WORLD BANK GROUP

DIGITAL DEVELOPMENT PARTNERSHIP

# Advancing Amazon Conservation Through Digital Technologies

# Table of Contents

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## Abbreviations

**ACA:** Amazon Conservation Association

**ACI:** Indigenous Climate Alert *(Alerta Clima Indígena)*, Brazil

**ACTO:** Amazon Cooperation Treaty Organization

**ADCP**: Acoustic Doppler Current Profiler

**AI:** Artificial Intelligence

**ANA:** National Water and Basic Sanitation Agency *(Agencia Nacional de Aguas e Saneamento Básico)*, Brazil

**ASL:** Amazon Sustainable Landscapes Programme

**ARO:** Amazon Regional Observatory

**AWS:** Automatic Weather Stations

**BNDES:** National Bank for Economic and Social Development *(Banco Nacional de Desenvolvimento Econômico e Social)*, Brazil

**CARE:** Collective Benefit, Authority to Control, Responsibility, Ethics

**CLUA:** Climate and Land Use Alliance

**COIAB:** Coordination of the Indigenous Organizations of the Brazilian Amazon

**COICA:** Coordinator of Indigenous Organizations of the Amazon River Basin

**COP:** Conference Of the Parties

**CPI-Acre:** Pro-Indigenous Commission of Acre *(Comissão Pró-Indígenas do Acre)*, Brazil

**CPTEC:** Center for Weather Forecasting and Climate Studies *(Centro de Previsão de Tempo e Estudos Climáticos)*, Brazil

**CSOs:** Civil Society Organizations

**DETER:** Real-time deforestation detection system

**DHIME:** Information System for Hydrology and Meteorology Data Management *(Información para la Gestión de Datos de Hidrología y Meteorología)*, Colombia

**eDNA:** Environmental DNA

**ENSO:** El Niño Southern Oscillation

**EWS:** Early Warning Systems

**FAIR:** Findable, Accessible, Interoperable, Reusable

**FAO:** Food and Agriculture Organization of the United Nations

**FONAM:** National Environmental Fund *(Fondo Nacional Ambiental)*, Colombia

**FPIC:** Free Prior Informed Consent

**FUNAI:** National Indigenous People Foundation *(Fundação Nacional dos Povos Indígenas)*, Brazil

**FVB:** Life and Biodiversity Fund *(Fondo para la Vida y la Biodiversidad)*, Colombia

**GBON:** Global Basic Observing Network

**GEE:** Google Earth Engine

**GEF:** Global Environment Facility

**GHG:** Greenhouse Gas

**GIS:** Geographic Information System

**GNSS:** Global Navigation Satellite System

**GSMA:** Global System for Mobile Communications Association

**IADB:** Inter-American Development Bank

**IBAMA:** Brazilian Institute of Environment and Renewable Natural Resources *(Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis)*

**IDEAM:** Institute of Hydrology, Meteorology and Environmental Studies *(Instituto de Hidrología, Meteorología y Estudios Ambientales)*, Colombia

**IDS:** Indigenous Data Sovereignty

**IGP:** Geophysical Institute of Peru *(Instituto Geofísico del Perú)*

**INDECI:** National Institute of Civil Defense *(Instituto Nacional de Defensa)*, Peru

**INMET:** National Institute of Meteorology *(Instituto Nacional de Meteorologia)*, Brazil

**INPE:** The National Institute for Space Research *(Instituto Nacional de Pesquisas Espaciais)*, Brazil

**IoT:** Internet of Things

**IPCC:** Intergovernmental Panel on Climate Change

**IPR:** Intellectual Property Rights

**ISP:** Internet Service Provider

**IP:** Indigenous Peoples

**IT:** Indigenous Territories

**KFW:** Credit Institute for Reconstruction *(Kreditanstalt für Wiederaufbau)*, Germany

**LAC:** Latin America and the Caribbean

**LC:** Local Communities

**LiDAR:** Light Detection and Ranging

**LPWAN:** Low-Power Wide-Area Network

**MAAP:** Monitoring of the Andes Amazon Project

**MADS:** Ministry of Environment and Sustainable Development *(Ministerio de Ambiente y Desarrollo Sostenible)*, Colombia

**MINAM:** Ministry of Environment, Peru *(Ministerio del Ambiente)*, Peru

**MONAN:** Model for Ocean-Land-Atmosphere Prediction

**ML:** Machine Learning

**MSA:** Mean Species Abundance

**MDBs:** Multilateral Development Banks

**NABIT:** Nucleic Acid Barcode Identification Tool

**NB-IoT:** Narrowband Internet of Things

**NDC:** Nationally Determined Contributions

**NDVI:** Normalized Difference Vegetation Index

**NGO:** Non-Governmental Organization

**NOAA:** National Oceanic and Atmoshperic Administration

**NORAD:** Norwegian Agency for Development Cooperation

**PA:** Protected Areas

**PAIS:** Sustainable Integrated Amazon Program *(Programa Amazônia Integrada e Sustentável)*, Brazil

**PPCDAm:** Action Plan for the Prevention and Control of Deforestation in the Legal Amazon

**PPP:** Public-Private Partnership

**RAISG:** Amazon Network of Georeferenced Socio-Environmental Information

**RBON:** Regional Basic Observing Network

**RedCIA:** Network of Research Centers in the Amazon

**SAR:** Synthetic Aperture Radar

**SENAMHI:** National Meteorological and Hydrological Service of Peru *(Servicio Nacional de Meteorología e Hidrología del Perú)*

**SENAMHI:** National Meteorological and Hydrological Service of Bolivia *(Servicio Nacional de Meteorología e Hidrología de Bolivia)*

**SMART:** Spatial Monitoring and Reporting Tool

**SMDK:** Kanindé Environmental Monitoring System

**SOMAI:** System for Observation and Monitoring of the Amazon *(Sistema de Observação e Monitoramento da Amazônia Indígena)*, Brazil

**SPA:** Science Panel for the Amazon

**STAR:** Species Threat Abatement and Recovery

**UAS:** Unmanned Aerial Systems

**UNGRD:** National Unit for Disaster Risk Management *(Unidad Nacional para la Gestión del Riesgo de Desastres)*, Colombia

**WBG:** World Bank Group

**WMO:** World Meteorological Organization

**WWF:** World Wildlife Fund

# Introduction

Environmental change in the Amazon is driven by the complex interplay between human activity and climate dynamics. This relationship not only intensifies climate-related processes—such as erratic rainfall patterns and heightened wildfire risks from prolonged droughts—but also directly impacts the livelihoods of Amazonian communities. The resulting threats to the Amazon biome are profound and demand an urgent, coordinated response. Digital technologies have been, and continue to be, critical tools for understanding, predicting, and mitigating these threats. However, realizing their full value requires the presence of critical enabling factors and institutional support. Reliable access to electricity, digital, and data infrastructure is fundamental— enabling the transmission and storage of data captured by devices, its analysis through software, and its delivery in a secure, accessible, and user-friendly format. Additionally, appropriately governing the collection or generation, processing and use of climate-related data is critical to ensuring data can be used to their full potential in furtherance of adaptation and mitigation goals. This requires putting in place the norms, rules, standards and institutions to support better access to quality data from different sources and ensuring they are used and shared in a trustworthy and rights-respecting manner. Governing data responsibly may also require regulating how technologies and applications are deployed, especially when they collect or generate sensitive data, for example through remote-monitoring tools.

The purpose of this report is to both explore how digital technologies can play a transformative role in monitoring climate change and examine what is required to ensure these solutions are sustainable over time. The report identifies three essential building blocks to unlock the full value of digital innovation solutions for climate monitoring: digital technologies for conservation and sustainable development, infrastructure and connectivity, and data governance. Given the unique enabling environments that need to be considered, these building blocks are not introduced in a specific sequence to follow as their ability to successfully support conservation efforts relies on their interdependency.

This document will not set out to detail the impacts of climate change on the Amazon, nor does it attempt to describe the large array of conservation approaches currently being undertaken at a regional and at local levels, as that is more than adequately considered in other works by variety of stakeholders, some of whom are referenced in this report. Instead, it is solely focused on how to ensure utilization of digital monitoring technologies can be accessed and used sustainably to ensure that they are used effectively for Amazon conservation and sustainable development in a rapidly changing world.

This report aims to guide policymakers, donors, civil society, and private sector actors in strengthening monitoring efforts across the Amazon biome through the adoption and effective use, of digital technologies for conservation.

This document is informed by a combination of desk research and extensive stakeholders' engagement with 40 different actors (see Appendix A). As well, this report integrated insights from subject-matter experts in biodiversity, data governance, and representatives of Indigenous Communities..

**Box 1: Navigating key terms:
Amazon, Amazon Biome, and Amazon Basin**

Different terms are often used interchangeably to describe the Amazon region, though they refer to distinct, but overlapping, geographic and ecological areas.

Note: Light green marks the Amazon Biome borders. Dark green marks Amazon Basin borders. Source: Data Basin, RAISG 2024

**Amazon:** A broad term that may refer to the overall region encompassing the Amazon River, its forests, and surrounding human and ecological systems. It is often used in a general sense to describe the cultural, environmental, and economic landscape associated with the world's largest tropical rainforest.

**Amazon Biome:** Refers to the ecological area characterized by tropical rainforest vegetation, biodiversity, and climatic conditions typical of the Amazon. The biome includes areas that share similar ecosystems but are not necessarily part of the hydrological basin.

**Amazon Basin:** Refers specifically to the hydrological basin drained by the Amazon River and its tributaries—the largest river system in the world by discharge and drainage area. It includes both rainforest and non-rainforest ecosystems such as savannas and wetlands.

In this report, unless otherwise specified, "Amazon" is used as an umbrella term encompassing both the Amazon biome and the Amazon basin, recognizing their ecological and socio-economic interconnectedness.

## Climate Change Impacts on the Amazon

The Amazon region hosts the world's largest remaining tropical rainforest and supports at least 10% of global biodiversity, including numerous endemic and endangered plant and animal species.[1] It is home to more than 50 million people, including from more than 420 Indigenous groups.[2] According to its biogeographical criterion, this area spans approximately 6.8 million square kilometres across eight countries and one territory: Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, Suriname, and French Guiana.[3] Characterised predominantly by dense, moist tropical forests, the biome also includes smaller areas of diverse vegetation, such as savannas, floodplain forests, grasslands, swamps, bamboo, and palm forests. Its watersheds extend beyond the biome, occasionally encompassing adjacent regions like the Cerrado.[4] The vast Amazon's terrestrial and freshwater ecosystems provide essential services, including carbon storage, hydrological regulation, and biodiversity support, across global, regional, and local scales. As a major carbon sink, the region absorbs and stores significant amounts of atmospheric carbon dioxide, playing a critical role in global climate change mitigation efforts.[5] Additionally, the Amazon is a major global source of freshwater, playing a crucial role in the hydrological cycle by maintaining and replenishing water supplies on a global scale.[6]

The Amazon's forests and freshwater ecosystems, along with the critical ecosystem services they provide at global, regional, and local levels, face significant threats from climate change, deforestation, degradation, habitat fragmentation, over-exploitation, pollution, and loss of sociological and biological diversity.[7] For the past half-century, legal and illegal human activities have driven the intensive exploitation of both renewable and nonrenewable natural resources. According to the Science Panel for the Amazon (SPA), approximately 17% of the Amazon biome has been deforested and converted to other land uses, with an additional 17% degraded. Human activities are the primary drivers of deforestation, including expanding pastures and croplands, constructing new roads, hydroelectric dam projects, exploiting minerals, oil, and natural gas, criminal forest fires, illegal selective logging, mining, and hunting.

Rural development in the region has led to extensive land-cover changes with unsustainable agricultural practices contributing to long-term environmental degradation.[8] For example, between 2001 and 2018, the agricultural frontier expanded by 220 percent in Protected Areas (PA) and 160 percent in Indigenous Territories (IT), primarily replacing forest areas. The cattle industry is the main driver of deforestation in the Amazon, contributing nearly 2 percent of global annual $CO_2$ emissions.[9]

Deforestation affects climatological patterns by disrupting humidity and rainfall, worsening droughts, and intensifying climate change.[10] These changes further contribute to deforestation and ecological risk. For example, the increasing frequency and intensity of droughts are making the Amazon more vulnerable to wildfires. In 2024, over 17 million hectares of forested land in the State of Amazonas, Brazil burned.[11] Continued biodiversity loss and persistent deforestation pose significant risks, potentially triggering irreversible changes to the region's tropical forests. This dynamic poses a risk not only to the ecological integrity of the Amazon but also to its capacity to provide critical ecosystem services essential for regional and global climate stability.[12]

IT and PA form a network of over 6,000 sites, collectively covering approximately 50 percent of the Amazon basin. These areas are foundational to conservation efforts and the

**2%**
of global annual $CO_2$ emissions are caused by the deforestation from the cattle industry

**420**
Number of indigenous groups living in the Amazon

**50 million**
Number of people who call the Amazon region home

**10%**
Percentage of global biodiversity is hosted by the Amazon region

**17 million hectares**
Amount of forested land in the state of the Amazonas, Brazil that burned in 2024

1 WWF, n.d.
2 United Nations ECLAC, 2024
3 Following administrative political criteria, the Amazon region's area reaches 7.4 million sq km (OTCA, 2018).
4 Flores, et al., 2010
5 Albert, et al., 2023; Araujo & Mourão, 2023; Artaxo, 2023; Science Panel for the Amazon, 2021
6 Papa, et al., 2013; Araujo & Mourão, 2023
7 Araujo & Mourão, 2023
8 Nobre, et al., 2016
9 Amazon Watch, 2022
10 Science Panel for the Amazon, 2021
11 Mapbioma Fogo, 2025
12 Science Panel for the Amazon , 2021

self-determination and land rights of Indigenous Peoples and Local Communities. They consistently exhibit lower rates of deforestation and forest degradation compared to unprotected forests. According to the Science Panel for the Amazon (2021), between 2000 and 2018, only 13 percent of the total deforested area in the Amazon basin was located inside IT and PA, even though they collectively cover more than half of the region's forests. Effectively managing and protecting these areas and strengthening territorial rights is critical for conserving the Amazon biome and for effective climate change mitigation. Moreover, IT help inhibit deforestation and the spread of associated fires within a 10-kilometre buffer zone surrounding their borders. This effectively reduces forest loss and degradation on a broader landscape scale.[13] Finally, establishing PA has also a positive effect on poverty reduction and other economic indicators. This is mainly due to the creation of jobs in PA management, ecotourism, and restoration among others.[14]

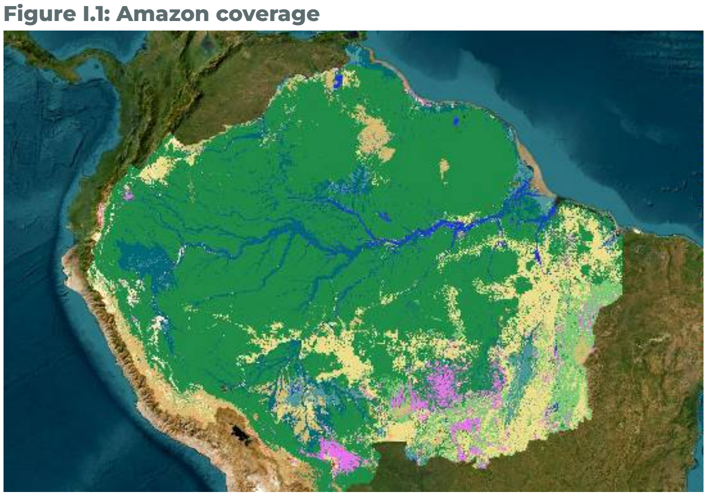
**Indigenous Territories** are geographic areas deeply connected to Indigenous Peoples' ancestral lands. Definition varies by country.

**Protected Areas** are designated geographical spaces managed to conserve nature, biodiversity, ecosystem services, and cultural values long-term, limiting resource exploitation and human presence. Their exact definition varies by country.

## Climate Change Impacts on the People of the Amazon

Despite protection of Indigenous lands resulting in less deforestation, threats to Indigenous Peoples and Local Communities are still higher because their dwellings and livelihoods are interconnected with these lands. Pressures such as agricultural expansion, gold mining, illegal logging, and crop cultivation linked to drug trafficking have intensified the challenges they face. This situation endangers not only the safety of local communities and environmental leaders but also the cultural diversity of affected groups. The growing frequency and duration of droughts have further exacerbated these challenges by lowering inland water levels, increasing air temperatures, and causing widespread fish kills. These prolonged dry periods are also disrupting how remote communities use inland waterways to access goods and services, connect with urban centers, and sustain their livelihoods.[15] The resultant effects have significantly decreased livelihood productivity. According to one study, "From 2006 to 2010, an annual average of 540,000 people was affected by climate disasters in the Brazilian Amazon; by 2018–2022, this number surged to 1.78 million annually, a 229% increase. Financial losses rose 377%, from $132.8 million per year (2006–2010) to $634.2 million per year (2018–2022)."[16]

**Figure I.1: Amazon coverage**



Source: MapBiomas (2023)
Note: In purple areas with no vegetation, in yellow areas for agriculture, livestock, and forestry, in dark yellow natural non-forest formation, and in green forest.

In addition to harming those living in rural areas, threats to the Amazon extend to those who have migrated to and are settled in urban areas. More than 70 percent of the Amazon's 50 million people live in cities, where they also suffer from rapidly escalating climate risks.[17] For example, from 2006 to 2022, nearly 2,000 climate-related disasters were officially recorded across the Brazilian Amazon, affecting over 10 million people, primarily through floods, droughts, fires, heatwaves, and landslide.[18]

Environmental threats in the Amazon also have global implications.[19] The consequences of land-use changes exacerbate local, regional, and global climate change through feedback mechanisms that diminish forest resilience. Ecosystem destruction and the deadly feedback loops are rapidly pushing the rainforest to a "tipping point" in which trees would be replaced by degraded grassland (ecological tipping point) and rainfall patterns would be disrupted (climate tipping point). This would lead to irreversible ecological changes.[20] A drier and warmer Amazon would release billions of tons of carbon dioxide equivalents into the atmosphere, worsening global warming and disrupting weather patterns across

13 Baragwanath & Bayi , 2020
14 Ma, et al., 2020
15 Lima, et al., 2024
16 Pinho, et al., 2025
17 United Nations ECLAC, 2024
18 Pinho, P.F., Silvestrini, R., Fellows, M. et al. "Vulnerabilities and compound risks of escalating climate disasters in the Brazilian Amazon". Nat Commun 16, 11579 (2025). https://doi.org/10.1038/s41467-025-66603-0
19 Science Panel for the Amazon, 2021
20 Shirai, et al., 2024

South America. Additional consequences would include loss of biodiversity, diminished carbon storage capacity, reduced nutrient and soil retention, and ongoing declines in natural capital, ecosystem services, and human well-being.[21]

**0.54 million** 2006 to 2010 | **1.78 million** 2018 to 2022

Annual average number of people affected by climate disasters in the Brazilian Amazon.

## How Can Digital Technologies Support and Even Accelerate Conservation Efforts in the Amazon?

Digital solutions can support an accelerated and systematic response to the compounding climate risks threatening the Amazon (see Table 1.1). The role of digital tools to support climate monitoring and conservation in the Amazon is not new, with the use of satellite imagery to measure environmental changes dating back to the 1980s in Brazil.[22] The term "digital conservation" began appearing around 2011 and includes the interface of digital technology and nature conservation. The application of digital technology has gained prominence in nature conservation and spans a wide range of areas including novel monitoring tools, digital public engagement, citizen science, crowd sourcing, e-learning, data connectivity, and decision making.[23] For instance, after peaking in 2004, deforestation in Brazil has been dramatically reduced, due in large part to monitoring using remote-sensing satellites.[24]

To ensure sustainability and scalability, digital solutions must draw on the knowledge of Indigenous Peoples and Local Communities and align with community-led approaches. Doing so will also enhance and accelerate benefits from both short- and long-term interventions. Indigenous Peoples and Local Communities, in partnership with Civil Society Organizations (CSOs), are progressively employing digital information and communication technologies to facilitate territorial monitoring and surveillance in response to pressures, impacts, and threats to their well-being and the conservation of local socio biodiversity.[25] These efforts build upon existing measures to support participatory mapping initiatives, critical in demarcating Indigenous Territories.

Digital technologies can play a critical role in supporting the Amazon's conservation and management. To ensure that, it is important to recognize the fundamental and foundational elements that need to be in place to support sustainable and scalable solutions.

**2,000**

Number of climate-related disasters, officially recorded from 2006 to 2022, across the Brazilian Amazon, affecting over

**10 million people**

For this report, we consider digital technologies for conservation and sustainable development, referring here to tools and applications that require, or can benefit from, internet connectivity for their full application. These represent a set of valuable tools that can be harnessed to bolster on-the-ground conservation efforts, offering crucial support in the face of these challenges.

**Table I.1: Examples of digital monitoring tools and technologies**

| Camera traps | Satellites | Spatial data analysis/ modeling software | Unmanned aerial systems (UAS) | Bioacoustics | Mobile applications and digital platforms | Artificial Intelligence (AI) and Machine Learning (ML) | Networked sensors/ Internet of Things (IoT) | Environmental-DNA (eDNA) |
|---|---|---|---|---|---|---|---|---|
| Cameras placed in areas with wildlife and other biodiversity that aid in remote data collection. | Used to generate images and data at a macro level for monitoring large areas. | Geographic Information System (GIS) is software that includes data visualization and analysis. | Hardware devices that can fly over areas of land and are controlled remotely. | Sensors placed in the field that capture and store acoustic data, which can be used for identifying species and patterns in diverse locations. | Applications and platforms that enable users to access information or tools to empower them to engage in conservation and restoration. | AI is the ability of a machine or computer to emulate human tasks through learning and automation. Machine learning uses computer-based algorithms to find patterns across data sets. | Underpins the connection of digital ecosystems. IoT is a network of sensors and device that are connected to the internet and are wi-fi enabled. | Used to collect a variety of biodiversity data usually by isolating and sequencing DNA samples from water or soil. |

Source: Morrell, et al., 2024

21 Science Panel for the Amazon, 2021
22 Faleiros, 2011
23 Arts, et al., 2015
24 Assunção, et al., 2013
25 Soares & Donario de Azevedo, 2023

This report does not just focus on technologies as standalone solutions. To illustrate this more clearly it is organized around the three building blocks. We use this framing to emphasize that digital technologies in and of themselves are not sufficient unless accompanied by strong consideration of the requisite infrastructure and policies that will ensure the relevance and durability of these solutions. A brief description of each of these building blocks follows:

### Chapter 1, Building Block 1

**Technology and applications:** Digital technologies and applications that can enhance monitoring systems, inform investment decisions, and support long-term conservation objectives especially for Indigenous Peoples and Local Communities. Examples of these technologies are described in Chapter 1 and in the corresponding Case Studies.

### Chapter 2, Building Block 2

**Digital infrastructure:** Universal and reliable access to electricity and the internet is critical to ensure digital technologies move beyond pilots to scaling and operationalization over time. Chapter 2 describes new insights for current digital network reach along with gaps to be addressed.

### Chapter 3, Building Block 3

**Data governance:** Data outputs from digital technologies are essential for providing feedback on conservation efforts, yet data is vulnerable without appropriate data governance frameworks in place. This chapter explains why data governance frameworks should be developed as a part of a broader policy deployment to support digital conservation technologies locally and regionally.

Finally, the report also prioritizes the relationship between key stakeholders, enablers, and the building blocks. A critical ecosystem to support the sustainability and scalability of digital technologies for conservation.

**Box 2: Brazil turning page in 2004**

In 2004, following several years of particularly rapid deforestation, public pressure turned the tide. That was the year the Brazilian government adopted an aggressive policy called the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm). The government created a large network of national and state parks, established protected territories for Indigenous groups, strengthened environmental enforcement agencies, made it more difficult to export goods produced on illegally deforested land, and strengthened satellite monitoring systems.

