological processes but also of long–term interactions among people, fire, and biodiversity (Levis et al., 2018; Palace et al., 2017).

These insights have important implications for conservation and restoration, which often aim to suppress fire or recreate ecological conditions observed during the recent past (Bowman et al., 2020; Shuman et al., 2022; Whitlock et al., 2010). Paleofire records identify the fire regimes under which ecosystems developed and maintained biodiversity, providing information that can improve restoration targets, support climate adaptation planning, and inform conservation strategies that recognise the role of Indigenous stewardship and traditional fire management (Dietl et al., 2015; IPBES, 2019; Maezumi et al., 2024).

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Pollen analysis as a proxy of reconstructing past vegetation composition and environmental change

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A major challenge facing conservation and restoration management is that the climate of the future is likely to be entirely different from conditions that are existing currently. These future climates are likely to be unfamiliar to contemporary ecosystems, contributing to high levels of uncertainty in ecosystem models and an increasing possibility of future "ecological surprises". In order to address this uncertainty, we need to understand how ecosystems respond to changes in climate. Furthermore, basing our understanding on observations of existing ecosystems alone is not sufficient as future climates may give rise to ecosystems that do not exist yet.

The study of environmental change in the past is one way in which researchers can explore possible ecosystem responses to climatic change. The analysis of fossil pollen, preserved within the sediments of depositional environments such as lakes, swamps, terrestrial and marine settings, has been widely used by a large number of studies, to decipher past climatic and environmental conditions (Birks et al., 2012a,b, 2019; Gajewski, 1993). The information available via the study of fossil pollen and their wide occurrence makes them an integral part of biological proxy analysis (Chevalier et al., 2020). Additionally, pollen has a high preservation potential, with fossil pollen observed in sediment cores dating back as far as the early Quaternary (Traverse, 2007).

Vegetation change, as derived from fossil pollen, has been used in various regions to interpret climatic variability over timescales from decades to millennia (Bartlein, 1984), using our understanding of the environmental conditions which different plants require for growth and reproduction. Pollen results have been used to determine species diversity through time, and various techniques, such as REVEALS modelling, have been developed which can be used to adjust pollen counts towards representative distributions of vegetation in a landscape (Sugita, 2007). Pollen analysis has also been used to quantitatively reconstruct past variables such as temperature, precipitation and drought (Bartlein et al., 1984, 2011; Birks et al., 2012a. Additionally, the potential to use pollen analysis for both local and regional climatic and environmental reconstruction makes them a preferred proxy for a broad range of applications in landscape reconstruction (Bartlein et al., 2011).

While fossil pollen analysis has been well-established, the majority of environmental reconstruction using quantitative pollen research has been focused in the northern

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While fossil pollen analysis has been well-established, the majority of environmental reconstruction using quantitative pollen research has been focused in the northern hemisphere, with Africa, Southeast Asia and South America forming the 'quantification desert' as referred to by Chevalier et al. (2020). Pollen studies within the East African region began in the mid 20th-century, with initial studies primarily focused on the mountainous regions in Uganda (Osmaston, 1958, Livingstone, 1962) and Kenya (Coetzee, 1967). The main focus of this early research was to use pollen to understand the response of the montane vegetation to climatic change. Following these pioneering studies, more studies within the East African region have exploited the use of fossil pollen analysis to reconstruct climatic and environmental change during the Holocene, using sediment cores recovered from a wide variety of environments, such as inland vegetated wetlands (Githumbi et al., 2018; Rucina et al., 2010), Rift valley lakes (Kiage & Liu, 2009; van der Plas et al., 2021), mangroves (Massuanganhe, 2016; Punwong et al., 2013; Gitau et al., 2023) and high-altitude lakes and bogs (Bonnefille & Riollet, 1988). These assessments have provided a deeper understanding of how savanna and forest ecosystems within the East Africa region responded to climate variability in the past.

Pollen analysis aids in the depiction of how landscapes and land cover has changed over time (Howe & Webb, 1983), which is of particular significance as these landscapes are the interface

via which human-environment interactions occur. The onset and continued human influence on the landscape is a key consideration in fossil pollen analysis, and the environmental effects of the clearing of vegetation and the introduction of species can be highlighted through high-resolution pollen analysis (Morrison & Hamilton, 1974; Hamilton et al., 1986; Perrott, 1987; Kiage & Liu 2009).

