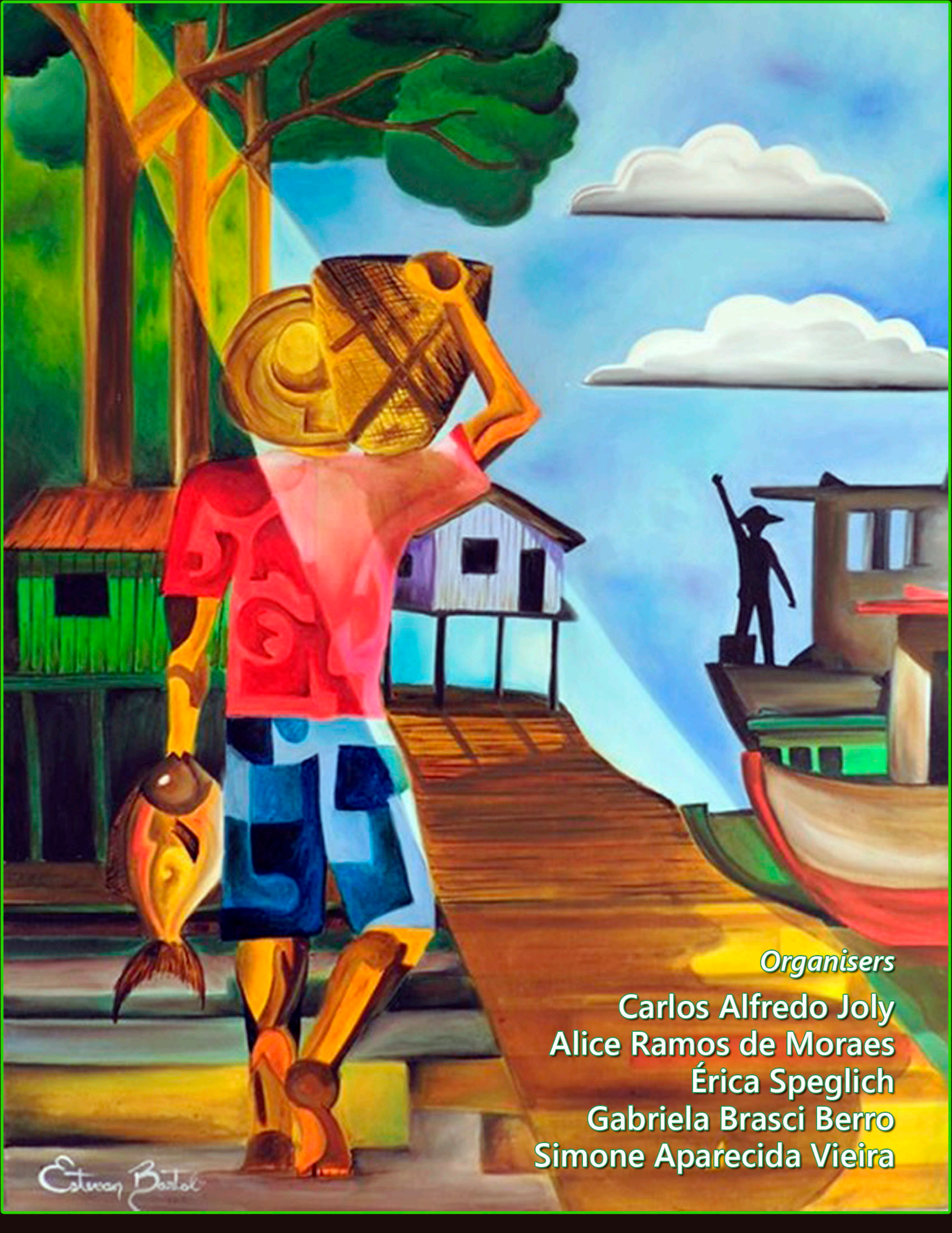
SPSAS SUSTAINABLE AND INCLUSIVE AMAZONIA

AMAZON DIALOGUES

CONTRIBUTIONS TO THE DEBATE ABOUT SUSTAINABILITY AND INCLUSION



Organisers

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Amazon Dialogues: Contributions to the Debate About Sustainability and Inclusion

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Summary

Vectors of degradation and large-scale impacts in the Amazon Basin

Inclusion and cultural diversity in the Amazon Basin, from the local to the transnational level

Dialogues for sustainability and inclusion in the Amazon Basin: local governance, participation and transdisciplinarity

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From assured destruction to sustainable transition

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Over the centuries, there has been a replacement of the axe, shovels, hoes, and slash-and-burn practices with increasingly refined, selective, and destructive tools. Technological advancements have brought with them an advancement of this destructive power. The potential for transformation associated with a better understanding of the laws governing the universe led, among other things, in the 1950s, to the development of the concept of Mutual Assured Destruction (MAD).

Since then, our species has confronted various threats, including the accelerated disappearance of animal (and plant) species, and has succeeded in the reintroduction of a few species into the wild. On a larger scale, the banning of chlorofluorocarbons (CFCs), in what is still "possibly the most successful international cooperation agreement of all time" (Kofi Annan), and the subsequent recovery of the ozone layer is a promising element.

The problems we continue to face today are manifold and challenging. For a layperson, it is difficult to understand how an open-pit mining operation can thrive in a world where satellite surveillance and electronic equipment monitoring have reached current levels. For rational individuals, it is hard to comprehend how, after Minamata, the use of mercury continues to occur on the scale of hundreds of tons and in a reckless manner as a deliberate action.

FAPESP has successfully developed various programs aimed at promoting and organizing the production of knowledge on biodiversity, bioenergy, climate change, and data science. However, the development of BIOTA, BIOEN, PFMCG, and eScience was carried out with little or no synergy between these remarkable programs. The Amazon Initiative, on the other hand, focuses on integrating these programs, creating a meta-program.

The first step of the Amazon Initiative, the São Paulo School of Advanced Science, brilliantly led by Prof. Carlos Joly, not only resulted in this book but also drew the attention of young and promising students to this subject. The sustainable transition we seek for the Amazon will not be achieved without quality science, without the involvement of experienced leaders and engaged youth, without a multifaceted vision, and without the participation of society as a whole. The different themes addressed in this book bear witness to the complexity of the challenge ahead. Science and scientists must play a leading role in this transformation.

The São Paulo School of Advanced Science for a Sustainable and Inclusive Amazon

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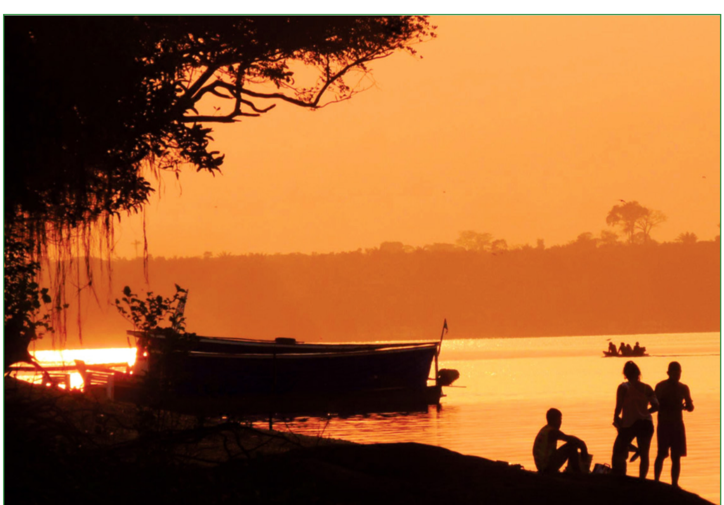

ABSTRACT

Between November 21 and December 5, 2022, the São Paulo School of Advanced Science for a Sustainable and Inclusive Amazon (SPSAS Amazon) took place in São Pedro, São Paulo, as part of the Amazon Initiative by the São Paulo Research Foundation (FAPESP). The aim of ESPCA Amazon was to contribute to the training and capacity-building of students, researchers, and professionals in the field of Biodiversity and Ecosystem Services who will be leading academic and research centers, government agencies, companies, industries, international organizations, and various other sectors and institutions in the future. The content of the school was organized into three main themes: The Amazonian territory and its sustainability, Amazonians as key players in Biodiversity Conservation and Climate Change Mitigation, and the Amazon and its inhabitants in harmony with their environment and the Sustainable Development Goals (SDGs). The results of the experiences and learning acquired in this process are captured in the works that make up this e-book.

Keywords: Interdisciplinarity; networking; ecosystem services, biodiversity and ecosystem services conservation; social participation

Contextualization

In mid-2021, at the initiative of the then Scientific Director of FAPESP, Prof. Luiz Eugênio Mello, the four Strategic Programs of FAPESP[1] began to discuss the possibility of a major research initiative in the Amazon. At that time, FAPESP had a history of funding around half a billion reais in excellent research on the Amazon theme. However, it was evident that there was a lack of integration among these initiatives and a disconnect with the social and human dimensions of the research.

These internal discussions led to two working meetings in which the main goal was to unite efforts and broaden the discussion of the Strategic Programs with experts in the field, particularly local stakeholders. Furthermore, the purpose was to outline what would be and how to implement an innovative, interdisciplinary research agenda with a focus on socio-biodiversity.

The meetings took place virtually on April 27 and 29, 2022, and brought together 64 participants from different states and sectors (academia, industry, and the third sector). The question, "What scientific research is necessary for a sustainable transition in the Amazon region?" guided the discussions on the first day, with the main objective of defining the priority issues that would be the focus of the first call for research projects. The outcome of this discussion was published as a central table in item 3 of the Proposal Call launched in June 2022, summarizing the main priority research areas for the region.

These discussions were used as input for the second-day debate on arrangements that would facilitate innovative research to advance solutions to the region's problems. The outcome of the discussion was a portfolio of possibilities for each State Research Support Foundation to assess the most suitable arrangements for use in future calls with a focus on innovation.

In parallel, in response to a challenge from the President of FAPESP, the National Council of State Research Support Foundations (Confap) progressed in discussions to create an agenda to identify a broad range of concrete research challenges that would provide solutions to real issues in the Legal Amazon. The maturation of these discussions led to the establishment of the Amazon Initiative +10, which, still in 2022, launched its 1st Research Call, involving the participation of 20 State Research Support Foundations. This call engaged more than

1. Research Program on Characterization, Conservation, Restoration and Sustainable Use of Biodiversity (BIOTA); Research Program on Bioenergy (BIOEN); Research Program on Global Climate Change and Research Program on eScience and Data Science.

500 researchers from 18 states plus the Federal District and resulted in the approval of 39 research projects in three major thematic areas: Territory, Amazon Peoples, and Strengthening Sustainable Productive Chains.

Another relevant parallel action was the event "How can research and research councils contribute to the sustainable development of the Amazon region?" held in 2022 during the annual meeting of the Global Research Council. The event, organized by FAPESP and the NWO (Dutch Research Council), involved the engagement of the Inter-American Institute for Global Change Research/IAI and resulted in the decision to approach the Belmont Forum regarding the possibility of an international call focused on Tropical Forests, particularly the Amazon. These discussions have evolved, and soon the Belmont Forum is expected to launch a call for a Collaborative Research Action (CRA) with this objective.

Returning to the discussions promoted by FAPESP's Scientific Directorate, in late 2021, there was significant debate about the need to train researchers interested in conducting research in the Amazon region, particularly in transdisciplinary research. This realization led to the development of a proposal for a São Paulo School of Advanced Science (ESPCA) focused on training young researchers from the Amazon, which has always been considered a biome that extends into neighboring countries. The establishment of the São Paulo School of Advanced Science for a Sustainable and Inclusive Amazon emerged from the intersection of all the discussions presented here, which aimed to create a research agenda for the region.

SPSAS Amazon structure

Always in collaboration with researchers and institutions from the Amazon region, the first step was the establishment of the Organizing Committee[2] to create the program. From the outset, the Committee defined that "The objective of the Sustainable and Inclusive Amazon ESPCA is to provide young postdoctoral researchers (in the final stages of their doctorate) with a multidisciplinary and interdisciplinary perspective, based on science and valuing indigenous and

2. Composition of the Organizing Committee: Carlos Alfredo Joly, Simone Aparecida Vieira (BIOTA), Paulo Artaxo (Mudanças Climáticas), Glaucia Souza (BIOEN), Eduardo Cesar Leão Marques (eScience), Marie-Anne Van Sluys (DC FAPESP), Adalberto Val (INPA), Marlucia Bonifacio Martins (MPEG), Helder Lima de Queiroz (MAMIRAUA), Ane Alencar (IPAM), Gustavo F. V. Silveira (OPAN), Altigran Soares da Silva (UFAM), Marcella Ohira (Inter-American Institute for Global Change Research/IAI).

traditional knowledge, of the main problems that have historically hindered sustainable development, conservation, and social inclusion in the Amazon Biome. It also aims to discuss the existing alternatives for these fronts and collaboratively build new proposals for solving these issues with these young scientists."

In addition to researchers, the organization had the invaluable support of a group of young researchers who not only collaborated in setting up the school but also volunteered to assist with all ESPCA activities as monitors, as well as organizing essential participant integration activities[3]. In the discussions for the school's organization, the importance of incorporating the inclusive aspect was strongly emphasized, both in its structure and in relation to the selection of participants and the topics to be addressed throughout the course.

Thus, for the selection of participants, criteria for diversity and inclusion were discussed and implemented, with special attention given to candidates with a direct connection to the Amazon and those with family ties to traditional Amazonian peoples.

Diversity and inclusion criteria were discussed and implemented to select the participants, with special attention to candidates with a direct relationship to the Amazon and kinship with traditional Amazonian peoples. A total of 88 out of 121 candidates were selected, giving priority to participants linked to the Amazon region as a whole, i.e., from all the countries that share this biome. At the end of the process, 60% of the participants were Brazilian and 40% from Amazonian countries such as Bolivia, Colombia, Ecuador, Peru, Suriname and Venezuela, and non-Amazonian countries such as Guatemala, Mexico, the United States, Italy, and the Netherlands.

3. Team of monitors: Alice Ramos de Moraes (Pós doutoranda no Centro de Síntese em Biodiversidade e Serviços Ecossistêmicos/SinBiose à época, atualmente pós-doutoranda no Núcleo de Estudos e Pesquisas Ambientais da Universidade Estadual de Campinas/ NEPAM-UNICAMP e jovem pesquisadora da Plataforma Brasileira de Biodiversidade e Serviços Ecossistêmicos/BPBES); Gabriela Brasci Berro (Doutoranda do Programa de Pós-Graduação em Ecologia da Universidade Estadual de Campinas/UNICAMP); Laura Barbon de Abreu (Mestranda do Programa de Pós-Graduação em Ecologia da Universidade Estadual de Campinas/UNICAMP); Henrique Simões de Carvalho Costa (Doutorando do Núcleo de Estudos e Pesquisas Ambientais da Universidade Estadual de Campinas/NEPAM-UNICAMP); Rafael Flora Ramos (Doutorando do Programa de Pós-Graduação em Ecologia da Universidade Estadual de Campinas/UNICAMP); Luis Carlos Quimbayo Guzmán (Doutorando do Programa de Pós-Graduação em Ecologia da Universidade Estadual de Campinas/UNICAMP); Victor Campos Khuriyeh (Bacharel em Ciências Biológicas pela Universidade Estadual de Campinas/UNICAMP, vinculado ao Laboratório de Ecologia e Manejo de Ecossistemas/LEME, do Núcleo de Estudos e Pesquisas Ambientais / NEPAM-UNICAMP).

The focus on inclusivity at SPSAS led to the provision of simultaneous translation services for the lectures held throughout the entire period. This allowed for presentations and contributions from participants in three languages – English, Spanish, and Portuguese. As a result, everyone felt more comfortable absorbing the content and making their contributions in their preferred language. In activities where simultaneous translation services were not possible, such as technical visits or integration dynamics conducted in other spaces, the participants themselves assisted one another, contributing to a collaborative, attentive, and respectful environment.

Taking into consideration the ongoing COVID-19 pandemic and the fact that SPSAS is an event with a large number of participants coming from various parts of the world, there was a concern regarding the sanitary protocols to be followed. The support of the Health Department of the city of São Pedro/SP (where ESPCA was held) was requested, and all those involved were tested on the first day. Furthermore, the use of masks in indoor spaces was consistent, and rapid tests were available in case any participant displayed symptoms.

Regarding the course structure, the focus on sustainability and inclusion led to the definition of the three modules of ESPCA Amazon: 1) The Amazonian territory and its sustainability; 2) Amazonians as key players in Biodiversity Conservation and Climate Change Mitigation; and 3) The Amazon and its inhabitants in harmony with their environment and the Sustainable Development Goals (SDGs).

In the first module, the following topics were presented:

- *Vision of inter and transdisciplinary research – decolonizing methods*, by Anita Hardon (NWO).
- *Characterization of the geological evolution of Amazonian ecosystems*, by Paulo Eduardo de Oliveira (USP);
- *The Amazon hydroclimatic system, water recycling, and climate regulation in the Amazon*, by Marcos H. Costa (UFV);
- *The carbon cycle in the Amazon*, by Luiz Eduardo O. C. Aragão (INPE);
- *Atlantic Forest: an unexpected forest*, by Simone A. Vieira (UNICAMP);
- *The changing Amazon in the context of our new climate*, by Paulo Artaxo (USP);
- *Evolution of the Amazonian biota*, by Alexandre Aleixo (Natural History Museum of Finland);
- *Impacts of climate change on amazon* fish, by Adalberto Val (INPA);
- *The evolution of Amazonian flora and the effects of human domestication*, by Mónica Moraes (UMSA);

- *The ancient history of the Amazon and its connections with cultural and biological diversity*, by Eduardo G. Neves (USP);
- *The historical depletion of Amazonian bioculturality*, by Nicolás Cuvi (FLACSO Ecuador);
- *Characterization of the main drivers of climate change and loss of biodiversity and socio-diversity*, by Philip Fearnside (INPA);
- *Conservation policies for protected areas and indigenous territories in the amazon from the past to the present*, by Thiago Mota Cardoso (UFAM);
- *Impacts of deforestation on infectious diseases and public health in the Amazon*, by Marcus V. G. Lacerda (FIOCRUZ Manaus);
- *Amazon + 10 Initiative*, by Luiz Eugênio Mello (DC FAPESP).

In the second module, the presentations were:
- *Bioeconomy: a future for the Amazon*, by Lauro Barata (UFOPA);
- *The fishing management of the Paumari indigenous people seen from other perspectives*, by Gustavo F. V. Silveira (OPAN);
- *Biocultural diversity and governance in the amazon: knowledge exchange and socio-environmental justice*, by Simone Athayde (Florida International University);
- *The contribution of Amazonian populations to ecosystem services*, by Helder L. Queiroz (Mamirauá Sustainable Development Institute);
- *The Amazonian Institute for Scientific Research – SINCHI Colombia*, by Juan Felipe Guhl Samudio (SINCHI);
- *Conservation measures to address the main threats to biodiversity, ecosystem services, and carbon stocks in the Amazon*, by Ane Alencar (IPAM);
- *Geospatial databases on the Amazon*, by Carlos M. de Souza Junior (IMAZON);
- *What can AI do for socio-environmental research*?, by Thiago Santos Gouvea (DFKI);
- *Initiatives to synthesize existing knowledge to advance governance for sustainability issues*, by Andrea Carolina Encalada Romero (USFQ).

In module 3, the program included:
- The contributions and role of the third sector for conservation and sustainable use of biodiversity and in climate change in the Amazon, by Paulo Moutinho (IPAM);
- Models and options for ecological restoration of Amazonian formations, by Ricardo Ribeiro Rodrigues (ESALQ-USP);

♦ Contemporary urbanization in the Amazon: territorial systems and the Parintins micro-region, by Estevan Bartoli (UEA).

In the third module, the lectures *Organizational Processes and social technologies that drive sustainable development, including cultural development and Tourism in the Amazon* (by Nelissa Peralta, Institute of Philosophy and Human Sciences-UFPA); and *Connecting and sharing diverse knowledge to support sustainable pathways in the Amazon* (by Francisca Arara, Regional Committee for Partnerships with Indigenous Peoples and Other Traditional Populations) were planned. Unfortunately, the speakers were unable to attend.

In addition to these presentations, we had an opening lecture entitled *The Amazon near a point of no return: the urgent need for a new bioeconomy of standing forest*, by Carlos A. Nobre (IEA/USP), and the closing lecture *Decolonizing Futures: Amazon beyond sustainability*, by Fábio Scarano (UNESCO Chair of Futures Literacy & UFRJ).

SPSAS dynamics

At the end of Modules 1 and 2, moments of discussion were organized involving all the speakers. Initially, they briefly presented their respective institutions, and then, collectively (including participants), they focused on specific issues. Some topics addressed included: the allocation of human resources for research in the region; the need for training in transdisciplinary research; difficulties in organizing productive chains, especially for seasonal products; the lack of integration among multiple actions and the respective databases generated; and the new problems brought about by the rapid expansion of organized crime and its impact on traditional communities and indigenous areas.

Integrative activities

The schedule of SPSAS Amazon included integration activities among participants, carefully designed and executed to incorporate lectures and other intellectual activities. The initial integration activities primarily focused on breaking the ice and fostering connections—after all, SPSAS brought together a diverse constellation of participants from 12 different nationalities, with professional and personal affinities, who would live and work together for the following two weeks. Subsequent activities were developed to permeate issues addressed during the lectures and, in this way, create opportunities for subjects to be revisited and deepened in a context alternative to conventional academic presentations and discussions.

In summary, the integration activities aimed to foster conditions for creating a welcoming and relaxed environment that encouraged participants to get to know and connect with each other beyond names, home institutions, and academic backgrounds. With this spirit, the broadcasts of the Brazilian men's national football team's matches in the FIFA World Cup were accommodated in the schedule as moments of integration among the attendees. The poster sessions were also designed to contribute to establishing connections among participants.

Poster session

In the SPSAS schedule, two moments were allocated for poster presentations early in the first module, with 40 participants in each session. Each participant provided a brief introduction to their interests and recent research lines, as well as the main motivations, questions, and challenges they identified regarding a sustainable and inclusive Amazon. Participants were also encouraged to share their expectations for SPSAS, possible suggestions for collaborative work, and how this collaboration could contribute to their own research agendas.

Participants whose current research topics were similar or complementary were placed in the same session, facilitating the exchange of information and experiences. Everyone in attendance visited the presentations, making it one of the initial moments of integration and networking, which intensified over the course of the days. It is worth mentioning that one of the lecturers said, at the end of the second poster session, that this was one of the best presentations he has participated in, due to the lively discussion among participants.

Technical visit to Natura Cosmetics

During Module 2, there was also a visit to the Natura Cosméticos factory in the municipality of Cajamar/SP. The purpose of this visit was to showcase, on-site, the effective viability of having an industry based on the active principles of Amazonian biodiversity in a sustainable manner. As preparation for this visit, starting from the beginning of Module 2, biologist Camila Brás Costa, Scientific Manager of plant species bioprospecting with cosmetic potential, began accompanying SPSAS Amazon to understand the focus on the sustainable development of the Amazon and to connect with the participants, addressing various questions from the participants about Natura's activities.

During the visit, Natura professionals discussed the company's activities specifically related to the use of Amazonian bio-ingredients extracted in partnership with traditional communities through the Natura Amazônia Program, and how this currently contributes to the conservation of two million hectares of standing forest. Optionally, Natura also offered the opportunity to participate in a workshop aimed at encouraging potential project proposals in collaboration with the company through the Natura Campus Hard Life Science.

Group work

In addition to lectures, posters, integration activities, and the visit to Natura, over the first ten days of SPSAS Amazon, participants engaged in various group activities as part of the dynamics used in each module. At the end of Module 2, with guidance from the faculty team and monitors, participants organized themselves into groups of up to ten people. Each group consisted of participants with backgrounds in both natural sciences and social sciences and humanities, coming from different countries.

This dynamic resulted in the formation of ten groups that worked intensively throughout the second half of the SPSAS to define their respective work themes. In this process, they could rely on the support of monitors and presenters for refining ideas, defining and refining the scope, as well as engaging in exchanges and receiving feedback from other participants.

Final semarks

SPSAS Amazon was a unique experience that brought together speakers and participants from various Amazonian countries, with backgrounds in both natural sciences and social sciences and humanities, and with vastly different previous experiences. They set out and achieved the goal of working in an interdisciplinary manner. Although the choices of topics by the groups were not unanimous, naturally leading to tensions at the beginning of the work, everyone committed to producing a rich and unprecedented contribution that could serve as a reference in the future. The works produced, compiled and organized in this e-book, result from the combination of previous experiences, knowledge, and lessons learned – individually and collectively. They, therefore, reflect the participants' learning and maturation.

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Vectors of degradation and large-scale impacts in the Amazon Basin

- Challenges and opportunities to eliminate deforestation in the Brazilian Amazon
- Why not continue building hydroelectric dams in the Brazilian Amazon? Contributions to a renewable and effectively sustainable electricity matrix
- Impact of pesticides in the Amazon Basin: a multidisciplinary review
- Mercury pollution in Pan-Amazonian Indigenous Communities: a portrait of reality

Challenges and opportunities to eliminate deforestation in Brazilian Amazon

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ABSTRACT

The escalating deforestation in the Amazon region poses a grave threat not only to biodiversity, but also to climate, ecosystems, and local and international communities. This paper addresses the issue of combating deforestation in the Brazilian Amazon in recent decades and proposes strategies to bring forest destruction to a halt. Although Brazil has made significant progress on this matter, there are still challenges to overcome in order to fully eradicate the practice of illegal deforestation in the region. Here, we aim to analyze the main initiatives that have been successful in reducing deforestation and identify opportunities to bring it to zero by the years 2030, 2040, and 2050. Our results suggest that actions to combat deforestation should depend on the land characteristics of the deforested areas, prioritizing the reduction in public lands, which are responsible for 51% of recent deforestation rates, followed by settlement areas and lastly by rural properties, mainly through command-and-control strategies (top-down), incentives for agroforestry reforestation and development of local bioeconomic chains.

Keywords: deforestation, Amazon, PPCDAm, budget management, public environmental management.

Introduction

Brazil presents solid knowledge in the development and implementation of anti-deforestation policies. This knowledge has emerged in response to three decades of state-sponsored deforestation in the Amazon, aligned with the public agenda of "Integrate to not Deliver". This in turn has resulted in the integration of the Amazon with other regions of the country at the cost of significant loss and degradation of natural habitats, land conflicts, and hostility towards indigenous peoples. The rapid conversion of the Brazilian Amazon's forests has also led to the emergence of forest conservation actions in the private sector and civil society groups. Many of these actions have resulted in public-private partnership initiatives and other governance mechanisms (Greenpeace 2006, 2009).

Among these policies is the creation of the Action Plan for the Prevention and Control of Deforestation in the Amazon (PPCDAm) in the early 2000s, and the revision of the Federal Forest Code (CFF) in 2012. Since its implementation in 2004, the PPCDAm has facilitated the creation of over 30 million hectares of protected areas in the Amazon, established new deforestation monitoring systems, imposed embargoes on municipalities with high deforestation rates, and contributed to the development of the Low Carbon Agriculture Program (ABC) to promote pasture restoration and integrated crop-livestock systems in the Legal Amazon (Nepstad et al., 2014a). Despite challenges in achieving high compliance rates, the revised CFF has set restrictions on the removal of native vegetation on private properties and legally established the Rural Environmental Registry (CAR), which includes over 4.6 million properties with declared boundaries available for environmental monitoring (SFB, 2022).

Private zero-deforestation policies have also emerged in the soy and meat sectors in Brazil. Soy is the primary monoculture produced in the Brazilian Amazon, and a substantial portion is exported. This necessitates that Brazilian producers not only comply with national legislation but also meet the requirements of international buyers. In 2006, when pressured by civil society, international soy processors signed the Soy Moratorium (MSoja), committing to cease purchasing soy from properties involved in deforestation. These companies formed an advisory group to assist the government and provide monitoring of soy properties. Since the implementation of the MSoja, in implementation of public anti-deforestation policies and the collapse of commodity markets in the region (Macedo et al., 2012), soy production in the Amazon is virtually free from deforestation (Gibbs et al., 2015; Kastens et al., 2017). Similarly, the meat sector signed the Cattle Agreements with Federal Prosecutors and Greenpeace in

2009, also pledging not to trade cattle from properties involved in Amazon deforestation. However, unlike the MSoja, the Cattle Agreements have had limited success in reducing deforestation, due to the complexity of the supply chain (Massoca et al., 2017) and lack of transparency in the necessary information to monitor the agreements, which could lead to leaks and cattle laundering (Gibbs et al., 2016; Alix-Garcia and Gibbs, 2017; Klingler et al., 2017).

Additionally, recently elected President Lula has committed to eliminating deforestation in the Brazilian Amazon by 2030 (Agência Brasil, 2023). In this report, we present an innovative strategy to assess the challenges and opportunities for accomplishing this commitment and achieving zero deforestation in the Brazilian Amazon by 2030. To do so, we consider the lessons learned from the implementation of the PPCDAm, which has contributed to reducing deforestation, as well as the budget allocated to the environmental agenda for the coming years. We analyzed the budget (actual and projected) of deforestation control actions implemented until 2014 to address the following questions: (i) What is the estimated budget required for deforestation control actions in different scenarios by the years 2030, 2040, and 2050? (ii) Does Brazil have sufficient financial resources to fund these deforestation control measures? (iii) What are the priority recommendations for achieving zero deforestation, considering the projected budgets? (iv) What are the main strategies that will enable the achievement of zero deforestation by 2030?

The PPCDAm and the Federal Public Budget

The PPCDAm is composed of four fundamental pillars: Territorial and Land Planning, Environmental Monitoring and Control, Promotion of Sustainable Activities, and Normative and Economic Instruments. Its implementation was carried out through an integrated strategy involving various ministries and federal agencies, and the budget came from diverse sources. As a result, estimating the budget figures is challenging. Verdum (2017) conducted the herculean task of estimating federal expenditures for combating deforestation, and the results were impressive. The total budget (projected) for the first three pillars of action amounted to R$ 13.8 billion for the 2007- 2014 period. However, the actual budget utilization reached R$ 8.2 billion (Figure 1), resulting in a budget inefficiency of approximately 41%.

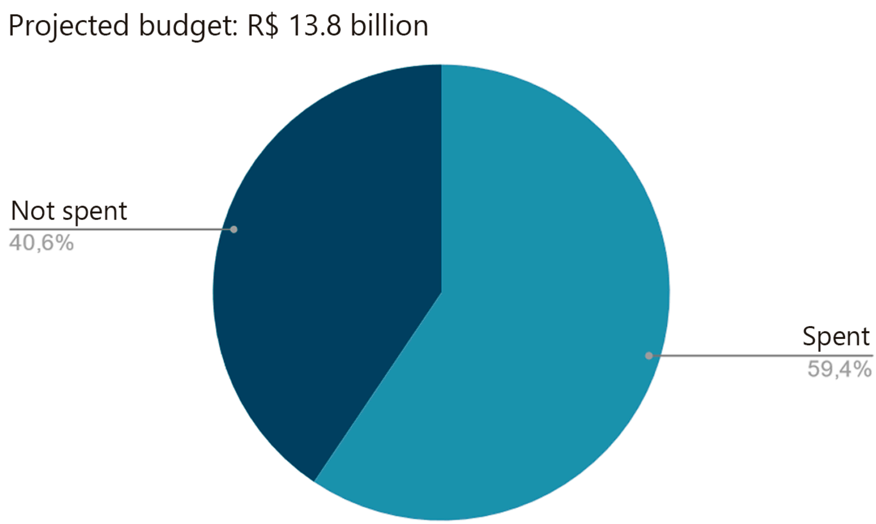

Figure 1 Projected vs. Spent Budget (R$ billion). *Source:* Adapted from Verdum (2017).

Out of the total budget, R$ 1.25 billion was allocated for the Territorial and Land Planning between 2007 and 2014. As for the Environmental Monitoring and Control pillar, the budget expenditure was R$ 1.66 billion. The remaining R$ 5.22 billion corresponded to the Promotion of Sustainable Activities pillar budget (Table 1).

Table 1 The PPCDAm and the Federal Public Budget (R$ million).

Planning Axis (2007-2014)			Monitoring Axis (2007-2014)			Promotion Axis (2007-2014)		
Year	Projected (R$ millions)	Spent (R$ millions)	Year	Projected (R$ millions)	Spent (R$ millions)	Year	Projected (R$ millions)	Spent (R$ millions)
2007	221,6	163,8	2007	142,8	108,4	2007	1.440,5	1.315,5
2008	316,2	172,6	2008	261,2	223,2	2008	2.387,3	1.914,9
2009	374,1	178,7	2009	425,9	333,8	2009	970,1	708,2
2010	539,4	304,7	2010	348,2	293,1	2010	1.189,4	645,9
2011	391,8	229,8	2011	262,5	225,4	2011	617,1	468,4
2012	115,5	7,1	2012	248,8	158,9	2012	343,8	63,3
2013	299,7	42,3	2013	205,3	145,5	2013	1.055,1	88,9
2014	545,9	156,8	2014	247,4	173	2014	902,6	17,2

Source: Adapted from Verdum (2017).

In summary, according to Verdum's survey in 2017, the PPCDAm's total realized budget amounted to approximately R$ 8.2 billion (Figure 2), with 78%

of the funds expended during the Lula administration (2007-2010) and 22% during the Dilma administration (2011-2014). The majority of this investment, up to 88%, occurred during the Lula era (around R$ 819.8 million between 2007-2010), and it began to decline during the Dilma era (2011-2014).

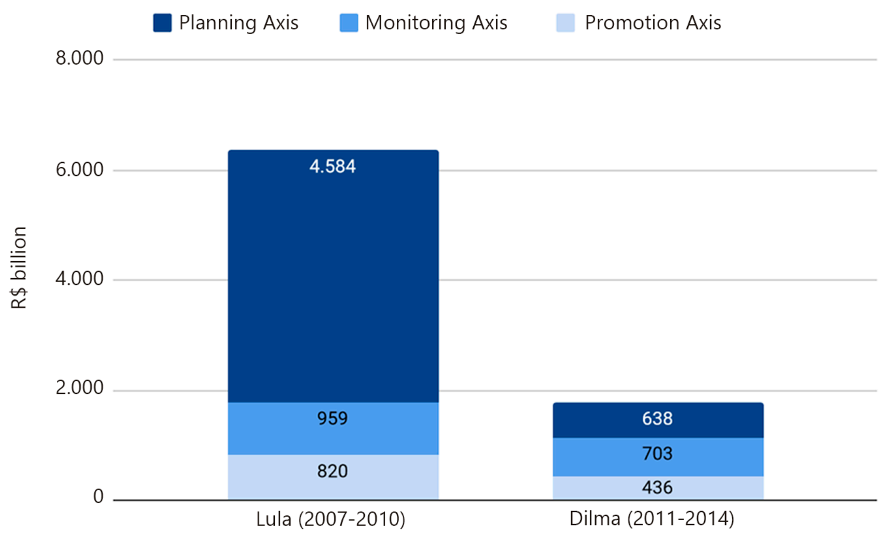

Figure 2 PPCDAm budget in the governments of Lula and Dilma. *Source:* Adapted from Verdum (2017).

Budget Scenario Forecast for 2030, 2040, and 2050

The implementation of the PPCDAm was divided into four distinct phases, highlighted in different colors in Figure 3. The first phase spanned the years between 2005 and 2008 (dark green), followed by the second phase from 2009 to 2011 (light green), the third phase from 2012 to 2015 (light blue), and the final phase from 2016 to 2020 (orange). According to PRODES (Program for Monitoring the Deforestation of the Brazilian Amazon Forest by Satellite), the largest annual decline in deforestation occurred during the first two phases, from 2005 to 2012, with an average annual reduction of 19%. Hence, this period was considered the calibration period for this study. Given the lack of information on the budget utilization in 2005 and 2006, we estimated the costs for deforestation reduction using the budgetary information available between 2007 and 2014.

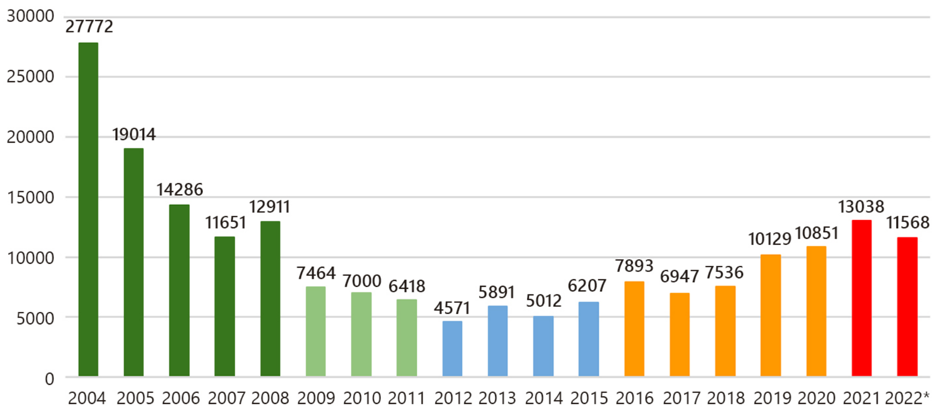

Figure 3 Deforestation in km^2 between 2004 and 2022). *Source*: INPE (2022).[1].

We propose a deforestation reduction model summarized in Table 2 based on the following assumptions: 1) For the period 2023-2030, an average annual reduction rate of 19% was proposed, similar to the 2005-2012 calibration period – which, as previously mentioned, had the highest observed reduction in deforestation rates; 2) Between 2031 and 2040, an average annual deforestation reduction rate of 9% was proposed, which represents approximately half of the calibration period rate; 3) For the final period, between 2041 and 2050, the model considered an average rate of 5% per year, corresponding once again to approximately half of the previous period rate.

Table 2 Deforestation reduction model in different scenarios (2030, 2040, and 2050).

Scenarios	Period	Annual Deforestation Reduction Rate (%)
Calibration	2005-2012	– 19%
A (Historical reduction)	2023-2030	– 19%
B (~ 50% of A)	2031-2040	– 9%
C (~ 50% of B)	2041-2050	– 5%

Source: Own elaboration.

1. The PRODES-Amazon released deforestation data up to 11/30/2022. Therefore, the data for December 2022 is not included in the information above.

The actual budget utilized to reduce deforestation from 11,651 km² in 2007 to 5,012 km² in 2014, totalizing approximately 6.6 million km², amounted to R$ 8.2 billion. This corresponded to public investment of around R$ 1.23 million per km² per year, and hence, was considered a benchmark in this study (Figure 4).

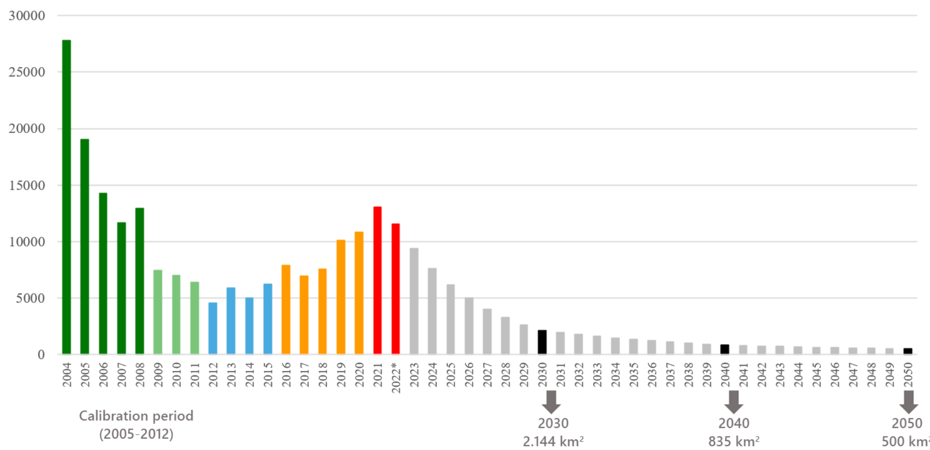

Figure 4 Deforestation reduction in 2030, 2040 and 2050. *Source:* Own elaboration based on INPE (2022).

According to the model presented in Table 1, the scenario for deforestation reduction between 2023 and 2030 predicts an average annual reduction rate of 19%, resulting in a decrease in deforestation from 11,568 km² at the end of 2022 to 2,144 km² by 2030, totalizing a reduction of 9,424 km². The estimated budget required to achieve this goal is approximately R$ 11.63 billion.[2] It is important to note that the original deforestation reduction rate of 19% was achieved during a period when the governance of the PPCDAm was primarily led by the Office of the Chief of Staff. During this period, ministerial integration efforts were coordinated directly by the government agency linked to the presidency of the republic (the head of the executive branch), providing significant institutional strength for implementing operational plans. Therefore, based on this study, it is assumed that the current governance against deforestation considers the relevance of this framework, at least until 2030.

Regarding the scenario between 2031 and 2040, where the average annual deforestation reduction rate is estimated at 9%, deforestation is reduced from 1,951 km² in 2031 to 835 km² by 2040, totalizing 1,116 km². The additional

2. The budgets (2023-2030; 2031-2040 and 2041-2050) have been estimated in nominal values. For more details, see the "Study limitations" section.

budget required to achieve this target is estimated at approximately R$ 1.32 billion. Finally, the scenario between 2041 and 2050 predicts an average annual reduction rate of 5% in deforestation, resulting in reducing deforestation from 793 km^2 to 500 km^2, totalizing 293 km^2. The estimated additional cost to achieve this goal is R$ 0.36 billion.

Table 3 Deforestation between 2004 and 2022 and estimation for 2030, 2040 and 2050.

Year	Deforestation (km^2)	Year	Deforestation (km^2)	Year	Deforestation (km^2)
2004	27772	2020	10851	2036	1217
2005	19014	2021	13038	2037	1108
2006	14286	2022*	11568	2038	1008
2007	11651	2023	9370	2039	917
2008	12911	2024	7590	**2040**	**835**
2009	7464	2025	6148	2041	793
2010	7000	2026	4980	2042	753
2011	6418	2027	4034	2043	716
2012	4571	2028	3267	2044	680
2013	5891	2029	2646	2045	646
2014	5012	**2030**	**2144**	2046	614
2015	6207	2031	1951	2047	583
2016	7893	2032	1775	2048	554
2017	6947	2033	1615	2049	526
2018	7536	2034	1470	**2050**	**500**
2019	10129	2035	1338		

Source: Until 2022, information was extracted from INPE (2022). From 2023 onwards, the elaboration was its own.

In summary, the total estimated cost for implementing the deforestation reduction policy, according to the proposed model, amounts to R$ 13.28 billion. However, considering the same inefficiency rate shown in Figure 1, of approximately 41%, the projected (budgeted) amount should exceed R$ 21 billion by 2050.

The discussion surrounding the availability of financial resources for the endeavor of deforestation reduction is a pertinent issue. The projected budget for the Ministry of Environment and Climate Change (MMAMC) in 2023 amounts to approximately R$ 3 billion, as indicated in the 2023 Budget Bill. Additionally, only a portion of this amount, approximately R$ 340 million, is allocated to the Program for Deforestation and Fire Prevention and Control in Biomes. However, additional financial sources can be directed towards environmental initiatives through federal government secretariats and subsecretariats, such as the Secretariat of Green Economy, Decarbonization, and Bioindustry, linked to the Ministry of Development, Industry, Trade, and Services, as well as the subsecretariats of Sustainable Economic Development and Sustainable Development Financing, both linked to the Ministry of Finance.

Table 4 Estimated cost (R$ billion).

Period	Estimated cost (R$ billion)	Budget type
2023-2030	11,63	Spent
2023-2030	18,55	Projected
2031-2040	1,32	Spent
2031-2040	2,19	Projected
2041-2050	0,36	Spent
2041-2050	0,57	Projected
Total cost	13,28	Spent
Total cost	21,17	Projected

An additional source of funding to combat deforestation in the Amazon is the immediate cancellation of the amnesty for environmental fines granted during the Bolsonaro government (2018-2022), which amounted to approximately R$ 18 billion, and the reinstatement of the fine and taxation system by environmental authorities. Additionally, plans to resume the foreign resources from the Amazon Fund would imply an estimate of at least R$ 3.6 billion for allocation to new projects (Bastos, 2023).

Strategies tied to potential actions in time and space to achieve zero deforestation in the Legal Amazon by 2030

While understanding and quantifying available financial resources is an important process for the operationalization of a public policy, it is necessary to incorporate different strategies to achieve the goal of Zero Deforestation in the Amazon. This involves prioritizing actions, maintaining or implementing well-established surveillance measures, and suggesting innovative mechanisms to combat deforestation. Here, we build upon the existing theoretical-economic model by proposing a second theoretical model based on the axes Deforestation Rate → Time (Figure 5). The 'complexity' (z-axis) in the theoretical model is considered a subjective vector, meaning that the difficult measurement of 'complexity' prevents us from stating that one priority action is 'more' or 'less' complex than another. However, we emphasize the importance of considering the 'complexity' as the proposed actions involve multiple factors for their effective implementation.

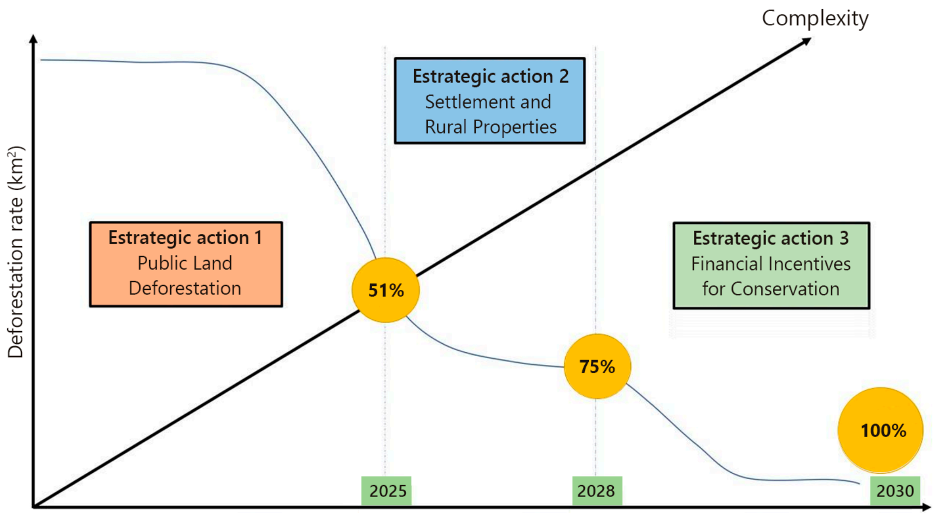

Figure 5 Representation of the theoretical model for achieving zero deforestation by 2030. The aim is to significantly reduce deforestation by 2030, employing different, non--conflicting, and complementary strategies from the present (2025) to 2030. Three distinct strategies have been defined to address the main drivers of deforestation in the Amazon (Strategies 1 and 2), leading to Strategy 3 (long-term | 2028-2030), which focuses on conservation incentives. These strategic actions are not mutually exclusive, which means that a specific action can (and should) be implemented simultaneously with another. For example, financial incentives are crucial for actions targeting the end of deforestation in Undesignated Public Lands (Strategic Action 1). Conversely, in the long-term perspective (2028-2030), strengthening the bioeconomy and nature-based solutions will be prioritized to enhance the biome's resilience against historical degradation drivers, such as deforestation.

The proposal, therefore, stems from identifying priority mechanisms to combat deforestation, such as identifying Conservation Units and Indigenous Territories that concentrate the highest deforestation rates, as well as focusing on Undesignated Public Lands (2023-2025) (Prioli et al., 2023; Qin et al., 2023; Moutinho & Azevedo-Ramos, 2023). It extends to the regularization and enforcement of the Rural Environmental Registry - CAR (2025-2028) (Azevedo-Ramos et al., 2020; Stabile et al., 2022; Bergamo et al., 2022), and includes complementary strategies that enable the achievement of the zero-deforestation goal, along with strategies to mitigate legal deforestation (Stabile et al., 2022). It also encompasses proposals for forest restoration (Gastauer et al., 2020), utilization of international funds, bioeconomy, nature-based solutions, and long-term public policies (Bergamo et al., 2022; Moutinho et al., 2016; Moutinho & Azevedo--Ramos, 2023).

Actions to combat deforestation

Strategic Action 1 – Deforestation in public lands

Brazil has approximately 56 million hectares (Mha) of Public Forests, areas designated for conservation and/or sustainable resource use, with nearly 92% concentrated in the Amazon region (National Registry of Public Forests, 2020). However, around 21% of the total Brazilian Public Forests remain undesignated. These areas lack regulation and can become targets for improper/irregular/illegal appropriation. Once again, it is in the Amazon region where the vast majority of undesignated Public Forests are found, accounting for about 50 Mha (Moutinho & Azevedo-Ramos, 2023).

The failure to designate these forest areas creates opportunities for land grabbing. According to the Rural Environmental Registry (CAR), which is self-declaratory, nearly 12 Mha (23% of the 50 Mha) of undesignated Public Forests in the Legal Amazon were irregularly registered as rural properties in the National System of Rural Environmental Registry (Azevedo-Ramos et al., 2020). Out of this total, around 8 Mha are in state-owned Public Forests, and 3.5 Mha are in federal Public Forests. A direct consequence of irregular self-declaration through the CAR is deforestation and the potential degradation of well-preserved areas (approximately 66% of the irregularly declared areas have been deforested). Moreover, there is a legal pretext that prohibits the occupation of rural properties located in federal public lands (i.e., land titling) without a specific purpose determined by the government (Law 11.952/2009). However, non-compliance with the law finds legal support due to Decree No. 10.952/2020. The decree assumes that any public forest can be designated for land regularization when the responsible entities for these areas do not explicitly manifest an interest in their designation (Brito, 2023).

Consequently, the first strategic action should involve combating the improper appropriation of self-declared state-owned Public Forests. This action would require command-and-control over erroneously self-declared areas, imposing legal and financial penalties, preventing and revoking requests for land regularization that overlap with Public Forests, and enforcing severe penalties for irregular entries through the Rural Environmental Registry. The amendment of Decree No. 10.592/2020 is also necessary. The second strategy focuses on direct intervention in the states with the highest deforestation rates in undesignated Public Forests in the Legal Amazon: Pará (56.5%), Rondônia (18.75%), and Amazonas (14.1%). By restricting illegal practices in these states, a greater reduction in deforestation can be expected as a whole.

The third strategy, finally, involves urgently allocating these undesignated territories to Conservation Units, Homologated Indigenous Territories, and/or Areas of Sustainable Use. Brito (2023) suggests that such undesignated federal Public Forests should be promptly converted into Areas of Provisional Administrative Limitation, which would then expedite their designation as Conservation Units. As indicated by the proposed economic model (Table 4), this strategy is estimated to cost at least R$ 3.5 billion, allocated between the years 2023 and 2025.

Deforestation in Protected Areas: The Importance of Indigenous Territories and Conservation Units in the Legal Amazon

The challenge of preserving and conserving forested areas in Brazil is immense. The Legal Amazon region covers more than 5.2 million km^2, with 83% of its area covered by forests (Prioli et al., 2023). Over half of the territory (52%) in the Legal Amazon is under some form of protected status, with 22% of the region being Indigenous Lands (ILs) and 30% consisting of Conservation Units (CUs) (Qin et al., 2023; Prioli et al., 2023). Among the CUs, 37% are designated as Strict Protection, while 63% are classified as Sustainable Use (Pacheco et al., 2018).

When properly implemented and managed, CUs and ILs act as shields against deforestation. Indeed, Qin et al. (2019) indicated that deforestation rates within Protected Areas (ILs and CUs) are 10 times lower than in unprotected areas. In terms of deforestation within CUs, it accounted for an average of 7.2% of the total deforestation in the Legal Amazon from 2008 to 2022 (Terra Brasilis/INPE, 2023).

Only three CUs (out of a total of 4,200) accounted for 71% of the deforestation that occurred in these areas between 2008 and 2022: (i) Triunfo do Xingu Environmental Protection Area (APA) (46%); (ii) Jamanxim National Forest (FLONA) (13%); and (iii) Jaci-Paraná Extractive Reserve (RESEX) (12%). In addition, in 2022, the Tapajós APA also stood out with 10% of the deforestation within Amazonian CUs (Terra Brasilis/INPE, 2023). It is worth noting that these four CUs are located in priority municipalities in terms of prevention, monitoring, and control of deforestation in the Amazon (MMA Ordinances 028/2008 and 361/2017) and were created during the first phase of the PPCDAm as a strategy to prevent deforestation (Table 5).

Table 5 Protected Areas with deforestation rates exceeding 10% within Legal Amazon Conservation Units during the period from 2008 to 2022.

Conservation units	Places (municipalities)	Establishment´s year	The managing organization	Management plan
Triunfo do Xingu environmental Protection area	Altamira (PA) and São Félix do Xingu (PA)	2006	Instituto de Desenvolvimento Florestal e da Biodiversidade do Estado do Pará (Ideflor-bio-PA)	There is no management plan available. The management council was established in 2011.
Jamanxim National Forest	Itaituba (PA) and Novo Progresso (PA)	2006	Unidade Especial Avançada do ICMBio de Itaituba – PA	The management plan was developed in 2010 and the management council was established in 2011.
Jaci-Paraná Extractive Reserve	Porto Velho (RO), Campo Novo de Rondônia (RO) and Nova Mamoré (RO)	1996	Coordenadoria de Unidades de Conservação CUC/SEDAM-RO	There is no management plan available. The management council was established in 2001.
Triunfo do Xingu environmental Protection area	Altamira (PA) and São Félix do Xingu (PA)	2006	Unidade Especial Avançada do ICMBio de Itaituba – PA	There is no management plan available. The management council was established in 2011.

Source: Elaborated by the authors. Note: The underlined municipalities are included in the list of priority municipalities for deforestation prevention, monitoring, and control actions (MMA Ordinances 028/2008 and 361/2017).

To develop effective strategies to combat illegal activities in CUs, we recommend the following:

- Development or updating of management plans for CUs, establishment (and strengthening) of management councils, and implementation of their respective management plans (projects that ensure the conservation objective).
- Assessment of the conservation impact and use of natural resources in Amazonian CUs.
- Land regularization of CUs, creation of new areas, and implementation of command-and-control mechanisms to cease illegal activities such as deforestation, hunting, illegal fishing, and mining.
- Ecological restoration of degraded areas.

- ♦ Strengthening the sense of belonging and contribution to social well--being in CUs. Involvement of local communities in CUs management, promotion of technical support and social capacity building for community management.
- ♦ Contribution to the establishment of sustainable and equitable bioeconomic models, with monitoring of the socioeconomic condition of Amazonians at the local level regarding employment opportunities, fair remuneration, and labor quality.
- ♦ Guaranteeing benefit-sharing according to the National Policy on Access and Benefit Sharing of Socio-biodiversity.

Preservation of Indigenous Lands (ILs), along with CUs, is crucial for the integrity of the forest (Sze et al., 2022), conservation of carbon stocks (Nogueira et al., 2018; Saatchi et al., 2011; Walker et al., 2014), maintenance of biodiversity (Fernández-Llamazares et al., 2021), climate regulation (Silvério et al., 2015; Baker & Spracklen, 2019), and preservation of the cultural diversity of indigenous peoples (Cunha & Almeida, 2000). Indigenous Territories in the Legal Amazon are part of the Public Lands system, with low absolute deforestation rates (3%) when compared to the accumulated deforestation in non-designated Public Lands. Approximately 58% of the Brazilian Legal Amazon is occupied by 352,000 indigenous peoples from 427 ILs, covering an area of 115,294,899 ha (Instituto Socioambiental, 2023). However, since 2013, deforestation in ILs has increased by 129%, with the highest deforestation (195%) occurring between 2019 and 2021 (Silva-Junior et al., 2023). Among all ILs in the Brazilian Legal Amazon, the Ituna/Itatá and Piripkura ILs experienced the highest illegal deforestation from 2019 to 2021 (Fellows et al., 2023). This scenario is primarily driven by illegal mining, which has increased from 1% in 2016 to 19% by mid-2022 (Silva-Junior et al., 2023). The political discourse during the Bolsonaro period (2019-2022) and the potential legalization of commercial mining in ILs (PL 191/2020), along with the increase in gold prices, may be behind this alarming situation (Siqueira-Gay et al., 2020).

Several studies have indicated that this 191/2020 bill could impact over 20% of the forest, resulting in a loss of at least US$5 billion per year due to the benefits provided by forest (Siqueira-Gay et al., 2020), leading to severe consequences for indigenous peoples, especially isolated groups at risk (Villén-Pérez et al., 2022). The bill would also have a negative impact on ecosystems (such as forest fragmentation, microclimate changes, biodiversity loss, trophic magnification, contamination of groundwater and water bodies, and carbon stock reduction), due to the creation of roads and urban centers generated by mining activities (Siqueira-Gay et al., 2020, 2022; Fellows et al., 2023).

According to Rorato et al. (2022), the most vulnerable ILs in the entire Brazilian Legal Amazon are located precisely in the Arc of Deforestation region, specifically in the Arc's southern part, as well as in Roraima and Pará (Rorato et al., 2022). The five most vulnerable ILs are (i) Tuwa Apekuokawera (PA); (ii) Praia do Índio (PA); (iii) Lagoa Comprida (MA); (iv) Urucu/Juruá (MA); (v) Rio Pindaré (MA). Dos Santos et al. (2022) identified the five ILs with the highest cumulative deforestation rates (from 1988 to 2021): (i) Alto Rio Negro (AM); (ii) Andirá-Marau (AM/PA); (iii) Cachoeira Seca (PA); (iv) Apyterewa (PA); (v) Alto Turiaçú (MA).

Other factors contributing to higher deforestation rates in ILs are forest fires and land grabbing. The former is mainly associated with mining activities and land grabbing on public lands (Fellows et al., 2021). Apyterewa and Kayapó (isolated groups) were the ILs with the most forest fires between 2018 and 2021, with a 50% increase in forest fires in Apyterewa IL in three years (Fellows et al., 2023). Land grabbing occurs through the self-declaration overlap strategy via the Rural Environmental Registry (CAR). In this case, landowners do not overlap in non-designated Public Lands but maintain this illegal strategy in Indigenous Territories. For example, the Ituna/Itatá and Tenharim do Igarapé Preto ILs had 94% of their territorial area overlapping with CAR, while the Piritti and Pirikura ILs had 56% and 22% overlap during 2018-2021 (Fellows et al., 2023). In 2019, the territory overlapping with CAR resulted in a 41% deforestation rate in ILs (Fellows et al., 2021).

Theoretically, ILs are protected by law. However, the lack of registration and territorial demarcation of ILs, along with the overlapping of Conservation Units and CARs, and the invasion by miners and land grabbers, make ILs vulnerable territories (Fellows et al., 2023). Therefore, to create strategies to combat illegal activities in ILs, we recommend:

- Strengthening Indigenous Land Rights (Article 231) and suspending any regulations that undermine the rights of Indigenous peoples (PL 191/2020).
- Registration of Indigenous Lands (ILs) and cancellation of all Rural Environmental Registrations (CARs) within ILs.
- Implementing rigorous command-and-control policies in ILs, removing illegal miners and land grabbers, and imposing substantial penalties for those who violate the law.

- Empowering the representative power of FUNAI, IBAMA, Federal Police, and the Federal Public Ministry.
- Developing social, biotechnological, and ecological projects that demonstrate the crucial role of indigenous peoples in preserving the integrity of the Amazon Rainforest, climate, biodiversity, and the bioeconomy of Amazonian natural products.
- Establishing sustainable projects that address not only contaminated water but also include the practice and education of bioremediation for polluted soils and plants.
- Creating an Emergency Rescue Program for isolated indigenous peoples residing in high-risk areas, with the support of the Federal Police and FUNAI, particularly through brigades.
- Assigning annual investments of approximately R$1 billion for the maintenance, establishment, and allocation of Indigenous Territories and Conservation Units.

Achieving zero deforestation in Protected Areas and ILs begins with identifying key areas with the highest deforestation and vulnerability rates and consistently investing and allocating resources, amounting to R$1 billion annually between 2023 and 2025 (Table 4). Unlike Undesignated Public Lands, which account for 30% of all deforestation in the Legal Amazon, the complexity and timeline to achieve zero deforestation in these protected areas should be lower, yielding positive results in a shorter timeframe. A combination of top-down strategies, such as command-and-control, rigorous enforcement, an end to environmental fine forgiveness, maintenance, establishment, demarcation, regularization, and implementation of Protected Areas/Indigenous Lands, along with bottom-up strategies, including support for socio-economic alternatives in ILs and Protected Areas, particularly Sustainable Use Conservation Units and Extractive Reserves (Pacheco et al., 2018), and strengthening collaborative management by traditional communities (Freitas et al., 2020), can enable the ambitious reduction of up to 51% of deforestation by 2030.

Strategic Action 2 – Settlements and Rural Properties

A significant portion of illegal deforestation in the Amazon Rainforest is linked to the production chain of beef and soy in rural settlements and private properties. In rural settlements, although these supply chains account for 20% of the total deforestation, over 50% occurs in only 10 settlements (Alencar et al., 2016). Moreover, among the deforested areas in rural properties registered in the Rural Environmental Registry (CAR) by 2020, 45% did not comply with the Forest Code legislation due to inadequate preservation of Permanent Protection Areas (APPs) and Legal Reserves, largely driven by illegal deforestation for pastureland (Rajão et al., 2020). Researchers estimate that around 48% of all beef and 22% of all soy exported to the European Union (EU) are linked to illegal deforestation in the Amazon, despite the soy moratorium agreement. In addition to incomplete property registration in CAR, especially regarding illegally seized lands, difficulties in the traceability of export products pose serious risks to monitoring the international trade chains of Amazonian products (Rajão et al., 2020). This suggests that control and monitoring mechanisms for the origin of export products are insufficient to identify and combat production chains associated with deforested areas.

