Beyond participation: Indigenous researchers leading biodiversity monitoring and territorial governance in the Amazon

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Abstract

Indigenous Territories harbor some of the world's best-preserved ecosystems and are central to biodiversity conservation. Paradoxically, the knowledge of the people who have historically maintained these ecosystems remains underrepresented in conservation science. Here we present a collaborative program for monitoring biodiversity and water quality of the Nãnsêpôtiti (Iriri) River in the Panará Indigenous Territory of the Brazilian Amazon. Integrating diverse knowledge systems through co-production between Indigenous and non-Indigenous researchers, digital technologies, and scientific methods, the program engaged Indigenous people throughout the research process and compiled a comprehensive database of aquatic and terrestrial organisms, including fish, aquatic insects, aquatic macrophytes, terrestrial plants, birds, mammals, amphibians, and reptiles. Grounded in co-production and the intergenerational transmission of knowledge, this initiative shows how equitable intercultural approaches can simultaneously strengthen conservation science, sociobiodiversity, and Indigenous territorial governance, while offering a potentially replicable model for addressing the challenges of biodiversity monitoring in other tropical regions.

Keywords: biocultural conservation, community-based monitoring, ecological indicators, intergenerational learning, multitaxon surveys, sociobiodiversity

1 INTRODUCTION

Territories managed by Indigenous Peoples protect forests, biodiversity, and carbon stocks at levels equal to or greater than those of protected areas (Sze et al. 2022; Nikolakis et al. 2026). These outcomes reflect long-standing knowledge systems, cultural practices, and stewardship rather than the passive persistence of intact ecosystems. Indigenous management has shaped the composition, structure, and resilience of Amazonian landscapes, including plant communities that constitute living biocultural heritage, while also contributing to climate change mitigation and adaptation through sustainable resource use and biodiversity conservation (Levis et al. 2024; Sangat et al. 2026). In Brazilian Amazonia, Indigenous Territories reduce deforestation by approximately 66% and promote secondary forest recovery in previously cleared areas (Baragwanath & Bayi 2020; Baragwanath et al. 2023).

Despite these contributions, Indigenous Peoples remain underrepresented in the formal knowledge-production processes that inform environmental policy and global conservation strategies (Turner et al. 2022; Silva Santos et al. 2026a). Scientific institutions often fail to recognize Indigenous knowledge as a valid and dynamic system of evidence, producing studies that use local information without fully integrating Indigenous interpretations, priorities, or authorship (Nikolakis et al. 2026). In biodiversity and ethnobiological inventories, this extractive practice can detach species from their names, uses, histories, and cultural meanings, reducing biocultural knowledge to isolated academic records.

Participatory biodiversity monitoring has increased the involvement of Indigenous Peoples and local communities in environmental data collection (Danielsen et al. 2009; Turner et al. 2022; Zhang et al. 2023). However, participation frequently remains restricted to field sampling, while academic researchers define the questions, sampling design, analyses, interpretation, and publication (Silva et al. 2025). Such arrangements limit recognition of Indigenous intellectual contributions and the transformative potential of collaboration among knowledge systems (Tengo et al. 2014; Levis et al. 2024). Moving beyond participation, therefore, requires Indigenous researchers to act as question-makers, interpreters, authors, and decision-makers in research concerning their territories (Mc Cartney et al. 2023).

Here, we present a pioneering integrated biodiversity and water-monitoring program co-developed and implemented in the Panará Indigenous Territory (TI Panará), within the Xingu Protected Areas Corridor across the Brazilian states of Pará and Mato Grosso. To our knowledge, this is the first initiative in the region to integrate biological and water-quality monitoring with Indigenous leadership across all stages of the research process. We demonstrate how the sustained engagement of Panará researchers, from defining research priorities and designing sampling protocols to interpreting results and communicating findings, generated multiple, interconnected outcomes for biodiversity conservation, botanical and biocultural documentation, scientific knowledge production, intergenerational learning, and territorial governance. This initiative marks a shift from conventional participatory monitoring toward genuine knowledge coproduction, in which Panará researchers exercise leadership and share decision-making authority and responsibility for the production, interpretation, protection, and communication of knowledge about their territory.