It has evidently been shown that with high-resolution analysis of fossil pollen and precise dating methods such as Carbon-14 dating, it is possible to reconstruct past vegetation composition at different time periods. By better understanding these past climate scenarios we can improve our estimate on the risk to future ecosystems and vegetation communities if species do not have the capacity to adapt, disperse, or migrate under future climate conditions. This information can be used to advise restoration programs, and build policies that may be most effective based on the history of the ecosystems that have gone before. In particular, this research can take into consideration local vegetation dynamics known or identified to be associated with human activities such as changes in land use allow for a more informed understanding of past environmental change.

Moving forward, these palaeoecological tools have implications and applications for conservation and restoration. Long-term baselines of ecological change developed using pollen analysis will enable practitioners to obtain a holistic understanding of a particular ecosystem, in order to address questions such as; What are the most realistic conservation and restoration goals? Do any past ecosystems provide a feasible baseline for conservation and restoration? If not, how might we instead plan to support ecosystems of an unfamiliar future?

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UAV-based remote sensing

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Unpiloted Aerial Vehicle (UAV)-based remote sensing uses low-altitude aerial platforms to record landscapes at resolutions that connect satellite imagery, field observation and local knowledge. In practice, UAV mapping is usually carried out through systematic flight lines, with many overlapping photographs. Structure-from-Motion photogrammetry then identifies matching points across the images, reconstructs camera positions and produces georeferenced spatial outputs such as orthophotographs, digital elevation models and 3D models. For biodiversity research, UAVs bridge broad satellite products and ground-based observation, allowing researchers to map small features that shape habitat condition, resource use and environmental change (Koh and Wich, 2012; Anderson and Gaston, 2013; Christie et al., 2016; Duffy et al., 2018). These outputs are increasingly useful in compact island and coastal landscapes, where vegetation, tidal flats, paths, erosion, shoreline change and locally maintained infrastructure can be recorded within a single spatial framework.

High-resolution UAV imagery has been used to assess forest biodiversity, support community-based forest monitoring, map habitat condition and identify tree crowns or visually distinctive species during restoration monitoring (Getzin et al., 2012; Paneque-Gálvez et al., 2014; Gonçalves et al., 2016; Williams et al., 2020). Integrated workflows combining satellite data, UAV photogrammetry and field survey can also map anthropogenic features and long-term land-use patterns that help contextualise present-day landscapes (Peters et al., 2026).

In the Philippines, UAV-based photogrammetry has been applied to coastal and small-island biospheres in the Gigantes Islands and on Vuhus Island. In the Gigantes Islands, UAV survey, satellite interpretation, historical review, snorkelling documentation and community interviews have been used to document stone tidal weirs (STWs). STWs are coral-stone barricades built across shallow tidal flats and used during ebb tide to capture fish (Zayas, 2004). They are constructed within intertidal environments and can shape habitat complexity, resource availability and local biodiversity. In South Africa, stone-walled vis vywers recorded higher species richness and diversity inside the weirs than in adjacent control areas, suggesting that maintained intertidal walls can create microhabitats for edible invertebrates and other organisms (Jeffery, 2013). In Palompon, Leyte, fish corrals contained 81 identified fish species across 27 corrals, with diversity linked to structural complexity and reef-flat conditions (Cabansag et al., 2011).

In Gigantes, UAV orthophotographs allow STW form, condition and coastal setting to be mapped. Combined with satellite imagery, historical sources, snorkelling observations,

interviews and field observations, they also make it possible to study STW occurrence, visibility and maintenance across different temporal scales. This helps assess how long-term changes in the maintenance or disappearance of intertidal fishing structures may affect habitat complexity, resource availability and local biodiversity. The Gigantes work also records how environmental pressures, changing fishing strategies, reduced maintenance and damage by outside fishers affect the continued use and ecological role of these structures (Peters et al., in prep. a). UAV-based monitoring can make such changes visible, measurable and comparable without assuming a simple history of decline.