These data impose serious risks to commodity exports to the EU, considering the potential advancement in the Mercosur-EU agreement sought by the third term of the Lula government. The current government has shown commitment to curbing deforestation and combating environmental crimes, receiving support from countries such as Germany, France, Norway, and likely the United States, as financiers of the Amazon Fund, to strengthen Brazil's commitment to international agreements. An initial measure by the new Minister of the Environment, Marina Silva, was to restore and restructure the PPCDAm, a successful program in reducing deforestation in the past (Sousa-Junior et al., 2021) but deemed insufficient in this new post-Bolsonaro scenario to achieve President Lula's electoral promise of zero deforestation in the Amazon by 2030 due to additional carbon emissions linked to increased droughts and wildfires (Aragão et al., 2018).

Given this new scenario, our proposal to combat illegal deforestation in private properties and rural settlements focuses on medium-term measures (from 2025 to 2028) for allocating resources dedicated to complementary actions to the PPCDAm. Therefore, we recommend the following:

- Law enforcement and punishment for offenders.
- Remediate environmental damages caused.
- Increase transparency in the supply chain and hold corporations accountable for using products linked to illegal deforestation.
- Strengthen the PPCDAm and CAR in private properties and rural settlements, while providing financial incentives to landowners who comply with Forest Code legislation, in conjunction with restricting access to credit for those who fail to comply with the PRAD (Recovery Plan for Degraded Areas).

- Enhance and expand the capacity of international markets to monitor the origin of commodities produced in the Amazon and broaden mechanisms for product embargoes resulting from deforestation (Golnow et al., 2018; Alix-Garcia & Gibbs, 2017).
- Allocate a portion of the Amazon Fund resources to implement technologies for identifying the origin of exported beef and soy through genetic monitoring.
- Invest at least R$3.5 billion from 2023 to 2028, particularly to achieve the projected reduction target of up to 75% of deforestation (Figure 5).

Strategic Action 3 – Financial Incentives for Conservation

The economic development model in the Amazon has so far been based on resource extraction and exploitation, which has historically resulted in socio-economic and environmental problems. In summary, the future bioeconomy strategy for Amazon should go beyond its forest products/resources. However, as indicated by our theoretical model (Figures 5 and 6), reconciling the advancement of the bioeconomy with zero deforestation in the Amazon will be of very high complexity.

The Amazon represents a vast territory with a low density of educational institutions, research facilities, and technological centers for the improvement of existing production chains. This technical assistance bottleneck, however, can be utilized to create new jobs and attract qualified personnel to the region, fostering the establishment of companies and government institutions. Initiatives such as the Amazon Institute of Technology (AmIT) seem to present a promising path in this regard. Achieving zero net deforestation in Private Protection Areas (APPs) and Legal Reserves in private properties and settlements will depend on strengthening command-and-control strategies, territorial planning, and land regularization, as seen in the first three phases of the PPCDAm. Simultaneously, investments are needed in the exploration of biotechnological derivatives from the immense biodiversity of the Amazon, financing for the bioeconomic transition, sustainable intensification of agriculture, promotion of low-carbon agriculture, agroforestry systems, including the possibility of reforestation with economically valuable species, and other nature-based solutions.

In this stage (2028-2030), the focus of strategic actions will be on advancing the transition to a bioeconomy, which will be facilitated by a net reduction in deforestation of up to 70% compared to the current projection for 2023. With the drastic reduction in deforestation, it is imperative to base the bioeconomy strategy on the sustainable exploitation of non-timber forest resources, such as açaí, Brazil nuts, and andiroba, as well as sustainable management of pirarucu fish (Freitas et al., 2020). The bioeconomy of the Amazon should incorporate its key stakeholders in the use and management of these resources: traditional communities, such as riverine dwellers and/or chestnut gatherers, as well as indigenous peoples. According to Nobre et al. (2021), Amazonian citizenship can be a key element for the development of the Amazonian bioeconomy, combining traditional knowledge and scientific research. Although we consider this stage as the final one among the strategic actions (Figure 5), we acknowledge that the bioeconomy must be strengthened through public policies, cultural diversity, and product diversification, particularly non-timber products, and that investments must be continuous. The path to achieving zero residual deforestation from 2030 onwards, therefore, requires investments of approximately R$10 billion. This amount should be seen as a cost of opportunity compared to the numerous projected impacts if deforestation reaches a point of no return (Nobre et al., 2016), especially if the 40% threshold of the total Amazon area for deforestation is breached.

Finally, we strongly advocate for the implementation of a highly intricate final stage, as it is crucial to understand and embrace the significance of financial incentives within the Amazon region, particularly through the lens of the bioeconomy. This endeavor requires the robust fortification of public policies, active engagement of the diverse Amazonian cultural heritage, non-timber product diversification, and that the public policy framework equally favors the different actors in this policy/strategy towards zero deforestation.

Final remarks

Despite the enormous challenges in achieving zero deforestation by 2030, the proposed model (Figures 5 and 6) presents an unprecedent approach by combining projected and actual government budgets aligned with top-down and bottom-up strategies. The three different strategies were designed with the aim of providing guidance and suggestions for public agents to promptly identify the main drivers of deforestation and public policies to be fought and/or implemented to achieve the proposed goals for 2025, 2028 and 2030. It is worth noting, however, that these strategies are not mutually exclusive. Under an effective governance/policy proposal, it is possible (and even recommended) for them to be implemented concurrently.

To fully realize the effectiveness of the proposed models (i.e., economic-theoretical model), various government challenges need to be addressed, such as changes in environmental and social legislation, land demarcation, and the adoption of rigorous measures against illegal actions. In addition to these measures, new complementary strategies, such as increased financial incentives for the conservation of the Legal Amazon, massive ecological restoration and mapping for the suspension of credit in the national financial system for owners involved in environmental and social illegalities, for example, should be implemented. By highlighting the increasing complexity of decision-making with multiple strategies over time, the model presented in this study serves as an analytical tool, capable of contributing to concrete actions at different scales, urgencies, and intervention intensities to achieve the ambitious goal of zero deforestation by 2030.

Study limitations

The first limitation of this study pertains to its development. This essay was the result of a theoretical-practical exercise proposed at the São Paulo School of Advanced Science (ESPCA) during two weeks between November and December 2022. The authors do not aim to propose a state-of-the-art model on the subject, but rather to present arguments and proposals for the debate to be expanded and discussed in various sectors of Brazilian society.

In addition, it is important to note the attempt to estimate the financial costs of deforestation reduction. Besides the already demonstrated difficulty in gathering the costs incurred in the PPCDam between 2005 and 2022, estimating the future value until 2050 is also problematic. To perform a valuation of the future, that is, to estimate the Net Present Value (NPV), mainstream economics advocates for the use of an Intertemporal Discount Rate as a cost-benefit analysis tool. Researchers in Ecological Economics, who question the environmental perspective of conventional economists, debate whether a higher or lower discount rate could favor the environment (Daly & Farley 2016). In terms of evaluating future projects, a high discount rate favors projects with costs primarily in the future and profits in the present, while penalizing those with current costs and future profits, as is the case with the present deforestation reduction model.

To avoid discussing whether the discount rate was underestimated or overestimated, the authors of this study chose to estimate the costs in nominal values, that is, without using a pre-established intertemporal discount rate.

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Ethics – This study does not involve human subjects and/or clinical trials that should be approved by the Institutional Ethics Committee.

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Why *not* continue building hydroelectric dams in the Brazilian Amazon? Contributions to a renewable and effectively sustainable electricity matrix

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ABSTRACT

The generation of electricity through large hydroelectric projects is often regarded as a renewable source; however, its sustainability is questionable. In the Amazon, these projects pose severe threats to the ways of life of indigenous and traditional communities, as well as causing significant damage to the region's fauna and flora. Paradoxically, while local populations lack access to electricity, the eletricity production in the Amazon is primarily directed to other regions of Brazil. This article proposes a critical analysis of the construction of hydroelectric projects in the Brazilian Amazon, starting from the fundamental question: **Why *not* continue building large hydroelectric projects in the Brazilian Amazon?** Based on this, we detail the ideal scenario – that being unattainable - in which such a possibility would exist. The elements of this scenario would include: (1) Ensuring zero deforestation, (2) Providing effective compensation to directly or indirectly impacted human populations, (3) Conducting ecological restoration, (4) Considering future climate scenarios, (5) Maintaining the natural flood pulse of the river (flow regime), (6) Ensuring the autonomy of the directly or indirectly affected population to decide on the construction of a hydroelectric project, and (7) Preserving the degree of endemism of the local fauna and flora. However, an analysis of ongoing, under-construction or planned projects reveals these criteria are not fully respected and cannot be fulfilled. This renders the construction of hydroelectric projects in the Brazilian Amazon unviable. To ensure access to electricity in isolated areas of the Amazon, we recommend directing investments towards more sustainable energy sources characterized by lower social and environmental impacts through small-scale production.

Keywords: Amazon, clean energy, energy policy, social justice, environmental impacts.

Introduction

The increasing expansion of hydroelectric dams represents one of the main threats to biodiversity and the livelihoods of populations in the Amazon region, whether in urban or rural areas (Couto *et al.* 2021). The global expansion of hydroelectric projects is often seen as an alternative to fossil fuels (Almeida *et al.* 2022) and as a renewable energy source, which is supposed to contribute to tackling climate change (Fearnside 2019a). This expansion occurs mainly in countries with emerging economies, and the justification is the energy demand to guarantee their economic and social development (Zarfl *et al.* 2015). In South America, the enormous hydropower potential of the world's largest rainforest makes the Amazon basin a theoretically ideal stage for expanding new hydropower (Almeida *et al.* 2019). Although exact numbers vary (Fearnside 2019b), at least 158 dams with individual installed capacities greater than 1 MW are operating and/or under construction in the five nations that make up about 90% of the Amazon basin, and another 351 new dams are in the feasibility study phase (Flecker *et al.* 2022, see Figure 1).

The construction of large hydroelectric dams in the Brazilian Amazon has significance for transnational politics in South America, as large areas are impacted, not limited to Brazil alone, but also affecting neighboring countries (Fearnside 2019a). Governments worldwide are making decarbonization pledges, with ambitious goals for emissions reductions and carbon capture (Mountford *et al.* 2021). In this scenario, Brazil claims to have a "clean" electricity matrix as it produces about 62% of its electricity from hydropower (ANEEL 2023). This discourse fuels the belief that hydroelectric dams are the best renewable source solution, concealing the seriousness of the negative socio-environmental impacts caused by hydroelectric mega-projects (Fearnside 2013, 2017). In the Brazilian Amazon, large projects such as the Santo Antônio and Jirau dams in Rondônia and Belo Monte in Pará are emblematic examples of the significant social and environmental damage caused in the Madeira and Xingu River basins, respectively (Couto *et al.* 2021).

The impacts of hydroelectric dams on the fauna and flora's biodiversity and local populations are underestimated in the Environmental Impact Assessments (EIA) carried out in the licensing process (Fearnside 2019c). During construction, traditional peoples are displaced, local populations are destabilized, and forests are removed or flooded alive to form reservoirs, harming aquatic fauna, due to increased decomposition, methane release, and reduced oxygen and food availability (Souza Jr *et al.* 2019). For years after the installation of the hydroelectric plants, the impacts continue to occur and expand, causing deforestation in the surroundings, massive mortality of flooded forests downstream (caused by disturbances in the hydrological cycle), and consequently, increases in greenhouse gas emissions. In addition, it results in health problems for riverine people living along the large rivers, leading to resource shortages (Fearnside 2014, Lees *et al.* 2016, Resende *et al.* 2019, Schöngart *et al.* 2021, Silvano *et al.* 2005).

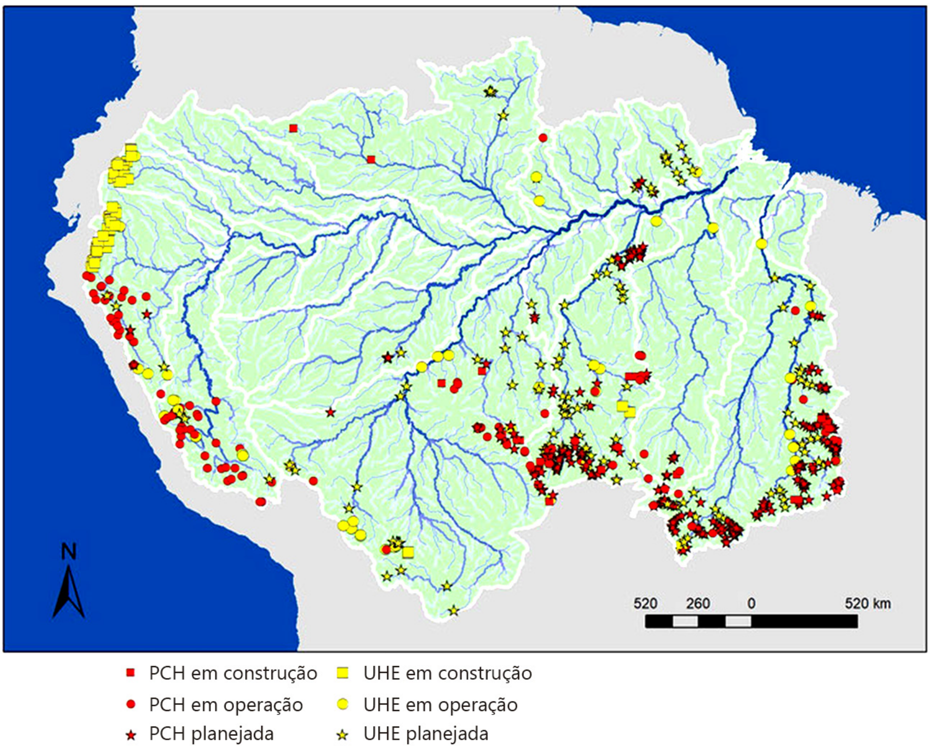

Figure 1 Illustrative map indicating hydroelectric enterprises in the Amazon Basin. Prepared by Thiago Couto. Available at: https://amazoniacienciaciudadana.org/pt/impactos-pequenas-hidreletricas/

Hydropower produced by the standard method in Brazil may be renewable, but it is far from sustainable. In order to produce energy through conventional hydroelectric plants, it is necessary to convert the mechanical energy generated by the passage of water through the turbines into electrical energy, and there must be a difference in the water level to activate the movement of the turbines (Bagher *et al.* 2015). Less impactful models, such as the "run-of-river" type installed in the Santo Antônio and Jirau hydroelectric plants and in Belo Monte, use the river current to generate energy, but precisely because they do not have large reservoirs, their electricity production is reduced during periods with low rainfall (Roberts 1995), which in parts of the Amazon can last up to seven months per year (Carvalho *et al.* 2021, Sombroek 2001). Another relevant point is that a significant part of the production of large hydroelectric plants in the Amazon is directed to other regions

The energy produced in the Amazon, and exported to other regions of the country, carries high economic, social, and environmental costs that are shifted onto the local populations, fauna, and flora (Randell & Klein 2021). At the same time, a recent survey found that Amazon has more than 990,000 people without access to electricity, with Pará being the state with the highest number of people without access to electrical energy (more than 409,000 residents) and Acre the one with the highest proportion of victims of electrical exclusion, affecting around 10% of its population (IEMA 2020). These excluded people lack the energy to carry out their daily activities, such as freezing fish or fruit pulp for their consumption or sale, studying, and accessing information via TV and/or the internet.

This white paper, produced by the working group "Free Waters" of the São Paulo School of Advanced Science Sustainable and Inclusive AMAZON (São Pedro-SP, Brazil – November 21 to December 5, 2022), analyzes the impacts of hydroelectric projects in the Amazon and elaborates an ideal scenario, never fulfilled and impossible to be achieved, for the construction of new projects, showing, in practice, why hydroelectric plants should not be built in the Brazilian Amazon. The white paper is complemented by a communication piece addressed to the Brazilian population, with crucial data and information regarding the impacts and costs involved in maintaining and constructing new large hydroelectric plants in the Brazilian Amazon.

Economic, ecological, and social impacts of large hydropower plants in the Brazilian Amazon

Hydropower is currently considered the largest source of renewable energy worldwide, playing an important role in clean, low-carbon development (Li & He 2022) and propelling development in the economy of the global power industry (Edwards 2005). This statement, however, does not comprise the whole truth since hydropower plants emit large amounts of carbon (Bertassoli Jr *et al.* 2021, Fearnside 2009), and the efficiency of energy production can be relatively low, as in the case of the Balbina hydropower plant (Fearnside 1995). Building a hydropower plant is expensive, and most developments take longer than expected. In addition, hydropower causes unquestionable negative environmental and social impacts, especially in the Amazon, given its richness and plurality of fauna, flora, and socio-cultural characteristics (Moran *et al.* 2018). This section will present the main economic, ecological, and social impacts of large hydroelectric dams in the Brazilian Amazon.

Economic impacts

The actual costs of hydropower construction are difficult to measure due to the particularity of the installation region's geology, hydrology, and associated ecosystems and social factors. However, it is given that large hydropower developments usually exceed the estimated economic costs (Ansar *et al.* 2014, Sovacool *et al.* 2014). A global hydropower construction report analyzed 245 large dams from 1934 to 2007 in 65 countries, showing that one in 10 dams cost more than three times the amount initially estimated (Ansar *et al.* 2014).

The cost of building large hydroelectric dams tends to be very high, limiting the positive return on investment, even without considering the project's socio-environmental impacts (Scudder 2006, Sovacool *et al.* 2014). For example, the Belo Monte hydroelectric plant had an initial budget of 19 million reais (Machado *et al.* 2011), however, by the year 2019, its cost had already risen 42 billion reais, with the activation of the 14th turbine of the Main Powerhouse. Belo Monte became the largest hydroelectric plant in Brazil, providing a capacity of 8,788.5 MW and becoming the largest investment project of the Brazilian government in the last two decades (Agência Brasil 2019). Due to the fluctuations in the level of the Xingu River and the installed "run-of-river" system, the capacity factor (physical guarantee or guaranteed capacity) is around 43% of the installed capacity for energy production (Almeida Prado *et al.* 2016). Therefore, the actual average production is 4,571 MW and not 11,223.1 MW (Norte Energia 2021, 2022). Only in 2019, four years after the start of Belo Monte's operation, the hydroelectric started operating with all turbines, having produced an average of 3,445.8 MW in 2020 and 2021, which corresponds to about 75% of the guaranteed capacity (Norte Energia 2021, 2022). Because of the Xingu River's seasonality, production is considerably reduced in the drier months, with Belo Monte producing an average of 431 MW in September 2021, less than 11% of the guaranteed capacity (Norte Energia 2022).

Arguments in favor of building hydroelectric dams are usually based on the country's growing demand for electricity. The national electricity demand is projected to grow by 2.2% per year until 2050 (PNE 2050). However, given the country's current economic situation, this estimate is overestimated and does not align with the projected growth. Current energy demand can be met with 48% of energy production capacity (Tolmasquim *et al.* 2021). Thus, constructing new hydroelectric plants in the Amazon with the primary justification of energy demand is misguided. The construction of hydroelectric dams and their economic viability need to be reassessed, especially considering their negative socio-environmental impacts..

Ecological impacts

Disruption of the natural flow of rivers impairs hydrological connectivity (Vannote *et al.* 1980), changing the dynamics and composition of aquatic and terrestrial communities at both local and regional levels (Fearnside 2013). In addition, this interruption of rivers results in changes in the physical, chemical, and biological characteristics of the aquatic environment and ecosystems at the terrestrial-aquatic interface in areas adjacent to hydropower plants (Fearnside 2019a). River impoundment affects environmental conditions upstream (i.e., new habitat within the reservoir) and downstream (i.e., altered water flow regime) of the dam, fragmenting longitudinal and lateral flood connectivity (Arantes *et al.* 2019). Altered hydrodynamics occur along with changes in the water chemistry of impoundment lakes, with excess river sedimentation that not only impacts hydropower production - due to loss of reservoir storage and/or damage to mechanical components of the facility - but also the environment (Fearnside 2013). Increased sedimentation upstream of hydropower dams leads to environmental effects that can persist for decades (Junk & Mello 1990). Sedimentation can culminate in turbid waters with reduced water transparency, decreasing plant productivity and negatively impacting fish and bird species (Melo *et al.* 2021).

In addition to changes in the chemical, hydrological and nutritional balance in the aquatic system and terrestrial-aquatic interface, the installation of hydroelectric plants generates Greenhouse Gas (GHG) emissions. GHGs are produced during the construction and operation of hydropower plants (Fearnside 2015). These emissions vary significantly depending on the size of the reservoir and the nature of the land flooded. Flooding causes increased vegetation decomposition and release of carbon dioxide and methane. The precise number of emissions is highly dependent on site-specific characteristics. However, GHG emissions from the water surfaces of the world's reservoirs are estimated to be 0.8 (0.5-1.2) Pg CO_2 equivalent per year, with methane (CH_4) accounting for the majority of this emission (Deemer *et al.* 2016).

Hydroelectric dams are also responsible for changes in the phenology and life cycle of tree species in flooded forests, causing massive mortality or relocation of communities downstream of the dam (Resende *et al.* 2019, 2020, Schöngart *et al.* 2021). This impact is caused by the irregular flow of water that eliminates predictability and changes the amplitude of the overflow effect of the river to the banks (flood pulse), leaving vegetation exposed to a new water condition. In addition, local populations of aquatic and terrestrial animals along the river may suffer from a reduced quality of available habitats, leading to the extinction of endemic species and changes in fauna composition (Fearnside *et al.* 2021).

For fish, the abrupt shift from lotic (river) to lentic (lake) environments with the construction of hydropower reservoirs results in adverse effects on abundance and taxonomic and functional richness (Keppeler *et al.* 2022). Hydropower construction raises the risk of extinction of endemic species that depend on maintaining local hydrological dynamics (Fitzgerald *et al.* 2018, Latrubesse *et al.* 2020, Zuanon *et al.* 2020). For example, long-migrating fish species are severely affected after the construction of hydroelectric dams, given the need for connectivity along the river to complete their life cycle, with the impoundment being a barrier that interrupts reproductive migrations (Duponchelle *et al.* 2021). Because of these processes, fish production tends to be drastically reduced after the construction of hydroelectric dams, especially of migratory species of high commercial value, which leads to a reduction in fishing income (Arantes *et al.* 2022, Lima *et al.* 2020). The impacts on fishing, therefore, also lead to harmful consequences for social dynamics, which are addressed below.

Social impacts

A series of cases analyzed by researchers, traditional peoples, and civil society organizations illustrate the severe impacts on the livelihoods of populations in regions flooded or downstream of hydroelectric dams in the Amazon region. Even if we consider only the Tucuruí, Balbina, and Belo Monte hydroelectric dams, there are notable examples of forced removal or compulsory displacement of populations, including indigenous peoples who had territories flooded or indirectly impacted by the reservoirs, in addition to severe health impacts, whether due to mosquito proliferation or mercury methylation, loss of food security and sovereignty or increased indicators of suicide and violence, especially against women (Barroso 2019, Brum & Glock 2020, Fearnside 2019a).

A series of irregularities in the licensing processes are associated with the social impacts of hydroelectric dams and the decision-making process that precedes them (Fearnside 2019c). The case of Belo Monte is again emblematic: In 2022, the Federal Supreme Court finally recognized that there was no widespread public consultation, with the necessary clarification of potential socio-environmental impacts - many of them severe and difficult to reverse - nor the necessary debate with society, as provided for in the Brazilian Constitution of 1988 and ILO Convention No. 169, to which Brazil is a signatory. In short, it is concluded that projects such as the Belo Monte hydroelectric dam are direct causes of ecocide and ethnocide (Observatório da Volta Grande do Xingu 2023).

The construction of hydroelectric power plants generates direct impacts on the quality of life of riverine populations, including health problems stemming from feelings of frustration, fear, and helplessness among those affected (Fearnside 2017, 2019a). Therefore, it is necessary to broaden health discourse and create room for interventions to be structured in order to consider those affected by hydroelectric power plants as empowered political subjects (Giongo *et al.* 2015). There is a need to incorporate and identify, within studies of impacts associated with the construction of hydroelectric power plants, the impacts on the quality of life of the affected populations (Grisotti 2016). Few research and evaluation programs longitudinally track the pre and post-installation processes of hydroelectric power plants., and there are few studies assessing health status beyond purely medical aspects, which is aggravated by the lack of official health data on affected populations (Grisotti 2016). Studies that consider assessing the impacts of hydroelectric projects on the population's health are fundamental, as they assist in decision-making regarding project proposals that integrate health promotion and prevention of health issues. Such studies can also contribute to the development of programs and public policies focused on the health of the affected population, based on integrated models that encompass economic, political, social, and environmental aspects (Okochi & Marques 2019).

Current government guidelines and growth trends in the electricity sector

According to the National Energy Plan for 2050 (PNE-2050, 2020), Brazil bases its energy production expansion planning on four fundamental pillars: energy security, adequate return on investment, availability of access to the population, and socio-environmental criteria. Although the fourth pillar, related to socio-environmental criteria, is mentioned, its approach in the plan must include further analysis.

One of the goals set in the PNE is Brazil's transition from an energy-importing country to an energy-exporting country. However, this goal raises concerns as it may exacerbate existing disparities in access to clean energy rather than focusing on ensuring such access for isolated communities. This transition would mean a reallocation of energy produced in one location to be transferred to other countries, potentially widening energy injustice.

The plan also foresees an increase in energy efficiency, with a growing interest in the electrification of the energy matrix. In addition to electrification, the PNE establishes guidelines for decarbonization and the pursuit of low-carbon energy sources. In Brazil, there is an adherence to the global trend of adopting more sustainable renewable energy sources, driven by the decline in costs of solar and wind energy generation technologies.

However, contrary to this discourse, the plan also foresees the expansion of the hydropower sector in Brazil (PNE-2050, 2020). More than 100% increase in hydropower production is planned through the modernization and repowering of old plants and the construction of already inventoried plants. This expansion comes amid a worrying 77% overlap of inventoried hydroelectric plants with protected areas in the Amazon. The Bem Querer, Castanheira, and Tabajara power plant projects are already underway (PNE-2050, 2020), which are part of these expansion plans in the Amazon region.

Hydropower construction: an ideal scenario never fulfilled

In order to highlight why we should not continue to build hydroelectric plants in the Brazilian Amazon, we have drawn up a summary of our proposal, presented in Figure 2. These guidelines or limiting criteria show the non-viability of building new hydroelectric projects. As previously pointed out, if these criteria are never respected in practice, it is not possible to continue building new hydroelectric plants in the Brazilian Amazon. In addition, the modernization and review of projects already in operation should follow these same criteria as far as possible. Next, we suggest some alternatives for electricity generation in Brazil, especially in the Amazon.

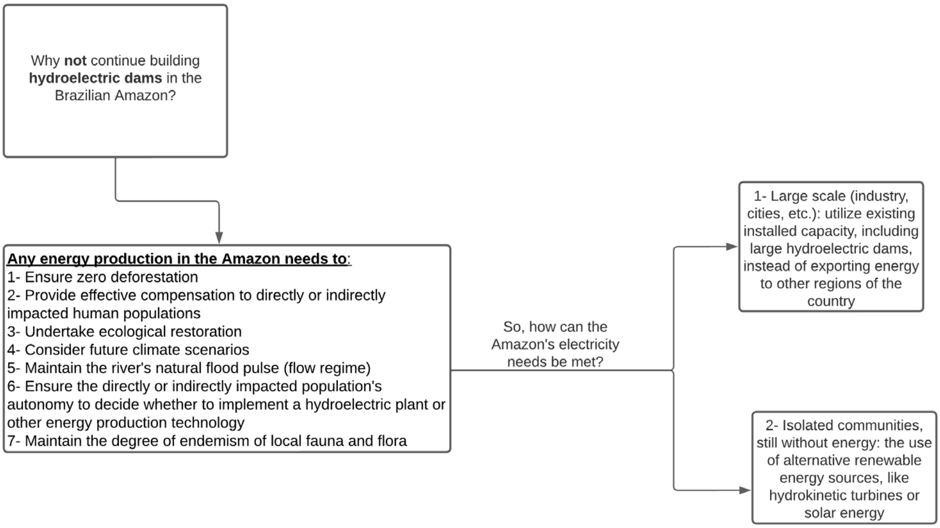

Figure 2 Why does it not make sense to continue building large hydroelectric dams in the Brazilian Amazon? Justifications and proposed intervention.

Ensure zero deforestation

Every enterprise brings environmental impacts (Barbosa Filho *et al.* 2015). Although several studies show a clear association between the construction of hydroelectric dams and increased deforestation (Barreto *et al.* 2011; Fearnside 2014, Nickerson *et al.* 2022), strategies that seek to mitigate or compensate for the loss of vegetation cover in the vicinity of hydroelectric dams are still little explored and rarely included in the planning of new projects. With this in mind, we propose the "zero deforestation" criterion, which consists of restricting any loss of native vegetation cover near hydropower plants.

As a strategy, hydroelectric projects should prioritize the creation of conservation units and indigenous lands to minimize predatory occupation around reservoirs (Silva Júnior *et al.* 2018). This criterion aligns with resolutions 10/1987 and 02/1996 of the Brazilian Environmental Council (CONAMA), which establish that licensing large environmental impact projects requires implementing a protected area in the public domain. In addition, it is essential to discourage occupation through settlements and the opening of roads, as these variables are key to increasing deforestation rates through, for example, the conversion of forests into plantation areas and cattle ranching (Fearnside 2005).

It is also suggested the establishment of methodologies for monitoring compliance with this criterion in projects already in operation. A possible methodology could be based on the definition of a radius of the impact of a hydropower plant (e.g., 120 km radius, see Resende *et al.* 2019) and the establishment of a reference forest cover (e.g., MapBiomas), based on the year in which the construction of a hydropower project is approved. In addition, a time horizon for annual monitoring should be established. In this case, an example would be: within the vicinity of a project (120 km radius), there are 30,000 km² of forest cover in the year 1989 (when construction begins); therefore, over the next 30 years, this cover should remain stable or increase, with the replacement of mature forests by young forests being unacceptable. Monitoring should be done by a reputable organization (e.g., MapBiomas).

Provide effective compensation to directly or indirectly impacted human populations

The removal of local populations occurs to make room for the construction of hydroelectric dams, either for the powerhouse (where power generation takes place), for the construction of water containment dikes or even due to the rise in the level of the river upstream, directly affecting riverside populations and urban areas on the banks of the rivers (Mayer *et al.* 2021). Population displacement is associated with significant social impacts produced by hydroelectric dams in the Amazon. This happens because the removal of populations from their original location results in these populations losing neighborhood relationships, connections with family members, and even their sources of subsistence (Mayer *et al.* 2022). Such problems are familiar and specific to the construction of hydroelectric dams in the Amazon. Studies around the world have already shown that population displacement is harmful to local populations, being associated with the loss of social capital in China (Tilt & Gerkey 2016), loss of agricultural land and livestock in northern Iran (Tajziehchi *et al.* 2013), impoverishment of the population in India (Cernea 2004) and growth of social inequalities in Vietnam (Huu 2015). It is important to note that these processes take place in developing countries, as it is in these regions that the expansion of hydroelectric construction is occurring, while developed countries have invested in harnessing their hydroelectric potential in the past and are now turning to alternative energy sources, potentially less harmful to the environment and the population (Moran *et al.* 2018).

In an ideal scenario, no infrastructure project in the Amazon could carry out compulsory population displacement. In this way, the main cause of the social impacts of hydroelectric dams in the Amazon would be extirpated. This scenario, however, does not find a basis in reality. Thus, the minimum to be guaranteed is that the local populations must consent, for the most part, to the construction of the enterprise, through effectively participatory and democratic processes and that they must be brought greater social and economic benefits than harm. Thus, local populations must be duly compensated for the impacts generated by the construction of hydroelectric plants, and such compensation must occur before the installation and effective operation starts, which was not the case, for example, of Belo Monte (Gauthier & Moran 2018).

However, there are rare studies that show some success in the process of providing compensation to local populations impacted by hydropower construction (Randell 2016). Compensation programs are often unavailable to all impacted population groups, especially downstream of dam construction (Castro-Diaz *et al.* 2018, Richter *et al.* 2010, Zhouri & Oliveira 2007). In addition, some losses resulting from hydropower construction are difficult to quantify, such as social capital, emotional ties to the site, and cultural heritage, so these are rarely included in compensation programs (Green & Baird 2016, Vanclay 2017).

As long as compensations are *pro forma,* in order to secure the installation license from the Brazilian Institute for the Environment and Natural Resources (IBAMA) and subsequently renew the operating licenses of hydropower plants, such programs will remain ineffective in terms of ensuring real and permanent improvement of life for impacted populations.

Undertake ecological restoration

Forest restoration has been promoted as the most effective solution for climate change mitigation due to the rapid storage of carbon in biomass at lower costs than available technological alternatives (Bastin *et al.* 2019, Griscom *et al.* 2017, Lewis *et al.* 2019). Restoration programs with bold goals have been established in Brazil and worldwide, in line with the decade of restoration proposed by the United Nations. The maintenance of several ecosystem services essential to the well-being of the population, such as the protection of springs and the production of forest goods, is of profound social and economic interest, and restoration is one of the main solutions for obtaining these services (Brancalion *et al.* 2019). Scaling up forest restoration brings immediate scientific and technological challenges since it has been developed as a local-scale activity, mostly planned, implemented, and monitored at the plot level (Holl 2017).

In addition to ensuring zero deforestation, hydropower projects should commit to restoring areas under their region of influence (e.g., 120 km radius), including areas that were converted before or during the project's period of operation. A maximum acceptable percentage of the area that can be restored should be established in advance. For example, every time there is an area larger than the value established by law for an alternative use area (e.g., 20% for the Amazon, since 80% must constitute the Legal Reserve and Permanent Preservation Areas in forest areas in the Legal Amazon), except in urban areas, within the radius of influence of the hydroelectric plant, ecological restoration of the original ecosystems must be carried out.

Considering future climate scenarios

Historically, most hydropower risk assessments have assumed a steady state in the variability of climate phenomena, including the frequency and magnitude of extreme events (Fluixá-Sanmartín *et al.* 2018). However, studies of hydroclimatic scenarios have been conducted, identifying the effects of hydrological changes, global warming, and deforestation on changes from mesoscale (respectively, Sorribas *et al.* 2016, Commar *et al.* 2023) to macro-scale (Arnell & Gosling 2016) and their impacts on hydropower operation (e.g., Kahaduwa & Rajapakse 2022, Men *et al.* 2019). This has raised concerns about water availability, and many investigations focus on future changes in the hydrological cycle. Such studies point to warmer and drier climate conditions, with prolonged droughts and a reduction in the amount and intensity of precipitation in several areas of the planet, including the Amazon basin (IPCC 2021).

For the Amazon, changes in rainfall distribution patterns and the intensification of seasonality are already being identified (Gloor *et al.* 2013). Such changes are pointed out in future projections, where a warmer and drier dry season and a cooler and wetter rainy season are observed in different portions of the Amazon (Baker *et al.* 2021, Duffy *et al.* 2015). One of the main consequences of climate change will be the loss of flood pulse predictability, making the variation of low and high waters increasingly imponderable (Sorribas *et al.* 2016).

Therefore, stationary climate baseline assumptions are no longer appropriate for long-term dam safety management (Kahaduwa & Rajapakse 2022). Consequently, hydropower developments must consider extreme climate scenarios and be designed for adaptation and decision support under a more resilient approach, thus avoiding large hydropower plants' failure in terms of power generation, with serious economic, environmental, and social consequences. Based on scientific studies, hydroelectric projects' climate variables that influence or can be influenced locally should be surveyed. Time horizons like those provided by future climate models should be considered.

Maintain the river's natural flood pulse (flow regime)

The combination of various factors, such as seasonal precipitation and the vast extents of different watersheds, causes the accumulation of water to be concentrated in one or more times of the year, thus characterizing the 'Flood Pulse' (Junk *et al.* 1989). In the large rivers of Central Amazonia, for example, the annual difference in level can be more than 10 meters. In large free-flowing rivers, this phenomenon is generally annual and predictable (Junk *et al.* 2011, Grill *et al.* 2019).

Changes in the natural river regime cause various direct damages to local animal and plant communities and human populations (Schöngart *et al.* 2021). Specifically, in the case of hydroelectric dams, the impoundment of rivers by power plants produces flood pulse losses and negatively affects riparian ecosystems downstream of the dam (Neves *et al.* 2019). In addition, in the operational period of dams, flooded *igapó* and *várzea* forests are strongly impacted by permanent flooding conditions at low topographic elevations. About 12% of floodplain forests are affected along a downstream river stretch of more than 125 km (Resende *et al.* 2019, Schöngart *et al.* 2021).

Thus, it is necessary to maintain the flood pulse to mitigate the impacts generated and avoid socio-environmental loss. It is possible to do so by taking into account the quantity, duration, and quality of water levels to sustain the aquatic ecosystem (Arthington *et al.* 2018). Parameters such as duration and timing of flood onset can be maintained in natural regimes without reducing energy production (Kuriqi *et al.* 2019). However, in cases comprising the detour of water from the natural channel, such as in the Volta Grande of the Xingu River, there is a need to reduce energy production due to the impacts of climate change on such hydrological parameters. Hydrological change metrics based on these parameters should assist decision-makers, ensuring the operation of the hydroelectric plant and the stability of wetland ecosystems in the Amazon basin, so fundamental for riverine and indigenous populations.

Ensure the directly or indirectly impacted population's autonomy to decide whether to implement a hydroelectric plant or other energy production technology

The decision-making process for constructing hydroelectric dams in the Brazilian Amazon faces serious problems. According to Fearnside (2019b, p. 79),

> […] the actual decision on whether or not to build a dam is made by a few people in government long before environmental studies

> are prepared, public hearings are held, and the environmental agency analyzes the information gathered. Because they are made before information on impacts is gathered, political decisions ignore many social and environmental consequences, and the licensing process becomes a mere bureaucratic step to legalize decisions already made.

That said, the decision-making process for the construction of hydroelectric dams must be reformulated. The autonomy of the population directly or indirectly impacted by the project must be respected. At the same time, it is necessary to promote a broader debate about the socio-environmental costs of hydroelectric plants so that the population can access qualified information.

To deal with this problem, we have two proposals. The first concerns the creation of a Permanent Forum on Energy Transition, made up of representatives of civil society and the public authorities, with functions of interdepartmental debate and dissemination to non-specialist audiences regarding hydroelectric plants and, more broadly, alternative sources. This forum would align with the proposals of Ministers Anielle Franco, Marina Silva, and Sônia Guajajara (Ministries of Racial Equality, Environment and Climate Change, and Indigenous Peoples, respectively). They emphasize that issues such as inequality, hunger, climate change, and racism - part of the problems surrounding hydroelectric dams in the Amazon - require transversal treatment, uniting different portfolios of public power and civil society (Vick 2023).

The second proposition includes the importance of adopting binding legal mechanisms that guarantee the population's autonomy, directly and indirectly impacting the decision to build hydroelectric dams in the Amazon. We highlight the need to recognize and adopt community/autonomous protocols for consultation and prior, free, and informed consent. These are documents provided for by Convention 169 of the International Labour Organization (ILO) and prepared by indigenous, *quilombola*, and traditional peoples that establish the rules for the procedure of prior, free, informed, and good faith consultation, in a manner that respects cultural specificities, their legal systems, forms of social organization and collective deliberation (Observatory of Community Protocols 2023; see also Marés *et al.* 2019). In addition to adopting those that already exist, we suggest allocating public resources so that new community protocols can be created. In cases with no such protocols, we emphasize the importance of the Federal Government conducting free, prior, and informed consultation processes in effective compliance with the Federal Constitution and ILO Convention 169.

Maintain the degree of endemism of local fauna and flora

The choice of the site for the construction of hydroelectric plants is fundamental for the preservation and conservation of endemic species (flora and fauna) due to the biodiversity and peculiarities of each region (Nunes-Gutjahr & Braga 2015, Ziober & Zanirato 2014). The physical and biological changes caused by the construction and implementation of dams can cause permanent damage to habitats and biodiversity (Wu *et al.* 2019), as they put at risk of extinction endemic species whose occurrence is limited to the area of direct influence of the project. It is known that the extinction of a single species in a given location causes an imbalance in the ecosystem since the species that retain an ecological relationship with it are affected and, consequently, extinct (Choueri 2013).

Thus, it is necessary to identify areas with endemic species, conduct flora and fauna inventories and species distribution models (Park *et al.* 2003), and consult peer-reviewed scientific papers. Finally, protected areas should be created to ensure species conservation, where they occur, and to reduce biodiversity loss. Regulatory bodies should require constant monitoring and reporting on the performance of endemic species populations.

Feasibility of the proposal: Alternatives to large dams for electricity generation in (and for) the Amazon

Considering the restrictive criteria outlined and developed in this paper, it is unlikely that new large hydroelectric dams would be built in the Amazon region. Therefore, in this section, we point out existing technological alternatives for electricity production in the Amazon, prioritizing the benefit of its residents.

First, we assume it makes no sense to maintain internal colonialism, based on which the Amazon exports most of the electricity it produces to other regions of the country (Randell & Klein 2021). Around 26% of the total national electricity is produced in the Amazon region of Brazil, mainly through hydropower; at the same time, the region consumes only 8% of the national electricity (EPE 2022, Schutze *et al.* 2022). Thus, it is assumed that the region already has enough electricity production to develop (on a sustainable basis, but we will not delve into this discussion) over the next decades for cities, large urban centers, and other areas connected to the power grid. However, about 1 million people are still without electricity in the Amazon (IEMA 2020), comprising especially isolated populations not connected to the grid, either by distance or by the environmental impact that the extension of the grid to them will bring (deforestation, for example). For such populations, technological alternatives already exist, but they lack public policies to become economically viable.

One of the most promising technologies, which has been improved for the Amazonian context, is small in-stream turbines for hydrokinetic energy generation. Such equipment, installed in rivers, enables energy production from the current itself without damaging the river flow or any deviation from its course. In addition, fishes can pass through the turbine propellers without being harmed. Finally, by not building dams, the connectivity and navigability of rivers are maintained, so crucial for connecting local populations. This technology is constantly being improved, is the focus of scientific studies, and has already been working in several places worldwide (Built *et al.* 2015, Mendes *et al.* 2020, Van Zwieten *et al.* 2015, Zhou & Deng 2017). Obviously, Amazonian rivers have specificities. Therefore, studies developed to adapt the technology to the characteristics of these rivers must be considered (Els & Junior 2015, Moran *et al.* 2022b). In this direction, a recent survey pointed out that 63% of the total energy planned to be generated by conventional hydroelectric plants in the Brazilian Amazon could be produced using turbines in the riverbed itself, using the kinetic energy of water as a source and without requiring dams (Chaudhari *et al.* 2021).

There are other promising sources for decentralized power generation in the Brazilian Amazon. Solar photovoltaics, currently the second largest energy source in Brazil (Canal Energia 2023), is also the basis of public policy in the Amazon to provide energy to isolated communities through the *Mais Luz Para a Amazônia* Program (Brazil 2022). Another potential to be explored in the Amazon, on a small scale, is the generation of energy from biomass. This source can be linked to bioeconomy activities, i.e., producing products with raw materials from the region to generate work and income for the local population from the valorization of the standing forest. The states of Amapá, Amazonas, Rondônia, and Roraima together can generate enough biogas to serve 107,000 households, which means about 429,000 people (Instituto Escolhas 2020).

Considering the diversity of potential energy sources in the Brazilian Amazon, we suggest that localized strategies for electricity production in the region be developed, based on the level of demand and, above all, the local environmental specifics that favor the use of certain technology over others. It is also worth mentioning that energy generation can be carried out in a combined way, that is, from hybrid systems, mixing different sources of production that enhance each other. As an example, a recent study pointed out the feasibility of using in-stream hydrokinetic turbines in conjunction with solar photovoltaic panels to produce electricity for isolated communities in the Brazilian Amazon, highlighting the importance of social sciences and engineering working together to develop effective and sustainable systems, appropriate to the local reality (Brown *et al.* 2022).

Conclusion

We are convinced that the restrictions proposed here can assist decision-makers in deeply reflecting on the inherent impacts of building hydroelectric dams in the Amazon and encourage them to prevent new hydroelectric developments in the region. We also hope they can use this framework to reevaluate the dams already constructed, with the aim of minimizing the damage already caused. It is likely that interested companies will argue that following the proposed restrictions is unfeasible, underscoring the impossibility of approving new construction requests. Therefore, our work points to the infeasibility of building new hydroelectric dams in the Amazon without causing harm to the environment and local communities, in line with what Fearnside *et al*. (2021) have indicated.

The increase in energy consumption and greenhouse gas emissions is often associated with the growth of wealth indicators, such as Gross Domestic Product (GDP). However, this correlation has been disassociated in many countries, including the United States and the United Kingdom. Brazil can also reduce its emissions, even with a rising GDP. To do so, it needs to reconsider the fallacy of “clean” energy produced by large hydroelectric plants since these, in addition to harmful social effects, also have evident and well-documented environmental impacts, including the growth of carbon dioxide and methane emissions. Furthermore, ideally, electricity generation should be close to the consumer market, avoiding not only energy losses and transmission expenses but primarily promoting environmental justice, as all energy generation causes externalities that should be shared, especially among those who benefit from them. Alternatives to large hydroelectric plants exist, but to become competitive, they need to be the focus of public policies centered on the well-being of the national population and the preservation of the country’s environmental heritage.

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ANEXX I
Infographic aimed at the general population, containing key data and information about the impacts and costs associated with the construction and maintenance of hydroelectric dams in the Amazon.

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Impact of pesticides in the amazon basin: a multidisciplinary review

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ABSTRACT

Pesticides are chemical substances used in agriculture to control pests and diseases in crops. However, their excessive and unregulated use can have severe repercussions on both human health and the environment. This review examines the utilization of pesticides in the Amazon basin, considering their socioeconomic impact on public health, regional biodiversity, and the availability of soil and water resources. For this purpose, the Scopus and SciELO scientific databases were consulted to gather relevant literature, including publications from various countries within the basin. The temporal distribution of information was also analysed. The findings reveal a significant increase in scientific research conducted in recent decades regarding pesticide usage in the Amazon basin. The study describes the impact regarding the loss of natural forest and the expansion of agricultural and livestock frontiers, especially in recent years. These practices have resulted in serious health issues, particularly among local and indigenous populations. Furthermore, there has been a decline in regional biodiversity, impacting crucial animal species that contribute to ecological balance by providing ecosystem services such as pollination and seed dispersal. Lastly, a case study is presented that showcases a successful agroecological model, emphasizing the urgent need for control measures to reduce pesticide usage throughout the entire Amazon basin. Such measures are vital for safeguarding human health and the environment. This demands the implementation of measures and policies that promote sustainable approaches by farmers and raise public awareness about the risks associated with indiscriminate pesticide use and responsible food consumption.

Keywords: deforestation, monocultures, pesticides use, human and environmental health, bioeconomy, Amazon basin.

Introduction

The Amazon basin is renowned for its rich biodiversity, hosting thousands of species of flora and fauna (Nobre *et al.* 2021). Furthermore, it is one of the three main centers of deep atmospheric convection, situated within the equatorial convergence zone (Reis *et al.* 2022). Despite its global significance, deforestation increased by approximately 30% between 2018 and 2019. In the year 2020, there was a resurgence of severe forest fires, which experts attribute mainly to factors such as land grabbing, the expansion of agricultural frontiers, pressure from international markets, inadequate public policies, and insufficient regulations for climate change mitigation and adaptation (de Araújo Mascarenhas *et al.* 2020).

Agricultural production has significantly increased in this basin since the advent of the "Green Revolution" (Júnior *et al.* 2022). This revolution resulted in a shift from diversified production systems to monocultures that require intensive use of chemical fertilizers and pesticides (Marin *et al.* 2022). These chemicals are currently considered "essential" for conventional and intensive agricultural practices. However, despite their importance in controlling weeds, pests, and diseases, their usage has significant adverse effects on human health and ecosystems (Arévalo-Jaramillo *et al.* 2019; Silva *et al.* 2019).

Some countries within the Amazon basin have laws that regulates the registration of pesticides, mainly concerning the active ingredients of the product, the demarcation of sites and cultivation areas where they will be used, the quantity and frequency of use, the timing of application, storage practices, and the proper disposal of waste and packaging (Júnior *et al.* 2022). However, it is not known how these laws support the commitment of the countries within the basin in issues such as responsible food production and consumption (Ochoa-Cueva *et al.* 2022), which is one of the Sustainable Development Goals (SDGs) of the United Nations (UN) (http://www.un.org/sustainabledevelopment/sustainabledevelopment-goals).

In Brazil, the country with the largest area of the Amazon basin , the use of pesticides has increased significantly over the past two decades. The quantity of active ingredients utilized rose from approximately 150,000 tons in the year 2000 to over 600,000 tons in 2019 (IBAMA 2020). Therefore, it is necessary to review the scientific publications on pesticides that have been conducted in all countries within the Amazon basin. Lastly, it is important to describe a success story from the basin that can be replicated by other communities, locations, or farms. Such a review would be immensely valuable for researchers, decision-makers, regulatory bodies, as well as local and regional governments operating within the Amazon basin. For this purpose, it is necessary to develop agreements and policies that contribute to the reduction of pesticide use and encourage the development of alternatives that are in harmony with the environment.

Material and methods

To carry out this systematic review, we used the method proposed by Page *et al.* (2021), called PRISMA (Preferred Reporting Items for Systematic and Meta-Analyses). This review was based on the collection of scientific articles that are available in the Scopus and SciELO repositories. The keywords for the search were: "pesticides" AND "Amazon"; and "Agrochemicals" AND "Amazon", respectively. We carried out the last search revision before data analysis in January 2023.

Study area

The Amazon River basin encompasses one of the most biodiverse regions on Earth, with eight recognized endemic zones (Rodrigues-Alcântara 2013). The Amazon Forest itself is the largest in the world, covering an approximate area of seven million square kilometers, stretching from the Andes Mountains to the Atlantic coast (Nobre *et al.* 2021). Moreover, the Amazon basin has diverse land cover and use (Figure 1), which have undergone significant changes over the years. While the natural forest cover remains dominant in the region, Brazil, the country with the highest deforestation rate, had an estimated loss of around 45 million hectares (Mha) of native forest between 1985 and 2021, amounting to nearly 12% of its total forest area. Conversely, agricultural land use has increased substantially during the same period, experiencing a growth of almost 244% (MapBiomas). The distribution of agricultural land use is concentrated in the eastern Amazon but is gradually expanding towards the interior (Figure 1; study area with the map of land cover and land use in the Amazon basin).

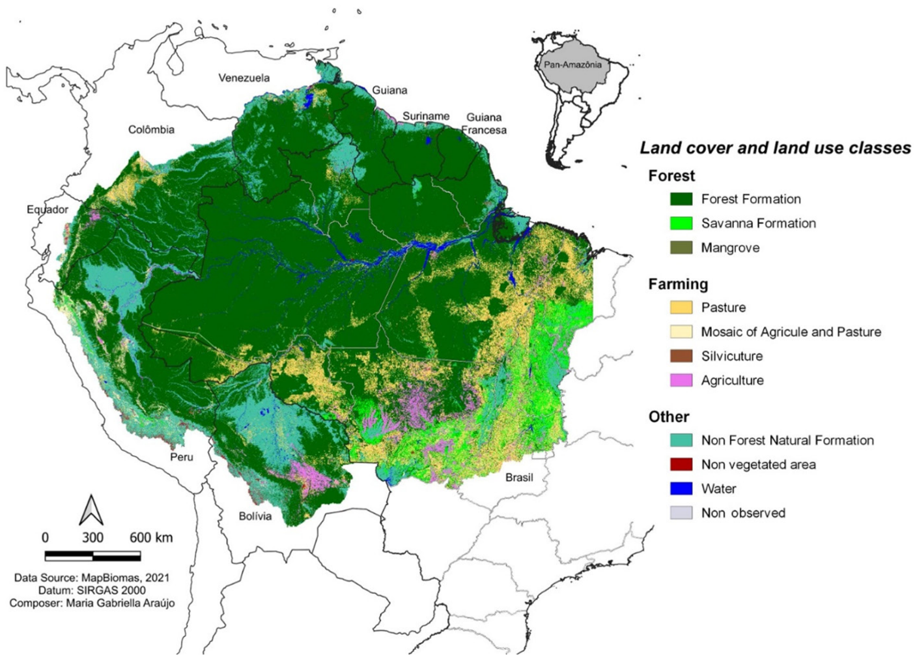

Figure 1 Study area with the land coverage and usage map of the Amazon basin.

Data selection and analysis

The articles selected for further analysis met the following criteria: 1) studies with the main theme of pesticides; 2) the research was carried out in the Amazon basin; 3) published in indexed journals. These three criteria were used to evaluate, initially, the title, abstract and document type (article, review, conference, or book chapter); to subsequently review the complete document of the investigations whose information was not consistent in the sections above.

For the analysis of the data from the selected and reviewed articles, a database was generated with information such as: a) Publication Year; b) Document Type (article, review, book chapter and congress article); c) Country of the Amazon basin in which the research was carried out, and d) specific issues related to the pesticides impacts. These issues were categorized based on the sustainability attributes, which are conceptually divided into economic, environmental, and sociocultural dimensions (Reid *et al.* 2005). Thus, five different subthemes were obtained: Bioeconomy, Deforestation and Biodiversity Loss, Human Health, Social Impact, and Water-Soil (Resources).

The R language was used for the analysis of the database in version 4.2.2. for Windows. For data tabulation, the "dplyr" and "reshape2" packages were used, and for generating graphs, “ggplot2” and “cowplot” were utilized (Team Core, R.).

Results and discussion

Publication trends over time

According to the results obtained for the Amazon basin, the first published reports on the topic of pesticide use began in the 1980s. A study conducted by Brinkman (1983) describes the nutrient imbalance between natural areas and agricultural systems with human interference. From the databases, about 100 articles were reviewed to analyze the historical trend of publications, taking care to identify the records that appear in both databases.

Figure 2 shows the temporal distribution of scientific articles on synthetic pesticides and their impacts in the Amazon basin. Initially, articles from the 1980s that address the characterization or description of the issue are recorded, but over time, the topics diversified and were published exponentially up to the current decade of 2020. Over 85% of the studies recorded in the databases were published in the last 15 years.

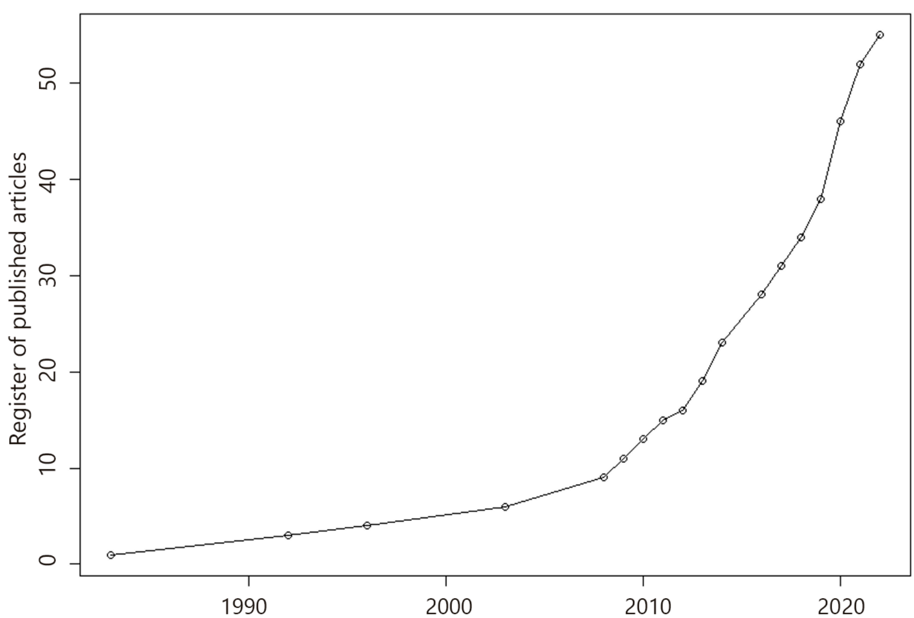

Figure 2 Temporal distribution of scientific articles on pesticide use in the Amazon basin.

Analyzing the data collected, it can be affirmed that research on the impact of synthetic pesticides in the Amazon basin is currently limited and unpublished, compared to the global context. When reviewing the same databases with the same general topic (pesticides), it was found that studies have been available since the 1940s, and these records exceed one hundred thousand articles. For that reason, despite the worldwide importance of this subject, the scientific capacity installed within the Amazon basin remains limited in comparison to the publication efforts of other regions.

Another important issue to highlight is the difficulty of access to the Amazon rainforest, which initially hindered the fragmentation of the natural forest and the expansion of the agricultural frontier. However, more recent studies, such as the one by Araújo Mascarenhas *et al.* (2020), mention that the use of herbicides and the implementation of intensive agricultural techniques are common practices nowadays in the Amazon, favoring river, aerial, and land-based navigation, but with strong negative impacts on human health and the environment. Vasco *et al.* (2021) mentioned that there have been more research efforts aimed at understanding the factors that drive deforestation in the Amazon, rather than understanding why the Amazonian population uses chemical fertilizers and pesticides for their agricultural production.

Trends of publications by country within the Amazon basin

As shown in Figure 3, the country with the greatest scientific production about pesticides is Brazil, accounting for 81.5%, followed by Ecuador with 11.8%. Interestingly, these countries show a significant difference in their Amazonian territorial extent. The record of publications from the other countries that share the Amazon basin is very low, at 1.3%. Figure 3 also shows studies developed in more than one country that is part of the basin, named "Regional." It is worth noting that Guyana, Suriname, and Venezuela, the remaining three countries in the basin, did not report any articles on pesticides in the reviewed databases.

This analysis reveals a lack of understanding regarding the number of published articles, their temporal distribution, and their correlation with the respective government policies implemented in each country. Furthermore, it raises questions about whether these policies have facilitated or hindered efforts in publishing, as discussed in the previous section.

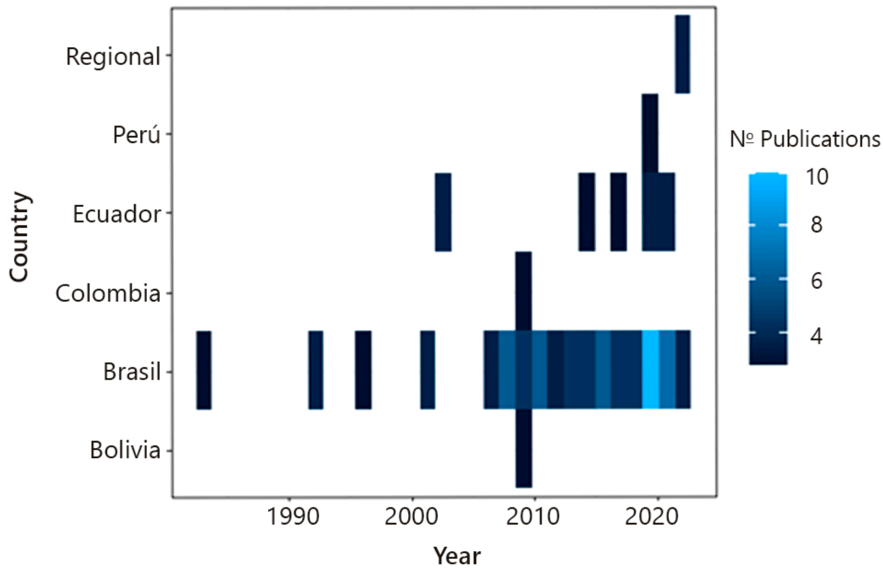

Figure 3 Temporal distribution of articles published by countries within the Amazon basin.

Trends in publications by topic

Figure 4 describes the themes in which the impacts generated by pesticide use on sustainability attributes were classified, which can affect economic, environmental, and/or sociocultural aspects. A detailed analysis of these five themes follows.

Water / soil (resources)

These two natural resources are the most frequent subject of study when investigating the impact of synthetic pesticides on the environment (Ochoa-Cueva *et al.* 2022). The review of this specific topic represents more than 30% of all the topics under analysis. Most of these studies have been conducted in Brazil with few exceptions, including a book chapter and an article covering the entire South American region. However, the first recorded research dates back to the mid-1990s with a foundational study conducted by Louter *et al.* (1996). The study's objective was to identify microcontaminants in samples of surface waters.

Subsequent studies were carried out with different approaches, building upon what was described by Winemiller *et al.* (2008), who examined the diversity and ecology of fish in tropical stream rivers, primarily focusing on sustainable food production and consumption to conserve tropical biodiversity. In the same year, Römbke *et al.* (2008) assessed the risks of pesticides in soils of central Amazonia, comparing them with temperate zones to ascertain potential effects on soil and biodiversity in the region. Studies conducted by Copatti *et al.* (2009), Pessoa *et al.* (2010), and Rico *et al.* (2011) centered their research on the water quality used for agricultural production, with Rico *et al.* (2011) specifically evaluating the toxic effects of pesticides on endemic freshwater fishes and invertebrates.

Later studies analyzed the impact of pesticides on soil quality. Mussy *et al.* (2013) identified microorganisms resistant to one of the most commonly used herbicides for weed and leafy grass control (2,4-D). Meanwhile, Mendez *et al.* (2016) and Rodrigues *et al.* (2017) studied the dynamics of Dichloro-Diphenyl-Trichloroethane (DDT) in soil and sediments in a tropical floodplain and in Belém, respectively. Both studies in the Amazon basin found traces of DDT despite its prohibition. Other research establishes comparisons between areas with natural cover and areas with palm oil production, demonstrating impacts on aquatic insect populations in these Amazonian streams (Shimano & Juen 2016).