2 THE BIODIVERSITY-MONITORING INITIATIVE

2.1 The Panará Indigenous Territory

The Panará Indigenous Territory encompasses approximately 500,000 hectares within the ecotonal region between the fire-prone savannas of the Cerrado and the Amazonian tropical rainforest (Figure 1). It is in the Iriri River (Nãnsêpôtiti) basin, whose river is the largest tributary of the Xingu River by discharge. The territory is part of a region of exceptional biological and sociocultural diversity, inhabited by the Panará, Mebengôkre (Kayapó), Ukaragma (Arara), Kuruaya, and other Indigenous peoples and traditional communities (Moutinho et al., 2025). Its boundaries, however, overlap major fronts of landscape transformation, including agricultural expansion, native-vegetation conversion, mining, the BR-163 highway, and the planned Ferrogrão-EF-170 railway (IAKIÔ 2019). The territory is also located in an Amazonian region projected to experience increasingly severe droughts and heat waves (Flores et al. 2024).

In response to environmental and climatic changes observed by the Panará, the Territorial Protection, Environmental Monitoring, and Sustainable Management of the Panará Indigenous Territory project was established through a partnership among Associação IAKIÔ, Universidade Federal do Pará (UFPA), Universidade Estadual de Campinas (UNICAMP), Jardim Botânico do Rio de Janeiro (JBRJ), Instituto Socioambiental (ISA), and Conservation International Brazil (CI), and several Amazonian scientific networks. From its inception, the program was based on knowledge coproduction. Community leaders selected eleven Indigenous researchers, including three women from seven villages, who participated in defining research questions, planning activities, choosing priority areas, collecting and interpreting data, presenting results to the communities and external audiences, and preparing publications.

The integrated inventories covered aquatic and terrestrial biodiversity, forest plot monitoring, and water quality in the Iriri River, whose banks support all Panará villages. Monitoring included fish, aquatic and terrestrial insects, aquatic macrophytes, terrestrial plants, birds, mammals, amphibians, and reptiles, using protocols compatible with major Brazilian biodiversity-monitoring programs (Lobato et al. 2026), as well as tree-plot inventories aligned with international forest-monitoring networks (ForestPlots.net 2021). Aquatic sampling focused on sites selected based on observed changes in the river over the previous three decades, while pesticide monitoring prioritized compounds commonly associated with soybean and corn cultivation in the area.

The botanical research integrated the Panará and scientific knowledge systems through two complementary axes conducted simultaneously. In addition to general botanical collecting across the Panará territory, we implemented a tree inventory in a 1-hectare plot in Sõkârãsã (adapted RAINFOR protocol), where all trees with DBH $\geq$ 10 cm were identified by both scientific taxonomy and Panará classification. Simultaneously, an intercultural ethnobotanical approach, which included workshops, forest and garden walks, and audiovisual documentation, recorded traditional knowledge regarding culturally significant species. Botanical specimens collected across both axes were deposited at the JBRJ Herbarium. Panará researchers acted as protagonists, documenting and mapping 487 tree individuals in the 1-hectare forest plot, belonging to 87 scientific taxa and 79 Panará names. Surveying the forest plot, agricultural fields, and homegardens, the intercultural effort yielded 183 plant names and 196 videos documenting the Panará's biocultural memory of plant uses.

