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Tailoring evidence into action: Using a co-design approach for biodiversity information in the Tropical Andes

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Abstract

Biodiversity conservation is a complex and transdisciplinary problem that requires engagement and cooperation among scientific, societal, economic, and political institutions. However, historical approaches have often failed to bring together and address the needs of all relevant stakeholders in decision-making processes. The Tropical Andes, a biodiversity hotspot where conservation efforts often conflict with socioeconomic issues and policies that prioritize economic development, provides an ideal model to develop and implement more effective approaches. In this study, we present a co-design approach that mainstreams and improves the flow of biodiversity information in the Tropical Andes, while

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creating tailored outputs that meet the needs of economic and societal stakeholders. We employed a consultative process that brought together biodiversity information users and producers at the local, national, and regional levels through a combination of surveys and workshops. This approach identified priority needs and limitations of the flow of biodiversity information in the region, which led to the co-design of user-relevant biodiversity indicators. By leveraging the existing capacities of biodiversity information users and producers, we were able to co-design multiple biodiversity indicators and prioritize two for full implementation ensuring that the data was findable, accessible, interoperable, and reusable based on the FAIR (Findable, Accessible, Interoperable, and Reusable) principles. This approach helped address limitations that were identified in the stakeholder engagement process, including gaps in data availability and the need for more accessible biodiversity information. Additionally, capacity-building workshops were incorporated for all producers of biodiversity information involved, which aimed to not only improve the current flow of biodiversity information in the region but also facilitate its future sustainability. Our approach can serve as a valuable blueprint for mainstreaming biodiversity information and making it more inclusive in the future, especially considering the diverse worldviews, values, and knowledge systems between science, policy, and practice.

KEYWORDS

Bolivia, EBV, Ecuador, essential biodiversity variables, mainstreaming, Peru, policy, stakeholder engagement

1 | INTRODUCTION

The Tropical Andes is a biodiversity hotspot where conservation efforts collide with socioeconomic issues and public policies prioritizing economic development (Fernández et al., 2015; Josse & Fernandez, 2021; Rodríguez-Echeverry & Leiton, 2021). Despite covering less than half a percent of the Earth's surface, this region contains over 10% of globally described species across 100 distinct ecosystems that provide vital provisioning, cultural, and regulating services to several South American countries (Anderson et al., 2011; Josse et al., 2011; Myers et al., 2000; Rodríguez-Mahecha et al., 2004). However, deforestation, mining, and other unsustainable practices, coupled with significant investments from multilateral financial organizations, pose threats to the region's biodiversity and the well-being of its inhabitants (Armenteras et al., 2011; Jarvis et al., 2010; Jetz et al., 2007; Josse et al., 2011; Rodríguez et al., 2013; Rodríguez-Echeverry & Leiton, 2021; Romero-Muñoz et al., 2019). Protecting the biodiversity and ecosystems of the Tropical Andes is essential for both the world's species and the well-being of millions who depend on its ecosystems.

Most efforts to halt and reverse biodiversity declines typically involve conservation policies that aim to balance protection, restoration, and sustainable use with societal and economic development (Smith et al., 2020); yet their failure to do so highlights a gap between the scientific community, society, businesses, and policymakers (Diedrich et al., 2011; Fernández-Llamazares & Rocha, 2015; Jolibert & Wesselink, 2012; Smith et al., 2020; World Economic Forum, 2021; Xu et al., 2021). Biodiversity conservation is a complex, multi-causal task that requires engagement and cooperation across scientific, societal, economic, and political institutions to meet the needs of all stakeholders (Jolibert & Wesselink, 2012). However, historically, input from relevant sectors has been lacking (Dempsey, 2013; Karlsson-Vinkhuyzen et al., 2017; Neßhöver et al., 2013; Pisupati & Prip, 2015). Despite all groups of society being vulnerable to biodiversity loss to varying degrees, economic, development, and societal sectors have typically been considered incompatible with the interest of conservation goals, leading to a perception that such goals do not align with their interests (Folke, 2006; Morley et al., 2021; Smith et al., 2020).

To identify effective conservation actions and foster engagement and ownership across stakeholders, cooperation and communication among diverse interest groups are essential (Pascual et al., 2021; Perino et al., 2021). Achieving this requires a collaborative, cross-sectoral, and

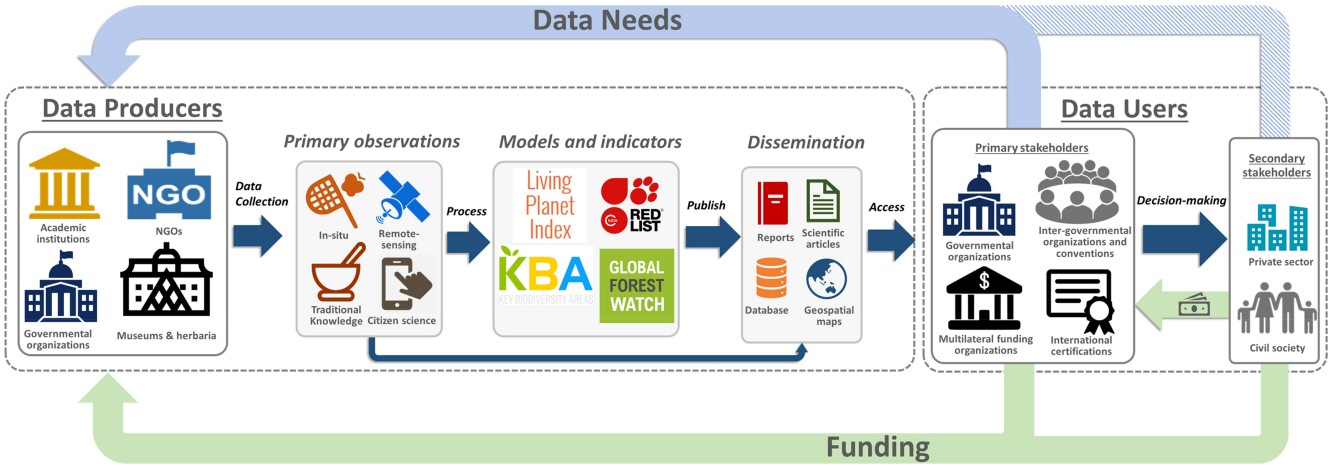

FIGURE 1 Mainstreaming the flow of biodiversity information between producers and users. Primary stakeholders are those groups and individuals who directly pay for or ask for biodiversity information. Secondary stakeholders are typically not directly involved in the process of information flow. The flow of information between producers and users relies on the resources (funding and capacities) of the data producers.

multinational approach that takes a pluralistic perspective on biodiversity given the multiple worldviews, values, and knowledge systems between science, policy, and practice (Bravo et al., 2016; Mansur et al., 2022; Muhl et al., 2022; Pascual et al., 2021; Zador et al., 2015). One promising approach is "biodiversity mainstreaming" whereby biodiversity and conservation considerations are integrated and embedded into the strategies and policies of key economic and societal sectors that impact or rely on biodiversity (Chandra & Idrisova, 2011; Huntley, 2014; Redford et al., 2015; Whitehorn et al., 2019). Biodiversity mainstreaming has already gained significant traction and has been incorporated by the United Nations Convention on Biological Diversity, International Union for Conservation of Nature, European Union Biodiversity Strategy, National Biodiversity Strategies and Action Plans, The Intergovernmental Platform on Biodiversity and Ecosystem Services, and global efforts such as the post-2020 Global Biodiversity Framework (Huntley, 2014; Josse & Fernandez, 2021; Perino et al., 2021). Despite the widespread application of the biodiversity mainstreaming process, there is currently a lack of established guidelines, recognized best practices, and empirical evidence on its effectiveness, which limits its integration into decision-making processes and makes its impacts unclear (Huntley, 2014).