Source: Volland, 2019

**Figure I.2: Building blocks to unlock and sustain digital technologies**

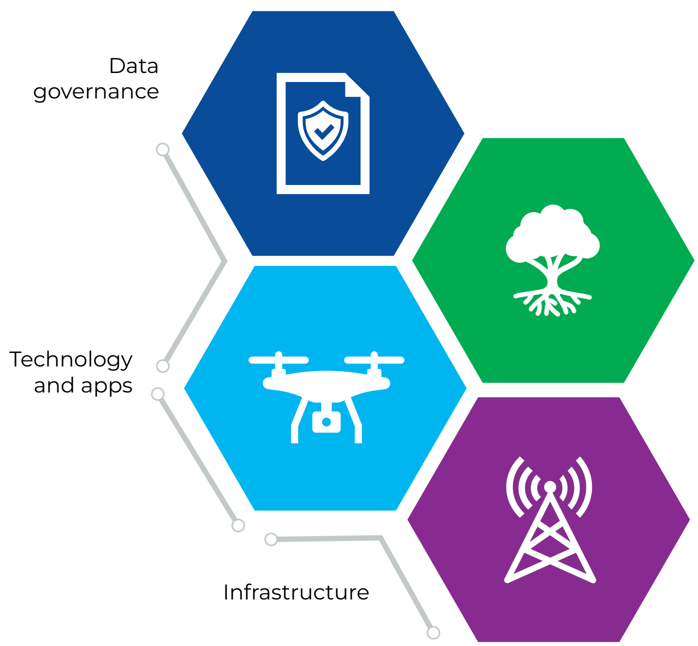
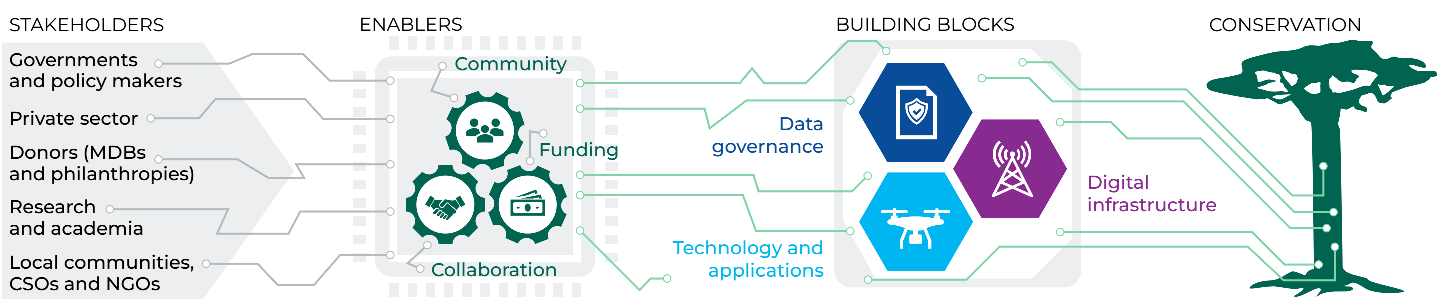



**Figure I.3: Supporting digital technology for conservation**



CHAPTER 1

# Digital Technologies for Monitoring the Environment in the Amazon

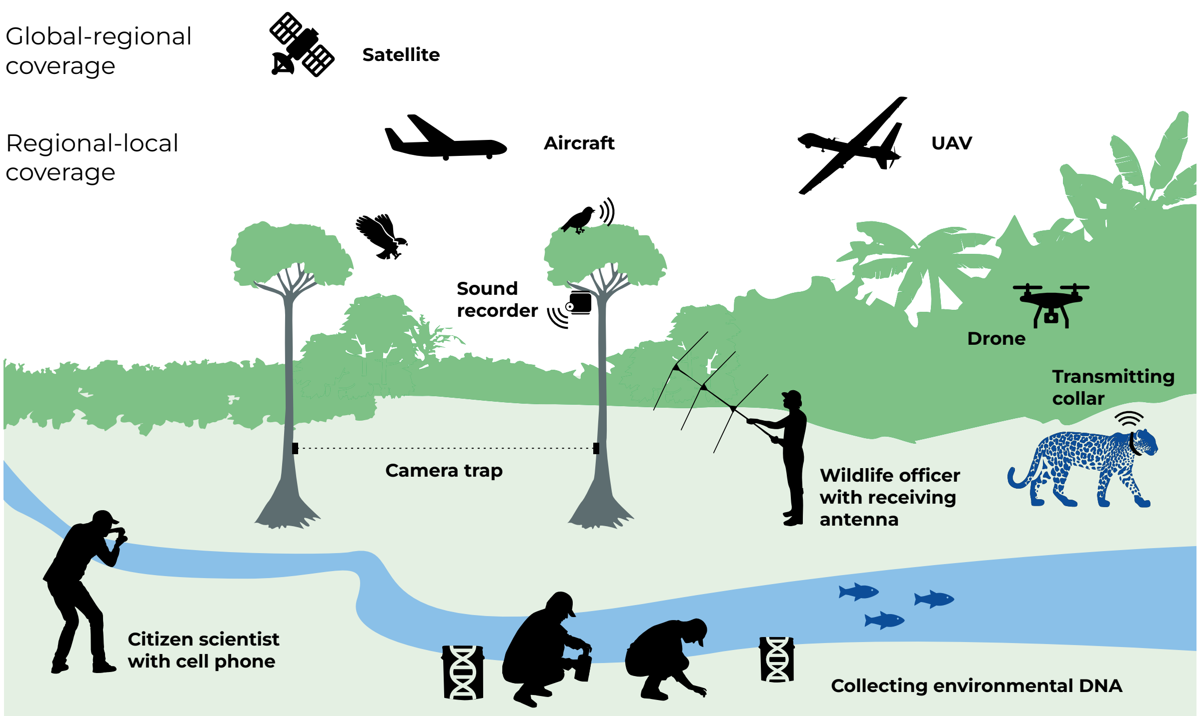
Main contributors: Niccolò Comini, Feipe Spina Avino

Digital technologies for monitoring conservation play a critical role in protecting and preserving the Amazon biome's natural resources by helping produce data to identify what needs to be protected and how. It is critical to understand the various types of technologies that can be leveraged, how they work, and ultimately how they support the needs of Local Communities. Understanding the latter also requires considering the role of the enabling environment within which digital technologies should operate, including how data collected or generated by these technologies should be governed so they can be used for conservation and other climate adaptation and mitigation efforts.

The increasing sophistication of digital conservation technologies allows for more frequent, large-scale, and high-resolution monitoring of the natural environment, including in remote or hazardous locations. They also enable analysis across multiple temporal scales—from near real-time observations to long-term environmental trends—and provide insights into ecosystems previously difficult to observe. When deployed inclusively, these tools can empower Indigenous Peoples and Local Communities by strengthening their role in conservation governance. Timely, accurate, and efficient monitoring is essential for assessing the effectiveness of forest conservation initiatives, emissions reduction policies, and for tracking progress toward international biodiversity commitments, including the Aichi Biodiversity Targets under the Convention on Biological Diversity.[26]

It is critical to distinguish between technologies that are designed to mitigate human behavior and illegal activity that further harms the Amazon biome directly from those technologies that assess the direct impact of climate change. In this section while we describe technologies that are designed to look at both activities, our emphasis, in line with the theme of this report, will be on those technologies that monitor climate change impacts. This chapter reviews existing digital technologies for both data collection and processing implemented in the Amazon. Our research approach reviewed the use of existing digital systems, tools, and devices through desk research and an extensive stakeholder engagement, including interviews conducted with 40 different actors and approximately 100 people across five Amazonian countries: Brazil, Bolivia, Colombia, Ecuador, and Peru, as well as with regional Amazonian stakeholders. Stakeholders included public institutions, non-governmental organizations (NGOs), Indigenous Peoples and Local Communities' organizations,

**Figure 1.1: Examples of digital technologies for conservation**




Source: Turner, 2014

26 Convention on Biological Diversity, 2020

as well as academic institutions, coalitions, and other entities (Appendix A provides the complete list of organizations interviewed). The consultations occurred between April 2024 and May 2025, both online and in person.

## What is Monitored?

Examples of what digital conservations technologies monitor include, but are not limited to:

**Forest Cover:** Deforestation remains one of the most significant threats to the Amazon biome, driven by illegal logging, agricultural expansion, and infrastructure development, contributing to climate change. Monitoring deforestation and forest degradation, restoring forests, and sustainably managing forest ecosystems are essential strategies not only to address climate change by preserving and enhancing carbon sinks but also to safeguard biodiversity, protect ecosystem services, and support the livelihoods of millions of people who depend on forests. There are key types of forest monitoring to consider:

- **Clear-cutting and selective logging:** refers to large-scale clear-cutting operations and more subtle selective logging activities.
- **Forest degradation and health:** refers to the deterioration of forest quality due to human activities including pollution and cutting, among other activities.
- **Secondary forest monitoring:** refers to the regeneration of secondary forests, which often occurs in areas previously cleared for agriculture or logging.

**Fires:** Fires in the Amazon are a growing threat and are almost entirely caused by human activities such as land clearing. Exacerbated by climate change-related extreme drought, they are becoming increasingly destructive and are now spreading quickly across large areas, including forests that have not been previously disturbed.[27] The repeated occurrence of such fires leads to permanent changes in the forest structure, turning once lush areas into degraded landscapes less capable of supporting biodiversity or absorbing carbon.[28] Because tropical forests are not fire-adapted, a single understory fire can kill a large proportion of trees and greatly increases the likelihood that the forest will burn again. Forests burned twice or more transition to a degraded grassland. Satellite data can play a role in helping to both anticipate and respond to these threats through technologies like the Normalized Difference Vegetation Index (NDVI), a remote sensing index that leverages satellite data to measure vegetation health to determine wildfire risk and ecosystem recovery after a wildfire.[29] These tools, together with AI-powered measures, such as FireSat, could enable more rapid responses to fire outbreaks, helping to minimise damage and prevent the loss of large forest areas. Post-fire monitoring and assessments include monitoring burn scars and soil erosion to evaluate wildfire damage to soil health and carbon storage. This data helps inform reforestation efforts and supports restoration of degraded lands.

**Carbon Stocks and Soil Monitoring:** Monitoring carbon stocks, particularly in areas affected by deforestation and fires, is essential for assessing the forest's contribution to global carbon cycling and its potential to mitigate climate change. Advanced tools—such as remote sensing, field methods, and modeling approaches—measure changes in carbon storage over time, and can inform strategies to protect and enhance this vital ecosystem service. Data collected by these tools are essential for informing carbon management strategies to help ensure the Amazon biome remains a significant carbon sink.

**Illegal deforestation in Indigenous Territory of Pirititi, in Roraima**

Photo: Felipe Werneck (IBAMA)

27 Goldman, et al., 2025; MacCarthy, et al., 2024
28 Science Panel for the Amazon, 2021
29 Rakholia, et al., 2021

**Biodiversity:** The loss of habitat and the resulting decline in species populations reduce the overall resilience of the Amazon's ecosystems. In addition, the loss of keystone species—those that play a critical role in maintaining the structure of an ecosystem—can lead to cascading effects that disrupt entire ecological communities. Quantifying biodiversity presents significant challenges due to its inherently complex and non-standardized nature. Unlike measurable units such as tons, degrees, or centimetres, biodiversity lacks a uniform metric. While species count or diversity can serve as proxies, the concept of "species" itself is not a consistent unit—each species exhibits unique sensitivities, rarity, range, and ecological connectivity. Efforts to establish standardised biodiversity metrics, such as Mean Species Abundance (MSA) and Species Threat Abatement and Recovery (STAR), offer promising tools for assessing biodiversity status and trends.[30]

**Climate, Air Quality, and Weather Monitoring:** Although limited, real-time air quality monitoring, including pollution levels, smoke from fires, and greenhouse gas concentrations, provides critical data for evaluating the health of the atmosphere over the Amazon and its ability to absorb carbon emissions. For example, in some locations air-quality sensors, like PurpleAir, help measure real-time airborne particulate matter concentrations. However, their application has been limited and, in some cases, discontinued.

**Water Quality and Hydrological Monitoring:** Effective monitoring of water quality and hydrological dynamics is essential for managing the vital ecological resources of the Amazon, predicting environmental changes, and mitigating climate change risks. Hydrological monitoring focuses on tracking changes in the Amazon's extensive network of rivers and waterways. Advanced technologies, such as satellite altimetry and Doppler systems,[31] measure water levels, flow rates, and variations in coverage during extreme weather events like floods and droughts. These tools provide critical data that aid in predicting hydrological events, managing water resources effectively, and understanding the broader implications of climate change on the region's water systems.

**Human Activity:** While this report mainly focuses on the use of digital technologies to monitor effects of climate change, it is important to note that similar technologies are also widely used to track other human-induced activities and environmental ramifications beyond the scope of this analysis.

- **Illegal activities, including mining, land grabbing, and illicit crop cultivation:** These activities present significant challenges to Amazon biome conservation, causing extensive environmental damage, including deforestation, water pollution, and displacement of Indigenous Communities. Comprehensive environmental monitoring is essential for enforcing environmental regulations and protecting the Amazon from illegal activities. Programs like Brazil's Federal Police MAIS Monitoring involve using high-resolution satellite imagery, AI and other technologies to monitor various environmental factors, including deforestation, illegal mining, land conversion for agriculture, clandestine airstrips, and illicit crop cultivation.[32] Another example is the Monitoring of the Andes Amazon Project (MAAP), developed by Amazon Conservation Association (ACA), which uses satellite-based technologies from multiple sources to deliver real-time actionable information on deforestation and fires across the entire Amazon Basin. Covering all the Amazon, MAAP enables rapid detection and response, supporting governments, local communities, and civil society. In addition to tracking urgent environmental threats, MAAP also produces strategic analyses on critical topics such as ecosystem tipping points, road expansion, carbon emissions, and climate impacts. Its accessible reports help

**Illegal logging operation in Piritití, Indigenous Territory, in Roraima Brazil**

Photo: Felipe Werneck (IBAMA)

30 Schipper, et al., 2019; Mair, et al., 2021
31 These systems utilize the Doppler effect to measure water flow velocity by transmitting sound waves and analyzing the frequency shifts of the reflected signals.
32 Policia Federal, 2024; Planet, 2022

inform decision makers, law enforcement, researchers, and the public, promoting evidence-based action to combat illegal deforestation. These programs generate alerts and reports that enable quick responses to environmental crimes and support enforcement of environmental laws across large areas of the Amazon.

- **Socio-Cultural and Community Resource Protection:** Monitoring community resources is essential for understanding and mitigating repercussions from environmental change on natural assets that sustain local livelihoods. This includes tracking the availability and quality of essential resources such as clean water, fertile agricultural lands, and forest products vital for food, medicine, and livelihoods. Biocultural Participatory Mapping,[33] for example, is a key approach to engage Indigenous Peoples and Local Communities in mapping culturally significant, agricultural, sacred, and other vital sites within their territories. This collaborative process documents the geographical and cultural dimensions of these areas and serves as a tool to protect them from external threats such as land grabbing, deforestation, infrastructure development, and resource extraction. By preserving traditional knowledge and practices, communities are empowered to assert greater control over their lands and resources, strengthening their capacity to manage and conserve their territories in alignment with their cultural values.

**Ilegal mining at Jamaxin National Park, a Protected Area in Brazil**

Photo: Felipe Werneck (IBAMA)

- **Infrastructural Expansion and Environmental Legislation Compliance:** Infrastructure development in the Amazon, such as the construction of roads, airstrips, dams, and ports, poses significant environmental and social challenges. Monitoring the environmental effects of these activities is crucial to mitigate adverse results, ensuring compliance with regulations, and safeguarding the region's ecological integrity. Tracking the expansion of infrastructure projects is particularly important in protected and ecologically sensitive areas, and this is traditionally done by combining satellite imagery with field surveys.

- **Supply Chain Traceability and Land Use and Tenure:** Effective monitoring of supply chain practices and land use is essential for reducing environmental effects, promoting sustainable development, and ensuring compliance with environmental regulations. Data generated through these monitoring systems supports informed decision making by companies and policymakers, enabling them to enforce environmental standards and advance sustainable sourcing practices. The Amazon is a critical region for global supply chains, particularly for commodities like soy and beef, which are major contributors to deforestation. Monitoring systems track land use changes linked to farm expansion to try to eliminate deforestation-related activities from these supply chains.

  Monitoring land tenure is crucial for combating deforestation, ecosystem degradation, and climate change, while also protecting Indigenous Peoples and Local Communities. Digital technologies such as satellite cadastral systems and blockchain-protected land registries can create an authoritative, up-to-date record of land use. When combined with real-time monitoring information, this can help identify illegal land occupation, land grabbing, and unauthorized deforestation. These tools improve transparency, support law enforcement, inform land use planning and conservation efforts, and enable communities to document their traditional territories, monitor environmental changes, and defend their land rights.

33 Cusens, J., Barraclough, A. M. D., & Måren, I. E. (2022). Participatory mapping reveals biocultural and nature values in the shared landscape of a Nordic UNESCO Biosphere Reserve. People and Nature, 4, 365–381. https://doi.org/10.1002/pan3.10287

## How it is Monitored? Evaluating Promising Digital Technologies

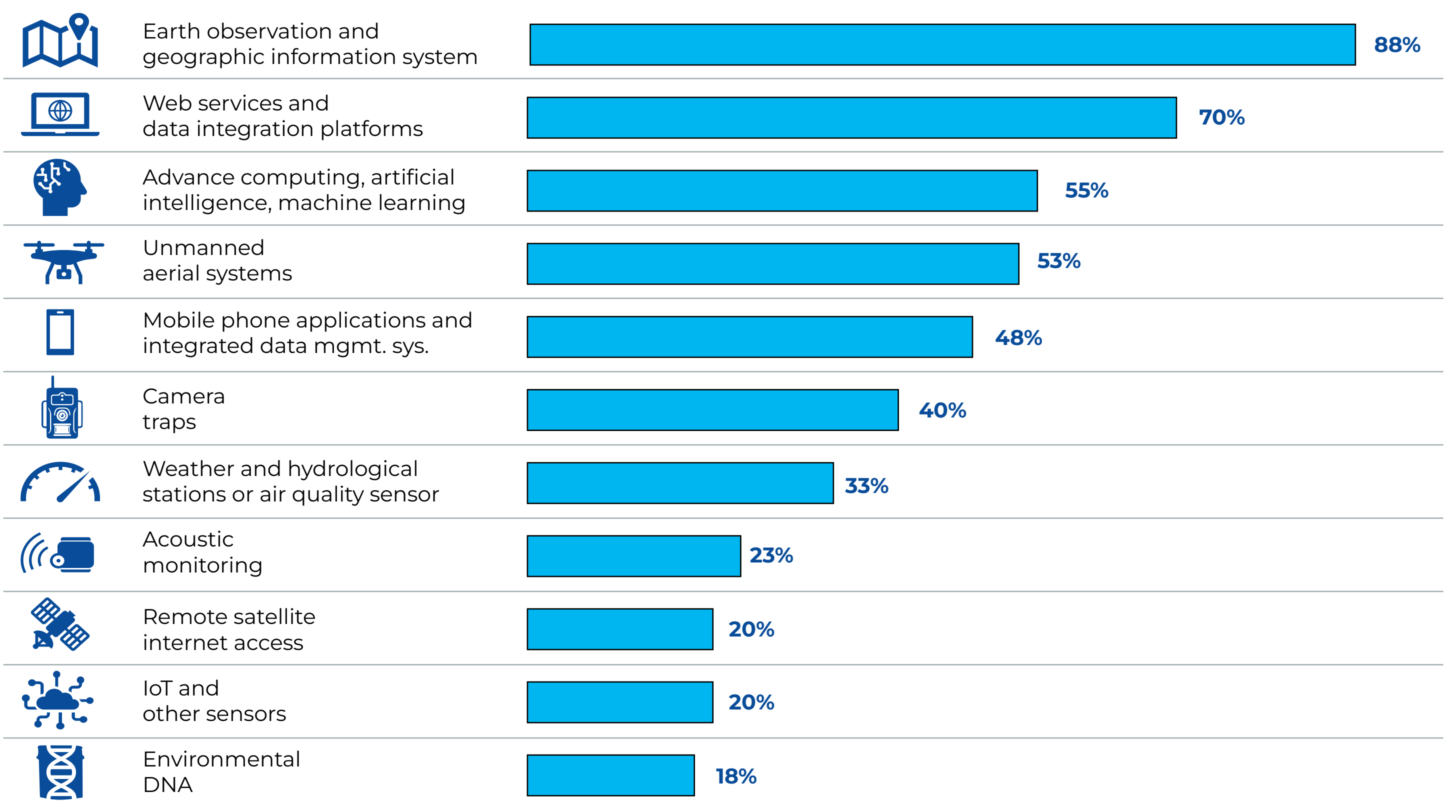
This section analyses some of the many promising digital conservation technologies currently used by the stakeholders in the Amazon biome as well as the efficacy of these technologies in supporting climate monitoring and adaptation. They span a continuum of spatial scales, from macro-scale solutions such as satellites to micro-scale sensing technologies, including acoustic sensors deployed in the field.

**Earth Observation and Geographic Information System:** The potential of GIS and satellite information in the Amazon biome monitoring is vast. Continuous advancements in satellite technology, including higher-resolution daily images, multispectral and thermal imaging, and radar imaging to overcome cloud cover issues—for instance, Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LiDAR)—significantly enhance the capability to monitor environmental changes at a landscape level. Satellite information, particularly from platforms such as Sentinel, Landsat, MODIS, and Planet, is a cornerstone of Amazon's biome monitoring efforts.

Different Earth observation portals are used extensively for mapping and analysing spatial data. These tools enable stakeholders to conduct comprehensive environmental assessments, monitor changes, plan conservation strategies, and respond to illegal activities in near real time. AI and cloud computing strengthens conservation efforts, making Amazon monitoring more accurate and proactive. Examples include INPE,[34] which manages key deforestation monitoring systems such as PRODES and the Real-Time Deforestation Detection System (DETER), which generate alerts for enforcement. Open-access portals such as TerraBrasilis, Global Forest Watch, and MapBiomas Alerta provide processed Earth observation data, increasing accessibility.

**Aerial Surveillance and UAS:** UAS, or drones, have become a powerful tool for environmental monitoring in the Amazon, providing high-resolution data to complement satellite imagery while enhancing the safety of frontline staff and Indigenous Peoples and Local Communities. Their ability to capture details down to 3-10 cm per pixel makes them invaluable for identifying critical climate risk features, such as flood zones, landslide-prone areas, and deforestation threats. Equipped with diverse sensors—including optical, multispectral, thermal, and LiDAR—drones support a range of applications, from tracking forest loss and assessing carbon stocks to surveying wildlife and mapping degraded areas. Their flexibility allows for effective monitoring of remote or inaccessible regions, with multirotor drones suited for smaller areas and rapid deployment, while fixed-wing models cover larger distances with extended flight times. Despite challenges such as regulatory restrictions, limited battery life, and the need for specialized data analysis tools like DroneDeploy and Pix4D, ongoing advances in AI, machine learning (ML), and real-time data processing continue to expand their role in conservation, environmental enforcement, and climate resilience efforts across the Amazon.

**Figure 1.2: Most used technologies for conservation in the Amazon**




Source: Authors' analysis

Note: Percentage of Stakeholders consulted using Digital Technology, N=40

34 Instituto Nacional de Pesquisas Espaciais - National Institute for Space Research (Brazil)

**Box 3: Drones to support the protection of Indigenous Territories in Brazil**

The World Wildlife Fund (WWF), for example, has provided drones to Indigenous communities such as the Kanindé Ethnoenvironmental Defense Association allowing them to monitor vast areas of their territories without exposing themselves to the dangers of direct confrontation with illegal loggers or land-grabbers. High-resolution images and GPS data collected by these drones are paired with remote sensing and field-gathered data and have been used as evidence in reporting illegal activities to authorities, leading to more effective enforcement actions. For more on this see *Case Study 1: Use of Technologies to Support Monitoring and Indigenous Territorial Protection in Rondônia, Brazil.*

Source: Kanindé, 2024; Brasil, 2024; Pfeifer, 2020

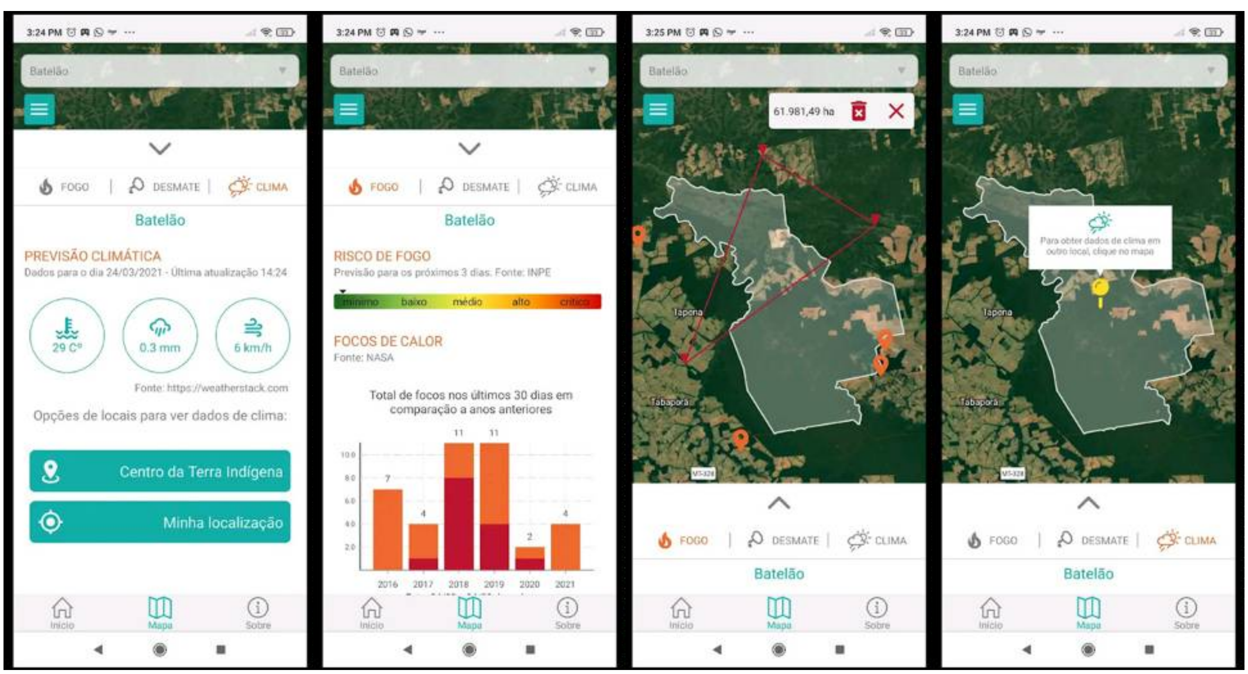
**Weather and Hydrological Stations:** Access to reliable climate and water data is essential for conservation and climate resilience efforts yet remains a challenge due to infrastructure gaps, high costs, and limited accessibility. International, national, and local monitoring networks play a critical role in tracking environmental changes, but many stakeholders still rely on manual data collection, delaying real-time responses. Expanding the deployment of Automatic Weather Stations (AWS) and air quality sensors—such as those used in initiatives like OASIS in Peru for drought monitoring and SONICS for flood tracking—can significantly improve forecasting accuracy and disaster preparedness. In Colombia and Peru, agencies like IDEAM[35] and SENAMHI,[36] respectively, operate extensive AWS networks, while innovative projects such as Bolivia's locally assembled "AJAYU" AWS use open-source technology to make monitoring more affordable and accessible.

**Mobile Phone Applications:** Mobile phone applications, or apps, have become essential tools for field data collection and environmental monitoring in the Amazon, often enhancing the accuracy, efficiency, and accessibility of data collection, particularly in remote areas. Mobile apps designed for citizen science have empowered non-experts to participate in data collection, enhancing the scope and scale of environmental monitoring efforts. The use of mobile technology in the Amazon region has also bolstered community-led conservation initiatives. Equipping Indigenous Communities with smartphones and specialized applications has enabled them to monitor and report illegal deforestation activities effectively. For instance, Alerta Clima Indígena (ACI) is an application developed by the IPAM[37] with the goal to expand the dissemination of information on fires, deforestation, rainfall, and temperature in the Indigenous Lands of the Brazilian Amazon. Another example is the Spatial Monitoring and Reporting Tool (SMART), a free and open-source software developed to enhance management and protection of PA and IT, used by rangers and Indigenous Peoples and Local Communities' monitors in countries such as Peru, Colombia, Brazil, and Ecuador.[38] This approach enhances the protection of vital ecosystems and fosters greater community engagement in conservation efforts improving PA management effectiveness.