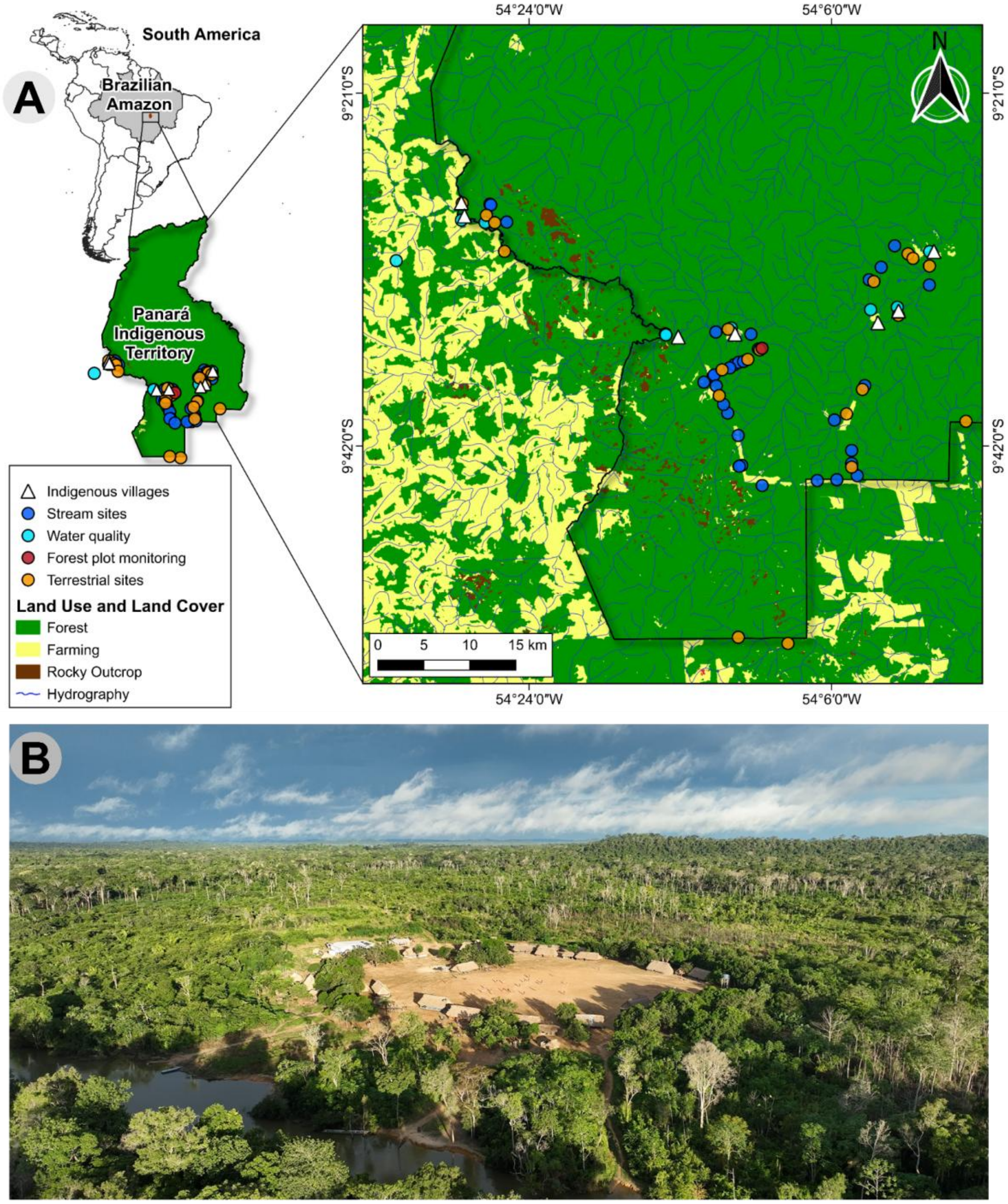

FIGURE 1 The Panará Indigenous Territory in the Brazilian Amazon. A) Spatial distribution of the aquatic and terrestrial sampling points used for biodiversity monitoring. B) Landscape overview of an indigenous village, demonstrating the interface between the community structure, the hydrographic network, and the dominant forest land cover.

Aquatic ecosystem sampling was conducted at strategic sites, considering changes that had occurred in the Iriri River over the past three decades. In addition, the monitoring of pesticide contamination prioritized the most used compounds in soybean and corn cultivation, since these are the predominant monocultures affecting the borders of the Panará Indigenous Territory.