Due to the complex and multifaceted nature of mainstreaming biodiversity, there are often numerous limitations and bottlenecks in the flow of biodiversity information from producers to users (data collection, analysis, decision-making, and dissemination; Figure 1), which can hinder the effective implementation and evaluation of mainstreaming initiatives. One issue is the lack of accessible and standardized data across different institutions, sectors, and regions, which impedes informed decision-making and assessment of the impacts of actions on biodiversity (Stephenson et al., 2017). This problem is further compounded by the lack of coordination and communication among all the stakeholders involved across the different levels of data flow, as well as the absence of clear policies and guidelines for mainstreaming biodiversity into decision-making (Josse & Fernandez, 2021; Muhl et al., 2022; Navarro et al., 2017). This often leads to confusion, conflicting information, and the risk of duplicating efforts and investments. Challenges in capacity, sometimes due to limited resources in parts of the Tropical Andes, can also contribute (Alvarado et al., 2022; Fernández et al., 2015; Josse & Fernandez, 2021). Additionally, the challenges and limitations of biodiversity mainstreaming vary at different scales, making it difficult to generalize solutions across local, national, and regional contexts (Alvarado et al., 2022; Karlsson-Vinkhuyzen et al., 2014).

Another main challenge of biodiversity mainstreaming is the lack of engagement with relevant stakeholders and the disconnect between producers of biodiversity data and potential end-users (Figure 1). The primary stakeholders that typically use biodiversity information are those who directly request and/or pay for it, and sometimes even collect it, such as policymakers, conservation practitioners, land managers, multilateral funding organizations, NGOs, inter-governmental organizations and conventions, and researchers (Figure 1). These primary stakeholders rely on up-to-date and accurate information to make informed decisions regarding biodiversity and conservation management. Another group, which we refer to as "secondary stakeholders," such as businesses, civil society groups, local communities, indigenous groups, and the general public (Figure 1), also benefit from and attributes values to biodiversity, but are not typically involved in the mainstreaming

process due to limited resources, are often mistakenly perceived as having a lack of knowledge or interest due to limited direct involvement, priority toward primary stakeholders, and limited recognition of their perspectives and contributions (Jolibert & Wesselink, 2012; Neßhöver et al., 2013; Smith et al., 2020). However, since secondary stakeholders have the potential to significantly influence policies and funding decisions that affect biodiversity, involving them in the mainstreaming process can also help raise awareness of the value and importance of biodiversity (Alvarado et al., 2022; Josse & Fernandez, 2021). Until now, barriers such as communication gaps, a narrow focus on environmental benefits, and a government and academic-driven approach often leave these secondary stakeholders feeling ignored and contribute to power imbalances, further hindering mainstreaming efforts (Alvarado et al., 2022; Chandra & Idrisova, 2011; Cvitanovic et al., 2016; Josse & Fernandez, 2021; Muhl et al., 2022; Vogel et al., 2007).

To address the challenges of biodiversity mainstreaming and to improve the flow of biodiversity information, it is crucial to implement strategies that involve all relevant sectors and groups (Alvarado et al., 2022; Gavin et al., 2018; Muhl et al., 2022; Sterling et al., 2017). This includes participatory research, multi-stakeholder dialogs, and adaptive frameworks, which can create a more comprehensive and inclusive mainstreaming process that better addresses the needs and interests of all stakeholders. Effective communication and coordination among all stakeholders, including local communities, national government agencies, and regional organizations, are also crucial for success. Although some strategies and approaches have been developed for mainstreaming biodiversity bringing together and addressing the needs of all relevant stakeholders in the decision- making process (Ginsburg et al., 2013; Muhl et al., 2022; Redford et al., 2015; Whitehorn et al., 2019), so far relatively few have been implemented and have mostly remained conceptual ideas. Tailoring biodiversity information to user needs in the region can play a vital role in creating more effective policies for sustainable development that balance the needs of the environment and people.

In this study, we aimed to develop a co-design approach to mainstream biodiversity information in the Tropical Andes and create tailored biodiversity outputs that meet the needs of primary and secondary stakeholders in the region. A key objective was to establish networks and foster collaboration between individuals, sectors organizations, and countries in the region. To achieve this, we employed a co-design approach adapted from a stakeholder engagement process outlined by Navarro et al. (2017) that brought together key stakeholders and sectors that produce and use biodiversity information at local, national, and regional levels. We conducted surveys and workshops to identify priority needs and limitations in the flow of biodiversity information and to design indicators that address financial and technical capacity constraints. Additionally, capacity-building workshops were incorporated to improve the flow of biodiversity information in the region and address identified limitations. Throughout this process, our co-design approach was intentionally designed to be open, flexible, and inclusive, actively challenging the academic-centric bias by valuing feedback from diverse stakeholders, particularly local and nonacademic sources. By incorporating novel elements and embracing fresh perspectives, our engagement with stakeholders ensured outcomes that transcended biases, addressing power imbalances and fostering an inclusive environment where all voices were heard.

2 | METHODS

We developed tailored biodiversity products for various groups and sectors using a co-design process that was loosely adapted from a stakeholder engagement process outlined by Navarro et al. (2017). The process in this study was comprised of five steps: (1) engagement of stakeholders, (2) assessment of user needs and existing monitoring efforts, (3) co-design of biodiversity indicators, (4) implementation of biodiversity products, and (5) capacity building (Figure 2). To design and develop biodiversity indicators, we used the essential biodiversity variables (EBVs) framework, which identifies a set of variables to monitor across genes, species, and ecosystems, as it enables the comparison of data across regions and sectors, identification of patterns and trends in biodiversity change, and provides a common framework for data collection, analysis, and interpretation (Geijzendorffer et al., 2016; Kissling et al., 2018; Pereira et al., 2013, 2017; Proença et al., 2017).

3 | ENGAGEMENT

In the initial phase, we collaborated with scientists, local experts, and policymakers in the region to establish a consortium of national partners and organizations, fostering an enabling environment in Bolivia, Peru, and Ecuador (Figure 2). The local experts within our consortium spanned diverse sectors, including industry, policy, and nonscientific domains. The institutions that participated in this initial process were the Instituto Nacional de Biodiversidad and the EcoCiencia Foundation in Ecuador; the Asociación Boliviana para la Investigación

