

WHITE PAPER

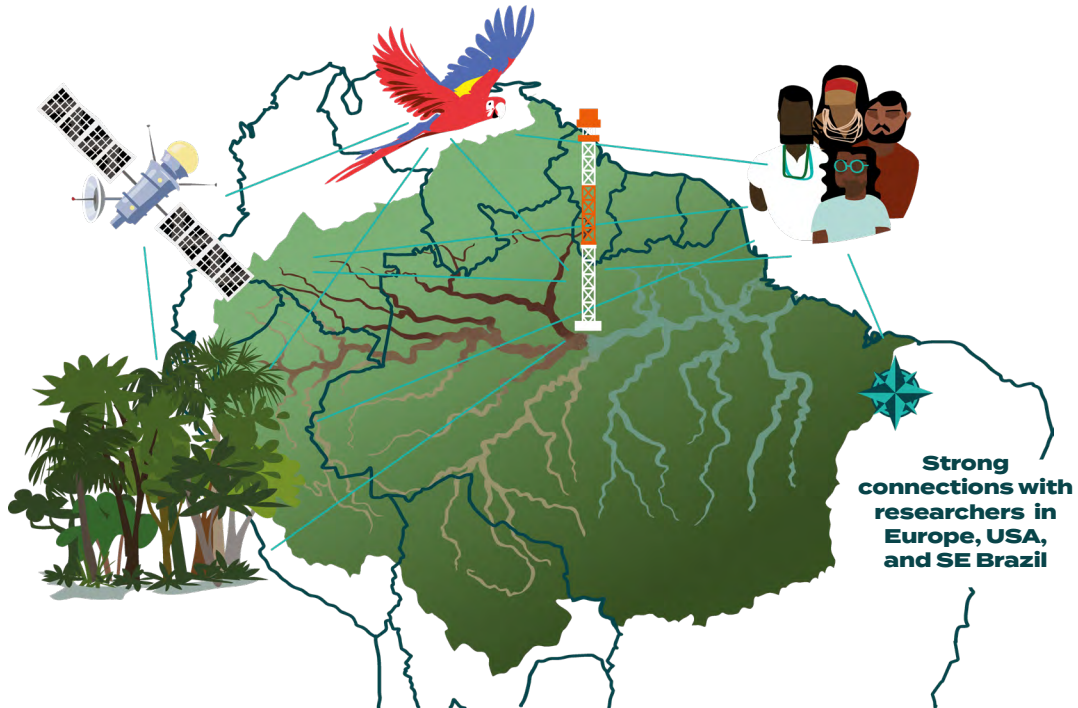
Supporting a Thriving, Integrated, and More Equitable Science Community Across the Amazon

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Executive Summary

The Amazon is among the most studied tropical regions in the world, yet the environmental and conservation sciences research communities based within it remain only loosely connected. This white paper examines that paradox and asks what, beyond funding, constrains an integrated and more equitable Amazonian research community. We explore this using a coauthorship analysis of ecology and biodiversity publications indexed in OpenAlex between 1993 and 2025 and analysis of data on travel connectivity through flights, the location of academic society meetings, and the alignment of national working calendars. Amazonian institutions collaborate with partners outside the basin far more often than with one another and are often linked to each other only through those external partners. Since 2012, the network has expanded considerably and become more integrated, although most of the growth involves partners outside the region rather than internal integration. Physical isolation and the uneven distribution of funding and research capacity, both between countries and within them, define and reinforce this pattern. We argue that the main constraints are structural and organizational as well as financial and that funding delivered through existing structures tends to reach institutions that are already well connected. Treating the Amazon as a distributed research network, we identify five interrelated challenges: communication across languages and knowledge systems, coordination under asynchrony, trust, the infrastructure of collaboration, and asymmetries between network nodes. Addressing these challenges requires multiple actions that support functioning of regional coalitions including the breadth of participation and respect for Indigenous and local communities data governance, changes to funding rules that treat coordination and training as legitimate costs, long-term investment in the small and therefore weaker institutions/partners, and changes in how extra-Amazonian researchers work in the region. Most of these changes fall within the scope of decisions that governments, funders, institutions, and researchers make routinely.

Globally important research occurs in the Amazon



Significant structural issues persist:



Weak research connections within the Amazon



Invisible informal research networks



Resource asymmetries



Difficulties building trust



Fragmented data infrastructure



Communication barriers

A thriving research community requires:



Funding for regional networks and coalitions



Integration of diverse knowledge around shared goals



Stronger institutional and human capacity



Sustained face-to-face exchange



Strengthening sustainable infrastructure



Shared protocols and multilingual tools

Graphical Abstract Environmental and conservation research conducted in the Amazon is globally important, yet the community that produces it remains internally fragmented. Amazonian institutions are tied more strongly to Europe, the United States, and southeastern Brazil than to one another. Persistent structural barriers sustain this pattern, while the enabling conditions shown here outline a pathway toward a research community that can thrive from within the basin.

1. The Amazon at the Forefront of Tropical Environmental Research

The Amazon biome stands out as one of the most important in both the tropics and worldwide. The Amazon holds by far the largest tropical forest and the largest river system, featuring the highest biological and cultural diversity, including many groups of Indigenous Peoples, Local Communities and Afrodescendant Peoples. The region is also at the center of global change assessments due to its significant carbon stocks, water and temperature regulating capacity^{1,2}, and high sensitivity to degradation³.

Given its importance and size, it is unsurprising that the Amazon has become a rich source of research on tropical ecosystems. The number of scientific publications in environmental sciences and conservation has increased rapidly over time, supported by initiatives such as the internationally funded Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)^{4,5} and by the growth in ecological and environmental sciences in Brazil^{6,7}. The Amazon also hosts some of the world's most important long-term experiments and observational networks, many of which have expanded beyond the biome (**Table 1**).

These initiatives have influenced research across the tropics and beyond. The Biological Dynamics of Forest Fragments Project (BDFFP), for example, has been cited worldwide²⁸, while the Amazon Forest Inventory Network (RAINFOR) provided the template for plot networks in other tropical regions¹⁸. The Brazilian Program for Biodiversity Research (PPBio) was first implemented in the Amazon; from its Amazonian roots, PPBio expanded across all major Brazilian biomes and beyond Brazil, becoming one of the largest coordinated biodiversity-monitoring initiatives in the tropics¹⁰. The Amazon Tree Diversity Network (ATDN) spurred substantial research on hyperdominance globally²⁹ and across different ecosystems³⁰. The success of these projects and initiatives is to be welcomed and, in many cases, reflects long-standing strategies among Amazon countries to promote the internationalization of research, including the sharing of infrastructure, knowledge, and technologies. These examples and the analysis that follows center on the environmental sciences, including research led by Indigenous Peoples, Local Communities and Afrodescendant Peoples and the community-based monitoring programs that have become central to environmental knowledge production in the region^{31,32}.

Table 1. A non-exhaustive list of examples of large internationally linked research projects and initiatives in the Amazon.