**Mobile phone application example**

Alerta Clima Indígena, an application developed by the IPAM with the goal of expanding the dissemination of information on fires, deforestation, rainfall, and temperature in the Indigenous Lands of the Brazilian Amazon

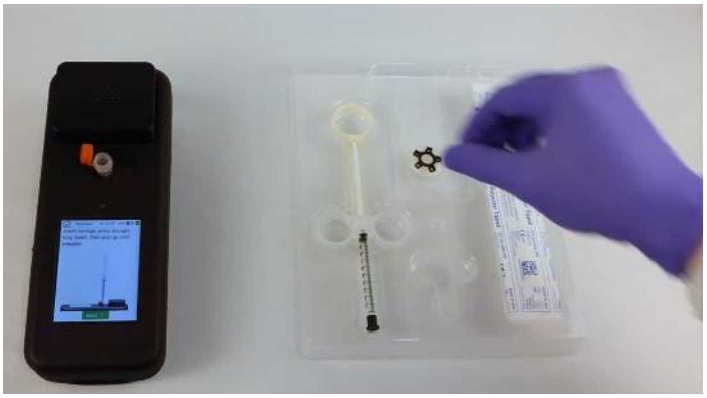
Image source: IPAM




35 Instituto de Hidrología, Meteorología y Estudios Ambientales - Institute of Hydrology, Meteorology and Environmental Studies (Colombia)
36 Servicio Nacional de Meteorología e Hidrología del Perú - National Meteorological and Hydrological Service of Peru
37 Instituto de Pesquisa Ambiental da Amazônia - Amazon Environmental Research Institute (Brazil)
38 WWF, n.d.; SERNANP, 2024; Kanindé, 2024; SEMA-AM, 2024; Brasil, 2024; SERNANP, 2016

**eDNA and DNA Barcoding:** eDNA and DNA barcoding is an emerging, non-invasive technology that allows researchers to detect species through DNA fragments found in soil, water, or air. This method enables biodiversity monitoring across vast regions like the Amazon, helping to identify species difficult to observe using traditional survey methods, such as nocturnal or cryptic animals. eDNA is particularly valuable for tracking rare, endangered, or invasive species, and assessing the health of ecosystems over time.

**Nabit, an eDNA device**



Source: Conservation X Labs

> eDNA is particularly valuable for tracking rare, endangered, or invasive species, and assessing the health of ecosystems over time

One of the key advantages of eDNA is its ability to monitor large areas with minimal infrastructure, making it ideal for remote regions. Several pilot projects in the Amazon have successfully used eDNA, sometimes in combination with other technologies like satellite imagery, camera traps, and acoustic monitoring, to provide a more comprehensive view of biodiversity.[39] However, challenges remain, including the need for specialized labs, extensive species databases, and addressing environmental factors that can affect DNA degradation. Initiatives like eBioAtlas are working to create open-access global repositories for eDNA data, helping to overcome these challenges. Another innovative example is the Nucleic Acid Barcode Identification Tool (NABIT), developed by Conservation X Labs, a low-cost, portable device that brings the genetics laboratory to the field. Designed for ease of use, NABIT allows users to verify the identity of wildlife or food products anywhere in the world without needing specialized training, laboratory equipment, reagents, or continuous power. Despite the high costs and technical complexities, eDNA and DNA barcoding holds significant potential to enhance conservation efforts by providing valuable insights into species distribution and ecosystem health.

**Camera Traps:** Camera traps have become a vital tool for wildlife monitoring, biodiversity assessments, and detecting illegal activities in the Amazon. These motion-activated devices provide a non-invasive way to document species, track population trends, and support conservation efforts. Particularly useful for studying elusive species like jaguars and giant armadillos, camera traps offer a solution for monitoring large, remote areas. They also engage local communities, raising environmental awareness and strengthening conservation management. While basic models store data on memory cards, advanced versions offer real-time image transmission, although network limitations in remote areas can hinder their use. Emerging solutions, such as LoRaWAN (see Box 7), are now being deployed to meet the need to transmit data over long distances with minimal power consumption. CXL's Sentinel overcomes some of these challenges by doing AI image analysis on the device itself, reducing the volume of data that must be transmitted by sending only the results of interest. Data collected by camera traps can be integrated with those captured by drones and acoustic sensors to further enhance biodiversity monitoring. Despite challenges like high data volumes, equipment failures, and logistical difficulties in harsh conditions, camera traps remain a cornerstone of long-term monitoring, with AI-powered tools like Wildlife Insights helping to automate data management and species identification, making conservation efforts more efficient.

**Box 4: The World Bank ASL Program**

When properly deployed, a single unit camera trap can generate thousands of images in weeks. However, much of this data remains underutilized due to challenges in organization, analysis, and access, especially for local communities and non-experts. To address challenges in processing camera trap data, the Amazon Sustainable Landscapes Program's (ASL) regional project recognized the need for a dedicated analytical tool and contributed to the development of Wildlife Insights, to support conservation decision-making.

> Funded by the GEF and led by the World Bank, the ASL promotes integrated landscape management and ecosystem conservation across priority areas in Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, and Suriname

**Acoustic Monitoring:** Acoustic monitoring is an emerging technology used to capture and analyze the sounds of the Amazon's ecosystems. By deploying devices like AudioMoth and Song Meter, researchers can track species such as birds, amphibians, insects, and mammals that are hard to observe visually. This non-invasive method helps assess biodiversity, monitor ecosystem health, and understand the effects of forest degradation. Acoustic sensors are particularly valuable for studying nocturnal or cryptic species, and can complement other monitoring tools such as camera traps and eDNA for a more comprehensive approach. These sensors can be used to

39 Dyson, et al., 2024

create long-term datasets that provide a continuous profile of animal activity, even detecting human disturbances like chainsaws or gunshots, which can, in turn, aid conservation efforts. Acoustic monitoring is also crucial for tracking species vulnerable to climate change and forest fires.

Though costs vary, with open-source models being more affordable, the challenges of remote deployment, data retrieval, and processing remain. AI-powered platforms, such as Arbimon, help automate species identification, but data complexity and background noise can complicate analysis. Finally, ensuring data security and addressing data protection and privacy concerns, particularly in Indigenous and Local Community territories, is crucial, as human voices may unintentionally be recorded without the appropriate legal basis (such as seeking prior consent). Despite these challenges, acoustic monitoring can be a powerful tool for biodiversity conservation, climate impact assessments, and detecting illegal activities and environmental threats.

## Support and Data Processing Tools

This section explores how cross-cutting support and data processing tools like web services, data platforms, AI, cloud computing, and IoT enhance digital technologies for climate change monitoring. However, it is important to stress that these systems alone do not deliver solutions: they generate and organize information but do not in themselves determine the legality or implications of the observed phenomena. Real progress depends on subsequent steps: rigorous review, interpretation, and, where relevant, the activation of legal, policy, or enforcement actions.

**Web Services and Data Integration Platforms**: These allow users to combine data from satellites, drones, and field sources to create a comprehensive environmental monitoring system for the Amazon. These platforms can provide near real-time data visualization, analysis, and alerts to inform actions tackling deforestation, illegal mining, and climate change. Tools like TerraBrasilis and Brazil Data Cube, and the ORA-ACTO GeoAmazon portal centralize processing of geospatial data, supporting decision making for conservationists, researchers, and local communities. Initiatives like Xingu+ Sirad X, using radar[40] imagery and Google Earth Engine, provide insights to detect deforestation, even under cloud cover. Meanwhile, MapBiomas Alerta consolidates alerts from various sources to track deforestation.

**Advanced Computing**: The potential of technologies like AI and cloud computing for environmental monitoring is immense, especially as these technologies evolve. For example, AI can help predict climate change effects on the Amazon, optimize conservation strategies, and improve detection of illegal activities such as logging and mining. AI-driven models can help forecast future climate scenarios and support decision making for better conservation outcomes.[41] However, they also raise concerns about data biases, transparency, energy costs, and the risk of over reliance on "black-box" predictions that may misguide conservation decisions.[42]

By combining various data sources, AI can identify patterns that may otherwise go unnoticed, enabling faster, more informed responses to environmental threats.[43] This is crucial in the Amazon, where timely intervention can prevent irreversible damage. AI, when integrated with satellite imagery, drones, and field sensors, can provide a more detailed and accurate picture of the Amazon's environmental conditions, enhancing satellite image analysis, species identification, and land-use change detection. For instance, AI is already improving species identification from camera trap images and acoustic recordings, like the Wildlife Insights platform, Colombian Project Guacamaya, powered by Microsoft AI for Good,[44] and Earth Ranger.[45] Cloud computing platforms like Google Earth Engine (GEE) enable large-scale data processing, while supercomputers (e.g., SENAMHI Peru's Nuna) support climate modelling. Quantum computing, though emerging, holds potential for faster, more precise climate simulations.[46]

SENAMHI: Data analysis for conservation

The Peruvian SENAMHI, within the Ministry of Environment (MINAM), can count on a high-performance computing center named NUNA. Launched in December 2023, NUNA informs decision making in climate-related risks and natural disasters. For more on this see Case Study 3.

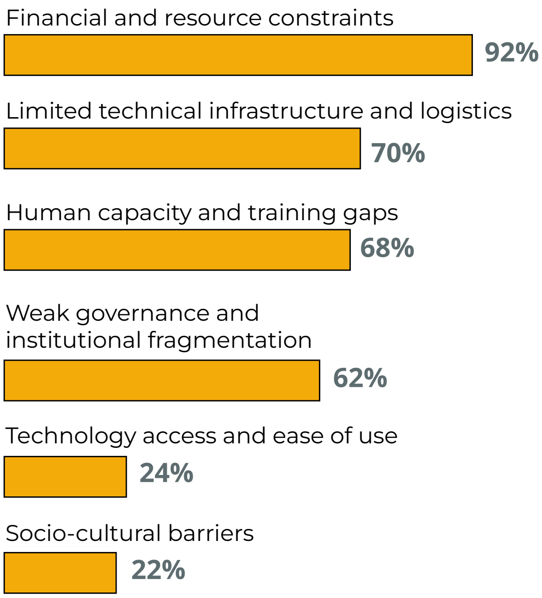
While there are challenges—such as the need for high-quality training datasets, limited digital infrastructure in remote areas, underutilization of data, and data integration difficulties—advances in AI and cloud computing can represent additional tools to improve conservation efforts.

40 Radar imagery is a powerful Earth-observation technique that creates images from reflected radio waves.
41 Ukoba, et al., 2025
42 McGovern, et al., 2022
43 INPE, 2024
44 Humbolt, 2024
45 EarthRanger, 2024; Gundi Partnership, 2025
46 Schwabe, et al., 2025

## Navigating Challenges: Barriers to the Implementation of Digital Technologies for Conservation in the Amazon

The full potential of digital technologies for monitoring climate change is jeopardized by critical barriers that may impede their abilities to support conservation, sustainability and wider adoption. These are presented in this section in order from most to least prominent, according to our stakeholder consultations.

**Figure 1.3: Percentage of the main barriers to using digital technology cited by consulted stakeholders**




Source: Authors' analysis — Note: N=40

**Financial and Resource Constraints**: The financial burden of acquiring, operating, and maintaining digital technologies is one of the most frequently mentioned challenges during our consultation. This aligns with findings from global surveys about conservation technology.[47] Many organizations and governments working in the Amazon region face strict budget limitations, restricting their ability to scale, sustain, and act upon digital monitoring efforts. These financial constraints make it challenging to keep pace with rapid technological advancements, monitor the region at scale, and integrate new tools into existing systems. Cost features include everything from developing the solutions to ongoing equipment maintenance. Even though some tools, such as open-source software, reduce initial costs, maintaining cloud services, data storage, and computational infrastructure remain expensive. Bureaucratic procurement processes delay equipment acquisition, slowing deployment of digital monitoring tools. Moreover, the import of technological devices is often subject to steep tariffs, making it harder for organizations to afford and sustain the technologies necessary for effective conservation efforts.

**Limited Technical Infrastructure and Logistics**: The Amazon's vast and remote areas make it difficult to ensure consistent and reliable internet connectivity. Additionally, the environmental characteristics of the region present challenges to reliably uptake and use various digital conservation technologies. For example, the region's extreme environmental conditions, including high humidity, heavy rainfall, and temperature fluctuations, reduce the durability and functionality of field digital monitoring equipment, leading to increased maintenance costs and the risk of equipment failure. The dense forest cover and vast river systems also make it difficult and costly to reach remote monitoring sites. Deploying and maintaining field equipment in these areas often requires significant financial and human resources, which are not always available. Limited digital infrastructure makes obtaining a comprehensive and consistent view of forest health, biodiversity, and conservation status challenging.[48] Infrastructural challenges, along with examples of solutions that are working to address these challenges, are discussed in Chapter 2.

**Human Capacity and Training Gaps**: Digital conservation technologies require adequate capacity to be effectively designed, implemented, and sustained over time. Many organizations and government agencies face a shortage of skilled personnel. For example, Brazil has one environmental agent for every thousand square kilometers of preserved areas, undermining monitoring and management efforts.[49] To provide a benchmark, the U.S. National Park Service has about twenty thousand employees[50] and about two hundred thousand agents; a ratio of about one person per ten square kilometers (assuming all employees qualify as environmental agents). Organizations responsible for managing and monitoring protected and Indigenous Areas need greater support to operate effectively. Additionally, attracting and retaining specialized human resources can be difficult due to budget and bureaucratic constraints (e.g., limited term contracts) and the region's remote nature. This leads to gaps in knowledge transfer and inconsistent data collection and analysis. This issue is particularly problematic in projects that require long-term commitment and sustained expertise, such as those involving complex technologies or large-scale data integration.

47 Speaker, et al., 2022
48 Nagano, et al., 2024
49 Altino, 2024
50 https://www.nps.gov/aboutus/faqs.htm

**Weak Governance and Institutional Fragmentation**: Lack of data sharing and interoperability frameworks, together with high fragmentation of initiatives led by multiple actors, limit the benefits of digital technologies for conservation. This is dealt with in greater detail in Chapter 3.

**Socio-Cultural Barriers**: Indigenous Communities in the Amazon face several socio-cultural barriers to adopting digital technologies. Language and literacy gaps, combined with limited availability of culturally relevant content, constrain meaningful use. Distrust stemming from historical exclusion and concerns over data ownership further limit engagement. Gender and generational divides often restrict equitable access within communities. In addition, communal norms of resource sharing challenge the individual-centric design of most digital tools. Limited legal recognition of community collected data and non-data-based knowledge, as well as a lack of support and incentives for conservation, undermine participatory monitoring efforts. Finally, the Amazon's linguistic and cultural diversity creates challenges for communication among and within countries.

**Box 5: Indigenous Peoples and Local Communities at the center of solutions**

Digital technologies for conservation will be successful if their deployment is planned in collaboration and consultation with Indigenous Peoples and Local Communities from the onset. Partnership in this way means building off community knowledge systems, co-designing complementary solutions, and promoting Indigenous Peoples and Local Communities' leadership and management. This includes, but is not limited to the following:

**Kayapo in Brazil**

Photo: Oliver Kornblihtt (Ministerio da Cultura, Flickr Creative Commons)

**Promote and support Indigenous leadership.** Strengthening the involvement of Indigenous organizations ensures that governance mechanisms are more inclusive and representative of the region's diversity. By integrating traditional knowledge with advanced monitoring systems, conservation initiatives can better address the challenges of climate change and human activities while empowering the communities most deeply connected to the Amazon. This can include supporting the work of organizations such as the regional COICA[1], and Indigenous country-level organizations, such as the COIAB[2] in Brazil to name a few.

**Strengthen participatory monitoring and community-led governance.** Participatory monitoring, where Local Communities are actively involved in data collection and analysis, improves the quality of the data collected and fosters a local sense of ownership and responsibility among Local Communities.

**Ensure local control and ownership of sensitive data.** Indigenous Peoples and Local Communities must retain ownership of collected data to better influence policy, promote community-led governance models and safeguard territorial rights. For instance, a dedicated data governance framework ensuring transparency, accountability, and local ownership is implemented by Kanindé in their Environmental Monitoring System (SMDK). The entire SMDK system is built using public-domain satellite data and open-source tools, avoiding licensing costs and ensuring broad accessibility. Automated reports compile information from multiple tools and are shared with Indigenous Leaders, who retain full control over access and data sharing, including with public authorities.

**Integration with traditional knowledge systems.** Integrating cutting-edge technologies with traditional knowledge systems is crucial for fostering a holistic approach to environmental conservation. This ensures that technological advancements complement, rather than replace, local expertise, strengthening both the accuracy and inclusivity of monitoring initiatives in the Amazon biome.

Note that this work recognizes the need to respect the existence and autonomy of non-contacted populations, and as such it is critical that digital conservation technologies are not implemented in such a way that would interfere with their desire to remain uncontacted.

1 Coordinadora de la Organizaciones Indígenas de la Cuenca Amazónica - Coordinator of Indigenous Organizations of the Amazon River Basin
2 Coordenação das Organizações Indígenas da Amazônia Brasileira - Coordination of the Indigenous Organizations of the Brazilian Amazon

## Key Recommendations for Enhancing Monitoring in the Amazon Biome through Digital Technologies

What actions can foster the growth and long-term sustainability of digital conservation technologies for monitoring climate change in the Amazon? Drawing on extensive consultations and research, this section presents recommendations to overcome barriers to adoption and enhance the effectiveness of these technologies.

IMPLEMENTATION TIME

Short term | Medium term | Long term

| RECOMMENDATIONS | DETAILS/BENEFITS/CAVEATS | STAKEHOLDERS |
|---|---|---|
| **Boost local manufacturing and maintenance capabilities.** Developing local maintenance capabilities and, when possible, manufacturing for digital infrastructure and specific technologies, such as drones and sensors.<br>Short to medium term | This will reduce import dependency and enhance self-sufficiency in monitoring efforts. This will also lower costs and make technology more accessible to local organizations and communities. Fostering local innovation and production can also create economic opportunities and build regional technical expertise. Finally, high costs for specific devices could be addressed partially by reducing import tariffs. | **Primary**<br>· Private sector<br>· Governments<br>**Additional actors**<br>· CSOs<br>· Indigenous Peoples |
| **Advance technological innovation and deployment.** Investments in research are needed to develop tools, technologies, and strategies that keep pace with evolving challenges of climate change and environmental monitoring in the Amazon.<br>Medium term | Investments in AI and intuitive platforms can enhance data collection and usability for a diverse array of stakeholders. In this regard, collaboration with the academia can offer the right platform to leverage the newest technologies, minimizing the financial commitment. However, given the high costs related to the most advanced tools, a careful assessment of trade-offs among different options is recommended. | **Primary**<br>· Private sector<br>· CSOs<br>**Additional actors**<br>· Governments<br>· Academia |
| **Strengthen digital and data infrastructure.** The Amazon needs significant investment in strengthening the digital, data, and energy infrastructure.[51] Existing data infrastructure needs to be updated and maintained.<br>Short to medium term | Internet coverage needs to be strengthened to unlock the full potential of digital technologies. Conservation efforts would also benefit from new regional facilities equipped for maintaining and supporting advanced technologies—such as cloud computing, high-performance computing, and AI-driven platforms to enable the handling of large and complex datasets, supporting comprehensive monitoring activities. These technologies also require proper strategies in place to develop and promote cloud usage complying with the local regulations on data protection and localization. Finally, it is equally important to consider the environmental footprint of deploying internet and data infrastructure, particularly as data centers can be located outside the biome and therefore do not require direct installation within sensitive ecosystems. | **Primary**<br>· Private sector<br>· Governments<br>· Indigenous Peoples and Local Communities<br>**Additional actors**<br>· CSOs<br>· Academia |
| **Promote data quality, standardization, interoperability and collaboration.** Stakeholders emphasized the need for common standards and protocols that facilitate data sharing, interoperability and integration.<br>Short to medium term | This includes developing data collection, processing, and storage guidelines that ensure consistency and accuracy. By standardising data practices, organizations can improve the reliability of their analyses and make more informed decisions about environmental management.[52] | **Primary**<br>· Governments<br>· CSOs<br>· Indigenous Peoples and Local Communities<br>**Additional actors**<br>· Academia |
| **Governance and collaboration.** Coordination and collaboration among stakeholders across the public, private, and social sectors are essential. Implementing and scaling digital conservation technologies demands a whole-of-system approach that fosters shared engagement and collective action.<br>Short to medium term | It is critical to consider the different incentives behind each actor together with the distribution of bargaining and political power. This means considering the roles and responsibilities of stakeholders within these sectors as they will be distinct and yet also highly dependent upon each other. Expanding collaborations through platforms such as ORA-ACTO, SERVIR-Amazonia, and MapBiomas enhances data sharing, resource pooling, and the capacity for regional monitoring. Strengthening partnerships among Amazonian countries, research institutions, and international agencies will improve coordination and attract funding.[53] | **Primary**<br>· Governments<br>· CSOs<br>· Indigenous Peoples and Local Communities<br>**Additional actors**<br>· Academia |

51 See Chapter 2 for detailed recommendations on how to close the digital gap.
52 Chapter 3 deepens the discussion about the data governance frameworks and practices that can facilitate trusted data interoperability and reuse for better insights and evidence-based decision-making.
53 Covered in greater detail in Chapter 3.

# CHAPTER 2

# Digital Infrastructure in the Amazon Biome

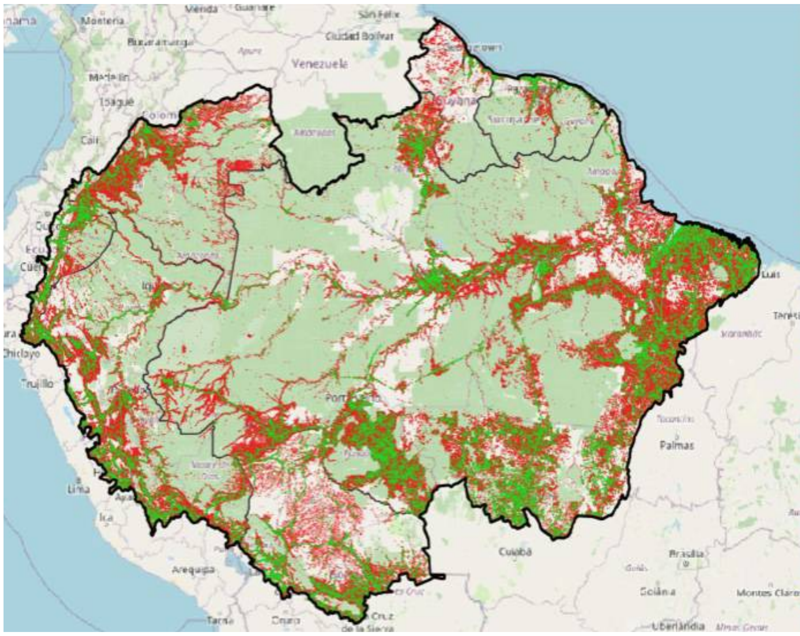
Main contributors: Niccolò Comini, Luciano Charlita De Freitas

Digital technologies for monitoring climate change cannot deliver their value when there is no, or inconsistent, access to affordable, fast, and resilient internet connectivity. This chapter presents an overview of this foundational building block, reviewing the current digital network coverage across the Amazon biome, with particular attention to both populated and sparsely populated areas. It draws on a combination of public and proprietary data sources, making this analysis a key reference point for understanding connectivity in the region.

The potential for communication and internet systems for monitoring the Amazon region is vast, particularly as new technologies become more affordable and accessible. Beyond GDP growth, reliable internet access is an enabler of environmental and climate change monitoring in the Amazon, providing the necessary infrastructure for data capture, transmission, coordination, and collaboration among stakeholders.[54] Expanding communication networks can enhance the effectiveness of existing monitoring systems by enabling more timely and accurate data collection and reporting. A study found that communities equipped with smartphones and relying on satellite images were more effective at reducing deforestation rates. The availability of reliable communication systems is especially important in remote areas, where the most common communication networks (e.g., fiberoptic and mobile) may be inadequate or non-existent.[55]

**Figure 2.1: Mobile and fixed broadband coverage in the Amazon**

Red and dark green dots are populated areas. Red areas are unserved by internet while dark green have access to internet




Source: Authors' analysis. Map adapted by the team from Data Basin (Riveros, 2012). It does not include Venezuela.

## The Status of Digital Connectivity in the Amazon

Efforts on closing the digital gap have traditionally focused on populated areas with the objective of unlocking socio-economic benefits related to internet access promoting an inclusive development. Dramatic improvements have been made in this field, with mobile coverage nowadays reaching about 95% of the population in Latin America.[56] Technology progress has created the case for internet connectivity to be impactful even in sparsely populated areas. The growth of devices and applications used for remote monitoring is now pushing the frontier of the internet even to geographies that before were not considered in the equation. This creates a new challenge for the telecommunications industry and requires careful planning when it comes to infrastructure deployment. A common feature among the countries that share the Amazon biome is the inconsistent level of internet coverage and usage in the Amazon departments.

### The Coverage Gap

This report has leveraged a unique dataset of Speedtest Intelligence® consumer-initiated results and signal scans provided by Ookla® to estimate fixed and mobile broadband coverage in the Amazon biome. Our coverage analysis did not consider satellite connectivity because this technology technically covers the whole area.

95%

Percentage of the population in Latin America that have access to mobile internet service

Figure 2.1 represents the status of internet coverage in 2024 in the region. Combining mobile broadband signals (4G and 5G) and fixed broadband Speedtest measurements, it is estimated that only 3.5% of the biome has access to the internet. Coverage concentrates along main river corridors, transport axes, and urban areas.

54 Ywata, 2025
55 Slough, et al., 2021
56 GSMA, 2025

In terms of population, 85%[57] is covered by broadband internet (both mobile and fixed). Looking at the different technologies, that can overlap each other, mobile internet plays a dominant role covering 85% of the population compared to fixed that reaches 69%.[58] Colombia and Peru are the countries reporting lower population coverage in the sample, 73% and 77% respectively.

3.5%

Percentage of the Amazon biome covered by internet

A more pronounced disparity emerges when results are disaggregated between Indigenous and non-Indigenous Territories:[59] Only 0.93% of Indigenous territories have internet coverage, reaching just 63% of the population. These results indicate that the broadband population coverage gap in Indigenous areas is nearly three times the level observed in non-Indigenous areas. The difference is consistent across both mobile and fixed broadband, but it is especially marked in fixed broadband coverage. At the country level, the lowest broadband population coverage in Indigenous areas is observed in Guyana (17.03%), Colombia (35.57%), and Brazil (37.67%).