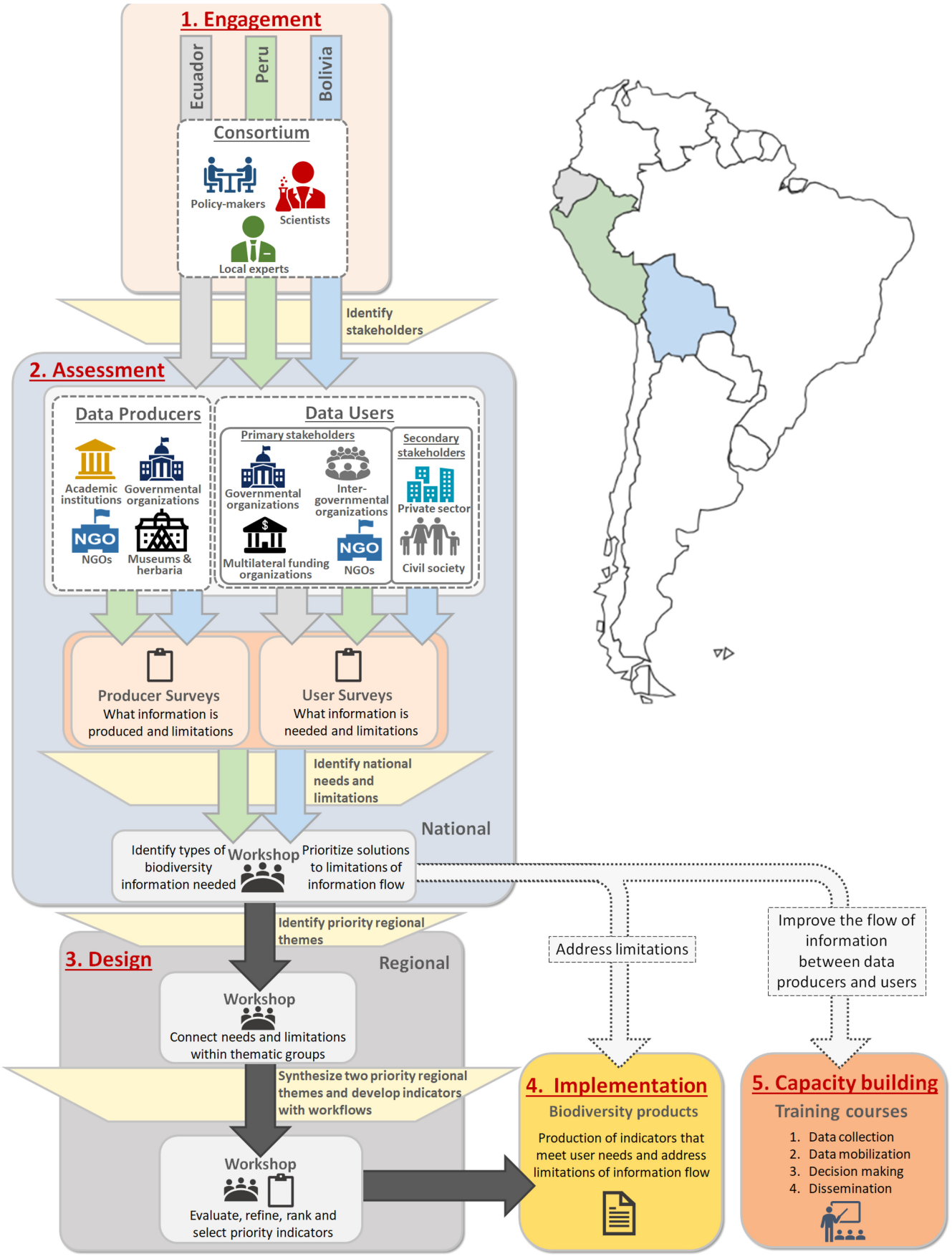

FIGURE 2 Legend on next page.

y Conservación de Ecosistemas Andino Amazónicos (ACEAA) in Bolivia; the Asociación para la Conservación de la Cuenca Amazónica (ACCA) in Peru; as well as international partners including NatureServe in the USA, Universidad de Cordoba in Spain, and the German Centre for Integrative Biodiversity Research (iDiv) in Germany. The engagement and knowledge of the national partners in the consortium were essential in identifying and engaging key stakeholders, encompassing both users and producers of biodiversity information within their respective countries. This collaboration laid a strong foundation for the subsequent stages of the co-design process.

4 | ASSESSMENT

4.1 | National surveys

For the assessment phase, we sought to bridge the gap between biodiversity data producers and users in the Tropical Andes region by designing user-needs and data-producers surveys in collaboration with our regional partners (Figure 2). These surveys were distributed via email, WhatsApp, and Facebook between November 2020 and January 2021. They were sent to a diverse range of stakeholders, including decision-makers, scientists, NGOs, educators, citizens, and individuals from the private sector; and tailored to accommodate the linguistic and contextual variations specific to each country. The surveys aimed to identify biodiversity data users and producers in the Tropical Andes, their specific interests and focus areas, the required data and its availability, existing limitations in production and accessibility of biodiversity information, and potential mechanisms for strengthening collaboration and relationships between these stakeholders (Appendix S1). Our main objective was to identify and prioritize the needs of biodiversity data users, as well as gain a better understanding of the biodiversity data collection and management practices within each country. The diverse expertise of the authors, including conservation management, ecosystem dynamics and mapping, remote sensing and technology, social and economic aspects, regional development and infrastructure, health, and natural resources, played a critical role in identifying and engaging the diverse stakeholders involved in the flow of biodiversity information (refer to the Positionality Statement section for additional insights). By leveraging our varied expertise, we were able to target stakeholders from various sectors, ensuring contextual relevance and inclusive representation that addressed the unique challenges of the Tropical Andes region.

We sent online surveys targeting a total of 1836 relevant stakeholders within the region. In Peru, we distributed surveys to 390 data producers and 470 users, while in Bolivia, the surveys reached 235 data producers and 141 users. Unfortunately, due to COVID-19-related financial and logistical constraints, we were unable to survey data users in Ecuador. To address this gap, we build on a previous 2018 survey conducted by our Ecuadorian partners in the consortium. This earlier survey, which targeted 600 data producers in Ecuador, served as the foundational model for designing the surveys tailored to the specific contexts of the other countries. Overall, our efforts garnered a total of 443 responses, yielding a total response rate of 24.13% across the three countries. Notably, the response rates varied among biodiversity producers, with Ecuador at 13.8%, Peru at 32%, and Bolivia at 46.8%. In contrast, user response rates were comparable between Peru (32%) and Bolivia (38.7%). Upon integrating the findings of the three national surveys, we identified the main limitations in the flow of biodiversity information. Additionally, we determined priority thematic sectors that were specific to each country.

4.2 | National workshops

The assessment phase continued with national workshops held by ACEAA and ACCA, aimed at refining the data needs identified in the surveys and identifying bottlenecks, as well as potential solutions to improve the flow of biodiversity information at the national level (Figure 2). Users and producers were brought together in these workshops, providing a platform for all of these stakeholders to engage in dialogue and co-create mutually beneficial solutions. This allowed us to start identifying possible networks of people and institutions within each country who work on similar issues, who have the same information or knowledge needs, or where there could be a chain connection between information creators and users. Keynote presentations, forums, and breakout groups were held in the workshops, gradually increasing the dialogue between different

FIGURE 2 Flowchart depicting the co-design process used to identify priority needs and limitations of the flow of biodiversity information in the Tropical Andes region. The main outcomes of this process were the development of tailored biodiversity products that addressed major limitations and the improvement of information flow in the region through capacity building. The figure is vertically oriented for better visualization and does not imply subordination of hierarchy.