2.2 Outcomes for biodiversity monitoring and conservation

The program generated one of the most comprehensive multitaxon baselines available for an Indigenous Territory in eastern Amazonia (Figure 2). Records included 64 aquatic macrophyte species, 65 fish species, 97 aquatic insect taxa, 315 bird species, 40 mammal species, 41 reptile species, 34 amphibian species, and 217 plant taxa, as well as 183 plant names documented in Panará language. The inventory recorded 25 threatened vertebrate species: 15 birds and nine mammals classified as Vulnerable (VU), two mammals as Endangered (EN), one mammal as Critically Endangered (CR), two reptiles as Vulnerable (VU), and one reptile as Endangered (EN) according to IUCN categories.

The program's contributions extend beyond recording species richness. Panará researchers used their detailed knowledge of seasonal dynamics, access routes, species behavior, plant uses, and historical environmental changes to guide site selection and interpret ecological patterns. This integration improved field efficiency and contextualized records that would otherwise remain disconnected from local histories and meanings. It also supported scientific outputs, with Panará researchers as coauthors (Miranda-Filho et al. 2026; Silva Santos et al. 2026a, 2026b), including publications on aquatic ecology and biodiversity monitoring, terrestrial vertebrate conservation, botanical and biocultural documentation, and participatory methodologies.