On Vuhus Island, the same method works across a whole small-island biosphere. Full-island UAV coverage records vegetation, tree crowns, vegetation types, paths, open areas, erosion features, tidal flats and coastal edges across a compact island environment (Peters et al., in prep. b). This allows individual trees and island-wide patterns to be studied together. Because Vuhus also preserves evidence for repeated human presence, cultivation, abandonment, grazing and coastal use, UAV data help document how present vegetation and tidal-flat surfaces relate to longer histories of land use and environmental change.

Additional sensors can extend this UAV framework from visible surface mapping to vegetation condition, canopy structure or terrain below vegetation. Multispectral UAV imagery has been used to assess habitat condition in fine-scale vegetation mosaics and to compare UAV-derived vegetation indices with Sentinel-2 products in Tanzania (Gonçalves et al., 2016; Mangewa et al., 2022). LiDAR adds a terrain and vegetation-structure layer by recording three-dimensional canopy and ground surfaces (Hamraz et al., 2017; Xiang et al., 2023). In the Philippine Cordilleras, LiDAR combined with UAV imagery and satellite data reveals terrace morphology extending into forested slopes, linking vegetation cover to earlier land use, abandonment, maintenance and forest regrowth (Peters et al., in prep. c).

UAV-based remote sensing can therefore connect biological observations, such as tree distribution, vegetation condition and canopy structure, with landscape processes such as erosion and regrowth, and with the effects of cultivation, grazing, resource use and inherited landscape infrastructure. For policy, this provides spatial evidence for coastal zoning, fisheries management, habitat restoration, climate adaptation and community-based monitoring. Consent, privacy and shared interpretation remain essential when UAV data are collected in inhabited or customary-use landscapes (Sandbrook, 2015; Duffy et al., 2018). Orthophotographs, annotated habitat maps, 3D models, shoreline-change baselines, vegetation inventories and repeatable monitoring datasets can support conservation and restoration planning where biodiversity, subsistence practice, living knowledge and inherited infrastructure are closely connected.

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Decoding Biodiversity from Historical Documents

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Tracing biodiversity across different temporal scales involves studying remnants of the past. Biological tissues, fossils, or sediments are often examined for this purpose, enabling insights that span millennia. Focusing on the last few hundred years, however, reveals a different, frequently overlooked, source of data: human-made, written records on biodiversity. Surveys conducted by naturalists, scientists, and collectors are obvious examples, yet many other sources including travel diaries, missionary accounts, and (colonial) administrative and forestry records contain valuable biodiversity information, particularly for the Global South [Navarro et al. 2025]. Historical climatology has already demonstrated the scientific potential of documentary sources by establishing methods to reconstruct past temperature, precipitation, and extreme events [Nash et al. 2021; Glaser 2025]. While documentary evidence has long been established in historical climatology, its application to biodiversity research has only recently begun to receive comparable attention. The growing availability of digitised archival collections, together with advances in machine learning, now enables historical biodiversity records to be analysed systematically and at scales that were previously unattainable.

These "archives of societies" complement the "archives of nature" [Brönnimann/Pfister/White 2018] by documenting historical interactions between people and the environment. While travel diaries record species observations, administrative records provide evidence of land use, forest management, agriculture, hunting, and resource exploitation. Unlocking these sources requires an interdisciplinary methodology combining historical expertise, archival research, computational methods, and biodiversity science. We refer to this approach as Computational Historical Ecology (CHE) [Rehbein 2025]. Its workflow comprises three phases: source preparation, extraction and transformation, and publication which are illustrated here using the 1845 Bavarian Animal Observation [Rehbein et al. 2025].

The first phase begins with identifying relevant archival material. Biodiversity information is frequently embedded in records that were never intended as natural history documents and whose catalogue descriptions provide little indication of their scientific value. Locating these sources therefore requires both archival expertise and historical contextualisation. In the Bavarian case, the Bavarian State Archives preserve responses to a systematic survey of 44 vertebrate species conducted by the Ministry of Finance in 1845 through the kingdom's forestry offices.