## The Usage Gap

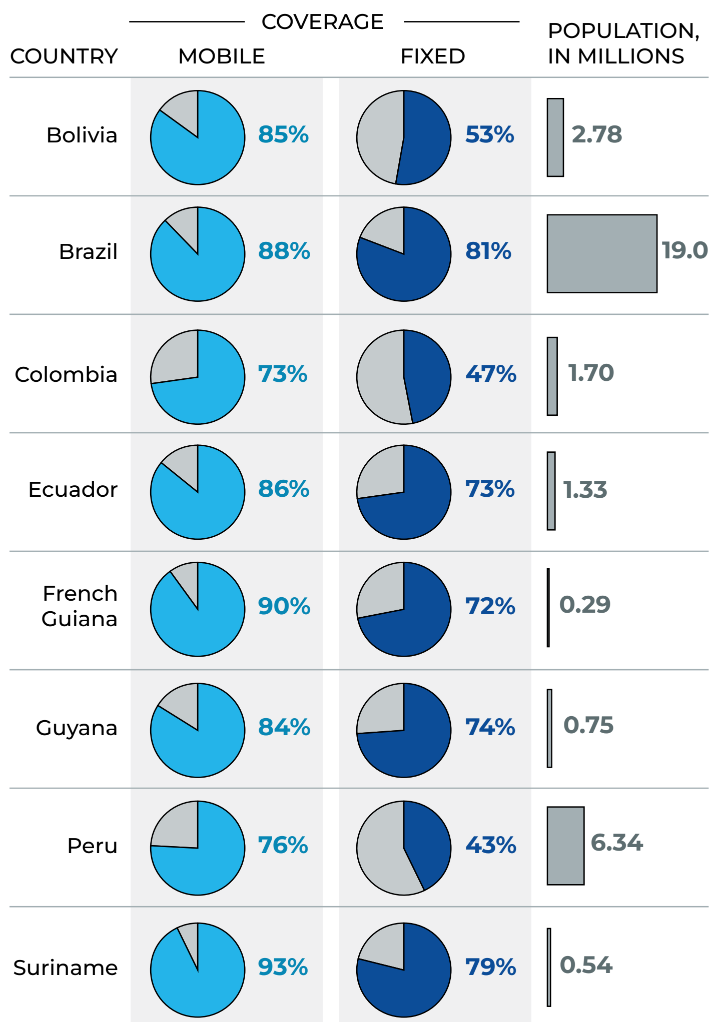
Access to internet connectivity doesn't correspond to usage. Although potentially covered for its entirety by satellite signal, population living in the Amazon lag significantly behind in internet usage. The World Bank report 'Closing the digital gap in the Amazonas department' shows that the highest levels of the digital divide in Colombia are concentrated in the departments located in the Amazon region.[60] In the department of Amazonas, Colombia, only 29% of households access the internet compared to the national average of 64%.[61] In Peru, 77% of the population uses the internet but only 59.5% in the Amazonas Department.[62] Brazil performs above the average as 87.5% of the population above 10 years old use internet in the Legal Amazon.[63] However, the definition of Legal Amazon entails highly urbanized territories compared to other countries.

There are different reasons why digital connectivity is limited in terms of access and usage in the Amazon biome. The geography of the rainforest can make it difficult and prohibitively expensive to install and maintain digital infrastructure, in addition to posing serious risks to the fragile ecosystem.[64] Additionally, there is a lack of economic and financial incentives for the private sector to invest in this region. Low population density, together with high economic constraints on the demand side, make this market unprofitable for telecommunications operators. For instance, more than a third of the population in the Brazilian Amazon's lives in poverty.[65] Similarly, the Amazonian departments in Colombia are among the poorest in the country.[66] Finally, provision of coverage also needs to consider ongoing maintenance costs. Part of this maintenance requires consistent access to infrastructure and related services, such as electricity, which is not necessarily readily available in rural areas of the Amazon.[67]

85%

Percentage of the population in the Amazon biome covered by mobile internet

**Figure 2.2: Broadband coverage in the Amazon biome**




Source: Authors' analysis

57 Total population of the area is 32,779,036 people. It is lower than the whole Amazon Basin whose population is around 50 million.
58 Fixed coverage is estimated through internet speed test results hence it could be under-represented.
59 Analysis based on Indigenous Territories map available at: https://www.raisg.org/en/maps/.
60 The World Bank Group, 2023
61 DANE, 2023
62 INEI, 2025
63 IBFE, 2024; Brazil's Legal Amazon, in Portuguese Amazônia Legal, is the largest socio-geographic division in Brazil, containing all nine states in the Amazon basin.
64 eSIMo, 2024
65 Hanusch and Marek, 2023
66 DANE, 2025
67 Soares & Donario de Azevedo, 2023

Even though these challenges persist, several initiatives are in place to address the digital gap in the Amazon region:

- The Connected North program, in Brazil, is aiming to expand connectivity in the Amazon region by deploying "12,000 kilometers of fiber optic cables in the riverbeds of the Amazon region by 2026"[68] benefitting 10 million people. This project is financed by the federal government partially leveraging the Universal Service Fund of the telecommunications sector, with additional support from Public-Private Partnerships (PPPs).
- The National High-Speed Connectivity Project[69] in Colombia aims to provide connectivity services to 235 public institutions, 953 rural community internet centers,[70] 56 urban community internet centers,[71] and creating 11,780 broadband internet accesses for low-income households.[72] Colombia's Ministry for the Information and Communications Technologies (MinTIC) is developing and funding this project.
- The "Conecta Selva" in Peru allowed more than 500 thousand Internet connections in rural areas of Loreto, Ucayali, Amazonas y Madre de Dios.[73] The Conecta Selva project is being carried out and financed by Peru's Ministry of Transport and Communications.
- The "Connect Forest People Network" project in the Brazilian Amazon is using solar energy kits and Low Earth Satellite technology to provide internet to 1,400 Indigenous Communities.[74] The project is financed by a combination of donations from philanthropic organizations and the private sector.

**Box 6: Infovias, the North Connected Program**

One of the most ambitious projects in expanding broadband infrastructure in the Amazon region is the North Connected Program in Brazil.[1] The Program includes eight high-capacity fiber optic networks (infovias) and aims to cover 12,000 km in the Amazon region through installation of sub-fluvial optical fiber cables, addressing public policies in telecommunications, education, research, health, defense, and the judiciary, as well as other potential public policies.

By 2024, the two first trenches were implemented connecting Macapá, a city closer to the Atlantic coast, to Manaus, located in the middle of the Amazon region. The governance of the program is managed by the Sustainable Integrated Amazon Program (PAIS), established by the Decree 10,800/2021,[2] which defines the structure and functioning of the Steering Committee responsible for monitoring and overseeing the project's execution.

The Infovias relied on a combination of public and private sector investments, facilitated through various initiatives and partnerships. Remarkable sources include public funds obtained from spectrum auctions.

This initiative also aims to improve internet access in the region and promote integration with neighboring countries in the Pan-Amazon. The objective for the countries in the region is to create an optical corridor that will connect Brazil, Colombia, Guyana, French Guiana, and international peers.[3]

1 Government of Brazil, 2024
2 Government of Brazil, 2021
3 Bucco, 2024

## How to Bridge the Digital Connectivity Gap in the Amazon

In recent decades, governments, industry, and practitioners have primarily focused on expanding internet coverage to populations, aiming to unlock the socio-economic benefits associated with digital connectivity.

Recently, connectivity aims have shifted from providing internet access solely to people and communities toward extending coverage to unpopulated areas—such as farms, forests, and protected ecosystems—where digital connectivity can unlock new efficiencies in agriculture, conservation, and climate resilience. In the case of the Amazon, technological devices located in remote areas with no or rare human presence may be installed to monitor the environment. This new approach presents technical and financial challenges, because of the large areas that are required to be covered and the lack of economic incentives given the absence of any significant demand.

There are distinct technical requirements for extending internet access to populated and unpopulated areas, reflecting their different patterns of use. While connecting people requires sufficient bandwidth to support basic online activities, devices operating in uninhabited zones—such as sensors or monitoring equipment—typically need far lower data transmission capacity using lighter, less-invasive infrastructure. Providing internet to the Amazon population can be achieved through three technologies: fixed, mobile, and satellite broadband. While this approach remains technically valid in unpopulated zones, its deployment often faces significant technical and financial constraints. In such cases, connectivity needs may be more effectively addressed by leveraging alternative wireless technologies (see Box 7).

68 Cavalcanti, 2024
69 Proyecto Nacional de Conectividad Alta Velocidad
70 Kioscos Vive Digital
71 Puntos Vive Digital
72 Government of Colombia, 2024
73 Government of Peru, 2024
74 Fundação Roberto Marinho, 2025; Schaeffer & Barrantes, 2023; Conexao Povos da Floresta, 2025

**Box 7: Alternative data transmission technologies for climate and environmental monitoring**

The choice of data transmission methods is critical to effectively deploy digital technologies for forest protection and environmental monitoring, especially in remote and infrastructure-scarce regions like the Amazon. While mobile networks remain the primary source of connectivity, alternative wireless technologies are emerging that can extend the reach and sustainability of IoT deployments.

Three prominent Low-Power Wide-Area Network (LPWAN) technologies—Narrowband IoT (NB-IoT), LoRa, and Sigfox—offer viable solutions for transmitting data across large distances with minimal energy consumption and operational cost. These technologies support a transition from human-centric mobile coverage to broader area-based connectivity, enabling real-time environmental monitoring in even the most inaccessible areas.

Each of these technologies brings specific strengths and trade-offs in terms of range, data rate, latency, scalability, cost, and security. In the Amazon and similar ecosystems, a mix of these technologies may offer the most effective coverage, tailored to specific environmental and logistical needs.

**NB-IoT**

| CHARACTERIZED BY: | IDEAL FOR: |
|---|---|
| • Operates on licensed mobile spectrum<br>• Deep indoor and underground penetration<br>• Long battery life (up to 10 years)<br>• Robust security | • Stationary sensors with infrequent data needs, such as soil moisture probes or tree health monitors |

**LoRa (Long Range)**

| CHARACTERIZED BY: | IDEAL FOR: |
|---|---|
| • Adaptable data rates<br>• Transmission ranges of up to 15 km in rural areas<br>• Energy efficient<br>• Scalable | • Dense sensor networks spread across large tracts of forest<br>• Biodiversity tracking<br>• Wildfire risk detection |

**Sigfox**

| CHARACTERIZED BY: | IDEAL FOR: |
|---|---|
| • Global, cost-effective connectivity<br>• Low bandwidth<br>• Minimal energy requirements | • Simple IoT devices, such as those sending small amounts of data, intermittently<br>• Asset tracking<br>• Remote infrastructure monitors in hard-to-reach regions |

## The Cost of Internet Connectivity in the Amazon

Technical, geographical, and demographic challenges make digital infrastructure deployment in the Amazon extremely costly. Some figures help us understand the magnitude of these costs. For example, a 2021 report indicated that closing the digital gap in Latin America would require an investment of USD $68.5 billion on both fixed and mobile networks.[75] The findings highlighted that strategic public investment is essential to foster PPPs that can reach the most remote and disconnected areas, potentially generating more than 15 million jobs across the Latin American and Caribbean (LAC) region. The World Bank estimates that about USD $100 million investment in Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) are needed to close the digital gap in the Department of Amazonas in Colombia.[76]

**15 million**

The number of jobs potentially created across the Latin American and Caribbean region through an internet connectivity initiative.

This report assesses the cost of providing internet connectivity to the entire population of the Amazon biome. Based on the coverage analysis presented in the previous section, it is estimated that between USD $6 and $7 billion in CAPEX and OPEX would be required to achieve 100 percent population coverage, ensuring a minimum connection speed of 10 Mbps per subscriber during peak hours. Additional USD $500–$800 million in CAPEX and OPEX will be needed for providing electricity to off-grid mobile towers. Fiber and mobile networks account for approximately 90 percent of the total costs, with satellite

**Satellite Internet Connect Forest People Network project**

Photo: Bruno Kelly. © Connect Forest People Network. Used with the permission of Connect Forest People Network.

75 Zaballos, et al., 2021
76 The World Bank Group, 2023

technologies covering the remainder. To minimize environmental impacts, fiber deployment has been planned along existing road infrastructure, connecting populations located within 10 kilometers of these corridors.

Figure 2.3 summarizes the cost assessment findings by country. Overall, fiber optic infrastructure represents approximately 60 percent of total expenditure. Brazil stands out as the country requiring the largest investment—about USD $4 billion, accounting for more than half of the region's overall cost. This is primarily because Brazil has the highest absolute number of unconnected residents. In the Colombian Amazon, most of the unconnected population will be reached using satellite technology, reflecting a more dispersed population distribution compared to other countries. The country also reports the smallest share of connections by fiber optic.

**Mobile tower in the Brazilian Amazon**

Photo: Mariana Kaipper Ceratti (Banco Mundial)

**Figure 2.3: Main results of cost assessments by Amazon region country**

| | NUMBER OF THOSE WITHOUT INTERNET COVERAGE | PROPOSED TYPE OF COVERAGE | | | PROPOSED TYPE OF FUNDING | |
|---|---|---|---|---|---|---|
| | | Fiber optic | Mobile | Satellite | CAPEX (USD BN) | OPEX (USD BN) |
| Bolivia | 419,960 | 77% | 22% | 1% | $0.91B | $0.06B |
| Brazil | 2,115,960 | 49% | 41% | 10% | $3.74B | $0.27B |
| Colombia | 460,644 | 45% | 43% | 12% | $0.49B | $0.04B |
| Ecuador | 182,825 | 79% | 18% | 4% | $0.17B | $0.01B |
| French Guiana | 24,231 | 69% | 25% | 7% | $0.04B | $0 |
| Guyana | 107,503 | 65% | 28% | 6% | $0.09B | $0.01B |
| Peru | 1,493,331 | 73% | 22% | 4% | $0.88B | $0.06B |
| Suriname | 36,039 | 46% | 49% | 5% | $0.13B | $0.01B |

Source: Authors' analysis

Note: This table does not report energy related CAPEX and OPEX.

## Key Recommendations to Connect the Amazon

Bridging the digital gap in the Amazon region embodies unique environmental, operational challenges and specific economic and financial complexities. Therefore, such investment requires coordination among a broad range of policymakers, governments, market participants, and consumers to undertake the following recommendations:

IMPLEMENTATION TIME

| Short term | Medium term | Long term |
|---|---|---|

| RECOMMENDATIONS | DETAILS/BENEFITS/CAVEATS | STAKEHOLDERS |
|---|---|---|
| **Blend finance to fund infrastructure.** To meet financial needs for connecting all populations in the Amazon biome with internet, a blended finance approach is essential.<br>Medium term | National governments should allocate budget resources and pursue co-financing through regional partnerships, leveraging universal service funds to support targeted connectivity efforts and engaging thousands of small and medium Internet Service Providers (ISPs) for last-mile delivery. International development banks, such as the World Bank Group (WBG) and the Inter-American Development Bank (IADB), can provide concessional loans and guarantees for large-scale infrastructure. PPPs should be promoted to mobilize private sector investment, technical expertise, and operational efficiency. Innovative financing mechanisms, including carbon credits and biodiversity bonds, can unlock new revenue streams, while crowdfunding and community-based funds may help reach remote and underserved populations. Blending these diverse sources will maximize impact, share risk, and ensure long-term sustainability for Amazonian digital connectivity. | **Primary Stakeholders**<br>· Ministries of Telecommunication/ Innovation<br>· Private sector<br>**Additional actors**<br>· Telco regulators<br>· Multilateral Development Banks (MDBs) |
| **Integrate telecommunications infrastructure across Amazon region.** Integrating the telecommunications infrastructure across the Amazon region is essential for creating a robust and resilient digital infrastructure.<br>Short to medium term | Existing initiatives in Brazil, Peru, and Colombia, such as the North Connected Program in Brazil, the National High-Speed Connectivity Project in Colombia, and the *Conecta Selva* project in Peru, provide a strong foundation for this integration. By connecting these national projects, it is possible to create an optical corridor that links Amazonian regions, facilitating cross-border data sharing and collaboration. | **Primary Stakeholders**<br>· Ministries of Telecommunication/ Innovation<br>· Private sector<br>**Additional actors**<br>· MDBs |
| **Implement a technology mix to accelerate connectivity in the Amazon Region.** Define a connectivity strategy selecting the appropriate technology that better serves the data needs of the target population/area.<br>Short to medium term | A mix of technologies, including LPWAN technologies such as NB-IoT, LoRa, and Sigfox, as well as satellite based broadband connectivity can provide cost-effective and energy-efficient solutions for regional data transmission. These technologies are particularly suitable for environmental monitoring and can support real-time data collection and analysis crucial for some conservation efforts highlighted in the study. | **Primary Stakeholders**<br>· Ministries of Telecommunication/ Innovation<br>· Private sector<br>**Additional actors**<br>· CSOs |
| **Promote community networks and small ISPs.** The Amazon's natural territorial features make it hard and expensive to deploy and maintain telecommunications networks. For maintenance operations, one solution is to strengthen and train community networks.<br>Short to medium term | Empowering small operators and local populations (e.g., Indigenous-owned connectivity infrastructure) with appropriate skills will make maintenance cheaper and faster while increasing local ownership of the infrastructure. Small ISPs can also play a critical role in closing the gap by offering flexible, low-cost solutions tailored to local needs, especially where large operators face limited commercial incentives. Their proximity to communities enables agile deployment and more sustainable last-mile connectivity in remote areas. | **Primary Stakeholders**<br>· Ministries of Telecommunication/ Innovation<br>· Community networks<br>· Private sector<br>**Additional actors**<br>· CSOs |
| **Reduce the costs of connectivity devices to match regional income levels.** The high cost of connectivity devices is a significant barrier to digital inclusion in the Amazon region, where many residents live in poverty.<br>Short term | To address this issue, policies should focus on reducing import tariffs for essential connectivity devices and promoting maintenance capabilities to increase the adoption of digital technologies among low-income households. Additionally, providing low-income subsidies or financial incentives for purchasing connectivity devices can further support digital inclusion efforts ensuring that more people will participate in the digital economy and access essential services, while contributing to conservation and monitoring efforts. | **Primary Stakeholders**<br>· Ministries of Telecommunication/ Innovation<br>· Private sector<br>**Additional actors**<br>· CSOs |

| RECOMMENDATIONS | DETAILS/BENEFITS/CAVEATS | STAKEHOLDERS |
|---|---|---|
| **Promote digital skills training.** To achieve safe and productive internet usage, it is essential to provide access to digital skill training to urban and rural populations, including Indigenous Peoples and Local Communities and youth.<br>Short term | Digital education centers in small and large cities, as well as communities, can be an important part of the solution. Training should not be limited to traditional usage of internet-enabled devices, but should also focus on maintenance and operation of the telecommunication infrastructure. | **Primary Stakeholders**<br>• Ministries of Telecommunication/ Innovation<br>• CSOs<br>**Additional actors**<br>• Private sector |
| **Prioritize contextualized solutions.** The need for tailored connectivity strategies and economic solutions contrasts sharply with a one-size-fits-all approach, emphasizing that any effective framework must be grounded in the unique economic, political, and social constraints of the target areas.<br>Short term | By distinguishing how to address demand and supply variables, as well as identifying binding constraints that impede digital economic development, it becomes possible to pinpoint areas ripe for private investment and those requiring public incentives and investments. Equally important, decisions on providing network connectivity in rural areas should be led by the communities concerned, ensuring alignment with their self-determined priorities. At the same time, deploying infrastructure within the fragile Amazon biome demands the highest environmental safeguards to ensure a minimal ecological footprint. | **Primary Stakeholders**<br>• Indigenous People and Local Communities<br>• Private sector<br>• CSOs<br>• Governments |

**Uru-eu-wau-wau Indigenous Territory, Rondônia, Brazil**

Photo: Kaninde

CHAPTER 3

# Governing Climate-Related Data in the Amazon for Trusted and Equitable Use

Main contributors: Niccolò Comini, Adele Barzelay

The preceding chapters explain how effectively leveraging digital technologies and applications can advance climate change monitoring efforts and how that can only be done through assurance of network connectivity and digital literacy. However, technology alone is not sufficient; its effectiveness depends on the ability of people and institutions to use the data it generates to produce research and actionable insights that inform policies and address climate challenges. The effectiveness of data-driven approaches in addressing complex, multi-dimensional risks depends largely on data accessibility, quality, usability, and representativeness, including the ease with which data can be combined and shared with third parties.

Data governance is a foundational component to support the sustainable deployment of digital conservation technologies in the Amazon. This chapter aims to provide a framework to understand the key elements needed to support more effective and trusted climate data collection and use for evidence-based decision making, and how these elements can be implemented in the Amazon region through coordination between national, regional, and international institutions.

Data governance is a foundational component to support the sustainable deployment of digital conservation technologies in the Amazon.

The ability to realize value from data requires more than facilitating access to it. The relevance, quality, usability, and trustworthiness of the data digital technologies generate or process, and that human-led initiatives collect, are critical to reliably measuring and addressing climate risks. For climate-related data to be effectively leveraged for environmental monitoring, clear norms, rules, and standards must guide how data are collected, classified, processed, shared, and integrated into decision making. A robust data governance framework establishes these principles, fostering trust among data providers and users in the data's origin and quality, and clarifying the conditions under which it can be used. These conditions should also ensure that data can be understood, used, and shared by multiple actors for diverse purposes—promoting proactive data disclosure and interoperability—while safeguarding both the data itself and the rights of data holders to build trust and equity in its collection and use.

For climate-related data to be effectively leveraged for environmental monitoring, clear norms, rules, and standards must guide how data are collected, classified, processed, shared, and integrated into decision making.

It is good practice for a data governance framework to be developed collaboratively with the individuals and groups whose data will be affected by its rules. In the Amazon, this means paying particular attention to the rights of Indigenous Peoples and Local Communities. Doing so ensures that the framework aligns with, and upholds, a social contract for data collection and use; supporting equitable access to data while safeguarding the rights of communities to define their representation and to influence how data concerning them, their territories, and local ecosystems is generated, shared, and used in decision making. Such an approach is essential for fostering trust, legitimacy, and meaningful participation from Indigenous Peoples and Local Communities—who are not only key producers and users of climate data but also among the most vulnerable to the impacts of climate. These considerations will be explored in greater detail throughout this chapter.

Data governance rules do not emerge in a vacuum; to be effective, they must be designed in alignment with clearly defined policy objectives and aimed at addressing specific challenges. In the Amazon, this may include closing gaps in proactively disclosed data or improving the interoperability of existing datasets.

Policymakers should engage the full spectrum of stakeholders in this ecosystem, from local data producers, including Indigenous Peoples and Local Communities to technology providers and researchers. Such engagement is essential to identify the key data challenges facing countries in the Amazon region and to determine how policies, laws, regulations, and institutions can be leveraged to address them. This process ultimately helps establish a coherent data governance framework that is responsive to real-world needs and grounded in collaboration.

The challenges of governing climate data responsibly and effectively are multi-dimensional, encompassing legal, technical, institutional and capacity issues.

The ability to access and use data generated by digital technologies in support of environmental conservation efforts requires addressing the availability, accessibility, quality, and usability of this data, while protecting data security and data rights. Each issue is addressed here:

**Data Availability and Accessibility:** Enabling access to data involves both *normative* and *technical* decisions. *Normative* decisions entail determining what data should be generated or collected for specific purposes, including being able to measure specific environmental or climate-related risks to Lo-

**Box 8: The risks of collecting climate data**

Collecting and processing certain kinds of climate data can be inherently risky:

**Data transmitted from remote sensing technologies and field sensors** (see Chapter 1) can contain potentially sensitive information—such as location data of individuals, communities, or endangered species—or voice recordings that may be used by mal-intentioned actors, such as poachers, or to surveil local populations.

**The use of camera traps and acoustic sensor** risks capturing photos and audio recordings that may be intrusive and contain sensitive information about Indigenous Communities. Camera traps images could potentially enable facial recognition of the Indigenous Peoples of the Amazon.[1]

**Other types of sensitive data include geographic coordinates** concerning relevant cultural or spiritual sites, and components of Indigenous ceremonial practices.[2] Data breaches can expose individuals, communities, and organizations, as well as the Amazon biome ecosystem.

At the same time, collecting and processing relevant, up-to-date, fit-for-purpose, and appropriately structured data, including data about local ecosystems, is critical to enable decision makers to adapt to and mitigate climate risks.[3]

1 Sandbrook, et al., 2021
2 Schilfgaarde, 2020
3 Carvalho, 2023

cal Communities, endangered species, and localities. Taking a problem and risk-driven analysis with input from Indigenous Peoples and Local Communities and technical experts (e.g., academia, civil society, industry specialists) is critical to ensure that the right data can be made available for [preferably public] use. Even when data on climate change in the Amazon are available, they are not always accessible, often because they are not proactively disclosed in a form and manner that promotes reuse; for instance, making it easily findable and downloadable through a portal that enables access to different data sources in a consolidated manner.

Accessibility challenges are compounded when it comes to monitoring climate risks that require measuring different variables found across different datasets, or collected or processed by a variety of data producers. A non-exhaustive survey of existing climate-related data sources conducted as background for this report identified that while varied data sources exist, they are not easily publicly accessible, and not always proactively disclosed. They are, instead, only available upon request. While this report does not recommend that all climate-related data be stored centrally, facilitating the consolidation of datasets through technical intermediations that support consolidation on the user-facing side (for instance, through a central portal) could meaningfully support data accessibility. The gathering of all such data in a single public portal would be key for climate change governance in the Amazon region. Centralization of data and information is not the objective, since such an approach increases data protection and cybersecurity risks, and can create a single point of failure. Conversely, making access to data more user-friendly by investing in integrating intermediaries (whether organizational or technical) to provide a series of common and publicly available repositories of key data sources and indicators held in federated networks can promote accessibility, reduce information silos, and offer a more holistic view of the climate risks facing the Amazon. This would also facilitate monitoring, research, and advocacy efforts by a broader range of actors across different sectors.

No single institution in the region has the capacity to gather, store and publish climate data through a unified portal. Partnerships between Amazonian institutions and regional or international actors offer a promising path to facilitate data consolidation and accessibility. The selection of which institution(s) should manage data portals and other data intermediation mechanisms should consider factors such as the institution's legal and political mandate, its core functions, as well as its operational and financial sustainability. Ensuring that the lead entity is viewed as legitimate or reputable by other actors, including considering its ties to established stakeholder groups, is critical to its ability to take on such a leadership role. Partnerships between CSOs that operate across the different Amazon biome countries, could be good candidates for supporting coordinated data collection efforts.[77] While government-led initiatives can be effective at mandating public sector data sharing, in many cases, multi-stakeholder consortia or coalitions can be more effective if they include established groups and have the technical capacity to collect, analyze and disseminate data. This is particularly the case where common data repositories feature data collected from

**Police officer in the Amazon, Brazil**


Photo: Mariana Ceratti (World Bank)

77 For example, The Amazon Network of Georeferenced Socio-Environmental Information (RAISG), is a consortium of civil society organizations from the Amazon countries, supported by international partners, concerned with the socio-environmental sustainability of Amazonia. RAISG produces and disseminates knowledge, statistical data and geospatial socio-environmental information on Amazonia developed through protocols common to all the countries of the region. RAISG enables a view of the Amazon biome as a whole, including threat mapping and socio-environmental intelligence reports to facilitate monitoring and mitigation efforts. RAISG is the outcome of cooperation between eight civil society organizations from six Amazon countries: Bolivia, Brazil, Colombia, Ecuador, Peru and Venezuela.

a broad set of participants, or relate to disputed areas.[78] Regardless of the stakeholders involved, these initiatives require a serious and evidence-based assessment of their associated financial and operational costs, including how to ensure their financial sustainability in the event they start out as donor or project funded, and therefore may be time-bound.[79]

When determining access modalities for climate-related data, it is important to consider both the type of data in question and their intended use. If the objective of data accessibility initiatives is to support public access to "open" datasets, then investing in the development of open data portals designed as "global public goods" could provide unrestricted access and use of climate data to a broader variety of stakeholders, such as policymakers, scientists, and the public in general. Examples such as the collaboration between the ACA and the MAAP on forest carbon dynamics showcase effective initiatives to facilitate evidence-based decision making by the Peruvian government. Not all data needs to be made "open" for it to be relevant for climate monitoring and other environmental uses. In some cases, data intermediation can still help improve access to third-party data on a restricted basis, including commercial data or sensitive government data; for instance, by leveraging more restrictive licensing terms and technical means (e.g., APIs). Both types of data access modalities are important, since they achieve different objectives that aim to support the same ultimate outcome of improving access to climate-related data.