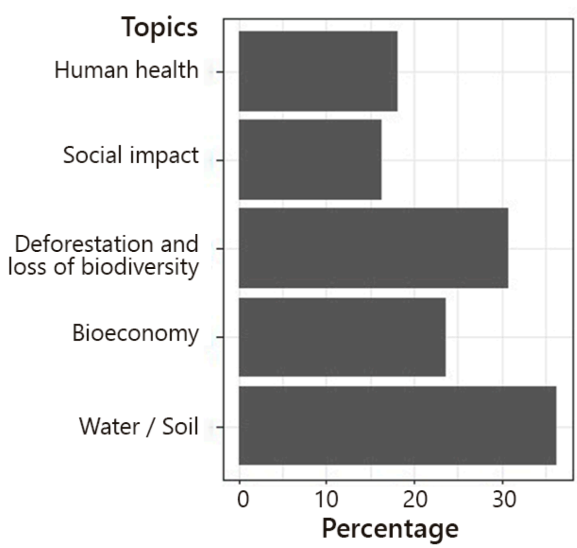

Figure 4 Publication trend of articles categorized by topics.

In the analysis of the last five years, publications are related to the deposition of pesticides in water and sediments (Neves *et al.* 2018; Viana *et al.* 2019). All the subsequent studies are recorded in this database and pertain to the assessment of ecological or environmental risks (Guarda *et al.* 2020; Rico *et al.* 2022; Val *et al.* 2022; Viana *et al.* 2020). This is a current trend detected for the entire region, and the ultimate goal of these studies is to establish a local, national, or with the support of international organizations, global regulatory framework (Daam 2023).

Deforestation and biodiversity loss

The expansion of agricultural frontiers is one of the main causes of deforestation in the Amazon rainforest, which covers approximately 7,000,000 km2 and harbors around 25% of global biodiversity (Nobre *et al.* 2021). It is precisely this vast territorial dimension combined with an inefficient state in managing its natural resources that made the Amazon basin attractive to many agribusiness entrepreneurs (Neves *et al.* 2018).

When discussing the Amazon, it is important to highlight that soy cultivation and livestock are the predominant activities in agribusiness. Synthetic pesticides play a crucial role in controlling weeds, pests, and diseases for the success of these practices. In addressing this issue, it is important to mention that Brazil has Law No. 7802, dated July 11, 1989, which regulates the initial phase of production, their use, and the final disposal of the packaging of these chemical products (Römbke *et al.* 2008; Waichman *et al.* 2007). However, despite this legislation, the intensive and widespread use and management of pesticides persist. Alternatives such as mitigation measures or integrated pest management (IPM) are minimal or nearly non-existent when compared to the availability of chemical solutions in the market (Waichman 2012). Unfortunately, this law has become ineffective in the Brazilian Amazon since 2018, as agribusiness has expanded exponentially without adequate regulatory or environmental oversight (Júnior *et al.* 2022; Lermen *et al.* 2018).

According to a study conducted by Kleanindustries in 2020, pesticides have been released into the Amazon rainforest via aerial means in an attempt to evade supervision by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA). Aerial fumigation with synthetic pesticides is used to cover hard-to-reach areas. As mentioned earlier, this practice has been employed since 2018, and this form of deforestation through tree poisoning is slower than clear-cutting or fires. Unfortunately, this tactic has gained strength due to its limited detection by real-time satellite imagery. According to Gonzales (2022), glyphosate and 2,4-D are the most commonly used pesticides to poison trees in natural areas. After their death, these trees are mechanically removed, facilitating the subsequent dispersion of seeds for agricultural crop establishment.

Glyphosate, carbosulfan, and 2,4-D were the pesticides used in the Vietnam War, where cases of congenital malformations are still reported. According to Agência Brasil, these pesticides have been found in clearings in the region of the deforestation arc, where the agricultural frontier advances towards the Amazon rainforest. Over 30,000 hectares of forest have already been cleared using chemicals to poison the trees. According to Ibama (2018), the crisis in the Amazon continues to escalate.

Despite numerous studies on pesticide use, or agrochemicals as they are commonly referred to in the agro-industrial sector to appear less offensive to foreign markets, their intensive use continues to persist as mentioned earlier. Although the international market demands measures to reduce or mitigate environmental impact, these are slow and ineffective (Marin *et al.* 2022).

The depicted in Figure 1 is the area designated for agricultural use. Only between 2000 and 2020, agricultural production in the Amazon saw a 327.3% increase, totaling 11.4 million hectares of harvested area, equivalent to approximately R$ 57.3 billion. The state of Mato Grosso alone accounts for nearly 70% of this total. Despite this, it is believed that Brazil requires more arable land to meet the demands of both local and export markets. Therefore, Martinelli *et al.* (2016) argue that it is necessary to reconsider the current agricultural and livestock model, as clearing the jungle for expansion is no longer a viable option. Cattle ranching areas in the Brazilian Amazon are often associated with illegal deforestation, where false land titles make regulation more challenging (Ribeiro 2020).

According to professionals from the Mamirauá Sustainable Development Institute: "Livestock farming itself is not the issue, but rather the production methods, which can be either beneficial or harmful." Expressions or positions like these weaken the arguments and efforts to combat deforestation in the Amazon rainforest, favoring the expansion of soy and livestock farming. Similar perspectives may exist within the academic and research institutes (Júnior *et al.* 2022). Therefore, it is crucial to disseminate studies that highlight the importance of land restoration, Good Agricultural Production Practices (GAPP), and Integrated Pest Management (IPM) as more sustainable alternatives.

Urgent action is needed to prohibit or limit the use of chemical pesticides in agricultural production, while suggesting the use of organic products to boost the region's bioeconomy. It is also crucial to have an effective state in combating deforestation in the Amazon, with robust control and oversight agencies, particularly concerning aerial pesticide spraying methods over the forest. This requires investments in technologies such as remote sensing and drones, necessary to enhance control and monitoring efforts.

Social impact

The issue of social impact can be approached from various areas, including the economic sector. However, given the specific concern related to the bio-economy, it will be examined from the perspective of ecosystem services. These goods and services are also obtained by humans from ecosystems, including supporting, provisioning, and cultural services (Reid *et al.* 2005). Pollination and seed dispersal fall under the category of supporting and provisioning services. Therefore, the analysis of these environmental services is crucial for ensuring human health and well-being, as well as for maintaining the balance and survival of numerous species on the planet.

Regarding the central theme of this review - pesticides - these can have a significant impact on certain ecosystem services. For instance, in relation to pollination, the use of certain pesticides has been linked to the decrease in bee populations (Sánchez-Bayo *et al.* 2016), having a negative impact on the health and behavior of these insects (Zhao *et al.* 2022), and diminishing their ability to forage, learn, and remember (Siviter *et al.* 2018). Colin *et al.* (2019) suggests that pesticide products such as neonicotinoids, even at sublethal doses, can promote the spread of diseases among bees. Beyond directly killing bees, pesticide exposure can also impact the overall health of beehives (Gill *et al.* 2012). Consequently, this affects the productivity of crops that rely on pollination services. In the Amazon region, bees play a crucial role in pollinating most of the plants that produce edible fruits (Paz *et al.* 2021). Therefore, the uncontrolled use of pesticides would have severe implications for the socioeconomic aspects and food security, particularly for the local communities in the Amazon basin.

Another important provisioning and cultural ecosystem service for biodiversity maintenance is seed dispersal, primarily carried out by birds and bats. They even facilitate the regeneration of degraded areas with this seed dispersal (Athiê & Dias 2016). On the other hand, the exposure of birds and bats to pesticide spraying can compromise their health directly or indirectly, through the consumption of food, water, or the destruction of their habitat (Oliveira *et al.* 2020).

The main effects of pesticide contamination on birds include the loss of safe habitats, changes in their habits or behaviors, particularly in feeding patterns, and a decline in their population due to reproductive disruptions, which may ultimately lead to local extinction (Arya *et al.* 2019). Conversely, bats that feed on insects are considered more susceptible to pesticides as they are at the top of the food chain (de Oliveira & Aguiar 2015). Insectivorous bats play a crucial role in controlling insect populations, including disease vectors such as dengue, leishmaniasis, and malaria, as well as agricultural pests (Oliveira *et al.* 2020). Thus, the biological control of pests, which is also a regulatory ecosystem service, is affected by the use of pesticides. Bats observed foraging in organically cultivated areas exhibited longer feeding times and greater species diversity compared to those found near chemically treated crops (Barré *et al.* 2018). These impacts on bats can significantly reduce the survival capacity of their populations, resulting in substantial losses not only in terms of ecological conservation efforts but also in socio-economic aspects.

Human health

In this matter of human health, several aspects need to be analyzed. One of them is the health of local populations, who are directly affected by the applications of pesticides for agricultural production in fields near their residences. At the same time, in many cases, these very local communities are the first to take action to protect the environment through their practices of sustainable management. Indigenous peoples, in particular, possess ancestral knowledge and hold deep respect for "Mother Earth," which provides them with a holistic view of their environment. This perspective enables them to provide multiple ecosystem services for the benefit of humanity as a whole (Ribeiro & de Sá Neto 2019).

However, despite their contributions, ancestral communities and indigenous peoples face various challenges, such as marginalization and negative impacts generated by society. They also confront destructive policies related to the encroachment on their territories (Oliveira *et al.* 2018). Pesticide contamination and intoxications are the main threats to municipalities, along with mining, which generates territorial conflicts due to its usage and gold-digging (Lima *et al.* 2022; Pignati *et al.* 2021; Ribeiro & de Sá Neto 2019).

As mentioned earlier, Brazil has a long history of pesticide use, which is reflected in current practices and observed harmful effects, especially among indigenous populations (Ribeiro & de Sá Neto 2019). Although it is impossible to disregard this historical problem, it is crucial to address recent cases of pesticide intoxication in Amazonian populations, often justified as mere accidental events (Oliveira *et al.* 2018). As mentioned, the majority of reported cases of intoxications involving indigenous peoples are concentrated in areas near the agricultural frontier, mainly in the southern Legal Amazon, specifically in the northern region of the state of Mato Grosso. This area has witnessed the widespread implementation and imposition of large-scale agro-industrial practices (Pìnheiro *et al.* 2022). Mato Grosso is one of the main contributors to deforestation in the Amazon region, and it also hosts numerous indigenous groups whose territories are increasingly invaded by the expansion of monocultures. This is an exemplary case of the environmental degradation that the agribusiness model can lead to if it continues to expand to other Amazonian states (Bombardi 2017; Oliveira *et al.* 2018).

Given the extent of problems resulting from the expansion of the agricultural frontier in the Amazon, it is crucial to comprehend the socio-environmental impacts that this expansion brings, especially in the context of indigenous communities. In this regard, representatives from organizations such as the Indigenous Amazon Operation (OPAN) have redirected their efforts towards a deeper understanding of the indigenous perspective on the effects of pesticide contamination, as seen in the case of the indigenous communities in the Juruena River basin hydrographic region, located in the northwest of the state of Mato Grosso (Oliveira *et al.* 2018). Indigenous communities like Paresi, Rikbaktsa, Manoki, Myky, and Nambikwara highlight the intrinsic relationship between pesticides, loss of biodiversity, and food insecurity, which poses a threat to the sustainability of their territories. It's noteworthy that indigenous perspectives on pollution and observed landscape changes differ from the dominant discourse in specialized academic fields.

From the perspective of indigenous knowledge, "attention is not only focused on the harm suffered by the human species, but rather on the concern for the well-being of various living beings that are also at risk of contamination." In indigenous narratives, this concern is reflected by highlighting the contamination of specific beings considered as rights-holders (Regina 2021). Furthermore, the way contamination occurs differs among various beings, both human and non-human. This underscores the intimate relationship between bodies and the territory they inhabit. The author further argues that the reciprocal nature of this relationship is evident, whether they are humans, fish, land animals, plants, or other beings (Regina 2021).

Another reference that illustrates the indigenous perspective on the impacts of agribusiness in Mato Grosso's territories is the short film "Para onde foram as andorinhas?" (available on YouTube), produced by the Socio-Environmental Institute and the Catitu Institute, in the Xingu Indigenous Park (PIX). The short film shows that in the last 30 years, 42% of the forests surrounding PIX have been deforested to make way for soy and corn monocultures. PIX is home to approximately 6,500 indigenous people from 16 different communities who rely on the forest for food, ritual materials, medicinal resources, and construction materials for their homes. The Xingu indigenous people have also observed the spread of forest fires and how the fruits from their fields rot before reaching maturity.

In Brazil, however, there is a lack of data or reports about pesticide poisoning in traditional populations. Incidents of poisoning in towns and villages are either unknown or not included in the government's official statistics (Marques *et al.* 2022). This limited availability of information hinders a comprehensive understanding of the issue and poses a significant obstacle to the development of public health policies that could protect local communities (Ochoa-Cueva *et al.* 2022). Consequently, addressing this issue at all possible scales becomes a challenge.

The adverse effects of pesticides on individuals living in areas near monoculture plantations remain a major challenge for public health. It is important to consider the historical context of pesticide spraying in regions close to local Amazonian populations and its detrimental health effects. It is also essential to examine how external and transnational agribusinesses promote the use of these chemical products for agricultural production, even within indigenous communities (Leite 2007). This latter aspect will be further addressed in the topic of bioeconomy, described below in more detail.

Bioeconomy

Concerning the field of bioeconomy, we have identified scientific publications, of which 70% originate from Brazil, 23% from Ecuador, and 7% from Peru. Publication records were discovered in only one article each during the 1980s, 1990s, and 2010s. Consequently, more than 50% of the publications on this subject have been documented in the last three years.

The Brazilian economy heavily relies on the agricultural sector (Ribeiro 2020), making the country one of the world's largest consumers of pesticides, second only to the United States (FAO 2022). Schiesari *et al.* (2013) emphasize that in the Amazon region, the lack of technical assistance leads to the improper use of these chemical products, resulting in overdosing or underdosing. Both short-term and long-term practices contribute to increased contamination of natural resources due to product ineffectiveness, leading to more frequent applications that directly and indirectly affect the population's health.

Given this reality, it is crucial to strategically change the dynamics of agricultural development in the region towards a more sustainable model that encompasses economic, social, and environmental aspects (Arvor et al. 2017;

Martinelli *et al.* 2010). Therefore, it is essential to promote and replicate successful cases of sustainable agriculture that have managed to eliminate or replace the use of these synthetic inputs with alternatives that are not harmful to the environment and human health. This is exemplified in Durofil *et al.* (2021) and Spletozer *et al.* (2021), which demonstrate that some Amazonian plants, such as *piperaceae*, have the potential to be employed as natural insecticides.

Impacts on the bioeconomy of Amazonian communities (Guaraná)

In the context of the bioeconomy related to agricultural production in the Amazon region, a native crop known as guaraná [*Paulinia cupana* var. *sorbilis* (*Martius*) *Ducke*] can be highlighted. Originally classified as a vine, it assumes a shrub-like form when cultivated in open environments. Brazil is the only country that commercially produces guaraná on a significant scale.

According to the Brazilian Institute of Geography and Statistics (IBGE 2021), the production of guaraná in 2021 amounted to approximately 2,732 tons. This was cultivated across an area of about 10,099 hectares, resulting in an average yield of 271 kg/ha. The total revenue generated from guaraná production was R$ 39,857,000.00. Among the states in Brazil, Bahia leads in terms of production, with around 1,831 tons and an average yield of 321 kg/ha. Amazonas follows with a production of 643 tons and an average yield of 160 kg/ha.

In this state, particularly in the city of Maués, a significant portion of guaraná production is carried out by family farmers. The Sateré Mawé indigenous people, who consider themselves the descendants of this plant, refer to it as 'Waraná,' a term that eventually evolved into its commercial name. They were the first to cultivate guaraná, utilizing it for medicinal, nutritional, spiritual, and ritual purposes. This ethnic group firmly believed that the fruit embodies the profound spiritual power of knowledge and wisdom inherent in the « Wará » . Guaraná holds profound significance for the local population in this municipality, serving as a symbol of their history and culture, while also playing a pivotal role in the local economy and, in turn, fostering social progress (Beaufort *et al.* 2008; Figueroa 2016; IDESAM 2018).

Currently, guaraná production primarily caters to the demand in the pharmaceutical industry for medicinal purposes and in the soft drink industry, where it is used as a main extract in beverages. The guaraná market has expanded, and in order to meet the strong demand, it became necessary to increase production. As a result, the traditional agricultural systems that used to cultivate guaraná shifted towards predominantly monoculture practices (Filoche & Pinton 2014).

To achieve higher productivity, reduced losses, and enhanced resistance, the Brazilian Company for Agricultural Research (EMBRAPA) has been conducting genetic improvement and studying matrix plants since 1976. This has led to the development of genetically improved and studied "clone seedlings" that form the basis of the monoculture system (Atroch *et al.* 2012).

To induce rooting of these clone seedlings, phytohormones are applied, with indole-3-butyric acid being the most commonly used. The substrate for cultivation consists of a mixture of forest soil, sand and simple superphosphate. Water, urea, and potassium chloride are typically used for seedling fertilization. Despite the resistance of these clones, there is still a risk of diseases such as anthracnose (*Colletotrichum gloeosporioides* (*Penz*.) Penz. and Sacc.) and pests like thrips (*Liothrips adisi*), which can affect the plants at various stages of growth. To mitigate infestations, agrochemicals such as acephate and deltamethrin, classified as insecticides, and fungicides like azoxystrobin, difenoconazole, methyl thiophanate, tebuconazole, and flutriafol are used (Pereira 2005).

According to Pereira *et al.* (2018), the application of cloned matrices in this "novel" production system has caused some small-scale producers to become dependent on agrochemicals and other inputs, resulting in increased production costs and rendering it economically unviable. A survey conducted by the Institute for Conservation and Sustainable Development of the Amazon - IDESAM (2018) reveals that 69% of producers in the region establish their guaraná plantations using clones, of which 25 to 30% employ chemical fertilization, while others adhere to traditional practices and apply organic fertilizers such as black earth, twigs, branches, dry leaves, and pruning remnants. Clones that do not receive adequate care, often due to the producers' lack of financial resources, become more susceptible to pest and disease infestations, which adversely affect the final production output.

In addition to economic problems, the use of agrochemicals has a direct impact on the populations of *Apidae* family, particularly the species *Meliponia seminigra*, *Xylocopa muscaria*, and *Apis mellifera*, which are considered the primary pollinators of guaraná (Gondim 1984; Lima & Rocha 2012). Nevertheless, dedicated studies that examine the behavior of bees in reaction to the pesticides employed in guaraná cultivation are imperative. It is also known that adopting agricultural practices that support pollinators, such as reducing pesticide usage, especially during flowering, and preserving nearby forests to create a favorable environment for nesting and the availability of floral resources for bees, is crucial for improving production (Wintermantel *et al.* 2022).

In line with the adoption of Sustainable Agroecological Models (SAM), the farmers from the communities along the Urupadi River have made the decision to revive the traditional approach to guaraná cultivation. They have replaced the use of clones with seedlings, often referred to as "offshoots" and obtained from the original liana plants known as "wild guarana" found in their natural state within the forest. The collection of forest seedlings is carried out in areas that harbor a diverse gene pool of wild guaraná. These seedlings are then planted in conjunction with existing trees, including fruit trees and other naturally occurring species.

This agroecosystem approach establishes an environment for the guaraná crop that closely mirrors its natural habitat. Therefore, the replication of the natural environment is likely to contribute to the natural regulation of pests and diseases. As a result, the cultivated area is transformed into a forest agroecosystem that benefits from natural fertilization sources (Aguiar *et al.* 2021).

In 2015, to strengthen the market, the producers of the Urupadi River formed the "Association of Family Farmers of Alto Urupadi" (AAFAU). This association gathered approximately 50 families engaged in sustainable guaraná cultivation through family farming. The association holds the ECOCERT seal (Guaraná Organic Conformity Certificates), which not only guarantees a 100% organic production but also highlights the product's value and the producers, ensuring equitable pricing for both domestic and international sales (Trindade *et al.* 2021).

The SAM approach, where its members actively participate in forest preservation and conservation, has proven to be successful. In addition to selling roasted guaraná beans, the association offers secondary products such as organic guaraná powder and a snack drink made from guaraná. In 2017, the producers of this association obtained the registration as a "Social Control Organization" (OCS), which allows them to sell their products directly in fairs, markets, or to the government (Pereira *et al.* 2020).

At present, AAFAU markets its products through both physical retail outlets and its website's online store. As a result, more and more guaraná producers are joining the movement and utilizing wild guaraná as their main product. It is essential to emphasize that these producers abstain from the use of pesticides, aiming to achieve a production that is more in balance with the environment.

Upon completing the review of scientific literature on the subject, a lack of comparative studies on productivity between the guaraná clone and wild guaraná has been observed. Although extensive research has been carried out on the guaraná clone, the study of wild guaraná in its current state represents a relatively recent area of investigation. This temporal discrepancy underscores the need for further studies to evaluate and compare the productivity of these two varieties. Additionally, it is crucial to conduct research that acknowledges the value of organic and family-based guaraná production, and other wild crops from the Amazon, taking into account not only economic aspects, but also the preservation and perpetuation of local culture.

Conclusions

This study makes a temporal review of the publications indexed in scientific databases on agrochemicals for the entire Amazon basin. It shows the beginning and the number of publications for decades of the different countries that compose it. It also describes how the different approaches to pesticide studies have been distributed, revealing possible biases and gaps in knowledge in the detailed data.

The use of pesticides and the expansion of the agricultural frontier are related and multifaceted issues that involve different sectors, with the economic aspect towards a global market being the one that currently prevails. Consequently, there is a pressing need to expand research efforts on all the issues addressed, but particularly on the adverse effects on human and environmental health (biotic and abiotic parts) of the Amazon.

It is also important to emphasize the need to describe sustainable production alternatives for the region. A potential solution includes taking advantage of the agricultural production of wild species with organic production and the transformation of these natural products with the same members of the local communities, activating the bioeconomy and social impact. Numerous case studies, such as the one on guaraná in this review, demonstrate the feasibility of replicating similar approaches in different communities, crops, and countries that make up the Amazon basin.

Although scientific research on pesticides has increased exponentially in the last 15 years, there is still a need to improve public policies and collaboration between the 8 countries that make up the basin. International links between universities and research institutes will allow the establishment of collaborative networks that will promote future research for the benefit of the sustainable management of the Amazon's natural resources.

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Mercury pollution in pan-amazonian indigenous communities: a portrait of reality

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ABSTRACT

This article discusses the issue of mercury contamination in the Amazon, a bioaccumulative metal used in artisanal gold mining. This socio-environmental problem has directly affected indigenous and riverine communities, causing neurological, cardiovascular, digestive and reproductive problems. Based on an interdisciplinary scientific perspective that aims to consider the complex reality of Amazonian indigenous peoples, the goal is to propose measures that can assist these communities in addressing this issue. In addition to the literature review on the subject, a research conducted by FioCruz in the Sawré Muybu Indigenous Land (Pará) in 2019, which is currently one of the most mercury-contaminated regions in Brazil, was used as a reference. The proposals for action include educational and preventive measures, guidance to the government, environmental and health monitoring, and the strengthening of the capacities of indigenous communities to deal with contamination. The study highlights the significance of an interdisciplinary and collaborative approach to tackle this intricate and pressing issue in the Amazon

Keywords: Amazon, mercury, indigenous peoples.

Introduction

The Amazon encompasses nine South American countries and its extent amounts to one-third of all remaining tropical forests in the world. This biome is home to more than half of the planet's biodiversity and is made up of at least ten distinct types of forests. The Amazon Basin, which expands over an area of 6.9 million km², plays an indispensable role in the climate and global hydrological cycle, being responsible for storing about 20% of the world's fresh water (Ab'Saber 2003). Over the past 11,000 years, the Amazon has been preserved and cultivated by a multitude of indigenous groups. These groups have upheld a symbiotic relationship with the ecosystem, revealing a deep connection between human communities and the biome (Neves 2006).

Although illegal gold mining is not a recent phenomenon in the Brazilian Amazon, the expansion of these activities has accelerated significantly in recent years. This expansion has been fueled by the rise in global gold prices and the inadequacy of regulations and oversight tailored to the complex economic, social, and political dynamics underlying this practice (Skidmore, 2022). In the context of this expansion, the use of mercury (Hg), a metal with high toxic potential, has posed significant challenges in terms of socio-environmental impacts. While its use in mining is allowed under authorization from the National Mining Agency (ANM), effective oversight and control of the trade, use, and disposal of mercury have proven problematic, particularly in the Northern region of the country, where this metal illegally reaches the mining sites.

Despite Brazil having undertaken international commitments to reduce mercury use, as established by the Minamata Convention, such commitments have encountered significant obstacles to their effective implementation. The trading of clandestine gold in the legal market, for example, is facilitated by financial firms authorized to purchase this metal (DTVMs), which often lack due diligence or oversight over the cited ore provided by the sellers (Skidmore, 2022). Such challenges have contributed to making the mercury issue one of the main socio-environmental problems in the Amazon currently. Illegal mining has led to significant deforestation and the displacement of local communities, while the use of mercury in gold extraction has caused severe damage to the environment, with the release of more than 1,000 tons of mercury per year from illegal mines (Skidmore 2022).

Indigenous and riverine communities in the Amazon are particularly affected by this problem, since their survival is directly related to access to and interaction with local biodiversity and a potentially contaminated environment

(Basta & Hacon 2020). Mercury is often used to amalgamate gold, helping to separate it from other substances. This almalgam is heated, causing the mercury to evaporate, leaving behind the gold. However, evaporated mercury does not disappear, it is released into the air and can be inhaled or settle in soils and bodies of water in the surrounding area. In addition, a portion of the mercury used in the amalgamation process does not evaporate, remaining in liquid form or in the form of small droplets and can thus be deposited in rivers or soil, affecting essential ecological processes such as decomposition and nitrogen fixation.

This mercury can also enter the food chain when it is converted by bacteria into methylmercury (MeHg), an organic form of mercury that is easily absorbed by organisms. MeHg is bioaccumulative, that is, it accumulates in the tissues of animals, especially in fish, and can be transferred to humans when they consume these animals. Chronic exposure can cause a variety of health problems, including neurological, cardiovascular, digestive, and reproductive problems (Heck 2014, Basta & Hacon 2020). In addition, mercury is particularly harmful to pregnant women, as it can affect the development of the fetus. In summary, mercury can kill or cause health problems in a wide range of animals, including fish, birds and mammals.

The region where the Munduruku indigenous people live, on the banks of the Tapajós River in Pará, is currently one of the most mercury-contaminated areas in Brazil (Risso *et al*. 2021). A field study conducted by FioCruz in 2019, within the Sawré Muybu Indigenous Land (IL), found that in the areas most affected by illegal mining, nine out of every ten Munduruku individuals were contaminated by the metal (Basta & Hacon 2020). This research included neurological, pediatric, genetic evaluations; skin samples and hair strands; measurement of hemoglobin levels, weight and height, as well as the assessment of mercury contamination in fish in the area. Considering this study, the objective of this article is to discuss measures that can be adopted by Amazonian indigenous communities that suffer similar processes. To this end, a bibliographic review of the scientific literature on the subject was carried out, including institutional and legal frameworks, medical recommendations, action plans in the health, environmental and socioeconomic areas, as well as an anthropological approach that takes into account the complex Amazonian reality. The problem that motivated the development of the present work is: how does mercury pollution cause problems in pan-Amazonian indigenous communities? This understanding will be built based on experiences encountered within the Munduruku Indigenous Community.

Sawré Muybu idigenous area: historical and social context

The Sawré Muybu indigenous land, located in the state of Pará (Brazilian Amazon), is part of the set of territories inhabited by the Munduruku indigenous people (Wuy jugu), whose nation extends along the Tapajós River basin (Figure 1):

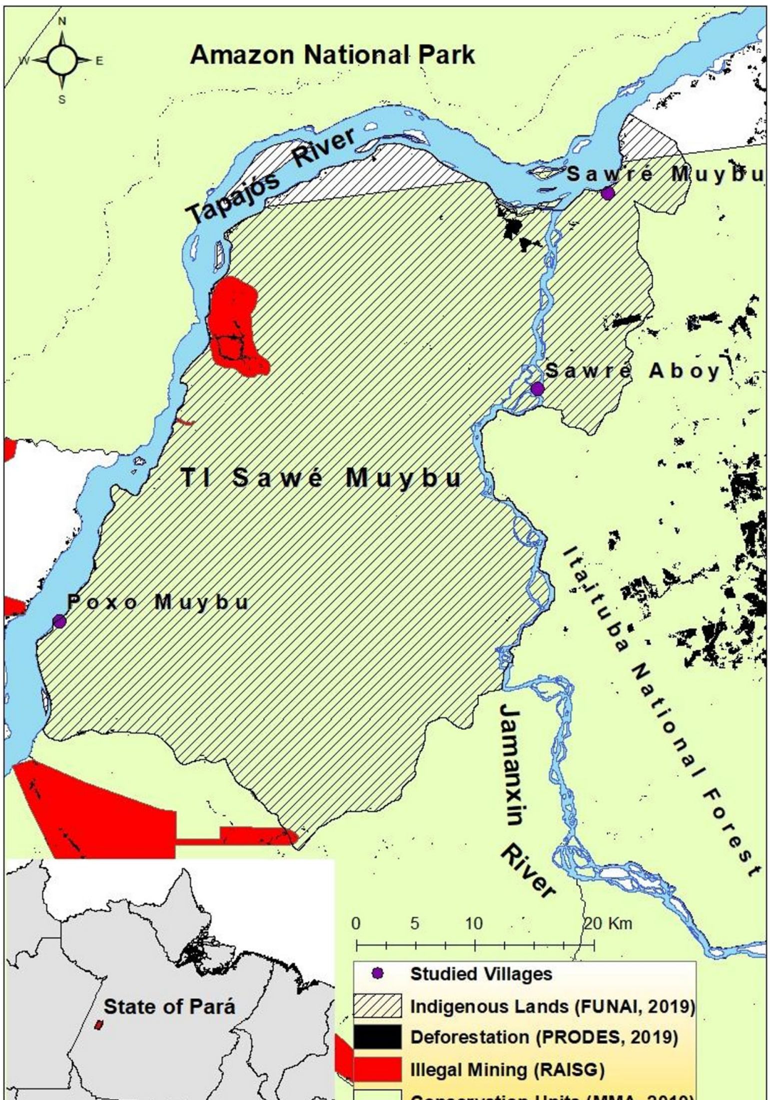


Figure 1 Map of the study area. Adapted: Just & Hacon 2020.

The Munduruku are historically recognized for their inclination towards warfare, which allowed them to impose their cultural presence in the Tapajós Valley. After the conquest, the Munduruku managed to resist the European invasion until the 18th century. During this period, missionaries led colonization efforts and facilitated the exploitation of natural resources in the hinterlands, such as cumaru wood and cocoa. However, the greatest extractive expansion experienced by the Munduruku occurred during the rubber *boom* in the 19th century. Rubber extraction led to a violent and rapid occupation of the Tapajós region, resulting in a direct assault on the indigenous population. These peoples were used as slave labor in the extractive activity (Melo 2008)

After the conclusion of the rubber extraction cycle, the territories inhabited by the Munduruku gained new value in the capitalist market due to the discovery of gold reserves in the area during the last third of the 20th century. During this period, the escalation of illegal gold mining intensified as a result of internal colonization processes sponsored by the State, such as the construction of the Trans-Amazon Highway in 1972. This pressure has escaleted in recent decades, particularly during the presidency of Jair Bolsonaro, who promoted policies aimed at strengthening the extractive fronts, which represented a setback for the advances achieved in the protection of these peoples, such as the demarcation of their territory. As Wark and Wyllys (2022) point out:

> The incursions of outsiders continue to this day, bringing violence and diseases, such as the measles epidemic of the 1940s that decimated the population, and now the mercury poisoning from wild mining. More recently, since Bolsonaro took office in January 2019, attacks by illegal miners and, directly or indirectly, by large ranchers, soybean growers, and other land grabbers have only increased, with the complicity of local and national authorities, especially after a decision by the Supreme Federal Court obliging the government to protect the Yanomami and Munduruku indigenous peoples. Bolsonaro promised not to keep "prehistoric men in zoos," not to "demarcate another centimeter" of the Amazon, and incites any kind of violence to get away with it because, for him, "where there is indigenous land, there is wealth beneath it" (Wark & Wyllys 2022).

The intensification of extractive activities in the territories inhabited by the Munduruku has led to a rapid increase in the contamination levels of essential resources for the survival of this people. Fishing is their main subsistence activity, which also supports ritual practices and community exchange. In addition to fishing, hunting, gathering and agriculture are indispensable practices for the life of the Munduruku, whose mechanisms of cultural reproduction are intrinsically related to the conservation of the environment, since it guarantees the continuity of their productive, religious and cultural practices. It's noteworthy that, for the Munduruku, the elements that define their tribes are rooted in the nature that surrounds them, so the conservation of the environment is a fundamental requirement for preserving their founding myths and the perpetuation of their ancestral language (Scopel *et al*. 2018).

The impact of mining pollution extends beyond considerations of the long-term effects that this activity can cause. This situation already shows an immediate impact not only on the inhabitants of the Munduruku territory, but also on future generations. According to a study conducted by the Oswaldo Cruz Foundation (Fiocruz) and the Center for Scientific Innovation of the Amazon (CINCIA) in cities adjacent to mining areas such as Sawré Muybu, Sawré Aboy and Poxo Muybu, 57.9% of its inhabitants have mercury levels in the body higher than the safety levels established by international standards. The main source of exposure to MeHg for indigenous peoples is the consumption of fish, which are contaminated in the waters of rivers exposed to artisanal mining. The contaminated fish, in turn, initiate a food chain that transfers mercury to individuals and even to their children through pregnancy or breastfeeding (Basta & Hacon 2020).

The accumulation of challenges that this group currently faces seriously jeopardizes their material and cultural survival. Therefore, their struggle is focused on territorial defense for the conservation of their forests and rivers, against threats such as mercury pollution derived from mining. Given this situation, the aim of this study is to undertake a holistic approach to the complex reality of Sawré Muybu, within the framework of concrete proposals for the potential execution of direct actions aimed at reducing the advancement of extractive activities in the territory.

Institutional and legal framework for the use of mercury

The Minamata Convention on Mercury (Ministry of the Environment of Peru, 2016) is a global treaty, established to safeguard human health and the environment from the harmful impacts of this element. Established in 2013 by the United Nations Environment Programme, this convention was ratified by

128 nations by the year 2021. The name "Minamata" dates back to the Japanese city that, in the 1950s, witnessed a devastating episode of mercury poisoning, resulting in thousands of lives lost and a lasting impact on the health and quality of life of the survivors. This international pact recognizes the magnitude of mercury as an environmental issue of global scale and aims at the proper management of this metal, mitigating its deleterious effects. To fulfill this purpose, the Convention stipulates a series of strategies aimed at controlling and decreasing the use, trade and disposal of mercury. Such strategies include the gradual extinction of mercury mining and its use in products such as batteries, fluorescent lamps and thermometers, as well as requiring the safe storage and disposal of mercury-containing waste. In addition, the Convention stresses the importance of international cooperation, technology transfer and capacity building as means to support the implementation of agreed commitments.

Faced with the serious dangers associated with the use of mercury, both Brazil and the international sphere have taken actions to discipline its use and mitigate its deleterious effects. In the Brazilian context, the main legal framework guiding the use of mercury is currently constituted by the "National Plan for the Reduction of the Use of Mercury in Artisanal and Small-Scale Gold Mining" (PNMC), established in 2022 by the Ministry of Mines and Energy (MME) and detailed in Sohn (2022). This plan outlines guidelines and strategies aimed at mitigating the use of mercury in gold mining, an activity highlighted as one of the main sources of environmental pollution. In addition, the PNMC aims to encourage the application of safer and more sustainable alternative technologies. Furthermore, it is based on a variety of international legal instruments aimed at regulating the use of this toxic metal.

The Judiciary and the Legislative branches have also been taking action against the improper use of mercury. In September 2021, the Federal Supreme Court (STF) unanimously ruled on the unconstitutionality of Law 1.453/2021 from the State of Roraima, which allowed licensing for mining activities involving the use of mercury. The law, challenged by the Sustainability Network through a Direct Action of Unconstitutionality (ADI) 6.672, was deemed by the rapporteur, Justice Alexandre de Moraes, as contrary to the federal model of environmental protection, which requires specific environmental permits for different phases of potentially polluting activities. In addition, the law was seen as a violation of the right to an ecologically balanced environment, according to article 225 of the Federal Constitution, and as a usurpation of the exclusive competence of the Union to legislate on mineral resources and metallurgy, in accordance with article 22, item XII, of the same Constitution.

The Bill 1011, proposed by Senator Randolfe Rodrigues in 2023, establishes the "National Policy for the Prevention of Mercury Exposure" and the "Mercury Exposure Control System" (SICEM), both aimed at monitoring mercury exposure in the Brazilian population, especially in regions affected by illegal mining. The project foresees cooperation between different levels of government and encourages epidemiological studies, providing data collected by SICEM to researchers. Additionally, it establishes an ongoing awareness campaign about the risks of mercury exposure and designates November 8th as the National Day to Combat Mercury Exposure and Intoxication. This legislation is particularly relevant in a context where Brazil, as a signatory of the Minamata Convention, seeks to reduce the use of mercury in gold mining and control its import and usage, especially in illegal activities, in compliance with international commitments.

These actions were triggered after studies revealed the alarming situation faced by the Munduruku people. Between 2018 and 2019, there was a drastic increase of 101.12% in the length of the devastated rivers in the Munduruku territory, jumping from 88.5 km to 178 km. According to a report by Greenpeace in 2020, the year in which President Jair Bolsonaro sent to Congress Bill 191/2020 - proposing the release of Indigenous Lands (TIs) for mining and energy exploration - a new wave of intense activities in the region becomes evident (Dantas 2021). As a result, on May 29, 2020, Greenpeace filed a complaint with the Federal Public Ministry of Pará (MPF-PA), requesting the immediate and permanent withdrawal of the miners from the Munduruku and Sai Cinza TIs. On June 16, the MPF filed a lawsuit requesting that the Federal Police (PF), the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama), and the National Indian Foundation (Funai) take action against illegal mining on indigenous lands in southwestern Pará and identify those who "consistently demonstrate disregard for compliance with laws that recognize indigenous rights and ensure environmental protection" (Greenpeace Brasil 2020).

In summary, the issue is complex and requires a multidimensional approach that unites local, national and international spheres. The Minamata Convention and national plans such as the PNMC are significant steps in this direction. However, it is still critical to increase public awareness of the risks of mercury exposure, implement alternative technologies in mining, and strengthen legislation and enforcement. After all, the protection of human health, the preservation of indigenous rights and the conservation of the environment are shared responsibilities, which demand the continuous and engaged collaboration of all the actors involved.

In December 2022, the Brazilian Socialist Party (PSB) filed a Direct Action of Unconstitutionality (ADI) 7273 with the Supreme Federal Court (STF) in an attempt to review the State's regulatory power over mining activities in the forest, including on indigenous lands. The arguments exposed say that the principle of good faith is highly questionable and misplaced. With that being said, the Distributors of Securities and Securities (DTVM) now adopt and store only the information provided by the sellers, who in many cases are squatters and illegal miners. It is also mentioned that Law 12,844/2013 aims to provide relief to family farmers who had losses caused by problems in the harvest (climatic events, for example), and not to deal with the transportation and commercialization of gold in the Amazon, or in Indigenous Lands (STF 2023).

Socio-environmental diagnosis

Environmental impact caused by the use of mercury in biotic components (flora and fauna) and abiotic components (soil, water and air)

Mercury is the third most toxic element on the planet, according to the U.S. Government Agency for Toxic Substances and Disease Registry (Rice *et al.* 2014). This metal occurs naturally in low concentrations in virtually all geological environments and takes various forms: elemental (or metallic), inorganic (e.g., mercuric chloride), and organic (such as methylmercury and ethylmercury) (Crespo-Lopez *et al.* 2019, Gerson *et al.* 2022). All of these forms of mercury have different toxicities and different implications for ecosystems because they are pollutants and bioaccumulative (UN Environment 2019).

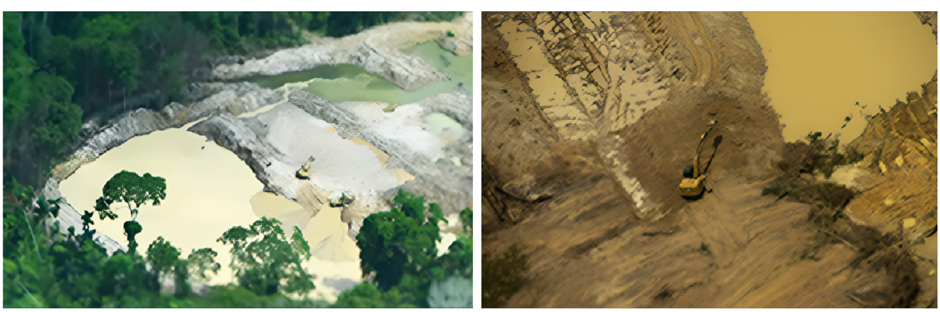
Naturally occurring mercury is introduced into the environment through volcanic eruptions and ocean emissions. Once on the air, it can travel thousands of miles in the atmosphere before being deposited back on earth in the form of rain, which involves the deposition of mercury through the actions of precipitation, snow or fog (UN Environment 2019), or dry gas, which occurs when mercury particles or vapor are deposited directly on the earth's surface (Steenhuisen & Wilson, 2019). The anthropogenic influence regarding mercury is evidenced by stationary combustion of fossil fuels (24%), biomass (21%), industrial activities (28%), and waste emissions, which include mercury-added products and account for about 7% of global emissions (Global Mercury Assessment 2018).

Anthropogenic activities such as mining pose a high risk to the environment due to deforestation, water quality degradation, and disruptions to associated ecosystems. It is even more concerning for human health due to water body contamination, where microorganisms can transform mercury into MeHg, which accumulates in fish, crustaceans, and animals that consume fish, including humans. (Steenhuisen & Wilson 2019, Crespo-Lopez *et al*. 2019, UN Environment 2019, Basta *et al*. 2021). These activities have had a historic impact on the Amazon (Sonter 2017, Paiva 2020, Couto 2021), causing intensive changes in land use (Asner 2016) and polluting fresh water with mining tailings (Webb 2004). Furthermore, the impacted areas continue to expand, encompassing both protected and unprotected regions of the Amazon basin (Roy 2018, Ferrante 2019, Rorato 2020), causing the environmental impact to grow disproportionately and making it more challenging to measure, resulting in serious consequences and negative impacts that cannot be remedied or mitigate (Tarras-Wahlberg 2000, Asner 2016).

From a historical point of view, mercury has been widely used in South America by the Spanish colonizers in gold and silver extraction activities. Between 1550 and 1880, about 200,000 metric tons of mercury were released into the environment (Malm 1998). Nevertheless, it is estimated that approximately two-thirds of the mercury present in the environment has been released during the 20th century, and the dispersed mercury load today is three times greater than that of the early 1900s (ibid.). Currently, the mercury used by illegal miners in the Brazilian Amazon would have clandestine origin in illegal markets located mainly in Bolivia. To give an idea of its high usage, for every kilogram of illegally extracted gold, approximately 2.8 kilograms of mercury are used (Indaga 2021), and it is estimated that illegal mining activity releases, on average, about 24 kilograms of mercury per square kilometer of prospected area (ACTO 2018). As pointed out by the Amazon Cooperation Treaty Organization (ACTO) in its 2018 Transboundary Regional Diagnostic Analysis of the Amazon Basin, it is estimated that the Brazilian Amazon alone received 2,300 tons of mercury until 1994, and then recorded volumes around 150 tons per year.

Mercury is extremely volatile and, in addition, does not disintegrate, that is, it does not disappear with time, but changes between different chemical forms (Crespo-Lopez *et al*. 2019, Gerson *et al*. 2022). In fact, the spread of mercury is governed by a complex global and transboundary cycle, which affects the atmosphere, hydrosphere and geosphere (UN Environment 2019, Gerson *et al*. 2022). This polluting cycle begins with the separation of gold from rock particles, sand, or other associated materials through the amalgamation process, with mercury then separated from gold through heating. This process takes place in open air and releases vapors that directly impact the health of individuals in contact, leading to organic, neurological, cognitive, and psychological deficits due to inhalation (Mercury and Health, 2017). Finally, once cold, this gas can be transported in air masses over long distances and recycled between major environmental compartments, such as lake sediments and subsurface soils, contaminating the living things that depend on these resources (UN Environment, 2019).

Contamination of soil and water resources are the most significant impacts caused by the incorrect discharge of mercury (Calderon 2020). As shown in Figure 2(a), illegal mining activity does not implement remediation or mitigation measures after the mineral extraction process. These practices lead to the formation of water pools and extensive areas of land contaminated with mercury exposed to the open air, which, through the action of microorganisms like anaerobic bacteria and fungi, have the capacity to methylate mercury in aquatic and terrestrial ecosystems (Beckers and Rinklebe 2017, UN Environment 2019, Crespo-Lopéz *et al*. 2021) This bioaccumulates in living beings (fish, macroinvertebrates, people, plants, etc.), altering the food chain of these ecosystems (Bayón 2015, Global Mercury Assessment 2018, El Comercio 2020). Another negative impact is the accumulation of sterile material from rock residues (Figure 2b), which modifies the physiography of the terrain and causes changes in land use (Calderón 2020), altering the habitat and causing sedimentation problems in the surrounding lake systems (Cao 2020).



(a) (b)

Figure 2 Impacts of illegal mining on the Tapajós River and on indigenous lands of the Munduruku people. a) Pools of contaminated water exposed along the Tapajós River; b) Debris generated by gold mining and the formation of dams for sedimentary accumulation. *Photo:* Adapted from Greenpeace Brazil 2020.

In aquatic environments, these conditions often include anoxic conditions (low oxygen) and a high level of organic matter. This is also a valid condition for terrestrial environments, where methylation can be facilitated in areas like wetlands due to the presence of certain plant species that promote microbial methylation (Crespo & López *et al*. 2021, Gerson *et al*. 2022).

However, in terrestrial ecosystems, this process is generally not as problematic because inorganic mercury tends to be less bioavailable in soils and therefore less available for absorption by organisms. Conversely, aquatic organisms can absorb different forms of mercury, primarily through food (indirect absorption), and, in a lesser extent, directly from water (direct absorption) (UN Environment 2019). Indeed, the mercury taken up by organisms undergoes bioaccumulation, a process through which organisms can absorb the contaminant more quickly than they eliminate it (Molina *et al.* 2010). Biomagnification can also occur, whereby the concentration of this pollutant increases as it moves to higher trophic levels in the food chain (Leung *et al.* 2017, Basu *et al.* 2022). In other words, as the trophic level in the food chain increases, MeHg accumulates and becomes concentrated in the tissues of higher-level predators, such as large fish and marine mammals. Therefore, carnivorous fish that feed on other fish can accumulate particularly high levels of MeHg in their tissues (Mahhaffey 1999, Leung *et al.* 2017, Basu *et al.* 2022).

Another resource affected by illegal mining is the flora. The ability of tropical evergreen forests to absorb mercury is favored by factors such as a large leaf area index and the duration leaves remain on the plant (Wohlgemuth *et al.* 2020; Feinberg *et al.* 2022). In other words, the longer lifespan of leaves also promotes absorption and higher concentrations of mercury in the forest vegetation of these ecosystems (Pleijel *et al.* 2021), which translates into impacts on indigenous populations and communities that depend on subsistence agriculture and the use of non-timber forest products**.**

In addition, the deforestation processes in these territories in the exploration and exploitation phases have caused the degradation and loss of all vegetation as can be seen in Figure 2 (a) (b), in addition to the alteration of drainage systems and the destruction of the habitat of numerous species of fauna associated with these ecosystems (Minam 2016). Thus, deforestation in these areas, which between 2010 and 2020 grew by 495%, according to a study conducted by the organization MapBiomas (MapBiomas 2020, Salazar 2021). The MapBiomas report points out that 65% of mining activities in the Brazilian Amazon basin are not legal and that the installation of "Garimpos" has quintupled on indigenous lands and grown 301% in conservation areas. Mining activity extended to an area of 6,500 hectares per year between 2010 and 2020, showing an average annual increase of 1,500 hectares in the period from 1985 to 2009 (MapBiomas 2020, Salazar 2021).

The Munduruku territory is one of the 34 protected areas in Brazil where illegal mining is present (Inpe 2021) and accounts for 60% of deforestation alerts in indigenous lands in the Amazon, identified by the National Institute for Space Research (Inpe) between January and April 2020 (Instituto Igarapé 2020). With the aid of satellite images, it was determined that in 2021, there was a 58% increase in the deforestation rate (Inpe 2021).

Impacts on human health

From a historical perspective, mercury has been utilized for almost 3000 years (Ye *et al*. 2016). Used by the Egyptians, Phoenicians, and Greeks, it held magical significance in alchemy, where it was known as "the messenger of the gods." Its name in the periodic table of elements comes from the Latin word "hydrargyrum" (Hg), which means "liquid silver." (Faria 2003)

The toxic action of mercury on human health has also been known for some time. Indeed, starting from the 17th century, hat-making was a notoriously hazardous occupation, as it involved the use of large quantities of this metal. Mercury poisoning has become so common among hat makers in Victorian Britain that Lewis Carroll is believed to have had the disease in mind when he invented the character of the Mad Hatter in "Alice's Adventures in Wonderland." In addition, the psychotic symptoms of mercury poisoning have been studied since the 18th century, when mercury drugs began to be widely used in the treatment of syphilis (Waldron 1983).

The story of mercury poisoning on both small and large scale has been amply illustrated by Coulter (2016). As mentioned historically, the first well-documented case of acute mercury poisoning due to the consumption of contaminated fish occurred in Minamata, Japan, in 1953. The clinical condition was officially recognized and named Minamata disease in 1956. However, many years later, the definition of this disease in terms of clinical symptoms and extent of lesions is still being debated. Biological measurement (biomonitoring) of mercury in hair, blood, nails, and urine, for example, allows quantifying the exposure and relating it to potential health effects**.**

Currently, the literature on intoxication and exposure to inorganic mercury in humans consists of clinical case reports (Teixeira *et al*. 2018). The most recent research focuses on the study of health effects in cases of chronic, low- or moderate-grade exposure (Ye *et al*., 2016). In this regard, it should be noted that numerous studies are still being conducted and that the clinical manifestations of mercurial syndrome and the pathophysiology of mercury poisoning also depend on the form and, in some cases, the route of contamination by the substance.

Methylmercury is a fat-soluble molecule easily absorbed and bioaccumulated by low-taxon organisms (Mahhaffey 1999) and therefore biomagnified along the food chain (Basu *et al*. 2022). In the Amazon this represents a major problem, as several communities depend on these fish species as a source of protein (Azevedo *et al*. 2020). MeHg neurotoxicity has been documented in several studies (Branco *et al*. 2021, Santos-Sacramento *et al*. 2021, Paduraru *et al*. 2022). This toxin can interact with enzymes, cellular membrane functions, and neurons, causing oxidative stress, lipid peroxidation, and mitochondrial dysfunction. Additionally, it hinders satisfactory synaptic transmission (the connection between a neuron and another cell) and disrupts the proper transport of amino acids within cells (Crespo-López *et al*. 2005).

In the case of the reproductive system, toxicity from MeHg can lead to chromosomal abnormalities (National Research Council 2000). High concentrations of MeHg cause a reduction in sperm count and testicular atrophy (United States Environmental Protection Agency 2001). In pregnant women, mercury is transmitted to the fetus through the placenta (National Research Council 2000), causing issues during organ development (Ha *et al*. 2017). Grandjean *et al*. (2010) reported issues in newborns, such as low birth weight, delayed neuronal development, and overall slow growth of children (United States Environmental Protection Agency 2001). A significant positive correlation has been documented between mercury concentrations in mothers' and children's hair, transmitted through breast milk (Marques *et al*. 2016).

Several symptoms of Minamata disease, associated with high levels of mercury exposure, have been observed in communities in the Amazon (Crespo-Lopez *et al*. 2021). The inhabitants of these communities can consume between two and six times the recommended maximum levels of MeHg (Crespo-Lopez *et al*. 2021), accumulating mercury levels higher than 6.0 µg/g, which is considered a health risk (Basta *et al*. 2021).

Lacerda *et al*. (2020) determined that the inhabitants of the Tapajós community (Pará) had significantly higher concentrations of mercury than the gold miners exposed to mercury vapors in Serra Pelada (Pará). This was linked to visual impairment in the Tapajós community. Basta *et al*. (2021) found somatosensory alterations and verbal fluency issues in individuals over 12 years old. The prevalence was higher in the Sawré Aboy and Sawré Muybu communities, where mercury exposure levels exceeded 10 µg/g (according to WHO, safe accumulation levels should be below 6 µg/g). Oliveira *et al*. (2021) found similar patterns in the residents of Poxo Muybu, despite lower mercury concentrations compared to the aforementioned communities. However, the population levels are also above the safe concentration limit for the body.

Other documented symptoms in Amazonian communities include motor deficits (problems with movement coordination, for example) (Costa *et al*. 2017; Basta *et al*. 2021) and emotional disorders such as anxiety and insomnia (Costa *et al*. 2017). Neuronal development issues have been detected in children, as well as psychomotor problems, visual disturbances (Fillion *et al*. 2013), and difficulty in processing and recalling information (Santos-Lima *et al*. 2020).

Socioeconomic impacts

In addition to the serious impacts on human health, the illegal gold mining and its polluting effects alter the lives of communities, which suffer from it in various ways. First and foremost, it is essential to acknowledge the scope of the problem generated by the constant expansion of the mining front into the territories traditionally inhabited by indigenous peoples in the Pan-Amazon region, particularly the Munduruku people along the Tapajós River. This threat is systematic because Brazil is part of an iron and gold extraction chain in which the country plays a decisive role, as it currently holds one of the world's largest gold reserves, along with others in the Amazon basin, such as Venezuela (Manzoli *et al*. 2021), which also holds a significant reserve located in areas primarily inhabited by Amazonian indigenous peoples.

In this scenario, indigenous peoples experience the greatest externalities of the extraction process in ecological, cultural, and economic spheres, resulting from illegal activities linked to mineral extraction, primarily gold. These activities are carried out using unregulated artisanal techniques that are not guided by any legislation aimed at containing or controlling the impact arising from the environmental liabilities left by this activity in the territory.

In the case of the Munduruku population and others in the Amazon basin, impacts stand out in the concentration of common goods, such as pollution in aquifers, soil deterioration, and the impact on flora and fauna, often consumed by these groups. On the other hand, illegal mining is detached from the state's tax system, as its activity goes undeclared, leading the state to bear its consequences (environmental remediation) without benefiting from its profits. According to a report from IWGIA, in the Tapajós basin, the Munduruku territory, at least "30 tons of gold per year, approximately R$ 4.5 billion in undeclared income, which is six times more than the legal activity in the region," are extracted (Alcántara 2021).

In the indigenous community areas, mining resorts to acts of violence and extortion by mining groups towards its inhabitants, degradation of the indigenous community fabric, recruitment processes, and pressure exerted by miners, occupation and establishment of external hubs whose social development occurs within a framework of urban dynamics and extensive pollution. This is further compounded by the alteration of the consumption habits of these communities, introducing new products detrimental to their health and social fabric, such as alcohol and drugs.

These impacts develop in parallel with an ecologically compromised context, widely contaminated by chemical residues such as mercury, which spreads in the water and fish consumed by these established populations. At the same time, we must add the forced displacement of communities threatened by the presence of miners, which, concurrently, leads to other phenomena, such as the labor exploitation of these communities, as well as the trafficking and sexual exploitation of children(Matos, 2016).

A study conducted by the NGO Global Initiative against Transnational Organized Crime in 2016 showed the links between illegal gold mining and organized crime in countries such as Bolivia, Brazil, Colombia, Ecuador, Guyana, Mexico, Nicaragua, Peru and Venezuela. The investigation revealed that this activity contributes to phenomena such as funding insurgent groups, money laundering, and corruption. In addition, it causes the forced displacement of the local population, accelerates environmental destruction and promotes the labor and sexual exploitation of its inhabitants (Global Initiative Against Transnational Organized Crime 2016).

In this scenario, mining has contributed to the exacerbation of one of the fundamental problems historically faced by Amazonian indigenous communities, which is the lack of demarcation of their territories. From this, one can get an idea of the legal void that enables the appropriation, contamination, and destruction of the lives and the environment of these communities. This state of abandonment became more extreme during the tenure of Jair Bolsonaro's administration, characterized by policies that turned genocidal and anti-indigenous. These policies facilitated the expansion of extractive activities in Amazonian territories, even in areas designated as protected.

Action plans

The development of an action plan requires a solid understanding of the sector in which mining activities take place, in order to support the formulation of realistic and effective strategies that are in line with the law and to measure progress in their implementation (Keane *et al*. 2023). This requires data collection regarding the utilization and practices of mercury in small-scale gold mining (ASGM) sites, stakeholder consultations, as well as reliable literature and socio-economic, health, and environmental information, as demonstrated by O'Neill & Telmer (2017).

The information should focus on data such as: the estimated amount of mercury used by the sector, the estimated amount of gold extracted, the estimated number of miners involved in the sector (by gender), and detailed geographical information about artisanal and small-scale gold extraction. Additionally, qualitative information has been collected, including the presence of worst practices, as well as various documented environmental, health, and socioeconomic information (Keane *et al*., 2023).

Environmental Impacts

Assessment of the importance of impacts

The assessment of the environmental impact will be conducted based on the significance and adverse effects caused to the environment, the geographical extent of the impact, the duration and frequency, the irreversibility of the impact, and the magnitude of the alteration of the component. The application of these criteria is subjective and will require justification with quantitative and qualitative data from the environmental assessment.

The suggested criteria for assessing the significance of the impact on the environment will be as follows: vegetation physiognomy, protected area or species; regional or global importance of the resource (flora and fauna); relationship of the resource with local populations; and socioeconomic factors. The suggested criteria for assessing the geographical extent of the impact on the environment will be related to whether the impact is local, regional, or international; the duration of the impact will be linked to the temporal scale of the activity, whether it's temporary, short-term, long-term, or permanent; frequency, based on the rate at which the activity occurs or repeats over a certain period of time, whether it's intermittent, seasonal, or constant; risk, based on the likelihood of the impact occurring: unlikely or probable; reversibility (resilience), determined by whether the impact is irreversible or the resource recovery is short or long-term; and the magnitude of the alteration of the environmental component, whether it's small, moderate, or significant; along with a plan for continuous monitoring of the influence of mercury on the environment. This information will be used to propose measures for controlling and mitigating the impacts caused to the environment.

Review and strengthening of the regulatory and procedural framework

The review of regulations and formalization procedures is proposed, involving the revision of the regulatory framework and assessing the need for updates. Additionally, conducting a mining census and updating the registry to understand the current situation (number of miners involved in the sector) are also proposed.

Strategy for reducing mercury releases and exposure risks, and eliminating worst practices

Promoting the adoption of efficient technologies for gold extraction and processing without using mercury involves conducting research on market-available technologies that could be applicable to the context, transferring applicable technology knowledge to the community, and fostering partnerships with universities and research centers to include alternative mercury-free technology research. Additionally, providing education and information through the development of training programs based on lessons learned and successful cases.

Strategy for controlling illegal trade and the use of mercury

Strengthen the control and monitoring system for the trade and use of mercury, by planning and executing control operations in coordination with competent state institutions, to verify the use of mercury.

Strategy for reducing illegal mining extraction

By enhancing local capacities for preventing and combating illegal mining activities and promoting alternative productive endeavors to discourage mining development in sensitive areas, as well as implementing intervention and early warning plans in areas vulnerable to the expansion of illegal mining.

Food

Carnivorous fish species, being at the top of the food chain, tend to accumulate higher amounts of mercury in their bodies (Leung *et al*. 2017). Therefore, it is advisable to avoid consuming these species until mercury levels are deemed tolerable as food.

In this regard, it is proposed to directly engage with local communities, in collaboration with Funai, to raise their awareness about the issue of mercury and its consequences. It is possible to identify fish species that are safer for consumption; for example, herbivorous and/or detritivorous fish with lower mercury concentrations. However, the abundance of aquatic species with these characteristics is lower. Another crucial measure would be to implement alternative protein sources. In the Amazon region, there are numerous plant species with high protein content, such as (Shanley *et al*. 2012):

- ♦ Bacuri – *Platonia insignis* Mart. 100 grams (g) of pulp contains 1.9g of protein.
- ♦ Burití, – *Mauritia flexuosa* L.f. whose pulp contains 11% protein.
- ♦ Brazil nut – *Bertholletia excelsa* Bonpl. whose flour contains up to 46% protein. Walnut can contain 12 to 17 percent protein, which is half the content present in beef and twice the calories.
- ♦ Patauá – *Oneocarpus bataua* Mart. 100 g of oil contains 3.3 g of protein, slightly more than cow's milk.

This is an emergency strategy that could drastically reduce mercury intake in indigenous communities. However, these measures should be introduced gradually and in line with local traditions, as these resources are essential for their survival.

Socioeconomic

It's important to acknowledge the pivotal role played by indigenous communities like the Munduruku in safeguarding their vital spaces and assets for proper management, organization, delimitation, and utilization of their resources. To achieve this, it's crucial to establish a legal framework of recognition (territorial demarcation) and consultation concerning the use and exploitation of the territory by third parties or under dynamics that deviate from the community's traditional practices.