The documents are subsequently digitised and transcribed using Machine-learning-based transcription. Recent advances in machine learning have shifted the main effort from manual

transcription towards the evaluation and correction of automatically generated text, making it possible to process thousands of handwritten documents efficiently while maintaining high data quality. Importantly, this workflow is designed to be reproducible and transferable across different source types. Although individual collections require source-specific adaptations, the underlying sequence-from source discovery to structured data publication-provides a common methodological framework for transforming heterogeneous historical documents into interoperable biodiversity data.

The second phase transforms transcribed text into structured biodiversity information. Relevant observations are extracted, interpreted, and formalised before being standardised through taxonomic, spatial, and temporal normalization. In the Bavarian project, large language models were used to convert qualitative descriptions of species occurrence into comparable categories [Haider et al. 2025], while historical species names were mapped to current taxonomy [Fillies et al. 2025]. The resulting observations were georeferenced and validated against modern reference data, highlighting the importance of close collaboration between historians, computer scientists, and biodiversity researchers.

The final phase integrates the resulting data into reusable research infrastructures while preserving links to the original archival sources. The resulting 1845 Bavarian Animal Observation Dataset (AOD1845) [Rehbein et al. 2024] contains more than 5,000 biodiversity records derived from approximately 5,400 handwritten reports and has been published on Zenodo for reuse in biodiversity research.

The CHE approach is readily transferable to historical sources from the Global South [e.g., Williamson and Pei 2020]. Travel diaries provide particularly rich examples. The journals of Alexander von Humboldt document landscapes, plants, animals, and environmental conditions across Latin America, while the expedition of Carl Philipp von Martius and Johann Baptist von Spix to Brazil (1817–1820) produced extensive descriptions and collections of Brazilian flora and fauna, now digitally accessible through the Munich Digitization Center. Another promising source corpus consists of potential records produced by international graduates of forestry academies such as Munich, who transferred Bavarian forest management practices to colonial contexts including British India or China, thereby generating extensive administrative and environmental documentation. Similar opportunities exist in missionary reports, forestry archives, shipping logs, local administrative records, and scientific correspondence throughout Africa, Asia, and Latin America. Together, these diverse source corpora provide complementary perspectives on past ecosystems and human–environment interactions that remain only partially explored.

These sources, however, must be interpreted critically. Most were produced from European perspectives and frequently reflect colonial power structures, racial discrimination, exoticism, and the appropriation of Indigenous knowledge. Moreover, the uneven geographical distribution of archival records complicates the universal application of documentary approaches [Navarro et al. 2025]. Integrating Traditional Ecological Knowledge (TEK) alongside written archives can help recover deeper ecological baselines while ensuring that biodiversity research and restoration efforts acknowledge and respect the environmental knowledge of Indigenous and local communities [McGregor 2008; Armstrong et al. 2017; McClenachan et al. 2024].

The potential of CHE extends well beyond biodiversity records. Comparable historical datasets exist for hydrological and environmental reconstruction, including river-level and tidal

observations from the Paraná River Basin, the Indian Ocean region, Mumbai, and the Mekong River [Rehbein 2026]. A key challenge for future research is therefore the identification and integration of source corpora originating from the Global South itself, including Indigenous knowledge, local-language records, and the archival documents of colonised communities. An abundance of such documents remain largely unexplored in archives, libraries, and museums worldwide, representing an enormous but underused source of historical biodiversity data [Rehbein et al. 2025]. Beyond reconstructing past ecosystems, these records may inform conservation planning, species reintroduction, rewilding, and ecological restoration [Meyer and Crumley 2012; Szabó 2014; McClenachan et al. 2024]. Combining these perspectives with computational methods promises a more comprehensive and globally balanced reconstruction of historical biodiversity and environmental change. At the same time, it creates opportunities to connect biodiversity science with archival research, digital humanities, and Indigenous and local knowledge systems.

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Conclusion

The contributions in this report show that biodiversity cannot be understood or conserved in isolation from the people, knowledge systems, cultures, and territories with which it is intertwined. Conservation actions should be grounded in long-term relationships of care, sustainable use, restoration, and intergenerational responsibility. Seed conservation, traditional ecological practices, community-led restoration, sustainable use of wild species, and the equitable collaboration or confluence between knowledge systems all demonstrate how biodiversity and biocultural diversity can be sustained together. These experiences also highlight the importance of meaningful community participation, including women's leadership and the transmission of knowledge to younger generations, particularly as climate change and other environmental pressures intensify.