**Data Quality:** Multiple sources collect environmental data about the Amazon and it is processed by different entities across multiple initiatives. As such, data processing, storage, and quality standards are not always uniform. Indicators for quality include whether the data is relevant, up-to-date at a frequency that is appropriate for the nature of the data, includes historical data to enable time-series analysis, and is validated for accuracy. For example, AI systems deployed for monitoring purposes require quality data. In this context, acoustic monitoring algorithms specifically require that data be cleaned to ensure noise does not interfere with the process of isolating relevant sounds. At the same time, it is important for a data governance framework to take account of the heterogeneity of data users and the purposes for which they may be interested in using climate data. A group of researchers might benefit from "cleaned" acoustic monitoring algorithms, while another may identify patterns in the "noise" that can be leveraged for research on a different sub-

AI systems deployed for monitoring purposes require quality data. In this context, acoustic monitoring algorithms specifically require that data be cleaned to ensure noise does not interfere with the process of isolating relevant sounds.

**ATL, an annual event held by The Articulation of Indigenous Peoples of Brazil (APIB), to Increase awareness of indigenous rights**

Photo: Felipe Spina

78 For example, in its new vision, ACTO includes non-government institutions in the steering committee of the ARO, including the Peruvian Amazon Research Institute (IIAP), and is also considering partnerships with civil society organizations that can gather data. See this link for reference

79 See for example SERVIR, a partnership between the National Aeronautics and Space Administration (NASA) and USAID and scientists and experts in Brazil, Colombia, Peru, Ecuador, Guyana and Suriname. They developed and managed SERVIR-Amazonia to bring together local knowledge in geospatial and Earth Observation technology to tailor decision-support services to prevent natural disasters, mitigate climate change and prevent deforestation in the Amazon basin.After the closure of USAID, the partners decided to continue the program under a consortium to ensure the continuity of this public repository of data.

ject matter.[80] As such, data governance framework developers should leverage tools such as labelling and metadata, as well as explanatory notes accompanying datasets, as a means to alert a variety of researchers to different possible use cases, while keeping the published dataset as clean and homogeneous as possible.

**Data Usability:** Data usability is influenced by factors including how restrictively data are classified at the source (under a data classification framework). The framework determines for what purpose(s) the data was collected or generated and defines how widely and under what restrictions data can be shared with third parties. Enabling classified datasets to be reusable requires ensuring datasets are shared according to clear, accessible, and non-revocable terms for reuse. Other factors that determine the usability of data include the format of the data (machine-readability and non-proprietary format), as well as the completeness of accompanying metadata. In the case of the Amazon, it must include various user groups to provide metadata in English, Portuguese, and Spanish, as well as less commonly used languages such as Surinamese Dutch and Indigenous languages.[81] According to our analysis, while the majority of climate-related data on the Amazon region is published in machine-readable format, accompanying metadata and licensing information are not always available. Spatially explicit data, namely maps, are generally complete in terms of inclusion of metadata and data quality, though may raise political issues if representing disputed territories.[82] But point or station-based data, like weather station data, have more gaps in terms of availability, quality, and spatial-temporal coverage (see Box 9). While countries and data producing organizations have discretion in the types of licenses and standards they adopt, they can facilitate data reuse and interoperability by aligning with international standards, such as the World Meteorological Organization's (WMO) Unified Data Policy Resolution, which mandates certain types of data production for data feeding into climate models.

**Data Bias and Representation**: Indigenous Populations and remote terrains remain inadequately represented in data from the Amazon. While this may legitimately be by choice, for example to avoid surveillance or prosecution,[83] a lack of representation of Indigenous Peoples and Local Communities and their localities can affect the ability of policymakers and researchers to ensure more representative and targeted data are feeding into decision making. A substantial number of Indigenous Communities remain unaccounted for in contemporary government planning. Lack of legal recognition (e.g., in Suriname) results in an inadequate transfer of land tenure and related rights to Indigenous Communities, preventing them from sustainably managing such lands.[84] Climate change has disproportionately increased the vulnerability of Indigenous Peoples and Local Communities to food shortages, diseases, and extreme climate events;[85] more representative data could help more accurately monitor these events, and enable remediation through policymaking. For geographic reasons, remote terrains are rarely fairly represented. For instance, the skewed coverage of weather stations in the Brazilian Amazon, which are predominantly located close to the main rivers, has meant that dissemination of early warnings for extreme climatic events (such as thunderstorms or cloudbursts) happening in remote regions are not communicated promptly and rely on informal communications.

**Box 9: Meteorological and climatic data collection in Brazil**

The Brazilian Amazon faces an acute gap of meteorological and climatic data collection. The map shows the coverage of meteorological stations in the Brazilian territory certified by the National Institute of Meteorology - Instituto Nacional de Meteorologia INMET. In green automated stations (with data transferred via satellite connection); in blue conventional stations (data collection and transference collected by human operators); and in purple automated rain gauges.


Source: Inmet: Mapa de Estações

Some privacy and access risks relate specifically to IT and data collected or owned by Indigenous Peoples.[86] These can be mitigated by ensuring data collection, processing, and use practices are informed by, and align with, principles such as FAIR (Findable, Accessible, Interoperable, Reusable) and CARE (Collective Benefit, Authority to Control, Responsibility, Ethics),[87] in addition to restricting the disclosure of data on the location of sensitive species to avoid misuse (for instance, by poachers).[88]

80 For more information, see National Oceanic and Atmoshperic Administration's (NOAA) Argo program, which collects physical and biogeochemical data from the ocean. Argo's sensors collected "noise" on non-plankton species that was labelled as "bad" data under the program's quality assessment rules, but the same were considered valuable for biologists studying mesopelagic species.
81 See the Local Contexts project that has developed, with support from IEEE, a standard for indigenous data labels.
82 Examples include Venezuela and Guyana, Suriname and Guyana.
83 See Friedman, S. (2025). The Law of the Sea Goes Digital—Indigenous Peoples' "Right to Exclude" Their Traditional Knowledge from the Digital Sphere.
84 Webb, et al., 2020
85 Song, et al., 2020; Schilfgaarde, 2020
86 Adams, 2024
87 As an example, relevant to North America, see Adams, M.M. Indigenous Fire Data Sovereignty: Applying Indigenous Data Sovereignty Principles to Fire Research.
88 There are laws preventing disclosure of data on the location of endangered species - see eg best practices by GBIF

## Designing a Data Governance Framework to Support Data-Driven Conservation Efforts in the Amazon

Designing a data governance framework to address the above challenges requires the adoption of agreed upon norms, rules, processes, and standards that govern how data and data infrastructure are managed to support specific policy objectives.[89] At the same time, collecting and processing relevant, up-to-date, fit-for-purpose, and appropriately structured data is critical to enable decision makers to adapt and mitigate climate change.

> “Public and private sector decision makers need access to robust overviews of the real and potential on-the-ground risks and opportunities that can impact businesses operating in the Amazon region. Data can help private asset managers, banks and corporations—in addition to public administrators and policy makers—improve due diligence by shedding light on local realities and providing a new perspective on territorial impacts that go beyond macro-level international ESG standards.”
> —Carvalho, 2023

Enabling data sharing and reuse for environmental conservation as a policy objective assumes that data can be reused for different [legitimate] purposes and by multiple stakeholders without losing any value, since data are non-rivalrous. As such, promoting access to information and proactive data disclosure, supporting data interoperability, and facilitating cross-border data flows are critical components of a data governance framework, as they facilitate evidence-based policymaking and managing environmental risks.

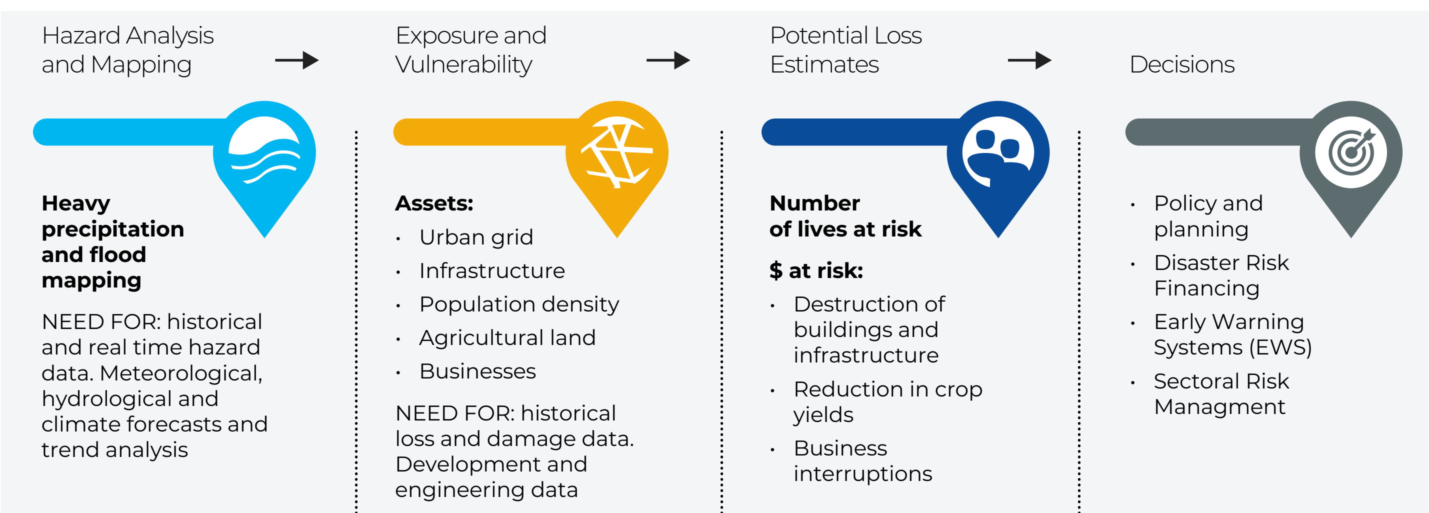
Figure 3.2 uses flood data to provide an example of the types of data and processing activities required to respond to flood risks. Effective risk mapping requires access to two sub-types of data:

- Data on hazard mapping (a form of observational data)
- Historical loss and damage data

Both aggregate data from different sources and under different processing conditions. Processing these types of data yields a risk model for floods, which, in turn, can inform climate adaptation policy. Within this pipeline, the series of actions involved in combining, accessing, and making this kind of high-quality data available for climate policymaking, constitute elements of data governance.

Implementing a data governance framework requires effective institutions to play key functions, ranging from supporting the development of rules and processes that govern what and how data should be collected, processed, used and shared, to ensuring these are enforced, and of course managing the data assets themselves. While many of these functions are led by public sector entities, namely in the development of policies, laws and regulations that govern data, non-government stakeholders play a critical role in data governance, whether it’s ranging from the private sector development of technical standards and agreement of contractual or licensing terms, or academia and even “citizen-scientists” collecting and maintaining key databases, sometimes in partnership with governments or international organizations and the donor community.

**Figure 3.2: Implementing data governance in practice**




Source: UNFCC Adaptation Committee, 2020

89 The Newberry, n.d.

Based on an analysis of existing data sources for climate-related data relevant to the Amazon region, this chapter focuses on key enabling and safeguarding elements of a data governance framework that can help improve the accessibility and usability of this data. This includes supporting the proactive disclosure and the interoperability of data, and improving the effectiveness and coordination of local, regional and international initiatives that currently support the collection and sharing of climate data on the Amazon. To this regard, the World Bank, through the ASL—a GEF-financed, World Bank-led initiative—is providing technical assistance to modernize the Amazon Regional Observatory (ARO)[90] of the Amazon Cooperation Treaty Organization (ACTO).[91] This support includes strengthening ARO's capacity to integrate and share high-quality scientific and monitoring data (for example, on climate, hydrology, fires, and ecological tipping points), fostering institutional coordination among Amazonian countries, improving tools and platforms for real-time and predictive modelling, and communication to support decision making. These upgrades are expected to help ARO to better enable policy makers and stakeholders to take actions required to avert the Amazon tipping point.

## Enabling Better Insights through Interoperability, Integration and Accessibility of Data Sources

Data interoperability refers to:

> “the ability for different systems to share and use data in a coordinated, timely manner” —Adeleke, 2022[92]

For data interoperability to take place, and for data and systems to be able to “talk to each other” (and be combinable for better insights), an interoperability framework must govern legal, organizational, technical, and semantic interoperability. For example, applying unified standards to land use data from different databases, such as TerraBrasilis and AdaptaBrasilia, allows them to be combined to produce more advanced insights. There are, however, technical, semantic, legal, and organizational issues to consider in operationalizing such an approach include:

- **Supporting Technical Interoperability.** Technical interoperability requires considering how interfaces hosting data can communicate with each other. In the context of the Amazon, satellite data, ground-based sensors, community observations, and historical records may be integrated or made interoperable to help create comprehensive maps and analytical models. The Gundi platform, for example, integrates data from multiple conservation technologies and sensors, including Global Navigation Satellite System (GNSS) sensors, IoT, and off-grid communication systems to comprehensively monitor the environment.
- **Developing Standards to Support Semantic Interoperability.** Semantic interoperability involves harmonizing the formats in which data is shared or disseminated, standardizing data models, and adopting shared vocabularies and taxonomies, among other elements. Integrating camera trap data—for instance, with acoustic data—helps conservationists identify how humans disturb endemic natural species in particular ecosystems. Standards are, however, needed to enable such data to interoperate. The content of these standards includes technical specifications on formats, ontologies and machine readability, among other elements. Coordination in the adoption of standards, ideally with internationally recognized ones, is an important enabler to ensure that data collected from the Amazon basin can feed into regional and global monitoring efforts.[93] The lack of interoperability, both among and within countries in the Amazon region remains a challenge. Efforts to address this require strategic and technical coordination among designated agencies, which could be facilitated by a regional body with the technical capacity to lead such an initiative.
- **Adopting Clear Rules to Guide Legal Interoperability.** Legal frameworks can contribute to facilitating data interoperability by providing a predictable framework for using climate data. First, they can mandate interoperability, including by requiring data to only be collected once (“once only” principle). Second, clearly defining rules around data access, whether through data sharing agreements or by adopting an open data license (e.g., Creative Commons Share-Alike), gives data users guidance to know under what terms they can access and use climate data. Data licensing agreements should include terms that maximize reuse, while addressing any obligations around protect-

**Mobile apps for conservation**

Photo: Ila Verus (CPI-Acre)

90 Observatorio Regional Amazónico (ORA) - Amazon Regional Observatory
91 Organización del Tratado de Cooperación Amazónica (OTCA) - Amazon Cooperation Treaty Organization
92 See also https://developmentgateway.org/wp-content/uploads/2025/02/Interoperability-Paper_DG_2024.pdf and https://www.data4sdgs.org/sites/default/files/services_files/Interoperability%20-%20A%20practitioner%E2%80%99s%20guide%20to%20joining-up%20data%20in%20the%20development%20sector.pdf
93 Buxton, et al., 2018

ing Intellectual Property Rights (IPR) and data protection considerations. This can be done by enabling the re-use of data for both commercial and non-commercial purposes, while retaining the right to attribute such data to the original author. Ensuring flexibility in licensing terms can be helpful but may create tension between different use groups. In particular, conflicts can arise between actors seeking to extract commercial value from data and those who rely on data collection for local, community-led, or non-commercial purposes—most often marginalized communities.

- **Establish the Right Organizational Architecture to Promote Interoperability in Practice.** Recognizing that governments have greater control over public sector data than private sector data, a data governance framework should both mandate the disclosure of climate-related data, where feasible, and create incentives for non-government stakeholders to share data among themselves and with third parties, including public institutions where relevant. This can promote interoperability between different types and sources of data.

Policymakers seeking to leverage policy, legal, regulatory and institutional mechanisms to support data interoperability within the public sector and with third parties can create organizational frameworks and standards. These frameworks should seek to align processes, standardize data use, ensure technical integration, and comply with legal requirements for data exchange among public sector entities, such as in the case of Peru's Digital Government Law.[94] Implementing these frameworks and standards requires entities to align their internal objectives and processes to facilitate data sharing. Clear and flexible data access policies and data sharing agreements can also facilitate data sharing between organizations by providing more detailed norms and rules around the sharing of specific datasets, purposes, and warranties between stakeholders.

The specificities of the Amazon region may require bespoke terms to account for local context; for example, by accounting for specific norms or practices adopted by Local Communities (including Indigenous stewardship practices), if they are amongst the stakeholders involved. An appropriate open data policy, coupled with organizational or contractual rules, can mitigate these challenges while making available high-quality data for decision making.

**Local farmers attend a workshop on ecology and social organization in Vila Da Canoas, in the Amazon region of Brazil near Manaus.**


Photo: Julio Pantoja (World Bank)

94 Legislative Decree No. 1412 of 2018, article 28 defines four levels of interoperability: organizational, semantic, technical and legal.

## Key Stakeholders for Amazon Data Governance

Achieving an integrated, effective data governance system for the Amazon requires contributions from a broad range of stakeholders (see Figure 3.3). Each group has a vital role to play in the data ecosystem. Harnessing and combining their strengths and addressing their concerns is essential for developing a sustainable data governance framework that aligns with agreed social contract norms.

**Figure 3.3. Mapping key stakeholders in the Amazon climate data governance ecosystem**

| Public Sector | Private Sector | Academic and Research Institutions | Regional Organizations | International Organizations | Civil Society Organizations (CSOs) | Indigenous Peoples and Local Communities |
|---|---|---|---|---|---|---|
| Generate, process, and use climate, hydrological, and environmental data for policy, planning, and service delivery | Both users and producers of climate-relevant data; contribute through satellite imagery, sensors, and analytics solutions; rely on public data for risk managment and planning | Advance climate modeling, data integration, and innovation; collaborate with public, Indigenous, and international partners | Promote standards, interoperability, and coordination; support joint monitoring systems and integration across borders | Finance initiatives that enhance data infrastructure, institutional capacity and governance frameworks across Amazonian countries | Facilitate data dissemination, transparency, and participatory monitoring; connect scientific and community-generated data with public audiences | Produce and use data through community-based monitoring of forests, biodiversity, and fire management, integrating traditional and scientific knowledge |

**Public Sector:** Governments are the primary collectors of public data, and remain the cornerstone of climate data governance. Public national agencies can break down internal silos within a country with different departments exchanging data and co-developing integrated information systems. A positive development in the past five years is that some countries have passed laws or reforms to improve climate data management. For example, Peru's Framework Law on Climate Change (2018) created a national Greenhouse Gas (GHG) inventory system called INFOCARBONO to centralize emissions data. This legal mandate pushes agencies to share data into one system.[95] Similarly, many countries are adopting open data policies and joining the Escazú Agreement, which commits governments to make environmental information accessible to the public and each other.[96] Public agencies are encouraged to implement and standardize how data is collected, so one national database serves multiple purposes, to actively participate in regional coordination and to ensure data quality and continuity.

**Private Sector:** By providing the technology that collects, generates, and processes data, and the infrastructure though which it flows, the private sector— ranging from technology companies to telecom providers and environmental consultancies —influences the design and implementation of data governance frameworks and practices in the Amazon. Telecommunications companies can expand connectivity in the Amazon, considering that good quality networks are a prerequisite for data transmission in remote areas. Cloud service providers and big tech firms also offer support. At the same time, relying on proprietary data infrastructure or technology applications for data processing can raise concerns around intellectual property rights restricting access to data, which needs to be accounted for in negotiated licensing terms, as well as broader concerns about consolidating control over core infrastructure in the hands of the private sector.

**Box 10: The role of public-private cooperation**

Public-private cooperation is critical to creating comprehensive data repositories relating to climate mitigation, though few existing policy and legal frameworks impose generally applicable obligations on the private sector to disclose proprietary data. Conventional open data laws do not apply to private sector data. Moreover, such data may further be protected as part of a relevant database or intellectual property right safeguard, restricting their sharing. Exceptions exist, for example in the case of laws that mandate data sharing for either certain types of data ("high value datasets", for example) or between specific groups (e.g., business to government [B2G] or business to research [B2R). Existing institutions can also develop platforms that encourage voluntary data sharing. An example of this is the AdaptAcción initiative in Peru, though it is limited in terms of replicability since companies primarily share reporting data, rather than commercially generated (and therefore proprietary) data. Maintained by the Peruvian Ministry of Environment, the platform is building a library of adaptive actions undertaken by companies in Peru. The portal is further supplemented by additional resources, such as toolkits and relevant standards, to facilitate such adaptation. Over time, with appropriate funding, integrating such data with public data can help improve policymaking related to fostering corporate commitments to tackle climate change.

95 Córdova & Lefevre, 2016
96 Ortiz, 2020

**Academia and Research Institutions:** Universities, research centers, and think tanks can complement these efforts, providing the technical know-how and innovation needed to enhance data collection and governance efforts. From developing new technologies for data collection and analysis, such as advanced satellite image processing or climate modelling tailored to the region, to academic initiatives that have already led the way in some areas, these institutions play a key role in generating evidence, informing policy, and fostering collaboration across sectors. MapBiomas, for instance, was driven by academic and NGO experts employing ML for land cover mapping.[97] Additionally, universities and research institutes can act as innovation hubs and trainers helping to standardize data protocols, and conducting training workshops and joint research.[98] In an ideal data coordination framework, academic institutions should be key partners in designing the systems to ensure scientific rigor and in interpreting the data to inform policy through assessments, alerts, and decision-support tools.

**Regional Organizations:** Regional organizations play a critical coordinating role in climate data governance in the Amazon by facilitating cross-border collaboration, harmonizing standards, and supporting data sharing among Amazonian countries. Because climate and environmental processes in the Amazon Basin are inherently transboundary, these organizations help address fragmentation across national data systems and promote regional interoperability. A central example is the ACTO (see next section for additional details). Regional organizations also act as intermediaries between national governments and global frameworks, translating international standards into regionally appropriate methodologies. By convening technical working groups, supporting shared platforms, and facilitating peer learning, these bodies help reduce asymmetries in data quality and availability across Amazonian countries. Their role is particularly important in sustaining long-term regional datasets and early warning systems that depend on political cooperation and institutional continuity beyond individual national administrations.

**International Organizations:** International organizations are highly influential actors in Amazon climate data governance due to their roles as funders, standard-setters, and technical partners. MDBs, UN agencies, and international environmental organizations often finance the development of national and regional data systems, shaping both the scope of data collection and the governance arrangements surrounding it. International organizations also integrate Amazon-specific data into global platforms and assessments, such as global forest cover maps or climate risk indices, increasing international visibility and comparability. However, this influence can raise concerns about sustainability of externally funded systems, and potential misalignment with local priorities. Effective climate data governance therefore requires that international support strengthens national institutions and regional cooperation, rather than creating parallel data infrastructures that are difficult to maintain once funding ends.

**CSOs:** CSOs play a vital role in climate data governance in the Amazon by acting as data producers, intermediaries, and accountability mechanisms. NGOs, grassroots organizations, and advocacy groups frequently collect, analyze, and disseminate environmental and climate data, particularly in areas where state presence is limited or where independent monitoring is needed to complement official datasets. Initiatives like MapBiomas—led by a coalition of NGOs, universities, and technical partners—have become essential sources of consistent, publicly accessible land cover and deforestation data used by governments, journalists, and researchers alike. Beyond data production, CSOs play a crucial governance role by promoting transparency, scrutinizing public and private sector actions, and advocating for inclusive and ethical data practices. Many work closely with Indigenous Peoples and Local Communities, supporting community-based monitoring initiatives and helping translate locally generated data into formats that can influence policy while respecting consent and data ownership. In climate data governance frameworks, CSOs therefore function as both technical contributors and normative actors, ensuring that data use aligns with environmental justice, accountability, and community rights.

**Yanachaga-Chemillén National Park, Peru**

Photo: Marlondag-CIFOR Sol Mujeres SF 048

97 Mulville, et al., 2024
98 Schaedler, 2024

**Indigenous Peoples and Local Communities:** Indigenous Peoples and Local Communities in the Amazon are essential partners in climate data governance. They often notice changes in the environment before satellites or external observers do. Their role begins with their traditional forms of knowledge production and practices. With their input and consent, it is possible to determine the role that data collected from and by them can play in helping monitor climate risks. Examples of their contributions to data collection are community-based monitoring programs, where locals are trained to use tools and applications described in Chapter 1, including, but not limited to, GPS, cameras, and mobiles apps to record deforestation, wildlife sightings, rainfall, or river levels. These programs can increase the spatial coverage of data and improve qualitative insights. Furthermore, engaging these communities in data initiatives can improve evidence-based understanding of specific knowledge or practices in these communities that may be underrepresented in existing data.

However, it is crucial to ensure data governance frameworks are designed in a manner that respects stakeholders' rights, including accounting for indigenous norms and culture. Any regional data platform should have protocols to ensure community-generated data is not published or shared without consent, and that the community benefits from any insights gained. While this approach is not yet mainstream, initiatives have been created to support the development of data access mechanisms that address local concerns around the expropriation of Indigenous data (whether by denial of access to the data itself, or of the tools used to interpret the data) and the unfair representation of Indigenous Communities within datasets and governance mechanisms.[99]

Some community data collecting initiatives have been designed around the concept of Indigenous Data Sovereignty (IDS). IDS confers on such communities the right to govern, own, collect and apply their own data,[100] including exercising control over how this data is used (e.g., to train AI). Such data include Indigenous knowledge, information and digital data. In the context of the Amazon, such sovereignty attempts to empower Indigenous Communities to ensure their active participation in making decisions around activities such as logging, territorial delimitation, and conversion of forest lands into pastures or other forms of cultivable land. Alternative data governance models include the adoption of the CARE principles[101] by the Global Indigenous Data Alliance.[102] The principles recommend that the optimal model for governance is one involving data management and stewardship. Such stewardship involves asserting collective rights, in addition to individual rights, over data. The former includes the right to collective self-determination over data, whereby communities determine how value is extracted from data, in line with Indigenous values and community interests.[103]

Subsequent commentary on the CARE principles has determined they apply to environmental data, which aligns with the position of groups such as the Data Sovereignty Network.[104] Specifically, such commentary favors Indigenous communities exercising ethical data stewardship over such data, complemented by community-defined codes of conduct.[105] Additional considerations include the incorporation of safeguards requiring specific, explicit consent[106] to data processing involving Indigenous communities. These recommendations, however, focus on data for research. In time, their application to uses other than research also requires careful consideration.