Project or initiative name	Global relevance
Brazilian Program for Biodiversity Research (PPBio)	Largest standardized biodiversity monitoring protocol for tropical forests ^{8–10}
Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)	Often cited as the largest research network ever developed in Brazil ^{4,5,11}
Amazon Tall Tower Observatory (ATTO)	Only tall tower observatory in the tropics ¹²
Amazon Free-Air CO₂ Enrichment (AmazonFACE) experiment	Only FACE experiment in tropical forests ¹³
Amazon Tree Diversity Network (ATDN)	Largest tree plot network in Amazonia ^{14,15}
Regional Initiative for Hydrological Monitoring of Andean Ecosystems (iMHEA)	Studies Andean hydrology and supports improved water resource management and ecosystem conservation across the Andes ¹⁶
Global Observation Research Initiative in Alpine Environments (GLORIA)	Monitors high-mountain biodiversity and climate change impacts through a standardized, low-cost protocol across a decentralized global network, including the 7,000 km transboundary GLORIA-Andes platform ¹⁷
Amazon Forest Inventory Network (RAINFOR)	First large-scale plot-based tropical forest monitoring network ¹⁸
Tropical Managed Forests Observatory (TmFO)	Examines the long-term resilience and carbon dynamics of logged tropical forests through a standardized pantropical network of permanent plots, supporting sustainable silvicultural and policy frameworks ¹⁹
Secondary Forests Research Network (2ndFOR)	Focuses on the ecology, dynamics, and biodiversity of tropical secondary forests and the ecosystem services they provide in human-modified tropical landscapes ²⁰
Rede Amazônia Sustentável (RAS)	Focuses on comprehensive assessment of social and ecological dimensions of land-use sustainability in eastern Brazilian Amazonia ²¹
Rainfall exclusion experiments	have been conducted at Caxiuanã National Forest the Tapajós National Forest, and Tanguro Research Station ^{22,23}
Biological Dynamics of Forest Fragments Project (BDFFP)	First experimental fragmentation experiment in tropical forests ²⁴
Observatório Regional da Amazônia (ORA)	A collaborative platform and reference center of the Amazon Cooperation Treaty Organization (ACTO/OTCA) that aims to strengthen cooperation and decision-making between the eight Amazon countries ²⁵
Science Panel for the Amazon	An innovative interdisciplinary international science panel focused on the Amazon ^{26,27}

While scientific excellence and international visibility can coexist with limited long-term strengthening of Amazonian scientific institutions, some of the very features that made these initiatives succeed—namely, international funding, external partnerships, and globally networked infrastructure—also shape who leads Amazonian research.

2. The Amazon Research Paradox

Impressive though these national and international activities are, they also struggle with major challenges for environmental and ecological research. Many core elements of the Amazonian research environment lag far behind its headline productivity, impact, and recognition. Chief among these are the limited set of collaboration networks originating within the Amazon and connecting countries across the region, a pattern closely tied to how research funding and capacity are distributed as well as to which research communities receive recognition. Here, we assess these issues by mapping research links and the geography of Amazonian institutions and collaborations, examining data on research events and physical connectivity, and reviewing evidence on (1) the connectivity of collaborations,

(2) funding asymmetries and research capacity, and (3) the inclusion of local knowledge systems. We outline each of these three areas below.

2.1. Limited Connectivity of Scientific Collaborations Within the Amazonian Research Community

The Science Panel for the Amazon (SPA) has made important advances in sharing and synthesizing knowledge across the Amazon Basin. It has assembled nowadays more than 300 scientists and knowledge holders, including Indigenous scientists from across the region, and its assessments have informed policy processes from the United Nations Framework Convention on Climate Change (UNFCCC) climate summits to the 2023 Belém Declaration²⁶. Taking a basin-wide perspective is crucial for understanding processes at the scales that matter and for considering connectivity across multiple levels²⁶. But SPA members are only a fraction of all researchers and institutions. What are the patterns of collaboration like for the whole research community? We assessed this by conducting a literature review of ecology-focused studies published between 1993 and 2025 in the OpenAlex database, an open-source bibliographic database³³ accessed via the “openalexR” package in R³⁴. See **Box 1** for methods and three important caveats.

BOX 1. Assessing scientific collaboration for studies on the Amazon's biodiversity

We searched in English, Spanish, and Portuguese using the following keywords: (“Ecology” OR “Biology” OR “Ecological” OR “Biodiversity”) AND (“Amazon rainforest” OR “Amazon basin” OR “Amazonian forest” OR “Brazilian Amazon”) AND (“species diversity” OR “species composition” OR “conservation biology” OR “ecosystem services”). Of the 2,783 papers returned, screening selected 240 on the Amazon. These were from 82 institutions inside the Amazon, with Brazil, Bolivia, and Peru having the highest numbers of institutions (47, 13, and 9, respectively). This within-Amazon number was dwarfed by the 861 institutions outside the Amazon that have published on the region, with the United States, non-Amazon regions of Brazil, and France being the most prolific (179, 118, and 60, respectively).

Results from this approach have three important caveats. First, our search terms were deliberately centered on ecology and biodiversity and did not include anthropology, sociology, economy, or the socio-ecological sciences. Our networks, therefore, best represent formal biodiversity research and underrepresent the interdisciplinary and social science work central to the socio-ecological research environment, which we address qualitatively in the sections that follow. Second, OpenAlex indexes peer-reviewed, predominantly English-language outputs far more completely than the gray literature, technical reports, and non-English materials through which much Amazonian—and especially Indigenous and community-based—research circulates. Third, coauthorship is one expression of scientific collaboration, not its full extent. Other activities, such as the coordination of postgraduate courses and other research capacity, may only be partially reflected in coauthorship networks. Therefore, while our networks capture the main trends in the scientific landscape, they may understate the many other forms of collaboration that are not formalized by coauthorship.

To assess how physically connected the Amazon Basin is to national and international travel and research networks, we assembled a global dataset of airports and routes from the OpenFlights database³⁵, accessed through the “airportr” R package³⁶, and classified each airport by size (small, medium, or large) following the OurAirports facility typology³⁷. The compiled dataset comprised 7,698 airports and 67,664 routes, most of which link small airports (42,403 routes). Within the Amazon Basin, we identified only 164 airports, of which 74 were small, 84 medium, and six large. The scarcity of these facilities, their predominantly small size, and their limited number of direct connections illustrate the spatial isolation of the basin and the practical barriers it imposes on field access, in-person collaboration, and the movement of researchers and materials across the region.

The patterns of collaboration are clear. Collaboration between Amazonian institutions is relatively rare when compared to the vast ties linking those institutions to external partners (**Figure 1**), reflecting human population densities, historical legacies of science, funding opportunities in other regions (e.g., the Fundação de Amparo à Pesquisa do Estado de São Paulo [FAPESP] in São Paulo and international research agencies), and the challenges of within-Amazonian research connectivity. This is more a matter of institutional structure rather than who takes part in the research. Because the ties are between institutions, a single paper involving many external institutions and few Amazonian ones generates a large number of external ties even where Amazonian researchers are full participants or lead the work. However, **Figure 1** shows that Amazonian institutions are linked to one another mainly through partners elsewhere rather than directly. These results echo other bibliometric evidence showing that collaboration among Amazonian countries is limited relative to partnerships with institutions in the Global North, and that research across the Amazon lowlands, the Andes, and the Guiana Shield likewise remains relatively disconnected³⁸.

This collaborative distance is strongly linked to physical connectivity. The Amazon's prominence in tropical science is often undermined by its weak connectivity with

the rest of the world and the fact that the major urban centers and international transport hubs in most Amazonian countries lie outside the biome itself (see **Figure 2**). The same distance that makes it hard to travel between Amazonian cities makes it hard and expensive for their institutions to work together. To provide one example, we assessed the meetings of 15 academic societies relevant to conservation and ecology from 2009 to 2025. A total of 65 in-person meetings were held in 29 countries, but only three were in Amazonian countries, and only one was in the Amazon itself. Although the bioeconomy forums held in the run-up to the 2025 UN Climate Change Conference (COP30), hosted in Belém, demonstrate that the region can convene international events at the highest level, these events have been the exception over the past decades.

Encouragingly, within-Amazonian collaboration is improving over time. Between 1993 and 2011, the institutional collaboration network was smaller, more fragmented, and organized around a small number of highly connected hubs, with just a few institutions linked to the broader network (**Figure 3**). From 2012 to 2025, the network expanded substantially, increasing from approximately 113 to 943 institutions, and developed a denser, more cohesive architecture, characterized by a larger central core and much stronger interconnectivity among institutions (**Figure 3**). However, much

of the expansion is driven by a rise in collaborations involving institutions outside the Amazon, particularly those functioning as major national and international hubs. Connections among Amazonian institutions themselves also increased but remain proportionally less frequent than cross-regional collaborations (**Figures 1** and

3). This trajectory of capacity expansion coexisting with persistent institutional asymmetry, is consistent with patterns documented in adjacent fields such as conservation genetics in Latin America, where regional research grew markedly after 2010 while structural inequalities endured^{39,40}.