Conservation actions should be grounded in long-term relationships of care, sustainable use, restoration, and intergenerational responsibility.

Quilombola experiences deepen these understandings by showing that territory is not merely a setting for biodiversity, but a living web of ecological, cultural, historical, and spiritual relationships. Drawing on Nego Bispo`s concept of biointeração, communities are participating within, not managers of the living world. Quilombola practices such as polyculture with ever-living flowers, goldengrass or honey, forest and water protection, seasonal harvesting and care for sacred memory sites, do not just conserve what sciences call nature, they actively regenerate it through generations of relational stewardship. Thus, in the Quilombola perspective shared here, biodiversity protection is not separable from collective territorial rights, cultural continuity, and the autonomy of Quilombola institutions and livelihoods.

At the same time, conserving biodiversity requires addressing the structures that determine who has access to biological resources, whose knowledge is recognised, and who benefits from their use. The development of biotechnology, genetic databases, and Digital Sequence Information is creating new opportunities for research and innovation, but also new forms of inequality and potential appropriation of Indigenous and local knowledge and resources. Existing frameworks such as the CBD and Nagoya Protocol provide an important basis for access and benefit-sharing, yet persistent imbalances in power and the treatment of traditional knowledge primarily through intellectual property frameworks remain unresolved. As biodiversity governance moves further into the digital sphere, it will therefore be essential to strengthen the rights and agency of Indigenous Peoples and local communities, ensure meaningful consent and equitable benefit-sharing, and recognise their knowledge as living systems rather than simply as resources to be documented or commercialised. Ultimately, moving from recognition to participatory governance means treating Indigenous Peoples and local communities not simply as stakeholders or beneficiaries, but as rights holders and partners in shaping the policies and futures that affect their territories.

In Quilombola cases, integration can sometimes be problematic. For them ecological knowledge is inseparable from collective experiences and practices of care. Nego Bispo`s concept of confluência offers an important principle that



not only illuminates the aspects of the Nagoya Protocol regarding knowledge appropriation and benefit policies, but sheds lights on what is participatory governance that moves beyond incorporating selected elements. The communities that participate in this project share an important aspiration: being recognised as knowledge authorities and governance institutions with power to define research questions, determine how knowledge may be accessed and used, refuse inappropriate documentation or commercialisation, and participate equitably in decisions and benefit sharing policies.

This means bridging the gap between formal recognition and effective territorial protection. Biodiversity policies fail to be locally grounded when territories remain untitled, reduced to administrative polygons or exposed to mining agribusiness, infrastructure, and conservation interventions imposed without the free, prior, and informed consent (FPIC). KMGBF implementation must therefore link biodiversity policies with accelerated collective titling.

Taken together, the contributions in this report reinforce that biodiversity policy must move beyond a narrow focus on species and ecosystems towards approaches that recognise the social, cultural, and territorial relationships through which biodiversity is sustained.

These lessons are directly relevant to the implementation of the Kunming–Montreal Global Biodiversity Framework (KMGBF) and the priorities of the Convention on Biological Diversity (CBD). The experiences presented throughout this report highlight that achieving the Framework's goals requires action across interconnected areas: mobilising adequate and accessible financing for biodiversity action, particularly in developing countries; securing Indigenous, Local and Quilombola collective territorial rights and supporting community-led biodiversity stewardship, strengthening capacity building and technology transfer; improving biodiversity monitoring, indicators, and reporting; and transforming productive sectors, including agriculture, fisheries, forestry, mining, and infrastructure, not only to reduce their pressures on biodiversity, but held accountable for their impacts on biodiversity, territories, and the communities whose long-term relationships of care have sustained them.

Across these areas, the contributions in this report underscore the importance of approaches that are locally grounded and responsive to the realities of the territories where biodiversity is sustained. Financing, technologies, monitoring systems, and sectoral transformations will be most effective when they build on existing community knowledge, institutions, practices, and priorities rather than treating them as secondary to externally defined solutions. Taken together, the contributions in this report reinforce that biodiversity policy must move beyond a narrow focus on species and ecosystems towards approaches that recognise the social, cultural, and territorial relationships through which biodiversity is sustained.



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