In this situation, three fundamental aspects come into play for the restoration of the territory and the affected communal structure due to the ecological and spatial deterioration caused by mining activities. The first aspect involves the detoxification of soils and rivers that impact the flora and, particularly, the consumable fauna (fish), which leads to the contamination of the inhabitants of the region. Secondly, there's the economic compensation arising from mining activities that directly affect the communities, preventing them from continuing their traditional productive practices. Lastly, there's the strengthening of the communal structure of the Munduruku people and other Amazonian indigenous and quilombola communities, who are socially impacted by recruitment, violence, and other strategies aimed at undermining the communal core in the presence of extractive fronts such as gold mining.

At the international level, it is important to highlight ecological consciousness and human solidarity in order to raise awareness about the consequences of consuming products or goods with proven ecological and social impacts, such as gold and other metals. Cultural degradation within communities should be averted by establishing a concrete state authority presence that safeguards indigenous populations like the Munduruku and other Pan-Amazonian peoples.

It's also important to control the resources derived from this activity, thereby preventing the excessive introduction of settlers associated with or near this type of occupation. This approach helps curb the development of semi-urban centers or villages within the Amazonian territory, which can carry substantial social and ecological impacts due high levels of pollution. It is also necessary to consider constant monitoring of decontamination and ecological restoration processes, where the self-organized participation of peoples plays a key role.

Conclusions

Among the practices employed in mining, one that has caused a significant impact is the use of mercury as an intrinsic component of the amalgamation process and subsequent gold recovery, an activity that has been carried out for decades within the Munduruku territory, systematically threatening human health and the environment. Impacts such as deforestation, loss of biodiversity, water body contamination, bioaccumulation in living organisms, and human health issues have been part of the reality of this area. Given this challenge, it is essential for state institutions to take a leading role and commit to constant monitoring, as well as establishing qualitative and quantitative indicators for tracking and assessment. This approach aims to propose strategies that encompass revising and strengthening the regulatory and procedural framework, controlling illegal mercury trade and usage, enhancing capacity, facilitating technology transfer, and promoting social and gender inclusion.

In recent years, the national governments that are signatories to the Minamata Convention have prepared "Initial Assessments of Minamata" reports to verify compliance with the obligations set forth in the protocol, which came into effect in 2017. The outcomes of these reports raise concerns, as it seems that governments and health ministries in various countries have not fully engaged in adhering to the signed agreements. Specifically, it appears that many nations have neither implemented the public health strategies (health data collection, healthcare professionals' training, and awareness initiatives through healthcare facilities) nor the strategies to prevent the exposure of vulnerable populations.

In this scenario, three fundamental approaches have been identified to comprehensively address the issue, focusing on both the ecological environment and the communities inhabiting it. The first involves the urgent implementation of river and soil decontamination processes, achieved through innovative solutions in collaboration with those communities and their environmental knowledge. Secondly, there's the economic restitution to communities affected by mining, as well as the promotion of traditional productive activities that provide viable survival alternatives, steering the population away from illegal dynamics driven by gold mining. Thirdly, it is necessary to formulate strategies to restore and enhance the communal structure of Amazonian indigenous and quilombola communities, encompassing effective state intervention to limit the expansion of colonization fronts and the infiltration of external actors into these communities' territories.

These processes undoubtedly should prominently involve community leaders. For this purpose, Law 1011 of 2023 (mentioned in the Legal Framework) introduces positive innovations, particularly by emphasizing the requirement to develop local strategies originating from communities and coordinating them with broader projects at the federal and national levels (Chapter III).

However, these are general recommendations, as the proposals should be adapted to the reality of the peoples inhabiting this territory. Clearly, the creation of an overarching intervention plan, studied on a broad scale, has its limitations, since each empirical reality presents ethnographic specificities that must be considered in developing practical solutions. In this regard, ethnobiology and ethnoecology – understood as the study of the knowledge, perceptions, and practices of human communities in relation to their surrounding environment – are indispensable analytical tools to ensure the effectiveness of any specific action plan.

Regarding the implementation of a health intervention plan, for instance, it's crucial to acknowledge the limits of medicine, based on therapeutic intervention techniques that take into account the anatomical and physiological dimensions of each organism. In other words, it's imperative to consider the meaning patients attribute to their illness experiences. Neglecting this dimension could undermine therapeutic effectiveness itself. Human experience is symbolically organized, and illness itself should be viewed as a culturally shaped experience. For a better understanding, the impact of mercury on health is depicted in Figure 3.

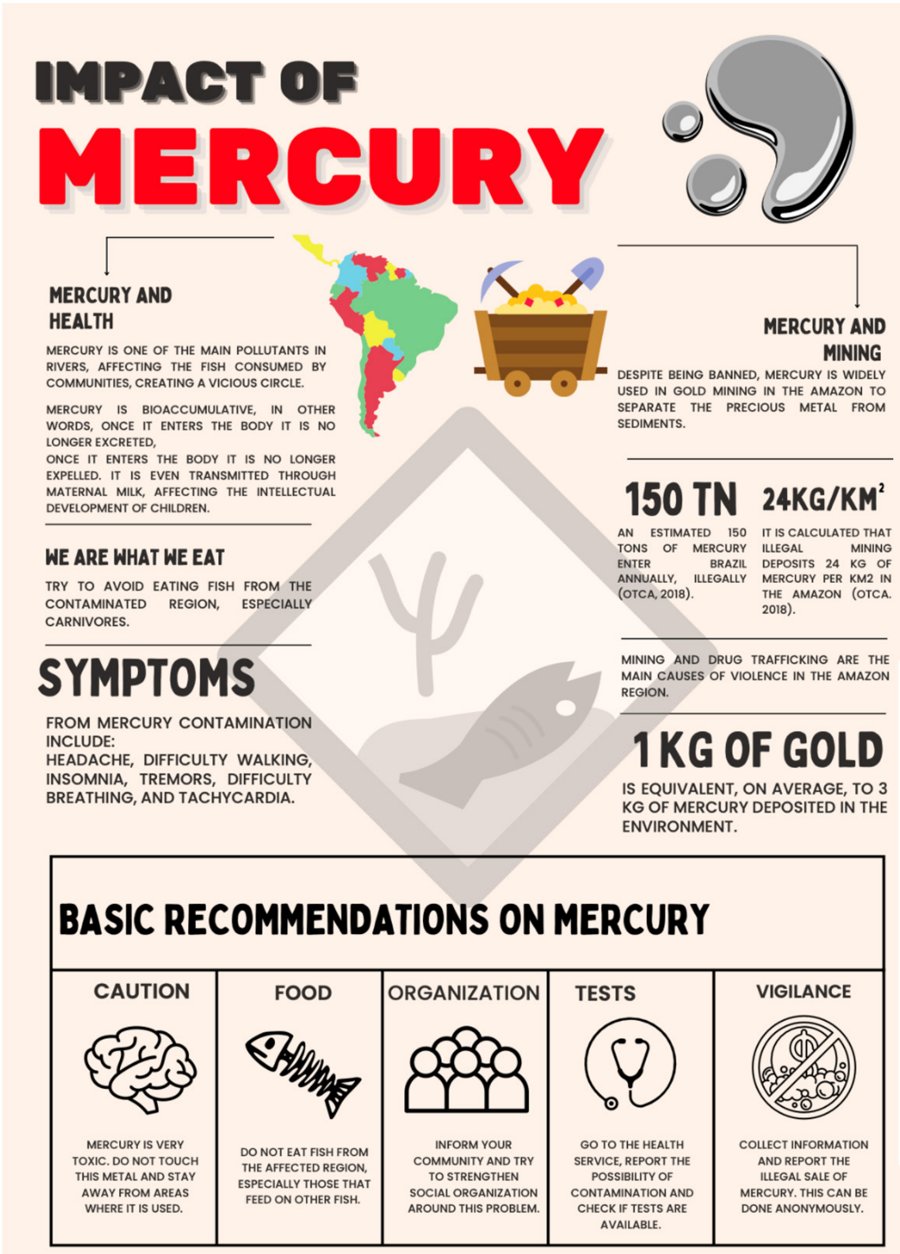


Figure 3 Infographic on mercury and mining.

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Ethics – This study does not involve human subjects and/or clinical trials that should be approved by the Institutional Ethics Committee.

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Inclusion and cultural diversity in the Amazon Basin, from the local to the transnational level

- Inclusion, access, and retention of Indigenous students in university: reflections on potential improvements for the University of the State of Amazonas
- Urban diversity in the Amazon and global agendas for urban sustainability: proposals and challenges for the Mesoregion of Marajó – Pará
- Territorial rights and biocultural diversity conservation in Amazonia: a case on demarcation and titling of indigenous and maroon territories in Brazil, Ecuador, and Suriname

Inclusion, access, and retention of Indigenous students in university: reflections on potential improvements for the University of the State of Amazonas

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ABSTRACT

The central aim of this work is to provide an overview of the current status, challenges, and potential solutions related to the inclusion, access, and retention of Indigenous students in Brazilian universities. Through an integrative review, data were collected regarding the perspective of indigenous university students on the subject. Due to the relevance of the state of Amazonas in concentrating the greatest diversity of Indigenous ethnicities (63) in Brazil, we selected University of the State of Amazonas (UEA, for its Portuguese acronym) as the focus of this work. The results were organized into five categories: (i) Access to the university; (ii) Retention; (iii) Discrimination against Indigenous students in the university environment; (iv) Indigenous and traditional knowledge within the university context; (v) Demands of the Movement of Indigenous Students of Amazonas (MEIAM, for its Portuguese acronym) for inclusion, access, and retention at UEA. We believe that the work has the potential to contribute to reflections and actions by individuals and collectives committed to guaranteeing the inclusion, access, and retention of Indigenous peoples in Brazilian universities. Our target audience are decision-makers in Brazilian universities, mainly at UEA, specifically those who work in the following departments of the institution: Pro-Rectory for Administration, Pro-Rectory for Extension and Community Affairs, Pro-Rectory for Undergraduate Education, Pro-Rectory for Interiorization, Pro-Rectory for Research and Postgraduate Studies, and Pro-Rectory for Planning. In order to reach a wider audience, we also produced a cartoon that discusses the theme.

Keywords: Indigenous education, inclusion, retention.

Introduction

Have you ever stopped to reflect on people's access to university? Do you believe that all Brazilians have equitable conditions to access and remain in higher education? What goes through your mind when you observe the cartoon below (Figure 1)?

Figure 1 Cartoon: University and Indigenous peoples (Albuquerque 2023).

In the cartoon, we see a representative of Indigenous peoples, a woman, paddling towards the university and encountering an institution surrounded by a fence. This demonstrates that, despite the efforts along the way, such as those related to literacy and basic education, moving to a different city, immersing oneself in another culture, and distancing oneself from the family, they are not always sufficient when an Indigenous person wishes to enter higher education.

According to data from the 2010 Census, there are approximately 896,917 Indigenous people residing throughout the Brazilian national territory, both in urban (324,834) and rural areas (572,083) (IBGE, 2010). There are 274 Indigenous languages used by 305 different ethnic groups, representing Brazilian cultural diversity (IBGE, 2010). The social organizations, customs, languages, beliefs, traditions, lands and territories of these peoples are supported by the Brazilian

Constitution (Art. 231, CRFB/88), as well as the right to education, which aims at the full development of the person, their preparation for the exercise of citizenship, and their qualification for work (Art. 205, CRFB/88). Sub-constitutional legislations, such as the National Education Guidelines and Bases Law (LDB) and the National Education Plan (PNE), are instruments that deal with the rights of Indigenous people to higher education. In 2009, only 8,411 Indigenous individuals had enrolled in Brazilian universities, but by 2019, this number had risen to 72,086, representing an increase of over 757% (INEP 2020). Although there is a growing number of enrollments, this percentage can still be considered small compared to the total number of Indigenous people in Brazil. Policies that concretely contribute to the inclusion, access and retention of Indigenous students in public higher education are still incipient and lack diagnoses about their effectiveness.

The logic of Western culture, introduced in Brazil through colonization, establishes hierarchies within educational systems focused on academic knowledge, sidelining non-academic, traditional, and Indigenous wisdom (Machado & Beltrão, 2018; Baniwa, 2019). Academic knowledge predominantly operates within a framework centered on the "monoculture of knowledge and the rigor of learning," elevating academic expertise while diminishing other forms of wisdom, like traditional knowledge (Santos, 2007). Consequently, only classroom-acquired knowledge is esteemed, which stands in contrast to Indigenous and traditional wisdom, often acquired through everyday practices within specific cultural contexts (Machado & Beltrão, 2018). The reproduction of these systems by universities occurs in various forms within the structures of these institutions. Examples include the assumption that the only existing logic is based on reasoning as established by a Western cosmovision, as well as the emphasis on writing as a central form of language expression. In contrast, one of the main characteristics of Indigenous knowledge is the diversity of languages, worldviews, ways of living and territories. These forms of knowledge are unique and, most of the time, shared orally and through practical means (Toledo & Barrera-Bassols 2008; Machado & Beltrão 2018).

In the Amazon Biome, traditional and Indigenous knowledge is especially relevant for the conservation of the region, for the maintenance of socio-biodiversity, and for both the material benefits (such as planetary climate regulation, maintenance of carbon stocks, biodiversity) and immaterial benefits (such as cosmovision, beliefs, symbols of a diversity of peoples) that diversity generates for quality of life (BPBES 2018; SPA 2021). Historically, the traditional knowledge of Indigenous peoples, their territories, and their population has been affected by various conflicts. The risks persist due to several factors: first, colonization, followed by scientism and spiritual persecution, and, more recently, global capitalism and current paradigms that support models of development and conservation (Gómez-Baggethun 2021). Currently, the differences between academic knowledge and the ways of seeing and inhabiting the world of Indigenous peoples make us reflect on the importance of the university to dialogue with different knowledge systems for the inclusion of Indigenous peoples, and to generate new knowledge capable of dealing with contemporary issues, such as the climate crisis. The challenge posed to Brazilian universities is "to enable the circulation and validation of other knowledges, based on other cosmological, philosophical and epistemological bases" (Baniwa 2013, p. 2).

Thus, the aim of this work is to provide an overview of the current status, challenges, and potential solutions related to inclusion, access, and retention of Indigenous students in Brazilian universities. Our focus is the Brazilian context, and we use the example of the University of the State of Amazonas (UEA) as a focal point for empirically articulating how these challenges unfold and what potential paths exist for solutions centered on the lived experiences, perceptions, and demands of Indigenous students. Specifically, the guiding questions of this work are: (i) What is the current panorama of inclusion, access, and retention of Indigenous people at UEA? (ii) How can UEA improve its strategies for Indigenous inclusion, access, and retention in higher education? To support our arguments, we also draw on experiences from other universities and countries in Latin America in order to discuss the issue.

It is important to highlight that we, the authors of this work, are researchers from different areas of knowledge and we are not Indigenous. We are motivated to discuss the theme due to our concern regarding the current situation that Indigenous people face in accessing and remaining at the university (Box 1). We present a perspective on the subject that by no means intends to exhaust the approach; in other words, it is one perspective among many other possible ones. We recognize the importance and necessity of redefining the ways in which scientific knowledge is produced and the structure of universities in order to enhance the inclusion, access, and retention of Indigenous students who aspire to pursue higher education. Furthermore, we believe that academic scientific knowledge can strengthen itself by drawing closer to the knowledge held by Indigenous peoples.

Box 1 – Positionality statement of the co-authors group

We are a group of Latin American researchers (from Brazil and Mexico) engaged in research, teaching, and outreach activities in the Brazilian Amazon. Our group comprises doctoral students, postdoctoral researchers, primary school teachers, and university professors working in various disciplines, including environmental education, law, communication, ecology, sustainability, and anthropology. We are a non-Indigenous group with experience in collaborating with Indigenous people. Our interest in the theme of inclusion, access, and retention of Indigenous students stems from our experience in higher education, where we have observed an underrepresentation of Indigenous students in the institutions we are affiliated with. Specifically, two co-authors are university professors who work directly with Indigenous students and movements at the University of the State of Amazonas and the Federal University of Rondônia.

Methods

A review aims to synthesize information and knowledge that already exist about a particular topic (Toronto 2020). There are several types of reviews (Grant & Booth 2009), with the most common being narrative, systematic, and integrative (Whittemore *et al*. 2014). In this work, we used an integrative review to describe an overview of the topic, using the research questions as a guide for our searches. The integrative review allows for a broader understanding of a subject (Broome 1993), as the method enables the identification of various types of materials (Soares *et al*. 2014). The sampling can be composed of empirical and/or scientific knowledge; in this study, we used letters, videos, interviews, and scientific articles.

This type of methodology can be put into practice through six phases (Souza *et al*. 2010, Whittemore & Knafl 2005):

1. **Guiding question**. In this stage, the research problem and objective are defined. The guiding questions in our case were: (i) What is the current status of inclusion, access, and retention of Indigenous people at UEA? (ii) How can University of the State of Amazonas improve its strategies for inclusion, access, and retention of Indigenous people in higher education?
2. **Literature sample**. In this second phase, the types of data, as well as the criteria for including and excluding reference materials, are outlined. In order to have a holistic view of the proposed topic, searches were conducted on Google and Google Scholar platforms, focusing on key-

words such as "student", "Indigenous", "university", and "University of the State of Amazonas". All searches were conducted in Portuguese. The keywords were used to allow for variations (for example, singular and plural versions of the same word). Additionally, a snowball sampling approach was employed. If the sources found cited other works that we considered relevant, they were also included in the sample. The searches were not limited to academic sources only because, given the chosen topic, Indigenous perspectives are crucial. Therefore, interviews, letters, and videos available on the YouTube platform, authored or featuring Indigenous students, were also considered as sources, as well as searches in UEA's data sources available on the official website. Specifically, to find news on the topic, a search was also conducted on the Amazônia Real journalism portal (Lima 2019).

3. **Data collection**. With the material in hand, the third stage involves selecting relevant information. In this case, we focused on information and data about the access and retention of Indigenous people in universities, Indigenous testimonies about their aspirations regarding their higher education, and success stories of Indigenous people at universities in Latin American. The documents were selected for data collection if they represented direct discourses of Indigenous people (Mendes *et al*., 2008).
4. **Critical analysis**. In this stage, the collected data is synthesized and critically analyzed. The results were grouped into 5 categories: (i) Access to university; (ii) Retention; (iii) Discrimination against Indigenous students in the university environment; (iv) Indigenous and traditional knowledge in the university context; (v) Demands of the Movement of the Indigenous Students of Amazonas (MEIAM) for inclusion, access and retention at UEA. The categories were created after a floating reading of the collected results and identification of emerging themes
5. **Discussion of results**. In this phase, the information is problematized. In the present study, gaps are identified and proposals for improvements are outlined for the construction of a more inclusive higher education for Indigenous people. In addition to this, there is a discussion based on identifying similarities and differences between UEA and other Latin American and Brazilian universities, considering certain educational policies.
6. **Presentation of the integrative review**. Finally, the sixth step involves the dissemination of the research results. A summary of what was iden-

tified and the proposed improvements are synthesized in the present text and in a cartoon (which uses drawing as a global language and has a critical appeal) (Silva 2008). Both communication resources have the potential to generate social mobilization in favor of improving Indigenous higher education.

1. Study area – University of the State of Amazonas (UEA): challenges related to inclusion, access, and retention faced by Indigenous students

University of the State of Amazonas (UEA) started its academic activities in 2001. As a public state university, UEA is maintained by the government of the state of Amazonas and is funded through a system linked to the revenue of the Industrial Pole of Manaus (also known as Manaus Free Trade Zone). Currently, it has approximately 25,000 students (undergraduate and postgraduate) and offers 286 undergraduate, 64 specialization, 15 master's, and 5 doctoral courses. UEA is the largest multi-campus university in Brazil, with units spread across various municipalities in the state (Figure 2). Thus, it is possible to recognize the significant role of UEA in the expansion of higher education in the Amazon. According to Sabino *et al*. (2022), UEA's presence in various locations has stimulated intellectual and socio-economic development while broadening the horizons of the population.

The process of interiorization also involved the adoption of multiple teaching strategies. Costa and Oliveira (2011) describe the teaching modalities adopted by UEA, including traditional face-to-face teaching, a modular face-to-face teaching system in which teachers travel to municipalities to fulfill their workload during certain months of the year, and a face-to-face teaching system mediated by technology in which live classes are transmitted via satellite to various municipalities, and each classroom has an in-person teaching assistant. The application of several strategies to increase access to higher education demonstrates how UEA "turned the state of Amazonas into a large classroom" (Costa & Oliveira 2011, p. 40). This underscores the university's significant role for the entire state of Amazonas.

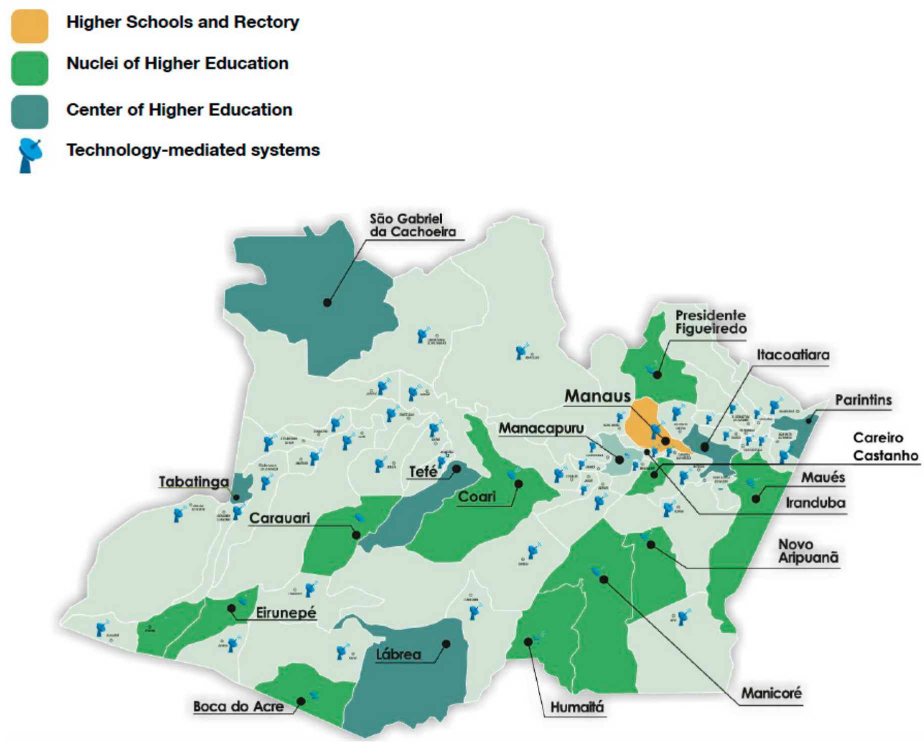


Figure 2 University of the State of Amazonas (UEA) in the state of Amazonas, Brazil. UEA has different units and infrastructures (schools, nuclei, centers, and technology-mediated systems) and models of teaching, research, and extension in different cities in the Amazon. *Source:* UEA Student Handbook (2020).

UEA has a mission to “promote education, build scientific knowledge, and foster technological innovation to meet societal demands and integrate with society in order to overcome the challenge of developing the Amazon sustainably,” based on values of respect, justice, freedom, innovation, social responsibility, citizenship, and the valorization of employees, teachers, and collaborators (UEA, 2020). Thus, we infer that UEA’s mission necessarily involves the inclusion and valorization of traditional knowledge, associated with the access and retention of Indigenous students in the university. It is worth noting that although our work focuses on Indigenous students, this mission also involves the presence and inclusion of Indigenous professors and staff in the university. Indigenous professors like Gilson Ipaxi’awyga Tapirapé at the Federal University of Goiás (UFG), Gersem José dos Santos Luciano Baniwa at the Federal University of Amazonas (UFAM), and Almires Martins Machado at the Federal University of Pará

(UFPA) are some of the leaders who work at the interface between Indigenous and academic knowledge. Therefore, we understand the relationship between Indigenous people and the university as a two-way street in which both can benefit, generating positive changes for education and society as a whole. Lima's report (2019), published on "Amazônia Real" investigative journalism portal, exemplifies the meaning of the university for an Indigenous student at UEA:

> *"When we enter a public university, we don't enter just for ourselves. It's not an individual thing, it's a collective, it's a people. We are representing, beyond the individual, our family, our clan, our ethnicity, our people, and the place we came from. So, they expect this from us, they expect this return. The family supports the idea of having a relative in the university. It's rewarding."* (Indigenous university student quoted by Lima, 2019).

Baniwa (2013) reinforces the challenge of individual entry into the university, given that the cultural and Indigenous rights system is based on a collective perspective, as mentioned by the university student above. However, it is worth noting at this point that the social impact of an Indigenous student's enrollment is significant due to their representation within their own people.

Starting from the premise that UEA is an agent of positive change in the state of Amazonas, but still faces several challenges to effectively value traditional knowledge and include Indigenous students, the following section (results and discussions) explores an overview of the current situation of Indigenous students, focusing on the main challenges. Based on the identification and discussion of challenges, we propose some strategies, inspired by success stories from experiences reported in the literature, as well as potential solutions to some of the identified problems.

Results and discussion

2. Access to university

Amazonas is the state with the largest Indigenous population in Brazil. According to the 2010 census, more than 180,000 Indigenous people inhabit the state, accounting for about 20% of the total Indigenous population in the country (IBGE 2010). Although UEA was established in 2001, the first record of Indigenous students enrolled only occurred in 2006 when three Indigenous students entered the university. This fact may be associated with the promulgation of Law

No. 2,894/2004, also known as the "UEA Quotas Law." This state law establishes guidelines for the allocation of seats in university entrance exams offered by UEA and stipulates that the percentage of seats made available to Indigenous students must be at least equal to the percentage of the Indigenous population in the state. The UEA Quotas Law establishes ten different access groups based on criteria related to time spent in public schools, territorial factors, and ethnicity, with Group 10 being related to Indigenous people. In addition to seat allocation, the law also requires the university to "offer specific undergraduate courses for the Indigenous population, establishing the necessary intercultural dialogue and prioritizing regions with a higher concentration of these peoples" (Amazonas State Legislative Assembly 2004). It is worth noting the questions regarding seat allocation based on population percentage. For example, Baniwa (2013) proposes that such criteria should be based on "socio-cultural existence and historical contribution to the formation of the Brazilian state" (p. 3). Therefore, the author suggests that when the Indigenous quota is considered unviable due to a low demographic coefficient in a particular state or region, a minimum quota of one seat should be allocated for the Indigenous peoples in those states.

Admission to UEA occurs mainly through the traditional university admission exam known as "*vestibular*", which is held annually in all cities of the state. Another pathway for admission is the Serial Entrance System (SIS), in which high school students take annual exams during their three years of school, and their performance is evaluated with respect to each grade. To a lesser extent, admission is also possible through internal transfer or transfer from other educational institutions (UEA, 2020).

Article 5, Paragraph 2, of the "UEA Quotas Law" establishes that the selection process for filling vacancies for Indigenous students should be established by UEA itself. However, the university does not have alternative admission systems focused on these students. Other Brazilian universities adopt what is known as "Indigenous *vestibular*", which are exams specifically designed for Indigenous students. In the state of São Paulo, for example, the Federal University of São Carlos (UFSCar) and the University of Campinas (Unicamp) have a unified "Indigenous *vestibular*", consisting of a test specifically targeted for these students and being applied in municipalities with a notable Indigenous population, including cities in Amazonas, such as São Gabriel da Cachoeira, Tabatinga, and Manaus (Sangion 2022). Another example is the "Indigenous Peoples' *Vestibular*" in Paraná, a selection process that encompasses eight public universities in the state and exclusively selects students from Indigenous communities located in Paraná (UNESPAR 2022). The demand for the adoption of an exam focused on

Indigenous people is shared by an Indigenous student interviewed by Estácio (2011):

> *"Admission should occur differently from what happens today. And this is something the University (UEA) needs to consider. Including conducting the exam (or even the entrance exam) in an Indigenous language. Because many people understand their languages better than Portuguese. It would be interesting to have this option that is currently not available."* (Indigenous university student quoted by Estácio 2011, p. 151).

According to the official UEA website, the institution offers two courses with an Indigenous focus, in a special format, created to meet specific demands. They are: (i) Bachelor's Degree in Education for Indigenous Teachers of Alto Solimões with seven specializations (Indigenous Ticuna Language, Portuguese Language and Literature, and Spanish; Indigenous Kokama Language, Portuguese Language and Literature, and Spanish; Arts and Physical Education, Biology and Chemistry; Physics and Mathematics; History and Geography; Anthropology, Sociology, and Philosophy); and (ii) Pedagogy - Indigenous Intercultural Bachelor's Degree in Education.

The education degree program for Indigenous teachers from the Alto Solimões region began in 2009 and focused on the final years of Elementary and High School, aiming to train professionals who could work both as teachers and as school managers of Indigenous education in the municipalities of Tabatinga, Benjamim Constant, Atalaia do Norte, Santo Antônio do Içá, Amaturá, São Paulo de Olivença, and Tonantins. This course was created with the support of the Indigenous Teaching Training Program (Proind).

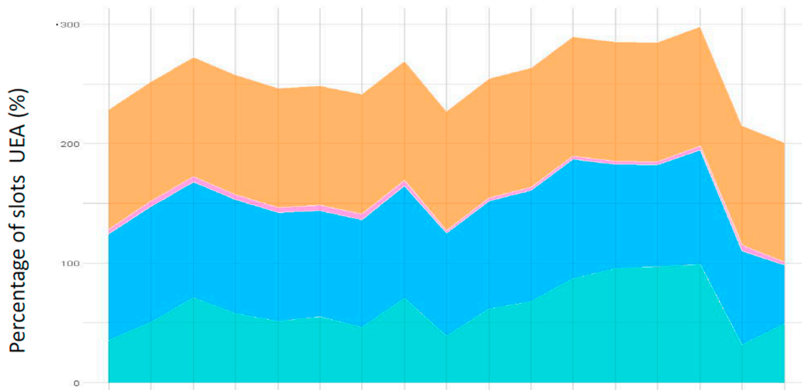
The Intercultural Indigenous Pedagogy course aims to train teachers to work in Early Childhood Education, Elementary School and school management. The course is offered in a modular face-to-face mode, characterized by the displacement of teachers to municipalities to fulfill the workload of the discipline, as well as interactions mediated by technology. The course was offered through the National Plan for Teacher Training in Basic Education (Parfor), an emergency teacher training program funded by Capes (Coordination for the Improvement of Higher Education Personnel), in 2014.

On June 30, 2023, the UEA website published Notice 079/2023 for the Indigenous Intercultural Bachelor's Degree in Education Program, exclusively for Indigenous students, to be held in the following locations: in Boca do Acre at the

Boca do Acre Higher Education Center (NESBCA/UEA), serving the municipalities of Boca do Acre and Pauini; in Parintins at the Parintins Higher Education Center (CESP/UEA), serving the municipalities of Parintins, Barreirinha, Itacoatiara, Maués, and Nhamundá; and in Tefé at the Tefé Higher Education Center (CEST/UEA), serving the municipalities of Tefé, Maraã, Alvarães, Uarini, Japurá, and Juruá. The selection process would be based on curriculum analysis. The program is the result of a partnership between the State Department of Education and Sports (Seduc – AM) and Indigenous movements.

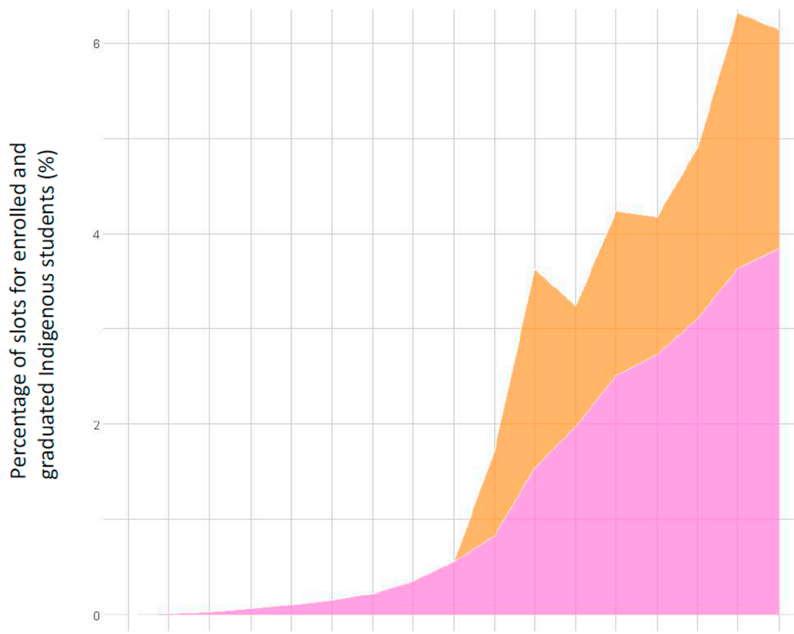
Despite the mentioned efforts, the number of Indigenous students at UEA is still small compared to the total number of students at UEA (Figure 3A). It can be observed that in the year 2021, 2,444 slots were filled through the entrance exam as a whole, but only 69 (2.8%) of these slots were occupied by Indigenous students (Figure 3A). However, slot filling refers exclusively to passing the entrance exam and is not linked to enrollment. For example, in the year 2006, 173 slots exclusively for Indigenous students were offered, 88 were filled, but only three Indigenous students enrolled (Figure 3A and 3B). Furthermore, even with enrollment, the dropout rate of Indigenous students due to withdrawal or abandonment of the course amounts to 37.5% of the slots filled between the period of 2013 and 2021 (Figure 3C). It is also noteworthy that the first Indigenous students enrolled in 2006, but the first graduations only occurred in 2014. We emphasize that the data on dropout due to abandonment or withdrawal are presented here in an unprecedented manner, as they are not publicly available (Figure 3C). The present study obtained access to the data through an official data request process with UEA (process number 01.02.011304.005260/2023-66).

A



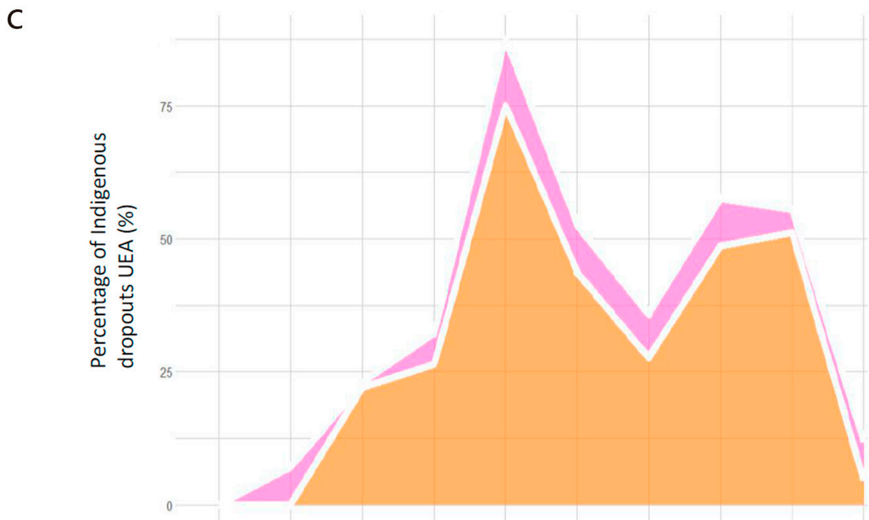
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Offered slots	3571	3709	3820	3865	4667	3780	5060	3569	5809	6657	4689	3272	5732	5337	3379	2992	4870
Offered Indigenous slots	146	174	170	173	204	170	270	164	146	176	128	92	139	138	112	142	140
Filled slots	3174	3587	3700	3687	4243	3357	4541	3365	4988	6005	4354	3267	4993	4555	3236	2354	2375
Filled Indigenous slots	52	88	121	100	105	94	125	116	57	109	87	80	133	134	111	45	69

B



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Enrolled Indigenous	0	3	7	16	22	32	50	77	126	206	334	459	599	643	739	737	810
Graduated Indigenous	0	0	0	0	0	0	0	0	0	31	85	28	58	39	76	29	33

Figure 3 Percentage of slots at the University of the State of Amazonas, comparing non-Indigenous and Indigenous students. A) Percentage of slots offered to Indigenous students and slots filled by Indigenous students in relation to the total slots offered and filled; B) Percentage of slots for enrolled and graduated Indigenous students in relation to the total enrolled and graduated students in the university. (Continues).



	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dropout due to abandonment	0	24	23	60	58	37	54	23	3
Dropout due to withdrawal	4	1	5	10	12	11	10	2	5

Figure 3 (*Continuation*). Percentage of Indigenous student dropout due to abandonment and withdrawal in relation to the total enrolled Indigenous students at the university. The tables represent the absolute number of slots offered, graduated, and enrolled at the University of the State of Amazonas. (Source: UEA in numbers, 2022; Internal process No. 01.02.011304.005260/2023-66.)

Among the challenges related to enrollment, there are bureaucratic processes within the university. At UEA, enrollment is linked to the presentation of the Administrative Record of Birth and Death of Indigenous People (RANI), a document issued by Funai (Estácio 2015). This requirement is related to the UEA's Quota Law, which defines as Indigenous only those who are formally recognized by formal institutions. This process reaffirms a "guardianship" relationship between the state and Indigenous communities, characterizing it as a practice with colonial roots that adds barriers to university access (Estácio 2015; Machado 2017). This perspective is supported by an Indigenous student who reports:

> *"I have always been Indigenous, but when I applied for the UEA entrance exam and was accepted, I had to get the Funai registration, which UEA required. But I was already Indigenous, I have always been. It wasn't the Funai registration that made me Indigenous. As I said, I was already Indigenous, I have been since I was born."* (Indigenous student quoted by Estácio 2011, p.155).

It is worth noting that, for enrollment in the Indigenous Intercultural Bachelor's Degree in Education Program, the submission of either the RANI (Administrative Record of Birth and Death of Indigenous People) or a Declaration from the Indigenous Community confirming the candidate's ethnic status and their belonging to the village is required. This declaration should be signed by two representatives of the community, such as chiefs, elders, or other Indigenous leaders, and should include their identification numbers and addresses (as specified in items 5.1.3 and 5.1.4 of Notice 79/2023). The creation of specific courses for the Indigenous population addresses several issues and is the result of the struggle and social pressure from Indigenous movements on the government. In personal communication with the coordinator of the Indigenous Intercultural Bachelor's Degree in Education Program (Notice 079/2023), he emphasized the importance and involvement of the Indigenous Movement throughout the negotiation and creation of the program. They brought the demands of each territory and proposed the creation of instruments to promote retention, such as class frequency, class location, and scholarships. It is worth noting, therefore, that admission to the university is just the first step; the challenge of retention and completion of the course then arises, as indicated by the high dropout rate (Figure 3C).

2.1 Retention

Baniwa (2013) emphasizes the importance of expanding the concepts of affirmative action policies, going beyond the perspective of admission and proposing actions for effective retention, as the absence of retention policies widens the socio-cosmocultural gap (Machado 2007). Thus, after entering the university, the challenges faced by Indigenous students change but persist. Interviews conducted by Estácio (2015) exemplify the students' reality. In one of the accounts, the following situation is described:

> *"UEA quotas only favor admission, and then you have to fend for yourself to stay. There is no support. There is no follow-up. Nobody comes and asks: How are you doing? How is your education going? What are your difficulties? There's none of that. When I had financial difficulties, because I had no money for transportation or photocopies, I had to stop studying. This was because nobody helped me, not Funai, nor UEA. My husband was also studying, and I decided to stop for a while so he could finish his studies. But now I'm back to studying, and no matter how long it takes, I'm going to finish college*." (Indigenous university student quoted by Estácio 2015, p. 7-8)

This statement highlights two of the main challenges for retention: the lack of financial resources and the lack of pedagogical and psychological support for students from the university, which have also been identified as crucial factors for continuity by Baniwa (2013) and Luciano & Amaral (2021).

UEA has a Student Assistance Program that includes six modalities: Student Housing; Transportation Assistance; Educational/Pedagogical Material Assistance; Socioeconomic Assistance; Meals (university dining facilities); and Daycare Assistance. In addition to these, there is the Psychosocial Support Center (Epsico) aimed at the psychological well-being of university students. Indigenous students have access to these programs like other university students, but we did not identify specific proposals tailored for Indigenous students, with qualified professionals to work with this specific population.

The lack of resources, support, and guidance is compounded by the challenges related to cultural differences, as one of the students portrays below:

> *"I came from the interior, and I don't have family here in the city (Manaus). Plus, I didn't know that you needed money every day here. Even to go to study, to pay for the bus. So, I had to work to be able to live here, and my work schedule is the same as my course. So, between working and studying, I had, I mean, I have to work."* (Indigenous university student quoted by Estácio 2015, p. 7).

The above account exemplifies how the lack of financial and material resources, coupled with the cultural specificities of urban life, influence the retention of Indigenous students in the university. In many cases, the challenges faced are so significant that they result in dropout, attrition, and/or withdrawal (Machado 2007; Baniwa 2013; MEIAM 2019; Luciano *et al*. 2021). Although the problem is systemic and persistent, some initiatives illustrate institutional mechanisms that provide greater support for the retention of Indigenous students in higher education.

In the universities of Paraná, after admission to higher education through the Indigenous Peoples' Vestibular in Paraná, students are supported by the University Commission for Indigenous Affairs (Comissão Universidade para o Índio or CUIA) (Krainski *et al*. 2022). This commission was established in 2004 with the aim of developing integrated actions that contribute to access, retention, and conclusion in undergraduate programs. Krainski *et al*. (2022) report that the commission contributes to inclusion, support, and retention by implementing measures to raise awareness of Indigenous students within the university, as well as providing scholarships.

In February 2023, the State University of Campinas, in response to a demand and mobilization from the Indigenous Collective of Unicamp, announced the creation of a working group to improve measures for the access and permanence of Indigenous students at the university. Among the various demands made by the Collective to promote retention, they include the hiring of Indigenous healthcare professionals, particularly focusing on mental health; an adjustment in the amount of retention grants; the establishment of spaces for academic and cultural coexistence; as well as the hiring of Indigenous teachers and researchers. Such educational policies suggest possible institutional pathways for university governance models that could potentially be applicable to Indigenous retention at UEA (Nunes 2023).

2.2 Discrimination against Indigenous students in the university environment

Prejudice, discrimination, physical and symbolic violence, mistreatment, omission, or restriction of rights are manifestations of racism committed against Indigenous peoples (Machado 2007; Machado 2017; Troquez 2022). Racism is a systemic problem, having certain specificities in the university context. For example, as discussed in previous sections, the lack of financial support policies focused on Indigenous students is a manifestation of racism. In this section, we focus on a specific type of racism manifestation against Indigenous peoples, in this case, the reports of discrimination identified in our review. It is noteworthy that structural racism is pointed out as one of the reasons for dropouts of Indigenous university students (Baniwa 2019; Luciano *et al*. 2021).

At UEA, Indigenous students report that they are discriminated against for having Indigenous names and not having Portuguese as their first language. Often, students are afraid of being identified as Indigenous. In fact, one student reports that "the university seems not to be ready for the new, for the different, nor for the richness of Indigenous peoples" (Indigenous university student interviewed by Melo 2019). Another student provides an account of their experience:

> *"The pressure was high, especially because of my last name, because people immediately identified me as Indigenous. Another thing they identified was my language. Today, I speak Portuguese better than before, but the prejudice was great; and I also suffered threats, me and my brothers."* (Indigenous university student interviewed by Lima 2019).

Moreover, cases of exclusion by other students are also reported:

> *"I felt prejudice on my own skin. I experienced this right away, in one of the first group assignments. The teacher divided the class into groups by row and my group arranged to do the assignment, completed it and excluded me. On the day of submission, I noticed that my name was not on the list. So, I told the teacher that I respected my colleagues very much and that the group I had joined had excluded me from the work. And so, I requested a new date to do the work alone. So, you have to assert yourself, otherwise you won't be respected."* (Indigenous university student group interviewed by Estácio 2011, p. 124).

Therefore, there is a need for anti-racist approaches that identify discrimination and propose solutions based on the experiences of Indigenous students. Anti-racist approaches are grounded in the recognition of power relations that structure our society with the aim of identifying, contesting, and changing the values, structures, and behaviors that perpetuate racism and other forms of oppression (Dei 2005). An education project based on an anti-racist perspective can contribute to increasing visibility on the issue and propose practices and measures to mitigate the problem (Troquez 2022). Although it is a systemic problem, certain efforts by other institutions point to possible paths for mitigating discrimination against Indigenous peoples in the university context. For example, the Federal University of Western Pará has a manual entitled "Racism in the university? Guidelines for ethnic-racial equality and overcoming racism" that describes how to identify cases of racism and the institutional mechanisms for reporting them to the competent university bodies (Ufopa 2017). According to Peixoto (2017), the publication of this manual occurred after a mobilization by Indigenous students who reported cases of discrimination. Although the publication of a manual does not necessarily imply a change in behaviors and other structural changes, the mobilization of Indigenous students against discrimination brings visibility to the problem, promotes debates, values the theme, creates anti-racist spaces and fosters decolonial practices (Peixoto 2017).

2.3 Indigenous and traditional knowledge in the university context

The education models adopted in Latin American countries as a whole are influenced by Western paradigms of modernity and development, in which multicultural diversity is not valued and access to education is unequally granted to people of different ethnicities and socio-economic positions (Nájera-Castellanos *et al*. 2018; Mato 2011). In higher education, the focus is mainly on scientific knowledge, and other knowledge systems, such as Indigenous and traditional knowledge, are not recognized or discussed (Baniwa 2019). In the context of UEA, there is a challenge for the university to intentionally recognize and integrate the knowledge that Indigenous students possess into teaching, research, and outreach activities (Estácio 2011). Such difficulties are reported in the following statements made by Indigenous students at UEA:

> *"When you enter the university, it makes us invisible; it doesn't have a cross-cutting curriculum that engages with our knowledge. And at UEA specifically, where I study, you have a 60 hours course, discussing the Indigenous issue in the state with the largest Indigenous population, but it doesn't incorporate our perspectives and knowledge. So, being within these spaces means distancing yourself from your own knowledge, values, and customs."* (Indigenous student interviewed by Lima 2019).

> *"I'm not enjoying some classes, like History, which have nothing to do with us Indigenous people. It's only about white people. All college classes should focus a bit more on the Indigenous people here. On our reality. Using our knowledge and what we know. Because much of what is in the teacher's texts is not our reality, it's not our truth. And we don't have space to speak, because we can only talk about what's in the text."* (Indigenous student interviewed by Estácio 2011, p. 172).

It is evident, therefore, that the issues related to Indigenous student's retention in the university are linked to the inclusion of their knowledge, also including the recognition that Portuguese is not the first language for many, as reported by one student:

> *"Here at UEA, the university accepts us Indigenous people into the courses, and the professors want us to speak well and master Portuguese. But I don't do that very well. If they allowed me to use my language, I would certainly do better. But the professors don't accept it because they say they won't understand. But I may not understand their texts either. And I don't accept that. It's not easy for me."* (Indigenous university student interviewed by Estácio 2011, p. 172).

In Latin America as a whole, there are proposals for intercultural education, or bilingual intercultural education, in universities that aim to include Indigenous peoples while considering their singularities and diversity (Mato 2011; Corbetta 2021). Intercultural education is an anti-hegemonic perspective that takes multiculturalism as a starting point for teaching, research, and outreach, emphasizing recognition, respect, and coexistence with diversity in university environments. The idea of interculturality in universities has been disseminated in recent years but has been little practiced and experienced beyond discussions in restricted groups (Baniwa 2019).

In order to concretize an intercultural perspective at UEA, some authors suggest certain guidelines for effectively practicing it. In a review of the state of the art of intercultural education, Corbetta (2021) offers the following recommendations to improve it in Latin America: (1) increase and report annually the budget allocated to intercultural education; (2) provide initial and ongoing training for teachers in bilingual education; (3) promote research in Indigenous languages and knowledge; (4) define curricula that incorporate the plurality of knowledge and epistemologies; (5) create inclusive educational materials; (6) provide training for mothers and fathers who demand education in accordance with their language and culture; and, finally, (7) involve Indigenous peoples in the conception, planning, monitoring, and evaluation of policies related to intercultural education. Additionally, Indigenous authors, such as Baniwa (2019), propose that, to reduce the dominance of ethnocentric thinking, the field of spirituality of Indigenous peoples should be taken into account, which comes from nature and is referenced in it. Such suggestions are relevant to ensure that intercultural universities do not become spaces for the homogenization and cultural assimilation of Indigenous peoples (Mato 2011).

UEA's own experience of conducting Intercultural Courses can and should foster an institutional reflection for the improvement of regular higher education in order to strengthen the inclusion, access and retention of Indigenous students. In the case of the Indigenous Intercultural Education Degree Course (public notice 79/2023) several instruments were provided to guarantee permanence: the course was held close to the Indigenous territory, financial aid grants, modular classes, and with pedagogical-cultural plan that maintains dialogues with traditional knowledge. Finally, beyond education, it is suggested that, to be truly transformative, intercultural education requires an approach that works in synergy with claims and improvements in social, economic, political, civil, cultural, cosmopolitical, and environmental rights (Varela & Lapique 2019; Baniwa 2019).

Another window of opportunity to enable dialogues, engagement with Indigenous communities, and integration of diverse knowledge systems is through the curricularization of extension. This curricularization involves the incorporation of outreach activities into the pedagogical projects of university courses, with defined workload in their curricula, according to Resolution 7/2018, which directs 10% of the workload of undergraduate courses to extension activities. In this sense, these are extension actions that involve "communities external to higher education institutions and that are linked to student training" (Brazil 2018). The aim is to include groups external to the university context (Arroyo & Rocha 2010) in order to promote the autonomy of communities in a dialogical relationship with society, to be strengthened and carried out critically (Freire 2014). The intention is to strengthen the capacity for impact and social transformation necessary for extension activities, collaborating with traditional communities to expand the exercise of their constitutional rights. Thus, practices and measures that promote the curricularization of extension in a collaborative manner between the university and Indigenous communities can contribute to the promotion of intercultural education and the valorization of traditional knowledge in higher education.

2.4 Demands of the Movement of Indigenous Students of Amazonas (MEIAM) for inclusion, access, and retention at UEA

Indigenous students in the state of Amazonas are the protagonists of a political articulation that demands improvements in conditions related to inclusion, access, and retention in the university. The Movement of Indigenous Students of Amazonas (MEIAM) leads this movement, which collaborates with various other Indigenous organizations, such as the Amazon Mobilization Front for the Defense of Indigenous Rights and the Forum for Indigenous School Education in Amazonas, as well as non-Indigenous organizations, such as the Association of Teachers of the Federal University of Amazonas. In August 2019, MEIAM published a letter that lists its main demands for obtaining improvements in UEA (Box 2).

Box 2 - Excerpt from the letter of demands of the Movement of Indigenous Students of Amazonas seeking improvements for Indigenous students at University of the State of Amazonas (MEIAM 2019, p. 2-3)

"I. To establish a Commission, with the presence of Indigenous students and Indigenous Organizations, to think and propose an articulated policy for successful access and retention of Indigenous students in UEA;

II. Conduct a study for the creation and establishment of a Hetero-Identification Commission, with the purpose of monitoring the registration, enrollment and admission process of Indigenous students through ethnic quotas at UEA. This commission should have among its members Indigenous students and representatives of Indigenous Organizations of Amazonas;

III. Creation of a seat on the University Council (CONSUNIV) and on the Board of Trustees of University of the State of Amazonas, to ensure, respectively, the presence and participation of both Indigenous students and members of Indigenous Organizations of the state of Amazonas;

IV. Establishment of an Indigenous advisory office, alongside the office of the Magnificent Rector of UEA, to monitor, articulate and develop actions for successful access and retention of Indigenous students at University of the State of Amazonas, as well as to articulate and strengthen the dialogue between Indigenous peoples and organizations and the higher administration of UEA. We demand that the indication for this advisory be discussed and forwarded to the rectorate by the Movement of Indigenous Students of Amazonas, and we commit ourselves to discuss the said indication together with Indigenous Organizations of Amazonas."

It is possible to observe that these demands focus on the creation and expansion of spaces within the university's administrative structure in which Indigenous students themselves can make and implement decisions that influence their lives. Thus, this positioning emphasizes the interest in sharing decision-making power in university governance and reinforcing the autonomy of students to determine what their problems and desired solutions are. The demands, therefore, characterize a paradigm shift compared to the historical models that Brazilian government institutions adopt regarding Indigenous peoples. MEIAM's letter can be considered as a manifesto of Indigenous peoples, in the sense of bringing to the scene their dissatisfactions, solutions, and ways of articulation that go beyond the traditional and fragmented management procedures imposed by universities, thus demonstrating that they have the potential to manage what concerns their peoples without depending on the State's agenda. The letter emphasizes the empowerment of Indigenous students and a departure from the model of "tutelage." Such perspective is aligned with the will for autonomy emphasized by other national Indigenous movements (Machado 2017).

In our review, we did not find any references or secondary data that discuss possible progress at UEA regarding the demands of MEIAM (2019). Therefore, monitoring potential compliance with the letter's demands constitutes a knowledge gap. This gap stands out as relevant, as the progress made in this process can also serve as a facilitator for the transformation of the educational institution itself.

Final considerations

The issue of inclusion, access and retention of Indigenous peoples in Brazilian universities - particularly in the context of UEA - constitutes a major institutional challenge. The difficulties presented should not be seen as an obstacle to proposing actions that can minimize the problem, but rather as an opportunity for the university to mobilize and make a difference in meeting the specific needs of Indigenous peoples, reaffirming its mission, which is:

> "*University oh the State of Amazonas (UEA) is a public university, autonomous in its educational policy, whose mission is to promote education, develop scientific knowledge, particularly about the Amazon, together with ethical values capable of integrating man into society and improving the quality of human resources existing in the region in which it is inserted*." (UEA 2023)

We believe that this work has the potential to contribute to reflections and actions of individuals and collectives committed to ensuring inclusion, access, and permanence of Indigenous people in Brazilian universities. Our target audience is decision-makers in Brazilian universities, especially at UEA, specifically those who work in the following departments of the institution: Pro-Rectory of Administration, Pro-Rectory of Extension and Community Affairs, Pro-Rectory of Undergraduate Education, Pro-Rectory of Internalization, Pro-Rectory of Research and Graduate Studies, and Pro-Rectory of Planning. In order to reach a wider audience, we have also produced a cartoon as a product that discusses the issue (Figure 1).

In the current structure of our society, academic knowledge allows for the education of Indigenous students to take on decision-making roles in various arenas, including universities themselves, potentially initiating a process of valorization of diverse forms of knowledge. Representation in these spaces can gradually bridge the gaps created by the lack of dialogue between scientific knowledge and traditional wisdom. The first step lies in non-exclusion, inclusion, access, and retention of Indigenous people in universities.

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Urban diversity in the Amazon and global agendas for urban sustainability: proposals and challenges for the Mesoregion of Marajó – Pará

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ABSTRACT

The process of urbanization in the Amazon region has been inadequately and incompletely addressed in global agendas for urban sustainability. This highlights the deficiency of the technical-operational apparatus of these agendas as evaluative tools, within the context of an urban environment shaped and consolidated in a socio-environmental complex and diverse setting. This article aims to contribute to this debate and encompasses five thematic dimensions related to the urbanization process in the Amazon: socio-environmental, economic, public management, education, and social organization. It suggests strategies for adapting some existing urban sustainability indicators to a specific socio-territorial context, the Marajó Mesoregion in the state of Pará, Brazil. To do so, the Sustainable Development Goals (SDGs) are adopted as a basis for discussion, and new metrics for urban sustainability are proposed. The results are synthesized in a framework of indicators that can help understand urban sustainability in a context of diversity and complexities, highlighting the importance of interdisciplinary approaches to grasp subtle elements that emphasize urbanization initiatives that do not conform to the single model and narrative of what is understood as a city and the urban phenomenon.

Kwywords: urban diversity; urban sustainability; small cities; Marajó Mesoregion.

Introduction

In an attempt to overcome the so-called "demographic void," policies to integrate the Amazon region were established after the 1960s, resulting in population concentration in cities that lacked basic infrastructure and urban services. The expansion of urban areas in the Amazon impacted the forest, fragmented the socio-spatial relations of cities, and generated territorial changes that are still visible today. As highlighted by Becker (1985), even though the process of urbanization in the region has been significant, these are cities that still lack basic urban infrastructure, employment, and service generation.

Historically, the process of Amazonian occupation, restructured by economic fronts and policies created in the 20th century, aimed at expanding the agricultural frontier towards the Midwest and North of Brazil. This occurred through the expansion of the agricultural frontier, with the presence of large landowners and agricultural companies (IANNE, 1979; PINTO, 1980). Becker (1990) also draws attention to the presence of large extractive economic projects that led to the formation of company towns, resulting from the diffusion and spontaneous or planned formation of cities and towns to meet the needs of industrial complexes. In addition to these aspects, the pattern of organization of the Amazonian urban territory is rooted in different landscapes, such as river-floodplain-forest cities and road-upland cities (GONÇALVES, 2001). In the case of river-floodplain-forest cities, there are riverside cities that follow an occupation pattern linked to the river and the forest. According to Oliveira (2006), riverside towns are urban centers situated along the banks of rivers with diverse spatialities, which are often connected to pre-existing local structures. "It is necessary to understand the territory that results from this process, which reflects not only harsh living conditions but also resistance and unwavering strength to build a new life that is not necessarily better or worse, but different" (OLIVEIRA, 2006, p. 9). The cities in the Marajó Mesoregion fit into this logic.

Marajó Island is composed of 15 municipalities, of which 13, namely Afuá, Anajás, Bagre, Chaves, Cachoeira do Arari, Curralinho, Gurupá, Melgaço, Muaná, Ponta de Pedras, Salvaterra, Santa Cruz do Arari, and Soure, are considered small cities with less than 21,000 inhabitants (IBGE, 2020). Among other infrastructure deficiencies, there are cities that lack landfill sites due to being surrounded by private farms, such as Soure, and others that, due to their location in flood-prone areas, dispose of garbage near urban centers, burn it in sawmills, or dump it directly into rivers, as is the case in the city of Afuá (CARMO, 2020).

According to Quintela *et al.* (2018), Marajó is an example of the coexistence of tradition and modernity, with its disputes and conflicts, which, in line with this article's proposal, is representative of urban diversity. Therefore, as a strategy for urban sustainability on Marajó Island, it is considered necessary to build academic approaches capable of capturing the territory's specificities in relation to the Sustainable Development Goals (SDGs) established by the UN (2016) for cities. Considering the SDGs, which establish the simultaneous optimization of social inclusion, economic growth, and environmental protection as a fundamental axis (UN, 2016), the 2030 Agenda proposes 17 goals to guide national policies and possible international cooperation activities in the coming years.

Although considered a comprehensive and broad approach, Hickel (2019) points out that there are two sides of this Agenda that are at imminent risk of contradiction: one side advocates for a harmonious relationship between humans and the natural environment, establishing limits on resource use at the level of planetary resilience and measures to contain climate change; and the other side appeals for continuous global economic growth, supporting an assumption that allows maintaining current or higher levels of economic growth. These contradictions also reflect the perspective of cities and demonstrate the inability to fulfill this agenda in the context of SDG 11 - Making cities and human settlements inclusive, safe, resilient, and sustainable - while seeking to fulfill SDG 8 - Promoting inclusive and sustainable economic growth, full and productive employment, and decent work for all. In this regard, the guiding question of this article is: *how can alternative paths be built that prioritize the link between cities and nature, considering an urbanization process that emerges and grows in a specific context?*

To advance in constructing answers to this and other questions, based on Ribeiro *et al.* (2021), who defines urban sustainability in the Amazon as a multidimensional system that encompasses: (i) traditional knowledge combined with technologies for territorial planning and management, (ii) paradigm shifts in consumption, land, and resources by valuing everyday practices, (iii) understanding the political-economic dynamics underlying the processes of production and reshaping of space, and finally, (iv) the resumption of development based on non-predatory use of socio-biodiversity resources, with cities and their surroundings as the basis for their reproduction. These elements of discussion help guide the understanding of the necessary dimensions of analysis for urban sustainability in the context of cities on Marajó Island.

To achieve this, the article is divided as follows: i) discussion on the society-nature relationship in the socio-territorial context of the analysis to compose the socio-environmental dimension; ii) discussion on economic dynamism to compose indicators for the socio-economic dimension; iii) discussion on urban infrastructure to compose indicators for the territorial management dimension; iv) discussion on the potential of planetary health to compose indicators for the education for sustainability dimension; v) discussion on the importance of civil society organization to compose indicators for the social organization dimension. Finally, as an annex, we propose a table with a synthesis of proposed metrics to assess the applicability of the SDGs to the region, considering the themes discussed in the previous sections.

Socio-environmental dimension: society-nature relationship

Life on Marajó Island is deeply rooted in the relationship between its people and nature, as it is a source of livelihood, a promoter of life, and a keeper of memories that perpetuate the history of the place. It is through the proximity to the natural environment that humans, land, rivers, and seas remain interconnected, a relationship that becomes more pronounced with the development of productive activities. In the specific case, the indigenous civilizations that settled in Marajó over 3,000 years ago left intriguing evidence, especially landscapes that brought fame to the world's largest deltaic island (ECURED, 2023). Currently, Marajó has its own culture, linked to livestock farming and buffalo rearing – meat that is prepared as a typical dish in regional cuisine, where the animals are raised on vast, often isolated, farms.