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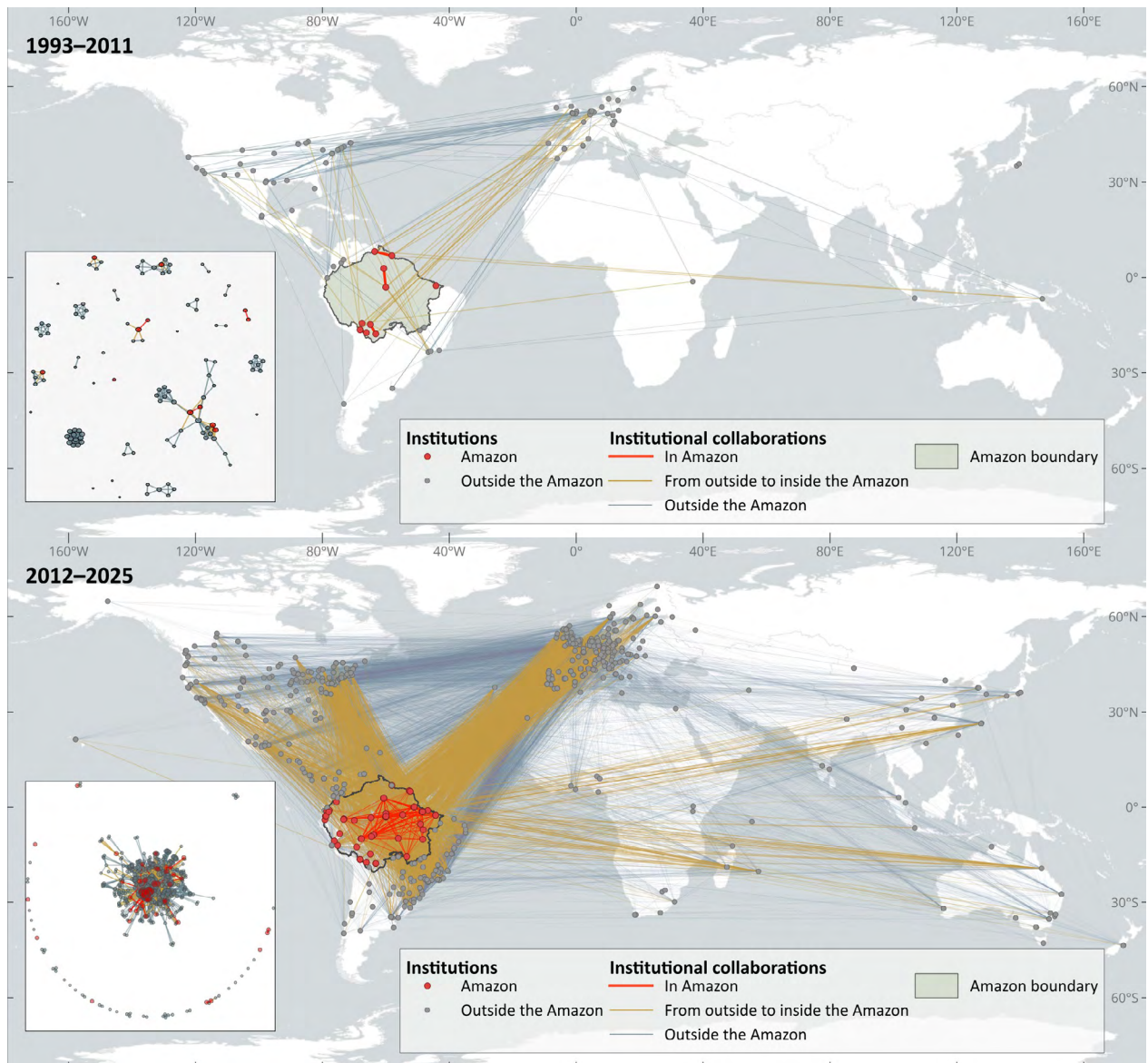


Figure 1. Institutional coauthorship networks for Amazon-related publications indexed in OpenAlex, 1993–2011 (upper panel) and 2012–2025 (lower panel). Red nodes represent institutions within the Amazon region, and gray nodes represent institutions outside the region. Lines link pairs of institutions appearing on the same publication, colored red for pairs of Amazonian institutions, gold for pairs joining an Amazonian and a non-Amazonian institution, and gray for pairs of non-Amazonian institutions. Each publication was decomposed into all pairs of its authors' institutions, so a single paper involving both Amazonian and non-Amazonian institutions may contribute to lines of all three colors. A gray line, therefore, indicates two non-Amazonian institutions on a shared publication and does not indicate that Amazonian institutions were absent from that publication. Insets show the same networks in a force-directed layout, where position reflects network topology rather than geography.

These findings carry two messages which exemplify the Amazon's research paradox. First, they demonstrate the effective promotion of internationalization by South American nations and the strong global interest in the Amazon. This thriving body of work underpins the networks and research projects in **Table 1**, and, when carried out collaboratively with Amazonian institutions, supports knowledge exchange, funding, and opportunities to enhance and develop local expertise and engagement. For example, sustained international attention has also helped to develop and advance conservation policies that support both nature and Indigenous Peoples, Local Communities and Afrodescendant Peoples in the Amazon, something that other biomes rarely manage to achieve. Second, there are also risks. These collaborations will only bring lasting benefits to the region if they are embedded within

equitable research practices⁴¹ and avoid “helicopter” or “parachute” science, in which research is conducted without engaging with or developing equal relationships with locally based researchers, students or communities. Furthermore, the sheer predominance of international and extra-Amazonian collaborations can compete with and reduce incentives for collaboration within the basin, exacerbating the divide with informal or local networks we discuss further in Section 2.3. These two messages concern different things, and it is worth keeping them apart. The first is about how well the research network functions, that is, how much knowledge, funding, and expertise it moves. The second is about how the network's benefits and authority are distributed: who leads, who is credited, and who is left dependent. A network can function well while distributing its benefits poorly.

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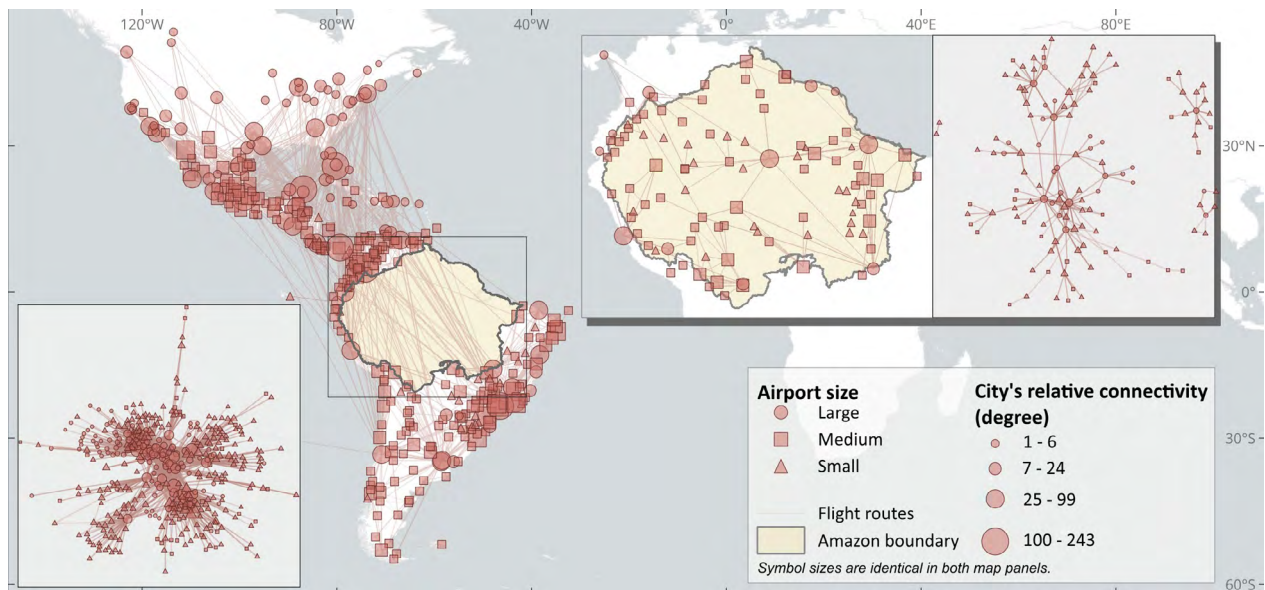