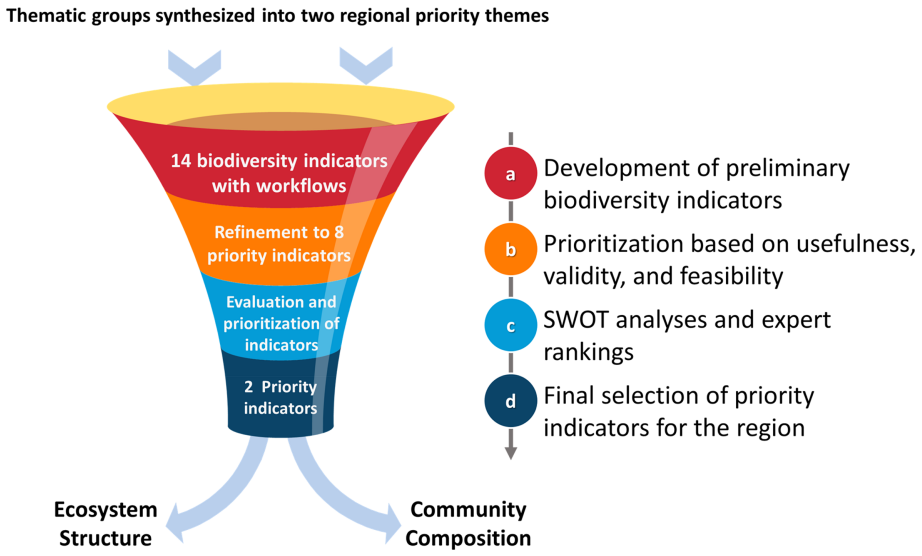

FIGURE 3 The design process for biodiversity indicators in the Tropical Andes region: (a) synthesis of thematic groups and preliminary indicators focusing on two priority regional themes, (b) indicator refinement and prioritization, (c) SWOT analyses and stakeholder rankings during a co-design workshop, and (d) final selection of priority indicators. This process resulted in the identification of two EBVs, "Community composition" and "Ecosystem structure," that addressed the region's needs.

sectors involved in the production and application of biodiversity information.

A total of 131 individuals participated in the workshops (65 in Peru and 66 in Bolivia), representing academic, policy, societal, and economic sectors. Due to the COVID-19 pandemic, the workshops were held virtually to adhere to the restrictions on travel and in-person meetings. To address the multidisciplinary nature of the participants and communication barriers that exist between domains, the workshops used storylines and ecological narratives (Guerra et al., 2019) to ensure that all participants spoke the same language and could efficiently communicate with each other (Appendix S2). The results from the survey and workshops were distilled to prioritize six thematic groups common between the countries and fed into the regional workshop (Thematic groups in Section 8).

4.3 | Regional workshop

To identify priorities for the Tropical Andes region regarding EBVs and the six thematic groups, a four-day virtual regional workshop was held, inviting participants from the surveys and national workshops across the three countries (Figure 2). The plenary sessions were held on the first and last day with 188 listeners on YouTube and Facebook. The participatory exercises were held during the second and third day with 84 guests from Ecuador, Peru, and Bolivia. The primary objective was to refine priority needs for biodiversity information that was specific to the six thematic groups distilled from the national workshops and to map these needs to corresponding EBVs (Appendix S3 and EBVs in Section 8). To facilitate communication and prioritize regional needs, breakout groups were held that once again utilized storylines and ecological narratives (e.g., Appendix S2). These breakout groups helped to ensure that the workshop was inclusive and participatory. Participants were able to share their experiences and perspectives, develop solutions to common challenges, and discover alternative approaches to producing, managing, developing, and utilizing information. They also exchanged experiences and knowledge, finding opportunities for collaboration and synergy among individuals, organizations, and countries.

5 | DESIGN

To address limitations identified in previous workshops and meet the needs of the region, we engaged in a design process to develop user-relevant biodiversity indicators (Figures 2 and 3). We synthesized the six thematic groups into two priority regional themes and created a preliminary list of 14 biodiversity indicators based on existing capacity and key spatial, temporal, and thematic priorities (Figure 3a, detailed indicators in Appendix S4). The list was then narrowed down to eight indicators based on usefulness, validity, and feasibility (Figure 3b), and easy-to-understand detailed workflows were developed (Appendix S5).

The final step involved a two-day workshop, bringing together a dozen carefully selected users, producers, and consortium team members to refine and develop two priority indicators for the Tropical Andes region. These individuals were strategically chosen to encompass a diverse range of expertise including the six distinct thematic groups, application of biodiversity indicators, ecosystem dynamics, species interactions, environmental impact assessments, and EBVs. This group was strategically

chosen to facilitate a comprehensive, efficient, and well-rounded discussion to refine and improve priority indicators tailored to the specific context of the Tropical Andes region. During the workshop, we provided an overview of the workflows and their connection to the regional themes, with participants offering feedback on methods to improve the indicators. We then conducted a SWOT analysis and rankings (Appendix S6) to select the most suitable candidates for the proof-of-concept design and implementation phase (Figure 3c). The result was the selection of two biodiversity indicators that met the region's needs (Figure 3d). This co-design process allowed us to formulate indicators that were not only meaningful, feasible, and relevant but also strongly aligned with the unique intricacies of the region (Section 8 for specific indicators).

6 | IMPLEMENTATION

The co-design process culminated in the production of biodiversity indicators (Figure 2) that were not only relevant to the needs of users but also scalable across different levels of governance (for specific indicators see "Biodiversity indicators" in Section 8). The indicators were designed to enable decision-makers to assess the status of biodiversity in the Tropical Andes region at different levels, from the local to the regional. However, the project also recognized that there were significant challenges in the flow of biodiversity data between data producers and users, which had to be addressed. To overcome these constraints, the project leveraged existing capacities and made the data accessible based on the FAIR principles (Findable, Accessible, Interoperable, and Reusable). This approach aimed to make the biodiversity indicators and its products more easily discoverable and accessible to individuals across the region, regardless of their level of expertise or location. By improving the flow of biodiversity information, decision-makers at different levels and sectors could access the information they needed to make informed decisions and contribute to the conservation and sustainable use of biodiversity in the Tropical Andes.

7 | CAPACITY-BUILDING

To improve the current and future flow of biodiversity information in the Tropical Andes region, a series of four capacity-building training workshops were organized. These workshops targeted biodiversity information producers, aiming to address challenges identified in data collection, analysis, decision-making, and dissemination, aligning with the specific limitations and needs identified during the co-design process. The training workshops specifically focused on building capacity in four key areas: (1) data collection and managing biodiversity information, (2) processing, analyzing, and synthesizing biodiversity information, (3) utilizing biodiversity information for decision-making, and (4) writing scientific papers and overcoming obstacles in the process (Table 1). The purpose was to build capacities across the biodiversity data cycle and foster collaboration between countries and institutions. The final workshop, centered on writing scientific papers was crucial to address the limited publication of research articles by producers who primarily target data for decision makers and policy advisors. This step aimed to enhance information availability beyond policy realms and foster broader knowledge dissemination across international and Latin American journals or other relevant outlets.

The participants were carefully selected based on criteria such as ensuring partner organizations had allocated slots, equal minimum numbers participated from each country, alignment of participants' expertise with workshop topics, experience with biodiversity data production, and potential for disseminating knowledge gained. The first three capacity-building workshops were held over 3 months and attended by over 40 selected individuals from 485 applicants across the Tropical Andes. The fourth and final workshop was a dissemination workshop held for 100 participants chosen from over 500 applicants beyond the three partner countries. Pre- and post-workshop surveys helped identify obstacles to biodiversity mainstreaming and topics for future workshops. These workshops equipped the producers with the knowledge and skills to better collect, manage, analyze, and disseminate biodiversity information, ultimately leading to improved decision-making and conservation efforts in the region. The workshops also promoted knowledge exchange through interactive sessions, hands-on exercises, and group discussions led by expert trainers.

8 | RESULTS

8.1 | Stakeholders of biodiversity information

The stakeholder surveys revealed that the majority of those who identified as biodiversity data producers were researchers (83.94%), followed by nonacademic executives/managers (9.76%). Users of biodiversity data were more diverse, including individuals from universities (25%), government (21%), private organizations (29%), and independent workers (21%). Among the users, the largest group was researchers (43%), with nearly equal affiliations between independent, government, and private institutions.