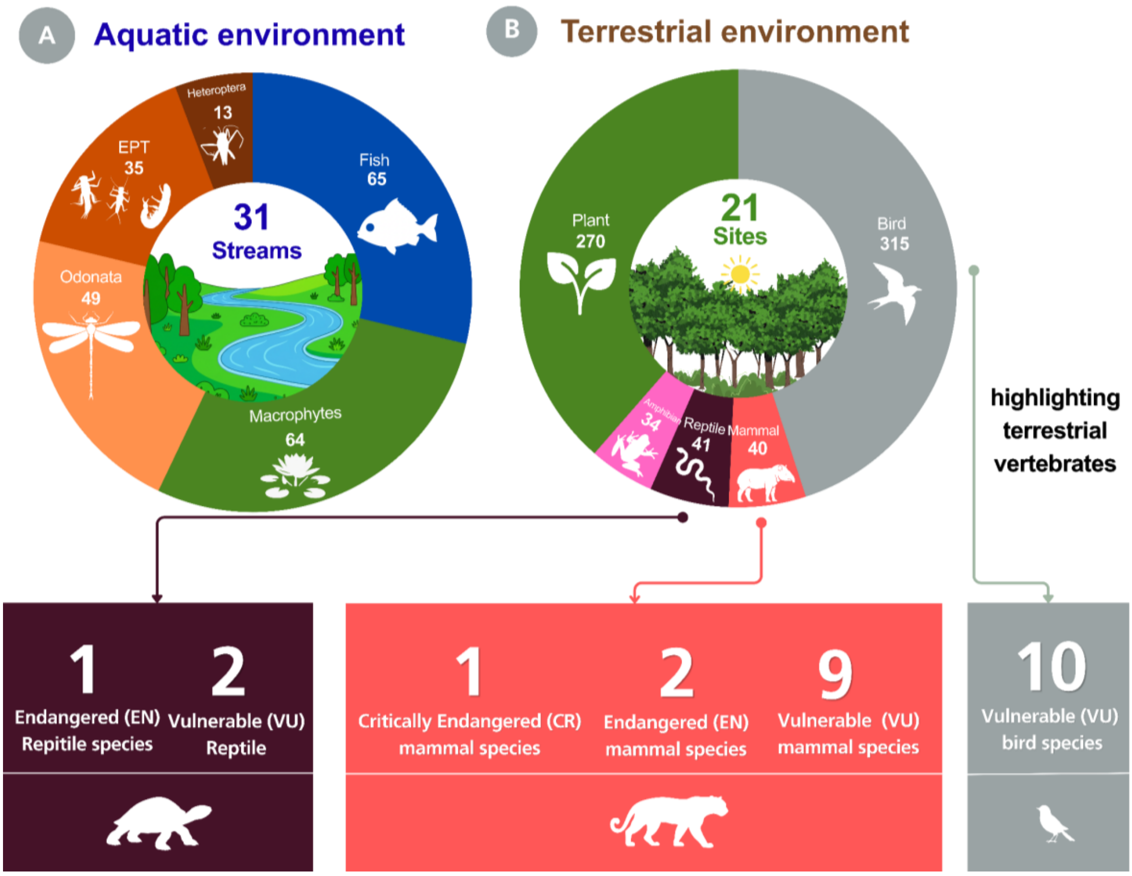

FIGURE 2 Summary of the aquatic and terrestrial biodiversity recorded in the Panará Indigenous Territory. (A) Richness of aquatic macroinvertebrates sampled in 31 streams in the region. (B) Number of threatened terrestrial vertebrate species (birds, mammals, and reptiles) recorded at 21 sampling sites. Conservation categories follow the vulnerability criteria, according to the International Union for Conservation of Nature (IUCN).

Digital tools expanded the spatial and temporal scales of monitoring, allowing Panará researchers to record observations beyond short, non-Indigenous scientific expeditions. They also strengthened communication among villages, scientific teams, and community assemblies. Panará researchers presented results, trained participants, contributed to technical reports, and represented the initiative at scientific events (Figures 3 and 4). These activities contrast with the historically dominant model in which traditional knowledge supports research without corresponding recognition of its holders’ intellectual contributions.

FIGURE 3 Main methodologies applied to the biological groups included in the participatory biodiversity-monitoring activities in the Panará Indigenous Territory: (A) fish, (B) aquatic insects, (C) aquatic macrophytes, (D) birds, (E) mammals, and (F) amphibians and reptiles, (G) sample sorting, and (H) Monitoring during floods.

FIGURE 4 Methodologies applied in the two axes of intercultural research on flora, conducted by Panará indigenous researchers and JBRJ botanists in the Panará Indigenous Territory. (A, B) Participatory workshops in the Nãpôôrô and Nãsêpotiti villages; (C) documentation of Panará botanical knowledge. (D, E) Tree inventory in a

permanent 1-ha plot in the Sõkârãsã village; (F) Participation of elders in identifying trees marked in the field.

The participation of Panará researchers also expanded the scale and quality of water monitoring (Figure 5). Their deep knowledge of the territory, combined with digital tools, enabled continuous data collection across a broader spatial and temporal scale than would be feasible for external teams conducting sporadic field campaigns. This collaboration also improved data interpretation by incorporating local ecological knowledge into the monitoring process.

FIGURE 5 Main stages of water monitoring: (A) Identification of research questions and indicators; (B) Sampling at village ports; (C) Discussion of preliminary results; (D) Sampling in streams; (E) Monitoring during floods; (F) Presentation of preliminary results at the general assembly; (G) Discussion circle with elders (Tapuntun, Tuatun) to record observations and changes in the river over recent decades.

2.3 Outcomes for territorial governance

The biomonitoring combined scientific measurements with indicators developed by the Panará through decades of daily interaction with the Nãnsêpôtiti River and surrounding forests. Community observations of changes in water color, odor, flow, sediment, fish, and other organisms helped define questions and sampling priorities. Scientific measurements did not replace these indicators; rather, the two evidence systems were interpreted together to support decisions about water resources, biodiversity, and external pressures. The resulting multitaxon baseline provides a reference for detecting future changes associated with land use, climate change, pollution, and other disturbances. It can support the identification of biodiversity loss, conservation, and restoration priorities, as well as evidence-based territorial claims. Digital applications and geotechnologies further increased local autonomy in collecting, storing, visualizing, and communicating environmental information, reducing full dependence on external teams (Figure 6).

The botanical component added a specific governance dimension by establishing community-defined rules for sensitive knowledge. Medicinal applications and other restricted information remain within the villages; herbarium vouchers deposited at JBRJ document species occurrence without disclosing Panará uses; and audiovisual materials are to be delivered to Associação IAKIÔ. These measures provide verifiable botanical records for conservation and territorial defense while respecting the community's authority over access to biocultural information. They should be understood as practical safeguards developed within this project rather than as a complete or universal protocol for Indigenous data sovereignty.

Together, these outcomes show that co-produced monitoring can function both as an environmental information system and as a mechanism for institutional strengthening. By controlling and interpreting evidence about their biodiversity, Panará researchers and leaders are better equipped to monitor external pressures, communicate concerns, guide management, and defend the territory.