The use of the environment by humans is perceived as an essential human activity for survival, through which humans transform nature and are transformed by it, where they produce and reproduce their existence, shaping the history of social beings (FERREIRA, 2006). The natural space, when adapted or incorporated into contemporary modernization, has become the locus of production and exchange activities. At the same time, modernity has presented humans with dilemmas and contradictions of a society that has moved and continues to move ever faster towards progress (CASTRO, 2017). The environment, understood as a concentration of natural resources, has become an object of interest and has been transformed into a system of production and exploitation. In this context, according to Sathler *et al.* (2009), the economic-spatial integration promoted by globalization has not been sufficient to reduce inequalities in the Amazon. This reality is reflected on Marajó Island.

In the early 18th century, the Marajoara economy was dependent on natural products such as rubber and Brazil nuts, which were responsible for the creation and expansion of settlements (COSTA *et al.*, 2022). In 1960, livestock farming based on traditional large estates became even more prominent in the economy due to the local environment, with the presence of extensive flooded fields. Nowadays, economic practices persist with the presence of large landowners who, through buffalo production, share extensive wetland areas with the riverside population living along streams and rivers, engaging in extractive economic activities. Moreover, while economic relations in the region used to occur at a local and regional level, in recent times they occur at different scales but in a disjointed manner (BROWDER; GODFREY, 2006).

In general terms, despite the relationships established between society and nature, issues related to climate change, rampant use of biodiversity, and the resulting increase in poverty have been factors that limited the region's development. A study by Santos *et al.* (2021) on the vulnerability of municipalities in the coastal region of Pará state shows that the most exposed and vulnerable municipalities to climate change and extreme events are in the Marajó Island region. Extreme climate events, such as precipitation and temperature anomalies, have led to climate changes that are already affecting socio-environmental relationships, resulting in an increasing intensification of vulnerability in the region.

According to the UNDP (2013), municipalities on Marajó Island such as Melgaço (0.418), Chaves (0.453), Bagre (0.471), and Anajás (0.484) have not achieved 20% access to seven prenatal consultations, with the exception of Afuá (0.489) and Portel (0.483), which have low HDI compared to other Brazilian municipalities. The sociodemographic aspect of the region is a factor that exacerbates and makes these cities even more sensitive to socio-environmental vulnerabilities, as marginalized populations are living in these areas and they are the ones facing the greatest difficulty in adapting to environmental changes resulting from climate change.

Connecting to the identified issues for Marajó Island, we have SDGs 12 and 14, which address the relationship between humans and nature (SDG 12 - Ensure sustainable consumption and production patterns), in a context that is fundamentally based on rivers (SDG 14 - Conservation and sustainable use of oceans, seas, and marine resources for sustainable development). These are important objectives, but they lack an understanding of the specificities of the Amazonian Territory, highlighted here by the Marajó context, and also consider social, cultural, and environmental plurality as determining factors in the society-nature relationship (Table 1).

Therefore, for Marajó Island to serve as a study object for urban sustainability under the socio-environmental dimension, it is necessary to consider how the relationship between society and nature is maintained in the complexity of spatial planning in the Marajó territory. In this regard, rivers and forests are part of the spatial organization and dynamics of cities, serving as mediators for the movement of people and goods. The conservation of a healthy environment depends on the type of sustainable strategic development that occurs in a region or country. The socio-environmental dimension, based on the relationship between nature and society, should be perceived through responsible resource use, but more than that, it is necessary to think about the territory and its multiple social practices, the different uses of natural resources, and their specificities, which are essential for the conservation of ecosystems and human life.

Advancing in this discussion implies a new economic and environmental reality, considering the socio-economic dynamism and the different scales of spatial occupation in the Amazon. Furthermore, how these realities reverberate in the relationships between society and nature. As a result of this discussion, the following section highlights general elements that can contribute to the construction of an indicator system that accounts for the economic dynamism in urban and rural territorial dimensions, linked to the context of Marajó cities.

Socioeconomic dimension: economic dynamism

The urban economies of the Amazon have a high potential to stimulate biodiversity-based economies (SILVA, 2018). On the other hand, rural economies are crucial when it comes to the dynamics of Amazon's development, especially regarding social inclusion and sustainability (COSTA, 2015). As a result, it is possible to conceive indicators that connect these two dimensions, as we seek to demonstrate in Table 1 (attached).

The Brazilian federal government has established strategies to achieve the SDGs, highlighting the following (BRASIL, 2017): i) creation of a national commission to disseminate the goals and foster dialogue between federative entities and civil society, ii) effort to adapt global goals to the Brazilian reality, taking into account legislations, development plans, and programs iii) development of diagnostics on the national reality and local realities, establishment of national priorities, and mapping of existing policies. To understand the importance of economic dynamism for urban sustainability in the context of Marajó cities, we discuss the role of SDG 8, which aims to promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. However, it is important to highlight its controversies, such as the premise of the relationship between economic growth and development and the possibilities of economic growth without environmental damage (GOIRIA; HERRERA, 2021). That being said, one of the challenges for researchers and public managers in the Amazon is the consolidation of a system that points towards economic and environmental sustainability, values local productions and living conditions, and favors integrated, non-dichotomous urban-rural articulations.

In this sense, we understand that the significant contribution of the economy to sustainability is the understanding and adoption of measures, policies, and strategies aimed at regional autonomy and economic dynamism (Table 1). One experience in this regard can be observed in the Ponta Alegre community - located on the Canaticu River, in the municipality of Curralinho. This is the Embarca Marajó Project: navigating the Tide of Sustainability. This project provides access to banking services for populations living far from urban centers with better infrastructure, and strengthens initiatives such as the creation of social currencies.

Social currencies are important strategies for economic dynamism in small cities (YUNNUS, 2000). They are nurtured in community banks through solidarity-based financial services networks and have three main characteristics: i) resource management done by members of society, ii) an integrated system of local development that enables credit, production, marketing, and training simultaneously, and iii) the circulation of social currency in the territory, which is accepted and recognized by producers, traders, and consumers in the area, thus enabling the creation of an alternative market for families and strengthening internal exchange networks.

Local residents exchange their official currency (Reais) for a social currency, the value of which is restricted to a specific acceptance area, meaning only pre--registered commercial establishments that adhere to this particular economic circuit are able to receive this currency at its face value for the trade of goods and services (SILVA, 2017). This practice has been developed on Marajó Island and is an example of how economic and environmental sustainability can go hand in hand, favoring the construction of territorial knowledge based on local practices. As an effective result of the actions of the "Embarca Marajó Project: Navigating the Tide of Sustainability" in 2016, the first community bank of Marajó was created in the community of São Miguel do Pracuúba, in the municipality of Muaná. It is worth noting that there are other experiences in other states, such as the case of the online social currency, e-dinheiro, a virtual currency created by Banco Palmas in Tocantins, adopted by several other agencies that are part of the Brazilian Community Banks Network. With this, it is suggested to demonstrate to the municipal public sphere the importance of joining initiatives that originate from the local sphere and are adapted to their socioeconomic context.

The broader actions of the SDGs draw attention to the need for promoting sustainable economic growth, but their local actions do not take into account the economic specificities of the territory and local practices as determining factors for promoting sustained economic growth. To ensure full and productive employment and decent work for all, it is necessary to consider that territorialization occurs based on the particularities of the place and to adopt more contextualized actions, considering a set of distinct factors, including social, economic, environmental, institutional, and cultural factors. Territorialization occurs based on different forms of appropriation and use of the territory. Each city, community, or village aggregates particularities in its sociocultural practices, which are determining factors in socio-spatial production.

In summary, given this clarification, in order to achieve Goal 8, which is "Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all," it is necessary to consider sustainable economic practices that are already being developed in some communities, recognizing territorial diversity together with the importance of this practice as a tool for sustainable economic planning in Marajó.

In addition to these aspects, the rural-urban spatial dimensions pose a challenge for more strategic articulation. The example of Marajó presents a promising scenario for socio-economic and environmental practices towards sustainability. However, these actions reflect the resilience of the population in the face of challenges posed by political and territorial management actions and policies that are appropriate to the reality of cities in the Amazon. We start from the premise that the urban diversity of the Amazon imposes challenges on the population, which must be overcome through management dimensions and strategic actions to address the diversity of cities in this vast region.

Territorial management dimension: urban infrastructure

The territorial organization of the Amazon, in the context of socio-spatial organization, is represented by the diversity of cities that have emerged at different historical moments, which have been, and still are, important in the economic and social structuring of urban space. It was in the 1960s that new urban centers began to emerge in the Amazon rainforest, intensifying the urbanization process. Furthermore, according to Browdder and Goldfrey (1997), although Belém and Manaus have consolidated themselves as the main primacies, there was, at that time, a regional trend that led to the deconcentration of Metropolitan Regions, which continued in the following years, favoring the expansion of peripheral regions with the construction of new settlements, areas without infrastructure and basic urban services. Disconnected urbanization created a differentiated urban environment and favored the emergence of new inter and intra-urban relationships that are specific to the region. According to Carmo and Costa (2019), the territorial organization has resulted in distinct institutional and economic identities and in the process of urbanization in cities of the Amazon delta, including Marajó Island's territory.

According to Silva (2015), the production of urban space in cities is related to different factors, including the characteristics of the site and its situation, the role of the urban nucleus in the local and regional context in the face of the contradictions of capitalism, the territorial division of labor, and the composition of the urban network. Regarding the urban network, it should be understood that, in Marajó, cities play similar roles but with singularities and particularities. The urban centers of the Marajó Archipelago offer basic urban infrastructure services restricted to their residents, which, when compared to polarizing urban centers, become the most necessary goods for the life of local communities. As they are located far from the "core" areas, access to infrastructure and services is not concentrated in a single hub but rather in different locations.

The Report on Impact, Vulnerability, and Adaptations of Cities (2017) shows that many cities, towns, and local communities in the Northern region of Brazil are in a vulnerable condition, which aligns with the data on urban infrastructure and basic services of the cities on Marajó Island made available by IBGE (2010). It is observed that all cities were classified as areas of high socio-environmental vulnerability due to intense occupation of floodplain areas. Because they are located in flood-prone areas and lack urban infrastructure services such as sewage treatment and access to treated water, these cities are highly environmentally vulnerable and may suffer from the effects of increased rainfall intensity and rising sea levels. On the other hand, Marajó cities have fewer resources and environmental oversight, and therefore urban management lacks specific urban and environmental public policies to minimize the problems encountered.

According to Costa and Brondizio (2017), the urban areas of the Marajó Archipelago, for the most part, are integrated into the urbanization process that has been consolidated in the region over the past 20 years. However, the concentration of urban centers has always occurred slowly and in a non-concentrated manner. These are urban centers with limited infrastructure and are also reliant on the allocation of public funds (COSTA *et al.*, 2008). Alongside urban areas in floodplain regions, there are also upland areas (Figure 1) that have been organized over the years as cities' urban areas expanded. Thus, it is possible to find cities in upland areas or the presence of both floodplain and upland within the same city.

a) Antero Lobato street (grounded).

b) Beginning of stilts from the Antero Lobato.

c) Stretch of Antero Lobato street (paved).

d) Stretch of Antero Lobato street (paved).

Figure 1 Floodplain and upland areas in the city of Ponta de Pedras, PA. *Source:* Valota, 2015.

There is a lack of access to urban infrastructure services, which hinders the quality of basic services provision, such as sewage treatment, treated water, garbage collection, and waste treatment. In a study conducted by Mansur *et al.* (2016) in the delineation of the Amazon River delta region, which includes all cities in Marajó Island, approximately 80-90% of the urban population is living in vulnerable conditions due to the combination of lack of sanitation services and unplanned settlements in unsuitable areas. Furthermore, according to the same authors, less than 20% of the riverine population in the delta have housing with access to sewage collection services, with collection being virtually non-existent in small towns (MANSUR *et al.*, 2016). Access to treated water, as well as sanitary sewage treatment, is inadequate and brings environmental problems, primarily related to public health. There are still dwellings without access to treated water, and many still use river water for domestic chores and consumption (CARMO, 2020). Many homes lack a drainage system, and domestic sewage is discharged directly into rivers (Figure 2).

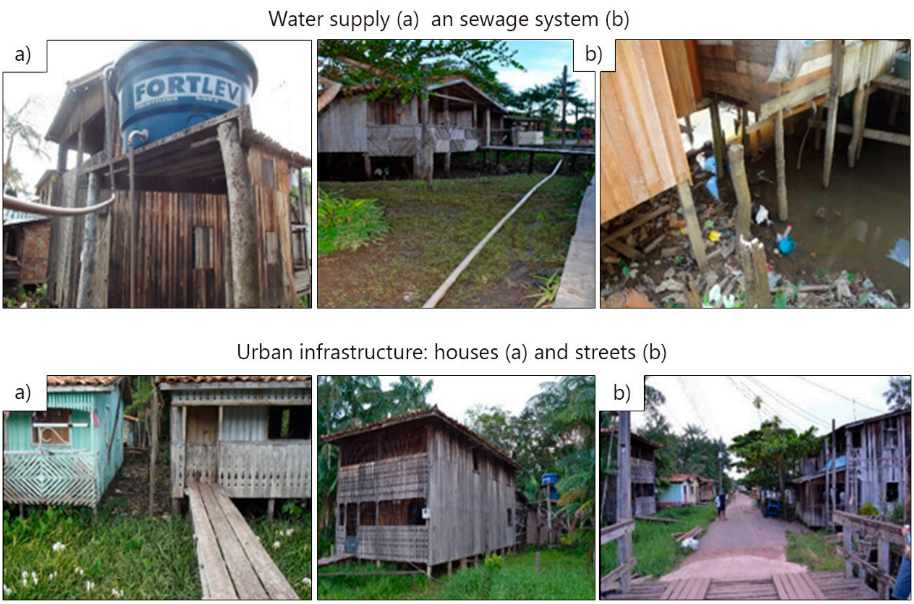

Figure 2 Neighborhood in a floodplain area in Ponta de Pedras – PA. *Source:* Carmo, 2020.

There is a disconnection between public policies and services (at the local, regional, and federal levels) and the local reality. The precariousness of these services has not been overcome by infrastructure public policies, nor have they been planned with consideration for the urban diversity of Marajó. It is necessary for public policies, as well as the SDGs, to have a sensitive approach to the region, as there are multiple territorialities (HASBAERT, 2005) that need to be recognized, just like in other cities in the Amazon. Therefore, these metrics need to be designed for local realities, taking into account their particularities, so that appropriate urban infrastructure public policies for urban diversity are implemented (TRINDADE JR. 2010). In order for Marajó cities to be sustainable, the main framework should be the promotion of a debate that includes the particularities of the urban area in the Amazon.

Regarding territorial management, SDGs 6 (Ensure availability and sustainable management of water and sanitation for all), 7 (Ensure access to affordable, reliable, sustainable, and modern energy for all), 9.1[1], and 11.2[2] highlight different elements necessary for the analysis of infrastructure in cities, such as access to public services for basic sanitation, electricity, and urban mobility. Given the context of urban diversity on the island, in order to achieve these goals and targets, it is necessary to recognize the different types of urban areas existing in Marajó Island and engage in discussions with public bodies to propose the implementation of basic infrastructure services in each urban area (Table 1). The main objective is to ensure that local particularities are considered in management plans. This factor will be crucial in providing an overview of the most vulnerable areas in terms of access to urbanity (urban infrastructure), through the implementation of public policies and services that are aligned with the territorial reality of Marajó Island.

Specifically, SDG 11's second goal addresses urban mobility, a challenge that needs to be approached according to the particularities of each region. In Marajó, intra-urban mobility is carried out by residents in rural areas who need to travel to the urban centers of the nearest cities. Inter-urban mobility occurs when residents of the cities need to travel to major urban centers, usually looking for services not available in their region, such as specialized healthcare and banking services. In the case of municipalities on Marajó Island, travel usually occurs towards Belém and Macapá, depending on the location and proximity. According to Bartoli (2020), the diffusion of adapted engines for rustic boats has been fundamental for the movement of people between their communities and commercial centers and their surrounding areas of influence.

In Marajó Island, the transportation of people and goods is carried out through multimodal means in waterways, and crossings can be made by speed-

1. Develop quality, reliable, sustainable, and resilient infrastructure, including regional and cross-border infrastructure, to support economic development and human well-being, with a focus on equitable access and affordability for all.

2. By 2030, ensure access to safe, affordable, sustainable, and accessible transport systems for all, improving road safety through the expansion of public transportation, with special attention to the needs of people in vulnerable situations, women, children, persons with disabilities, and older persons.

boats (taking up to 2 or 3 hours), ships (taking from 4 to 40 hours), or "rabetas"[3]. Depending on the route and type of transportation, trips can take anywhere from 2 to 40 hours between cities on the island. SDG 11.2 discusses access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety through the expansion of public transportation, with special attention to the needs of vulnerable populations, women, children, persons with disabilities, and the elderly (UN, 2022). However, it does not mention the inclusion of waterway transport systems. According to Bartoli (2020), river transport in the Amazon has a significant influence on the structuring of the urban network and, especially, the construction of diverse territorialities. They represent "territorialities of diverse networks of subjects, with the formation of territorial systems" (BARTOLI, 2020, p.33).

Given urban diversity, in order to achieve the goal of "Making cities and human settlements inclusive, safe, resilient, and sustainable," it is necessary to recognize the different types of urban areas existing in Marajó Island and engage in discussions with public bodies to propose the implementation of basic infrastructure services in each urban area. The main objective is to ensure that geographical particularities (location, construction of adequate housing, and implementation of urban infrastructure) are considered in management plans. This factor will be crucial in providing an overview of the most vulnerable areas in terms of access to urbanity (urban infrastructure), through the implementation of public policies and services that align with the territorial reality of Marajó Island.

Dimension of Education for Sustainability: Planetary Health

Planetary health is a concept that fosters a field of transdisciplinary research, essential for understanding the interrelationship and interdependence between humans and the environment (WHITMEE *et al.*, 2015). The concept provides practical foundations and aims to safeguard the health of the planet and, consequently, the health of people through individual and collective actions. As a transdisciplinary approach, Planetary Health allows for connections across all areas of knowledge. Therefore, it is a discussion that proposes a new approach to the Sustainable Development Goals (SDGs) by incorporating metrics that

3. "Rabeta" is a small propulsion engine that is attached to the hull.

encompass urgent issues discussed within the context of the 2030 Agenda and urban diversity in the Brazilian Amazon. Teaching children and youth through Planetary Health Education involves fostering dialogues across diverse areas of knowledge, emphasizing responsibility for human and environmental health. It empowers children and youth to become future leaders in emerging issues and provides them with improved living conditions.

As planetary health is a cross-cutting approach, it's possible to observe it permeating all the goals of every SDG. However, in this topic, the discussion is focused on the SDGs associated with the theme of Education (SDG 4 - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all), discussing its goals and the need for adaptations to the socio-territorial context of Marajó. In this sense, the Sustainable Cities Program (PCS, 2017) complements this SDG and emphasizes the need to integrate formal and non-formal education, including knowledge, values, and skills.

The municipalities of Marajó Island have 1,255 schools, with 143 schools located in urban areas and 1,112 officially designated as rural areas, serving 172,573 enrolled students. Out of the total number of enrolled students, 68,722 study in urban areas, and 103,851 in rural areas (TCMPA, 2022). In 2022, a report from the Project to Strengthen Education in municipalities of the state of Pará was published, highlighting the need to develop actions in Marajó, considering the existing educational problems, with indicators pointing to low performance of the education system in all municipalities of the Archipelago and high dropout rates.

A relevant data highlighted in the Basic Education Development Index (IDEB) report is the average failure rate in the municipalities of Marajó, indicating that the average student failure rate is 17.22% in the early years and 15.21% in the final years, which is the highest failure rate in the state of Pará, also resulting in high rates of age-grade distortion. All these issues are interconnected with other indicators, such as Adequate Learning, assessed based on data from the Prova Brasil, which indicates insufficient levels of adequate learning in the basic education level of students in Marajó (TCMPA, 2022).

Given the educational scenario presented in these reports for Marajó Island, it is important to consider that there are quantitative indicators that, although needing strengthening, provide a general diagnosis of formal education. Therefore, the decision was made to present new indicators that can contribute to a more comprehensive and inclusive understanding of education, highlighting the particularities of the Amazon region, specifically Marajó Island. The proposed metrics for Education for Planetary Health aim to emphasize the need to better represent the aspects of non-curricular education, which shape ways of life and are strongly interconnected with nature (Table 1). One of the important factors is to understand the residents' perception of the environment they live in, considering the fragility of the environment they inhabit. Thus, the proposed metrics intend to (re)consider educational and institutional practices that foster a critical, responsible, and resilient formation with the environment, considering the issues that severely impact human and environmental health.

Dimension of social organization: civil society organization

The strategies adopted by the United Nations (UN) to achieve the SDGs include mobilizing the necessary means to implement a work agenda via global partnership involving different actors at various levels (UN, 2015), such as local governments, non-state actors, civil society, and the private sector. In this context, national governments are responsible for implementing work agendas to achieve development goals. However, there is a significant presence of non-state actors involved, considered effective and innovative instruments for sustainable development policy (BEISHEM, 2012; BOECHA, 2021).

The presence of different social actors in the implementation of public policies with global or national goals is extremely important for the consolidation and legitimacy of sustainability agendas. In this strategic context, Civil Society Organizations (CSOs) play a relevant role, particularly as protagonists in multilevel relationships that involve national, global, and multilateral relations focused on the SDGs (MELLO; PEREIRA, 2022). These organizations emerge through social participation, focusing on the development of actions of public and collective interest, without profit motives (MELLO; PEREIRA, 2022), and play an important role in local organizations and in the effectiveness of public policies, as well as contributing to the adoption of context-specific policies and fostering necessary social changes.

In Brazil, there are 815,676 active civil society organizations, with 41.5% of these organizations concentrated in the Southeast region, 24.7% in the Northeast, and the North region ranking last, accounting for 7.2% of the country's CSOs (IPEA, 2021). On Marajó Island, the context of organizations reflects the need to consider strategic actions for investment and support for regional-level organizations. A study conducted by the "Escuta Marajó" program, as part of the Viva Marajó project, mapped civil society organizations and leaders operating in the region - a total of 62 organizations - and found that half of them are represented by entities of civil society organizations, while the other half by institutions connected to the public setor.

The institutions with the greatest presence in the region are part of the Territorial Development Collegiate of Marajó (CODETEM), related to the Territory of Citizenship - a policy coordinated by the Ministry of Agrarian Development (MDA) - representing the largest network of coordination in the region. The leadership composition includes members of Marajó's civil society, such as the social movement of fishermen, women's groups, rural workers, cultural organizations, and the Catholic Church through the Prelature of Marajó and the Diocese of Ponta de Pedras. In addition to these institutions, the study by the "Escuta Marajó'' program highlights the actions of organizations such as the Marajó Museum, Caruanas - culture and ecology, and Lupa Marajó, as well as research institutions such as the Emílio Goeldi Museum, which maintains a scientific base on Marajó Island (Ferreira Penna Scientific Station in the Caxiuanã National Forest).

All of these institutions represent a strong possibility for regional coordination, forming partnerships to articulate the necessary actions to address the need to include the agenda of urban diversity in the Amazon within the context of the SDGs. However, the activities and investments directed towards institutions in this region have certain weaknesses, such as ensuring the financial sustainability of institutions that are considered isolated from major centers. It is important to guarantee the autonomy of these organizations, providing security for them to act comprehensively and effectively, especially in terms of monitoring socio-environmental public policies (INSTITUTO PEABIRU, 2013). Civil society organizations have a relevant role as social agents in the implementation of the global agenda, considering the alignment between their areas of operation and the SDGs' goals. Thus, CSOs work together with government institutions, defining strategies for action and project monitoring. Without the necessary investment, these institutions are unable to operate at different levels of organization.

In the context of the SDGs, social organization and civil society participation in decision-making spaces are addressed within the context of SDG 16, Goal 7 - Ensure responsive, inclusive, participatory, and representative decision-making at all levels. In 2014, the Civil Society Working Group for the 2030 Agenda (GT Agenda 2030) was created, composed of 50 participants, including NGOs, social movements, forums, and Brazilian foundations (ESCUERDO, 2020). The actions of the GT ranged from raising awareness about the SDGs, highlighting their impacts on people and territories, to gathering, analyzing, and producing content that captures the effectiveness of actions aimed at achieving the goals. This is annually disseminated through the 'Relatório Luz' (Light Report). (GT Agenda 2030, n.d.). Among the institutions participating in the GT, only the International Education Institute of Brazil (IEB) operates in the Marajó region, indicating the need to include institutions representing organizations located in the riverine cities of the Amazon.

On a larger scale, the implementation of the SDGs in Brazil presents a series of challenges that reflect the context of multiple economic and political crises contrary to democracy and environmental policies, which compromises alignment towards the causes led by the UN and reverberates in the achievement of established goals. It is in this sense that increasing social participation in decision-making becomes necessary, considering that residents are familiar with the needs of their cities, as well as increasing the number of initiatives to strengthen and support civil society organizations operating in the region.

These overlapping issues highlight the need for assistance in the process of implementing goals, adapting, and monitoring existing indicators. Considering these aspects, the contribution of this work is to suggest metrics to observe the participation of CSOs in decision-making spaces, their strength in serving the population, financial sustainability, and gender and ethnic equity in these social spaces (Table 1).

Conclusions

The 2030 Agenda proposes new perspectives for sustainably overcoming unequal development, both in Brazil and worldwide. But how do these goals encompass cities like those on Marajó Island? How can they contribute to overcoming the multiple territories and their environmental, cultural, economic, geographical, and social particularities? The discrepancy between the expectations set by the indicators derived from this Agenda and the local reality reinforces the inadequacy of operational-methodological frameworks for studying urban sustainability in the Amazon. This fact reveals the need to incorporate processes that originate and define the characteristics of the Amazonian urban context and the importance of an approach that addresses the demands and characteristics of each region. In the context of the 2030 Agenda, this is called the territorialization process of indicators. The fulfillment of the SDGs' 2030 Agenda in Marajó Island will only be possible if the territorial diversity of the Marajó Archipelago, including cultural, social, environmental, and economic practices, is included as an important and decisive factor in local development projects.

The effort to synthesize dimensions for analyzing the sustainability of cities in the context of the Marajó Mesoregion resulted in a synthesis framework of indicators that help understand urban sustainability within a context of urban diversity. Divided into five main dimensions, the fundamental role of interdisciplinarity in understanding subtle elements of the urbanization process could be observed. The final assembly of an indicator system requires further research to define sustainability parameters and collaboration with municipal governments in the Marajó Mesoregion and their associations to enable the regular collection of information not covered by official surveys. Our objective was to elucidate and propose interesting metrics that expand the view of urbanization in cities that are not fully converted to the urban-industrial model, where a close connection with nature and its cycles remains. However, we believe that the development of a system of urban sustainability indicators at the regional level could be a tangible outcome of the current proposal, and the individuals endorsing this text are available to engage in discussions with institutions interested in this matter.

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Table 1 Summary of metrics for the composition of indicators to assess urban sustainability in the geographical context of the Marajó Mesoregion.

DIMENSION	SDG	PROPOSAL OF ADDITIONAL INDICATORS	JUSTIFICATIONS AND POSSIBILITIES
SOCIO-ENVIRONMENTAL	Goal 12: "Ensure sustainable consumption and production patterns." Goal 14: "Conserve and sustainably use the oceans, seas, and marine resources for sustainable development."	● Variables and types of land use and land occupation, classified by ecosystem type. ● Mapping of the location of traditional community dwellings. ● Type and quantity of hazardous waste generated per capita. ● Proportion of hazardous waste treated, classified by type of treatment.	● Ensure the indication of the relationship between sustainable production and consumption patterns by considering the relationship between society and nature. ● Reduce the complexities of spatial planning considering the social, cultural, and environmental peculiarities of the Marajó region. ● Include the human-nature relationship as determining factors of the spatial organization and dynamics of cities. ● Include water quality as crucial for riverine cities and their residents.
SOCIO-ECONOMIC	Goal 8: "Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all."	● Number of formal and informal workers employed in activities related to socio-biodiversity product chains. ● Socioeconomic information per household (Number of people with access to benefits, Number of literate responsible individuals). ● Percentage of own municipal tax revenues. ● Percentage of companies in the municipality that produce or sell products related to local biodiversity. ● Strategies focused on sustainable or community-based tourism. ● Number of community banks (local social currency).	● Formal employment level assists families in accessing social security benefits, regular income, and credit systems (through the use of social currency). ● The economic exploitation of Amazonian biodiversity can be seen as one of the means of articulation between rural and urban areas. ● The possibility of providing credit for individuals and businesses. ● The potential to boost tourism and generate employment and income.

Table 1 Summary of metrics for the composition of indicators to assess urban sustainability in the geographical context of the Marajó Mesoregion (*continuation*).

DIMENSION	SDG	PROPOSAL OF ADDITIONAL INDICATORS	JUSTIFICATIONS AND POSSIBILITIES
TERRITORIAL MANAGEMENT	Goal 6: "Ensure availability and sustainable management of water and sanitation for all. " Goal 7: "Ensure access to affordable, reliable, sustainable, and modern energy for all." Goal 9.1: "Develop quality, reliable, sustainable, and resilient infrastructure, including regional and cross-border infrastructure, to support economic development and human well-being, with a focus on equitable access and affordable prices for all." Goal 11: "Make cities and human settlements inclusive, safe, resilient, and sustainable." Goal 11.2: "By 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all."	● Rate of unplanned occupation in peri-urban areas. ● Rate of occupation in irregular, unsafe, and disorderly areas. ● Number of households connected to the general sewage system, treated water, and waste collection. ● Commuting mobility based on microdata from IBGE (profile of residents engaged in commuting flows: study and work).	● Ensure the importance of regional dynamics. ● Ensure the specific urban characteristics to enable the implementation of adequate urban infrastructure policies for urban diversity. ● Propose urban and regional planning methodologies that are sensitive to the geographic reality of cities in the Marajó Island. ● Ensure quality and safe river transportation and its importance in various territorial contexts.

Table 1 Summary of metrics for the composition of indicators to assess urban sustainability in the geographical context of the Marajó Mesoregion (*continuation*).

DIMENSION	SDG	PROPOSAL OF ADDITIONAL INDICATORS	JUSTIFICATIONS AND POSSIBILITIES
EDUCATION FOR SUSTAINABILITY	Goal 4: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all."	● Number of schools where interdisciplinary proposals in environmental education are included as a cross-cutting theme in the curriculum. ● Partnerships between schools and communities regarding environmental education. ● Financial support for the development of projects for schools and environmental education. ● Residents' perception of the space they inhabit	● Ensure interdisciplinary subjects related to environmental education. ● Increase partnership between schools and communities in promoting environmental awareness. ● Include residents' perception as a fundamental aspect in the development of environmental education proposals and methodologies.
SOCIAL ORGANIZATION	Goal 16.7: "Ensure responsive, inclusive, participatory, and representative decision-making at all levels."	● Rate of social participation in decision-making processes. ● Financial sustainability profile of organizations. ● Number of initiatives to strengthen and support regional civil society organizations. ● Number of riverine and quilombola residents participating in organizational leadership. ● Number of women in leadership positions in organizations.	● Increase social participation in decision-making processes. ● Ensure initiatives to strengthen and support regional civil society organizations. ● Ensure greater participation of riverine and quilombola communities in leadership roles within organizations and decision-making processes. ● Promote the participation of women in leadership positions within organizations

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Territorial rights and biocultural diversity conservation in Amazonia: a case on demarcation and titling of indigenous and maroon territories in Brazil, Ecuador, and Suriname

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ABSTRACT

Recent studies have highlighted the crucial role of indigenous peoples and traditional communities in environmental conservation and sustainable management in the context of the climate crisis, shedding light on what indigenous and maroon organizations have been advocating for decades. This article seeks to understand what measures should accompany the demarcation and titling of indigenous and maroon lands to ensure the effective conservation of biocultural diversity in the Pan-Amazonia region. To achieve this, it focuses on three case studies representing different stages of the territorial rights acquisition process: indigenous territories in Yasuní, Ecuador; the Arara do Rio Amônia Indigenous Territory in Brazil; and the territory claimed by the Saamaka maroons in Suriname. By analyzing the main threats and actors involved in each case, this work aims to highlight successful solutions and recommend possible innovations that should accompany the recognition and implementation of territorial rights to ensure the conservation of biocultural diversity in these territories.

Keywords: territorial rights; biocultural diversity, indigenous peoples, maroon communities, Pan-Amazonia.

Introduction

During the last two United Nations climate conferences, held in Glasgow (COP 26, Scotland) in 2021 and in Sharm El Sheikh (COP 27, Egypt) in 2022, the Articulation of Indigenous Peoples of Brazil (2021) emphasized that "there is no solution to the climate crisis without Indigenous Lands and Peoples." Alongside the Coordination of Indigenous Organizations of the Amazon Basin (COICA) and the Black Coalition for Rights in Brazil, these delegations underscored the importance of delimiting and demarcating indigenous and maroon territories for reducing deforestation and conserving the environment.

In an unprecedented initiative, the Report of the Scientific Panel for the Amazon, launched at COP 26 in 2021, brought together over 200 experts from various fields within the region with the purpose of assessing the current situation of the Amazon Basin, home to more than 47 million inhabitants, in dialogue with indigenous peoples and local communities. By situating the Pan-Amazonia as a regional entity within the planetary system, the report focuses on socioecological transformations over the last 50 years and highlights the need to find solutions and define future paths for the sustainable development of the region and its peoples (Nobre et al. 2021).

Two main conclusions emerge from its more than 1200 pages. The first is the assertion that the region is closer than ever to its tipping point, meaning the irreversibility of degradation to the extent that it can no longer recover. The second is the recognition that the acknowledgment and exercise of territorial rights of indigenous peoples and traditional communities in the Amazonia constitute a fundamental mechanism for the conservation of the region's biocultural diversity (Nobre et al. 2021, chapters 10, 13, and 31). Expanding the concept of sociobiodiversity, the notion of biocultural diversity stems from the inseparable relationship between cultural and biological diversity (including nature, territory, knowledge, languages, ways of life, and governance), such that the conservation of the former goes hand in hand with the conservation of the latter (Athayde et al. 2021). Furthermore, the scientific panel also highlighted the profound gap between constitutional recognition and the operationalization in practice of ethnic and territorial rights of indigenous peoples and traditional communities (Berling & Vanhulst 2015).

Therefore, the main objective of this work is to investigate which measures should accompany the demarcation and titling of territories to ensure the conservation of biocultural diversity in the Pan-Amazonia region. To address this issue, this article focuses on three case studies representing different stages of territorial rights recognition and implementation processes: indigenous territories in Yasuní, Ecuador; the Arara do Rio Amônia Indigenous Territory in Brazil; and the territory claimed by the Saamaka maroons in Suriname(Figure 1). By analyzing and comparing the main threats and challenges faced in each case study, as well as the key actors involved, this article aims to highlight successful solutions and suggest possible innovations that should accompany the process of recognizing and implementing territorial rights to ensure the conservation of biocultural diversity in the Amazon in a context marked by the climate emergency. While most of the solutions were generated by indigenous peoples and maroon communities themselves throughout their paths of struggle, the innovations aim to be original contributions from the authors of this research (Alencar 2022) based on the experiences learned from each case study, in dialogue with specialized literature and the demands of social movements.

Figure 1 Indigenous Peoples and Maroon Communities in the Pan-Amazonia. A: Location of Indigenous territories in different stages of demarcation (Raisg 2020), delimited quilombola territories in Brazil and those under claim in Suriname (Brazil: Incra; Suriname: Planatlas 1988; ACT 2001), and conservation areas. The available information on maroon territories in Brazil is scattered and not up-to-date, as in 2022, there were more than 1,000 quilombola communities in the Brazilian Amazon, and at least half of them were still waiting the demarcation process (Fundação Cultural Palmares 2022). B: Waorani People (*Source:* www.amazonfrontlines.org). C: Apolima-Arara People (Source: Blog Lindomar Padilha). D: Saamaka People (Source: Waterkant.net).

Despite there being a vast legal framework regarding the recognition of territorial rights and the demarcation and titling of indigenous and traditional community territories at the international level, what we witness at the national level, especially in countries within the Pan-Amazonia region, is that these rights are still not fully utilized by these populations, either due to the lack of legal provisions in domestic legislation or the non-application of existing laws. It is worth noting that the case studies analyzed in each country have different territorial demarcation and/or titling processes. On one hand, demarcation refers to the official process of defining and recognizing the geographic boundaries of indigenous territories in Brazil. This process is referred to as "delimitation" in Ecuador, which in Brazil specifically applies to maroon territories. On the other hand, titling refers to the legal mechanism for regularizing the occupation of public lands after the delimitation of territories traditionally inhabited by quilombolas and maroons, respectively in the contexts of Brazil and Suriname.

According to International Labour Organization (ILO) Convention No. 169 on Indigenous and Tribal Peoples (1989, Articles 14 and 15), the property and possession rights of indigenous and tribal peoples over the lands they traditionally inhabit should be recognized, and governments should take the necessary measures to determine these lands and ensure the effective protection of such rights. Additionally, the rights of indigenous and tribal peoples over the natural resources existing in their lands should be specially protected, including the right to participate in the utilization, management, and conservation of these resources.

It is important to highlight that Brazil and Ecuador are signatories of Convention 169, ratified by their respective parliaments, and therefore, its provisions are already part of national legislation. Suriname, however, has not yet acceded to this Convention. In Ecuador, the Waorani Indigenous Territory in Yasuní was recognized and established in 1990, encompassing an area that was part of Yasuní National Park, created in 1979 and recognized as a UNESCO Biosphere Reserve in 1989, though subject to ongoing redelimitation (Crespo Plaza 2007). Considered one of the most progressive constitutions in Latin America, Ecuador's 2008 Constitution recognized the rights of nature (Article 71) and the collective right to "live in a healthy and ecologically balanced environment, which guarantees sustainability and *buen vivir*, *sumak kawsay*" (good living). It also declared as a public interest "the preservation of the environment, the conservation of ecosystems, biodiversity, and the integrity of the country's genetic heritage, the prevention of environmental damage, and the recovery of degraded natural spaces" (Article 14). The Ecuadorian Constitution also recognizes and guarantees various collective rights to communes, communities, indigenous peoples, and nationalities, including the maintenance of possession of ancestral lands and territories and the obtaining of their free adjudication (Article 57, No. 5), the preservation and development of their own forms of coexistence and social organization, as well as the generation and exercise of authority in their legally recognized territories and ancestral communal lands (No. 9).

In the Brazilian Amazonia, the Arara do Rio Amônia Indigenous Territory was one of the 13 Indigenous Territories in the final stages of the demarcation process identified to be homologated according to the Final Report of the Technical Group for Indigenous Peoples of the Transitional Government in 2022. This means that the requirements set forth by Decree No. 1,775, dated January 8, 1996, which establishes the administrative procedure for demarcating Indigenous Territories, had already been fully met, in accordance with the Statute of the Indian (Law No. 6,001/1973) and Article 231 of the Brazilian Constitution. It's worth mentioning that in a previous ruling on the Raposa Serra do Sol Indigenous Territories, the Brazilian Supreme Federal Court established the so-called "institutional safeguards," which became "new" requirements for Indigenous Territories demarcations, as a result of an interpretation of Article 231 of the Brazilian Constitution. In the ongoing deliberation of the Marco Temporal bill, it is yet to be determined whether these new rules will have a general impact and replace the requirements of Decree No. 1,775/1996. The Marco Temporal bill (PL 490/2007) only recognizes indigenous claims to lands that were provenly occupied and used by them for their physical and cultural production and reproduction at the time of the promulgation of the 1988 Constitution. In May 2023, the Marco Temporal bill was approved in the Chamber of Deputies. The vote took place with urgency, in response to the interests of deputies associated with the ruralist caucus and the mining and exploitation lobby within these territories. Despite the strong resistance and mobilization of indigenous organizations and peoples, the bill is currently in the Senate. If approved, the consequences for their struggle for territorial rights could be devastating.

Lastly, the Surinamese Constitution does not even provide for the recognition, demarcation, or titling of indigenous or tribal lands. However, as a member of the Organization of American States (OAS), Suriname is subject to the Inter-American Human Rights System and has thus been the subject of legal proceedings before the Inter-American Court of Human Rights, as in the Case of Saramaka vs. Suriname in 2007. In the verdict of this case, the Court ruled that the State of Suriname must repeal or amend legal provisions that hinder the protection of property rights of the Saamaka[1] people and, through prior, effective, and fully informed consultations with the Saamaka people, adopt the legislative and administrative measures necessary to recognize, protect, ensure, and legally enforce the Saamaka people's right to collective titling of the territory they traditionally use and occupy. This verdict included both the lands and the natural resources necessary for their social, cultural, and economic survival, as well as those necessary to effectively manage, distribute, and control the territory in accordance with their customary laws and traditional collective land tenure system, without prejudice to other tribal and indigenous communities. Even after more than a decade, Suriname has not amended its policies or legislation. In other words, Suriname has not taken measures to ensure the collective rights of indigenous and traditional communities in line with the decision/precedent of the Inter-American Court of Human Rights (Koorndijk 2019).

In the last fifty years, in Latin America, the demand for recognition of collective rights by indigenous peoples and traditional communities has transformed, gradually shifting from the legal sphere of land rights to the political arena of the struggle for territorial rights (Porto-Gonçalves 2002; Arruti 2022). Although "territory" is a polysemic concept with plural ontologies and multiple interpretations, in general terms, it can be defined as a multidimensional space to which different meanings (legal, political, economic, cultural, etc.) are attributed by the human groups that collectively experience, delimit, appropriate, and/or exert power over it through their relationships. In this sense, the guarantee and protection of territory have emerged as a demand of indigenous peoples and traditional communities to ensure the (re)creation of their ecological, economic, and cultural practices and the (re)production of their environmental knowledge and biocultural diversity – which has been managed by indigenous peoples in the Amazonia for over 12,000 years (cf. Escobar 2010; Neves 2022). As Leff (2021) eloquently stated, territory is at the heart of Latin American political ecology.

The delimitation of territories and national borders during the creation of most Amazonian nation-states in the 19th and 20th centuries was a highly violent process, driven by the capitalist expansion of commodity frontiers in the region, such as rubber, gold, oil, among others, and by their ruthless global economic cycles. The Western perception of the Amazonia as a virgin and empty territory to be occupied and as an unlimited repository of wild resources to be tamed and exploited still prevails today. Furthermore, this Eurocentric percep-

1. How they self-identify.

tion clashes with the worldviews of most indigenous peoples – and traditional communities – in the Amazon, for whom territory is the "fundamental element" around which all aspects of their ways of life, culture, and collective identity are articulated (High 2020; Scazza & Nenquimo 2021). Their relationship with it "is not one of ownership, exploitation, and appropriation, but of respect and management of a common good" that serves all humans and non-humans (Articulation of Indigenous Peoples of Brazil 2021).

Case studies

Indigenous territories in Yasuní, Ecuador

Located in the northeastern part of the Ecuadorian Amazon (Figure 2A), Yasuní is one of the most biodiverse forests per square kilometer (UNESCO 2018). Recognized as a biosphere reserve by UNESCO in 1989, the area covers a surface of 2.7 million hectares. Its core area, the Yasuní National Park (PNY), spans over 1 million hectares. Yasuní is home to more than 20,000 inhabitants, including indigenous peoples such as the Waorani, who number over 3,000 individuals (CONFENAIE n.d.). Within this group, the Tagaeri-Taromenane (TT) clan is among the last known indigenous peoples living in voluntary isolation and initial contact (PIACI).

It is estimated that about 20% of Ecuador's total oil reserves are located underground, along with a significant quantity of various types of commercially valuable timber. These resources have made this area vulnerable to the expansion of intensive extractive practices, reshaping the region as an extractive frontier, similar to other Amazonian countries (cf. Cardoso de Mello & Van Melkebeke 2019; Coy *et al.* 2017). Due to the involvement of external actors in this area and its significance to the national economy, the Yasuni has been a disputed territory. This is primarily due to the expansion of state and private oil interests, which not only threaten access to land and the territorial rights of indigenous peoples (Finer *et al.* 2009) but also their traditional practices of mobility, semi-nomadism, and forest management (Mena *et al.* 2000).

Regarding recognition and territorial demarcation, from a historical perspective, their struggle for territory reveals an intersection of different actors, the power exerted by the State and private companies, and interests related to conservation (Figure MC1). The first traces of the Waorani presence and conflicts with invaders were detected in the early years of the 20th century (Figure MC1). Later, in the 1940s, the oil giant Shell began its extraction operations in Waorani territory. Up to that point, the state's presence in the Ecuadorian Amazon was quite marginal, ignoring indigenous occupation and considering the region as empty land. From the mid-20th century onwards, there was increasing contact between the Waorani and North American evangelical missionaries. These intrusions into their territory led to hostilities against oil industry workers and missionaries, as well as interethnic and interclan conflicts, and changes in their mobility patterns.

The first conservation initiatives led to the establishment of the Yasuní National Park (PNY) in 1979. A year later, the oil company Texaco built infrastructure and a road in Waorani territory, known as Block 31. Since then, the Ecuadorian state has modified the boundaries and size of the park more than once, favoring oil extraction. It was only in 1983 that the first Waorani reserve was recognized and titled, and the Waorani Ethnic Reserve would be created in 1990. With the recognition of the TT as the last indigenous peoples to live in isolation, the Ecuadorian state established the Intangible Zone (ZITT) in 1999, although without defined borders. This area would only be demarcated in 2007, disregarding the occupation and consultation of the PIACI, and aligning with the demands of the oil industry (Lu et al. 2017).

In the 2000s, oil companies with interests in the area included Occidental Petroleum, Texaco, and Petrobras; meanwhile, illegal logging was also on the rise in the ZITT. This scenario of threats escalated conflicts and worsened the socio-environmental situation, leading to strong protests by the Waorani, which prompted the government to halt the construction of the road in the area and the Inter-American Commission on Human Rights to issue precautionary measures.

With the rise of progressive left-wing leadership in power, the Ecuadorian state created the Yasuní-ITT[2] Initiative in 2007 to leave the oil underground in exchange for carbon payments, positioning the area at the center of the fight against climate change. Additionally, in 2008, a new constitution was approved, innovatively incorporating the indigenous worldview regarding *Pacha Mama* (Mother Earth). Thus, the Constitution granted rights to nature, recognized communal land ownership, and ancestral territories of indigenous peoples, and prohibited any intensive extractive activities in the territories of the PIACI. However, the Yasuní-ITT Initiative failed in 2013. Through a constitutional exception to the Declaration of National Interest (DNI), the state legalized oil extraction in the PNY, changing its environmental stance and justifying oil activities with discourses based on resource distribution and poverty eradication. The state's

2. Ishpingo-Tambococha-Tiputini (ITT) refers to the oil field that gives its name to the Yasuní-ITT initiative.

commitment to the extractivist model involves the creation of "sacrifice spaces" (cf. Silveira et al. 2017), where territorial reorganization favors oil zones, marginalizes local populations, and threatens their rights. The Yasuní-ITT Initiative and the opening of the oil frontier led the Waorani to reorganize and expand their territorial defense, particularly from 2010 onwards, seeking international support to make the conflict visible to the world. It is worth noting that the Waorani's struggle combined ethnic elements and the central leadership role of Waorani women (Blasco 2020), demonstrating that the fight for territorial rights is strategically political (Cardwell 2023).

While the left-wing government had established rules for oil extraction, the right-wing party in power continued the extractive policy that promotes the expansion of the oil frontier. The current government announced the auction of an oil block in the heart of the PNY (Orozco 2023), despite the 12-month oil moratorium agreed upon in September 2022 on leasing new oil fields (Koenig 2022). Furthermore, a change in the boundaries of the PNY, which also affects the boundaries of the Waorani Reserve and the ZITT, has been ongoing since 2019 and is still pending resolution due to the contestation of various actors, including oil companies. In August 2022, the IACHR held a historic public hearing in Brasília regarding the ongoing violations of the rights of the PIACI by the State (Land is Life 2022). Recently, by means of a popular consultation in August 2023, it was decided to indefinitely keep the crude oil from Block 43 in Yasuni underground, a request that had been made for over ten years by various civil organizations and local populations (Geografía Crítica Ecuador 2023). Nevertheless, environmental organizations and indigenous peoples are still concerned about the implementation of this popular decision and fear possible governmental noncompliances.

Therefore, regardless of the type of government and existing legislation regarding territorial recognition and delimitation, Yasuní and the indigenous peoples, especially the PIACI, still face various threats. These threats range from the country's excessive dependence on the commodity market, which leads public policies and environmental legislation to favor the extractive interests of private and state-owned oil companies at the expense of nature conservation and biocultural diversity, to illegal logging, particularly in the ZITT, and the successive changes in border demarcation by the state in both the Waorani Reserve and the ZITT to accommodate the interests of the oil industry (Lu et al. 2017). These constant overlaps and changes in the delimitation of indigenous territories and their areas for hunting, gathering, and resource collection within the PNY also contribute to the growing interethnic conflicts between the Waorani and the PIACI (Rivas 2017). These factors are further exacerbated by the state's lack of knowledge about the ancestral occupation of indigenous peoples and their mobility patterns (Cabodevilla 2010).

Faced with these external threats and internal pressures, the indigenous peoples of Yasuní organized themselves politically and actively mobilized for the recognition and exercise of their territorial rights. They sought political and environmental education and training to better prevent and resist changes in border demarcations that greatly affect their ways of life. They strengthened their support networks among stakeholders and indigenous leaders, especially women, both at the national and international levels, to gain more visibility for their cause. This visibility strategy also included communication campaigns, international press coverage (cf. Korn 2018), and collective actions by citizens, especially in urban areas (Rivas 2017).

At the same time, the Yasuní case study demonstrates the importance of establishing legally-backed conservation strategies, such as national parks. These protected areas have the potential to further support conservation efforts in indigenous territories, and vice versa. As long as these measures are well implemented, the national park and its buffer zones can protect native populations and their lands from oil extraction. Furthermore, thanks to their traditional ecological practices and use of natural resources, indigenous peoples have played a decisive role in conserving biocultural diversity and regenerating natural cycles (Pohle 2008). This interdependence with nature extends beyond differentiated land management practices, ways of life, and governance, and in the case of Ecuador, it has also been incorporated into the country's *Magna Carta*.

The Arara do Rio Amônia Indigenous Territory in Acre, Brazil

At the end of 2022, the indigenous movement in Brazil formed the Technical Group of Indigenous Peoples in the Transition Government of the newly elected president, Lula da Silva. The final report of the Group provides a brief critical assessment of the dismantling of indigenous policies in Brazil during the tenure of former President Jair Bolsonaro and suggests some priorities for emergency actions by the new Lula government. These suggestions included the repeal of normative acts, such as the Temporal Framework, the creation of the Ministry of Indigenous Peoples, the end of mining in Indigenous Territories (TIs), and the demarcation of 13 TIs within the first 30 days of the government (Technical Group of Indigenous Peoples 2022). These lands were selected because they were in the final stage of the territorial demarcation process, thus symbolizing affirmative action for indigenous rights after four years of neglect and attacks by the Bolsonaro government.

Located in the state of Acre, in the southwestern region between the Brazilian Amazonia and the Peruvian Amazonia, the Arara do Rio Amônia Indigenous Territory (TI) was one of these 13 prioritized TIs for demarcation (Figure 2B). The territory covers 20,764 hectares and is inhabited by approximately 400 indigenous people, divided into roughly 80 families belonging to five groups: Novo Destino, Hilda Siqueira, Txaná, Nova Esperança, and Nova Morada (pers. comm. 2023)[3]. The name Apolima-Arara originates from the mixture of indigenous peoples from the Txama (Conibo), Amawaka, Santa Rosa, Arara, and Kaxinawá ethnicities (Aquino 2010). Apolima refers to a locality in Peru where their first ancestors resided. The majority of Apolima-Arara speak their mother tongue, and despite the prevalence of the Pano language, some also speak Portuguese, Spanish, and Ashaninka (Aruak), with whom the Apolima-Arara coexisted (Silva & Aguiar 2011).

The struggle for the demarcation of the Apolima-Arara territory dates back to the end of the last century (1999). The main milestones of this struggle are highlighted in the timeline illustrated in the Supplementary Material (Figure MC2). However, the people's ancestral territory struggle dates back even further and is strongly associated with the beginning of the rubber extraction cycle in Acre since the late 19th century when the first explorers reached the border of Brazil and Peru. This process was marked by violent "raids," which involved the expulsion and dispersal of indigenous populations from their territories, as well as the capture of women and children who were taken as rewards for their work by rubber tappers (Iglesias & Aquino 2005).

The largest population of Apolima-Arara people traditionally occupied the banks of the Amônia River, in areas that partially overlap with the territory of the Extractive Reserve (RESEX) of the Upper Juruá on the right bank and the Settlement Project of Incra, known as PA Amônia, on the left bank. Overlapping[4] these areas and a small extent of the southern boundary of the Serra do Divisor National Park (PNSD), the Arara do Rio Amônia Indigenous Territory was identified by Funai in September 2008 (Aquino 2010) and declared a year later by the indigenous agency through Ordinance 2,986. The main milestones of this struggle are highlighted in the timeline illustrated in the Supplementary Material (Figure MC2).

Concerning the network of actors and/or institutions working with the Apolima-Arara, it's worth mentioning the Indigenous Missionary Council (Cimi), an

3. Personal communication between co-author Marcos Catelli Rocha and the agroforestry agent of the Apolima-Arara people, José Ângelo, Rio Branco/AC, Feb 8, 2023.
4. For a more detailed analysis of the overlap between Indigenous Territory and conservation units, with a focus on the Apolima-Arara case, see Arruda 2014; Rezende & Postigo 2013; Costa 2012.

organization affiliated with the Catholic Church that has supported the struggle for the demarcation of their territory, as well as ICMBio, the NGO Commission Pro-Indio do Acre (CPI-Acre), and other indigenous peoples such as the Kampa (Amônia River) and the Ashaninka, as represented in the actor map (Figure MC2).

The main threats currently faced by the Apolima-Arara people are related to road construction, illegal logging and forestry concessions, deforestation, oil and gas exploration, mining, and drug trafficking. On the Peruvian side of the border, much of the Amazonia has been divided for some of these ventures. As emphasized by a member of the Apolima-Arara people, many of these impactful activities have not yet been mapped, underscoring the need for participatory mapping (ethnomapping) with the Apolima-Arara to georeference these threats and find ways to combat and prevent them. For instance, according to José Ângelo, Apolima-Arara leader and agroforestry agent, the trail is a very old route that connects the Indigenous Territory to the Peru border and is used for drug trafficking by "strange people, all the wrongdoers, come and go through there" (pers. Comm. 2023). Ângelo points out that the fact that the Indigenous Territory is not demarcated makes it difficult to control this route and the movement of people by the indigenous, who are even facing threats. As he highlights:

> *The issue of drug trafficking is very complicated because this trail that goes through our land is affecting it greatly. I'm facing many threats, we've already reported it to the police, especially Funai. There are many threats against the leaders, especially me, who live here inside the land, fighting alongside the people.*

The opening of new roads and highway branches in the region is aggravated by the indigenous territory's proximity to the municipality. At least two of the road branches are in the vicinity of the TI, one of which connects to the RESEX, where many people are settling. This fact is already known by ICMBio and is an object of concern for the Apolima-Arara people. The other branch goes through the Serra do Divisor National Park (PNSD), which is an Incra's settlement. As José Ângelo states, this branch crosses the TI without the communities' authorization. He criticizes Incra, claiming that the agency "settles people and leaves them there with nothing to do, they have no choice but to invade, so it's a major concern for me. This is a great threat to the land, the people, and our future." The indigenous leader also highlights the difficult situation in the PNSD because it is "a conservation area where no one can even live inside, and here in our region, they are destroying everything."

Furthermore, there is another proposal to construct the Nuevo Itália-Porto Breu road, which will connect the Ucayali and Juruá rivers in Peru. Part of the road's route is located on the border with Brazil, in the Kampa do Rio Amônia Indigenous Territory. This is a matter of particular concern to the Apolima-Arara people, who have called upon the authorities, especially Funai, to take the necessary measures against the road construction. According to a dossier prepared by indigenous and indigenist organizations from both Brazil and Peru[5], the road will have severe socio-environmental impacts, as this transnational region includes conservation units and is inhabited by nine indigenous peoples, in addition to traditional communities. Specifically, the project will directly impact at least 34 Peruvian native communities, as well as the Kaxinawá Ashaninka Indigenous Lands on the Breu River, the Kampa on the Amônia River, the Arara on the Amônia River, the Kuntanawa, and the Alto Juruá Extractive Reserve in Brazil.

Another threat is the presence of traditional extractivist residents who currently inhabit the Alto Juruá Extractive Reserve, as some of them refuse to leave the Indigenous Territory and receive the federal government compensation they would be entitled to. As José Ângelo explains: "Many of them stayed in bad faith, and others didn't want to receive their compensation. This kind of people, when they remain within an indigenous land and they have to leave, they go about destroying everything during those moments when they are here." These non-indigenous residents consist of approximately eight families and around 20 individuals who engage in various forms of intrusion into indigenous territory, including illegal fishing, hunting with dogs, and the extraction and sale of processed wood into boards and planks.

In light of all this, the leader José Ângelo emphasizes that the Apolima-Arara people eagerly await the demarcation and formal recognition of their Indigenous Territory (TI). This is not only to exercise their territorial rights and ways of life but also to reclaim and reforest the degraded lands. It's worth mentioning that the upper Juruá River region, where the Arara do Rio Amônia Indigenous Territory is located, is one of the most biodiverse areas on the planet (Brown & Freitas 2002). It encompasses a mosaic of protected natural areas for the conservation of both its natural resources (National Parks) and the ways of life of indigenous peoples and traditional communities (Indigenous Territories and Extractive Reserves). This mosaic is part of a binational transborder region that borders the state of Acre in Brazil and the Ucayali Department in Peru.

5. Available in: https://apiwtxa.org.br/wp-content/uploads/2021/08/Dossiê-Estrada-Ilegal-Nueva-Italia-–-Puerto-Breu_ok.pdf. Acessed in 10 fev. 2023.

Regarding the solutions found, this transborder context has allowed for significant collaboration among indigenous, indigenist, and environmental organizations in the region over the past two decades[6]. Another important strategy has been the development of an alliance among the forest peoples, which emerged between the 1980s and 1990s. In recent years, this alliance has facilitated regional meetings and gatherings among indigenous peoples and traditional extractivist communities, aiming to strengthen common objectives for biodiversity management in these protected areas. This work shows great promise, in the words of José Ângelo:

> *Because this division [of territories] is only about boundaries, we need to implement integrated management, with each side respecting the boundaries of the other. An Extractive Reserve (RESEX) is no different from an Indigenous Territory (TI); the reserve has a usage plan, and the TI has a management plan because both lands are conservation areas. Some of the wrong activities conducted within a reserve are illegal, just as those within a TI are. People may engage in such activities, but there must be consequences; justice must be served. What we want is for people from TIs and Reserves to live within an alliance project, to be involved in this alliance of forest peoples. The problem is these people who are still here inside, and most of them are from the Reserve. There could be conflicts [...]; several meetings have taken place, and the Apolima-Arara people do not accept [their presence].*

While the presence of non-indigenous residents continues to be a problem for the Apolima-Arara people in the Arara do Rio Amônia Indigenous Territory, this case study has demonstrated how the creation of an alliance among forest peoples has led to an improvement in coexisting alongside the traditional extractivist community in the Extractive Reserve (RESEX). It has also identified the need for an integrated territory management approach that reconciles the common demands of the diverse residents without compromising the rights of indigenous peoples and traditional communities. During the writing of this article, the Arara do Rio Amônia Indigenous Territory was finally officially demarcated by President Lula on April 28, 2023, on the last day of the 19th edition of the Terra Livre Camp in Brasília, organized by the APIB (Articulation of Indigenous

6. More information available at: https://cpiacre.org.br/dinamicas-transfronteiricas/. Accessed in Feb. 2023.

Peoples of Brazil). This event represents a unique opportunity to assess whether the proposed measures have been successful and/or to identify alternative approaches that should be implemented alongside territorial demarcation to ensure the conservation of biocultural diversity in the Apolima-Arara territory.

The territory claimed by the Saamaka maroons in Suriname

Suriname covers only 2% of the Amazonia rainforest. However, these 2% account for 90% of the country's forested area. Suriname boasts the largest expanse of undisturbed tropical forest in the world and one of the highest levels of biodiversity. Part of the Guiana Shield, the Marowijne Greenstone Belt region consists mainly of highland forests and is rich in minerals, making it the focal point of mining activities in Suriname.

Furthermore, Suriname is the only country in the Americas that has not legally recognized the rights of indigenous and tribal peoples (ITPs) to their traditional territories. In 2006, the Surinamese government was summoned by the Inter-American Court of Human Rights (IACHR) for violating the collective rights of the Saamaka people (Heemskerk 2005; Koorndijk 2019; Price 2018). The Saamaka are a maroon (quilombola) people with a population of over 34,000 inhabitants living in 71 villages along the upper Suriname River, in the districts of Brokopondo and Sipaliwini (see Figure 2C). They are organized into 12 Saamaka clans or Lo's. Traditional authority among the Saamaka is exercised by community leaders known as Kabitens (captains) and Basja's. The paramount chief, or Granman, leads the group and is chosen based on matrilineal lineage. The Saamaka people are organized and represented through the Saamaka Traditional Authorities Association. The Surinamese government recognizes the self-governance of these traditional authorities and provides leaders with a subsidy for their roles and responsibilities in the communities.

The Saamaka were one of the first communities to sign a peace treaty with the colonial government in 1762 (Figure MC3). This treaty included an exclusion clause that stipulated that settlers were not permitted to occupy lands already inhabited by indigenous and maroon communities (Price 2018; Santokhi 2021; Smith 2019). The exclusion clause was one of the reasons why the populations living in the interior remained "undisturbed" for centuries, in addition to the fact that development primarily concentrated along the Surinamese coast and in the capital city, Paramaribo.