TABLE 1 Summary of biodiversity capacity building workshops and focus.

Workshop name	Focus
Collecting and harmonizing: Management of primary and biodiversity data	Organizing information considering standards, structure, and data quality to make it useful and publishable at different scales. Learning about international support, such as that offered by GBIF, and how to use its portal and tools free of charge.
Mobilizing: Processing, analysis, and synthesis of biodiversity information	Covering methodologies of digital processing satellite or aerial images, spatial analysis, and developed variables, which participants found essential for decision-making. Learning about open-source tools and the basics of remote sensing and how to interpret the results to make a critical reflection in a multi-scale spatiotemporal visualization to highlight key aspects of biodiversity conservation.
Decision: Use of information to support decision-making	Understanding decision theory, evidence-based decision making, and its applications in management, from problem identification to planning necessary information. Facilitating different methodological approaches such as multicriteria analysis (qualitative) and correlational statistics (quantitative), to evaluate alternative management scenarios, and estimate the impact of different decisions. Specific seminars on species distribution modeling and process-based modeling were included.
Dissemination: Writing scientific papers and overcoming barriers	Equipping participants with the necessary skills to effectively write and disseminate biodiversity information in the region. Covering why they should publish, how to overcome obstacles, and understanding the scientific publication process.

Note: The table shows the four modules of the workshop, their respective names, and the focus of each module.

Independent researchers, who work on short-term contracts or freelance, were commonly represented. Secondary stakeholders included teachers (12.7%) and private sector professionals (11.07%). More than half (54.93%) of the survey respondents identified themselves as both producers and users of biodiversity data.

Regarding the participants in the workshops, accurately capturing the demographics and affiliations presented a challenge due to the unpredictable nature of attendance and participation. Nonetheless, we can infer based on our observations and the individuals we invited, that the majority of workshop participants belonged to three main categories: public citizens, private sector employees, and academic researchers from universities, research institutes, and NGOs. A critical secondary stakeholder group, indigenous organizations, actively engaged in the workshops, benefiting from their access to mobile internet connectivity. However, their involvement in the survey was hampered by pandemic-related obstacles and the challenge of completing lengthy phone surveys, which was made more difficult by limited computer access. Additionally, as the pandemic began, many indigenous individuals returned to villages with minimal or no internet service, making it difficult to reach them for the surveys.

8.2 | Biodiversity focus and needs

The survey results revealed that users of biodiversity information had a greater work emphasis on the social impacts of biodiversity in the region, while producers focused on applied research. Both groups shared a general work focus on species, environmental management, and impacts, but there were notable differences between them (Figure 4a). Producers had a significantly higher specific focus on certain species aspects, particularly those related to endangered, migratory, and invasive species, as well as genetics and microbiology. While both producers and users had strong interests in environmental management (Figure 4a), producers had a higher percentage of work specifically focused on conservation management, while users had a stronger emphasis on natural resource management. Additionally, users had a more pronounced focus on general ecology as well as the social impacts of biodiversity, including economic factors such as food safety, tourism, and risk management (Figure 4a). Based on the survey, the need for biodiversity information could be broadly categorized into three areas: species, ecosystems, and impacts. Species were the most frequently cited, specifically in terms of abundance, presence, and taxonomic diversity (Figure 4b). Ecosystem composition, structure, and extension (distribution) were the most commonly mentioned ecosystem topics, while human-wildlife interactions and ecological disturbances were the most frequently cited impact-related topics (Figure 4b).

8.3 | Limitations and bottlenecks

The survey results revealed that the highest-ranked limitations among users and producers regarding the flow of

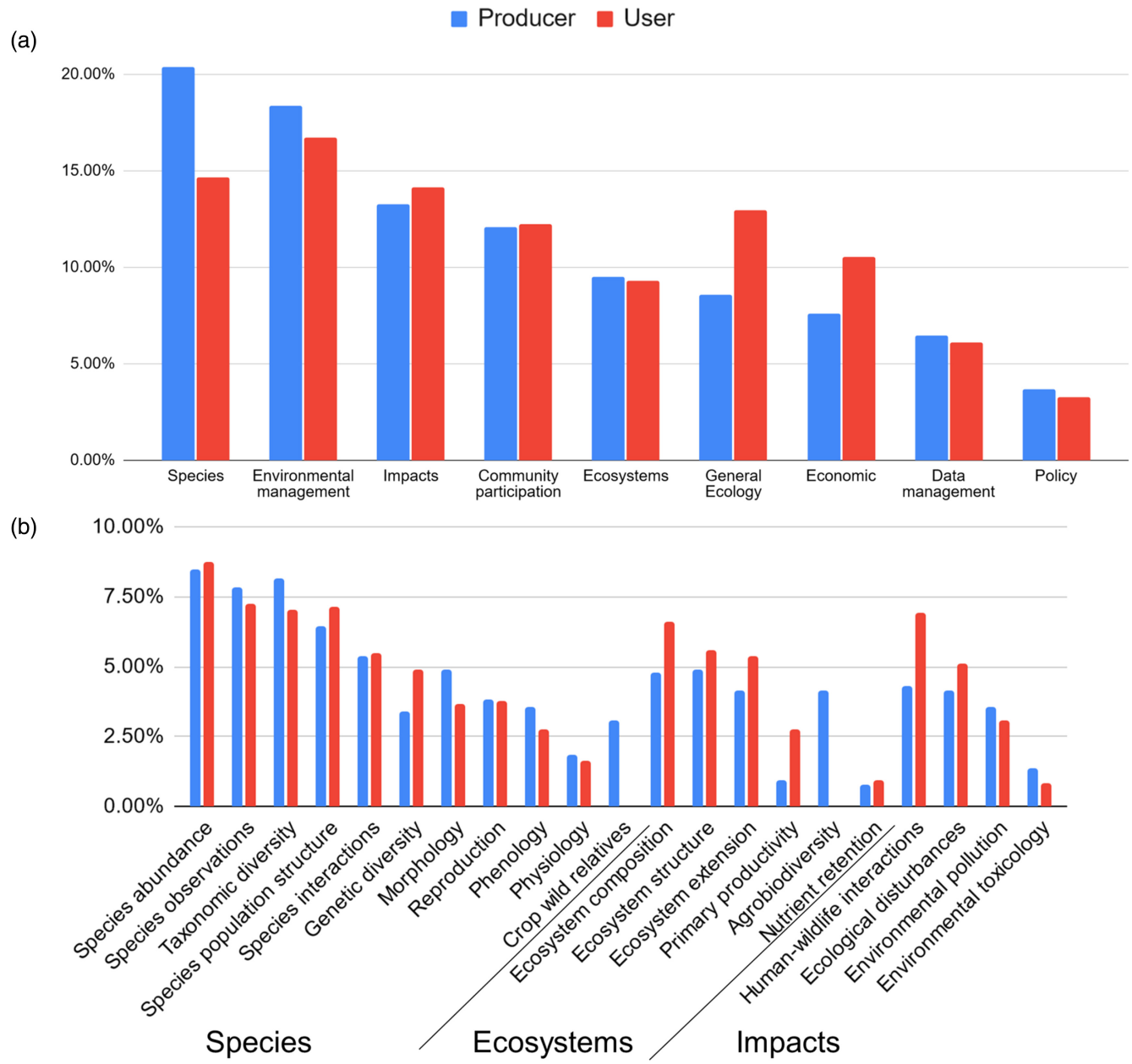

FIGURE 4 Percentage distribution of survey respondents who indicated (a) the focus of their work involving biodiversity information and (b) the types of biodiversity information they are interested in, according to producers and users in the Tropical Andes. The survey questions were open-ended, allowing respondents to elaborate on their work focus and interests. The percentages represent the proportion of respondents within each group (producers or users) who selected each option, rather than combined percentages.