Figure 2. Connectivity networks derived from commercial flight routes for cities in South America. The main map shows routes between cities outside the Amazon. The boxed panel at upper right shows routes between Amazonian cities. Each network is also shown as a force-directed layout, in which node position reflects network topology rather than geography: at lower left for the non-Amazon network and at the right of the upper boxed panel for the Amazon network. Nodes are cities and lines show direct flight connections between them. Node size is proportional to each city's relative connectivity (degree, i.e., the number of other cities to which a city has a direct flight connection) within the network. Node shape denotes the size class of the city's largest airport. See **Box 1** for more details.

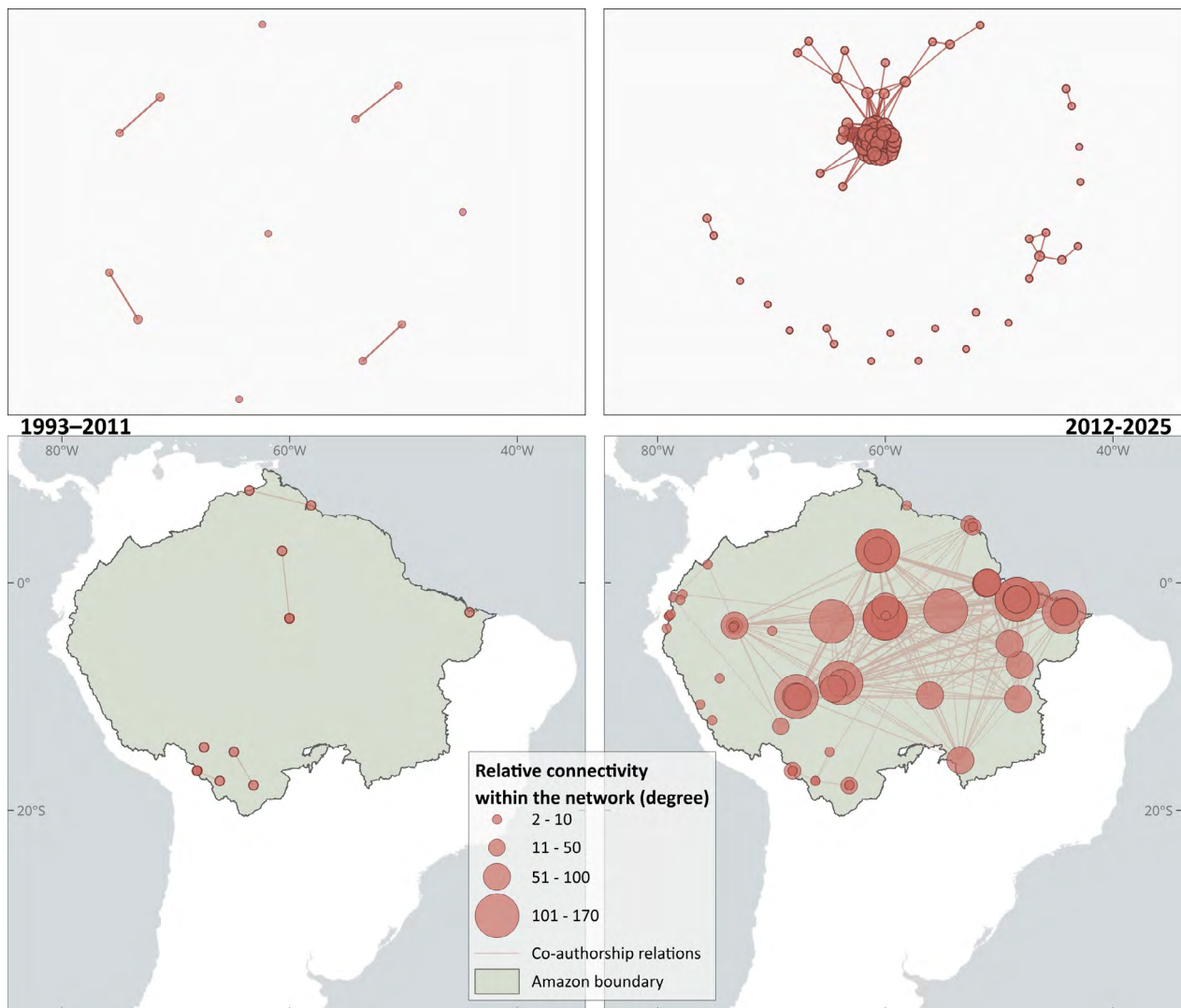


Figure 3. Amazonian institutional collaboration networks, filtered from the database of Amazon-related scientific publications indexed in OpenAlex. The left column covers publications from 1993 to 2011 and the right column, those from 2012 to 2025. The upper panels show each network in a force-directed layout, in which position reflects network topology rather than geography; the lower maps show the same two networks with each institution placed at its geographic coordinates. Nodes are institutions and lines show coauthorship ties between them; node size is proportional to degree, the number of other Amazonian institutions with which an institution shares at least one publication. Institutions in the same city overlap at map scale.

2.2. Strong Asymmetries in Funding and Research Capacity Between and Within Amazonian Countries

The connectivity gaps described above do not arise in a vacuum: they are underpinned by asymmetries in how research capacity and funding are distributed across the Amazon, both

among countries and within them. Brazil invests about 1.1% of its GDP in research⁴², roughly one percentage point less than France, while the other Amazonian countries generally invest no more than 0.5%. Despite these differences, the share of national research funding directed to the Amazon is broadly similar across countries⁴²,

ranging from 10% to 20%, even though the Amazon makes up 40% to 60% of the national territory in most of them. Within countries, the same asymmetries reappear, following the patterns already noted in the collaboration data. Across the Amazonian nations, research institutions, universities, and even prominent NGOs tend to concentrate in national capitals and better-served regions, so the Amazonian territory of each country remains peripheral within its own national system⁴³. Brazil illustrates the pattern well. The Brazilian Amazon receives a small fraction of national biodiversity investment (~10%), and most of the resources that do reach it are concentrated in two cities, Manaus and Belém^{44,45}. One could argue that this distribution simply reflects competition for funding and the uneven density of researchers and institutions, which is probably true. Yet the same competitive logic has left large parts of the basin with little institutional presence and few postgraduate training opportunities⁴⁴.

In the other Amazonian countries, the concentration of academic institutions and research-focused NGOs in highland administrative centers widens the gap in scientific integration and monitoring between the Andes and the lowland Amazon. These patterns reflect the absence of a shared vision of the Amazon as an integrated socio-ecological system, and of a research effort organized around that view, so that science remains as divided as the

region it describes. This divide also constrains Indigenous researchers, Afrodescendent peoples and local communities who often face barriers to exchanging knowledge and experience with other Indigenous communities across the basin.