**Box 11: Safeguarding Indigenous data sovereignty through Free Prior Informed Consent**

The principle of Free Prior Informed Consent (FPIC) allows Indigenous People to give or withhold consent to projects that "may affect them or their territories."[1] Conventionally, the requirement is applied to overland activities. Notably, however, novel legal developments in the Amazon suggest that they may apply to data as well. In 2022, the Constitutional Court of Ecuador noted that the requirement of free, prior informed consent for land projects must not be constructed to apply to overland projects only. Instead, consent must be obtained for such activities that could affect Indigenous Communities environmentally or culturally.[2] Relatedly, Peru's Law No. 27811 of 2002 requires entities interested in accessing collective knowledge for scientific, commercial or industrial purposes to obtain PIC from representative Indigenous organizations. Specifically, the law notes that Indigenous Communities may dispose of their collective knowledge in ways they see fit.[3] Once consent is sought, these organizations are in-turn required to communicate the request to the highest number of people within the community. Considered together, these legal mechanisms illuminate the link between data and Indigenous rights. Implementing an FPIC framework can, accordingly, safeguard such rights and ensure that collected data is used for purposes strictly connected to climate change adaptation and mitigation.

1 The Food and Agriculture Organization of the United Nations (FAO), 2016
2 Amnesty International, 2022
3 Government of Peru, 2002

99 Cruz, et al., 2020; More, 2022
100 Davies et al., 2019
101 Collective Benefit, Authority to Control, Responsibility, Ethics.
102 Global Indigenous Data Alliance, 2018
103 Carroll et al., 2020. For literature on Indigenous People participation in digital data/environment See e.g., "Co-producing autonomy? Forest monitoring programs, territorial ontologies, and Indigenous politics in Amazonia" ; and "The adoption of earth-observation technologies for deforestation monitoring by Indigenous people: evidence from the Amazon"
104 Indigenous Data Sovereignty Networks: https://indigenousdatalab.org/networks/
105 Angarova, et al., 2022
106 By specific consent, we refer to such consent frameworks that rely on obtaining consent for each data processing activity. Explicit consent, meanwhile, refers to such consent mechanisms that disclose the risks associated with the data processing activity, and involves individuals providing consent through clear, affirmative action. Pre-ticked boxes do not constitute explicit consent.

## The Challenge of Coordination Among Institutions

**Local inhabitants attend a course on integration and dynamic involvement with others in the Brazilian Amazon**

Photo: Julio Pantoja (World Bank)

Institutions are critical to the design and implementation of data governance frameworks, and can improve the coordination of disparate climate data collection initiatives in the Amazon biome. However, coordination among them is complex and fragmented at the national and regional levels, with several ministries, agencies, and organizations operating in parallel, with overlapping mandates and limited coordination. This fragmentation makes it difficult to obtain a big picture of Amazon's health and hinders effective climate action. A collective effort is needed to improve institutional coordination and collaboration across the Amazon. The following section assesses the status quo in the region and explores how a regional institution such as the ACTO could help develop a more integrated approach to data governance for more effective use of existing data, as well as a rationalized and coordinated effort to identify new data needs. It also discusses the roles of academia, public agencies, the private sector, and the local Indigenous Communities, who are critical stakeholders in an integrated data system.

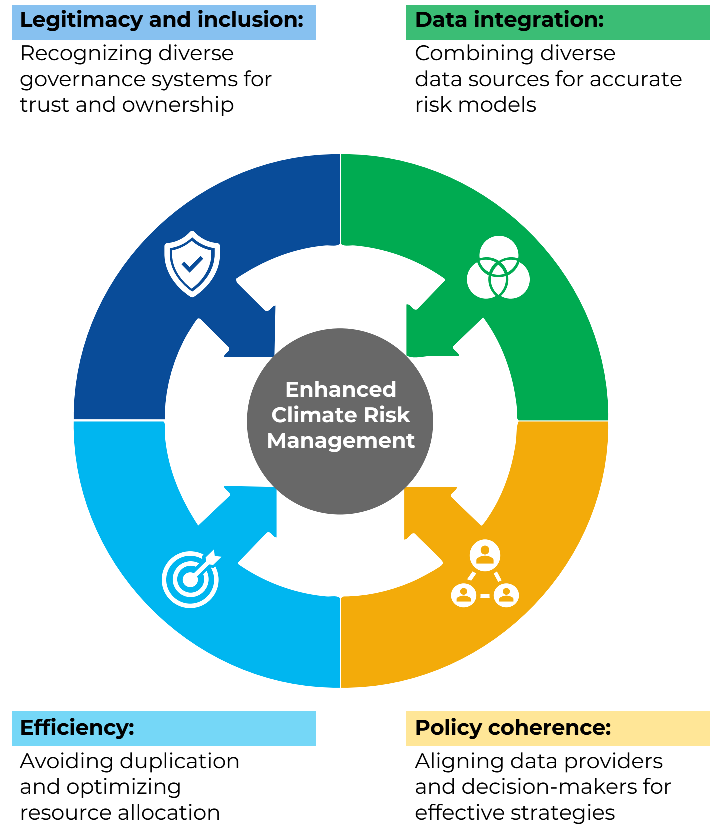
In each Amazon country, multiple institutions are responsible for climate-related data, including environmental ministries, forestry or agriculture agencies, meteorological and hydrological services, and research institutes. In Peru, IGP[107] leads long-term climatological analysis and geophysical research. In 2024, IGP signed an agreement with SENAMHI to enhance climate hazard monitoring and research, unifying their technical capacities.[108] In Brazil, INPE through its CPTEC[109] provides long-term climate projections using its advanced computing capacity and modeling expertise, and is leading the development of the computational model MONAN,[110] which can be formally included in the list of climate models used in the Intergovernmental Panel on Climate Change (IPCC) reports.[111] Altogether, CPTEC, INPE, and INMET monitor oceanic conditions that influence weather and seasonal climate patterns across the Amazon, such as the El Niño Southern Oscillation (ENSO). In Colombia, IDEAM serves as the primary public authority for hydrometeorological data, climate analysis, and EWS. It manages national climate scenarios and maintains a climate services platform called DHIME,[112] which compiles information from regional and local observatories to support risk management and environmental planning. Smaller countries such as Ecuador, Bolivia, and the Guianas, face capacity constraints, and the agencies handle climate data with limited resources, relying on international data or support. In all cases, institutional roles have evolved, resulting in a patchwork of data management efforts that are not fully synchronized.

National legal frameworks also vary significantly. Environmental legislation and data policies are not harmonized across Amazon countries.[113] For instance, approaches to monitoring deforestation need to be based on policies consistent in their remit meaning including consistency in definitions of terminology, identification, and measurement, to name a few. Limitations of current definitions of "forest" and "deforestation", for example, due to variations across geographies and contexts, lead to inconsistent estimates of forest and deforestation, even resulting in significant areas of unaccounted deforestation. Current definitions are also too often incompatible with satellite observations used to monitor forests and deforestation. This is not limited to multilateral partnerships; even within a single country, definitions of forest can vary.[114]

One country might mandate open publishing of deforestation data, while another treats such data as sensitive or pro-

107 Instituto Geofísico del Perú - Geophysical Institute of Peru.
108 SENAMHI Peru, 2024
109 Centro de Previsão de Tempo e Estudos Climáticos - Center for Weather Forecasting and Climate Studies (Brazil).
110 This refers to a computational system developed in Brazil "MONAN - Model for Ocean-Land-Atmosphere Prediction" that simulates the interaction between the atmosphere, oceans, land surfaces, ice, and living systems, based on an Earth system model designed to capture these complex dynamics.
111 Hoschsprung Miguel, et al., 2019
112 Sistema de Información para la Gestión de Datos de Hidrología y Meteorología - Information System for Hydrology and Meteorology Data Management.
113 States Parties to the Amazon Cooperation Treaty, 2023
114 UNFCC REDD+, 2024; Zalles, et al., 2024

**Figure 3.4: Benefits of institutional coordination**




Source: Authors

prietary. Methods for measuring climate indicators—such as deforestation rates, carbon emissions, or water levels—often differ by countries, and even withing a country, preventing easy comparison. This lack of standardization is a result of a lack of binding requirements for standardized reporting across countries, including for Nationally Determined Contributions (NDC).[115]

Some aspects of interoperability and data sharing require coordination at different levels, including local, national, regional, and international. For climate issues that require cross-border data sharing, public and academic institutions may play a role in facilitating collection, consolidation, interlinking, and sharing of data for research and decision making around climate change. IDEAM and other entities have been undertaking initiatives to support data interoperability. These efforts have led IDEAM to be able to leverage data management and delivery portals and applications to allow more advanced data-driven environmental alerts in cases of extreme weather events by combining image and geospatial data. In addition to EWS, IDEAM's work on data governance is also enabling the publication of a web-accessed nationwide monitoring system for deforestation in Colombia.[116]

Effective data governance requires well designed institutional arrangements to enable coordinated implementation of legal and technical requirements across multiple countries and actors. Given the nature of the Amazon biome and the diversity of data type relevant to climate change, institutions collect data related to climate change adaptation and mitigation for different purposes. To effectively collect and process them, institutions further develop competence in building and deploying digital technologies. A coordinated approach to data collection and sharing does not necessarily imply that only one agency or institution collected specific datasets; it may be helpful for data to be collected in a coordinated manner (e.g., on methodology) by multiple stakeholders to ensure sufficient redundancy to support the sustainability of data collection and processing. This is especially important for data that may be considered politically sensitive and possibly subject to financial or political restrictions. In addition, some data may be considered part of critical infrastructure or may be required to be collected at the national level, such as meteorological data per WMO rules.

A regional institution can support coordinated ownership over the data for climate agenda in the region, including agreeing on norms, policies and approaches around data use. As noted, a wide array of institutions, varying by country and sector, manage these activities, resulting in overlapping roles and fragmented approaches. For example, national meteorological and hydrological institutes such as Brazil's INMET and ANA,[117] Colombia's IDEAM, Peru's SENAMHI, Bolivia's SENAMHI,[118] and Ecuador's INAMHI[119] collect and disseminate critical climate variables, but they lack coordination. Also, CEMADEN[120] and Defensa Civil[121] in Brazil, UNGRD[122] in Colombia, and INDECI[123] in Peru, generate and use data to issue alerts and respond to climate-related events. However, they often operate in fragmented ecosystems where alert generation and disaster response lack coordination.

One example of a regional institution that is trying to address this fragmentation is ACTO. ACTO could be uniquely positioned to serve as the coordinator of climate-related data governance in the Amazon region. Established in 1978 by eight Amazonian countries (Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname, and Venezuela), ACTO's mandate is to promote the development of the Amazon Basin through cooperation. It is the only intergovernmental organization encompassing all the Amazon nations. In recent years, there

115 As determined in the Paris Agreement, even with recent Advisory Opinions from the ICJ and IACHR highlighting the responsibility of states to collect climate-related data.
116 Sensors & Systems, 2012
117 Agencia Nacional de Aguas e Saneamento Básico - National Water and Basic Sanitation Agency (Brazil).
118 Servicio Nacional de Meteorología e Hidrología - National Meteorology and Hydrology Service (Bolivia)
119 Instituto Nacional de Meteorología e Hidrología - National Institute of Meteorology and Hydrology (Ecuador).
120 Cemaden Centro Nacional de Monitoramento e Alertas de Desastres Naturais - National Center for Monitoring and Early Warning of Natural Disasters (Brazil).
121 Civil Defense (Brazil).
122 Unidad Nacional para la Gestión del Riesgo de Desastres - National Unit for Disaster Risk Management (Colombia).
123 Instituto Nacional de Defensa Civil - National Institute of Civil Defense (Peru).

is growing recognition that ACTO could be the ideal platform to tackle the fragmentation and overlap by facilitating data sharing, standardization, and joint strategies.

One reason ACTO could be ideal is that its structure was designed for coordination from the onset, with a permanent secretariat in Brasília but also with Permanent National Commissions in each country. Under the treaty, each country's commission should ensure treaty provisions, including cooperation in research and information exchange. This mechanism could be used to improve inter-agency coordination at the national level in line with regional agreements. Furthermore, ACTO has experience managing regional projects, such as the joint hydrometeorological database and climate co-operation efforts pursued under its framework in the 2000s. With climate change intensifying, member states have recognized the need for a new cooperation agenda through ACTO as evidenced by the 2023 Belém Summit, where participants tasked ACTO with new responsibilities. Effective data governance involves adopting strategies that enable data sharing to stakeholders across the Amazon, but there are bottlenecks to such governance. As discussed, data exists in "siloes". Moreover, finding or aggregating this information requires additional, onerous effort. Addressing this requires nuanced policy interventions aimed at collaborative sharing, appropriate application of openness-by-design,[124] and incorporation of appropriate data safeguards.

Unifying access points to enable easier access to open data sources and indicators for users can improve data accessibility and use. Data on climate change in the Amazon is distributed, and may be categorized differently. One framework is to categorize data by type of purpose:

- (i) data that reveals changes in temperature, rainfall, and other meteorological variables;
- (ii) data on the impacts of, and adaptation to, climate change; and
- (iii) data related to mitigation actions.

This division reflects the organization followed by the IPCC. While not authoritative, it could provide a framework to systematically categorize disparate data sources under coherent themes, and align with international practices, as well as legal documents and reports, including for major climate change funds.

A portal that would intermediate a federated climate data ecosystem would require the designation of a competent steward to facilitate its maintenance and sustainability. Given the number of players in the ecosystem, and the need for both a political stewardship function and a technical implementation role, the proposed model for data stewardship is likely to require a multi-stakeholder approach. A candidate for such stewardship could be a coordinated role between ACTO (to lead on the political mandate and intergovernmental coordination function) and the SPA, which would lead on the technical side. The SPA is convened under the auspices of the United Nations and has experience in coordinating and publishing research commissioned by governments. Moreover, the SPA is already staffed by a significant number of scientists who may continue to develop best practices in processing, refining and sharing this data. More generally, prior coordinating experience and the ability to build scientific consensus are desirable attributes in a steward for climate change data. To scale this proposal successfully in practice, it will be important for the stewards to continue meaningfully engaging with existing networks of researchers and contributors to data collection and processing efforts, including researchers, businesses, students, Indigenous Peoples and Local Communities, who will need to be included to ensure the appropriate processing of indigenous knowledge. Some of these groups may be formalized into structured committees, working groups, or other forms of partnerships. Other existing networks that could potentially be leveraged include the Network of Research Centers in the Amazon (RedCIA), which is currently a complementary initiative to ACTO's ARO.[125]

**Territorial protection workshops bring Indigenous Peoples together at the Forest Peoples Training Center**

Photo: Ila Verus (CPI-Acre)

124 The decision to make data open by design and default has implications with the rise of AI, since open data is available for the training of Large Language Models (LLMs). There may be broader policy questions around how to balance between openness and protecting IPR, especially for data generated or collected by the private sector. A coordinated discussion on what should be made "open" and what should be disclosed with access conditions is a critical question for the region, and one that could be facilitated through ACTO and others.
125 Ruffino, 2024

## Key Recommendations for Addressing Data Governance in the Amazon

As discussed, data governance must be prioritized for digital conservation technologies to achieve their intended goals. More importantly, data governance is needed to ensure Indigenous Peoples and Local Communities, which these technologies intend to benefit, are able to play an active role in developing and enforcing governance processes. Given this, the following represent recommendations to consider:

IMPLEMENTATION TIME

Short term | Medium term | Long term

| RECOMMENDATIONS | DETAILS/BENEFITS/CAVEATS | PRIMARY STAKEHOLDERS | ADDITIONAL ACTORS |
|---|---|---|---|
| **Improve access and quality of climate data.** Enabling effective use of climate-related data requires working on both improving access to and the quality of data. Achieving these objectives requires a combination of legal, technical, semantic, and organizational reforms, with capacity building and change management to support implementation.<br>Medium term | This can be facilitated through standardizing data processing and sharing protocols and standards, developing collaborative platforms for facilitating data access, and integrating public data sources to fill gaps. Legal frameworks such as Brazil's Access to Information Law, Peru's Law on Transparency, and Ecuador's Open Data Policy establish clear mandates for proactive disclosure of environmental and climate datasets. Interoperability frameworks, including Peru's four-level model and Brazil's data-sharing provisions, offer structured approaches to harmonizing exchange across agencies, allowing faster integration of datasets for monitoring deforestation, biodiversity, and disaster risk and impact. | • Ministries of Environment, Climate, Forestry and Water<br>• National meteorological and hydrological services<br>• National statistical and geo information agencies<br>• Digital government and data governance units<br>• Public agencies managing national environmental or climate data portals | • ACTO<br>• Scientific networks<br>• Universities and research centers<br>• Civil society groups working on environmental monitoring and transparency<br>• Private sector |
| **Promote multi-stakeholder partnerships for data governance.** Engaging academic institutions and the private sector in the design and implementation of data governance policies and standards can improve their quality and support PPPs for more diverse data and more innovative solutions to tackle climate change.<br>Medium term | Collaborative approaches have supported tools such as Colombia's integration of environmental monitoring with emergency response databases, which demonstrates how shared expertise can translate technical standards into actionable platforms for risk mapping and early warning. For these platforms to be effective, it is equally important that relevant government users and other stakeholders have the capacity to interpret and respond to the data being delivered. | • Ministries of Environment and Climate<br>• Ministries of Science, Technology and Digital Transformation<br>• National environmental and meteorological agencies<br>• Universities and research institutes active in climate science | • Private sector<br>• Civil society organizations working on monitoring and advocacy<br>• International organizations and development partners supporting climate and data programs |
| **Co-design data governance frameworks with Indigenous Peoples and Local Communities.** Ensure they are empowered to participate in data collection processes. Integrating Indigenous knowledge in monitoring and validation processes can enhance the legitimacy and accuracy of climate-related data.<br>Medium to long term | Data governance frameworks should align with Indigenous norms, provide mechanisms for consent and benefit-sharing, and prioritize ethical stewardship consistent with community values and approaches. Peru's Law on the Protection of Collective Knowledge and Ecuador's constitutional consent provisions reinforce free, prior, and informed consent, while inclusive practices such as Ecuador's multilingual data notices and Peru's requirements for offline dissemination ensure equitable access. | • Representative Indigenous organizations<br>• Indigenous and Local Community groups at national and regional level<br>• Ministries or agencies responsible for Indigenous affairs, social inclusion and human rights<br>• Ministries of Environment, Climate and Forestry operating in Indigenous territories | • CSOs<br>• Academia and Indigenous knowledge holders involved in participatory research<br>• MDBs |

| RECOMMENDATIONS | DETAILS/BENEFITS/CAVEATS | PRIMARY STAKEHOLDERS | ADDITIONAL ACTORS |
|---|---|---|---|
| **Strengthen regional data integration and custodianship.** Support regional data integration efforts to reduce duplication (while allowing for data redundancy needed for sustainable data collection and data verification/calibration efforts), improve access to coordinated and reliable climate-related data, and expand data accessibility to a broader range of stakeholders.<br>Medium to long term | This requires carefully evaluating what regional institutions have the characteristics to be effective custodians of regional data repositories and platforms, ensuring sustainable funding streams, sufficient technical capacity and leadership to play this role. National initiatives provide relevant models to inform regional platforms, such as Brazil's sectoral committees linked to the Amazon Fund and its open data governance framework. Scaling open data portals in Colombia and Ecuador could also support deforestation, water quality, and disaster risk data aggregation to benefit a broader range of stakeholders. | • ACTO and ARO<br>• National environmental, meteorological and hydrological agencies<br>• Ministries of Foreign Affairs and regional integration bodies. | • Scientific networks<br>• National open data and digital government units<br>• CSOs and academic coalitions contributing to validation and quality control |
| **Strengthening ACTO's role in regional climate data governance.** ACTO is uniquely positioned to coordinate climate-related data governance in the Amazon, bringing together eight countries under a single intergovernmental framework. Its structure—with a permanent secretariat and national commissions—facilitates regional cooperation and information exchange.<br>Medium term | ACTO's experience managing joint projects, and its expanded mandate from the 2023 Belém Summit, highlight its capacity to address data fragmentation. Effective governance will require collaborative sharing, standardization, and robust safeguards. Strengthening ACTO's role can help overcome institutional siloes and advance integrated climate data management across the region. | • ACTO Secretariat<br>• National Permanent Commissions of ACTO member states<br>• Ministries of Environment, Climate and Foreign Affairs | • ARO<br>• Science Panel for the Amazon<br>• National climate data agencies<br>• MDBs |

**Training of indigenous population in ACRE using digital technologies**

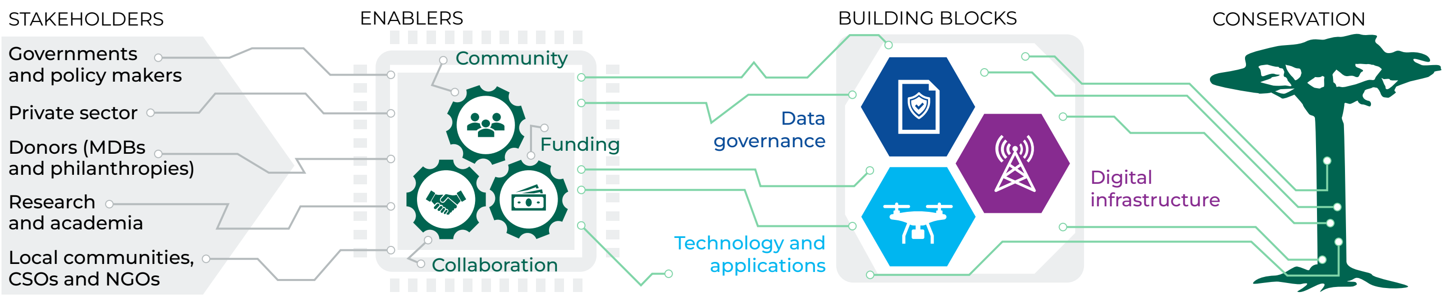
Photos: Ila Verus (CPI-Acre)

## CHAPTER 4

# Conclusions and Recommendations

Digital technologies hold significant potential to contribute to the Amazon's conservation and management. The rapid advancements over recent decades, paired with enhanced connectivity, have already transformed environmental monitoring by enabling near real-time integration of data, innovative ideas, and new facilities, allowing for quicker detection of threats and more effective responses. Yet, the development of a technological solution is not enough to ensure its path to scalability and sustainability. For that to happen, there needs to be an emphasis not only on the technologies themselves, but on the enabling elements that support their uptake.

This report focused on three key building blocks for digital conservation technologies to support sustainable and scalable conservation in the Amazon. In this chapter recommendations are provided that go beyond quick solutions but rather provide insight on how to prioritize stakeholder engagement as a part of creating buy-in and ensuring long-term sustainability of these solutions.




### Building Block #1 Technology and applications

**Conclusion**: Digital technologies and applications can enhance monitoring systems, inform investment decisions, and support long-term conservation objectives.

**Main recommendations:**

- It is essential to involve Indigenous Peoples and Local Communities in the design and implementation of digital technologies for conservation.
- Local manufacturing and maintenance of digital devices reduces import dependency, lowers costs, and builds regional expertise.
- Investing in research and innovation, particularly through academic collaboration, advances tools and technologies for environmental monitoring while carefully balancing cost trade-offs.
- Strengthening internet coverage and regional computing infrastructure is essential for digital conservation tools, while ensuring regulatory compliance and minimal environmental impact.

### Building Block #2 Digital infrastructure

**Conclusion**: 85% of the population living in the Amazon has access to the internet but only 3.5% of the region is covered by mobile or fixed connectivity. The gap is even higher across Indigenous Territories. To untap the potential of digital technologies for conservation is essential to reach remote areas with internet leveraging all data transmission technologies. However, bringing internet to unconnected populations requires appropriate safeguards to minimize the risks and ensure a positive socio-economic online experience.

**Main recommendations:**

- A blended finance approach combining public budgets, development bank funding, PPPs, and innovative mechanisms like carbon credits is essential to fund Amazonian digital connectivity infrastructure.
- Integrating existing national connectivity initiatives across Brazil, Peru, and Colombia can create a unified Amazonian optical corridor, enabling cross-border data sharing and a resilient regional digital infrastructure.
- A mix of technologies offers cost-effective, energy-efficient connectivity solutions to accelerate internet coverage and support real-time environmental monitoring across the Amazon.
- Empowering community networks, small ISPs, and local populations with skills and ownership reduces maintenance costs and delivers sustainable last-mile connectivity across remote Amazonian territories.
- Broad digital skills training for all populations, including Indigenous communities and youth, is essential for safe internet use and local capacity to maintain and operate telecommunications infrastructure.
- Effective connectivity strategies must be tailored to local economic, political, and social contexts, community-led, and designed with the highest environmental safeguards for the Amazon biome.

**Building Block #3 Data governance**

**Conclusion**: Data from digital technologies can pinpoint where conservation efforts need to be increased and where gains are being made. Yet without solid data governance frameworks, that value risks being lost entirely.

**Main recommendations:**

- Improving climate data access and quality requires standardized protocols, interoperability frameworks, collaborative platforms, and supportive legal reforms to enable effective environmental monitoring across the Amazon.
- Multi-stakeholder partnerships strengthen data governance frameworks and translate shared expertise into actionable climate monitoring and early warning platforms.
- Data governance frameworks must be co-designed with Indigenous Peoples and Local Communities, embedding consent, benefit-sharing, and Indigenous knowledge to ensure ethical, legitimate, and equitable climate data practices.
- ACTO is uniquely positioned to lead regional climate data governance, leveraging its intergovernmental structure to overcome fragmentation and advance data integration.
- Strengthening regional data integration requires identifying capable custodian institutions, ensuring sustainable funding, and scaling open data platforms to reduce duplication and broaden access to reliable climate data.

## The Role of Enablers to Support the Building Blocks

While understanding the building blocks that ensure the sustainable impact of digital conservation technologies is crucial, these components as a standalone are insufficient to ensure wholesale adoption and usage of these technologies. There must be a prioritization in engaging the communities for who the output of these solutions are meant to benefit at the onset of solution design. As well, planning for ongoing utilization and sustainability of these solutions cannot be isolated to fit within funded project cycles with one or two partners, but require an intentional plan for long-term funding and cross-sectoral partnerships. Some examples of what should be considered to support promotion of these building blocks with sustainability in mind are shared below.