biodiversity information in the Tropical Andes were bureaucracy (administrative processes and institutional regulations), financial restrictions, and data accessibility (Figure 5). During the workshops, the lack of accessibility and availability to biodiversity information was a major limitation cited. Stakeholders across producers and users reported that there is currently very little openly accessible information in the region, with many producers either unwilling or unable to openly share their data or findings. This challenge is further complicated by a significant volume of crucial biodiversity information that remains unpublished, primarily residing within inaccessible reports and documents. The significance of this issue is particularly pronounced for producers, primarily scientists, who require essential background literature for their research and decision-making processes. Even in cases where the information is available, stakeholders stated that a significant number of research articles are inaccessible due to being locked behind paywalls. This accessibility barrier renders a wealth of information unavailable to researchers,

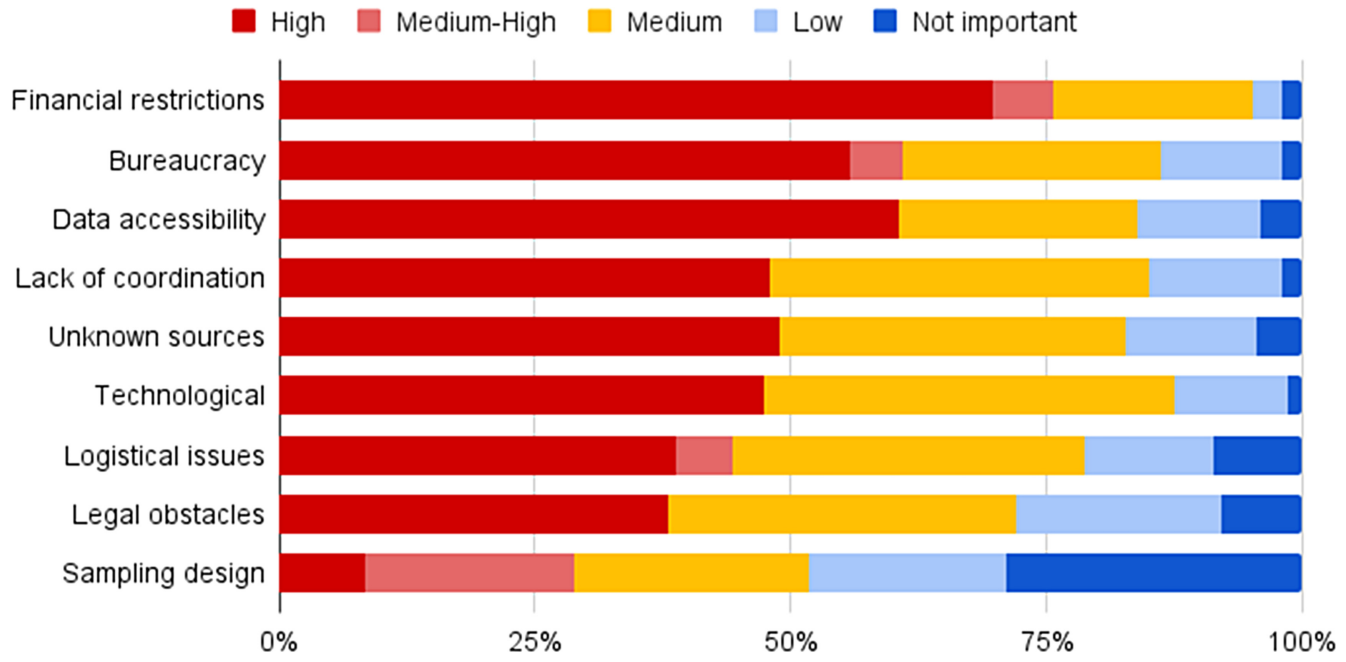

FIGURE 5 Main limitations and their importance for producing and obtaining biodiversity data in the Tropical Andes based on surveys of data producers and users.

NGOs, indigenous organizations, and academic institutions, which often struggle with limited funds for accessing such services within the region. Technical capacity issues exacerbate this limitation, making overall access to information extremely limited. For example, indigenous people and the nonacademic public often rely on academic technicians as intermediaries for biodiversity data. These limitations were further confirmed during the workshops.

8.4 | Solutions to limitations and bottlenecks

During the national workshops, a comprehensive set of strategies was collaboratively proposed by producers and users, aimed at overcoming bottlenecks and improving the flow of biodiversity information within the Tropical Andes region. The most commonly cited proposed solutions included:

1. *Data accessibility and usability*: Stakeholders recognized the significance of open access in enhancing data accessibility and usability, acknowledging the need to balance this with respect for cultural, intellectual, and traditional knowledge rights, specially in a region as diverse as the Tropical Andes. The proposal to make data and platforms freely accessible aimed to break down barriers hindering information flow. Coupled with user-friendly platforms and standardized protocols, this approach ensures that biodiversity information becomes more accessible, usable, and readily integrated into decision-making processes.
2. *Financial support and capacity building*: Amidst financial constraints, the call for increased financial support stood out as a critical solution. This infusion of funds was viewed as pivotal in strengthening the flow of data and knowledge exchange. Concurrently, capacity-building initiatives through workshops and training were highlighted to empower individuals and institutions with the skills essential for optimizing biodiversity data production, dissemination, and application.
3. *Collaboration and knowledge exchange*: The proposal for networks aimed to harness collective expertise through collaborative platforms. Complemented by transdisciplinary spaces and knowledge exchange initiatives, this solution fosters an environment where data producers and users interact seamlessly. This synergistic approach fosters enriched collaboration, informed decision-making, and robust strategies to tackle biodiversity challenges.
4. *Data harmonization and standardization*: Efforts to harmonize practices and standards resonated strongly among stakeholders. The proposition of clearer rules for data use and standardized protocols sought to streamline data sharing and enhance consistency. This harmonization was envisioned to catalyze collaboration and cooperation, yielding a more integrated and effective approach to biodiversity information mainstreaming.

TABLE 2 Thematic groups identified as key priorities for biodiversity information flows in the Tropical Andes region, as determined through surveys and stakeholder engagement in national workshops.

Sector	Description
Industry, development, and infrastructure projects	Projects include mining, oil extraction, renewable energy, transportation, telecommunications, and pharmaceuticals. Agricultural insurance is also a growing sector in the region.
Ecotourism, gastronomy, and national parks	Activities related to scientific tourism, nature tourism, ecotourism, community tourism, and gastronomy in national parks.
Education and capacity building	Formal and informal educational initiatives related to biodiversity in the region, including capacity-building activities from primary school to university studies.
International mechanisms and agreements	Commitments made by the countries of the Tropical Andes region to comply with international mechanisms and agreements such as the UNFCCC Framework Convention on Climate Change, the UNCBD, NBSAPs, NDCs, and SDGs.
Territorial planning and risk management	Monitoring of both human and natural threats such as illegal deforestation, mercury in water, floods, landslides, fires, zoonotic diseases, and bio-prospecting pharmaceuticals, and collaboration between public and private health services.
Indigenous peoples and traditional knowledge holders	Utilization of traditional practices and knowledge to sustainably manage biodiversity through activities such as hunting, fishing, gathering, and agriculture, often in communal conservation areas. Also includes small-scale activities such as producing artisanal coffee, cocoa, and honey.