2.3. Overlooked Research Communities Within the Amazon

A strong within-Amazon research community is fundamental to bringing local knowledge to the fore, sustaining long-term links with policymakers and practitioners, undertaking much of the core fieldwork that requires local management, and training a future generation of Amazonian researchers. Despite being less prominent in our analysis of the peer-reviewed literature in Section 2.1, this research community is far from absent. Amazonian and Amazonian-based researchers sustain ambitious, locally led networks operating across the basin (**Table 2**), among them the Amazon Network of Georeferenced Socio-Environmental Information (RAISG), the North Amazon Alliance (ANA), and Brazil's National Institutes of Science and Technology [INCT]. Several of these initiatives now provide the spatial and environmental data infrastructure on which Amazonian science itself depends. The biome boundaries and land-tenure layers used in regional ecological syntheses, for example, are products of RAISG^{26,31,46}.

Table 2. A non-exhaustive list of examples of research projects, networks, and programs coordinated by institutions based in Amazon countries, many of them working with international partners.

Name of project, network, or program	Description
Tanguro fire experiment	First forest-scale experimental fires in humid tropical forests ⁴⁷
Comunidad de Manejo de Fauna Silvestre en la Amazonía y en Latinoamérica (COMFAUNA)	Focused on wildlife management and conservation ⁴⁸
Amazon Waters Alliance	Focused on freshwater connectivity and fisheries; produces the Ictio data platform and has published and disseminated multiple papers; brings together more than 30 organizations from Bolivia, Brazil, Colombia, Ecuador, France, Peru, and the United States ⁴⁹
Amazon Network of Georeferenced Socio-Environmental Information (RAISG)	A consortium of eight civil society organizations—based in Bolivia, Brazil, Colombia, Ecuador, Peru, and Venezuela—that produces georeferenced socio-environmental information covering the entire Amazon ⁵⁰
INCT Centro de Estudos Integrados da Biodiversidade Amazônica (INCT CENBAM)	A network of Amazonian and non-Amazonian institutions linking biodiversity research to applied outputs and building research capacity outside the major regional centers; part of Brazil's National Institutes of Science and Technology (INCT) ⁵¹
INCT Sínteses da Biodiversidade Amazônica (INCT SinBiAm)	A transdisciplinary network of 32 Amazonian and non-Amazonian institutions producing synthesis research on Amazonian terrestrial and freshwater biodiversity to inform conservation policy and practice; part of Brazil's INCT ⁴⁵
Brazilian Long-Term Ecological Research Program (PELD)	Brazilian long-term ecological research network, funded by the Brazilian National Council for Scientific and Technological Development (CNPq) since 1999, with 14 Amazonian sites ⁵²
North Amazon Alliance (ANA)	A coalition of nine civil society organizations working to safeguard ecosystem and socio-cultural connectivity across the northern Amazon, grounded in Indigenous knowledge systems and the leadership of Indigenous Peoples and Local Communities ⁵³
Centro Integrado da Sociobiodiversidade da Amazônia (CISAM)	A network led by the Federal University of Pará (UFPA) that brings together the 13 federal universities of the Brazilian Legal Amazon to integrate research, training, and outreach on Amazonian socio-biodiversity, reduce regional inequalities in research investment, and inform public policy ⁵⁴
Amazonia 4.0 Initiative	Project to demonstrate the importance of value-adding of biodiversity products for development the socio-bioeconomy ^{55–57}
Red Bioamazonia	A scientific cooperation platform established in 2024 that connects eight scientific institutes from five countries within the Amazon biome: Bolivia, Brazil, Colombia, Ecuador, and Peru ⁵⁸
Red Pan-Amazónica por la Bioeconomía	A multisectoral platform that connects more than twenty organizations across the Pan-Amazon region, spanning research institutes, producer organizations, development banks, and investors ⁵⁹

Box 2. Making informal networks more visible and integrating diverse knowledge

The initiative named Monitoramento Ambiental Territorial Independente da Volta Grande do Xingu (MATI-VGX) shows how an underrepresented research community can change the scientific agenda from within. After official monitoring of the Belo Monte hydroelectric power plant failed to capture the changes residents were experiencing, the Juruna/Yudjá people of the Paquçamba Indigenous Land began collecting and analyzing their own socio-environmental data in 2014. In 2020, that effort grew into MATI-VGX, an intercultural alliance of Indigenous and ribeirinho researchers and academics⁶⁵. Belo Monte diverts the Xingu River along the 130-km Volta Grande do Xingu, cutting its flow there by roughly 90% and turning the seasonal flood pulse into something close to a permanent drought⁶⁵. The alliance monitored coupled hydrological and ecological variables at resolutions the official programs never offered. It recorded flooding that arrived months late, a sharp decline in catch per unit effort across the water cycle—with prized species such as the peacock bass (tucunaré, *Cichla* sp.) nearly disappearing—and the progressive decay of the flooded igapó forest^{65,66}. In the process, it shifted the discourse from a narrow technical question about how the plant should be operated to a broader one about how the Xingu's water should be shared and what that sharing means for the livelihoods and territorial rights of the people downstream.

Fortunately, MATI-VGX is not an isolated case, and much of this kind of knowledge moves through circuits that conventional measures of academic activity do not capture. For instance, the North Amazon Alliance (ANA) ran regional encounters in Leticia, Colombia, for five years, bringing together field-tested experiences from five Amazonian countries around local economies, community-based monitoring and territorial surveillance, Indigenous governance, and landscape connectivity, and it applied a structured methodology to systematize what was shared⁶⁷. In Colombia, the Humboldt Institute has supported community biodiversity monitoring initiatives in which residents define the objectives, design the protocols, and analyze the results⁶⁸. Locally defined governance instruments add a further body of evidence: Life Plans and territorial and environmental management plans (PGTAs), built through participatory mapping and research led by Indigenous specialists, generate socio-environmental information that rarely enters regional or international scientific collaborations^{69,70}.

Despite the Amazon's global visibility and remarkable scientific output, there are signs that the within-Amazon research community does not play as prominent a role as it should. For example, some local researchers have been overlooked, relegated to the role of data contributors rather than equal collaborators⁴¹. They also face the application of standardized performance measures across very unequal institutional environments. Researchers are evaluated through global performance metrics while simultaneously operating under logistical, institutional, and financial conditions that differ profoundly from those of better-resourced centers or central nodes within research networks. The result is often a mix of perceived underperformance and chronic overload, reducing capacity to invest in long-term collective action⁶⁰. Therefore, the roles of local researchers are often peripheral to scientific authority, strategic decision-making, and long-term agenda setting⁴¹.

This marginalization is reinforced by the structure of funding and visibility. Almost all of the large research initiatives in the Amazon are supported by significant funding from the European Union, the United Kingdom, or the United States (**Table 1**). While these are important and welcome, their prominence risks overshadowing a broad suite of informal research networks. These are, by their nature, harder to map and often rely on smaller, more diverse forms of funding

(including goodwill). Their outputs are often in local languages rather than English, are often published in the gray literature—such as reports and technical contributions instead of peer-reviewed journals—and are largely uncited or ignored by the more established research community (e.g.,^{61–63}). This invisibility, along with the separation of these local networks from the international research community, is a major barrier to progress (**Box 2**). These are precisely the networks most likely to be closely embedded within local communities and policy development, the most likely to be led by Amazon-based and Amazonian researchers, and the best placed to contribute the action-oriented and co-created knowledge that has so often been called for^{38,64}. Making them visible and integrating them into the wider research network is central to building a resilient socio-ecological research environment.