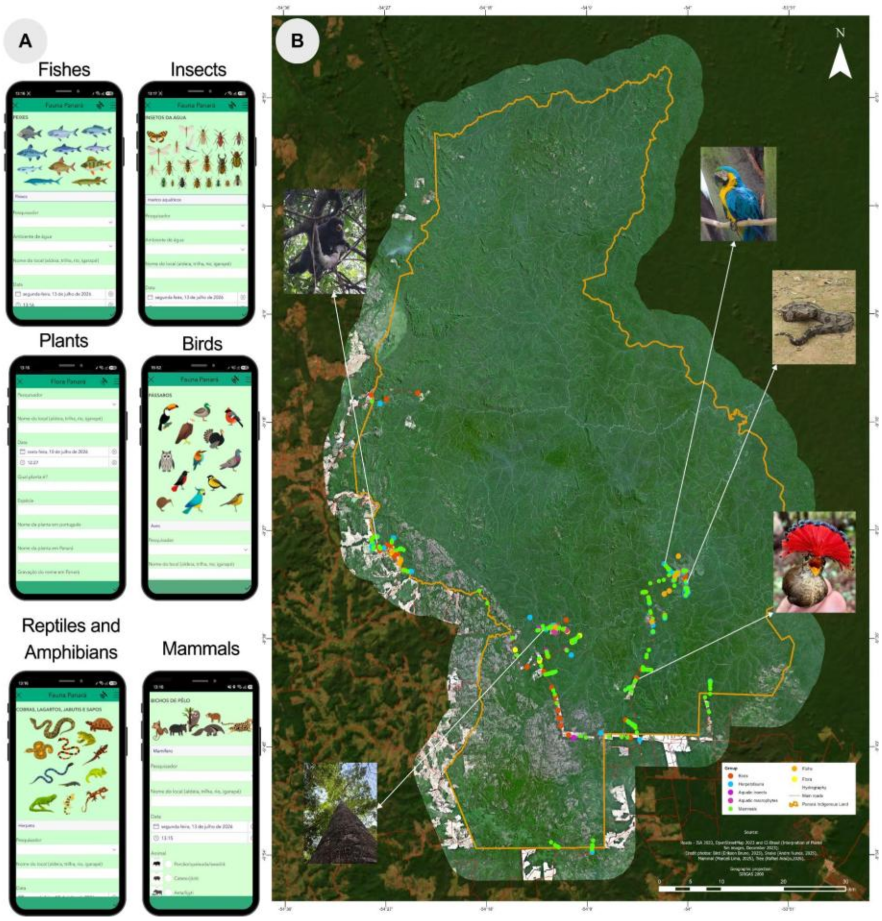

FIGURE 6 On the left, an example screen from the integrated data-collection application used by the Panará community in the project. On the right, a map showing fauna records collected by Panará researchers.

2.4 Sociocultural outcomes

The Panará biomonitoring program also created opportunities for intergenerational learning. When the Panará returned to their current territory in 1996, their population was 186; approximately 30 years later, it had reached about 850, including more than 500 people under 20 and only 54 over 50. This demographic structure makes the transmission of territorial knowledge particularly urgent. Field activities allowed young researchers to visit less-frequented areas and learn directly from elders about species, environments, and environmental change.

Botanical work provided a concrete setting for this exchange because elders shared Panará plant names, uses, and ecological observations during conversation circles and field walks. The project is preparing a bilingual Portuguese–Panará educational publication on 30 culturally important plants for use in Indigenous schools. Organized from the perspective of Indigenous researchers, the material combines scientific identification and ecological information with community-approved knowledge for circulation.

Recording traditional names for plants, animals, environments, and ecological processes strengthened the visibility of the Panará language within the monitoring program. Women participated as researchers and in community decision-making spaces, while young researchers developed skills in scientific methods, digital technologies, and communication. Non-Indigenous researchers, in turn, adapted their field practices and interpretations to Panará knowledge, language, priorities, and temporalities, creating a reciprocal rather than unidirectional learning process.