**Foster community engagement:** Align digital technologies development with community priorities, beginning with a clear understanding of their needs to ensure that innovations effectively support local conservation efforts. This includes, but is not limited to:

- **Prioritize contextualized solutions:** Digital conservation technologies need to be informed by Local Communities, while connecting with a larger goal. Design and deployment of solutions should be grounded in the unique economic, political, and social constraints of the region.
- **Build community-level awareness of conservation opportunities and their benefits:** Community-level awareness and buy-in of conservation opportunities are critical to ensuring the long-term adoption of conservation technologies. This requires fostering understanding of both the short- and long-term impacts of environmental degradation, while demonstrating how conservation interventions can advance communities' long-term socio-economic well-being.
- **Promote digital skills training and longer-term capacity building:** Digital barriers related to accessing digital devices, maintaining networks, and using technologies—along with pre-existing social-cultural factors—can significantly impede the ability of individuals to use digital conservation technologies. Digital skills training that focuses on building digital literacy can increase community engagement while, at the same time, addressing the shortage of skilled personnel with expertise in digital technologies.

**Secure funding:** Finance is a critical obstacle both in the short- and long-term, significantly constraining the efficacy of digital conservation technologies. This is not limited to finance for the solutions themselves, but also includes long-term investment in infrastructure deployment, policy design, implementation, and innovation. There is no one funder who should be considered for this as actors from across sectors play a role.

**Seek partnership and multi-sectoral collaboration:** The complexity of climate adaptation demands an interdisciplinary approach. This report has highlighted the importance of the roles of public, private, and social sector actors in facilitating the use of digital conservation technologies. Enabling their use requires bridging disciplines and fostering stakeholder collaboration and coordination across sectors and countries. Coordination is also essential for data governance frameworks to be fit-for-purpose, and designed in consultation and collaboration with institutions across sectors. Reducing institutional fragmentation by expanding collaboration through platforms such as ARO-ACTO, RAISG, SERVIR-Amazonia, and MapBiomas enhances data sharing, resource pooling, and regional monitoring capacity. Strengthening partnerships among Amazonian countries, research institutions, and international agencies will improve coordination and attract funding.

## Recommendations by Stakeholder Groups to Promote the Building Blocks' enablers

Promotion of these components requires support from a variety of stakeholders. These stakeholders include Local Communities, researchers/academia, the private sector, public sector, and donors. Engagement needs to extend beyond creating awareness, but rather esnuring support is dependent on understanding the value proposition of these solutions to each stakeholder group. Some suggestions are shared below.

GOVERNMENTS AND POLICY MAKERS

| Community engagement | Funding | Partnerships and multi-sectoral collaboration |
|---|---|---|
| • Co-create a comprehensive and long-term Digital Conservation Strategy approach that recognizes both local and regional needs.<br>• Ensure that Indigenous Peoples and Local Communities retain ownership of collected data to better influence policy, promote community-led governance models and safeguard territorial rights.<br>• Design infrastructural policies that expand internet coverage in remote areas, while ensuring they support the conservation ambitions of communities in the Amazon.<br>• Deploy digital conservation technologies prioritizing data inputs relevant to local communities. Deployments must also promote the uptake and usage by local communities who will directly interact and benefit from these technologies.<br>• Co-design and implement data governance policies that support development of data governance frameworks that prioritize data protection, while also supporting integrated use of data to support regional conservation. | • Prioritize financing the foundational infrastructure needed for digital technologies for conservation across the Amazon. This includes investments in broadband connectivity, energy access, and data infrastructure.<br>• Allocate budget resources and pursue co-financing through regional partnerships, leveraging universal service funds to support targeted connectivity efforts and engaging thousands of small and medium ISPs for last-mile delivery.<br>• Provide catalytic grants and concessional finance to de-risk private investment, while aligning national and local budgets with environmental priorities to sustain long-term commitments.<br>• Develop public policies focused on reducing import tariffs for digital devices and promoting local manufacturing and maintenance capabilities. By making devices more affordable and accessible, it is possible to increase the adoption of digital technologies among low-income households. | • Play a critical role in coordinating the multitude of actors working in the Amazon for increased benefit and accountability. |

LOCAL COMMUNITIES, CSOS, AND NGOS

| Community engagement | Funding | Partnerships and multi-sectoral collaboration |
|---|---|---|
| • Support local communities and help them advocate for solutions that respond to their daily realities and development priorities.<br>• Co-design training on usage of digital conservation solutions with a focus on digital literacy, along with support for community-level implementation of these solutions.<br>• Provide input into accountability mechanisms that ensure external solutions pursue the intended objectives for which they are designed. | • Foster mechanisms such as community-based funds and crowdfunding initiatives. | • Act as a convener, aligning diverse funders and partners around shared conservation goals and building trust among stakeholders.<br>• Empower small operators and local population (e.g., Indigenous-owned connectivity infrastructure) with appropriate skills to decrease the cost and speed of maintaining conservation technologies, while also increasing local ownership of the infrastructure. |

PRIVATE SECTOR

| Community engagement | Funding | Partnerships and multi-sectoral collaboration |
|---|---|---|
| • Invest in conservation technologies without harming the Amazon region, its people, and its natural resources. | • Provide capital to accelerate adoption of digital technologies for conservation. This includes impact investments, venture funds, corporate social responsibility programs, ESG-investments, PPPs, and related approaches. | • Work closely with both public, academic/research, and social sector stakeholders (including communities) to ensure solutions are relevant to the contexts in which they are deployed. |

RESEARCH AND ACADEMIA

| Community engagement | Funding | Partnerships and multi-sectoral collaboration |
|---|---|---|
| • Integrate cutting-edge technologies and research insights with traditional knowledge systems as part of conservation solutions. This ensures that technological advancements complement, rather than replace, local expertise, strengthening both the accuracy and inclusivity of monitoring initiatives in the Amazon biome. | • Invest in research needed to develop tools, technologies, and strategies that keep pace with the evolving challenges of climate change and environmental monitoring in the Amazon. | • Position themselves as trusted partners to the public and private sector to leverage the latest scientific conservation findings. |

DONORS (MDBS AND PHILANTHROPIES)

| Community engagement | Funding | Partnerships and multi-sectoral collaboration |
|---|---|---|
| • Increasingly direct funds for community-based organizations and Local Communities to support their ability to pursue conservation efforts.<br>• Ensure intermediaries partner directly with community-based organizations as part of their implementation efforts. | • Foundations can help fill critical financing gaps that neither governments nor markets are positioned to address, while international NGOs channel resources directly to Indigenous Peoples and Local Communities to strengthen stewardship of ecosystems.<br>• Regional development banks and multilateral institutions can play an important role in channeling funds toward large-scale digital projects that individual states cannot finance alone. | • Make funding approaches multi-dimensional and flexible. |

## Looking Ahead

As development and implementation of digital technologies evolves, so does the potential for these tools to support Indigenous Peoples and Local Communities and governments in advancing conservation efforts across the Amazon biome. Emerging AI applications, including large language models and agentic AI, can play a role in improving data collection and dissemination and in addressing existing inconsistencies. To fully realize the potential of such technologies, a higher degree of regional integration will be required. The data infrastructure needed to harness the value of AI can be prohibitively costly, and individual countries may face challenges allocating sufficient resources. Multi-country partnerships—ideally involving the private sector—can substantially reduce individual country costs while fostering synergies and improving overall outcomes. In parallel, establishment of appropriate normative and environmental safeguards will be essential to promote the secure and responsible uptake of advanced technologies. Finally, it is important to consolidate and preserve systems and approaches that are already functioning effectively, rather than pursuing new technologies indiscriminately, as the newest solutions are not necessarily the most effective.

Beyond conservation outcomes, leveraging digital technologies holds significant socioeconomic promise for the Amazon's inhabitants. The development, deployment, and maintenance of digital conservation tools can generate meaningful employment opportunities in data collection, systems management, community monitoring, and local capacity building — sectors where Indigenous Peoples and Local Communities can take leading roles. This is particularly relevant given that Amazonian populations face considerably higher rates of unemployment and poverty compared to national averages across the region's countries, reflecting decades of underinvestment and limited access to formal labor markets.

In summary, the path to advancing digital conservation technologies in the Amazon—and beyond—depends on a tapestry of intentional prioritization, sustained funding, multisectoral collaboration, robust policy frameworks, and local capacity building. By centering the voices and needs of Indigenous Peoples and Local Communities, fostering inclusive governance, involving traditional and scientific knowledge in the decision making process, and investing in scalable, resilient solutions, we can help ensure that technological innovation genuinely serves both people and planet. The journey is complex and requires commitment on many fronts, but with deliberate action and shared purpose, digital conservation can become a cornerstone of climate adaptation and sustainable stewardship for generations to come.

**CPI-Acre headquarters**

Photo: Felipe Spina Avino

# APPENDIX A

## Stakeholders Interviewed

This is a list of 40 stakeholder organisations, involving over 100 people consulted for this evaluation. The consultation occurred between April 2024 and May 2025, both online and in person.

| STAKEHOLDER | COUNTRY | TYPE |
|---|---|---|
| Conservación Amazónica - ACEAA | Bolivia | NGO |
| Amazonas State Secretariat for the Environment. SEMA-AM | Brazil | Government |
| Acre State Secretariat for the Environment. SEMA-AC | Brazil | Government |
| Amazon Environmental Research Institute - IPAM | Brazil | NGO |
| Brazil Federal Police | Brazil | Government |
| Brazil Ministry of Environment and Climate Change | Brazil | Government |
| Brazil National Institute for Space Research - INPE | Brazil | Government |
| Connect Forest People Network - Conexão Povos da Floresta | Brazil | Other |
| Conservation Strategy Fund - CSF | Brazil | NGO |
| Coordination of Indigenous Organizations of the Brazilian Amazon - COAIB | Brazil | Indigenous People and Local Communities |
| Institute of Forest and Agricultural Management and Certification - Imaflora | Brazil | NGO |
| Kanindé Association for Ethno-Environmental Defense - Kanindé | Brazil | NGO; Indigenous People and Local Communities |
| Pará State Secretariat for Environment and Sustainability. SEMAS -Pará | Brazil | Government |
| Pro-Indigenous Commission of Acre. CPI-Acre | Brazil | Indigenous People and Local Communities |
| Rondônia State Secretariat for Environmental Development - Sedam | Brazil | Government |
| Socioenvironmental Institute - ISA | Brazil | NGO |
| World Wide Fund For Nature Brazil. WWF-Brazil | Brazil | NGO |
| Ethnollano Foundation - Fundación Etnollano | Colombia | NGO |
| Colombia Ministry of Environment and Sustainable Development | Colombia | Government |
| Gaia Amazonas Foundation - GAF | Colombia | NGO; Indigenous People and Local Communities |
| Instituto Humbolt | Colombia | Govt; Academia |
| EcoCiencia Foundation - EcoCiencia | Ecuador | NGO |
| Foundation for the Conservation of the Tropical Andes - FCAT | Ecuador | NGO |
| Amazon Conservation – ACCA | Peru | NGO |
| Geophysical Institute of Peru - IGP | Peru | Government |
| Interethnic Association for the Development of the Peruvian Rainforest - AIDESEP | Peru | Indigenous People and Local Communities |
| National Meteorological and Hydrological Service of Peru. SENAMHI | Peru | Government |
| Peru Agency for the Supervision of Forest and Wildlife Resources - OSINFOR | Peru | Government |
| Peru Ministry of the Environment - Geoforests platform | Peru | NGO |
| Peru National Service of Natural Areas Protected - SERNANP | Peru | Government |
| Amazon Conservation Team - ACT | Regional | NGO |
| Amazon Cooperation Treaty Organization . ACTO | Regional | Other |
| Amazon Network of Georeferenced Socio-Environmental Information - RAISG | Regional | Indigenous People and Local Communities |
| Conservation X Labs | Regional | NGO; Other |
| EarthRanger | Regional | NGO |
| MapBiomas Brazil | Regional | Other |
| Rainforest Foundation Norway | Regional | NGO |
| Rainforest Foundation UK | Regional | NGO |
| SERVIR Amazonia | Regional | Academia; Other |
| WildLabs | Regional | Other |

# APPENDIX B

## English Survey Guiding Questionnaire Used for Stakeholder Consultations

This instrument was used as part of the key informant interviews that were used to inform findings, especially in Chapter 2 of this note.

Authors' note: Our hope is that this instrument may be of interest to readers who wish to further interrogate or update these findings for their own benefit.

**Digital technologies to fight climate change in the Amazon —consultation of key stakeholders**

PART 1: OVERVIEW:

Name ____________________ Date ________________________

Organization _____________
Country_________________

Role ______________________ Email _______________________

**Overview questions (Comments /Instructions)**

**1. Organization type** Please, select from the list:

☐ Government environmental/protected areas agency

☐ Law Enforcement/Environmental Enforcement Agency

☐ IPLC (Organization of Indigenous Peoples and Local Communities)

☐ Conservation NGO

☐ Academic/research organization

☐ Private sector

☐ Others (specify):_________________________

**2. What is being monitored?** Check all that apply:

☐ Deforestation

☐ Land conversion for agriculture

☐ Forest fires

☐ Illegal mining

☐ Drought/floods/water quality

☐ Air quality/air pollution

☐ Biodiversity

☐ Illegal livestock/livestock farming

☐ Others (specify): __________________________________

**3. What technologies do you work with?** Please check all that apply:

☐ GIS/remote sensing (satellite, multispectral and thermal imagery; LiDAR)

☐ GIS Web services

☐ Protected area management systems (e.g. SMART, EarthRanger )

☐ UAV/drones

☐ Camera Traps

☐ Acoustic sensors

☐ Mobile apps

☐ Biologgers /tracking devices

☐ eDNA / environmental DNA

☐ Other sensors (water/air sensor, IoT , off-grid communications)

☐ Machine learning/computer vision

☐ GNSS (positioning systems)

☐ Cloud technologies (for storage and/or computing)

☐ Others________ (specify)

**4. How would you rate the overall performance of this technology?** Rate only the technologies that you use, in one of the categories.

VERY POOR (VP), POOR (P), ACCEPTABLE (A), GOOD (G),

_____ GIS/remote sensing (satellite, multispectral and thermal imagery; LiDAR)

_____ Protected area management systems (e.g. SMART, EarthRanger )

_____ UAV/drones

_____ Camera traps

_____ Acoustic sensors

_____ Mobile apps

_____ Biologgers /tracking devices

_____ eDNA / environmental DNA

_____ Other sensors (water/air sensor, IoT , off-grid communications)

_____ Machine learning/computer vision

_____ Cloud technologies (for storage and/or computing)

**5. Where is the technology used? Which geographic location?** Please briefly describe for each technology that applies:

___________________________________________

___________________________________________

___________________________________________

**6 Please detail the main objectives of the initiative.** Please describe briefly:

___________________________________________

___________________________________________

___________________________________________

**7. Does this initiative respond to an established Digitalization Agenda** Please, select: ☐ Yes ☐ No ☐ I'm not sure

**8. Are you linked to any regional monitoring network/regional organization in the Amazon?** Please describe briefly:

___________________________________________

___________________________________________

___________________________________________

**9. What are the advantages or positive aspects that you find in this technology?** Please describe briefly for one or more of the technologies you use from the list above:

___________________________________________

___________________________________________

___________________________________________

**10. What are the main barriers/performance issues you have encountered in relation to the use of technology?** Please describe briefly for one or more of the technologies you use:

___________________________________________

___________________________________________

___________________________________________

**11. What do you consider to be the results/impacts that you have achieved in your initiative that would have been impossible or more difficult to achieve without the use of technology?** Please, describe briefly:

___________________________________________

___________________________________________

___________________________________________

**12 What would be necessary if you wanted to scale this technology to a broader geographic area or other places in the Amazon?** Indicate priority number for each:
1 Crucial, 2 High, 3 Medium, 4 Low

_____ Greater technological development

_____ Better/available infrastructure

_____ Capacity building

_____ Financial investments

_____ Government support

_____ Other

**13. In your expert opinion, what are the most significant threats and on-the-ground impacts of climate change in the Amazon Rainforest, such as forest fires, deforestation, droughts, biodiversity loss, and others?** Please, describe briefly:

___________________________________________

___________________________________________

___________________________________________

**14. In your opinion, what are the 2-3 Digital Technologies that have the most potential and should be further supported to increase the scale and efficiency of Monitoring in Amazon?** Please, indicate the name of the most relevant technologies:

___________________________________________

___________________________________________

___________________________________________

**15. How can we monitor the Amazon Forest effectively (with the technologies you mentioned above)?** Please, describe briefly:

___________________________________________

___________________________________________

___________________________________________

PART 2 – ADDITIONAL DETAILS:

**Type of data collection:**

☐ Remote collection (e.g., satellite, crowdsourcing, or remote sensing)

☐ Primary data survey.

☐ Human field data measurements (e.g. points collected with GPS or cell phone by a park ranger or local community)

**How is data collected/recorded? Who contributes to data collection?** Please describe briefly:

___________________________________________

___________________________________________

___________________________________________

**Does it allow for participatory data collection by external collaborators?** Please describe briefly:

______________________________

______________________________

______________________________

**Data type and format**. Please describe briefly:

______________________________

______________________________

______________________________

**Does it require an Internet connection for data collection?**
☐ Yes, internet is required ☐ No, it can be done offline

**Does it require an Internet connection for data transmission?** ☐ Yes, internet is required ☐ No, it can be done offline

**Is reliable internet available at the local site?**
☐ Yes, reliable internet is available ☐ No, not available

**Is additional infrastructure needed?** Please describe briefly (e.g. power, sensors; phones, computers, vehicles, etc.)

______________________________

______________________________

______________________________

**Who receives the information? What is the information used for?** Please describe briefly:

______________________________

______________________________

______________________________

**Do you have a web platform for viewing and exchanging information?** Please describe briefly:

______________________________

______________________________

______________________________

**Is the data publicly available?** Please describe briefly:

______________________________

______________________________

______________________________

**What are the data ownership, sharing and access protocols?** Please describe briefly:

______________________________

______________________________

______________________________

**What are the data security measures?** Please describe briefly (encryption, password, etc.)

______________________________

______________________________

______________________________

**What is the complexity of use, the need for training and the availability of support material?** Please describe briefly:

______________________________

______________________________

______________________________

**Other considerations:**

- What was the approximate initial cost for implementation?
- What is the approximate annual running/operating cost?
- What is the financial sustainability/longevity strategy?
- What financial mechanisms or investment strategies are necessary to fund the development and deployment of digital technologies for climate action in the Amazon region?
- What regulatory or policy frameworks are needed to support the integration and deployment of digital technologies for climate resilience in the Amazon ecosystem?
- What are the potential socio-economic benefits and co-benefits associated with the widespread adoption of digital technologies for climate resilience in the Amazon, and how can these be maximized?

Do you have any additional comments or additional details?

______________________________

______________________________

______________________________

Do you have any suggestions on other key actors to consult for this initiative?

______________________________

______________________________

______________________________

# APPENDIX C

## Tools and Initiatives Mentioned Across the Report

| TOOLS AND INITIATIVES | WEBSITE |
|---|---|
| FireSat | https://sites.research.google/gr/wildfires/firesat/ |
| PurpleAir | https://www2.purpleair.com/ |
| DroneDeploy | https://www.dronedeploy.com/ |
| Pix4D | https://www.pix4d.com/ |
| CXs Sentinel | https://sentinel.conservationxlabs.com/ |
| AudioMoth | https://www.openacousticdevices.info/ |
| Song Meter | https://www.wildlifeacoustics.com/ |
| Brasil Mais | https://plataforma.redemaisbr.com.br/#/ |
| MAAP | https://www.maapprogram.org/ |
| PRODES | https://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates |
| DETER | http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/deter/deter |
| Terra Brasilis | https://terrabrasilis.dpi.inpe.br/en/home-page/ |
| Global Forest Watch | https://www.globalforestwatch.org/ |
| MapBiomas Alerta | https://alerta.mapbiomas.org/en/ |
| OASIS | https://www.senamhi.gob.pe/?p=monitoreo-pronostico-sequias |
| SONICS | https://www.senamhi.gob.pe/?p=observacion-de-inundaciones |
| Alerta Clima Indígena (ACI) | https://ipam.org.br/cartilhas-ipam/aci-alerta-clima-indigena-informacao-na-palma-da-mao-para-as-terras-indigenas-da-amazonia-brasileira/ |
| Spatial Monitoring and Reporting Tool (SMART) | https://smartconservationtools.org/en-us/ |
| eBioAtlas | https://ebioatlas.org/ |
| Wildlife Insights | https://www.wildlifeinsights.org/ |
| Arbimon | https://arbimon.org/ |
| Brazil Data Cube | https://data.inpe.br/bdc/en/home-page-2/ |
| Siradx | https://xingumais.org.br/categoria/Sirad X ENGLISH |
| Project Guacamaya | https://news.microsoft.com/source/latam/features/ai/amazon-ai-rainforest-deforestation/?lang=en&msockid=0fc2b56d1df668081caea1a81c31699f |
| AdaptAcción | https://www.adaptaccion.org/ |
| DHIME | http://dhime.ideam.gov.co/atencionciudadano/ |
| EarthRanger | https://www.earthranger.com/ |
| The Gundi Platform | https://projectgundi.org/en-us/ |
| Adapta Accion | https://www.adaptaccion.org/ |
| CPTEC | https://www.cptec.inpe.br/ |
| Connect Forest People Network | https://conexaopovosdafloresta.org.br/ |
| BioModelos | https://biomodelos.humboldt.org.co/en |
| BioTablero | https://biotablero.humboldt.org.co/ |
| PHISIS | https://www.senamhi.gob.pe/servicios/?p=pronostico-hidrologico |
| SILVIA | https://www.senamhi.gob.pe/?p=silvia |
| IDESEP | https://idesep.senamhi.gob.pe/portalidesep/ |
| SOMAI | https://somai.org.br/ |

## CASE STUDIES

The Amazon plays a central role in global carbon regulation and biodiversity conservation, but faces intensifying pressures from deforestation, illegal activities, and the growing impacts of climate change. In response, a range of digital technologies, from mobile apps to drones and environmental sensors, is being used to enhance forest monitoring, inform conservation decisions, and support sustainable resource management. These technologies improve the capacity to monitor ecosystems even in remote regions, offering powerful tools to strengthen biodiversity protection and climate resilience. However, challenges such as fragmented funding, lack of basic infrastructure, limited evaluation of solutions, and uneven technology adoption continue to restrict the realization of broader benefits.

The case studies here were selected to be representative of the Amazon geography and the multiplicity of stakeholders, providing in-depth insights into the role of digital technologies in environmental monitoring within the Amazon biome. Building on extensive stakeholder consultations and the findings presented in the report "Advancing Amazon Conservation through Digital Technologies", they highlight practical examples of digital technology applications in the field. For each case study, we present an overview of the challenges, the implemented digital technologies, the stakeholders involved, the financial requirements, and the strategic considerations for effective implementation and sustainability. Together, these insights provide a nuanced understanding of current practices and strategic pathways for scaling digital conservation tools across the Amazon biome. Ultimately, the case studies show that realizing the value of digital tools for conservation in the Amazon requires more than technology, it demands resilient infrastructure, context-sensitive tools, and robust, community-driven data governance. Success depends on inclusive design, sustained funding, and institutional recognition of local knowledge and data. By following these pathways, stakeholders can build a more effective, equitable, and resilient digital monitoring ecosystem for the Amazon's future.

**Figure C.1: Map of the Amazon biome, with the numbers indicating the selected case study locations**


**Case Study 1**

Use of Technologies to Support Monitoring and Indigenous Territorial Protection

**Rondônia, Brazil**

**Case Study 2**

Integrating Digital Technologies for Climate and Biodiversity Monitoring

**Colombia**

**Case Study 3**

Enhancing Meteorological, Agrometeorological, Climate, and Hydrological Monitoring through Integrated Digital Technologies

**Peru**

**Case Study 4**

Digital Technologies Supporting Indigenous Territorial and Environmental Management and Monitoring

**Acre, Brazil**

# CASE STUDY 1

## Use of Technologies to Support Monitoring and Indigenous Territorial Protection

### The Basics

| 22 | Geography: | 90 | 10 | 6.4 |
|---|---|---|---|---|
| **Indigenous Territories monitored** includes over 44 Indigenous communities and uncontacted groups | **Rondônia, Brazil** | **Indigenous monitors trained** | **Satellite internet hubs** operational in Indigenous lands to support monitoring and protection | **million** hectares monitored |

### The Challenge

IT cover 13 percent of Brazil and contain 98 percent of the country's remaining preserved forests, making them vital for efforts to combat climate change and conserve biodiversity, both nationally and globally.

However, ITs face growing threats due to weak enforcement of land rights and illegal activities, including deforestation, land grabbing, mining, forest fires, unlawful agriculture, and cattle ranching.

### The Stakeholders

**CIVIL SOCIETY**

- The Kanindé Ethnoenvironmental Defense Association (lead institution)
- Indigenous partner asstociations (co-mangement): Jupaú, Metareilá, Waypã, Santo André
- WWF-Brazil (techinical and financial support)
- Connect Forest People Network
- Donor organizations: The Gordon and Betty Moore Foundation, USAID, BMZ/BENGO

**PRIVATE SECTOR**

- DroneDeploy: dronedeploy.org (3 years of software access support)
- SOLVED: Geoinformation Solutions (SMDK plataform co-development)

**PUBLIC SECTOR**

State indirect support, enforcement, prosecution and management

- FUNAI
- IBAMA
- PrevFogo
- Public Ministry

### Overview and Key Achievements

This case study highlights a compelling example of Indigenous-led environmental monitoring that utilizes advanced digital technologies to protect ecosystems throughout the Amazon biome. Launched in 2021 after two years of planning, the initiative now operates across 22 Indigenous territories in Rondônia, Brazil. It integrates satellite-based remote sensing with field data collection, entirely driven by Indigenous associations and their partners. Operating in remote regions with minimal energy and internet infrastructure, the initiative relies on off-grid solutions such as solar panels, satellite internet, and digital radios to ensure effective monitoring. The solution set consists of a robust toolkit, including drones, camera traps, mobile apps like SMART, and the Kanindé SMDK, that enables early detection of deforestation and illegal activities. From the beginning, the project activities were planned in a participatory and inclusive way, encouraging the Indigenous Peoples to define and build the monitoring protocols and safeguards strategies to defend their territories.

Both tools have been adapted and co-developed specifically for Indigenous use. For instance, the SMART interface is based on icons developed in collaboration with Indigenous monitors to reduce reliance on reading and writing skills and make the tools more accessible to different age groups, as some elders are less familiar with Portuguese. The SMDK integrates complementary data from third-party databases, such as environmental fines and rural property registration, which were identified as important by the Indigenous Communities to support advocacy and enforcement of conservation policy through legal action.

Solar panels in the Uru-eu-wau-wau Indigenous Territory in Rondônia, Brazil

Photo: Kaninde

These tools play a key role in producing real-time alerts of forest degradation. Currently, field-based biodiversity monitoring occurs in four territories through portable drones, mobile apps, and non-connected camera traps. Camera trap images are automatically sorted using Wildlife Insights, a free AI-powered platform, which speeds up the image sorting process and reduces the need for technical expertise. Alerts generated by these data are then prioritized by severity, enabling communities to focus their response efforts effectively. For example, the SMDK integrates medium-resolution optical and radar satellite data with machine learning (ML) through Google Earth Engine. Analysts then cross-check these alerts using high-resolution imagery and, where necessary, verify them on the ground.