3. Why We Must Think Beyond Calls for Funding

Previous calls to strengthen Amazonian research^{44,46} have rightly emphasized the need for sustained increases in funding, and we share that position without reservation. However, increases in funding alone will not fix a problem that is structural. First, funding channeled through existing structures will tend to flow to already well-connected hubs,

amplifying the very disparities it is meant to close and reinforcing rather than redistributing the patterns of concentration^{45,46} documented in Section 2. Second, funding is inherently unstable. Both national and international research funding are highly sensitive to shifts in government and political will, and they rarely offer the permanence required to develop a thriving research community. Third, some of what sustains a research network cannot be attributed to a single partner or funder. Governance structures with defined decision rights, coordination mechanisms that survive changes in personnel, shared protocols and explicit arrangements for data stewardship, and deliberate provision for leadership renewal have to be built and maintained by the network itself. A recent assessment of Amazonian science governance identified fragmented coordination and the absence of durable institutional frameworks, rather than the volume of investment, as the principal constraint on the region's research capacity⁷¹. Strengthening Amazonian research therefore requires more than resources; it requires attention to the structural and organizational conditions that enable long-term collaboration, knowledge exchange, and capacity to endure. There is no single silver bullet for this, and here we focus on a suite of measures and actions that, taken together, could help build a more resilient and integrated community and support the current and next generation of researchers.

4. The Amazon as a Distributed Research Network

Enhancing physical connectivity within the Amazon is not easy. Travel distances by rivers are often measured in days rather than hours and depend on seasonal water levels. The distances and the sparse flight network cannot be engineered away. Even highway paving would not bring places close enough for routine collaboration—and would carry significant environmental costs^{72,73}. To overcome these challenges, the Amazon could be viewed as a distributed research network, a system in which geographically separated nodes collaborate despite limited opportunities for real-time interaction. Research on distributed development networks, developed largely in corporate, software development, and virtual team settings, has identified recurring barriers that limit the efficiency and cohesion of collaboration⁷⁴, and many of these closely mirror the barriers observed in Amazonian research systems. Below, we examine five interrelated challenges that shape the functioning and resilience of the wider research community and discuss practical pathways to mitigate them.

4.1. Communication and Clear Roles

One of the central challenges identified in distributed development networks is communication⁷⁵. In remote teams,

misunderstandings are amplified by the absence of contextual cues and informal mechanisms for clarification, often leading to delays, duplication of effort, and misalignment of objectives⁷⁶. These challenges closely parallel those faced by Amazonian biodiversity research networks, which bring together institutions embedded in distinct national, linguistic, and cultural traditions⁷⁷. Recent advances in artificial intelligence, such as real-time translation tools and AI-assisted transcription of meetings, may substantially reduce some of these barriers, and multilingual writing assistants can facilitate communication across language boundaries, enabling more inclusive participation. However, most of these tools run in the cloud and assume stable internet connections, which many Amazonian institutions and field sites lack. Where that condition is met and these technologies become more accessible, linguistic diversity may increasingly become a manageable component of large-scale research networks rather than a constraint on them.

Technology alone, however, is not sufficient. Beyond the most spoken languages of the region, the networks may operate across various Indigenous languages, each carrying its own classifications of species, seasons, and ecological processes. Coverage of Indigenous languages in AI tools remains thin, which places the burden of communication back on human

interpreters and on network design. Shared vocabularies and explicit communication protocols help mitigate misunderstanding and avoid the ambiguous use of terms that carry different traditional meanings across communities. Recording these agreements in a code of conduct is therefore among the first practical steps⁷⁸ and helps to manage expectations around reward, participation, and leadership. In multilingual networks, the code must explicitly address linguistic diversity and cultural differences, including the Indigenous languages in which much Amazonian ecological knowledge is held and transmitted. It should also work toward a more equitable distribution of positions across genders. Despite recent progress, women remain underrepresented, particularly in senior decision-making roles⁷⁹, and this exclusion falls most heavily on Black, Brown, and Indigenous women, who face compounding barriers of gender, race, and ethnicity. That pattern is difficult to reconcile with the long history of knowledge production in the region, where Indigenous women have developed and transmitted knowledge over generations⁸⁰. The code of conduct should be codeveloped and openly discussed with network members at the outset, establishing a shared framework in which the diversity of knowledge systems, institutional cultures, and worldviews across the Amazon is recognized as a source of innovation rather than homogenized.

4.2. Day-to-Day Coordination

Distributed teams rarely operate under conditions of full synchronicity. Time-zone differences, uneven availability, and capacity constraints make it difficult to rely on real-time interaction as the backbone of collaboration. Although Amazonian researchers do not face extreme global time-zone separation (just two hours, from -3 to -5 GMT), they experience analogous, and in some respects deeper, forms of asynchrony. These arise not only from fieldwork cycles and teaching timetables of academic researchers but also from the

rhythms of the many contributors who work partly or wholly outside academia such as Indigenous researchers, community monitors, and local knowledge holders whose availability is shaped by agricultural and fishing calendars, harvests, territorial governance duties, and community and ceremonial obligations. These human rhythms compound environmental ones. For instance, the flood-to-dry pulses in the north occur at opposite times of year to those in the southern Amazon⁸¹, so that the very seasons structuring fieldwork, farming, and fishing are themselves out of phase across the basin.

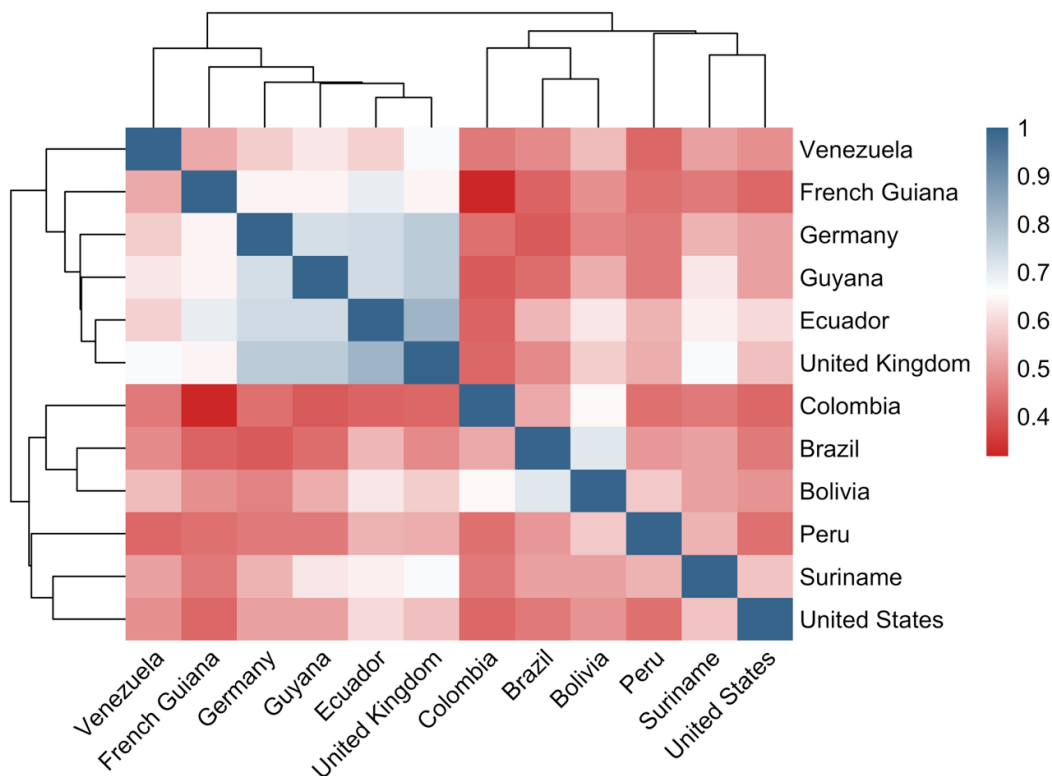


Figure 4. Heatmap showing pairwise similarity in annual working-week schedules among the nine Amazonian countries and territories and the three most frequent external collaborators identified in **Figure 1**. Each country's year was coded as a binary vector over its 52 weeks, distinguishing weeks that fall within school holiday periods from all other weeks. Weeks classified as regular working periods or general holidays were treated as equivalent states, whereas school holiday periods were considered distinct interruptions with potentially stronger effects on mobility, collaboration, and institutional activity. Pairwise similarity is the Jaccard index computed on working weeks, ranging from 0 when two countries share none to 1 when their calendars coincide. Countries were hierarchically clustered using the unweighted pair group method with arithmetic mean (UPGMA; average linkage) based on Jaccard distances ($1 - \text{similarity}$), grouping countries with more similar annual temporal structures. Cold colors indicate higher temporal congruence among working weeks.