5. *Language accessibility and dissemination*: Addressing communication challenges across diverse languages and outlets within various stakeholders and sectors, a multifaceted approach was proposed. Through initiatives and training programs, they aim to foster inclusive dissemination of research findings. By utilizing simple language and user-friendly platforms, this strategy navigates the complex linguistic landscape, ensuring crucial information is comprehensible and accessible. Moreover, stakeholders advocate for publication in regional, Spanish, and international journals, not only empowering effective decision-making within the region but also demonstrating a collective commitment to addressing local and global biodiversity challenges.
6. *Establishment of a collaboration network*: Stakeholders recognized the potential of a collaboration network as a means to synergize the proposed solutions. This network would facilitate the implementation of various mechanisms, such as improving data and platform accessibility, ensuring publication and transparency of results, and fostering greater cooperation among stakeholders.

8.5 | Thematic groups

Based on surveys and national workshops, six thematic groups were identified as key priorities for biodiversity information flows: (1) industry, development, and infrastructure projects, (2) ecotourism, gastronomy, and national parks, (3) education and capacity building, (4) international mechanisms and agreements, (5) territorial planning and risk management, and (6) indigenous peoples and traditional knowledge holders (Table 2). These groups cover a wide range of activities and initiatives related to biodiversity conservation and management in the region.

8.6 | Essential biodiversity variables

The six sectors from the national workshops were used to map the requirements of specific EBVs (Appendix S3). Among the broader EBV classes required by all six groups, community composition, and ecosystem structure were identified as the most essential (Appendix S3). Specific EBVs were mainly community abundance, species abundance and distributions, and taxonomic diversity (Appendix S3). Genetic differentiation, inbreeding, and ecosystem phenology were not identified as relevant in any of the groups, while morphology and physiology, were discussed only in one thematic group (Appendix S3).

8.7 | Biodiversity indicators

The six thematic groups were synthesized into two regional priority themes: (1) land-use planning and risk

management, which focused on large-scale development and infrastructure projects, and (2) international agreements and commitments, which emphasized the use of natural resources by local communities. Following in-depth workshop discussions and final rankings, the two priority indicators were selected aligning with the "Community composition" and "Ecosystem structure" EBVs that emerged from identified needs in the region. These selected EBV-derived priority indicators were "Species richness of terrestrial vertebrates by ecosystems" and "Terrestrial ecosystem distribution" (Appendix S7). To develop our indicators, we utilized the NatureServe IVC hierarchical classification structure, allowing for scalable indicators that link measures of ecosystem diversity across different scales of conservation action (Comer et al., 2022). This hierarchical classification structure facilitates linking measures of ecosystem diversity across scales of conservation action. The regional assessment at the scale of the Tropical Andes provided insight into regional conservation and was readily scalable for reporting at continental or global scales. At the same time, these measures could be linked to ecosystem concepts defined and mapped for focused attention by land-use planners and managers working at more local scales.

8.8 | Capacity-building

Feedback from attendees of the virtual workshops was overwhelmingly positive, with participants expressing the value of the acquired skills and their applicability to their regular activities, as well as the potential for enhancing the quality of biodiversity information. Recognizing the benefits of ongoing communication and networking, participants strongly recommended the workshops to others seeking to improve their understanding and management of biodiversity information. The dissemination workshop was also highly rated by 93.5% of participants, who felt that the workshop exceeded their expectations.

9 | DISCUSSION

Our study aimed to improve the flow of biodiversity information within the intricate context of the Tropical Andes region through a rigorous co-design process. Through active, meaningful, and respectful engagement with diverse stakeholders across various sectors, with diverse stakeholders, especially local partners and communities, ensuring their rights and perspectives were central to the process, we harnessed their collective expertise in producing and utilizing biodiversity information to cultivate a comprehensive understanding of the challenges and opportunities present in the region. By purposefully fostering a dynamic and inclusive environment that welcomed and incorporated novel ideas and diverse viewpoints, we generated insights that transcended biases, ensuring a holistic perspective that surpassed traditional academic limits. Enriched by diverse narratives, languages, and insights from local communities and economic sectors, this approach extended beyond academia, resonating with stakeholders and significantly contributing to the discourse on biodiversity information exchange. This systematic co-design approach not only amplified diverse stakeholder voices but helped identified priority needs, limitations, and bottlenecks in the region. Leveraging these insights, we integrated commonly cited mechanisms to enhance information exchange between data producers and users, and improve the flow of biodiversity information in the region.

A key outcome was the development of two biodiversity indicators, which leveraged existing capacities while also addressing major limitations in the region. For example, we incorporated commonly cited mechanisms to improve the flow of information, such as using simple language, freely accessible data, publication and transparency of results, establishing transdisciplinary spaces, using standardized protocols, and creating user-friendly platforms. The EBV-derived indicators were also integrated with existing national land cover products to increase their usability and applicability. Technical bottlenecks and cited limitations were further tackled through capacity-building workshops for producers to facilitate the future flow of biodiversity information in the region. The workshops adopted a holistic approach and aimed to empower researchers and conservation practitioners, providing them with essential skills and knowledge throughout the various stages of the biodiversity information flow. This facilitated knowledge exchange, connection among like-minded peers, insights into diverse perspectives, collaborative efforts, and the establishment of impactful connections and knowledge exchange. By equipping participants with these fundamental capabilities, the project not only contributed to immediate outcomes but also laid the foundation for long-term sustainability in biodiversity information collection and utilization in the region.

The biodiversity products also effectively tackled key limitations from the assessment phase, notably addressing the challenge of biodiversity information dissemination in the region. Despite active research efforts, a lack of incentives often deters researchers from publishing (Owens, 2022). While many producers generate reports for policy and decision-makers, these documents often face challenges in terms of accessibility and discoverability.

This situation ultimately results in a squandered opportunity for sharing valuable insights and inhibits the potential contributions of various stakeholders, particularly among producers such as local scientists. These individuals rely on this information to not only prevent redundant efforts but also to conserve resources and gain a comprehensive understanding of the broader context. Interestingly, even though these research articles are tailored for scientific audiences, their publication in national or international journals frequently garners attention from local and national media outlets, extending their impact beyond the confines of academia. Enhancing dissemination across various media platforms can effectively bridge the information gap beyond the confines of academia, ensuring that critical insights reach their intended recipients, fostering informed decision-making, and maximizing the impact of biodiversity information.

In response to these challenges, the resulting indicators played a pivotal role in the creation of a highly impactful scientific paper (Comer et al., 2022), presenting an extensive regional analysis of biodiversity status, trends, and potential drivers in the Tropical Andes region. Notably, the manuscript and associated data were meticulously developed in accordance with FAIR principles, ensuring open accessibility to the complete geospatial datasets of the scalable indicators (Valdez, 2023) and available for visualization in the GEO-BON EBV Data Portal (Valdez et al., 2022). Moreover, recognizing the intricate complexity of biodiversity issues, coupled with the need for effective information synthesis across diverse audiences beyond academic articles, our approach extended to the translation of scientific knowledge into easily comprehensible and contextually engaging actionable insights. This is exemplified by a Spanish article in Mongabay (Paz Cardona, 2022) magazine tailored for Latin American audiences, strategically tailored to resonate with Latin American readers. This article bridges the gap between academia and practical application, broadening reach and ensuring accessibility for stakeholders not typically engaged with conventional scientific publications. This comprehensive approach significantly contributes to addressing information dissemination gaps, catering to the communication needs of a wide spectrum of audiences, from producers to users including the scientific community, general public, decision-makers, and stakeholders. In doing so, it further enhances the flow of information within the region, contributing to a more cohesive and informed network of biodiversity knowledge.