3 DISCUSSION

The experience of the project developed together with the Panará demonstrates that biodiversity monitoring can fulfill functions far broader than generating ecological data over time. When built on horizontal relationships, recognition of the historical context of Indigenous Peoples, and the legitimacy of Indigenous knowledge as part of scientific production, monitoring becomes a tool for strengthening territories, valuing cultures, and training new leaders, contributing to the conservation of culturally relevant, threatened, and endemic species (Mc Cartney et al. 2023). Monitoring programs jointly led by Indigenous and non-Indigenous researchers can generate synergistic benefits for sociobiodiversity conservation, local governance, and the co-production of scientific knowledge. This integration increases the social legitimacy of research and the potential for real-world applications of results in decision-making processes (Brittain et al. 2024).

Across all components of the monitoring program, integrating digital technologies with Panará ecological knowledge enhanced data collection, documentation, and communication. Beyond methodological advances, the co-production process also promoted equitable recognition of Indigenous intellectual contributions, with Panará researchers serving as coauthors of scientific articles, technical reports, and conference presentations (https://www.youtube.com/watch?v=wqM6TtBp1sU). This represents a shift from conventional conservation research practices, in which Indigenous knowledge has often informed scientific outputs without equivalent recognition of its holders as partners in knowledge production (Brittain et al. 2024; Voisin et al. 2025).

Recent studies conducted in cooperation with Indigenous Peoples, and even led by them, have also demonstrated their technical capacity and autonomy in conducting investigations aimed at maintaining biodiversity and defending their territories (Brittain et al. 2024; Voisin et al. 2025). Biodiversity research must follow the autonomous and collective agenda of the Indigenous community, with co-participation at every stage of the process and guaranteed Indigenous authorship. This dynamic values traditional knowledge, particularly in its scientific dimension, which is validated by its own methods and empirical evidence, and should not be understood merely as ethical issues but as elements that enhance the quality and relevance of the science produced (Turner et al. 2022).

To advance beyond participatory models that focus exclusively on data collection, we propose a research agenda informed by the Panará researchers' reflections on lessons learned, knowledge gaps, and future priorities for Indigenous monitoring (Table S1). Moving beyond participation requires recognizing Indigenous researchers not only as collaborators in data generation but also as protagonists who can strengthen the scientific, institutional, and sociocultural processes associated with conservation in their territories. Rather than focusing only on externally defined research questions and answers, intercultural research must respect collective decision-making spaces, and the autonomy of Indigenous communities must be respected (Smith 1999). This principle is central for the Panará People, for whom research questions, priorities, and results must be discussed and validated in their main collective forums, particularly the assemblies of the Indigenous People.

In a context of rapid environmental transformations and growing recognition of the contribution of Indigenous Territories to global conservation, monitoring programs must evolve to address emerging needs. Thus, these protocols must be based on training; the identification of biodiversity information priorities and gaps; knowledge co-production; Indigenous leadership in defining research questions and interpreting results; and the planning of future agendas. These actions can simultaneously increase the scientific relevance, social legitimacy, and applicability of conservation efforts, representing a promising strategy across tropical regions worldwide (Brittain et al. 2024).

4 CONCLUSION

The experience developed in the Panará Indigenous Territory demonstrates that Indigenous researchers act synergistically not only as biodiversity monitors but as primary knowledge producers and guardians of their biocultural memory. By integrating academic science, digital technologies, and traditional knowledge, the program generated relevant conservation outcomes and strengthened local sociocultural processes. Significantly, this equitable approach reconfigured traditional research dynamics by establishing practical protocols for Indigenous data sovereignty and the protection of sensitive intellectual property. Transforming the relationship between external researchers and the community into a space for bidirectional learning required non-Indigenous scientists to adapt their methodologies to the territory's logic, language, and timing, thereby establishing genuine epistemological symmetry. By producing tangible tools for intergenerational knowledge transmission, such as bilingual educational materials, this immersive experience offers a potentially replicable model for conservation initiatives seeking to combine scientific rigor and Indigenous leadership to develop solutions to contemporary socio-environmental challenges.

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