Because detailed information on fieldwork calendars across Amazonian countries is not available, we used the school calendar as an example to explore the asynchrony between Amazonian countries and the main collaborating countries outside the region. We found substantial variation in the temporal synchronization of working weeks among countries (**Figure 4**). The most synchronized pair of countries was Ecuador and the United Kingdom, whereas the least synchronized pair was Colombia and French Guiana, which shared only ~32% of the year as regular working or general holiday weeks. Hierarchical clustering further revealed two broad groups: one composed predominantly of countries with more continuous annual working periods and more concentrated school recesses, and another characterized by stronger alignment with extended holiday periods. Countries such as Brazil, Colombia, and Peru showed lower average synchronization with international partners than Ecuador and Guyana, potentially creating additional logistical barriers to collaborative fieldwork and coordination. Programs organized around continuous data collection can operate irrespective of the working calendar, but for contributors whose work follows livelihood and community rhythms rather than institutional ones, availability varies at a finer grain still and rarely maps onto the academic year at all. Amazonian research networks must therefore be explicitly designed for asynchrony, relying on shared digital documents and platforms, transparent and flexible workflows, and clear task ownership to maintain momentum.

4.3. Trust

Trust is a prerequisite for the risk-taking that underpins the development of novel research. The sheer scale and lack of physical connectivity across the Amazon poses a particular challenge here: trust matters more for team effectiveness as collaboration becomes more virtual and distributed⁸², yet it is difficult to build trust without informal face-to-face interaction, and remote teams that fail to cultivate it tend to revert to transactional exchanges, limiting knowledge sharing and reinforcing hierarchical or extractive dynamics. Distributed collaboration also depends on more than one kind of trust. There is also a distinction between competence trust, confidence that a partner can do what they say, and relational trust, the harder won confidence in a partner's intentions and reliability over time^{83,84}. New networks often run initially on "swift trust," a provisional confidence extended on the basis of roles, credentials, and shared norms, which can carry a collaboration through its early stages but must be converted into relational trust if it is to endure⁸⁵. Distance slows that conversion, which is why remote collaboration in the Amazonian context depends on deliberate opportunities for sustained face-to-face engagement⁴¹. Workshops, regional conferences, and collaborative programs play a critical role here, not as one-off events, but as the repeated, reciprocal encounters through which relational trust accumulates. They build commitment, enable cross-pollination across research

nodes and knowledge systems, and let partners align agendas and demonstrate reliability over time. Because few existing initiatives enable these regional links and because their benefits are long term and diffuse rather than immediate, research grants should explicitly allocate resources for organizing and participating in them.

In the Amazon, however, the challenge is often not simply that trust is slow to build across distance. In many relationships it must first be repaired. Decades of extractive research have given Indigenous Peoples, Local Communities and Afrodescendant Peoples, and Amazon-based institutions ample reason for caution: data collected and never returned, collaborations that ended when the funding did, and authorship and recognition that flowed outward to distant partners. “Helicopter” or “parachute” science⁸⁶ and the more recently identified “remote-control science”⁸⁷, in which short-term, externally driven collaborations fail to generate durable local capacity or mutual accountability, are the visible form of this history. Building trust therefore begins with reciprocity, understood as a set of commitments that outlast the funding period. At the design stage, communities and local institutions should help define the research questions. Local researchers, guides, and knowledge holders should be compensated on terms negotiated with them, and budgets should cover training that leaves capacity in place once the visiting team departs³². Results

should be returned to the communities and institutions that made them possible, sharing data and authorship on equitable terms and respecting local and Indigenous data sovereignty.

4.4. Infrastructure of Collaboration

Successful distributed networks require appropriate tools and clearly defined processes. For Amazonian biodiversity research, for example, it is strategically important to establish interoperable data infrastructures and shared metadata standards that enable geographically distant research centers to function as an integrated system⁹. Several initiatives across different research areas can be used or adapted to integrate data and establish an organized metadata repository (e.g., Darwin Core, Metacat, ForestPlots). There are also examples of how to develop workflows for managing large groups of authors in publications and in research activities conducted through collaborative networks^{88,89}. However, one issue rarely discussed in debates about digital scientific infrastructures is coordination costs.

Coordination, curation, administration, communication, financial management, and data management are part of the scientific infrastructure—not ancillary costs. In many Amazonian countries, funding agencies often prohibit or strongly restrict funding for the

general coordination of scientific networks and large research projects, including funding for administrative assistants, financial managers, and technical personnel responsible for budget administration and project logistics. For example, the Advanced Centers in Strategic Areas for the Sustainable Development of the Amazon Region, from Brazil's National Council for Scientific and Technological Development (CNPq), places the administrative burden for up to R\$15 million on a single principal investigator and relies on scholarships rather than salaries for key tasks such as data management. As a result, these tasks are frequently taken on by researchers themselves, diverting time and energy away from research, collaboration, and mentoring. An obvious solution to this problem is for funding agencies to allow a portion of project resources to be allocated to administrative and coordination costs, including logistics, data management, financial administration, and other operational support activities. This is particularly important for large-scale projects and distributed research networks, where coordination demands increase substantially with the number of institutions, collaborators, and countries involved.

4.5. Resource Asymmetries and Network Resilience

Beyond challenges typically discussed in the distributed networks literature, Amazonian biodiversity research faces another structural constraint: strong asymmetries

between internal nodes of research within the networks. Amazonian nodes operate under different national funding systems and enter the network from markedly unequal positions. Therefore, very small research centers, laboratories, or locally based monitoring groups are intrinsically vulnerable. They struggle to sustain daily collaborative activity and maintain continuity amid staff turnover or funding gaps. In such contexts, collaboration becomes episodic and fragile, relying heavily on individual effort.

This is not just an Amazonian phenomenon. The same logic that development economics applies to growth, where human capital raises output faster than physical capital does⁹⁰, applies to research networks. Strengthening fragile nodes depends on the expertise they can attract and retain. No universal threshold defines a minimum viable institutional or research group size, but a critical mass of expertise is what allows a node to absorb personnel changes, support multiple concurrent projects, and sustain the informal day-to-day interactions that underpin productive scientific collaboration. In many Amazonian regions, local universities and institutes have either limited funding or weak institutionalized academic careers, prioritizing administrative or teaching positions over research⁹¹. Additionally, they lack the resources needed to conduct research effectively. In response, highly qualified researchers have formed consortia and coalitions to apply for international

funding and, in this way, overcome budget and resource constraints.

The marginalization of nonacademic knowledge holders discussed earlier has a direct structural consequence for the network. Indigenous Peoples, Afrodescendant Peoples, local research groups, and community-based monitoring initiatives maintain extensive place-based knowledge systems and long-term environmental observations⁶⁶, yet these remain weakly connected to formal scientific networks. For instance, endogenous research methodologies have provided the foundation for Life Plans, PGTAs, and other locally defined governance instruments, generating valuable environmental and socio-ecological information that is rarely incorporated into regional or international research collaborations^{65,69}. NGOs occupy a comparable position, carrying out sustained grassroots work that seldom enters formal research networks. These networks of knowledge holders and community-based research groups must play a much more prominent role in research collaborations. One possible solution is to increase the visibility of these groups through platforms that compile and organize the information and initiatives already developed across different territories. Strengthening the smallest nodes is what separates a distributed network from a set of strong centers with peripheral participants.