The most crucial component of the co-design process was connecting stakeholders who produce and use biodiversity information was crucial for the co-design process, particularly secondary stakeholders such as local communities and economic sectors. Although this transdisciplinary approach is not a novel concept (Díaz et al., 2015; Kellert, 1997; Muhl et al., 2022), it is often overlooked. These stakeholders play a key role in decision-making related to biodiversity conservation and management as they can impact and be impacted by biodiversity (Görg et al., 2014; Reyers et al., 2010). Engaging secondary stakeholders can raise awareness and appreciation of biodiversity, leading to greater support for conservation (Görg et al., 2014). Local communities possess invaluable traditional ecological knowledge. We ensured that this knowledge was accessed with their explicit consent, ensuring proper attribution and collaboration, and that any benefits derived were shared equitably, complementing scientific data and enhancing understanding of local biodiversity (Gewin, 2022; Görg et al., 2014; Muhl et al., 2022). Citizen science initiatives also further enrich our knowledge and lead to more informed decision-making (Agnew et al., 2022; Pettibone et al., 2018). Incorporating diverse stakeholders across the flow of biodiversity information fosters collaboration, builds trust, and promotes more effective and sustainable conservation efforts, considering diverse perspectives and needs (Mitchell et al., 2017; Muhl et al., 2022). In regions like the Tropical Andes, it is essential to guard against "parachute" science. We actively worked to engage local experts, recognizing local governance and structures, and prioritized community-driven initiatives over external impositions (de Vos & Schwartz, 2022).

Nevertheless, despite the notable achievements of the project, a significant challenge that remains unaddressed pertains to funding limitations. While the scarcity of resources for biodiversity research presents a worldwide challenge, it is particularly accentuated in low and middle-income countries, such as those found in the region (Romero-Muñoz et al., 2019). This situation is further exacerbated in the Tropical Andes by national policies that prioritize development projects, infrastructure, and extractive industries over biodiversity concerns, as a response to socioeconomic challenges (Romero-Muñoz et al., 2019). The lack of funding, coupled with complicated bureaucracy, affects all stages of the information flow, from the collection of new information to updating, integration, technical management, and long-term storage and curation. Another obstacle lies in the absence of basic technological infrastructure and standardized guidelines for biodiversity information management, leading to fragmented knowledge and duplication of efforts.

The main suggestion to improve the limitations and facilitate the flow of biodiversity information in the Tropical Andes was to establish a transdisciplinary and inter-institutional biodiversity network. A sustained, user-driven, locally operated, harmonized, and scalable biodiversity observation network (BON), such as

developed by the group on earth observations biodiversity observation network (GEO BON), could help achieve this by improving the acquisition, coordination, and delivery of relevant and timely biodiversity data to users (Kissling et al., 2018; Navarro et al., 2017; Scholes et al., 2012; Walters & Scholes, 2017). Harmonized observation networks could optimize current observation efforts and data, and adopting an approach based on essential variables (EBV or EESV) could help identify biases and prioritize data mobilization and modeling efforts (Balvanera et al., 2022; Geijzendorffer et al., 2016; Navarro et al., 2018). Although the EBV-based indicator identified in this study provides only a snapshot of the current state of biodiversity and does not capture changes over time, it can serve as a valuable baseline for monitoring and detecting future biodiversity changes. Furthermore, it can also serve as a starting point for the development of an EBV for a BON in the region. More specifically, the production and subsequent use of these indicators can incentivize further, in-situ data collection to both verify and improve the accuracy in future iterations and form the backbone for a collaborative, transboundary monitoring approach for the region. The establishment of a Tropical Andes biodiversity network could consolidate data, improve discoverability, access, and utility of information, and serve as a valuable tool for monitoring and detecting changes in biodiversity. This approach has shown promising results in other regions, such as the Arctic, New South Wales in Australia, Colombia, and Europe with EuropaBON (Moersberger et al., 2022; Navarro et al., 2017; Pereira et al., 2022).

Overall, this study aimed to develop biodiversity information tailored to the needs of users in the Tropical Andes and test a model for mainstreaming biodiversity. To achieve effective mainstreaming, several actions are necessary, including engaging secondary stakeholders, facilitating the flow of biodiversity information from data producers to users, and incorporating the social and economic benefits of biodiversity into mainstreaming strategies (Figure 1). Scientists and policymakers should collaborate in participatory processes to ensure that biodiversity information is understandable and accessible to a broader range of stakeholders (Bickford et al., 2012; Davis et al., 2014). To achieve this, they can develop plain language summaries, use multimedia formats, and engage in targeted outreach and engagement (Bickford et al., 2012; Diedrich et al., 2011; Jolibert & Wesselink, 2012; Novacek, 2008). Additionally, efforts must be made to incorporate the social and economic benefits of biodiversity into mainstreaming strategies, which requires the development of clear policies and guidelines that balance the needs of different stakeholder groups (Muhl et al., 2022; Smith et al., 2020; Xu et al., 2021). Translational ecology has recently emerged as an effective approach to integrating scientific knowledge into decision-making processes and making biodiversity information accessible to a wider range of stakeholders (Davis et al., 2014; Schwartz et al., 2017). Prioritizing bottom-up approaches that involve local communities in mainstreaming strategies can also ensure context-specific and responsive strategies that foster buy-in and ownership across the broader community (Diedrich et al., 2011; Muhl et al., 2022; Pascual et al., 2021; Perino et al., 2021). By collaboratively working with and genuinely valuing inputs from diverse groups, we aim to foster a sense of ownership, identify bottlenecks and determine ways to improve the flow of biodiversity information (Figure 1). Implementing these strategies can help us overcome the disconnect between academic research and the diverse information needs of stakeholders, and help improve the integration of biodiversity considerations into decision-making processes across different sectors. The co-design approach implemented in this study and its outcomes can be used as a proof-of-concept of the BON development process that could be applied to other regions.

10 | CONCLUSION

Effective biodiversity conservation requires a collaborative and multinational approach that involves a diverse range of stakeholders, including local communities and the economic sector (Bravo et al., 2016; Zador et al., 2015). Achieving a balance between biodiversity conservation, and political, economic, and socio-cultural development requires effective integration and communication between scientific communities and organizations that use biodiversity information (Cvitanovic et al., 2016; Neßhöver et al., 2013; Pascual et al., 2021). When developing biodiversity information that may inform public policies and development plans, it is therefore essential to engage with local community groups and organizations in order to effectively identify and address the diverse needs of all relevant sectors of society (Huntley & Redford, 2014; Redford et al., 2015). Managing priorities reciprocally can lead to better conservation of biodiversity while sustaining equitable use (Armenteras, 2021). A bottom-up, results-based co-design approach that engages and considers the needs and perspectives of all groups that would benefit from biodiversity information can promote inclusive and responsive biodiversity mainstreaming and contribute to the successful implementation of biodiversity policies and conservation goals (Perino et al., 2021). Given the multiple worldviews, values, and knowledge systems between science, policy, and practice the process presented here can be a valuable blueprint to mainstream biodiversity information and make it more inclusive in the future.

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DATA AVAILABILITY STATEMENT

Data available in article supplementary material.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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