In 1954, Queen Juliana of the Netherlands visited the Saamaka village of Kadju to announce the construction of a dam on Saamaka territory. As a result of the construction of this dam, a significant portion of Saamaka territory was flooded, and the Saamaka people were displaced. Families were separated and forced to relocate, some to Sipaliwini, while others were transferred to transmigration villages in Brownsweg (Brokopondo). In 1964, the Surinamese division of Alcoa, a U.S.-based aluminum company, completed the construction of a dam on Saamaka territory to generate electricity for bauxite refining. Nieuw Koffiekamp, a village that had to be relocated after the floods, is currently situated in the midst of one of the most prosperous and mineral-rich veins of the Greenstone Belt.

In June 1982, land tenure decrees, commonly known as L-Decrees, were formulated to regulate land use and ownership by Surinamese citizens (Decreet Beginselen Grondbeleid – De Nationale Assemblée n.d.). These laws addressed individual land tenure rights such as ownership, grants, leasing, and land rentals in Suriname. Nevertheless, the integrity of the Saamaka territory was increasingly threatened by numerous land concessions to multinational companies, albeit not without resistance. In 2007, the international appeal made by the Saamaka Traditional Authorities Association to the Inter-American Court of Human Rights (IACHR) was finally upheld, and the Surinamese government was ordered to recognize the collective rights of the Saamaka people. The government was required to support the Saamaka people with territorial demarcation projects, among other obligations, and was fined SRD 600,000 (approximately U$ 200,000 in 2006), which was to be invested in Saamaka community projects.

The Ministry of Regional Development, which was involved in implementing the IACHR decree, organized a land rights conference in October 2011, but the event ended abruptly. A representative of indigenous and tribal peoples read a statement claiming ownership of both above-ground and below-ground resources. This meant that revenues from gold mining, bauxite, and timber exploitation would belong exclusively to indigenous and tribal peoples. The government disagreed, as it considered these resources to be of "national interest" – as in the case examined in Ecuador – meaning they should be allocated for the economic development of the entire country. The government argued that, according to the 1987 Constitution, Suriname's land was one and indivisible. According to Smith (2019), this turned the issue of land rights into a conflict between the government and indigenous and tribal peoples.

In 2012, the State appointed a commission composed of representatives from various government agencies and indigenous and tribal peoples to develop a strategic plan to address the issue of land rights. The result was a bill on collective property rights of indigenous and tribal peoples, which included territorial rights. This bill was presented to the National Assembly in 2019 but did not proceed with its approval. In 2020, the new government also prioritized land rights on its political agenda.

For the first time, a maroon was appointed as vice-president of the country. Two presidential commissions were established to work on the land titling for indigenous and maroon peoples. The first presidential commission was formed in September 2020 to address land conversion and the modification of land policies. This commission consisted of lawyers, notaries, and tax officials, with the primary goal of amending the existing L-Decrees from 1982, which focused on individual land ownership. The second presidential commission, composed of government representatives and civil society organizations, was established in November 2020 to address the collective land rights of indigenous and tribal peoples and find effective ways to implement them. Another bill was presented to the National Assembly in June 2021. As of 2023, indigenous and tribal peoples were still awaiting the approval of these laws.

One of the main threats to the recognition of Saamaka land rights is gold mining and its effects on deforestation (Baldewsingh 2022) and the loss of traditional lands and livelihoods (Figure MC3). High gold prices, combined with the lack of land use regulation and employment opportunities for local communities, have led to a boom in the mining industry in Suriname. Between 2000 and 2014, gold mining in Suriname increased by 893%, with the majority of small-scale miners coming from local communities. Over 14 years, the average deforestation rate resulting from mining increased from 3,000 hectares to 5,713 hectares (DGR Colorado Plateau 2015). Suriname's annual gold production per land area ranks it as the 10th country in the global market for gold export commodities. Much of the gold mining in Suriname, both small-scale and industrial, occurs within the boundaries of traditional territories of local communities, and most small-scale miners are either maroon or Brazilian prospectors.

The American company Newmont Corporation is the world's largest gold mining company, with active gold mines in the Saamaka region. While the company has recruited members of the Saamaka people, enticing them into industrial mining activities, maroon and small-scale foreign prospectors also operate in the region. According to a study conducted by De Theije & Heemskerk (2009), the current vice-president of Suriname is said to have invited the first Brazilian prospectors to work on dredges, which would later be confiscated from the Government's Department of Geology and Mining (GMD) when he was the leader of the Jungle Commando, a guerrilla group during the civil war (1989-1992). Therefore, the actor map for the Suriname case study reflects a complex scenario in which traditional

Saamaka territory is exploited by Surinamese concessionaires and Brazilian and maroon prospectors, including individuals from the Saamaka community.

The release of mercury in the mining process and the impact of this neurotoxin on the region's populations pose a significant threat to the Saamaka people. Recent studies have shown that mercury levels in rivers cause neurological impairments in children exposed during the prenatal and postnatal phases (Baldewsingh 2022). The consumption of fish and wild game is one of the main ways mercury is ingested. In addition to families relying on income from mining activities, they are forced to develop their ways of life in a contaminated environment (Baldewsingh 2022; Heemskerk & Kooye 2003). Similarly, the increase in malaria cases resulting from mining activities – due to the creation of large stagnant water pools (Baldewsingh 2022; De Theije & Heemskerk 2009; Heemskerk 2005) – has a significant impact on Saamaka communities.

Also situated within the Saamaka territory is Brownsberg Nature Park. Created in 1969, this tourist and research destination, with its 14,000 hectares, used to be a mining zone – its name originates from mining pioneer John Brown. Unfortunately, since 1999, small-scale illegal mining has also increased in this protected area and its vicinity. It's a rather complex scenario in which the small-scale mining activities of the Saamaka communities coexist with illegal mining, directly impacting the struggle for the recognition of collective land rights.

Another threat that the Saamaka people face is logging. Although their land rights are not recognized by national legislation, the Surinamese government designated the so-called "community forest" for local tribal and indigenous communities. These communities are allowed to use the surrounding forests for economic activities to ensure their subsistence. However, there are cases where community leaders have invited timber companies to extract tropical wood, while non-indigenous/maroon individuals have also applied for and received government concessions to exploit these communal lands. Consequently, the management of these community forests has led to internal conflicts between community members and leaders regarding the allocation and distribution of revenues, which eventually reached the Ministry of Regional Development.

Finally, the lack of institutional and interpersonal trust between local communities and the government can be considered another challenge to the advancement of the Saamaka people's collective land rights (De Theije & Heemskerk 2009; Heemskerk et al. 2015). Although previous governments have attempted to regulate the mining sector by establishing government oversight bodies, the involvement of some government officials in mining activities within Saamaka territories has also hindered their struggle for collective land rights.

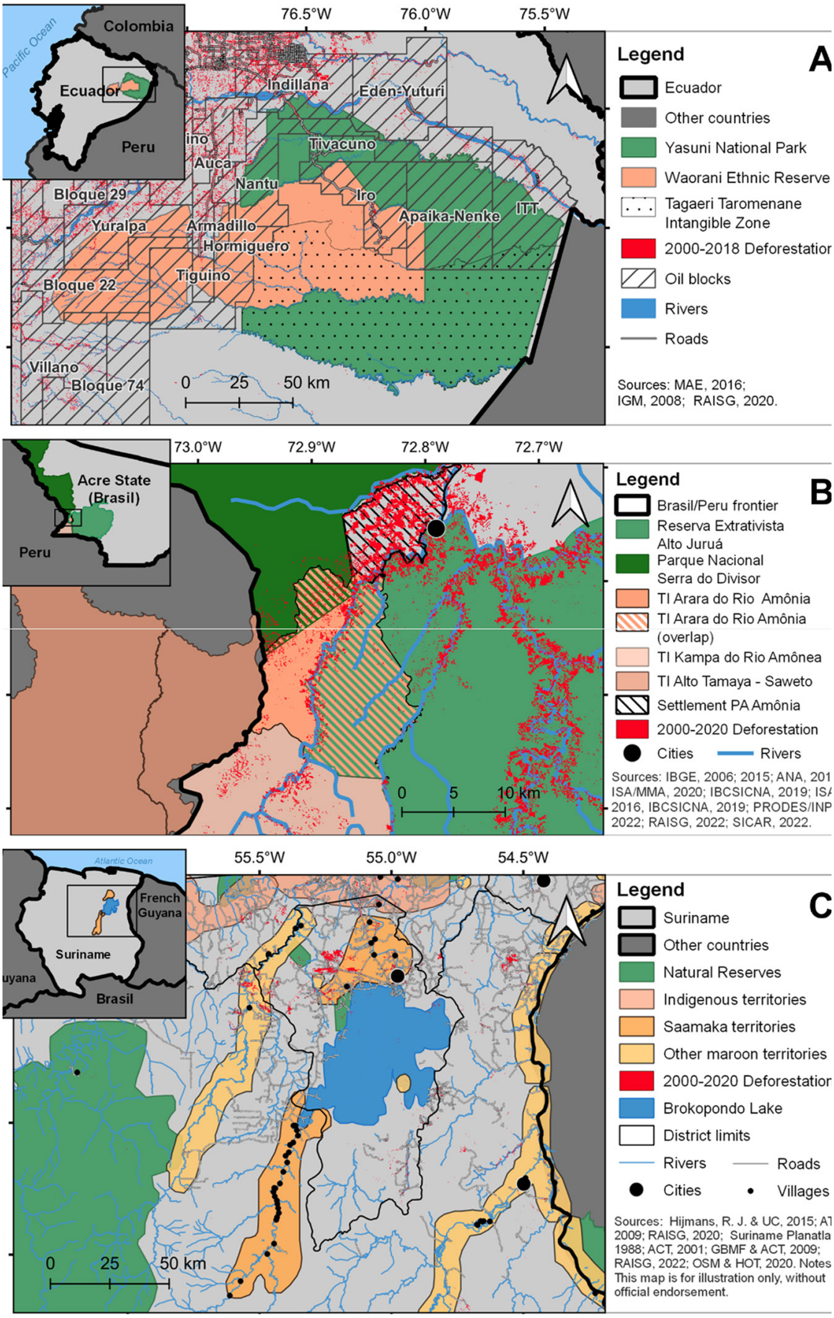

Figure 2 Geographic Location of the Indigenous and Maroon Territories Studied. A: Waorani Territory and ZITT, Ecuador. B: Arara Territory, Brazil. C: Saamaka Territories, Suriname. All maps are based on the SIRGAS 2000 Geographic Coordinate System Datum.

In 2007, Suriname signed the UN Declaration on the Rights of Indigenous Peoples, which recognizes their right "to the lands, territories, and resources which they have traditionally owned, occupied, or otherwise used or acquired," as well as the right "to maintain and strengthen their own spiritual relationship" with the territory (UN 2007, articles 26 and 25). Since then, the Surinamese government has felt pressure to initiate various legislative projects, as well as territorial demarcation and communication projects related to "grondenrechten" (land rights) to the public. Participatory mapping projects with indigenous communities supported by the Amazon Conservation Team have opened up space for new negotiations on the delineation of territories. The bill focuses on three fundamental collective rights of indigenous and tribal peoples (ITP) in Suriname. Firstly, the legal recognition of collective property rights over traditionally occupied areas of ITP and the natural resources traditionally used. Secondly, the recognition of traditional authority/governance structures of ITP, granting official status to traditional leaders. Lastly, free, prior, and informed consent (FPIC) in all decisions that may impact the territories and ways of life of ITP. Nevertheless, considering the complexity of various actors and stakeholders, the effective implementation of Saamaka's territorial rights has not yet been achieved.

Learned solutions and recommended innovations

The analysis of the three case studies has shown that, although the recognition and demarcation of territorial rights are essential for environmental conservation in Amazonia, these measures have not been sufficient to effectively ensure the conservation of biocultural diversity – including nature and traditional ways of life and knowledge – as the territories analyzed in the three studies continue to face serious threats, despite having been officially recognized and/or demarcated. Therefore, this section brings together the different experiences of the indigenous Apolima-Arara and Waorani peoples in Brazil and Ecuador, respectively, and the Saamaka maroon communities in Suriname, to recommend innovations that should accompany the processes of recognizing territorial rights and demarcation so that they can effectively contribute to the conservation of biocultural diversity in their territories.

Based on the theoretical approach proposed by Alencar (2022) regarding the need to consider "renewed" innovations for the effective reduction of deforestation in line with the demands of indigenous and maroon organizations, the sixteen innovations recommended here have been organized into four categories: Autonomy, self-governance, and political participation; Law enforcement, monitoring, and sanctioning; Conservation and promotion of traditional knowledge; and Community-based and sustainable economic sovereignty:

I. Autonomy, self-governance, and political participation	**II. Law enforcement, monitoring and sanctioning**
1. Legally recognize the rights of nature, in accordance with indigenous worldviews (such as *sumak kawsay*/living well), so that nature can also be considered an active actor in territorial disputes, territory demarcation, and socio-environmental policies. **2.** Promote and strengthen local and cross-cutting alliances (cross-border, women's, rural-urban), not only to reinforce social resistance against market pressures but also to address conflicting interests and common agendas of indigenous peoples and traditional communities, without compromising their collective rights and the rights of nature. **3.** Implement indigenous environmental paradiplomacy, through which different stakeholders at the subnational level (indigenous peoples, traditional communities, scientists, representatives of social movements, industrial sector representatives, etc.) actively participate in the process of discussing and resolving environmental issues, and whose deliberations can be legally binding (instruments of hard law or soft law, such as protocols, agreements on good conduct practices, decrees, and laws) **4.** Promote participatory mapping and demarcation of traditionally occupied territories (including resource gathering areas and sacred sites) as an important tool to serve as a basis for project planning and negotiation, as well as for conflict resolution with other stakeholders, and for monitoring and preventing deforestation and other illegal activities. **5.** Ensure political, territorial, and religious autonomy by recognizing traditional decision-making processes, supporting community authority, and protecting community leaders.	**6.** Implement laws to prohibit the allocation of traditionally occupied lands to private companies and ban non-traditional extractive activities in demarcated and titled indigenous/maroon territories when they do not exist. **7.** Strengthen indigenous and environmental public bodies to ensure law enforcement, surveillance, and sanctions, as well as to prevent conflicts of interest or exploitation by capital and facilitate the demarcation and titling processes of the territory. **8.** Enforce the prohibition of intensive extractive activities (such as mining and logging) in demarcated and titled territories through effectively coordinated monitoring and alert mechanisms to prevent, intercept, and penalize any illegal activities or land grabbing in these territories. **9.** In cases of overlapping indigenous or maroon territories and conservation areas (including extractive reserves or protected natural reserves and conservation units), public policies and legislation should interpret traditional territory and resource management as beneficial (rather than antagonistic) to biodiversity conservation, and vice versa. **10.** Integrate and intersectoralize socio-environmental public policies and territorial information – the latter being particularly urgent for maroon territories in the Pan-Amazonia – to improve the coordination of surveillance and sanction measures, as well as the development and enforcement of the law.
III. Conservation and promotion of traditional knowledge	**IV. Community-based and sustainable economic sovereignty**
11. Promote access to education and/or political, legal, and environmental training to help community members and leaders resolve economic and interest-related conflicts. **12.** Implement means for differentiated intercultural education to valorize traditional knowledge, languages, and ways of life and enhance higher education and vocational training in biodiversity conservation and management. **13.** Foster the creation of platforms for creative development and artistic expression (such as arts and crafts, cinema, hip-hop, graphic arts, gastronomy), not only to channel and highlight the demands, resistance, and struggle of indigenous and quilombola peoples but also to celebrate their knowledge, ethnicities, and cultures, creating alternative opportunities, especially for the youth.	**14.** Develop a fair economic system in which the Global North and large transnational corporations take responsibility for their direct impact on climate change and its effects on countries in the Global South, especially in biodiversity-rich regions. **15.** Officially recognize, learn from, and promote the traditional management of territories and their resource use practices, with the aim of systematically applying this knowledge as an effective tool to regenerate degraded lands and develop sustainable economic activities in the Amazonia. **16.** Support and financially incentivize community agroforestry economies and sustainable agroecological production chains as alternatives to reduce their economic vulnerability and exposure to illegal and environmentally harmful activities (such as mining and drug trafficking).

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Ethics – This study does not involve human subjects and/or clinical trials that should be approved by the Institutional Ethics Committee.

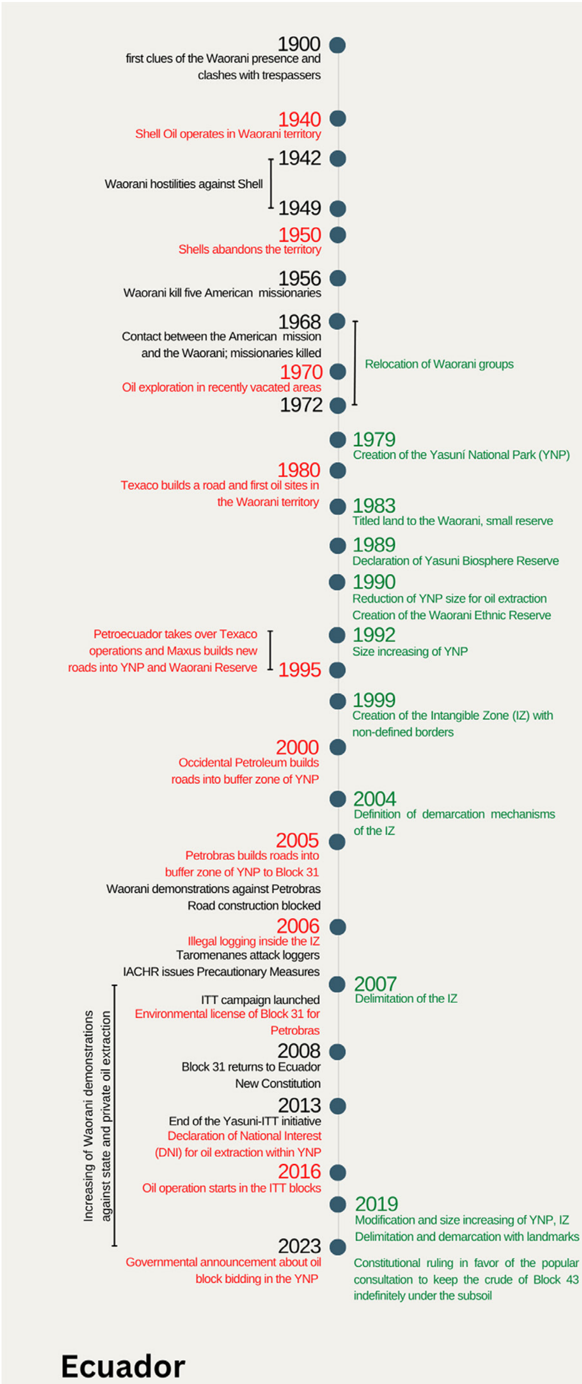

Figure SM 1 Time scale of events associated with the case of the Yasuní Indigenous Territory in Ecuador. In green, the events related to territory demarcation/titling; in red, the threats.

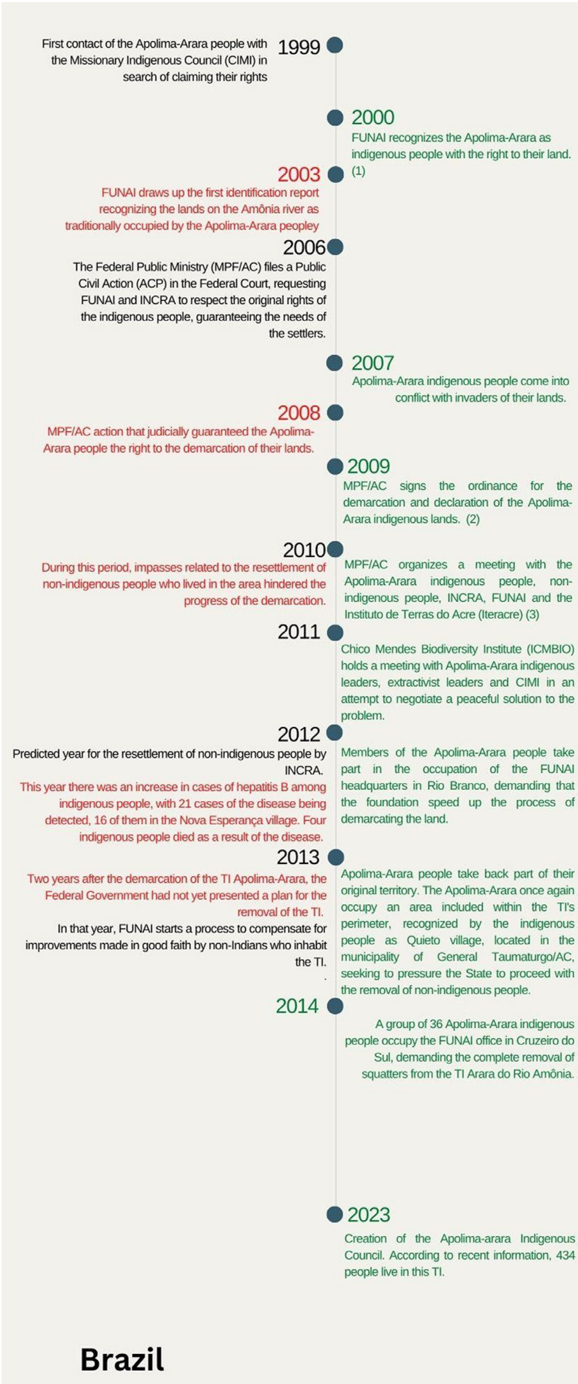

Figure SM 2 Time scale of events associated with the case of the Arara do Rio Amônia Indigenous Territory in Brazil. In green, the events related to territory demarcation/titling; in red, the threats. (1) During this period, the Apolima-Arara population was represented by approximately 135 people, distributed across the towns of Pedreira, Assembly and Jacamim, in addition to others spread across neighboring regions. (2) (Ordinance 2,986 - 09/10/2009) Indigenous people occupy the FUNAI building to press for speed in the process. (3) In order to continue the actions related to the definitive demarcation of the Apolima-Arara Indigenous Land. (4) ICMBIO's proposal was for the indigenous people to share the land with residents of the Alto Juruá Extractive Reserve. On that occasion, indigenous people refused to accept the agreement, alleging that federal justice had already, on several occasions, reaffirmed the legitimacy of their territorial claim.

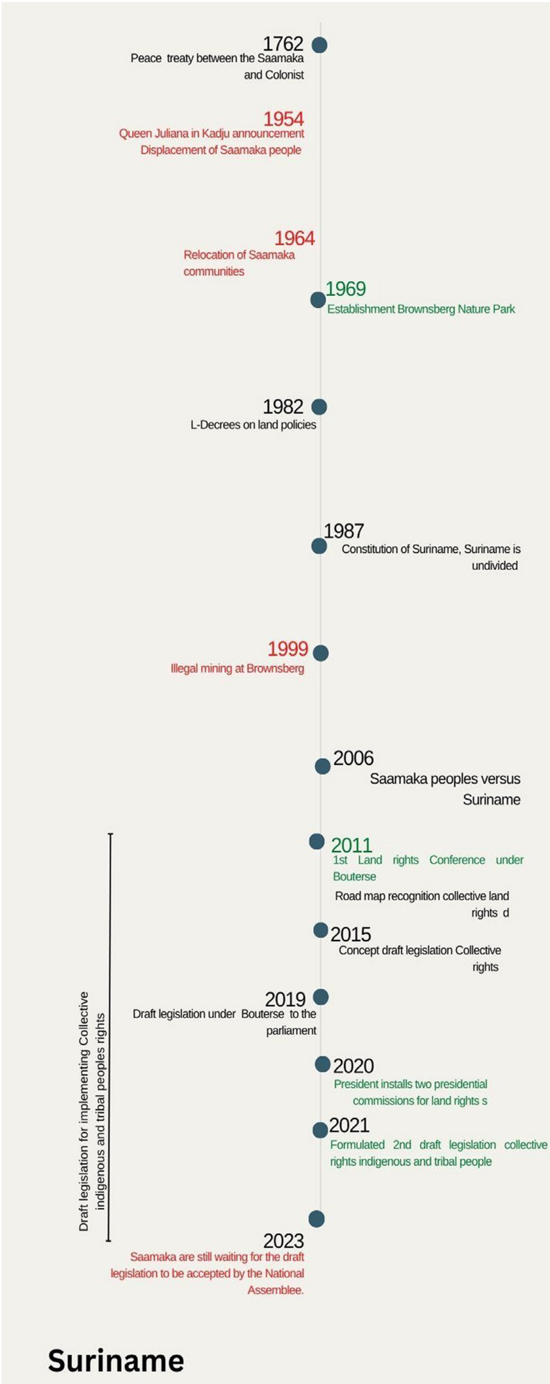

Figure SM 3: Time scale of events associated with the case of the Saamaka maroon people in Suriname. In green, the events related to territory demarcation/titling; in red, the threats.

Table SM 1 Actors involved in the Yasuní indigenous territory in ecuadorian Amazonia.

Type of actor	**Actor's name**	**Description**
State	Ministry of Environment, Water, and Ecological Transition (MAATE)	In charge of the border definition of YNP, the protected area connected to the Waorani people. The last update has been in process since 2018. The pressure of external actors, such as oil companies.
	Local governments	Territorial management. Public work in cities and in the rurality, e.g. roads
	Oil companies: Petroecuador	State oil company. Oil interests that promote extraction in Yasuni.
	Oil companies: Petrobras	Oil company of Brazil. Oil interests in Yasuni.
	Ministry of Agriculture: former IERAC, Office of Lands and Agrarian Reform	Land titling
	Ministry of Justice and Human Rights	Promotion of human rights, including indigenous peoples and PIACI
	Ministry of Energy	Defense of the oil sector
	Police and military forces	Territorial control in the name of the national State
Private	Oil companies: Shell	First Oil company operating in Yasuni
	Oil companies: Texaco	Oil interests that promote extraction in Yasuni.
	Oil companies: Occidental Petroleum	Oil interests that promote extraction in Yasuni.
	Oil companies: Repsol	Oil interests that promote extraction in Yasuni.
	Illegal loggers	Intruders in indigenous territories
Civil society Civil society, International	NAWE	Waorani representative organization
	AMWAE	Representative organization of Waorani women, key leaders defending their rights and the territory
	WWF	ONG. Research and promotion of sustainable projects
Sociedade civil, internacional Communities	WCS	ONG. Research and promotion of sustainable projects
	PIACI	Peoples in Voluntary Isolation. Their territory under threat
Intergovernmental	Inter-American Commission on Human Rights	Hearing about State violations against indigenous rights
	UNESCO	Declaration of biosphere reserve
International cooperation	Development Agency (e.g. Germany)	Financial support of projects and part of the former contributors to Yasuni-ITT Initiative

Table SM 2 Actors involved in the Arara do Rio Amônia indigenous territory in brazilian Amazonia.

Type of actor	**Actor's name**	**Description**
State	Institute for Agrarian Reform (INCRA)	Conflicts over land overlap
	National Indigenous Foundation (FUNAI)	Supported the struggle for land demarcation in TI Arara do Rio Amônia
	Chico Mendes Institute for Biodiversity Conservation (ICMBio)	Management of Nature Conservation Units. History of conflicts involving the demarcation of the Indigenous Land. Currently, the relationship with the indigenous people is advancing
	Extractive Reserve (Resex) of Alto Juruá	Conflicts over land overlap
	Federal Public Ministry	Support in the demarcation process of the Arara do Rio Amônia Indigenous Land
Civil Society	Missionary Indigenous Council (CIMI)	Supported the struggle for land demarcation in TI Arara do Rio Amônia
	Comissão Pró-Índio do Acre (CPI-Acre)	Support in agroecological production initiatives and in articulation with indigenous peoples and partner organizations
Private and State	Legal and Illegal Loggers lobbying	Conflitcts and threat that increases the difficulty of indigenous autonomy
	Oil and gas exploration lobbying	Conflitcts and threat that increases the difficulty of indigenous autonomy
	Road construction lobbying	Conflitcts and threat that increases the difficulty of indigenous autonomy
	Drug trafficking	Conflitcts and threat that increases the difficulty of indigenous autonomy
Communities	Alliance of the peoples of the forest	This alliance has favored regional encounters and meetings between indigenous peoples and extractivists in order to strengthen the common agendas for the management of biodiversity in these protected areas
	Ashaninka indigenous peoples	Support in agroecological production initiatives and in articulation with indigenous peoples and partner organizations
	Rubber extractivists	Conflitcts and threat that increases the difficulty of indigenous autonomy

Table SM 3 Actors involved in the Saamaka maroon people in Surinamese Amazonia.

Type of actor	Actor's name	Description
State	Ministery of Regional Development and Sport (ROS)	Leading government body for concept law on collective indigenous and marron rights, including land entitlements
	Ministery of Natural Resources (NH)	Government body responsible for allocating an mining natural resources such as gold, timber,
	Ministery of Land policy and Forest Conservation (GBB)	New government body in charge of land rights and entitlements
	Presidential Commission for land rights	Consists of Government officials and representatives of indigenous and marroon communities
	Presidential Commission for reviewing land policy and land conversion	Consists of Notaries, Lawyers, Tax Officers to support the government in conversion of land entitlements
	Landrights bureau	
Civil Society	Traditional Authority; Indigenous and Marron self governance	
	Nature conservation Organization: Stinasu, Brownsberg	Supporting the landrights of Saamaka with demarcation projects
	Amazon Conservation Team (ACT)	Supporting the communities with land demarcation and negotiating land rights
	STAS	Communicating the Conceptlaw to the public
	Association of Saamaka authorities	Leaders in land rights and entitlements for Saamaka
	Association of Indigenous authorities	Leaders in land rights and entitlements for INdigenous
	Stichting A Marron Kompas	Negotiating partner (Njduka)
	Stichting Projecta	
Civil Society International	Forest Peoples Program	Supporting local communities in their collective rights
Civil Society, Private	Tourism organizations	Income generation for Saamaka communities
Private, International	Mining Companies: New Mount	Income for private and government bodies
	Mining Companies: I am Gold	Income for private and government bodies
Private, National, sometimes State	Small Scale miners & Garimpeiros	Private income, also for government officials
Private, National and International, sometimes State	Timber logging companies	Private income, also for government officials
Intergovernmental	Organisation of American States (OAS)	
	IACHR	International legal body for human rights
Communal	Community forests	Income for the communities

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Dialogues for sustainability and inclusion in the Amazon Basin: local governance, participation and transdisciplinarity

- Adaptation to drought in the Amazon: participatory approaches to strengthening the perspective of riverside communities
- Local governance, climate change, and natural resource management in the Amazon
- Transdisciplinarity is crucial to reformulate a sustainable future for the Amazon

Adaptation to drought in the Amazon: participatory approaches for strengthening the perspective of riverside communities

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ABSTRACT

The Amazon has experienced, in recent decades, extreme drought events (e.g., 2005, 2010 and 2015/16) with severe impacts to local populations: isolation of communities due to restrictions on river transportation, scarcity of food, medicine, and fuel in rural areas, increase in prices of crucial supplies, loss of agricultural crops, forest fires with consequences for human health, among others. While the dry season constitutes a natural part of seasonal variability in water availability, reflected in river levels and soil moisture, severe droughts, on the other hand, are periods during which water deficit occurs in an exacerbated manner in intensity and/or duration, leading to negative and serious consequences for ecosystems and human populations. Historical data shows an increasing trend in the number of dry days in the southern region of the Amazon basin and an opposite trend in the northern region, demonstrating that the changes the basin is undergoing are spatially heterogeneous. Climatological projections for the Amazon basin indicate a significant increase in the area exposed to moderate and severe droughts over the next eighty years, alongside an increase in the frequency of extreme events such as droughts and floods. In this regard, how can we address adaptation at the local level? Participatory experiences with local communities in the Amazon region have shown that communities have developed strategies by themselves based on traditional knowledge that can help in coping with the impacts of severe droughts. In the present work, we bring forth some experiences reported in the literature, including: housing and transportation adaptations, agricultural activity adjustments, development of an ecological calendar, and hybrid governance systems involving various social actors (e.g., community leaders, scientists, and government representatives) to address climate extremes. Finally, we provide some recommendations on technical and public policy aspects. The target audience for this document includes socio-environmental leaders, public servants, elected political representatives at local, regional, and national levels, researchers, educators, as well as individuals interested in learning more about the significance of local populations' perspectives in the process of adapting to extreme droughts.

Keywords: climate extremes, impact, adaptation, traditional knowledge, climate change, Amazonian populations.

Cobra-grande tanta seca estorvou
O prenúncio da Amazônia é savana
Uirapuru, amiúde não cantou
Chora, chora Amazônia

Lyrics from the song "Amazônia Eterna", Munduruku tribes

Definitions of drought and its local and regional perceptions in the Amazon

1. What is drought?

The word "drought," in a general sense, corresponds to a lack of water. The concepts and notions about drought are complex and vary across literature. Drought can be categorized as: *meteorological*, when there is a low rainfall rate, meaning significantly less rain than expected; *agricultural*, when drought affects, in the short term, the soil during crop growth periods; *hydrological*, when there's a reduction in river flow and water levels of lakes, reservoirs, and other surface water bodies, as well as affecting groundwater levels; *socioeconomic*, due to its impact on living conditions, economic assets, and human well-being; and *environmental*, when it leads to fire, land degradation, and sandstorms (Tonna *et al.* 2009, UNISDR 2009, Stanke *et al.* 2013). In this sense, drought can be defined as a phenomenon that, although recurrent and natural, can become severe (extreme drought), entailing negative consequences for the socioeconomic activities of local populations and ecosystems (Alpino *et al.* 2014).

It is common for the dry season to be defined by the rainfall regime. The dry season varies widely across the Amazon basin. If we define the dry season as the consecutive months with precipitation below the evapotranspiration rate, it is possible to identify 74 regions with distinct dry seasons in the Amazon territory (Carvalho *et al.* 2021). This definition takes into account the water stress imposed on the forest, which means that if the amount of rainfall is less than the water evaporated into the atmosphere from the forest, water bodies, and the soil, the forest loses more water than it replenishes, and therefore, would be under water stress. This is a technical definition, which may delimit a seasonality that is different from the local perception of drought. However, it is a useful definition for the identification of extreme events, that is events in which the expected dry season is more intense and/or longer than normal.

The Amazon basin has been undergoing changes in its rainfall regime. There is no clear consensus regarding a single trend concerning historical precipitation in the Amazon (Marengo *et al.* 2018), however, some studies indicate an increase in the number of wet days in the northern region of the Amazon in recent decades and an increase in the number of dry days in the southern region (e.g., Espinoza *et al.* 2019). Li *et al.* (2008) found evidence of a precipitation reduction across the entire basin, equivalent to 0.32% per year. In addition to these observed changes in recent decades, there are also natural events like the El Niño Southern Oscillation (ENSO) and other phenomena related to changes in sea surface temperature (e.g., Atlantic Ocean) that cause extreme droughts in some parts of the Amazon (Aragão *et al.* 2007; Yoon & Zeng 2010). It is possible to identify at least four regions that have experienced extreme droughts in the Amazon in recent decades:

1. Southwestern Amazon: the region that includes parts of Bolivia, Brazil and Peru has experienced one of the most severe droughts in the Amazon in recent years. The combination of climate change and deforestation has made this area particularly vulnerable to water scarcity and forest fires (Panisset *et al.* 2018);
2. Eastern Amazon: in 2015-2016, an El Niño-related drought caused widespread damage to forests and plantations in the eastern Amazon (Panisset *et al.* 2018);
3. Transition zone between the Amazon and the Cerrado: area located in central Brazil, in which deforestation is concentrated. The conversion of forest to to agricultural fields and pasture has reduced the area's capacity to retain moisture, making it more susceptible to droughts; and,
4. Peruvian Amazon: a region that has experienced many severe droughts in recent years, including one in 2010 that caused widespread damage to forests and crops (Marengo & Espinoza 2016). Deforestation, mining, and other human activities have contributed to the vulnerability of this area to droughts.

Climate change is expected to have a significant impact on these phenomena, increasing the intensity, extent and frequency of extreme droughts (Anderson *et al.* 2018). As temperatures rise and rainfall patterns change, Amazonian ecosystems become increasingly water-stressed and more susceptible to the deleterious effects of droughts, such as forest degradation, biodiversity losses and higher carbon emissions (Marengo *et al.* 2011; Duffy *et al.* 2015). In addition to the changes mentioned above, some areas of the basin, currently less vulnerable to droughts, may become more susceptible. The implications of these changes are potentially significant, as Amazonian ecosystems and human communities are adapted to historical patterns of rainfall, temperature and river regime. Changes in the spatial distribution of droughts can change species distribution, lead to changes in vegetation types (Esquivel-Muelbert *et al.* 2017), and affect the regional hydrological cycle, among other impacts that will be discussed in more detail in this document. Droughts could also exacerbate existing social and economic inequalities in the Amazon, as some regions may have more resources and adaptive capacity in relation to droughts than others (Marengo & Espinoza 2016). In this sense, the local perception of changes in drought regimes is fundamental for the elaboration of adaptation plans and mitigation of their impacts in a contextualized and useful way.

How drought phenomena are perceived and defined based on Amazon's local and regional perspectives?

In the Amazon, populations have a strong connection with water, and therefore, their lives are linked to the pulses of rising and falling river levels. Water constitutes a transformative agent of the region's way of life (Tocantins 2000). At the same time, the rainfall regime guides sociocultural activities in the Amazon, as the waters alter spaces and landscape, a movement referred to as seasonality (Pereira & Oliveira 2012). The seasonality of the rivers is described in four phases: rising water, high water, falling water, and dry season. Each phase of seasonality imposes, in its own way, strategies of use and exchange between humans and nature, sometimes limiting, sometimes providing their resources (Figure 1).

When assessing how Amazon populations use the term "drought," we can identify that it is not related to disasters, but rather as one of the phases of seasonality, as mentioned earlier. The dry season of the rivers is associated with a period of reduced rainfall in the region. In most of the Amazon basin, populations traditionally define two climatic seasons, marked by the period of higher or lower occurrence of rain: they name them "winter" and "summer". The intensity and distribution of the rainy season, as well as the seasonality of the rivers, are not homogeneous throughout the basin, due to its extension (Alves 2013). However, with the latest occurrences of extreme climatic events, populations have noticed an increase in the intensity and frequency of droughts after the 2000s and have called the events: extreme droughts, major droughts, severe droughts, intense dropping water level, and/or extreme low-water period (Nascimento 2017; Vasconcelos 2020; Silva 2022).

Figure 1 Drought in the Nova União community, in the Extractive Reserve of Médio Juruá, in the municipality of Carauari, Amazonas, Brazil (August 2022). *Photo:* Mônica Vasconcelos (2022).

Amazon populations engage in a range of socioeconomic activities based on the natural resources of rivers and forests, forming a connection with their environment. They organize their annual agricultural calendars according to the cycles of rainfall and river levels, and for this reason, they have noticed changes in recent years (Vasconcelos 2020). In a study conducted in the lower Negro River, women perceived the occurrence of drought events as:

> There is a change in the regular rainfall calendar, and this contributes to the occurrence of forest fires. Furthermore, they state that major droughts make it challenging to carry out fishing, farming, and wood extraction activities. During significant droughts, the difficulty of access requires the use of smaller canoes. The major droughts are associated with periods of reduced rainfall and increased heat, according to community members of the Rio Negro Sustainable Development Reserve (Vasconcelos 2020).

Due to this dynamic exchange with the environmental system, traditional populations adjust their ways of life to a certain predictability of the seasonality of rivers. For Fraxe (2004, p. 330), "the river is a dominant factor in the physiographic and human structure, an ethos and a rhythm to regional life". However, in the year 2005, for example, the residents of the riverside community of Terra Nova, located in the Careiro da Várzea District, Amazonas (Amazon River), were taken by surprise with an extreme decrease in water levels that made it difficult to obtain water for household use and irrigation, also causing disruptions in the transportation of goods and people, particularly that of children transportation to school (Nascimento 2017). Furthermore, in years of severe droughts, the floating houses cluster in smaller spaces, which can damage their structures.

In a study that sought to evaluate the perception of riverside populations along the Madeira River, Silva (2022) pointed out that, in episodes of abnormal receding water levels, residents report: isolation of riverside communities, leaving them without access to clean water or fish in lakes and rivers, increased vulnerability to fires due to the potential for it to reach the communities, as well as an increase in the cost of fuel, cooking gas, and basic necessities. According to the Wapichana indigenous people, who occupy the valleys of the Uraricoera River and the Tacutu River in the state of Roraima, the warming of river water has caused fish to migrate, reducing their food availability. They believe that this is a consequence of climate change (Alcantara 2019). Although the problems caused by major droughts in the Amazon are notorious, the perceptions of local populations indicate that, depending on the case, it can also have positive impacts on their livelihoods, such as increasing the availability of fish for consumption due to their confinement in restricted spaces like lakes.

Finally, the perceptions of the drought phenomenon are quite plural in the Amazon. Traditional populations have evolved their practices in the context of the seasonality of rain, of the rivers, and of the different crops, recognizing the connection between these dynamics. The rain plays a leading role in this seasonality, marking the seasons of the year. The onset of rainfall is greeted with prepared fields and a sociocultural dynamic that anticipates the rise of the rivers, and it is evident that, beyond the sociocultural context influenced by the river's seasonality, there is a change in the local landscape due to the dynamics of water covering the land (Figure 2). However, climate change affects this seasonality and what was once known and predictable becomes an additional factor of vulnerability for populations living in close relationship with the rivers.

Figure 2 Rainy season in the São Raimundo community, in the Extractive Reserve of Médio Juruá, in the municipality of Carauari, Amazonas, Brazil. *Photo:* Mônica Vasconcelos (2022).

It should be noted that the phenomenon of drought in the Amazon is related to a change observed in the climatic cycles of the ecological calendar, which, in some cases, includes the prolongation of dry season. These changes have led local populations to reduce their ability to maintain their traditional socioecological adaptation systems, change the dynamics of fishing, hunting, planting, and collecting forest products. They have had to address these needs by adopting lifestyles that are more dependent on markets and the state. According to Moraes and Schor (2010), in certain items of the regionally adjusted basic food basket, there is a cost variation depending on the river's seasonality, with this cost being higher during periods of extreme droughts. This is due to the difficulty of boats reaching more distant cities and, especially, riverside communities, which increases the freight cost.

Future perspectives of droughts in the Amazon

Scenarios that take into account the phenomena associated with drought in the Amazon play a role in demonstrating how this type of event can negatively impact the future of the forest and local populations (e.g., riverside, urban and indigenous). Climate models projections can assist decision-makers in developing actions to reduce the impacts of droughts in the Amazon and contribute to strengthening adaptation strategies of local populations to drought events, particularly those associated with severe droughts (Duffy *et al.* 2015). Through a diagnosis of the climatic conditions observed in a historical period, it is possible to understand the mechanisms that drive drought events in the Amazon (Nobre *et al.* 2007; Philips *et al.* 2009; Mu *et al.* 2023). This understanding is essential to project the occurrence of future severe drought events and their potential negative impacts on the forest and local populations.

Climatic prediction models can indicate, with some advance notice, where, how, and when possible severe drought events may occur. For instance, the model developed by the Center for Weather Forecast and Climate Studies at the National Institute for Space Research (CPTEC/INPE) managed to provide indications and drought conditions for the events that took place in 1998, 2005, and 2010 with one month of anticipation (Borma & Nobre 2013). Despite the relatively short time, with this information, public institutions can issue alerts and propose emergency measures to mitigate the impacts associated with these phenomena, especially in areas that may be highly affected by these events. With an effective governance and alert system in place, the local population can, with government support, prepare in advance, thereby reducing economic, social, and environmental damages (Borma & Nobre 2013).

Factors such as deforestation, forest degradation through logging, forest fires, edge effects in the forest, extreme droughts, and urban area expansion have accelerated climate change and/or intensified its local effects (Foley *et al.* 2007; Lawrence & Vandecar 2015). It is estimated that approximately 2.5×10^6 km^2 (38%) of the remaining forest in the Amazon is degraded, which can reduce evapotranspiration by up to 34% during the dry season, causing significant disruptions in the forest's functioning, loss of biodiversity, and impacts on the way of life of local populations (Lapola *et al.* 2023).

1. What do the climate projections indicate?

Studies based on climate observations have already shown evidence of variations in precipitation in regions of strong anthropogenic pressure in the Amazon, especially in the dry season, in the coming decades. In the future, the dry season may become longer and more intense. In addition, severe drought events drought events, such as those that occurred in 2005 and 2010, may occur more frequently (Gatti *et al.* 2021; Marengo *et al.* 2011; Mu *et al.* 2023; Soares & Marengo 2013). Climate projections in the Amazon region have also shown that the trend is for the climate to become drier and warmer in the future (Marengo *et al.* 2010). According to a probability model for the occurrence of drought events like that of 2005, the frequency of such events was one every twenty years in the past but may increase, reaching nine every ten years by 2060 (Cox *et al.* 2008). On the other hand, some regions of the Amazon may face major floods more frequently in the near future (Duffy *et al.* 2015).

Studies based on deforestation scenarios indicate that the increase in deforested area in the Amazon may contribute to an increase in the number of days with water deficit in the southwest region, particularly in the Juruá and Purus River basins, due to changes in precipitation (Lima *et al.* 2014). These and other hydroclimatological changes projected from studies with models and scenarios are summarized in Table 1.

Table 1 Expected hydroclimatological changes for the Amazon basin according to some studies based on scenarios and simulation of climate change models.

Study area	Changes projected by the models	Reference
Amazon River basin	The size of the area currently affected by moderate droughts will double by the year 2100. Furthermore, the area affected by severe droughts will triple, and there will be a tendency for an increase in the annual average precipitation in the western part of the basin.	Duffy *et al.* (2015)
Amazon River basin	Extreme drought events like the one in 2005 could occur 9 times every 10 years by 2060.	Cox *et al.* (2008)
Western Amazon	Extreme flood events will occur more frequently after 2040.	Duffy et al. (2015)
Western Amazon	An increase in the annual average temperature of approximately 6°C in western Amazonia, with potential increases of up to 8°C during the dry season.	Marengo *et al.* (2010)
Amazon basin	By the end of the 21st century, the annual average flows will decrease in the southern tributaries of the Amazon basin. Seasonal flow rates are projected to increase during the wet season and decrease even further during the dry season, thus increasing the amplitude of flow rates throughout the annual cycle.	Nakaegawa *et al.* (2013)
Eastern Amazon	Water stress during the dry season is likely to increase in eastern Amazonia over the 21st century. Several factors contribute to this, including increasing temperature and evapotranspiration rates, increased deforestation and forest degradation.	Malhi *et al.* (2009)
Madeira River basin	Scenarios projected through hydrological modeling using climate change projections indicate a reduction in the minimum flow rate regime in the Madeira River basin. In the presence of combined climate change and deforestation, projections suggest a reduction in minimum flow rates in the upper part of the basin, and changes in flow rates overall throughout the hydrological year in the lower part of the basin.	Siqueira Júnior *et al.* (2015)

Therefore, the vulnerability of the Amazon and its inhabitants to climate change is related to the climatic variability observed in recent decades and the impact caused by the increase in greenhouse gases in the atmosphere, for which anthropogenic activities related to the degradation and deforestation of the remaining forest are important vectors. Studies indicate that increased deforestation in recent years and the intensification of the dry season cause an increase in fire occurrence and carbon emissions, especially where the ecosystem is already under water stress, such as the eastern part of the Amazon (Gatti *et al.* 2021). Consequently, projection models that relate the effect of deforestation to the temporal and spatial variability of the dry season at different intensities throughout the Amazon region can represent the future impacts associated with land use and land cover changes in the Amazon more accurately (Staal *et al.* 2020). It is important to emphasize that models are simplifications of reality, therefore, all climate projections have uncertainties and limitations, since it is not possible to represent all the complexity of the climate system and the changes in land use and land cover associated with forest loss in a model (Soares & Marengo 2013).

The Amazon rainforest plays a key role in maintaining the global climate, however, with increasing greenhouse gas emissions, deforestation and forest fires, Amazonian ecosystems are more susceptible to global climate change (Albert *et al.* 2023; Marengo & Souza Jr. 2018). This has a major effect on Amazonian populations that depend on forest resources. The risk of climate change for these populations is enormous. Thus, it is fundamental to strengthen local perception about the best ways to adapt to climate change. This can be done by associating the knowledge and experience that Amazonian residents already have about drought events, as well as the strategies used by them over the years in which they have experienced extreme events, with studies of climate change projections that show the possible trajectories of changes in the Amazon basin.

Impacts of droughts on local populations

Rivers are the main transportation routes for a significant portion of the Amazonian population, being essential throughout most of the basin and playing a fundamental role in the local economy through the transportation of various consumer goods. Inland water transport is particularly important in regions where road access is not available or where roads are not in good condition, especially during rainy season when many roads become unsuitable for traffic. Thus, traveling along the rivers is part of the routine, the means of life and the culture of many Amazonian populations, especially the riverine (David 2019).

Extreme droughts can cause major mobility and accessibility problems, as the water levels of rivers are considerably reduced (Pereira *et al.* 2021; Lima *et al.* 2023). Vessels require a minimum depth for traffic on rivers and streams. If the water level is too low, boats can run aground on sandbanks or be damaged by colliding with rocks and gravel from the exposed riverbed. When the drought is very intense, boats can be stranded in the port itself, with no way out (Kolanski *et al.* 2021). Furthermore, even when boats are still accessible, drought can force passengers to walk across sandbanks that form between the port and the boat anchorage point. All of this poses significant challenges to the water transport sector (Lima *et al. in prep.*).

When the boats manage to make the journeys during intense droughts, they still encounter many difficulties until they reach their destination. Heavy and large boats need to be replaced by lighter vessels that can navigate in shallower waters. However, these boats also tend to have a reduced capacity for transporting passengers and cargo. Therefore, several trips are necessary to transport the same amount of goods or passengers, and this can increase the cost of transport. To further complicate the situation, due to the risk of accidents, journeys need to be made more slowly and often involve zigzag routes to avoid obstacles. With the increased risk of accidents, it is common for authorities that control transportation via rivers to establish navigation restrictions, either regarding the maximum draft of the vessel or regarding the permitted transit hours (Lima *et al. in prep.*).

Transportation via rivers is crucial for numerous Amazonian communities in terms of access to consumer goods such as food, clothing, electronics, medicines, as well as household appliances and construction materials. For this reason, during severe droughts, the supply of consumer goods can be severely compromised and can lead to an increase in prices, causing, as well, temporary shortages in entire communities (Pinho *et al.* 2015; Pereira *et al.* 2021; Silva 2022). This is particularly alarming when it comes to essential immediate consumer goods, such as food and medicines (Marengo *et al.* 2013). Severe drought not only leads to shortages, but also hinders the transportation of agricultural production from rural communities. In some situations, communities may lose their entire crop yield due to the difficulty in transporting it to regional consumer centers or intermediary markets that trade the products (Lima *et al.* 2023).

Severe droughts also impact fishing, hunting, farming, and forest products extraction activities. When intense droughts occur, species that are typically fished or hunted may have their behavior altered or become less abundant due to food scarcity in the environment or ecological changes resulting from the drought (Pinho *et al.* 2015). In lakes and streams, the heat and reduced water levels can lead to fish mortality due to their impact on water quality. However, depending on the severity of the drought event, in some Amazonian regions, the opposite can occur; that is, fishing can be facilitated because the reduced water levels concentrate fish schools in smaller spaces. In contrast, with low water levels, the displacement of individuals engaged in fishing, hunting, or extraction can be compromised, making it difficult to access resources. Depending on the severity of the drought event, farming activities can also be affected. This is because, during severe droughts, the amount of water stored in the soil can be significantly reduced, leading to crop loss. Drought can also hinder plant germination and delay harvesting schedules.

Fuel is another important product whose access is reduced during severe droughts (Pinho *et al.* 2015). Several sectors of the local economy can be impacted by this shortage, given that fuel is not only strategic for local and regional transport, but also for power generation. Many communities in remote regions of the Amazon are not connected to the electrical grid and, therefore, rely on diesel-powered generators to operate household appliances, local businesses, schools and healthcare facilities. Refrigerators and freezers are essential for storing perishable foods, such as meat and fish, as well as some medications, such as vaccines and insulin. Therefore, during fuel shortages due to a severe drought, many communities may lose perishable items due to a lack of electrical power (Lima *et al. in prep*.).

Severe drought can also lead to a significant restriction of access to services that are of great importance to the population, such as healthcare and education. Complex situations involving various accidents, pregnancy and childbirth, chronic illnesses, care for newborns and the elderly can be tremendously worsened due to transportation difficulties (Garnelo *et al.* 2020). Reduced and slower travel impacts the arrival of patients at healthcare facilities, as well as the arrival of healthcare workers, nurses, and doctors at the homes of affected families (Lima *et al.* in prep.). Similarly, access to schools is impaired during periods of intense drought due to disruptions and delays in the school calendar. All the materials that students depend on also become scarce, compromising the progress of classes.

Finally, another major challenge posed by severe droughts is the increase in forest fires due to low air and soil humidity and the increase in tree mortality. Forest fires can occur due to illegal activity in the forest or uncontrolled use of fire in agricultural fields and pastures and can rarely be of natural origin. These events cause major problems for Amazonian populations, increasing the incidence of respiratory problems, which mainly affect the health of children, the elderly, and individuals with chronic problems (Marengo *et al.* 2013). Forest fires also hinder transportation via aircrafts and vessels, as the smoke reduces visibility during journeys, and they cause economic losses by damaging infrastructure (fences, houses, and cultivation areas).

Adaptive strategies based on local knowledge and participatory approaches to cope with droughts

Adapting to climate change refers to "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC 2018). Here, we refer to adjustments related to extreme drought events in the Amazon. Adaptation can be classified, in terms of intentionality, as planned or spontaneous (Lindoso & Rodrigues Filho 2016). According to Smit *et al.* (2000), "planned adaptations" are those carried out by governments, typically through public policies, while "spontaneous adaptations," as the name suggests, are autonomous and reactive; for example, those carried out by rural populations in the Amazon. Many of these adaptations occur in the absence of government actions, primarily due to the initiative and resilience of these populations in the face of climate change scenarios.

Some proposals for adapting to drought phenomena are based on innovations that integrate the knowledge of local populations with scientific knowledge. Many of these proposals originate from participatory experiences in which practices were implemented, with relative success, approached the resolution of technical adaptation challenges and anticipated measures to mitigate severe droughts in the Amazon. In this regard, many non-governmental organizations (NGOs), government agencies, social movements, universities, and research institutes are leading initiatives with significant outcomes for the adaptation and mitigation of the effects that drought can have on the food, health, and well-being of indigenous peoples (Abdenur *et al.* 2019). We illustrate some experiences in this present work, including: housing and transportation adaptations, agricultural activity adaptations, the development of an ecological calendar, and hybrid governance systems involving different social actors to address climate extremes (i.e., community leaders, scientists, and government representatives).

1. Housing and transport adaptations

We begin with the case of the Lago do Catalão Community, located in the municipality of Iranduba, at the confluence of the Negro River and the Solimões River. In this community, due to the phenomenon of "landfall" (*terras caídas*), which is the riverine erosive process caused by the action of rivers and significantly intensified by hydrological extremes (Guimarães *et al.* 2019), all houses, as well as the local school, are constructed on top of tree trunks that serve as floating structures for support, in such a way that the buildings are adapted to the seasonality of water levels (Menin 2021). Due to the increased erosion of the community's shoreline, starting in 2007, residents began relocating to the upland area, so the floating constructions themselves became an adaptive strategy (Guimarães *et al.* 2019; Menin 2021). However, life on floating houses has its challenges as well: during years of severe river droughts, the foundations and beams of these houses are often damaged and require replacement.

During severe droughts, the main watercourse becomes quite distant from the houses, and hydraulic pumps are used to access water. Additionally, a temporary dam made of sandbags is built in Lago do Catalão to prevent the water from completely flowing out in the direction of the river course (Menin 2021). An important adaptation to highlight in this community is the one made to recreational structures, particularly for soccer, a popular sport in rural areas of the Amazon. In the Lago do Catalão Community, soccer is played on a field created on top of the floating tree trunks (Vasconcelos 2020).

In the lower Negro River, adaptations made during years of severe droughts are primarily associated with transportation along the rivers, using smaller canoes. These canoes are used for various productive activities such as the extraction of forest products, agriculture, fishing, gathering, and hunting. They are also essential for accessing schools, healthcare services, and recreational activities. Additionally, artesian wells have been constructed over the years due to the difficulty of accessing water (Vasconcelos 2020). The use of smaller boats during severe droughts is a common adaptation in many parts of the Amazon because it allows for navigation on rivers and streams with very low water levels, which would not be feasible using larger boats. However, since these smaller vessels have limited capacity, more trips are required to transport the same amount of load or individuals.

Similar responses were identified in Nascimento 2017, however, in the Lago do Rei Community, the mais adaptation is related to housing: during severe droughts, traditional floating houses need to be moved to areas that still have water, and this is not always possible. Moreover, the restricted space poses a risk of collision with other houses or boats. Nascimento (2017) describes an alternative of floating houses on plastic drum floats, which do not need to be relocated in extreme droughts and are more affordable when compared to traditional floating houses built on açacu logs (*Hura crepitans* L.). In the Madeira River basin, an interesting adaptation involves the logistics of boat transportation: local populations changed their timing for transporting goods during years of extreme drought. The event occurs during the same period as the Amazon summer, with high temperatures, and due to the formation of long sandbars, community members find it challenging to reach the boats due to thermal discomfort. Therefore, transportation is carried out in the late afternoon (Silva 2022).

2. Agricultural strategies

Among the various strategies for adapting to climate change in the Amazon region, there are those aimed at addressing the impacts on agriculture. Here, we report on some participatory experiences that illustrate the efforts of different social groups to promote soil conservation and adjust harvest times to climate variability, as well as other actions to protect traditional agricultural practices with the support of science.

We begin with the collaboration between scientists and indigenous peoples in efforts to enrich soils in chagra systems. Chagra is an ancestral agroforestry system practiced by traditional communities in the Amazon and Andean regions, originating from indigenous knowledge (Marentes *et al.* 2022). A close synonym would be "slash-and-burn agriculture" or "traditional swidden agriculture." This rotational farming system is mainly practiced in countries such as Ecuador, Colombia, and Peru and involves a series of activities that promote both food production and biodiversity. It's important to emphasize that when carried out by traditional populations, its impact on the forest is minimal compared to modern agriculture, where extensive cutting and burning occur, making it a driver of deforestation and an unsustainable practice.

Soil enrichment in chagras is an important issue in some regions of the Amazon due to adverse climatic conditions. Drought is one of the major challenges faced by farmers in the Amazon, as it can severely impact crop productivity (UN Periodico 2022). Changes in droughts and rainfall periods have resulted in alterations to the slash-and-burn activities in the chagra system (UN Periodico 2022). In the case of communities near the city of Leticia in the Colombian Amazon, soil enrichment through agroecological practices has proven effective in enhancing crop productivity in chagras and increasing their resilience to drought events. These practices include crop rotation, diversification, the use of organic fertilizers, and soil conservation.

In addition, continuous monitoring and evaluation of soil conditions and crop yields are essential to ensure the long-term success of soil enrichment in the Amazon. The active participation of traditional communities in this process is important to ensure the effective and sustainable implementation of agro-ecological practices (UN Periodico 2022). For example, indigenous groups in the south and east of the Colombian Amazon, in the Caquetá-Putumayo interfluve (Uitoto, Muinane, Nonuya) and in the Colombian Amazon trapeze (Ticuna and Cocama) have implemented soil fertilization and enrichment practices for horticulture.

Traditional chagras have a limited lifespan, lasting only a few years before being temporarily abandoned and converted into fallow areas for local conditions to recover. While the shifting cultivation forest system benefits from the ecological succession process to replenish soil nutrients during the fallow period, traditional populations are not accustomed to soil enrichment practices adopted in other regions. To promote soil enrichment in chagras, the idea of composting and soil maintenance practices has been promoted by the Sinchi Institute, a government institution in Colombia, in the Amazonian trapezoid and the Igaraparana River region (Caqueta-Putumayo). The institution recommends avoiding forest burning and, instead planting in existing fields, maintaining productivity and adding natural fertilizers (ashes, decaying wood, etc.). This system is still in its early stages, and its results still genarate expectations. It requires much more intense dedication to horticulture, which competes with the available time for other subsistence activities (UN Periodico 2022).

An example of how soils are treated for the cultivation of aromatic and culinary medicinal plants in agroforestry backyards and swidden fields in floodplain areas is described by Chagas (2011) in two communities, São Francisco and Santa Luzia do Baixio, located on the left bank of the Solimões River, specifically in the Careiro da Várzea District, a microregion of Manaus, in the state of Amazonas. In these communities, cultivation is done directly on the ground during the dry season and on raised beds during the river's high-water season. Therefore, as the flood season approaches, the soil enriched on the ground is transferred to the raised beds for planting (Chagas 2011). To aid in soil fertilization, both chemical and organic fertilizers are used, such as poultry and cattle manure, ashes from burned organic materials (e.g., wood, branches, and leaves), and residue from cultural practices (Chagas 2011).

A recent study by Silva (2022) describes adaptation strategies in cultivation systems implemented by residents of four riverside communities in the Rio Madeira Sustainable Development Reserve, located in the municipality of Novo Aripuanã, Amazonas. These strategies became necessary due to the high mortality rate observed in fruit trees, arboreal, and short-cycle crops (Silva 2022). The first strategy involves cultivating in upland areas, as they are generally not affected by sediment and sandy soil deposition. The second strategy is related to the way manioc (cassava) is planted and an increase in the depth of the planting pit. Residents started planting manioc vertically and increased the depth of the pit by 20 cm for banana cultivation (Silva 2022).