The entire SMDK system is built using public-domain satellite data and open-source tools, avoiding licensing costs and ensuring broad accessibility. Automated reports compile information from multiple tools and are shared with Indigenous Leaders, who retain full control over access and data sharing, including with public authorities. A dedicated data governance framework ensures transparency, accountability, and local ownership. Local capacity was created, and the Indigenous Associations have developed the necessary means to process and manage their field data independently and forward this information to be used by the advocacy and communication teams.

Beyond surveillance, the initiative aims to curb territorial invasions, generate legal evidence, and strengthen Indigenous land rights, governance, and environmental stewardship. The digital evidence gathered supports advocacy and media campaigns that bolster law enforcement, reverse illegal encroachments, and elevate the visibility of Indigenous Peoples' rights in global conservation dialogues, and may also be used by public bodies if they so wish. Daily alerts, complete with georeferenced imagery, videos, and automated reports integrating data from multiple sources have already sparked joint enforcement operations, leading to equipment seizures and arrests, proving the system's power to catalyze official responses.[126] Safety and surveillance capacity have improved markedly, with technology reducing communities' exposure to conflict. Monitors receive training in patrol strategies, safety procedures, and human rights, and many go on to train others as peer facilitators. These groups adopt several precautions, such as never going alone on an inspection trip, sticking to and informing patrol plans, using a drone to scout ahead for danger from a distance, and having communication capacity. Finally, powerful visual documentation, especially drone footage, has significantly amplified international advocacy efforts, including presentations at the UN Conference Of the Parties (COP) 26 and coverage in the acclaimed documentary "The Territory." These efforts have helped forge stronger ties with public institutions such as FUNAI,[127] IBAMA,[128] and the Environmental Police.

#### Implementation and Operational Challenges

Given the vast territory and challenging logistics, ongoing operational costs remain substantial. These include expenses for data validation and storage, equipment maintenance and replacement, ongoing community stipends, and regular training. For example, the Uru-eu-wau-wau territory is almost the size of Wales and is considered one of the most important Indigenous territories in Rondônia state, given its rich biodiversity and vital freshwater sources. However, it is also a hotbed for environmental crime, especially deforestation. Sustaining the initiative requires continuous funding, yet financial support remains uncertain. High turnover among community monitors and constant training needs also affect the consistency and effectiveness of field verification efforts.

#### Operational Support and Costs

The operation currently uses around 5 drones (costing

126 Órgãos Federais combatem crimes ambientais na Terra Indígena Uru-eu-wau-wau em Rondônia
127 Fundação Nacional dos Povos Indígenas - National Indigenous People Foundation (Brazil).
128 Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - Brazilian Institute of Environment and Renewable Natural Resources.

approximately USD$2,000 each) and 20 standard camera traps (about USD $400 per unit). Development of the SMDK platform required an investment of roughly USD $40,000. Funding had initially been secured from a range of sources, including the Gordon and Betty Moore Foundation, USAID,[129] and BMZ/BENGO[130] (through WWF-Brazil). WWF-Brazil also provides both technical and financial support. Key partnerships, with the Kanindé Ethno-Environmental Defense Association, CTI,[131] Acre, and the Connect Forest People Network project, have been instrumental, particularly in securing internet connectivity in remote areas. Securing ongoing funding for continuous support remains a perpetual challenge.

**Recommendations**

Indigenous Territories serve as vital barriers against deforestation. Empowering Indigenous Peoples and Local Communities with appropriate technologies, combined with ancestral knowledge, can significantly enhance their ability to monitor and protect their lands. For example, encouraging peer-to-peer training and technical exchange among various Indigenous groups is essential to further strengthening local capacity and advancing cooperation. Integrated digital tools improve data collection, safety, and visibility. Effective models of data governance led by communities are also essential for sustaining these efforts. There is strong potential to scale and replicate these initiatives across other Indigenous territories, Protected Areas, and ecological corridors. This requires adaptation to the unique social and cultural dynamics of each group, ongoing peer support, and coordinated efforts to unify existing initiatives. Successful expansion also depends on the formal recognition of Indigenous monitoring by government institutions and command-and-control bodies, including validating community-generated data and more effective law enforcement. Long-term sustainability hinges on continuous funding, institutional support, and user-friendly tools. Direct financing mechanisms—managed by Indigenous and indigenist associations, and backed by international partners—are key to ensuring the autonomy and resilience of these monitoring systems. Establishing clear governance frameworks and securing government endorsement will be critical for scaling and sustaining these efforts across the Amazon and beyond.

**More Information**

- ASSOCIAÇÃO DE DEFESA ETNOAMBIENTAL KANINDÉ
- CNN Feature on Kanindé Drone Use
- The Territory
- Case Study #6, Embedding Human Rights in Nature Conservation: From Intent to Action, 2022

**Indigenous peoples using drones to monitor their territories**


Photo: Pi Surui (Kaninde)

129 U.S. Agency for International Development.
130 Bengo is a specialized advisory center within Engagement Global, commissioned by the German Federal Ministry for Economic Cooperation and Development.
131 Centro de Trabalho Indigenista - Center for Indigenous Work (Brazil).

## CASE STUDY 2

# Integrating Digital Technologies for Climate and Biodiversity Monitoring

### The Basics

| | | | | |
|---|---|---|---|---|
| 8,800 **species distribution models produced*** (models predict the distribution of a species across geographic space and time) | Geography: **Colombian Amazon** (as well as rest of country) | 400+ **Employees and collaborators** | 1,766 bird species mapped for vulnerability due to climate change | 1.7+ **million** camera trap images processed |

### The Challenge

The Colombian Amazon faces increasing pressure from deforestation, biodiversity loss, and degradation of ecosystem services driven by changes in land use and climate variability.

These developments weaken ecosystem functions, such as water regulation and soil fertility, while reducing habitats for various species, directly affecting local livelihoods.

### The Stakeholders

**PUBLIC SECTOR**

- Humboldt Institute (lead institution)
- Ministry of Environment and Sustainable Development
- ACTO
- Cornell University
- German Development Cooperation (GIZ)

**CIVIL SOCIETY**

- Local Communities in the Amazon
- Civil Society Networks

**PRIVATE SECTOR**

- Microsoft
- Universidad de los Andes

*Current and projected to 2030

### Overview and Key Achievements

The Humboldt Institute is a Colombian entity linked to the Ministry of Environment and Sustainable Development (MADS).[132] The Institute works with different actors to collect data on biodiversity and foster evidence-based policies. It has deployed a comprehensive digital monitoring framework that integrates satellite-based remote sensing, sensor technologies such as camera traps and acoustic monitoring devices, drones, eDNA technologies, machine learning models, and community-based monitoring to monitor biodiversity, tracks climate change impacts and ecosystem degradation in the Colombian Amazon, and other parts of the Country.

The Institute undertakes monitoring to assess patterns of degradation of vegetation and biodiversity and doing so enhances the country's environmental information system. Through specific projects such as the Yaguará initiative in Meta, Caquetá, and Guaviare, the Institute monitors 51 ecological restoration plots (420 hectares) using technologies like Earthscanner and satellite inputs, along with camera traps in partnership with the local Indigenous Communities. These technologies assess vegetation recovery and biodiversity, informing targeted conservation interventions. Historical multitemporal satellite imagery and vegetation indices are used to identify transformation patterns and prioritize degraded zones. Digital modelling and species maps informed national planning, including 8,800 species models used in future conservation scenarios.

An example of the Institute's monitoring activity is the Amazon Monitoring project, through which the Institute aims to enhance the country's environmental information systems, implement a community biodiversity monitoring strategy with the local community, and establish the Amazon Community Monitoring Network. Based in the *La Esperanza* district (5,000 hectares) within the municipality of La *Macare-*

132 Ministerio de Ambiente y Desarrollo Sostenible - Ministry of Environment and Sustainable Development (Colombia).

*na*, in the *Meta* Department, it trains biodiversity monitors in various sampling techniques: camera trapping, bioacoustics, bird counting, uses and benefits, and biodiversity practices and governance. Furthermore, it aims to connect, highlight, and enhance decision making of local communities, ethnic groups, scientific communities, and institutions interested in implementing monitoring schemes within their territories. In this context, the project bolsters multi-scale and multi-stakeholder biodiversity monitoring systems for the Colombian Amazon and, consequently, the sectoral interoperability of environmental information systems.

The Humboldt Institute also uses a variety of technologies and approaches—such as machine learning, cloud technology, data science and others for faster identification of deforestation patterns which allows for quicker action to be taken in at-risk areas. Data outputs from these technologies is analyzed via in-house software and is done so in partnership with universities.[133] The Institute also utilizes multispectral and LiDAR-equipped drones for high-resolution landscape diagnostics and ecological assessments.

A good example of multi-stakeholder collaboration in which the institute engages is the Proyecto Guacamaya, a joint effort of the CinfonIA Research Center at Universidad de los Andes, Instituto SINCHI, Instituto Humboldt, Planet Labs PBC, and Microsoft AI for Good Lab that uses best-in-class AI models to monitor deforestation and protect the biodiversity of the ecosystem using a combination of satellite imagery, camera traps, and bioacoustics. Approaches like these ensure continuous flow of high-quality data, facilitating environmental monitoring and enhancing decision making related to territorial management, conservation, governance, and sustainable practices used by local communities, authorities, and other stakeholders at regional and national levels.

### Operational Support and Costs

The Humboldt Institute receives funding from a mix of public, private, and international sources. Public funding comes from the General Budget of the Nation, the General Royalties System (including Royalties for Science), the FONAM,[134] and FVB.[135] Additional support is provided through private partnerships and international cooperation. The Institute has been designated as a subregional technical-scientific support center for LAC under the Convention on Biological Diversity, which increased its access to multilateral environmental funds. In 2024, Humboldt managed a total budget of COP 131.07 billion (approx. USD$ 34 million) across 77 projects, with 44 initiated in 2024 and 33 from previous years.

### Operational and Implementation Challenges

The Humboldt Institute has made significant progress in advancing digital monitoring in the Amazon, yet several key barriers persist. Limited internet and power infrastructure in remote areas restrict real-time data transmission and device functionality, particularly for camera traps and acoustic sensors highly vulnerable to humidity and energy loss. At the same time, massive data volumes generated by sensors and satellites continue to overwhelm local data processing and storage capabilities. Effective adoption of emerging tools such as eDNA and AI-enabled acoustic monitoring is further constrained by insufficient laboratory infrastructure, limited species reference libraries, and the need for expert-validated annotations to improve model precision in the complex Amazonian ecosystem. On the capacity side, many non-specialist users struggle with software tools that are not intuitive, and sustained community involvement hinges on continuous training, support mechanisms, and clear data ownership frameworks. Lastly, ensuring the long-term viability of large-scale monitoring efforts requires stable and diversified funding, without which the expansion and maintenance of digital monitoring systems remain at risk.

### More Information

- Humboldt Institute
- BioModelos Platform
- Biotablero Platform
- BioModelos: A collaborative online system to map species distributions[136]

**Camera Trap installation to support participatory monitoring at Yaguara II Indigenous Reserve, located in the Llanos del Yarí, an ancestral territory of vital importance for the conservation of Amazonian biodiversity.**

Photo: Humboldt Institute

133 For instance, acoustic data is processed using Raven, a software developed at Cornell University.
134 Fondo Nacional Ambiental – National Environmental Fund (Colombia).
135 Fondo para la Vida y la Biodiversidad – Life and Biodiversity Fund (Colombia).
136 Velásquez-Tibatá, J. et al. (2019) 'BioModelos: A collaborative online system to map species distributions', PLOS ONE, 14(3), p. e0214522. doi:10.1371/journal.pone.0214522.

# CASE STUDY 3

## Enhancing Meteorological, Agrometeorological, Climate, and Hydrological Monitoring through Integrated Digital Technologies

### The Basics

| | | | | |
|---|---|---|---|---|
| 1,053 meteorological, agrometeorological and hydrological stations in operation | Geography: **Peruvian Amazon** (as well as rest of country) | 6,300 processing cores | "Nuna" High-performance computing platform | 4.8 petabytes of storage |

### The Challenge

The Peruvian Amazon faces mounting environmental pressures, including deforestation, illegal land use, illegal mining and increasingly severe climate threats. In 2023, major tributaries such as the Ucayali and Marañon experienced historically low river flows, leading to water shortages and disruptions to transportation, fishing, and agriculture, as well as the provision of basic services, including energy, health, and education.

Forest fires have become more frequent and intense, driven by prolonged dry seasons and rising temperatures. Effective monitoring to allow for and prioritize the prevention of these threats remains limited by sparse weather station coverage, particularly in remote areas such as Loreto, Ucayali, and Madre de Dios.

### The Stakeholders

**PUBLIC SECTOR**

- SENAMHI (lead institution) Servicio Nacional de Meteorología e Hidrología del Perú
- Office of Information Technologies (implements data infrastructure and platforms)

**SOCIAL SECTOR**

- Local Communities

### Overview and Key Achievements

SENAMHI has established a comprehensive national framework for meteorological and hydrological monitoring, leveraging advanced digital technologies and localized operations. It operates 1,053 conventional and automatic meteorological and hydrological stations and four high-altitude observation areas across the country. These stations monitor variables such as rainfall, temperature, air quality, river levels, and soil humidity, among others, to provide timely and accurate services to the Peruvian national society. Likewise, SENAMHI, in order to optimize meteorological, climatic, water and environmental monitoring and adapt to climate change and anthropogenic environmental impacts, has one global atmospheric monitoring station with GHG measurements, 19 stations integrated into the Global Basic Observing Network (GBON) and 12 into the Regional Basic Observing Network (RBON), all of them contributing to the Integrated Global System of the World Meteorological Organization.

The high-performance computing platform "NUNA" (meaning "soul" in Quechua), is central to this framework, featuring 6.300 processing cores and 4.8 petabytes of storage, which supports real-time forecasting and advanced climate modelling. To put it into perspective, this is like having more than 6,300 laptops working together as a high-capacity system. This setup can process in a day what it would take a regular laptop decades to compute, and it has enough memory to store over a million HD movies. NUNA enables SENAMHI to generate and develop products related to numerical modelling, reduce information gaps in meteorology, hydrology, and agrometeorology, decrease prediction uncertainty, and minimize the time required to develop climate change scenarios, while increasing its spatial resolution up to a 5km x 5km grid at the national level.

SENAMHI employs a diverse array of digital technologies, including high-resolution satellite imagery, LiDAR, drones, mobile applications, cloud storage systems, and off-grid sensors. Data from automatic stations are updated hourly and transmitted directly to institutional databases. Conventional stations transmit data two to three times a day, contingent on connectivity. In remote areas, satellite communication systems facilitate data transmission.

The Institution has also developed an in-house, low-cost meteorological station that leverages 3D printing technology, and it is currently undergoing trials to test its potential. Additionally, the agency utilizes the HYDRONE RCV echosounder for fluvial flood studies, and the Acoustic Doppler Current Profiler (ADCP) M-9 to enhance river flow estimates. This layered monitoring approach ensures comprehensive coverage, even in hard-to-reach zones.

SENAMHI has been strengthening and integrating digital IT platforms to provide information services, including PHISIS, SILVIA, SONICS, and OASIS, among others.[137] Platforms like OASIS and SONICS facilitate drought and potential flood assessments, while PHISIS enables real-time tracking of hydrological data. SENAMHI has also developed IDESEP,[138] an institutional spatial data infrastructure platform to integrate geospatial data across its directorates and share official data with stakeholders. This platform facilitates the exchange of geospatial information through reliable and standardized interoperable services, while promoting regional cooperation in environmental data management. It aims to contribute to analysis and decision-making based on reliable, timely, official, and standardized geospatial hydrometeorological and climatic information through efficient management of various production, centralization, and distribution processes developed by the different technical units of the institution. Among its services, SENAMHI also provides specialized climate services for the health sector, including maps projecting the probability of dengue and malaria occurrences up to 2050. These services support public health planning and adaptation measures in response to climate change.

### Operational Support and Costs

SENAMHI's operations are primarily funded through national budget allocations. The cost of acquiring a single monitoring station exceeds USD$ 30,000, while maintenance and logistics, especially in remote areas of the Amazon, can be very expensive. Annual operational costs exceed USD$ 1 million, with total system expansion not yet estimated. Three investment projects to cover the Amazonian regions of Loreto, Ucayali, and Madre de Dios are estimated to cost approximately USD$ 32 million. To diversify its funding, SENAMHI is exploring and, in some cases, implementing PPPs, as well as climate finance mechanisms such as green bonds and carbon credits, alongside grants from multilateral environmental funds. These efforts are bolstered by a financial sustainability roadmap that prioritizes institutional partnerships and decentralized capacity building.

The high-performance computing, "Nuna"

Photo: SENAMHI

### Operational and Implementation Challenges

Several implementation challenges exist, particularly regarding the lack of digital infrastructure and the high costs associated with expanding, maintaining and operating SENAMHI's monitoring efforts. Many stations suffer from unreliable internet and power, which delays data transmission and analysis. Monitoring stations and remote fieldwork necessitate considerable investment, especially in the Amazon, where there are very remote and difficult-to-access locations. Harsh conditions, such as humidity and dense canopy cover, shorten equipment lifespan and hinder aerial monitoring. Numerous components require maintenance, updates, and upgrades to remain effective. Furthermore, there is a shortage of local experts with specific digital skills, which limits the scalability of advanced technologies. Difficulties also persist in harmonizing data across systems and formats.

To address these challenges and enhance its digital monitoring capabilities, SENAMHI has identified several strategic priorities. These include the expansion of automatic monitoring stations to enable more accurate, frequent, and autonomous data collection, as well as investments in connectivity solutions such as radar installations, satellite internet and off-grid energy systems to facilitate real-time data transmission from remote sites. Strengthening local capacity through targeted training and community engagement is also deemed essential to enhance operational sustainability. Additionally, SENAMHI is prioritising improvements in data interoperability and transparency, including the expansion of platforms like IDESEP to promote open access and information sharing.

### More Information

- SENAMHI
- SENAMHI Station Map
- Spatial Data Infrastructure (IDESEP) of SENAMHI Peru
- Air Temperature and Precipitation Atlas of Peru
- ¿Qué es el Atlas de Temperaturas del Aire y Precipitación del Perú?
- Catálogo de productos, estudios e investigaciones disponibles de la Sub Dirección de Estudios e Investigaciones Hidrológicas (SEH), período 2021-2025

137 See https://repositorio.senamhi.gob.pe/handle/20.500.12542/4186
138 Infraestructura de Datos Espaciales del Senamhi Perú – Spatial Data Infrastructure of Peru

CASE STUDY 4

## Digital Technologies Supporting Indigenous Territorial and Environmental Management and Monitoring

### The Basics

| 20+ | Geography: | 150+ | 360 | 2.4 million |
|---|---|---|---|---|
| **Number of Indigenous Communities** equipped with solar-powered satellite internet systems | **State of Acre, Brazil** | **agroforestry plots documented** through apps and satellite imagery by Indigenous Agroforestry Agents | Indigenous monitors trained in the use of digital technology, including a growing number of women (currently 19%) | hectares of forest monitored by **30+ Indigenous Territories** |

### The Challenge

Indigenous Territories in the Amazon biome are vital for biodiversity and carbon storage, yet they face increasing threats from climate change, illegal logging, poaching, land grabbing, and environmental degradation. In Acre, Brazil, Indigenous Communities also face severe climate events, including historic floods and prolonged droughts that have destroyed crops, livestock, homes, and infrastructure. Environmental changes and external pressures can disrupt traditional practices and spiritual connections to the land.

These issues are worsened by limited public funding, poor infrastructure, and the absence of formal recognition for Indigenous environmental monitors. Surveillance of voluntary isolation groups and borderland dynamics further complicates territorial protection in the region. Many Indigenous Lands in Acre still have uncertain legal status, with demarcation delayed or disputed by political actors and economic interests. Even in areas that are demarcated, enforcement of rights remains weak, exposing communities to external threats and violence.

### The Stakeholders

**PUBLIC SECTOR**

- FUNAI
- IBAMA
- ICMBio[1]
- Federal police
- MPF[2]
- SEPI-AC[3]
- MPI[4]

**DONORS AND PARTNERS**

- Amazon Fund-BNDES[5]
- NORAD[6]
- KFW[7]
- Rainforest Foundation Norway
- IPAM

**SOCIAL SECTOR**

- CPI-ACRE (lead institution)[8]
- Indigenous Communities

1 Instituto Chico Mendes de Conservação da Biodiversidade – Chico Mendes Institute for Biodiversity Conservation (Brazil)
2 Ministerio Público Federal - Federal Public Ministry (Brazil)
3 Secretaria Extraordinária dos Povos Indígenas do Acre - Indigenous Peoples Secretariat of Acre (Brazil)
4 Ministério dos Povos Indígenas - Ministry of Indegenous People (Brazil)
5 Banco Nacional de Desenvolvimento Econômico e Social – National Bank for Economic and Social Development (Brazil)
6 Norwegian Agency for Development Cooperation
7 Kreditanstalt für Wiederaufbau - Credit Institute for Reconstruction (Germany)
8 Comissão Pró-Indígenas do Acre - Pro-Indigenous Commission of Acre (Brazil)

### Overview and Key Achievements

This case study highlights the efforts of the CPI-Acre and several Indigenous groups to strengthen Indigenous-led territorial monitoring and environmental governance through digital technologies. Implemented across various Indigenous Territories through a multi-layered digital strategy, CPI-Acre has supported the development of Indigenous-led monitoring systems that combine geotechnologies, traditional knowledge, and participatory governance. Initiatives have focused on territorial and environmental management, as well as on strengthening sustainable value chains within Indigenous Territories.

Key technological components of the indigenous-led monitoring systems include satellite imagery and GIS tools to detect land-use changes and identify deforestation hotspots. Drones are deployed to capture high-resolution imagery to identify and document environmental degradation and productive plots. Field monitors use mobile applications such as the Indigenous Amazon Observation and Monitoring System (SOMAI) and Indigenous Climate Alert (ACI) application. The SOMAI-ACI system gathers, records and disseminates data and information on Indigenous Territories in the Amazon. These records are compiled into cloud-based databases that support spatial analysis, map generation, and targeted communication with external stakeholders. The IPAM developed the tools associated with SOMAI-ACI at the request of Indigenous partners including COIAB.

CPI-Acre also plays a key role in strengthening Indigenous agroforestry systems through its long-standing support for Indigenous agroforestry agents. These operate in multiple Indigenous Territories promoting sustainable land use, biodiversity conservation, and climate resilience through revitalization of traditional agricultural practices. Working closely with CPI-Acre's technical team, the agroforestry agents are trained to monitor and document agroforestry plots, assess soil and crop health, and identify climate change impacts, such as floods and droughts. Their work not only contributes to environmental restoration but also supports food security and income generation through the cultivation of native and commercial species. To enhance the monitoring capacity of agroforestry agents, CPI-Acre has introduced the use of a mapping mobile application that allows agents to navigate, collect, and visualize spatial data in offline environments. Using geo-referenced maps, provided by CPI-Acre's geoprocessing team, agroforestry agents can track the boundaries of agroforestry plots, mark relevant ecological features, and document changes in land use or productivity over time. The app supports the integration of GPS points, photographs, and field notes, all of which are later exported and analyzed to generate reports and inform community and institutional decision making.

The introduction of mobile applications to capture data has helped modernize and standardize field data collection while preserving Indigenous autonomy in environmental management. Its use has also strengthened the link between traditional agroecological knowledge and digital innovation, demonstrating how tailored technologies can support culturally grounded approaches to climate adaptation and territorial governance. These technologies have enabled more structured and effective documentation of environmental threats, qualified reporting for enforcement bodies, internal conflict resolution, and better understanding of climate change impacts on Indigenous Territories.

Community participation represents a critical component of local data collection. Since 2017, participatory training sessions, including over 50 technical workshops, have been conducted, many at the “Forest Peoples Training Centre” (Centro de Formação dos Povos da Floresta) and others directly in Indigenous villages to tailor training to local contexts, strengthening the capacity of hundreds of Indigenous monitors. These monitors participate in peer-to-peer training, identify territorial priorities, and ensure the flow of culturally and politically relevant information. They also support community mobilization, conflict resolution, and internal governance. Information is analyzed and fed back to communities through an ongoing exchange that enhances local decision making and advocacy. Regarding data governance, CPI-Acre promotes Indigenous data sovereignty, participatory mapping, and the integration of traditional knowledge with digital innovation. CPI-Acre and Indigenous representatives are finalizing a jointly developed data governance protocol.

**The Acre Pro-Indigenous Commission promoting a training course for Indigenous Agroforestry Agents**

Photo: Ila Verus (CPI-Acre)

### Operational Support and Costs

The implementation of digital monitoring technologies in the Indigenous Territories of Acre requires a mix of infrastructure, human capacity, and financial resources. Key infrastructure includes solar power, smartphones, drones, GPS, boats, satellite internet, and mapping software. Training is adapted to varying educational levels and languages across Indigenous communities.

A typical monitoring setup, including a solar power kit, smartphone, basic GPS device, drone ,and internet connection, for one community costs approximately USD$ 3,000 to $15,000, depending on technical features, location, and logistical complexity. Field visits and missions, often requiring boat transport and overnight stays, can cost USD$ 800 to USD$5000 per trip, depending on distance and team size. Project implementation and operations are currently funded through short- and medium-term grants, with an estimated annual operating cost of USD$ 200,000 to $300,000 to sustain field monitoring, technical support, equipment maintenance, and community engagement.

### Operational and Implementation Challenges

Despite recent progress, significant operational and systemic challenges persist. Unreliable electricity and limited internet connectivity continue to constrain real-time data transmission and reduce the functionality of digital tools such as GPS devices, drones, and mobile applications, especially in remote areas. Logistics further complicate monitoring activities, with many territories requiring multi-day boat travel or air transport, driving up operational costs and delaying equipment maintenance due to the lack of local repair options. Funding remains unstable, as Indigenous monitoring efforts rely largely on short-term donor projects rather than a sustained public budget, limiting the continuity of trained personnel and preventing the scale-up of successful initiatives. While more than 360 Indigenous monitors have been trained in the use of digital tools, digital literacy barriers endure; ongoing learning needs are shaped by linguistic diversity, varying educational backgrounds, and distinct cultural contexts. Insufficient long-term support restricts full integration of these technologies into everyday territorial governance. Moreover, although CPI-Acre is nearing completion of a shared data governance protocol to safeguard secure data management and Indigenous sovereignty, full operational integration with public systems is still pending.

### For more information

- CPI - Acre

**Building-capacity trainings in Acre**

Photo: CPI-Acre

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