5. A Practical Pathway to Enhance the Amazon's Research Community

The barriers described above show that strengthening Amazonian socio-ecological research requires coordinated action on several fronts at once and that no single actor can deliver this: the agenda depends on researchers, institutions, funding agencies, and policymakers acting together. Several of its priorities are not new. Strengthening local institutions, investing in local talent, and facilitating responsible research by external partners were identified more than fifteen years ago^{63,92}, and their persistence is a sign that increases in funding alone have not been enough. The five barriers set out in Section 4 do not

call for five separate actions. We envision a sequenced pathway, one that moves from the lessons of durable networks, through the participation and coalitions on which progress depends, to the funding design, institutional strengthening, and shifts in extra-Amazonian practice that will allow those gains to hold.

The initiatives cataloged in **Table 1** include several of the most productive research networks in the tropics, and their track records offer a template for what a more connected regional system could look like; **Table 2** shows that parts of that system are already in place within the region. Although a full comparative analysis is beyond our scope, three features recur among those

initiatives that have proved most durable and are worth making explicit. Chief among these is standardization: low-cost, shared protocols are what allow distant and unevenly resourced nodes to contribute comparable data, whether across Brazilian biomes (PPBio¹⁰), tropical forest plots (RAINFOR¹⁸), or the transboundary Andes (GLORIA¹⁷ and iMHEA¹⁶). The second is a coordinating core that maintains those standards without concentrating all activity in one place. The third is continuity of support over one or more decades, which is what lets institutional memory and trust accumulate. These three features describe how a network holds together once it exists. They say less about who it includes, which is where a practical pathway has to begin.

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The starting point for such a pathway is the breadth of participation. Including Indigenous scientists and other underrepresented groups is essential to building a more equitable and representative research community, and it is also a matter of epistemic completeness³⁸. Indigenous Peoples, Local Communities and Afrodescendant Peoples often hold extensive empirical knowledge derived from long-term observations of environmental processes and intergenerational transmission, while academic science contributes formal hypothesis testing and standardized evidence. Bringing these together allows the coproduction of knowledge that neither tradition could generate alone, provided

it is done on equitable terms and respects Indigenous data governance by following principles such as CARE (i.e., collective benefit, authority to control, responsibility, and ethics⁹³). Those terms are a matter of design rather than intention.

If participation defines who the network is for, coalitions are how it takes shape in the near term. Strengthening research coalitions among Amazonian scientists and institutions should therefore be a priority. Collaborative platforms, joint workshops, mobility schemes for early-career researchers, and shared research agendas can foster interaction, raise the visibility of within-basin science, and accelerate the formation of networks capable of addressing regional challenges. They can also draw local research groups and community-based monitoring programs, so often peripheral to broader collaborations, into the center. For such coalitions to endure rather than dissipate once a grant ends, two things matter from the outset: members need common goals that are genuinely shared rather than imposed, and each collaboration needs concrete, agreed outputs to work toward, against which progress can be judged. Shared purpose and tangible deliverables are what convert a temporary aggregation of projects into a durable community. One possibility is an academic society explicitly for Amazonian science, which could integrate researchers and develop more equitable research processes (**Box 3**).

Coalitions, platforms, mobility schemes, and any society of this kind all depend on research funding, and how funding is designed matters as much as how much there is. Funding schemes should be inclusive, supporting gender and ethnic diversity as well as small and decentralized organizations. Administrative procedures should remain flexible, while preserving accountability⁹⁴. Budgets should also reflect the logistical realities of remote Amazonian regions, where transport is slow and costly and research infrastructure is sparse. Digital connectivity warrants separate attention. Reliable internet access is distributed across the basin as unevenly as roads and airports, and it determines who can join a videoconference, deposit data in a shared repository, or take part in an asynchronous learning network. Funders should treat bandwidth, equipment, and data plans as legitimate budget lines, a position already advanced in international open science policy⁹⁵ and echoed in Amazonian recommendations for democratic connectivity and internet access as a foundation for equal opportunity in education and governance²⁷. Where needed, grants should also fund targeted training in areas such as research design, statistics, remote sensing, participatory action research, and the use of technical equipment. Writing and synthesis should likewise be treated as network functions to be resourced rather than tasks individuals absorb unaided.

In the longer term, sustained progress will depend on structural investments in higher education, graduate training, research infrastructure, stable funding mechanisms, and institutional incentives that retain highly qualified researchers and reward long-term cooperation across the basin. Structural investment of this kind, however, only takes hold where local institutions are equipped to absorb it. Funding and capacity tend to concentrate in a few large hubs, yet a resilient network depends just as much on the many small, local nodes that are most in need of deliberate support. Strengthening them means consolidating their institutional autonomy on three fronts: securing dedicated funding lines rather than leaving them to compete on equal terms with far larger centers; cultivating academic leadership through long-term instruments, such as scholarships reserved for researchers based at these institutions; and building the administrative and financial capacity to manage larger budgets independently. These measures should go hand in hand with the gains in communication, coordination, and trust discussed throughout this paper, because improvements on those fronts are difficult to sustain where local institutions lack the stability to participate from a position of strength.

BOX 3. How an academic society for the Amazon could help support a more connected and equitable science community

The interconnected socio-ecological complexity of Amazonia requires greater scientific connection. Across the world, academic societies play a vital role in developing and supporting science, but at the moment there is no society that specifically supports or connects the Amazon. National scientific societies from Amazonian countries are based outside of the basin, and many societies are organized and defined by their disciplinary focus, when the complex nature of the problems facing the Amazon requires interdisciplinary understanding and transdisciplinary actions.

An Amazon-focused society could be one route to supporting the region's science and, while complementary to existing national and international societies, could provide unique support if constructed around five core features:

- **Inclusive but tiered membership:** having membership open to all but with tiered fees would mean researchers outside the basin and from the Global North would contribute more.
- **Using membership fees to (1) support events aiming to connect scientists and other actors from across the region,** bringing overlooked networks to the fore, and **(2) award fellowships to local researchers,** including research secondments to other Amazonian research nodes.
- Dissemination of research from formal and informal research networks in a **new multidisciplinary journal** that allows submissions in local languages.
- **Mapping and promotion of within-Amazon expertise** that allows journals and media to locate and access overlooked researchers or other interested parties.
- **Linking the needs of local institutions and the expertise of international and extra-Amazonian researchers,** supporting mechanisms that allow contributions to teaching, reviewing, supervision, and engagement.

Finally, resolving the paradox of thriving national and international research alongside under-resourced or invisible researchers requires action from outside the basin and, above all, a more reflective and engaged extra-Amazonian research community. The

global importance of the Amazon often acts as a magnet for remote science and advocacy and has resulted in peer-reviewed papers, assessments, and reports involving little or no collaboration with Amazonian organizations or other interested parties.

However well-intentioned, these efforts can undermine locally led research and the collaboration practices the region is working to build. The failure to engage locally also damages the science itself: without local knowledge, remote analyses often rely on flawed assumptions about the Amazon's socio-ecological system or produce out-of-touch recommendations. The region needs partnerships planned at the design stage rather than assembled at the point of fieldwork, budgets that reach Amazonian institutions rather than passing through them, and a commitment to returning to the same places and partners over time³². Extra-Amazonian researchers can contribute a great deal to teaching, supervision, and peer review within the region, and mechanisms that channel those contributions toward locally defined priorities would let them do so without displacing local leadership (**Box 3**).

6. Conclusions

Building a thriving, integrated, and more equitable Amazonian research community would help the region adapt to climate change, promote innovation, and advance sustainability in place of the destructive development of recent decades. The Amazon research community has changed enormously over that period, and it can point to both international and regional successes, but much more is needed. Increases in funding matter, but not on their own. We set out the structural changes that are also needed: changes

to how resources are allocated, how researchers work together and build trust, and how agencies fund research and judge success. Most of these changes are within reach of decisions that funders, institutions, and researchers already make.

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