3. Ecological calendar

For thirty years, indigenous organizations, with the support of NGOs and state organizations, have been promoting the systematization of agricultural, climatic, and cultural knowledge through what has been called an "ecological calendar" in the Colombian and Peruvian Amazon. These initiatives aim to strengthen community research and the self-government of local, indigenous and community organizations. Through the "dialogue of knowledge" approach, knowledge of ecosystem changes in biocultural, climatic, and seasonal cycles is represented in the ecological calendar (Echeverri 2009).

The ecological calendar is a concept adopted to describe the knowledge about the use and management of nature and the productive systems of indigenous communities. It is considered a participatory, community-driven process, led by the efforts of indigenous leaders, researchers, government officials, and activists interested in generating learning experiences in which indigenous ecological knowledge and scientific understanding of animals, plants, soils, and landscapes are collected and organized.

In academia and institutions, the ecological calendar is named as such because it has been represented in this way through contributions from Western knowledge, both graphically and in written form. This tool is also used in Indigenous Education programs, particularly in the Natural Sciences, where curricula have been structured under the management criteria of indigenous groups (a process that the Indigenous Major Council of Tarapacá - CIMTAR - has been implementing in the Colombian Amazon). These programs aim to place scientific and traditional knowledge on an equal footing, without one superseding the other (De La Cruz 2013).

Ecological calendars have also been implemented in the Amazon as a local strategy for adapting to climate change. In the southern Colombian Amazon, the outcomes of these reflections have established two dimensions for addressing the topic: firstly, how phenomena associated with climate change are understood or interpreted based on cultural traditions, and secondly, assessments of the impact of these changes on the daily activities of the communities (Lasprilla 2015).

The ecological calendar (Figure 3) is based on traditional knowledge of indigenous communities and scientific research and is used to anticipate the expected availability of natural resources in the region according to local seasonality. For example, it is used to predict the best moment for hunting, fishing, fruit gathering and planting. The calendar is also used to promote the sustainable management of natural resources, encouraging conservation and long-term sustainability. By utilizing local knowledge and science, the ecological calendar becomes a valuable tool to help communities make informed decisions and protect the region's biodiversity and natural resources.

Figure 3 (a) Abundance calendar of ethnic groups in the central region of the Colombian Amazon. *Source:* Sinchi Institute (2012). (b) Development of the ecological calendar at the OPIAC training school. *Source:* OPIAC (2018).

4. Hybrid governance

Current environmental governance models are increasingly adopting community-based proposals, grounded in local knowledge and traditional practice. In the southwestern Amazon, specifically in the MAP region, an experiment – the MAP[1] Initiative – has been ongoing for over a decade. It employs a hybrid approach to environmental governance that combines the perspectives of local communities, scientific knowledge, and state participation, with the state providing public resources to support local governance (Perz *et al.* 2008).

The MAP Initiative is a trinational network that emerged from the interaction among scientists, community leaders, and government representatives, recognizing that solutions to cross-border challenges, such as environmental threats and climate change, require integrated environmental planning (Rioja 2005). The initiative comprises various organizations in each member country, serving as nodes in a larger network of governmental and non-governmental organizations and communities, with the primary focus on collectively identifying and advocating for strategies to mitigate environmental impacts (Brown *et al.* 2002). The success of the initiative in its initial actions gave rise to working groups, referred to as mini-MAP, with specific objectives.

The drought in 2005 and the floods in 2006 in the southwestern Amazon primarily affected the state of Acre (Brazil) and the Department of Madre de Dios (Peru), resulting in significant material damage and serious health issues due to the smoke resulting from increased slash-and-burn activities and forest fires (Perz *et al.* 2022). The prolonged drought led to over 300,000 hectares of forest burned in the southwestern Amazon and at least $50 million in direct economic losses (Brown *et al.* 2006). Due to these events, the MAP Initiative took measures to improve governance in response to natural disasters and adaptation to climate change. One of these measures was the creation of the risk management working group called "Mini-MAP Risk Management" (MMGR), with the aim of enhancing planning for extreme weather events (Perz *et al.* 2022).

Through this working group, regular public forums were established to discuss participatory regional environmental planning actions involving members of regional universities, NGOs, local governments, and some national ministries, as well as civil defense authorities, including firefighters and the military (Perz *et al.* 2022). The public forums provided spaces for participatory dialogues, enabling the sharing of experiences with the goal of co-producing knowledge on future risk management to be used as a foundation for drought response preparedness. In addition to the forums, this co-production of knowledge and response preparation also included regular visits to communities in high-risk areas to discuss experiences and coordinate emergency plans (Perz *et al.* 2022). The continuity of the MMGR working group was based on the development of regional capacities to, alongside initiative partners, coordinate emergency responses during extreme events using real-time data on rainfall and hydrological conditions from the early warning system (Perz *et al.* 2022).

Another initiative that has contributed to the early warning system in the MAP region and the capacity building for climate change mitigation and adaptation in the southwestern Amazon in recent years is the MAP-Fire project (Multi-Actor Plan to Address the Increasing Risk of Forest Fires[1]). This project quantifies the risk of forest fires in the MAP region and studies the interaction between potential impacts and risk management (Anderson *et al.* 2020). Two key outcomes of this project are: (i) a platform for managing the risk and impacts of forest fires, providing real-time monitoring and access to geospatial data to support the activities of technicians and decision-makers, and (ii) the book "É Fogo!" (It's fire!)[2], written for the school community with the aim of incorporating the topic of fire into the curriculum (Anderson *et al.* 2020). Both products were co-produced with stakeholders through workshops and training, allowing the content to be adapted to local needs and specificities. The MAP-Fire project serves as an example of dialogue between science and society, an essential action for disaster risk governance that transcends boundaries, whether political, environmental or disciplinary (Anderson *et al.* 2020).

Final considerations

This work sheds light on the relevance of severe droughts in the Amazon, exploring both scientific definitions and local perceptions of this phenomenon. The impact of extreme droughts on the livelihoods and well-being of local communities in the Amazon is already evident, as reported in the literature regarding recent extreme events. Climate projections indicate that the scenario may become even more challenging if nothing is done to curb deforestation and forest degradation in the Amazon. The projections also underscore the importance of urgently adopting measures to reduce the negative impacts of climate change on local populations and the forest.

1. The acronym MAP-Fire in the original English means: Multi-Actor Adaptation Plan to cope with Forests under Increasing Risk of Extensive fires.

2. The book can be accessed for free at https://efogo.weebly.com/

In this context, scientific knowledge and the experience of local communities must be combined to strengthen climate change adaptation strategies in the Amazon region. The participatory experiences explored in this work suggest possible ways to adapt and mitigate the drought in the Amazon through the integration of indigenous, local, and scientific knowledge. By involving local populations, particularly traditional peoples, these approaches facilitate the development of context-specific strategies, enhancing resilience and reducing the vulnerability of these populations. Ultimately, a holistic and inclusive approach is essential to address the complex dynamics of droughts in the Amazon and ensure the sustainable future of the region and its inhabitants. Some recommendations are provided below, both in terms of research conducted in the Amazon and the implementation of adaptive strategies and participatory approaches:

- ♦ Promote the adoption of adaptation and mitigation measures for extreme events, such as droughts and floods, based on the traditional knowledge of affected populations, while also facilitating access to information systems and alerts generated through remote sensing applied to monitoring for meteorological phenomena, in a combined strategy of scientific and traditional knowledge.
- ♦ Implement mechanisms to bring communities and local governments closer to participatory experiences through integrated, long-term approaches that promote the full participation of civil society in defining and planning more effective measures to address extreme events.
- ♦ Permanently halt deforestation in the Amazon biome, primarily by containing the expansion of agricultural and cattle ranching frontiers, considering its effects on precipitation patterns in the Amazon, as well as carbon emissions resulting from deforestation and forest degradation. Additionally, strengthen the protection of conservation units and indigenous lands, especially those located in areas under high deforestation pressure. As previously illustrated, deforestation greatly contributes to the lengthening of dry periods in the Amazon and is also linked to forest fires.
- ♦ Increase the adoption of drought mitigation and adaptation measures in the Amazon by promoting sustainable practices in the agricultural, forestry, and energy sectors. Encourage collaboration among government organizations, non-governmental entities, universities, and research institutes to develop drought adaptation and mitigation strategies, integrating scientific, indigenous and local knowledge. Promote active participation of local communities in decision-making and policy implementation related to droughts, recognizing and valuing

their knowledge and experiences. Strengthen the capacity of indigenous and local communities to cope with droughts by providing technical support, resources, and access to relevant information.

- Strengthen existing drought monitoring and early warning systems (e.g., Cemaden/MCTI - National Center for Monitoring and Early Warning of Natural Disasters), providing them with budgetary resources and advanced technology for comprehensive and detailed coverage of the Amazon basin, facilitating timely planning and response to extreme weather events. Additionally, invest in data transparency policies, funding and enhancing open data platforms, as well as encouraging open scientific publications, to facilitate access to scientific knowledge about climate extremes.
- Regional and national governments should invest in transdisciplinary studies on vulnerability to extreme drought events, identifying regions and communities in critical exposure situations to these events (or those that will face critical situations in the future), as well as investigating local conditions that increase risk or support adaptive capacity in the face of these events. Strengthen the National System for Civil Protection and Defense, particularly local civil defense agencies, by providing financial resources, technical training, and logistical support for the development of strategic actions that involve the participation of local populations. The goal is to anticipate mitigation actions for the impacts of extreme droughts on society.

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Local governance, climate change and natural resource management in the Amazon

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ABSTRACT

Strengthening community-based natural resource management initiatives is critical in dealing with the effects of climate change and pressures from predatory exploitation on ecosystems and fostering the adaptive capacities of communities. Adaptive capacity directly depends on the adopted governance system. The Amazon is home to a great diversity of ecosystems and traditional peoples (for example, indigenous peoples, extractivists, quilombolas), and plays a fundamental role in regulating the global climate. One of the current major challenges is to control and mitigate the impacts of climate change and the predatory exploitation of natural resources on both natural and human systems. These impacts compromise families' income and quality of life, the guarantee of their basic rights and the effectiveness of public policies for the region. To consider traditional, indigenous and quilombola peoples in jointly creating solutions to these problems is crucial to achieve effective results. We argue that strengthening and valuing local governance should be the starting point and guideline for natural resource management projects to ensure that challenges are overcome and enable the development of an effective socio-biodiversity economy.

Keywords: climate change, governance, natural resource management, traditional peoples.

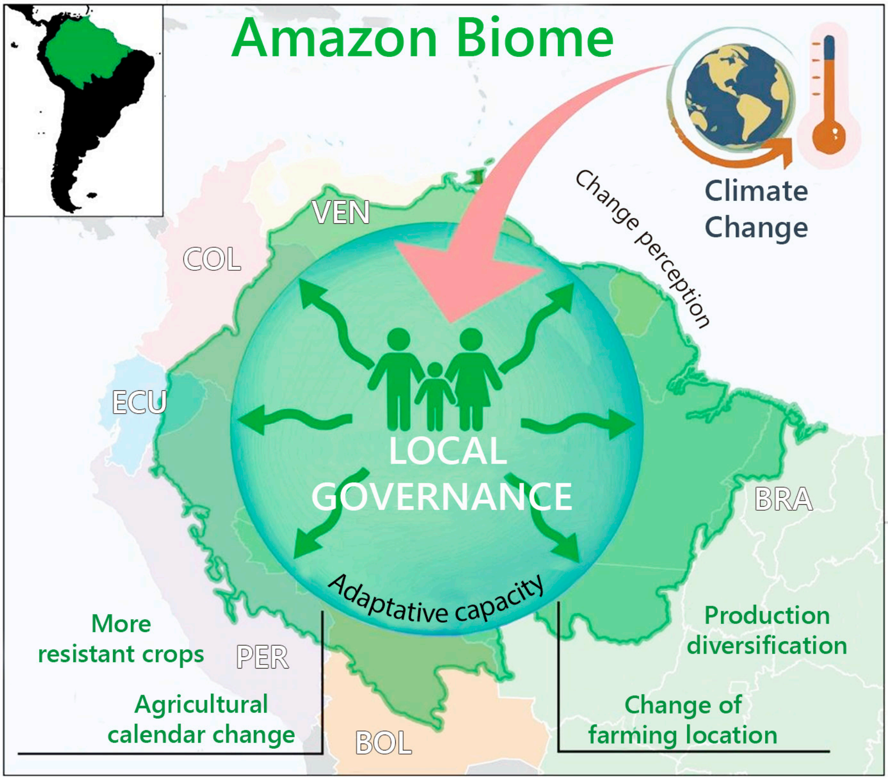

Figure summary: Local communities are constantly under internal and external pressure from various factors: social, economic, political and climatic. Governance can strengthen communities' capacities to cope with these external pressures. Thus, the effects of climate pressures on projects for the sustainable management of natural resources in the region can be mitigated due to changes in governance.

Introduction

The Amazon Biome is a vast and complex socio-ecological system, sheltering the greatest biological diversity on the planet, playing a key role in global climate regulation and in providing essential ecosystem services to human society (Antonelli *et al.* 2018). The region shelters a diverse range of peoples, including indigenous communities, quilombolas, small farmers, extractivists and artisanal fishermen, each one with its own culture and practices for managing nature (Lima & Pozzobon 2005).

Biodiversity and ecosystem services represent the basis of Amazonian cultural maintenance and are connected with traditional activities such as fishing, hunting and the extraction of forest products (Sunderlin *et al.* 2005). Governance over the Amazon territory and its natural resources is complex and needs to conciliate sustainable paths for biodiversity conservation, poverty reduction, social security for communities and economic growth. This governance is essential to communities, as it provides their resilience in the face of disturbances, such as global climate change and environmental degradation caused by deforestation and other predatory forms of natural resources (de Andrade *et al*. 2022).

Estimates from the Sixth Intergovernmental Panel on Climate Change (IPCC) indicate that the Amazon region will be strongly affected by ongoing climate change, especially regarding the increase in temperature and decrease in soil moisture (IPCC 2023). These impacts have a high potential to bring significant consequences for Amazonian production chains (Evangelista-Vale *et al.* 2021). Even if mitigation and adaptation policies are implemented, the greenhouse effect should cause a cascade of climate consequences for a long time, with major impacts on ecosystems and traditional Amazonian communities (Pörtner *et al.* 2022). Such impacts can be exacerbated by forest degradation (e.g., forest fires and timber extraction), which will make the forests more vulnerable (Matricadi *et al.* 2020).

Climate impacts may vary in intensity over the different regions of the Amazon (Estevo *et al.* 2022), affecting agricultural practices, timber forest management and non-timber extraction (Bergamo *et al.* 2022). Many of these practices, besides representing the ways of life of local communities, are forms of income generation and contribute to the conservation of large portions of native forests (Silva *et al.* 2021), playing an important role as carbon sinks (Smith *et al.* 2023). For this reason, several community-based strategies for the management of natural resources have been adopted in order to promote sustainable forms of production and territorial sovereignty (Bergamo *et al.* 2022; Medina *et al.* 2022).

The strengthening of governance at the local level, led by grassroots organizations, is essential to overcome the challenges posed by climate change and to make projects for the sustainable management of natural resources in the Amazon viable (de Andrade *et al.* 2022). Several studies have shown that strengthening local governance about the use of natural resources is effective for the conservation of biodiversity and for the economy of communities that inhabit forests (Ostrom 2005; Brondizio *et al.* 2019; Campos-Silva *et al.* 2020; Athayde *et al.* 2021). Community management of natural resources has been particularly successful in the Amazon, promoting important ecological benefits, such as the conservation of a large set of taxonomic groups and the population recovery of overexploited species (Castello *et al.* 2009; Campos-Silva *et al.* 2018). This level of governance should also be aligned with other administrative, institutional and jurisprudence levels, in regional, national and international scales (Cordeiro-Beduschi *et al.* 2022).

Forms of community governance manifest themselves through formal institutions, such as associations, cooperatives and unions, duly regulated by statutes and rules, or even informal ones, such as kinship and affinity networks, which mediate exchange relationships within a group (Ostrom, 1990; 2005; Meinzen-Dick & Mwangui 2008). These forms of governance operate instances of representation to seek rights and public policies, they are spaces that create rules for relationships with the state (for example, legislation, taxes, among others) and with the market, that is, they represent training spaces for the management of collective goods and negotiation of products (Campos-Silva *et al.* 2020).

In this proposal, we bring together some elements about the importance of strengthening local governance in Amazonian communities as a way of overcoming challenges during the implementation of projects for the sustainable management of natural resources. In addition, we assess how local governance can be used to deal with the effects of climate change on the agro-extractive activities of Amazonian communities. Finally, we provide recommendations on the importance of this issue, highlighting the main challenges and potential solutions for decision makers, such as State agents, private entities, non-governmental organizations (NGOs), etc.

Impacts of climate change in the Amazon: *lato sensu*

Climate change is one of the main ecological and social challenges today (Dietz *et al.* 2020). Understanding this challenge is essential to guide policies to reduce environmental risks, in addition to combating food insecurity and its impacts on the economy on global, regional and local scales (Ericksen *et al.* 2011; Mondal *et al.* 2023). The food security of the global population can be directly compromised by climate change, considering the losses in agricultural and extractive productivity associated with extreme variations in precipitation and temperatures (Asseng *et al.* 2015; Hasegawa *et al.* 2018).

In the Amazon, this situation is no different. The region hosts half of the planet's remaining rainforests, which are under intense pressure from deforestation, mineral extraction, livestock and agricultural cultivation. These intense changes include a significant reduction in precipitation, an increase in temperature and in the frequency of intense drought and flood events (Erfanian *et al.* 2017; Matricardi *et al.* 2020; Assis *et al.* 2022; Marengo *et al.* 2022; Smith *et al.* 2023), directly affecting the productivity of small-scale agriculture and extractivism and the composition and diversity of species in these ecosystems. Recent studies indicate that both the structure and composition of the tree flora in the Amazon have undergone adaptations to a drier and hotter climate (Brienen *et al.* 2015; Esquivel-Muelbert *et al*. 2019).

However, the adaptations of biological communities are not able to keep up with the rapid pace of climate change, which is leading to large-scale tree species mortality events (Esquivel-Muelbert *et al.* 2020) and consequent reduction in forest productivity (Brienen *et al.* 2015). These effects vary between Amazonian regions, being more intense in the southern and eastern portions of the biome (Marengo *et al.* 2022). These regions have a more seasonal climate when compared to the western and central portions, and exhibit the highest mortality rates in the biome, where the effects of climate change have already conditioned a regional 'tipping point' (Lovejoy & Nobre 2019). Degradation and deforestation associated with climate change have changed the status of these forests from being carbon sinks to becoming carbon sources (Reis *et al.* 2022).

Furthermore, local human communities that depend on forest and water resources are seriously threatened by these climate changes. For example, the expected increase in severe droughts and the consequent reduction in the volume of water in the Amazonian rivers could render fishing activities economically unviable, due to the precariousness of transportation and difficulties in exporting production from remote or isolated communities. These changes can lead to a degradation of living conditions and the exodus of these communities to urban centers (Silva *et al.* 2021).

Challenges for the sustainable management of natural resources in the Amazon in the face of global climate changes

Currently, the impacts associated with climate change and the predatory exploitation of the Amazon biome are changing the dynamics of ecosystems and directly impacting the production chains of traditional communities. This trend may spatially reduce the climate suitability of plant populations and affect the production of basic crops such as cassava, maize and banana (Beltrán-Tolosa *et al.* 2020). Crops such as wheat, for example, are very sensitive to the effects of climate change: a 1°C increase in temperature can lead to a decrease of up to 6% in the global production of this commodity (Asseng *et al.* 2015). These effects can also be extrapolated to non-timber forest products, which are the main source of income for traditional Amazonian communities (Igawa *et al.* 2022).

Future estimates show that communities in the 56 extractive reserves (RESEXs) located in the Brazilian Amazon will be affected by climate change by 2050 (Evangelista-Vale *et al.* 2021). Eleven out of the eighteen evaluated commercial species may present a reduction in their environmental suitable areas (area suitable for the occurrence of the species according to its tolerance to environmental conditions) and nine of them may disappear from some of these reserves. For example, species such as Brazil nut tree (*Bertholletia excelsa*), rubber tree (*Hevea brasiliensis*), buriti palm(*Mauritia flexuosa*), açaí (*Euterpe oleracea*), single-stemmed açaí (*Euterpe precatoria*) and copaiba tree (*Copaifera multijuga*) have shown a decrease in environmental suitability areas within the RESEXs where they are extracted. *B. excelsa*, extracted in 50 reserves, may no longer occur in nine of these areas, which would affect 996 extractive families. Both açaí species (*E. precatoria* and *E. oleracea*), extracted in 45 reserves, could be locally extinct in two RESEXs, which would affect 288 extractive families (Evangelista-Vale *et al.* 2021).

Considering the agricultural scenario, even though the Amazon has 17% of areas with suitable soils for cocoa cultivation (*Theobroma cacao*), the increase in temperature and reduction in precipitation can make this productive potential unfeasible, especially in areas with consolidated economic activities (Igawa *et* *al.* 2022). This reduction in production areas could cause a 4.2% decrease in national cocoa production and affect the income of almost 9,000 families. Likewise, Pastana *et al.* (2021), evaluating the effect of the 2015/2016 El Niño on the annual production of Brazil nuts (*B. excelsa*) in the Rio Cajari Extractive Reserve (Amapá), found a strong relationship between the reduction in precipitation and the increase in temperature with the decrease in Brazil nut production. The authors report that the reduction in production and the consequent low supply of Amazonian nuts in a strong market with rising prices led to invasions and conflicts in extractive units. Thus, the negative consequences of climate change on socioecological systems become evident, pointing to the need for the creation of adaptive strategies to these changes in order to promote the resilience development of these systems (Scarano 2017).

Solutions to mitigate the effects of climate change: local governance and sustainable management of natural resources

Climate-related changes occurring in the Amazon substantially impact socio-ecological systems, affecting the livelihoods of communities heavily dependent on natural resources (Estevo *et al.* 2022). The forms of local governance carried out by traditional communities, indigenous peoples, quilombolas and family farmers can play a fundamental role in the sustainable management of natural resources and in adapting to climate change. These forms of governance promote and can expand i) awareness of climate change and, ii) conservation practices and sustainable use of natural resources.

Through local governance, it is possible, for example, to establish monitoring and control systems for extractive activities, ensuring that they are carried out in a responsible and sustainable way, without harming biodiversity and local ecosystems. Forms of local governance can also act as mediators between communities, government and private entities, advocating for community rights and the pursuit of public policies that promote sustainability and environmental conservation. Thus, it is important that these organizations have an active voice in the decisions that affect their members and that they work in partnership with other institutions to adapt production methods to the conditions imposed by climate change, seeking sustainable development.

Communities perceive the effects of climate change and the impacts of deforestation and large extractive projects. This perception is important for defining joint strategies to mitigate these effects. A recent study indicated that the majority (72% of respondents) of traditional Amazonian populations are noticing climate changes, especially reduced rainfall (62% of respondents). In addition, a significant part of the respondents (30.8%) associate these changes with deforestation, dam construction and soil and environmental degradation (eg pollution, silting) (Funatsu *et al.* 2019). This is worrying, as alterations caused by global warming do not have the same level of reversibility as the changes caused by land use, which impact precipitation and temperature in a given location.

Adaptations in the production system to better deal with problematic exposures and sensitivities (social, environmental, climatic) are manifestations of the adaptive capacity of community-based organizations. These adaptations can occur at different levels. For an agricultural system under drought, for instance, a simple adaptation could be the use of cultivars that are more resistant to water scarcity, while a more substantial adaptation would be to transitioning from agriculture to livestock grazing. An even more substantial adaptation would be to abandon agriculture altogether (Smit & Wandel 2006).

Other adaptations involve the need to align agricultural practices to the climate calendar, although in some places crop planning is more associated with market price, change of crop, change in sowing date, installation of greenhouses and use of irrigation, which has become more frequent in the Amazon (Funatsu *et al.* 2019). However, the high cost of irrigation systems in relation to land prices should be considered (Costa *et al.* 2019), as well as the impacts on water reserves. To minimize climate risk, an adaptive measure would be to select crops based on the start date of the rainy season, although a forecast system that is not yet available would be necessary (Costa *et al.* 2019). The study by Igawa *et al.* (2022), on the inadequacy of cocoa production in areas in the Amazon in scenarios of climate change, shows that it will be necessary to implement, in a large area, the process of transition and diversification with the planting of another crop that is more resistant to drought and heat.

Given the studies presented, we can identify two possible solutions for production chains to be less affected by climate change: use of crops and/or species that are more resistant to high temperatures and low precipitation, and diversification of production. In addition to more resistant species and genetic improvement (a procedure that can select a specimen that is more adapted to new climatic conditions), the selection of provenances and progenies (materials with greater genetic diversity from different matrices and locations) can provide a higher adaptive capacity of the cultivar to adverse conditions and ensure production. Agroforestry systems, which simultaneously combine trees and agricultural crops, could be an alternative for restoring degraded areas with economic returns in the short, medium and long term (Brandão *et al.* 2022). In the Amazon, this system has achieved greater productivity than monoculture. For example, agroforestry systems allow for a more shaded environment and protect cocoa from extreme climate conditions (Niether *et al.* 2018).

However, adaptive capacity depends on different types of capital, such as cultural capital (how people perceive and interact with their world), human capital (people's skills and knowledge to develop and multiply the benefits from their resources) and social capital (connections between individuals and organizations that allow them to collaborate or help each other) (Freduah *et al.* 2019). These capitals, together, enable better utilization of the skills and knowledge of local and external actors to address the impacts of climate change and to foster more partnerships and collaborations in order to respond to the impacts of climate change. Adaptive capacity can be influenced by governance, as in socio-ecological systems it is decisive and poor governance can be another stress factor, in addition to the effects of climate change itself (Freduah *et al.* 2019).

Local governance carried out by communities

Several authors and civil society organizations worldwide argue that it is necessary to pay attention to local governance carried out by communities in the context of implementing conservation and income generation projects, as well as promoting the inclusion of these organizations in the construction of projects and decision-making (Brondizio *et al.* 2021; Abramovay *et al.* 2021). Such authors and organizations rely on consolidated experiences, on a variety of theoretical and conceptual models to defend these arguments. Among these debates, we can highlight the development of the theory of common resources, carried out between the 1970s and 1990s, which brought significant contributions to the recognition of local governance of communities within academia and within global strategies for nature conservation (Ostrom 1990).

In general terms, this theory proposes that communities that sustainably manage the natural resources they depend on, typically exhibit specific governance characteristics, including cultural, ecological, and economic particularities, for example. Eight governance principles (Design Principles) were established, based on case studies with human groups around the world and with laboratory experiments on human behavior (Ostrom 1990, Ostrom 2005, Cox *et al.* 2015), and serve as criteria for evaluating the extent to which the principles of local governance of common resources are being met by grassroots organizations (Box 1). Studies using these principles show that the organization of communities and their ability to carry out collective actions are among the variables that influence the success of community-based initiatives for natural resource management around the world (Pagdee *et al.* 2016).

Box 1

Principles of governance (Ostrom 1990, 2005, 2009, modified by Cox *et al.*, 2010)

Principle 1: a) Are there clear boundaries between who can be a resource user and who cannot? b) Is it easy to separate the resource system from the surrounding systems?

Principle 2: a) Are the norms of appropriation and provision of resources adequate to the local conditions (spatial and temporal heterogeneity, local culture)? b) Is there congruence between the norms of appropriation and provision, in other words, is there proportionality between the costs that users have to bear to care for the resource and the benefits they receive when participating in collective action?

Principle 3: Can the individuals affected by the exploitation rules participate in the change of the same?

Principle 4: a) Are there people responsible for supervising the use of resources by users? Does the supervisor also benefit from the resources? b) Is there a control of the conditions of the resources (medium-environmental)?

Principle 5: Are graduated sanctions imposed on users who disobey the rules?

Principle 6: Is there a scope for resolving conflicts between users or between users and external agents that is fast, low cost and local?

Principle 7: Do government agencies allow local users to believe in their own institutions? Are local institutions recognized by government bodies?

Principle 8: Is the local governance system nested in other levels of governance? Do you have horizontal connections with other community systems?

More recently, when the topic of sustainability projects involving communities and income generation is analyzed in the Amazon, the principles remain intact. Medina *et al.* (2022), for example, identified more than 100 innovative and sustainable initiatives in communities across the Brazilian Amazon. The authors demonstrate the importance of scientists and policymakers involving local communities in decision-making, adopting *bottom-up* approaches.

In this way, promoting and strengthening the local governance of communities helps in the fairer distribution of benefits among the actors involved in natural resource management projects. In addition, this strengthening provides security to communities and the possibility of changing paternalistic, integrationist and colonialist biases that occurred in the past and were unsuccessful, enabling the long term sustainability of projects (Campos-Silva *et al.* 2021).

Step-by-step guide to strengthening local community governance

We list some points that can help decision makers – agents of the State, NGOs and private institutions – to recognize, include and/or strengthen local governance of communities in contexts of natural resource management projects, given the impact of climate change:

- The communities involved in the projects must have, *a priori*, guaranteed rights to land and territories, among other fundamental rights and public policies. The lack of tenure security and the absence of demarcated territory for the reproduction of the way of life can threaten local governance in the long term (Pagdee *et al.* 2016; Barreto-Filho *et al.* 2021). Observing in which conditions of territorial rights the communities are inserted and working so that these conditions are guaranteed and improved is fundamental. The State, through public policies, is primarily responsible for addressing these issues. Territorial public policies should serve as catalysts for sociocultural processes that guarantee the autonomy of groups, their rights to control their own lands, resources, institutions, their social and cultural organization and their own ways of relating to the State. Life Plans and Territorial and Environmental Management Plans, developed by indigenous peoples and traditional communities, are examples of management instruments that promote territorial security based on the practices and knowledge of these peoples; the National Policy for Environmental and Territorial Management of Indigenous Lands (in Brazil, Decree No. 7,747, of June 5, 2012) is an example of public policy that contributes to the realization of territorial security and sustainable production practices (Barreto Filho *et al.* 2021).
- Differences between the assumptions and forms of knowledge production (ontologies and epistemologies) of external actors (project supporters) and communities must be recognized by the partners. Based on this

recognition, it is possible to establish more efficient dialogues between implementation knowledge and execution of the project, so that both technicians and communities improve their understanding of each other, in a more equitable way, with appreciation and respect (Bensusan 2019). This is important, as for technological innovation to occur, it's necessary to value marginalized local knowledge (Medina *et al.* 2022; Abramovay *et al.* 2021) and address power imbalances between different types of actors (Campos-Silva *et al.* 2020; Medina *et al.* 2022). "Community biocultural" protocols and consultation protocols, for example, are instruments developed by communities to communicate to external actors – commercial partners and others – how the community organizes itself, works and should be consulted.

- There are often more chances for project success when local governance bodies share values of the group's "sense of identity" and help to create and/or promote common values/goals in relation to the project. It is also necessary to strengthen, or create, spaces for the elaboration of rules within the project, which include pre-existing mechanisms in local governance - mainly rules for appropriation and provision of natural and financial resources that the project deals with - for decision-making and conflict resolution, in a way that promotes a distribution of benefits considered fair by the group. These spaces may include other actors, such as technical assistance agencies. In addition, it is necessary to prioritize pre-existing local governance mechanisms or create mechanisms capable of carrying out adaptive project management (Pagdee *et al.* 2016; Medina *et al.* 2022; Ostrom, 1990; 2005; 2010).
- Nesting local forms of organization with other initiatives within projects at different levels of governance (Pagdee *et al.* 2016; Ostrom 2010; Cordeiro-Beduschi *et al.* 2022). For example, establishing networks of institutional support and decentralized and continuous funding models for the project, well-coordinated with local governance. (Barreto Filho *et al.* 2021). Building and maintaining a long-term community-based natural resource management project requires collective effort (actor network) and available financial resources. Pre-existing forms of local community governance cannot and should not sustain investments in human and financial resources for innovative projects by themselves. Thus, an institutional arrangement that facilitates access to resources is important (Vidal *et al.* 2021).

Table 1 The first column lists the governance principles (Ostrom, 1990 2005). The two columns below show the characteristics that we highlight, throughout the document, as important to strengthen local governance. The colors highlight the features in common with the governance principles. Characteristics that do not have colors are those that promote collective action. Caption: RUC = "Resources in common use".

Principles of institutional design (Ostrom 1990)	Points evaluated in the bibliography		
1) Clearly defined boundaries	Group identity, values and goals aligned		Collective identity in the community
2) Coherence between the rules of appropriation and provision with the local conditions	Collective instances to elaborate rules, decision-making and conflict resolution	Appropriation and provision rules	Effective inter-institutional agreements
3) Collective election arrangements		Adaptive management	Common interests and incentives between actors
4) Supervision: actively monitor the conditions of the RUC		In the long run	Defined property rights
5) Graduated sanctions	Biocultural community protocols: Management of the same languages		Context dependency
6) Conflict resolution mechanisms	Exchange of experiences		Recognition of marginalized local knowledge
7) Minimum recognition of organizational rights	Institutional support networks: Public authorities, own initiatives		Dialogue of knowledge (Science and traditional knowledge)
8) Nested entities	Multilevel action		

Conclusion and recommendations

Climate change poses major challenges for maintaining Amazon's indigenous, traditional and quilombola communities' natural resource management systems sustainability. The main challenges are: the reduction in the suitability of production areas, the reduction of areas of environmental suitability and the reduction in the production of usable and marketable resources by Amazonian communities. Once these effects on production systems are perceived, mainly by the communities involved, a series of technical solutions are suggested to promote mitigation or adaptation to these impacts, for example: the use of more resistant crops, production diversification, changing the agricultural calendar, shifting cultivation location, and adpting natural resource management practices (fish, wood, non-timber products).

We argue that these technical solutions require the strengthening of governance by the communities involved in the projects, in order to be implemented and sustained in the long term, and to ensure their success. We also present five strategic points for strengthening local governance: 1) promoting territorial security and other fundamental rights for the involved communities; 2) promoting shared values and objectives concerning the project; 3) having well-defined operating rules and agreements; 4) promoting actions and solutions based on knowledge sharing; 5) connecting local governance with other forms of multi-level and multi-scalar governance.

The strengthening of local governance, combined with technical solutions provided by scientists, public policies or private sector, provides greater adaptive capacity of communities – including their forms of governance – when facing challenges imposed by climate change on their production systems (Figure 1). This strengthening is the backbone of long-term community-based management and conservation initiatives. Large-scale projects that do not engage with the local level, which is directly involved in Amazonian socio-ecological systems, are bound to fail, whether due to a lack of social reach or economic and ecological unsustainability.

In this sense, attention to local, participatory actions, aligned with the perspectives of traditional, indigenous and quilombola communities, can provide the strengthening of projects and policies of broader scope, at the level of the Pan-Amazon region. Such measures must ensure the sustainability of production methods that keep the forest standing and the rivers abundant in life forms. Considering the current climate emergency scenario, as well as the future projections for the Amazon biome, this type of engagement with communities becomes a crucial solution for addressing this crisis. Traditional communities must necessarily be included in this process, so that these projects reach their potential for recovery and maintenance of community income, thereby contributing to the ongoing mitigation of climate change.

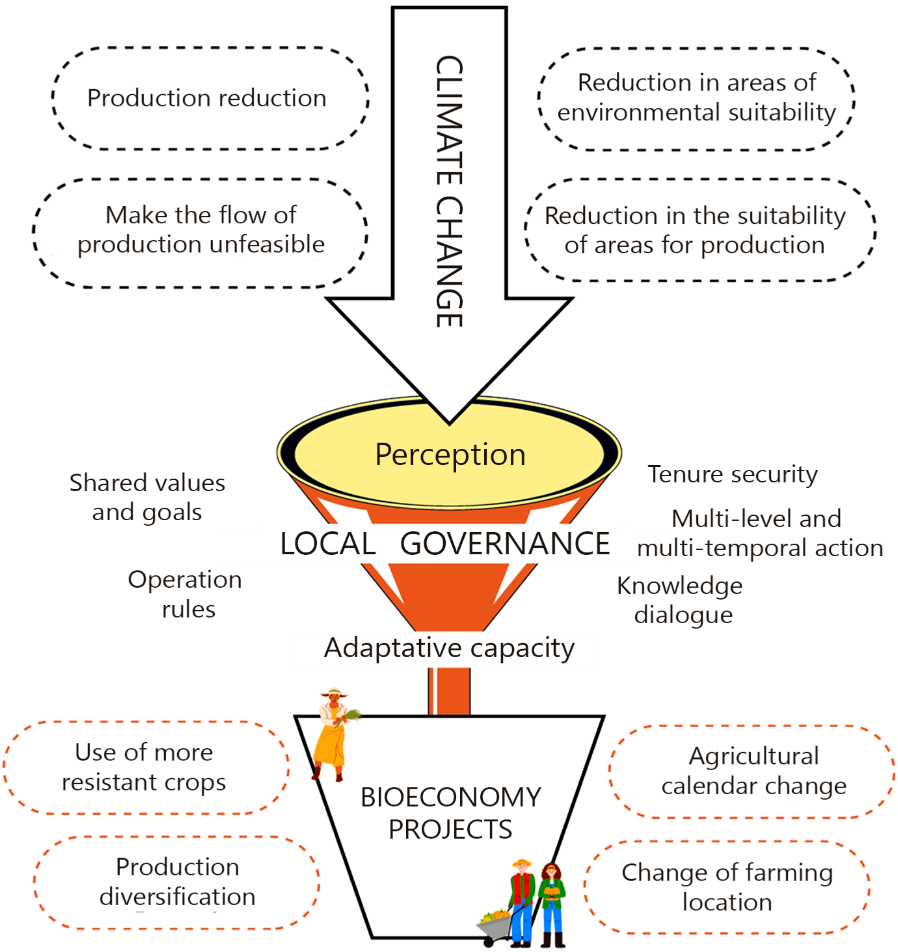

Figure 1 Illustrative summary of how local governance can overcome the challenges posed by climate change to sustainable natural resource management projects.

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Transdisciplinarity is crucial to reformulate a sustainable future for the Amazon

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ABSTRACT

The Amazon, with its multidimensional nature, diverse in organisms, cultures and in its biophysical aspects, plays a prominent role in regulating the climate and providing ecosystem services essential to life on Earth. Its complex nature leads to equally complex problems in the human-nature interface, bringing forth the urgency of promoting transdisciplinary discussions to create innovative, equitable, fair and sustainable solutions. Here, we present the opinion of professionals from academia, companies, funding agencies, non-governmental organizations, civil society and government, from different areas of knowledge (environmental, social, biological and health sciences) on how to perform an inclusive and transdisciplinary science with the objective of finding solutions for the sustainability and conservation of the Amazon. We applied a semi-structured questionnaire with five complementary discursive questions aiming to synthesize the multiple visions for the application of transdisciplinary science in the Amazonian context. Scientist training, appreciation of traditional knowledge, broader spaces and time for promoting knowledge integration and co-creation of policies involving multiple actors were identified both as the main bottlenecks and the main solutions for transdisciplinary science in the academic environment and in policy decision-making. Most interviewees had already gone through transdisciplinary experiences during their education, indicating that initiatives to promote and implement transdisciplinarity exist elsewhere. However, we emphasize that greater coordination is needed between large research groups and funding agencies so that these experiences can be linked to a long-term transformative process, essential for the consolidation of transdisciplinary practices across various sectors of society.

Keywords: Amazon, transdisciplinarity, conservation, sustainable solutions, social inclusion.

Introduction

Transdisciplinarity integrates different fields of knowledge to solve complex problems that go beyond individual disciplines (Nicolescu, 2014). This approach is important for addressing global challenges such as human impact on the climate (IPCC 2022), overexploitation of natural resources (Pörtner, *et al.* 2021), social inequality (Scherhaufer, 2021), utilization of ecosystem services (Geerts 2008) and socio-ecological resilience (Folke *et al.* 2016). By recognizing that complex issues cannot be solved through a single discipline or perspective, transdisciplinarity is necessary for discussions on sustainability and development at multiple scales, issues that require the integration of different perspectives towards common goals.

The Amazon is a region of 7 million square kilometers that spans nine countries, characterized by a rich diversity of flora, fauna, indigenous communities, and ancestral knowledge. It is home to millions of plant and animal species, many of which are still unknown to science, as well as over 3,300 indigenous and traditional communities with diverse cultural, linguistic, and ancestral knowledge on the use of natural resources (Raisg, 2023). However, the region faces challenges such as environmental degradation, deforestation, mining, illegal mining, land grabbing, and illegal exploitation of natural resources. These human activities have had negative impacts on the region's biodiversity and the livelihoods of communities that depend directly on it (Lapola *et al.* 2023). On the other hand, the Amazon also presents unique potential for sustainable solutions to the human-nature relationship, playing a crucial role in providing ecosystem services such as climate regulation, water provision, pollination, carbon sequestration, soil protection, and the prospecting of products such as medicines, timber, food, and high-value natural ingredients (Costanza *et al.* 1997; Levis *et al.* 2020). It is therefore important to think multidimensionally about the use of the region's resources and sustainable practices that respect the rights of communities and the forest's support capacity.

Transdisciplinarity can be a catalytic approach in addressing the complex problems of the Amazon, integrating different systems of knowledge and epistemologies that have been overlooked due to the colonial stance of hegemonic perspectives in Latin America (Taylor 2012). However, the application of a transdisciplinary approach faces numerous challenges, including linguistic differences, perspectives, and methodologies, disciplinary hierarchy, and difficulties in securing financial resources for transdisciplinary research. Additionally, the lack of coordination and resistance to change also need to be addressed. To overcome these potential obstacles, it is important to adopt a collaborative and open approach, encourage communication and mutual understanding, have effective leadership and coordination processes, and be open to experimenting with new approaches and ideas (Jahn and Keil 2015).

Considering the need to create spaces for the discussion of multifaceted and interconnected issues, the São Paulo Research Foundation (FAPESP) organized the São Paulo School of Advanced Science on Sustainable and Inclusive Amazon (SPSAS Amazon) with the aim of promoting the advancement of science and technology for the benefit of the Amazon, with a focus on sustainability and social inclusion. Professionals from diverse fields gathered in São Pedro, São Paulo, between November 21 and December 5 2022, to discuss, collaborate, and integrate knowledge to solve issues in the Amazon. The interaction between disciplines and a holistic approach were extensively discussed in the first module of the course, with the goal of understanding the multifaceted phenomena of the region. This discussion aimed to level, inspire, and immerse participants/professionals in relevant concepts and discussions. In line with this, the objective of this article is to bring together the experiences and proposals of the course participants to promote knowledge related to Amazon sustainability. Through a specific questionnaire, researchers identified bottlenecks, proposed solutions, and shared experiences of transdisciplinary research. The raised issues aim to guide future initiatives in the construction of an inclusive science capable of integrating knowledge from different academic disciplines and other sectors of civil society in the formulation of public policies for the co-creation of alternatives for the conservation and sustainability of the Amazon.

Material and Methods

In order to facilitate a detailed investigation into how science can be conducted in a transdisciplinary and inclusive manner in the Amazon, we administered a questionnaire to professionals from various specialties, nationalities, genders, institutions, and fields of activity working in the Amazon. Data were collected during the São Paulo School of Advanced Science in the Sustainable and Inclusive Amazon (SPSAS), which took place from November 21 to December 5 2022. A total of 93 participants, including researchers from Biological and Agricultural Sciences, Social and Exact Sciences, as well as professionals from non-governmental organizations and private sector were invited to fill-up a semi-structured questionnaire in an online survey format (questionnaire shared via ‘google forms’). The purpose of the questionnaire was to raise a wide range of perspectives on the central problems and possible solutions for the interaction between the human and the natural context in the Amazon region. All SPSAS participants fulfilled the inclusion criteria to answer the questionnaire, i.e., being of legal age and voluntarily agreeing to the anonymous data usage.

During the first week of the SPSAS, all participants gather together in oral presentations by invited researchers, followed by deep discussions on the importance of a transdisciplinary approach in science. Once aware of the concepts discussed, as well as their variations and specificities, the participants were then invited to respond to our questionnaire, entitled: '*Bottlenecks and solutions for the inclusion of transdisciplinary science in socio-political decision-making*'. In the first part of this, we identified the profile of the participants, including gender, age, nationality, area of activity, region of activity, institution and sector of activity. Then the following questions were presented:

(**Q1**) In your opinion, what are the main bottlenecks for promoting transdisciplinary science?
(**Q2**) How to build a truly transdisciplinary science?
(**Q3**) How to incorporate the cultural and social diversity of the Amazon into academic spaces?
(**Q4**) How can science connect with the cultural and social diversity of the Amazon in spaces of political decision-making?
(**Q5**) Have you ever participated in transdisciplinary science experiences?

Questions 1, 3 and 4 were elective, with closed answers, while questions 2 and 5 were discursive. The complete questionnaire can be consulted in the Supplementary Material (Annex I).

Ethics in accessing sensitive data

The participants gave their consent for the use of the informed data, in which the confidentiality and anonymity of their identity, as well as their personal data and their answers, were guaranteed. For this purpose, we included an item about permission and use of data for analysis in the body of the questionnaire.

Methodological script and data analysis

There were four main phases in our methodological framework (Figure 1). First, participants attended conferences related to the "Sustainable and Inclusive Amazon" to acquire knowledge and engage in inclusive dialogues - (I) inspiration. Second, a space for exchanges and discussions was used to design the research strategy for this study - (II) construction of the questionnaire. Then, the sampling method was defined through a semi-structured digital questionnaire, which catalyzed data collection for analysis and subsequent discussion (phases III and IV, sampling and data analysis respectively). Questions with closed answers (Q1, Q3, Q4) were analyzed quantitatively in R language (R Core Team Team 2015). The open questions (Q2, Q5), as well as the discursive answers of Q1-Q5 were qualitatively analyzed and grouped by categories.

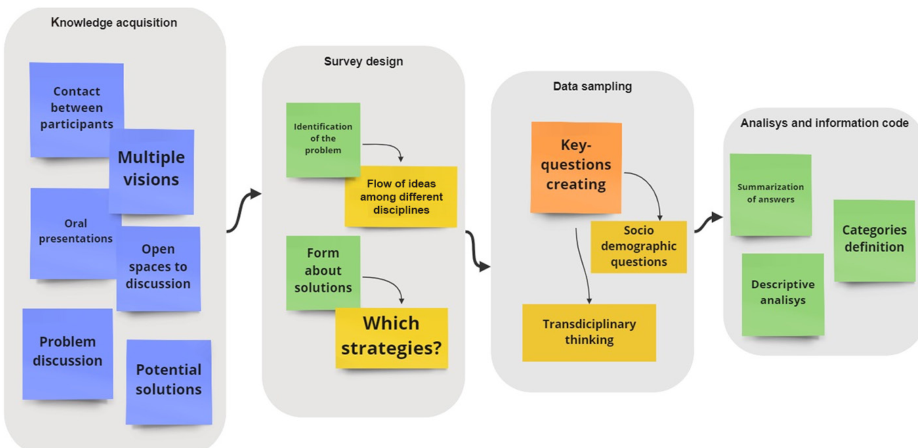

Figure 1 Methodological flow describing the steps for inspiration and reflection on transdisciplinary science, questionnaire construction, sampling strategy, and data analysis.

Study limitations

An obvious limitation in the present study is that we approached the transdisciplinary theme in a context where only researchers were present. We are aware about the need to diversify the participation of distinct actors, including and not exclusively indigenous peoples, environmental leaders, educators, politicians and artists in the creation of a transdisciplinary knowledge generation system in the Amazon. This reflection is an important part of this article and, even though it was not contemplated in the execution of this work, it was not neglected so that it can illuminate future actions. We tried our best to incorporate professional experiences and reports from academic spaces on the direct relationship with traditional peoples and communities. Whenever possible, we carefully insert this perspective into our discussions, taking into account the importance of treating this topic with due sensitivity.

Results

Next, we show the results obtained from the online questionnaire on transdisciplinarity for a sustainable and inclusive Amazon. The subsections correspond to the questions presented to the interviewers through the online form.

Participant's profile

In total, 66 questionnaires were answered, representing 70.97% of the participants in the SPSAS 2022. Of these, 35 declared themselves to be women, 29 men and two women CIS, aged between 29 to 64 years (avarage = 39), 28 to 67 (38) and 31 to 33 years (32), respectively (Figure 2A). The interviewed participants are from different nationalities, with a significant participation of Brazilians (79.5%), followed by Bolivians and Colombians (6.8% each) (Figure 2B). None of the interviewees identified themselves as members of a traditional or indigenous community.

Regarding the professional profile, most of the interviewees work as researchers in academic institutions (53%), 29% are doctoral students and the other activities are related to non-governmental organizations (NGOs, 9%) and government agencies (6 %), and none of the participants declared working in the private sector (Figure 2C). Among the areas of knowledge of the participants, the major areas of Biological Sciences (39%) and Humanities (35%) stand out, with a wide range of specializations, predominantly Ecologists and Anthropologists (Figure 3).

The geographic distribution of the participants, both in terms of their origin and areas of activity in the Amazon, were primarily concentrated in Brazil and in the eastern Amazon region and Ecuador, respectively (Figure 4). However, 70% of the institutions where the researchers work are not installed within the limits of the PanAmazon.

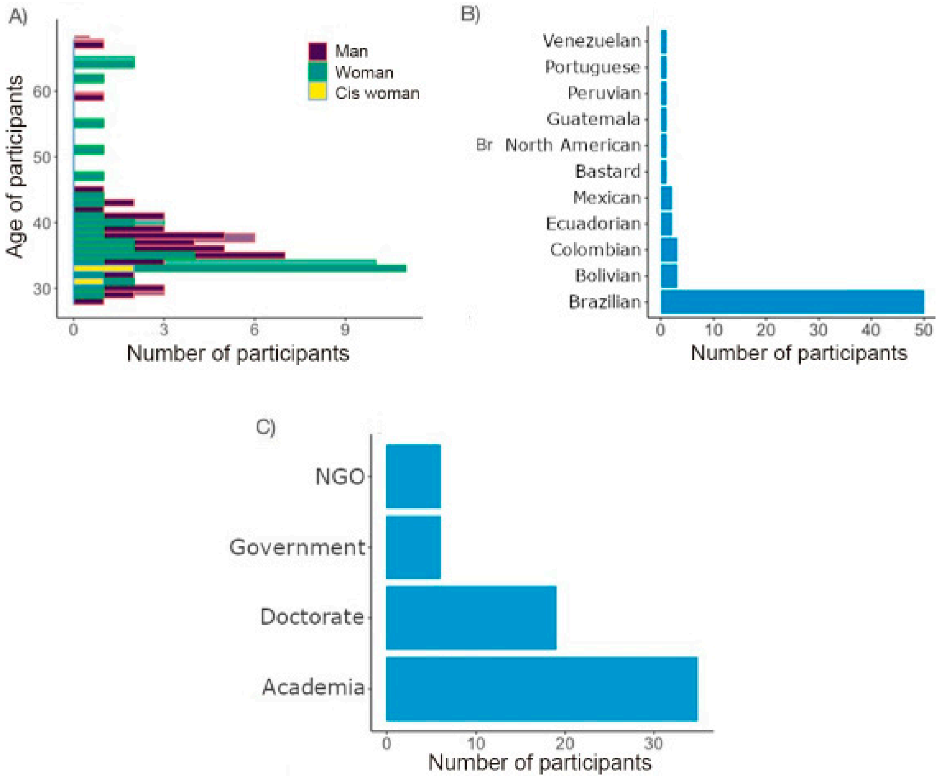

Figure 2 Profile of participants who responded to the semi-structured questionnaire on transdisciplinarity in Amazon conservation during the School of Advanced Studies on Inclusive and Sustainable Amazon 2022. A) Distribution of participants' age by gender; B) Nationality; and C) Sector of activity of the participants.

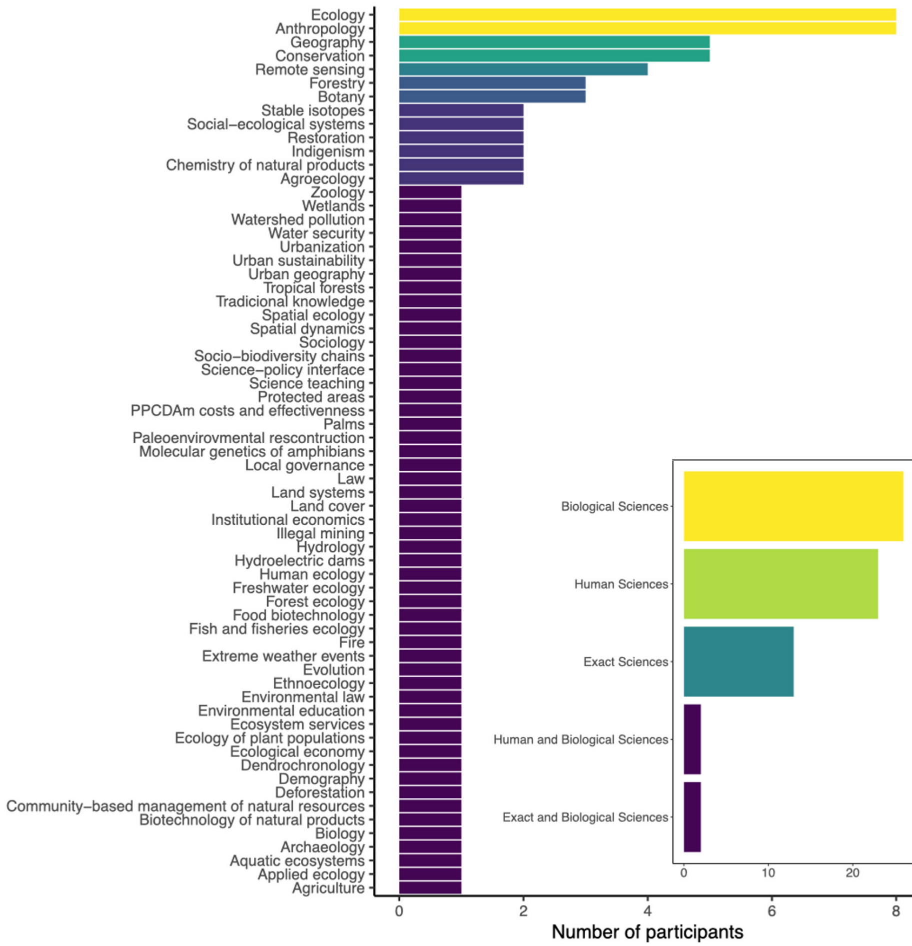

Figure 3 Categorization of participants who responded to the semi-structured questionnaire regarding the role of transdisciplinarity in Amazon conservation during the School of Advanced Studies on Inclusive and Sustainable Amazon 2022, by areas of expertise. The internal graph displays the areas of expertise grouped according to the major fields of activity of the interviewed participants.

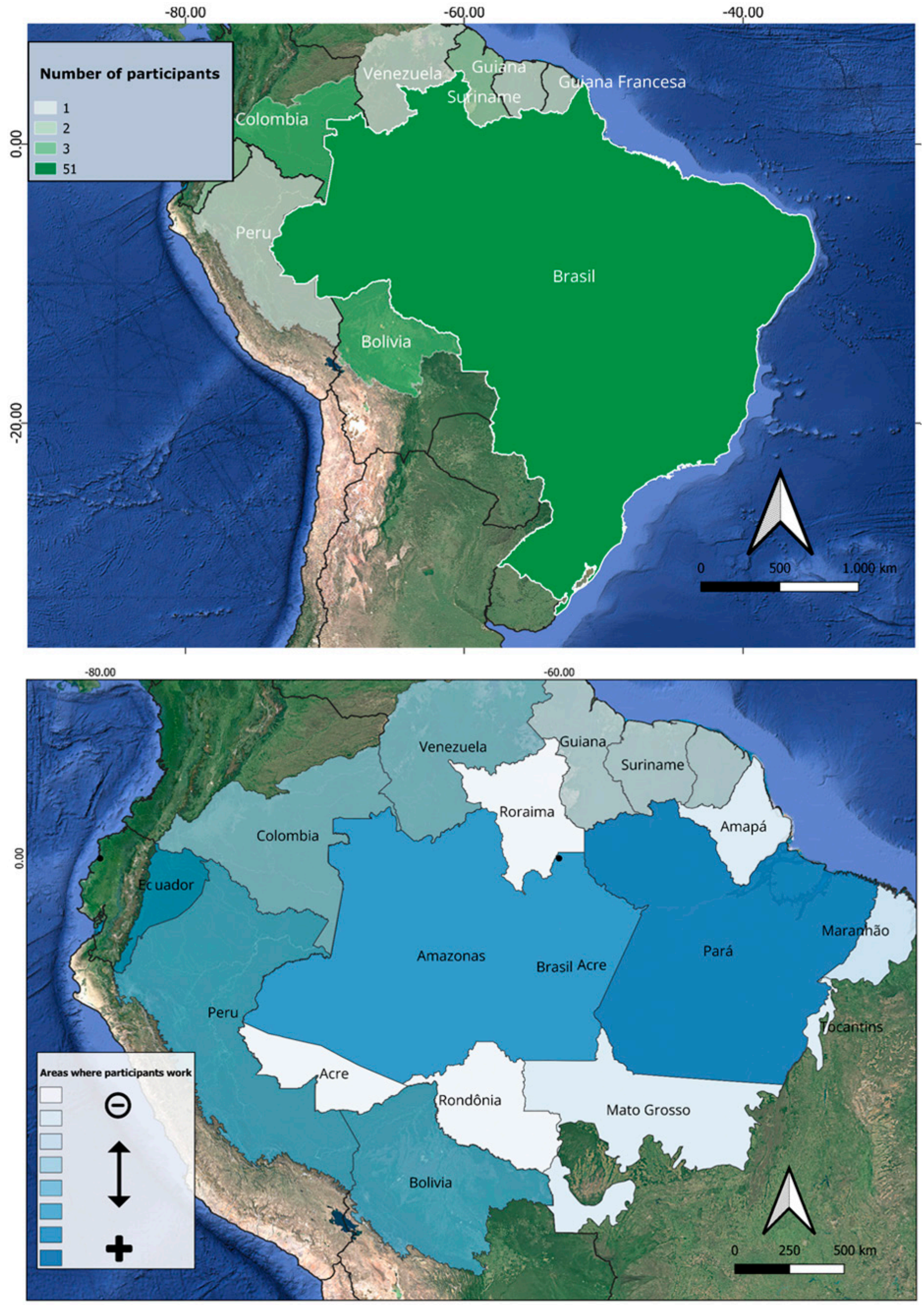

Figure 4 Map of the distribution in the Pan-Amazon region showing the nationality (above panel) and field of activity (below panel) of the participants of the School of Advanced Studies on Inclusive and Sustainable Amazon 2022.

Bottlenecks and solutions for the inclusion of transdisciplinary science in sociopolitical decision-making

Q1. Main bottlenecks promoting transdisciplinary science

The ranking of importance for the use of transdisciplinary science pointed training of scientists as the main bottleneck, followed by the devaluation of traditional knowledge and lack of spaces to promote knowledge integration. The non-inclusive language was mentioned but was less relevant (Figure 5). The participants also described other important points to achieve transdisciplinary in Amazonian science, including transdisciplinary methodologies combining practice and theory, recognition of transdisciplinary education in concourses, restructuring of methods, academic programs and tools to include transdisciplinary science, government interest, lack of resources and scientists' interest in including other areas of knowledge, and others (Supplementary Material – MSQ1).

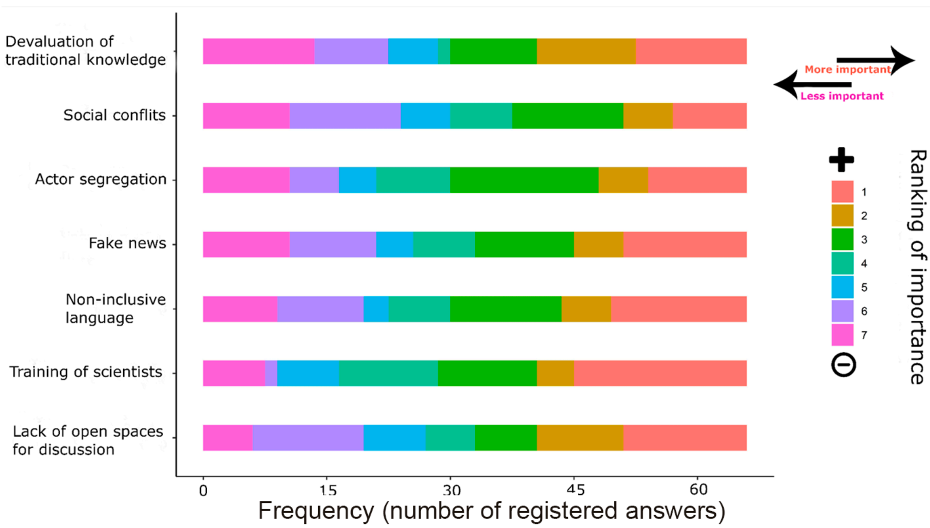

Figure 5 Main bottlenecks to promote transdisciplinary science identified by participants of the School of Advanced Studies on Inclusive and Sustainable Amazon 2022. The segments of the bars represent the frequency of participants who considered the bottlenecks more or less important in promoting transdisciplinary science.

Q2. How to build a truly transdisciplinary science?

Many responses mentioned time as an important point to develop transdisciplinary research, which needs to be "sufficient", "longer", "takes time" and "project deadlines are sometimes too short for transdisciplinary networking and exchange to occur". The participants also brought up the need for "open", "horizontal co-construction" spaces, with "a variety of actors" that promote "dialogue" and "discussion", both between different actors and between different areas of knowledge. In addition, the need for changes in the formal structure of education, greater approximation between academia and other sectors, greater participation of marginalized people in scientific research processes and the origin of the Amazonian reality, and appreciation of non-scientific knowledge were pointed out. The ability to listen was also mentioned as a necessary practice for building transdisciplinary knowledge: "training to listen"; "Implementing a listening and caring policy that promotes co-constructed knowledge through experience."

The importance of "homogeneous" and "common" language and communication was mentioned so that "different actors can express themselves and be understood by others, as well as an education on how to behave and listen in different environments." In this sense, the suggestion of developing "literacy workshops in foreign languages" arose. Some skills were highlighted as necessary, such as "Respect for different opinions, acceptance of what is new and humility"; "Talking with multiple social agents"; "Fighting the egocentrism, Cartesianism, sexism and colonialism of scientists"; "Good communication" as well as collaboration and integration practices: "Integrating all actors and knowing the problems of each place"; "better integration"; "Integrate different actors and equally"; "Open interaction between different fields of knowledge, as well as with traditional knowledge."; "Through networking with scientists from other countries." In addition, the need to bring together different kinds of knowledge and establish how they are related and how they diverge"; "Creating a vast number of chains of transdisciplinary scientific networks". Only three answers said 'I don't know', one answer said it was a "Good question" and one researcher seems to have understood that the answer should come from the person who asked the question.

The complete answers can be found in the Supplementary Material (MSQ2). In summary, we highlight the following points: "developing research processes collaboratively from the beginning with different specialists (here understood as those who hold relevant knowledge, regardless of whether they are academics or not); design research projects that address concerns raised by civil society or that combine these concerns with gaps in scientific knowledge; combine methods developed jointly with stakeholders and experts that are verifiable and robust; establish dialogue between different ways of interpreting the world, treating them as complementary and not exclusive, but at the same time recognizing different interpretations (sometimes antagonistic) for the same phenomena under study; truly transdisciplinary science must also be pursued without romanticizing the production of knowledge, but recognizing the different sources of uncertainty that can affect different systems of knowledge".

Q3. Main pathways to incorporate the cultural and social diversity of the Amazon into academic spaces

The most mentioned mechanism for incorporating the cultural and social diversity of the Amazon into academic spaces was the need to apply traditional knowledge in research, followed by the creation of transdisciplinary spaces in discussions and the transdisciplinary training of scientists (Figure 6).

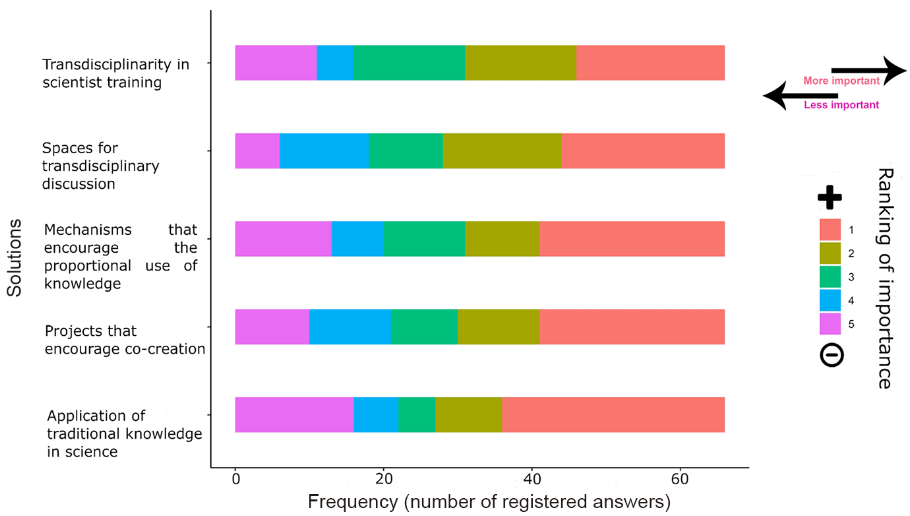

Figure 6 Main mechanisms identified by participants of the School of Advanced Studies on Inclusive and Sustainable Amazon 2022 for incorporating transdisciplinary and inclusive scientific practices within academic spaces. The segments of the bars represent the frequency of participants who considered the solutions more or less important.

Participants also mentioned other relevant points, such as local knowledge, indigenous language in knowledge production, themes proposed by the community, restructuring curriculum grids and ensuring the participation of representatives of other epistemologies in conventional science discussion spaces (MSQ3).

Q4. Main pathways to incorporate the cultural and social diversity of the Amazon in political decision-making

The co-creation of policies involving multiple actors was identified as the main mechanism for transdisciplinary inclusion in the Amazon, followed by the need for synthesizing scientific knowledge to enhance information accessibility (Figure 7). From the analyzed questionnaires, it was also possible to list other ways of incorporating cultural and social diversity in public policies, including the co-production of knowledge between decision makers and local actors and a greater connection between scientific and local concepts; definition of research themes based on listening to the actors' demands; recognition of science, create a network of environmental paradiplomacy; non-hierarchical stance towards other explanations of the same phenomena and creation of a transdisciplinary curriculum (MSQ4).

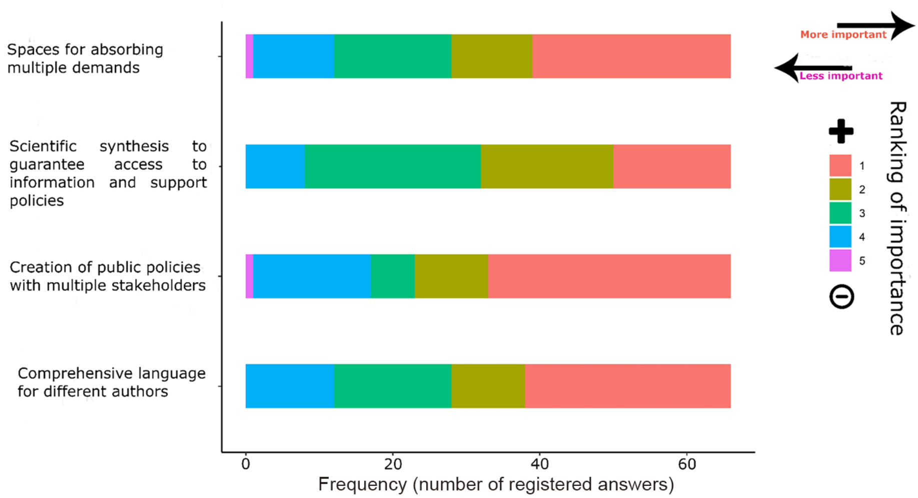

Figure 7 Main mechanisms identified by participants of the School of Advanced Studies on Inclusive and Sustainable Amazon 2022 for the inclusion of science as a support for decision-making in public policy spaces. The segments of the bars represent the frequency of participants who considered the solutions more or less important.

Q5. Participation in transdisciplinary science experiments and mechanisms that made the experience successful or unsuccessful.

In total, 63.6% of the participants had already had some kind of transdisciplinary experience, while 36.4% had never had any contact. Most of the answers (92%) were positive regarding the transdisciplinary experiences, and the main mechanisms highlighted for the success of the experiences were: listening, space and time for broader discussions, dialogue, comprehensive language and communication, planning and common objectives, inclusion of different actors and areas of knowledge, participatory methods, experience and posture (see details of each mechanism in the supplementary material, MSQ5).

However, negative points were also listed in transdisciplinary experiences, such as: *not having a return to the community*; research projects *implemented only by purely academic interests did not prosper*; proposal of the research project to be conceived in a transdisciplinary way, but the execution to be carried out by groups separately; *not previously defining what it means to be interdisciplinary*, difficulties with language and/or oral expression (foreign/common language); and finally, *the greatest difficulty is the dialogue with the decision-making agencies.*

Discussion

The São Paulo School of Sustainable and Inclusive Amazon Science (SPSAS Amazônia) featured researchers from different countries and regions of the Amazon. In summary, the critical issues related to the sustainable development of the Amazon include: (I) sensitizing scientists about interdisciplinarity, transdisciplinarity, and traditional knowledge; (II) considering different perspectives, including local communities and other decision-makers to favor inter and transdisciplinarity; (III) co-create public policies with multiple actors to connect science and politics. In this work, we demonstrate the importance highlighted by SPSAS Amazônia participants in creating spaces for dialogue with the participation of different actors to represent the social, cultural, and epistemological diversity in the Amazon. We also discuss alternatives to overcome challenges in the development and application of transdisciplinarity in broader contexts to promote the conservation of Amazonian biodiversity.

Transdisciplinarity has become an essential tool in approaching complex subjects such as socio-ecological sustainability, mainly due to its ability to promote co-design, co-production, and co-dissemination of knowledge (Mauser *et al*. 2013; Page. *et al*. 2016). From this perspective, the importance of considering local ecological knowledge (LEK) is increasingly perceived to better understand the dynamics of Amazonian environmental systems. According to the responses of the Advanced School participants, a transdisciplinary approach, involving several disciplines, is essential for this purpose. However, scientists must be open to adopting transdisciplinary approaches that value both practical science and theory, incorporating traditional knowledge. The LEK developed over millennia of coexistence between communities and their natural environments (Berkes 2004).

Transdisciplinary development research (TDR) for example, has the possibility to go beyond the limits of traditional research, engaging and articulating with the underlying causes of the sustainability issue, due to its emphasis on the co-production of solution-oriented knowledge, seen as a catalyst process for systems transformation (Marshall *et al.* 2018). The emphasis of approaches to TDR is to inform action and policy making. A fundamental feature is the possibility of building alliances and opening cognitive, normative, social and material spaces/arenas that are dynamic, responsive and lasting for the coordinated exercise of agency in this new way of thinking and acting in politics.

In this sense, it is important to encourage policies that recognize and promote transdisciplinary approaches in the contemporary context, overcoming linguistic and institutional barriers that hinder the promotion and sustainability of these initiatives. Indigenous peoples and traditional communities in the Amazon have a profound knowledge of the natural environment, transmitted from generation to generation and based on their cultural and subsistence practices (Berkes 2004). This knowledge is fundamental for understanding ecological processes, socio-environmental dynamics and developing strategies for conservation and sustainable use in the Amazon region. Valuing and respecting LEK is essential for fairer and more effective management of Amazonian ecosystems (Estevo *et al.* 2022). Therefore, the development of public policies for conservation and environmental management in the Amazon requires the integration of different areas of knowledge, not only for an in-depth understanding of socio-ecological phenomena, but also to increase the legitimacy of findings and recommendations (Fearnside 2010).

On the other hand, interdisciplinarity, even with a focus on support for solutions, does not necessarily guarantee an inclusive science (Persson *et al.* 2018) and in this sense, transdisciplinary principles and assumptions need to be adopted for urgent social transformation to actually occur (Popa *et al.* 2015), as also mentioned in the responses obtained. Among the main paradigms of transdisciplinarity (Nicolescu 2014) is the creation of a field that aims to build knowledge with a focus on sustainability, in which there is the possibility of stimulating the meeting of different knowledge, visions and practices, promoting symmetrical institutional approaches and, according to our results, horizontally co-constructed. Or, furthermore, the "*creative use of models, analogies and insights from a variety of fields and disciplines [...] Its objective is the comprehension of the present world, for which one of the imperatives is the unity of knowledge*" (Nicolescu 2014). Within this understanding, aspects reported by the participants are involved, notably "listening training" associated with a series of skills such as “respect for divergent opinions”, “welcoming the new” and “humility”, at the same time that this same understanding needs to consider the different terminologies and language specific to each discipline. Expanding researchers’ listening involves the development and absorption of the concept of alterity in research. Otherness is fundamental to improving science, as it recognizes the importance of different perspectives and experiences in fully understanding a phenomenon. Valuing otherness in science contributes to more accurate, reliable and representative results of the diverse communities served by science (Harding 1998), aligned with the social, economic and institutional aspirations of marginalized groups (Boisselle 2016).

Our results also indicate the time scale for the actions in these spaces to take place, being necessary to consider the natural time for the development of transdisciplinary research, which needs to be “sufficient”. This does not correspond to the understanding that knowledge systems must be transdisciplinary or that we need a single transdisciplinary science. Science exists by itself, however, its results when applied must be inserted in a transdisciplinary approach to be added to other perspectives and epistemologies, embarking on different ways of seeing, analyzing and feeling the world. A “truly transdisciplinary science” could make knowledge production systems have to give up some important aspects inherent to each one. We use here, especially, the definition: “transdisciplinarity as a discipline and as a way of being” (Rigolot 2020). Or as one of the participants responded: “Transdisciplinarity should not be seen as an end, but a means of seeking answers or solutions to complex problems or issues that cross-disciplinary fields”.

As part of possible solutions to catalyze the inclusion of the Amazon’s social and cultural diversities in knowledge development environments, emphasis was placed on the application of traditional knowledge in the design and conduct of research, recognizing traditional knowledge systems. This same solution was pointed out by many as having less value, which confirms the challenges of implementing a science that encompasses multiple views and disciplines. This approach is increasingly recognized by researchers, activists and local communities not only in the Amazon, but throughout Latin America. Western science has historically been imposed on local cultures and societies, ignoring their histories, knowledge and ways of life, resulting in the devaluation and marginalization of local knowledge, as well as the exploitation of natural and human resources in the region for the benefit of external interests (De Lima Grecco and Schuster 2020). The decolonization of science - as we can call the aforementioned points - requires transformation in the practices and values that guide the production of scientific knowledge from the recognition of the cultural and epistemic diversity of the region, establishment of partnerships based on reciprocity and solidarity, and work in favor of a fairer, more inclusive and socially responsible science education (Blackie and Adendorff 2022).

The recognition, appreciation, and inclusion of traditional Amazonian knowledge cannot depend exclusively on the presence of hegemonic science actors in the spaces of discussion, training, and research. It must be led by canonical institutions, funding and defining scientific knowledge, as well as political decisions. It is essential to understand traditional knowledge as equally valid, having its own empiricism, method, reflection, and analysis, even in a different way, but on an equivalent level. This approach, perhaps, allows us to bring together academic work and social participation, as pointed out by Merçon (2018), being always attentive to the instrumental use of social research. Ailton Krenak (2022) speaks of affective alliances, especially when referring to the experience of the Aliança dos Povos da Floresta, as a concept that does not necessarily seek equality of knowledge, but perhaps equivalences. And here another link can be made with the discussion proposed by Almeida (2013) on ontological connections and disconnections in specific contexts of research and knowledge in the discussion of pragmatic encounters.

The implementation of a transdisciplinary science also goes through a heated debate about the need for a new science that requires a more comprehensive approach, going beyond technical skills or traditional "hard skills", and includes socio-emotional skills or "soft skills" (Holloway and Hill 2021). Hard skills generally refer to discipline-specific technical skills, such as the ability to perform statistical analysis or design experiments. However, to build a fairer, more inclusive and socially responsible science, it is also important to develop skills such as empathy, collaboration, clear communication and conflict resolution - the so-called soft skills (Schulz 2008). These skills are critical to working with diverse communities and groups, building alliances and partnerships based on reciprocity and solidarity, and addressing the complex social, environmental, and ethical challenges we face today (Holloway and Hill 2021). Associated with multiple skills, it is necessary to ensure that scientific knowledge is applicable to different realities, transforming complex results into useful information for people's daily lives. This is in line with our results, which emphasize the co-creation of policies involving different actors, together with the reanalysis and recontextualization of scientific knowledge, to improve the use of science in science-driven policy.

Although quite challenging, most of the participants went through transdisciplinary experiences during their training, evidencing several specific initiatives for the promotion and implementation of transdisciplinarity. Among the points highlighted as necessary for the success of the activities, we highlight, in addition to the creation of transdisciplinary spaces, the use of accessible languages for greater integration between different groups of actors and the co-creation of strategies and public policies for the development of sustainable and socially fair solutions for the Amazon. In this context, a greater articulation between large research groups and funding agencies is discussed so that these experiences can be connected to a long-term transformative process that is fundamental to consolidate transdisciplinary practices in research groups. It is noticed in the answers that it is easier to point out problems (Q1) than solutions (Q3 and Q4). However, more positive than negative points are pointed out when referring to the transdisciplinary experiences lived by the participants (Q5).

Conclusion

The implementation of transdisciplinary and inclusive science for the resolution of socioecological problems in the Amazon requires consideration of the value and forms of inclusion of traditional knowledge, adequate spaces and times for broader discussions and adjusted language of communication between the parties. The planning and execution of research associated with a broad and philosophical view of the research object, bringing them closer to biophysical and social realities through co-creation, is crucial for producing results that adhere to public policies and decision-making.

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Annex I

SUPPLEMENTARY MATERIAL

RESPONSES

This section presents the participants' responses in detail, synthesizing broader ideas without losing the individual responses' originality.

MSQ1. Key bottlenecks to promote transdisciplinary science:

i - Application of transdisciplinary methods in practice, not just in theory;

ii - Lack of recognition of transdisciplinary backgrounds in competitions;

iii - Lack of academic structures, programs, and curricula, as well as tools and methods, to develop transdisciplinary science;

iv - Government interest;

v - Precision with data and research;

vi - Leadership;

vii - Lack of alignment of roles and responsibilities between academic and non-academic partners;

viii - Lack of encouragement from funding agencies, and evaluation criteria for researchers and undergraduate and postgraduate courses that do not value transdisciplinarity;

ix - Lack of empirical studies, as most projects do not start due to social demand but academic interest;

x - Lack of interest among scientists in including other knowledge systems;

xi - Transdisciplinary training;

xii - Lack of a network of connections between different expertise and institutions;

xiii - Colonial perspectives;

xiv - History;

xv - Maintenance of traditional bases and systems among university professors;

xvi - Academic colonialism in developing countries at various scales and levels, including regionalism within Latin America and countries;

xvii - Lack of funding for transdisciplinary research and seed grants to co-create relevant questions and proposals.

MSQ2. How to build truly transdisciplinary science?

Details of the suggestions mentioned by the participants of SPSAS 2022 in the open field:

Spaces/Scenarios:

Promoting a safe environment for each person to share their knowledge.

Valuing this knowledge and creating professional spaces for the researcher to work in.

It is important to find scenarios that require transdisciplinary research. Integral problems stem from integral approaches, where disciplines coincide in time and space to solve them.

Work outside the office, dialogue with society, and participate in political spaces.

Changes in the formal education structure:

Modifying the entire education system; Integrating the transdisciplinary approach into various school curricula, from high school to postgraduate education; More participatory and simplified education; Inclusive transdisciplinary education at all levels and scientific disciplines.

Closer alignment between academia and other sectors:

Transdisciplinary science should begin within the academic space, at the beginning of any undergraduate program, to establish a solid foundation and a unique path. Extension projects must be more valued within the university to instill the same pleasure of execution in a scientist as in a research project. The connection between the community and academia must be strong for transdisciplinary science.

Bringing academia closer to other sectors, peoples, and communities is an extremely important step.

(...) pursuing solutions involving academia should go hand in hand with the affected sectors.

Scientists should receive training to deeply understand how different knowledge and sciences are constructed and how they are useful for solving concrete problems. Properly training scientists and promoting the integration of multiple actors in policy development.

An example of this is the “Notório Saber” titles for traditional masters and mistresses granted by some universities in Brazil, which allow these knowledgeable individuals to navigate the university in recognized positions and sometimes with resources for research and teaching activities.

Starting at the undergraduate level, introducing students to courses and lectures to learn about this, but more importantly, they learn to work with other people. Always include community leaders and teachers in projects.

Funding agencies and academia should require that research is more accessible (from the initial collaboration phase to the final stage with results) to local communities, including urban and rural areas, with appropriate communication and language.

Greater participation of marginalized people in scientific research processes and in the origin of the Amazonian reality:

Inclusion of underrepresented parties; Involvement of local actors as researchers.

Ensuring the inclusion and presence of historically excluded peoples in decision-making and knowledge formation.

We need more people from the Amazon showing the Amazonian reality.

Ensuring the participation of representatives from other knowledge systems in spaces related to the Amazon.

Valuing traditional knowledge and including traditional populations in scientific debates.

Social inclusion, considering all social classes and not just distinct groups. The tendency is always to think in terms of groups rather than how society, especially in Brazil, is "organized."

Transdisciplinarity is a political issue, and politics cannot be carried out without a body. The body I seek for it is a hybrid, human and non-human body.

Valuing non-scientific knowledge:

Recognizing other worldviews as sources of wisdom.

Not excluding traditional knowledge; Using strategies adapted to the reality of each population; Involving and valuing different forms of knowledge.

Considering it as the field of the new, of contingencies. Transdisciplinarity must stir epistemological and ontological questions, as it is not only associated with the path in constructing knowledge but also with the agencies of those who construct it. For this, it is crucial to recognize the multiple alterities in world constructions.

Making the process of consultation, dialogue, and dissemination with the local communities involved an ethical principle of research, valuing traditional knowledge and collective memory and assuming social contribution through the production of concrete and applicable results as a commitment.

Ensure that IPLCs (Indigenous Peoples and Local Communities) have their basic services and rights respected, so they can more easily engage in science. In fact, place IPLCs in stable positions of academic power so they can create research and study programs.

Methods and approaches:

Conduct applied science based on socio and ecosystemic needs.

Build and approve transdisciplinary projects.

Interdisciplinarity arises from the practice of research. It requires a group of professionals with different backgrounds willing to step out of their comfort zones.

Align research objectives with the solution of problems according to the perception of different stakeholders.

Include art, be creative, think of (action) solutions beyond disciplinary understandings of specific questions and doubts to be addressed.

Shift the orientation of science from mere data to transformational science. Implement methodologies that include aesthetic aspects and diverse languages.

Indigenous and traditional peoples should be involved in the design of research and public policies. The themes of these instruments should be determined by these people.

Start by having a shared vision of what is desired and the objectives; hold workshops to identify values shared by project members; hold workshops to identify biases and underlying epistemologies that each person uses; build a shared vocabulary; start with the problem.

1. Identify a working group that can incorporate an integrative perspective for the research question; 2. Co-create from the idea to the development of proposed products; 3. Listen and dialogue among different team members of the project. 4. Identify the capabilities and limitations of each team member; 5. Maintain frequent meetings/sessions; 6. Assessments and feedback on activities among team members.

Academic colonialism, racism, and socioeconomic inequality homogenize scientific thought and hinder transdisciplinary research. Without addressing these issues, we can only imagine what would be transdisciplinary from a Eurocentric and non-inclusive perspective.

I think it’s a challenge because it requires some systemic changes, including the evaluation of scientists’ output and, of course, transdisciplinary training as well.

MSQ3. Key ways to incorporate the cultural and social diversity of the Amazon into academic spaces

In addition to the points mentioned, the following aspects were raised:

i - Local knowledge of cultural systems;

ii - Developing policies to value and incorporate indigenous languages and local dialects in the knowledge production processes;

iii - Challenging and critiquing our own ways of viewing the world and knowledge systems;

iv - Supporting inter/multicultural education and promoting the dialogue of knowledge;

v - Research topics indicated and discussed with traditional peoples, acting as researchers and data analysts, participating in all stages of knowledge production;

vi - Placing International Private Leased Circuits (IPLCs) in positions of power, such as FAPESP and the Brazilian Academy of Sciences;

vii - Valuing scientific, traditional, and indigenous knowledge equally;

viii - Ensuring that all actors have access to information;

ix - Leveraging and valuing university extension course structures with a transdisciplinary focus, encouraging larger funding and longer projects that respect a consolidated schedule and process for solving complex socio-environmental problems;

x - Ensuring the participation of representatives from other epistemologies in conventional science discussion spaces;

xi - Establishing trust-based interpersonal relationships;

xii - Preventing colonialism, structural racism, and socioeconomic inequalities in research agendas and institutions, expanding access to financial resources for minorities.

MSQ4. What are the key ways to incorporate the cultural and social diversity of the Amazon into political decision-making?

i - Facilitate the co-production of knowledge between decision-makers and local actors, creating bridges between local and scientific concepts, perspectives, and knowledge to inform policies that can integrate common objectives and issues;

ii - Define research topics based on listening to the demands of the actors and jointly reflect on the causes of the presented problems;

iii - Recognition by decision-makers of science as a planning tool;

iv - Create a network of environmental paradiplomacy (various actors with different experiences) to address environmental issues;

v - The process of consultation, dialogue, and dissemination with community organizations/associations as an ethical principle of research;

vi - Identify the governance systems of common goods at the local level and public policies that are built from the bottom up;

vii - Think of co-creation as a way to ensure implementation;

viii - A non-hierarchical approach to other explanations of the same phenomena; the ability to collaborate for new ways of thinking and solving “urgent issues”;

ix - Create a transdisciplinary curriculum to connect and value the knowledge and needs of traditional and ancestral peoples;

x - Listen to demands and understand the realities in the field.

MSQ5. Participation in transdisciplinary science experiences and mechanisms that made the experience successful or unsuccessful.

Details of the mechanisms mentioned as positive in previous experiences by participants in SPSAS 2022:

Listening: "broad listening," "listening to each member's demands," "listening to the opinions of people from different areas on the same topic," "listening to traditional peoples for innovative practice with adherence," "respectful listening and idea exchange."

Space/Time: "time for dialogue," "spaces to hear demands," "discussion and exchange of approaches in a horizontal, flexible, and proactive environment were the most important inputs."

Dialogue: "dialogue about activities," "dialogue and the need to exchange ideas on a common theme."

Language/Communication: "Adoption of local languages in meetings, project concept glossaries"; "learning another language in science/creating shared vocabulary"; "detecting aesthetic languages, social codes, and dynamics upon which to project methodological proposals departing from the scientific conventionality of data science"; "facilitating appropriation by local actors."

Planning/Common Objectives: "having a clear goal for the work"; "clearly defined roles and responsibilities"; "co-creation with representatives of other knowledge production systems at all stages of the approach."

Inclusion of Different Actors and Areas of Knowledge: "It is very important to be attentive to the approaches of each discipline and include them as fundamental in defining strategies, action plans, or, in short, solutions"; "inclusion in discussion groups of many members from different cultures and different traditional peoples from various parts of the planet"; "better relationships between areas"; valuing "all knowledge, and everyone felt equally a part of the group"; participation of "anthropologists, philosophers, artists, transgender individuals, children"; "recognition of the capabilities and aspirations of traditional communities"; participation based on "gender equality, race, location of activity, subject of activity, level of education, etc. (diversity of actors)."

Method: application of participatory methods; local validation of field methodology; fieldwork in the community, respecting the schedules and rules of interlocutors; consideration of various forms of knowledge, information, data, and evidence.

Experience: researchers with previous experience working with traditional peoples and local communities; participants who are genuinely prepared to negotiate and not to impose views; "international and national experience in other universities, researching different ecologies, environments, and cultures."

Attitudes: joint action, goodwill, patience, "being humble is a good starting point," respecting new perspectives, stepping out of one's comfort zone, respect for different perceptions, a sense of reality (moving forward with what is possible), tolerance, respect, constant communication, contributing to autonomy. Mutual trust is based on the sincerity of purposes and expectations, shared (and rotating) leadership, clear communication strategy, trust, and interpersonal skills development among participants, as well as openness and inclusion of diverse perspectives.

Others: good governance of communities; epistemological and ontological symmetry between sciences, environmental knowledge (Enrique Leff); Freirism.

In addition, although participants were not asked to describe their experiences in transdisciplinary research, many chose to do so. One response stated that their experience was "very relevant and powerful." Participants shared the following transdisciplinary science experiences:

- Community Archaeology Project for Ethnoeducational Heritage "For a Living Fort Museum: Public Archaeology with the Quilombolas of Fort Príncipe da Beira in Times of Pandemic," an experience that won the 10th edition of the largest award in the field granted by IPHAN - the Luiz de Castro Faria Award - in the scientific article category.
- Agroecological Project: carried out by a diverse team (academics, farmers with training in agroecology, local residents, and indigenous people), where dialogue occurred in a horizontal manner, and most of the work was done in the field rather than in classrooms.
- Participatory and Sustainable Management of Pirarucu, specifically a course for learning how to count pirarucu, where novice fishermen learned to organize their perceptions of fish behavior for population surveys. Technicians and experienced fishermen shared their knowledge about pirarucus, sparking conversations with the students. The course included elements of ecology theories and traditional knowledge of fishermen about pirarucus. The joint coordination of the activity allowed multiple perspectives on fish and lakes, with both types of knowledge being considered valid without hierarchy. Experienced fishermen also guided students in practical fish counts in lakes, providing empirical guidance in the collective knowledge-building process.
- Alternation Pedagogy: a model recognized by the Ministry of Education in Brazil for education in rural areas, prioritizing modular curricula adapted to the rural reality and the traditional knowledge of these communities.
- Aesthetic Pedagogy: a proposal that seeks to identify convergent elements to work from an Autopoietic and Transdisciplinary perspective, incorporating art concepts into all subjects of the elementary school curriculum, enabling the emergence of a Pedagogy of the Sensitive.

- Cartographies/Social Mapping with Traditional Peoples and Communities: In this research experience, the positive aspects mentioned included the systematization, valorization, and dissemination of traditional knowledge in the Western pattern, materializing, recording, and translating oral and empirical knowledge into a universal cartographic language. However, the challenge and difficulty of this experience were the limited time to overlay and deepen the records of these traditional knowledge cartographies with scientific information already established (ecological analyses, data on socio-environmental conflicts, areas sensitive – hot spots, areas of greatest biodiversity, demographic and socioeconomic data).
- The collaborative development of a book with anthropologists, biologists, and young local researchers from the Terra do Meio Extractive Reserve (RESEX) in Altamira, PA. The book focuses on the research results related to the management of Brazil nut groves, wildlife, agricultural fields, forest regrowth, and the daily life of the riverine communities, among other topics. The research was conducted between 2016 and 2020, and the writing process began in June 2021, but it has not been completed yet. This experience required a significant amount of time for dialogue, multiple revisions of the texts based on suggestions from all participants, and the need for each person to adapt their personal expectations regarding the outcome of the work. Effective non-violent communication and mediation were necessary at various stages.
- A vocational training course for Indigenous Agroforestry Agents in Acre, which aims to provide intercultural training at the high school level.

Questionnaire

Copy of the digital questionnaire sent to the participants of SPSAS 2022, titled "**Inquiry about transdisciplinary science.**"

Transdisciplinary Science – Connecting Different Worldviews

This questionnaire aims to capture the perception of SPSAS 2022 participants regarding their current and future experiences in applying sustainable and inclusive transdisciplinary science in the Amazon. The responses will be analyzed and discussed to create a guidance manuscript for transdisciplinary practices.

Here, we use the term "**transdisciplinary science**" as a discipline that includes non-academic stakeholders in the knowledge production process and as a way of being in terms of researchers' personal dispositions and expression in multiple spaces.

Questions

Participant's General Information

- Email
- Gender
- Age
- Nationality
- Do you identify as a member of an Indigenous/traditional community? If yes, please specify.
- In which region of the Amazon do you work?
- Area of expertise
- Institution
- Position/sector (Ph.D. student, Academic researcher, Private sector, NGO researcher, Government researcher).

Questões específicas/abertas

Specific/Open Questions

Q1. List, in order of importance, the main challenges in promoting transdisciplinary science (1 = most important). If there are other relevant points, please describe them.

(Non-inclusive language, Social conflicts, Fake news, Segregation of stakeholders, Lack of transdisciplinary training for scientists, Undervaluation of local knowledge, Lack of spaces that promote the integration of knowledge, among others.)

Q2. How to build truly transdisciplinary science?

Q3. How to incorporate the cultural and social diversity of the Amazon into academic spaces? List in order of importance (1 = most important). If there are other relevant points, please describe them.

(Valuing traditional knowledge in research development, Including/creating transdisciplinarity in the curriculum, More inclusive discussion spaces with actors from underrepresented groups, Co-created extension projects with communities, Creating mechanisms to reconcile different forms of knowledge, among others.)

Q4. How can science connect to the cultural and social diversity of the Amazon in political decision-making spaces? List in order of importance (1 = most important). If there are other relevant points, please describe them.

(Co-creation of public policies with actors from different spheres, Scientific synthesis to improve access and use of information, Accessible and understandable language for different actors, Implementation of spaces to listen to the demands of different actors.)

Q5. Have you ever participated in transdisciplinary scientific experiences (yes or no)?

Q5.1. If you answered yes to the previous question, please identify some mechanisms that made the experience successful or unsuccessful.

Authorization

If formal publication is required, do you authorize using the provided data as anonymous (yes or no)?

Authorization

If formal publication is required, do you authorize using the provided data as anonymous (yes or no)?

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New stories for the Amazon

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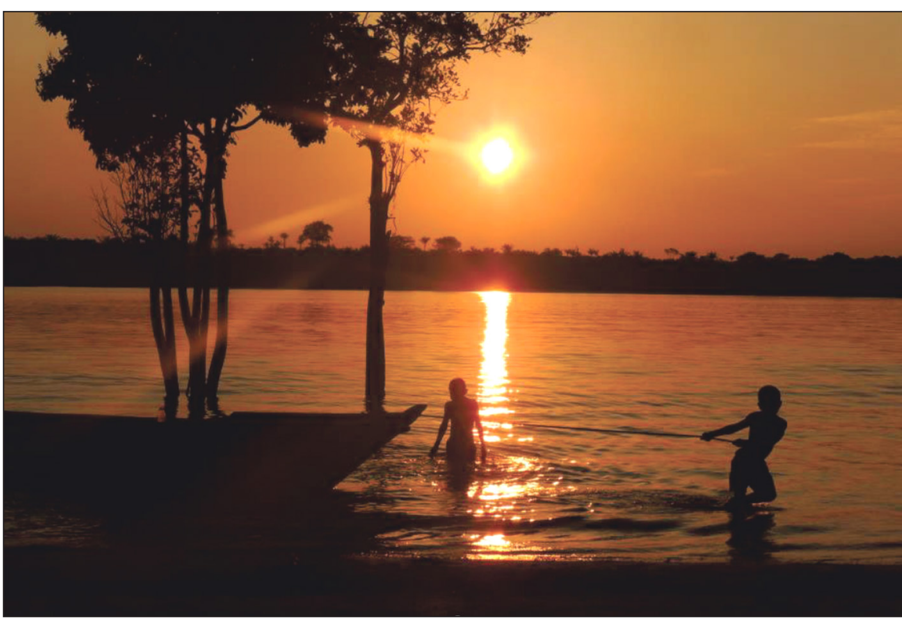

I felt compelled to ask
myself, with all the seriousness in
the world, the following question:
"What is the myth you are living?"
(Jung 1956, xxiv)

The name "Amazon" began to take shape with the publication of the chronicle of the journey in 1541-1542 by Gaspar de Carvajal (2007). This Spanish clergyman recounted the existence of a people comprised of women living in over 70 villages. He described them as very fair and tall, with long, braided and tangled hair, armed with bows and arrows, and fierce warriors. From then on, the South American region became associated with the Greek myth of the Amazons, a society of women skilled in war and hunting, fierce combatants. In 1544, the Venetian Sebastiano Caboto already included them on his world map; there he illustrated soldiers in armor, shields, and swords engaged in open combat with these women (Figure 1).

Figure 1 Detail from: Sébastien Cabot, Mapamundi, 1544. French National Library. http://catalogue.bnf.fr/ark:/12148/cb40593927f

Later, narratives emerged in which the human and non-human aspects of the Amazon were depicted as conflicting, at least in the eyes of the European worldview. The emergence of these narratives alluding to a territory that needed to be contested, subjugated, and domesticated is not merely anecdotal; they are long-lasting narratives that are part of an ongoing process, coloniality, which constantly resurfaces or weaves new layers of colonialism for the construction of alterity and the exercise of power (Cuvi 2018). In this text, I aim to illustrate these narratives and some discourses that challenge them. Moving from the myth of the Amazons to other myths, I will reflect, among other things, on the vast array of connections that can exist in the immense Amazon, with both its human and non-human inhabitants. This range of accounts includes those found in this book, one of the outcomes of the São Paulo School of Advanced Science: Sustainable and Inclusive Amazon (hereinafter referred to as "the School"). Within these records, we can see tensions and potential solutions in the face of adversity and what may seem inevitable, as well as the escapes made by heroes and heroines, both ancient and modern.

A story that comes to mind when I think about the past and present of the Amazon is the Greek myth of the labyrinth of Crete. This place was built by the skilled craftsman Daedalus to contain a voracious Minotaur, a being that was part-human and part-non-human, to whom several youths had to be sacrificed each year. The Athenian hero Theseus joined a group of sacrificial victims, determined to slay the Minotaur with his combat skills, but he didn't know how to navigate the labyrinth. That's when Ariadne, the daughter of King Minos of Crete, appeared. Following advice from Daedalus, she gave Theseus a ball of yarn, the end of which he tied to the labyrinth's entrance (Figure 2). After killing the Minotaur, the hero used the thread to avoid the tragic fate.

In this myth, I find several parallels with the past and present of the Amazon biome. I view this forest as a labyrinth inhabited by various Minotaurs, the customary extractive[1] activities of the Anthropocene and their accelerations (McNeill & Engelke 2014; Steffen *et al.* 2015). There's the ruler of Crete, determined to keep these monsters and artificial order in place. There's also Daedalus, the inventor of the system, who seems uncomfortable with his creation and wishes to see it overthrown. There's Ariadne and her guiding thread: knowledge, reason, affections, and cunning to prevail in the face of tragic foreboding. There are heroines and

1. In Spanish, the word "extractivismo" refers to large-scale extraction activities, especially of materials and energy. In Portuguese, "extrativismo" refers to the sustainable use of resources by communities. In this article, I will use the Spanish meaning.

heroes who, like Theseus, have the skills and the will to annihilate the devouring beast, although sometimes the Minotaurs are transformed into a Hydra of Lerna, a mythical entity whose head, when severed, gives rise to two new ones.

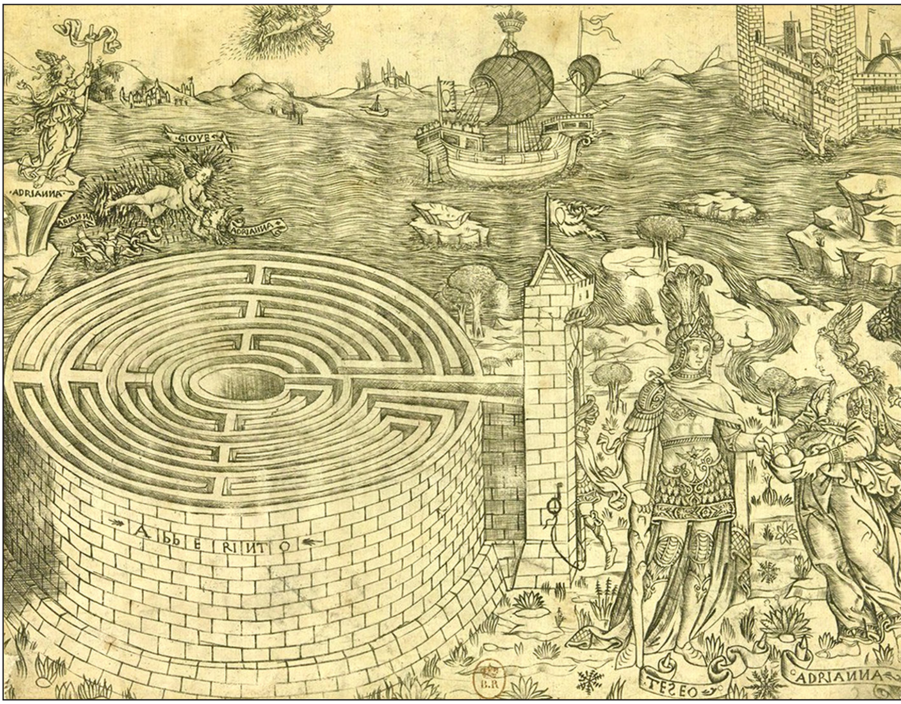

Figure 2 Baccio Baldini, *The Labyrinth of Crete and the story of Theseus and Ariadne*, 1460-1475. French National Library. http://catalogue.bnf.fr/ark:/12148/cb40346597v

Several Amazonian myths also make me reflect on the complexity of this South American tropical biome. One of them, from the Bororo indigenous people, called "the macaws and their nest," contains elements similar to the Cretan labyrinth (Lévi-Strauss 1964, 43-45). It tells the story of a young hero whose father wants to kill him but is saved multiple times by the wisdom of his grandmother, who advises him to trust bird-like beings or gives him a magical staff, elements that save him from death. His path is winding, fraught with suffering, and marked by death, betrayal, and revenge. Like Ariadne with her ball of yarn, the Bororo hero's grandmother saves him with a mixture of affection and reason, ideas, and desires.

Another relevant Amazonian tale is that of the Twins in their Napo Runa version, which illustrates the complexity and incommensurability of the symbolic and the material in local worldviews. Pregnant, the mother of the Twins went to the cave of the jaguars with the intention of being devoured. The jaguar mother hid her to save her, but her jaguar offspring found her, killed her, and removed the two babies from her womb. Instead of consuming them, the jaguar mother chose to raise them. In the meantime, these jaguars continued to prey on people, so the humans wanted to annihilate them. One day, the Twins set a trap for their jaguar siblings and killed them, providing an apparently paradoxical solution: helping the humans and betraying the jaguar mother who had saved them. The jaguar is, therefore, both predator and prey, admired, imitated, and respected, as well as abhorred, hunted, and feared (Uzendoski & Calapucha-Tapuy 2012). Although feared, humans seek to connect with these felines because they provide wisdom and teach how to live in the jungle; in other Amazonian legends, they teach humans how to use fire and end up being stolen, as in the myth of Prometheus (Turner 2017).

For a scholar of myths from a psychological perspective, the Austrian Carl Jung (1952) suggested that the mythologies of all peoples and eras integrate, among other things, what he called the "collective unconscious." He proposed that we have common ideas, some of which have been with us for a long time. It is understood that we are also capable of creating new collective unconscious elements that coexist with the ancestral ones. What are these myths that we live with or try to create about the Amazon biome? I am interested in highlighting two narratives that have been very present in the School and in this book: the narrative of Knowledge and the narrative of Life. These are two semiotic and material places that exist or could exist as utopias or dystopias.

Narratives of knowledge and life

The ten articles in this book, as well as the lectures at the School, provide scientific and political explanations and positions on the processes occurring in the Amazon. Some refer to specific cases, distinguish localized biogeophysical processes, or integrate various worldviews. They analyze and challenge the tensions surrounding pollution, deforestation, infrastructure, social exclusion, and other manifestations of genocidal and ecocidal violence, and, based on empirical evidence and theoretical reflections, they point towards actions that lead to inclusive, peaceful, and sustainable directions. They identify both the winners and losers in various activities. Positioned in the here and now, they point to dystopias and allude to possible utopias.

At the School, it became clear that in order to envision the utopia of transitions towards a robust sustainability, actions must be guided by an ethical component, an environmental ethics (Brennan & Yeuk-Sze 2002-2021). Starting from an ontological stance that reflects on the relationships between humans and between us and non-humans, from a horizontal and renewed perspective, it seems possible to redefine and redirect aspects of the economy, politics, regulations, financing, and education. This requires the integration of contemporary epistemologies, including epistemic, affective, and ontological turns, ecologism, decoloniality, and feminism. Interdisciplinary fields such as Environmental History and Science, Technology, and Society Studies have been discussing and charting the convergence of humans and non-humans, along with their respective agencies for decades. Buddhism (a philosophical proposal that has existed for centuries), the more recent Romanticism, and Aldo Leopold's Land Ethics (2005) are also in line with this perspective.

In the Americas, there's pachamamismo, or sumak kawsay, with its conceptual and practical virtues and problems (Bretón, Cortez & García 2014). The sociology of associations by Bruno Latour (2008), which alludes to the reassembling of the social, is suggestive. Similarly, emerging from Amazonian studies and ontological anthropology, the idea of "perspectivism" explains that both humans and non-humans experience and understand the world in unique ways, and that each perspective is valid and coherent, even if it is different (Viveiros de Castro 2013). These and other proposals move towards hybridity and complementarity, leaving no one and nothing behind, incorporating and understanding the agency of all actors. They contrast with the assumption that there is an objective and universal reality; they challenge univocal, sometimes hegemonic models. By being open to multiple perspectives, it is possible to articulate "sustainability algorithms," sets of systematic operations that lead to socioecological systems of greater virtuosity and resilience (Cuvi 2022).

Part of the School's objectives was to have "a multi and interdisciplinary vision, based on science and valuing indigenous and traditional knowledge." The conjunction between modern technoscience and local, some ancestral, knowledge under the broad framework of what is being called "knowledge" (Barahona & Raj 2022; Daston 2017) is part of environmental ethics. All the works are transparent regarding this shift. They follow a path that has been given names such as Post-Normal Science (Funtowicz & De Marchi 2000) or dialogue of knowledge. They gather the opinions of actors who have not been adequately highlighted, in part because their knowledge is not mobilized through mechanisms such as scientific publications or academic conferences. The invitation to construct wisdom horizontally in order to arrive at solutions is a central part of what I refer to as the narrative of Knowledge, which goes beyond technoscience.

Amidst the tribe of the moderns, technoscience has been imposing itself as a powerful narrative since the 18th century. This set of norms and ways of appreciating the world has undermined the power of various institutions. Nevertheless, it has not been accepted by everyone; currently, there is denialism for various reasons, including its inadequacy in the face of socio-environmental crises and its failure to provide satisfactory answers to all questions, sometimes addressing only a part of them. The narrative of Knowledge goes beyond this: it acknowledges that modern technoscience works best when combined with other forms of knowledge, forming a nested system with unique properties. This Knowledge is like Ariadne's thread or the Bororo grandmother's magic staff; it encompasses many perspectives.

There have been and still are knowledgeable masters, descendants of ancient inhabitants, who managed soils, built roads and cities, navigated rivers, and domesticated plants. Their legacy is, above all, tacit, alive in practice, not always readily available in the academic world. Historically, technoscience has appropriated this knowledge, although it has not always recognized it. Amazonian explorers like Louis Agassiz, Henry Walter Bates, Alfred Russel Wallace, William Henry Edwards, or Richard Spruce relied on these people and their practical knowledge to construct technoscience (Pereira Antunes, Massarani & Castro Moreira 2019).

In the first section of this book, four articles address Knowledge about the macro-impacts of activities in the Amazon region. They analyze these impacts and propose ways to avoid or modify them through organizational and governance strategies, drawing on both technoscientific knowledge and local and ancestral knowledge. The first article argues that the economic, ecological, and social impacts of large hydropower dams have been underestimated, questions the narrative of "clean energy," and suggests that providing electricity to remote communities would require planning alternative infrastructures (Resende et al. 2023). These conclusions emerge from the knowledge of technologies, political economy, and the experiences of communities.

In the second article, Lima et al. (2023) address the systemic issue of deforestation, presenting strategies that have been effective in reducing it. They argue that on both public and private lands, it's necessary to combine knowledge with incentives, command, and control. They propose a theoretical model based on what is known, from various perspectives, about the complexity of deforestation processes. This article is followed by another that analyzes the concerning contamination by mercury in indigenous communities, especially in the Munduruku territory. The authors claim that this is not a new problem but is growing daily, exacerbated by the fact that national and international policies and commitments are not being fulfilled (Cantuária *et al.* 2023). The title of this text contains the word "reality," although "reality" is multidimensional, almost never univocal. Regarding issues like the quantity of mercury in people, biodiversity, and soils, the data is indisputable, especially when observed in conjunction with statistics on neurological, cardiovascular, digestive, and reproductive diseases. Equally serious is what Ochoa *et al.* (2023) expose in their article on pesticides; like mercury, pollutants associated with agricultural production affect people and the environment from a multidimensional perspective. The authors present a very valuable case related to the guarana bush. The agroecological model, based on traditional techniques using genetic material from the forest, without extensive artificial pest controls and with extraordinary results, is contrasted with productions that require laboratory varieties and many pesticides. Based on Knowledge, these four articles on impacts propose solutions ranging from the suppression of mega-hydropower dams to zero deforestation and the eradication of pollution sources. In all cases, education, communication, inclusion, prevention, and monitoring are presented as crucial, working with communities, teaching, and learning.

The block of articles dedicated to local governance also incorporates the narrative of Knowledge. The first of them explains the problems caused by droughts, particularly in the south, a topic that has mobilized a lot of research due to its impacts on mobility, access to food and medication, prices, crops, wildfires, fishing, and hunting (Pessôa *et al.* 2023). The most important aspect that this work reveals, from my perspective, is that adaptation to this recurring and increasingly intense phenomenon can be achieved through dialogue between local knowledge and technoscience, integrating knowledge about ecological agricultural calendars, chacras, information systems, and early warning systems, among others. The authors emphasize that "the identification of the drought phenomenon is quite diverse in the Amazon," which demonstrates the incommensurability that Knowledge must encompass.

The second article in this section addresses a broader issue: the relationship between resource management, climate change, and local governance (Guimarães *et al.* 2023). It reaffirms the value of local knowledge, some of it ancestral, in the face of challenges that include droughts, rising temperatures, impacts on biodiversity, and economically significant forest species, among others. It also alludes to the recovery of the traditional agricultural calendar as an adaptation measure.

The third set of articles addresses the inclusion of cultural diversity at different scales. Dedicated to analyzing the inclusion of indigenous students in universities, the article by Lembi *et al.* (2023) is closely tied to the narrative of Knowledge since academia should be at the center of integration processes. Based on the case of the State of Amazonas, Brazil, they inquire about how to enhance the access and retention of indigenous students, prevent discrimination, and promote them to representative positions in universities. I can't think of a more fitting essay on post-normal science, on the dialogue between technoscientific knowledge and indigenous knowledge. A similar situation occurs with the article on urban diversity, focused on the mesoregion of Marajó Island, State of Pará (Carmo *et al.* 2023). Considering that cities are dynamic spaces where multicultural encounters take place, the authors question the most appropriate urban sustainability indicators. Without naivety but in a poignant manner, they document the singularities of this region and how local knowledge and its consideration could be used to make urban development more relevant for its inhabitants.

The governance section concludes with an article on the territorial rights of indigenous and Afro-descendant populations in three countries. Cañadas *et al.* (2023) argue that the preservation of the biocultural diversity of the Amazon is crucial and requires the assurance of certain conditions for indigenous and Afro-descendant peoples, including their territories. They analyze three cases: the Apolima-Arara in Brazil, the Waorani in Ecuador, and the Saamaka in Suriname. They present timelines and detail the processes, conflicts, achievements, and needs. They mention the lack of concrete activities to ensure the actual preservation of biocultural diversity and propose innovations in four dimensions of the processes: autonomy, self-governance, and political participation; law enforcement, monitoring, and sanctions; conservation and promotion of traditional knowledge; and sustainable community-based economic sovereignty.

Finally, the fourth section features an article on transdisciplinarity. It is mentioned not only as a "possible" category but also as "indispensable" for a sustainable future in the Amazon (Krainovic *et al.* 2023). The authors conducted numerous interviews to reflect on the strategies that implement transdisciplinary science. The results call for more work with communities, both in incorporating their knowledge and in policy formulation. In summary, approaches are needed that are not just top-down or from academia to communities but are co-created, horizontal, and interactive.

The inter/multi/trans/polydisciplinary approach lies at the heart of the Knowledge narrative. Among other things, it predisposes to overcome the idea of "purity" in both technoscience and local knowledge. It understands that this epistemological unfolding can put an end to narratives such as the one that led to the naming of the "Amazon" basin from colonial perspectives to construct narratives of complementarity, not alterity. In a similar vein, a few years ago, the

Scientific Panel for the Amazon published a synthesis report that, in addition to combining technoscience and local and ancestral knowledge, provided policy recommendations (Nobre *et al.* 2021).

The second narrative I want to address, very present in the School, is that of Life. It dates back centuries but gained renewed strength with the second wave of environmentalism from the 1960s and 1970s (Guha 2000). Its central narrative is that the destruction of biocultural diversity is problematic and that it is necessary to reframe the Amazonian space from both a semiotic and material perspective. For example, it invites leaving behind the idea that these forests are empty, that they are "devastated lands," devoid of people (Cuvi, Guiteras-Mombiola & Lehm 2021). This also leads to burying the notion that these are spaces whose exploitation is indispensable and necessary, intended to convert their natural heritage into financial capital as quickly as possible. This view has been used for centuries to promote "progress," "development," or "modernity," from the mythical tale of the city of El Dorado to the Brazilian government's posters from 50 years ago that referred to the Amazon as a place to "profit" (Figure 3), or in messages about the inescapable need for extractivism and sacrifice zones to achieve development in the 21st century.

The Life narrative considers erosional trends, pollution, decline, and the extinction of cultural, biological, and agricultural diversity problematic. It is supported by Knowledge, for instance, in statements from the recent Intergovernmental Panel on Climate Change report, which alludes to our high level of confidence that the Amazon, "one of the world's largest repositories of biodiversity and carbon, is highly vulnerable to drought," and could become a carbon emitter rather than a sink due to massive tree die-off (Castellanos *et al.* 2022, my translation). It is also based on the Scientific Panel for the Amazon, which reports potential tipping points, steps into unknown territory, labyrinths where we are unsure if we have an Ariadne's thread, where Knowledge may find itself in terra incognita. According to this report, based on empirical evidence, there are four potential ecosystem configurations toward which Amazonian forests could be headed. Among them, "the degraded open canopy state and the closed canopy secondary forest state are the most likely to occur over large areas, particularly along the 'deforestation arc'" (Hirota *et al.* 2021, my translation). These scenarios are concerning as they warn of transitions towards a dystopia of deforestation, drought, and social unrest.

Figure 3 Banco da Amazonia's advertisement in 1972, in the magazine *Realidade*. Taken from: https://revistacenarium.com.br/chega-de-lendas-vamos-faturar-anuncio-de-1972-vendia-a-amazonia-ao-capital-predatorio/

The Life narrative argues that economic growth, while generating well-being for some populations, produces negative legacies for many others and for nature. It questions whether Gross Domestic Product (GDP) is the supreme authority among well-being indicators. It calls for moving beyond the number of shovels, excavators, mines, mega-construction projects, exported biomass, or hectares added to the agricultural frontier each year. It asserts that the breath of progress, this Promethean myth, has left devastating traces that threaten the Earth's fragile balance (Steffen *et al.* 2015). Furthermore, it notes the increasing transgression of planetary biogeophysical boundaries and local boundaries as the true contemporary "tragedy" (Gligo *et al.* 2020). It puts an end to historical ideas of prodigality and abundance, which have been crucial in the mindset and actions of the American republics since their inception (McCook 2018); there are no longer inexhaustible or infinite resources to be exploited.

The narratives of Life and Knowledge resist the forms of denial of climate change and global change, in lobbying efforts that support the need to squeeze the last drop from natural assets (wood, oil, minerals, fibers, fertility, water) to gain financial capital. These counter-narratives are upheld by various old ideologies that have no interest in ending ethnocide and ecocide in order to build transitions toward a strong sustainability and the culture of the Ecocene.

Transitions to a strong sustainability

Various mentalities, intentions, desires, countries, indigenous and Afro-descendant people, peasants, urban residents, and millions of non-human actors converge in the Amazonian space. Sometimes, they coexist peacefully, while at other times, they clash with destructive force. Biodiversity conservation or ecological restoration, with their benefits for communities, contrast with deforestation, mining, and pollution. Personally, I see these processes as oppositions between life and death instincts (Freud 1922, p. 253), between anthropocentrism and biocentrism, between conventional and ecological economic approaches, between extractive intentions and resistance. The question is whether we can establish a dialogue between these intentions, some of which are so at odds with each other that they mutually cancel out, leading to a zero-sum game, a path to nowhere.

There are undoubtedly Minotaurs-Hydras-Jaguars that need to be eliminated to build transitions towards strong sustainability. This book points out ways to do so, both practical and theoretical, based on various narratives. However, as we try to apply these tactics and strategies, or expand them when present, we may end up overwhelmed by slow progress or setbacks, feeling incapable of escaping the prediction of our tragedy towards a fatal destiny.

We need a lot of creativity. Among the forms of resistance to the layers of colonialism, many solutions have been proposed. Some of them are more unusual, but they can help redefine the incommensurability of possible processes. Let's go back to the Napo Runa people, who for centuries fled from the conquerors in the form of soldiers, religious figures, and officials, whom they portrayed as cannibals who appropriated their bodies (Alvarado 2010). After many escapes, they eluded total conquest by submerging themselves in a lagoon created through magical acts. They fled to resist within an alternative reality: "From the Native perspective, the ancestors were only 'conquered' and colonized within one field of reality, that of ordinary reality. The ritual superiority of the ancestors in the realm of alternative reality allowed them to survive and continue assisting their descendants inhabiting the region" (Uzendoski 2020, own translation).

This lagoon, in the symbolic realm, provided a place from which other resistances and transitions were enacted. What is this lagoon in the Amazon today? I see it as a multidimensional space, political, economic, social, legal, and emotional, from which local Amazonian communities can be supported, granting them space in urban areas to engage in political processes, share their stories, assert their rights, and market their products through fair value chains. The lagoon is a hyperspace where processes of education, communication, and dissemination emerge and converge. It's where local and international funding is channeled to implement restoration projects and other initiatives that regenerate and cool the planet, transforming people's lives with local participation, in harmony with the rhythms of nature. This is not a utopia: in a community within Napo Runa territory, we investigated how community visions and practices were combined with state funds and European-based technoscience to diversify livelihoods. Community ecotourism, sustainable forest management, promotion of the Amazonian chakra, value addition to timber and non-timber products, a community carpentry workshop, a forest nursery, handmade soap production, essences, medicinal plants, and the revaluation of ancestral knowledge in conjunction with modern knowledge are all taking place there (Ariza-Montobbio & Cuvi 2020). The lagoon is a community empowerment hub where words like bioeconomy, strong sustainability, and biocultural diversity are freely used to forge new societies.

Transitions to strong sustainability – a demand of the articles in this book – require thinking outside the box. This is happening in more spaces, as in a recently published book of ucronias or counterfactual histories (Yánez 2023). In it, colleagues associated with universities wonder how the Ecuadorian Amazon and Ecuador would be if oil had not been exploited since the 1970s. Just a dream? Not at all. On August 20, 2023, a few days before sending this article for publication, a referendum was held in Ecuador. The question was: Do you agree that the Ecuadorian government should keep the oil in the ITT, known as Block 43, indefinitely in the ground? Sixty percent of the population voted in favor of permanently halting oil operations in a sector of Yasuní National Park. A Minotaur was defeated but quickly reemerged as a Lernaean Hydra with two new heads: legal and political maneuvers to disregard the outcome.

Transitions to strong sustainability require the transformation of materiality, defeating the mythical and contemporary beasts that continue to devour people, fertility, water, biomass, animal blood, plant sap, to feed the concrete jungles, near or far, to sustain unsustainable lifestyles. It is a challenging task, especially when considering the willingness to eliminate resistance without respect for life, as is the case with the increasing murders of environmental leaders in Latin America, especially in Brazil, which ranked third in the world in the number of environmentalists and land defenders murdered in 2019, with the state of Pará being the most dangerous for these individuals (Santos 2019). Extractivism goes to such extremes, or deceives us by doing Penelope's work: it pretends to support change but secretly undoes everything. The hegemonic, highly entropic culture engulfs, co-opts, and distorts meanings. This is what happened with the word sustainability, which was so contested that it became necessary to refer to "weak sustainability," "strong sustainability," and, more recently, "hyper or super-strong sustainability." Environmental ethics cannot be naive: many people want – or claim to want – to be environmentally correct but are obscenely hypocritical or ecologically naïve[2]. Even fewer are those who understand the necessary transformations and are willing to redefine narratives.

In the mythical stories I presented at the beginning of this text, Ariadne, the Bororo grandmother, and the mother jaguar are women. The colonial history has been patriarchal, and a peaceful transition cannot occur in this way, whether men or women govern. I also like to think that the solutions in these myths are carried out by human beings, confronting and transforming the apparent destiny with their Knowledge.

Will we flee or will we resist? Will we find saving affections, will we find the cunning to defeat the Minotaurs-Hydras-Jaguars, to escape the worst omens? It will depend on what we make visible or invisible, and whether we accept embracing incommensurability, which requires more than just including diversity. I began by explaining that the word Amazon has meant, for five centuries, a space associated with conflicts. Today, it brings together fractal lives and intentions that emerge and converge in one place. It is perceived in many ways, with various myths, stories, metaphors, and places: home to millions of people, the Earth's lungs, a water reservoir, a climate regulator, a carbon sink, a green hell, a merciless jungle, a source of wealth, a lost paradise, a green paradise... When I asked myself, following Jung, what myth or story I construct and live in relation to this biome, I visualized the Amazon as the forest that holds and sustains the world, a kind of contemporary Atlas.

2. People who are easily persuaded by any distorted information or who manipulate socio-environmental evidence to fit their way of life. They claim to care about nature and appear to care about nature, but they refuse to scrutinize their ideas and practices in detail to avoid challenging them. They are deeply naive and lack malice, unlike deniers, but they are equally dangerous to socio-environmental culture (Cuvi 2022).

The narrative of economic growth as the only path has been responsible for exacerbated impacts before and during the Great Acceleration of the Anthropocene. It seems that it can only be countered by its alter ego, a Great Deceleration, which involves the agroecological revolution and the restoration of nature as starting points for new social, economic, and political systems at all scales. The Amazon has the environmental conditions for this, as well as a population and Knowledge. We need to work on these and other meanings to free it from its worst atavisms and tragic omen.

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