Community-based monitoring in tropical environments: Establishing indigenous participation without direct western involvement

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Abstract

This article constitutes a socio-technical exploration of how community forest monitoring operates and circulates within indigenous and tropical contexts. Authored collaboratively by a western anthropologist and two indigenous cartographer-activists from Panama, this study meticulously explores the pathways through which a novel form of geospatial monitoring, based on high-tech, lightweight and easy-to-handle instruments, finds its way into indigenous strategies for territorial control and defense. It offers an in-depth insight into the endeavors of committed indigenous cartographers who are actively engaged in the dissemination of an autonomously-led monitoring device in Central America and contributes to the still relatively limited body of literature on the topic. This study sets aside a results-oriented approach, focusing instead on analyzing basic processes of technological appropriation in indigenous communities. We demonstrate how, despite the diversity of cultural and ecological contexts across our case studies, the socio-technical system we propose proved to be similarly implemented, precisely because it manages to bring into tension technologies with indigenous geographical knowledge and practices.

Keywords

indigenous monitoring system; cartographic literacy; indigenous data sovereignty; tropical forests; geospatial technologies

1. Introduction

Environmental monitoring systems and citizen science are rapidly converging, with indigenous peoples increasingly becoming involved in the process (Chandler et al., 2017; Danielsen et al., 2018; Tengö et al., 2021). Monitoring is generally recognized for improving governance, ecological and social benefits, natural resource management, and addressing climate change (Conrad & Hilchey, 2011). Whether they are community-based, collaborative, grassroots, or cross-cultural, monitoring systems are, from a social and technical standpoint, highly diverse. Existing large-scale studies on participatory monitoring have identified a wide variety of possibilities regarding the degree of engagement and responsibility of local stakeholders (Danielsen et al. 2021; Thompson et al., 2020). Exploring current documentation on these initiatives reveals that there is no dominant technical framework, and cases where indigenous and local populations control every step of the process are particularly rare (see for instance: Berkes et al., 2007; Dobbs et al., 2016; Thompson et al, 2019). During

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monitoring, indigenous participants are often relegated to the status of data collectors and therefore excluded from the design, interpretation, and management action processes (Danielsen et al., 2021). Little is known about the tools, methodologies, and challenges faced when indigenous people decide to learn, use, and routinize socio-environmental monitoring for their own objectives (Thompson et al., 2020).

Despite limited documentation, autonomously-led indigenous forest monitoring is notably active in Central America, with an organization called Geoindigena leading the charge in Panama (Voisin et al., 2022). Like elsewhere in the Americas, indigenous peoples in Panama have a rich history of appropriation of western digital mapping technologies (Palmer, 2012). Authored collaboratively by a western anthropologist and two indigenous cartographer-activists who founded the organization, this paper introduces a simple forest monitoring toolkit currently being deployed across several indigenous territories of Central America. Suited for tropical ecologies and remote areas, this toolkit exhibits several applications. It can be used for evaluating tree cover losses, demarcating and regulating customary land use, alerting governmental authorities to the presence of illegal settlers, monitoring tropical biodiversity, or mapping the spread of a disease in isolated communities. Combining lightweight and easy-to-handle digital instruments with local geographical knowledge, the device stands out as one of the few systems establishing itself in indigenous territories without direct western involvement. Designed to safeguard indigenous sovereignty over data collection, analysis, and decision-making, this system can be labeled as a form of Indigenous Forest Monitoring System (IFMS).

What are the components and processes involved in this particular IFMS? How does this system circulate in different cultural and geographical contexts? This article follows the implementation of this monitoring toolkit in two indigenous territories of Central America: the Miskito's ancestral territory of southern Honduras and the Mayangna's ancestral territory of northern Nicaragua, in order to understand 1) the components and processes involved in this particular IFMS, as well as 2) how this system circulates in different cultural and geographical contexts. It offers a clear insight into the technical components, practices, and associated knowledge of the system and provides elements regarding the mechanisms of 'cartographic literacy,' understood in its etymological sense as 'having competence in a system of knowledge' (Johnson et al., 2005), which are central to the challenges surrounding the critical adoption of such geospatial technologies by indigenous communities.

2. Research Design and Methodology

2.1 A tropical forest monitoring toolkit

In Science and Technology Studies (STS), the concept of sociotechnical system refers to a system of social and technical components that are independent and intertwined in mutually influencing relationships (Cozza, 2020). Examining how forest monitoring functions is particularly useful to acknowledge how human and technical systems interact. The components of the IFMS presented in this paper involve combinations that have been gradually forged in practice in the tropical forests of Panama. It emerged from a global framework rooted in the technical requirements of forest and carbon inventory (foreshadowing REDD and REDD+ policies in the tropics) and was then refined by geomatics experts from NGOs supporting indigenous environmental struggles (Voisin et al. 2022). Finally, indigenous peoples themselves, through their usage and replication at the local level, contributed to stabilizing a technically exportable version, which we present here.

The entire framework is based on lightweight and easy-to-handle instruments that support their appropriation at the local level (see Figure 1). Software was chosen because they are free and open source (we mention here the models and names for better information sharing). The technical setting starts with a smartphone equipped with geolocation software usable without network connectivity (LocusMap). It can be complemented by a GPS, depending on the desired level of precision in geolocation. Although it is rarely used in the field, a laptop equipped with software designed for constructing geographic information systems (QGIS) is necessary, as it is used to process the data once it has been collected. In addition, a quadcopter drone (with corresponding batteries), managed through a software accessible from the smartphone (Drone Harmony, DJI GO, PIX4D, Maply Mission Planner), comes into play. These three primary technical elements serve as the basis for data collection, visualization, and analysis. The chosen models must be compact, light, and resilient, capable of withstanding humidity, sunlight, mud, and the long hours (or days) of walking during which indigenous people will use them. Other technologies such as talkie-walkie and a machete are also useful when monitors are in the field, as they help coordinate and facilitate monitors movements in the forest.

Figure 1: Key technical tools of the Indigenous Forest Monitoring System proposed by Geoindigena. (Source: Yann Voisin)

This simple system is framed not only to favor local appropriation but also due to the environmental particularities of tropical areas. Due to the biophysical characteristics of tropical forests, like an almost constant cloud cover and dense vegetation, surveillance practices relying solely on satellite imagery are inadequate (Liang et al., 2011; Townshend et al., 2012). Smartphones and GPS are then used below the canopy and complement remote sensing technologies when they cannot see through. Drones are particularly suited for flight from clearings, allowing indigenous monitors to achieve long-range vision, even if cloud cover blocks the satellite surveillance capacities. Satellite imagery can be very useful specifically to detect forest fires and deforestation areas. Detailed information on mapping and monitoring practices associated with these tools is provided in Section 3.1. The entire system operates only with and through the surveying practices of indigenous monitors, who are equally crucial to the system's functioning as digital tools. There is no monitoring without local geographic knowledge and the abilities of indigenous monitors to carry these geospatial tools through the forests (a particularity that we will explore further in section 4.1). Because tropical environments present technical challenges for any organization engaged in mapping, monitoring, or modeling, local communities and indigenous peoples are particularly well-positioned to address these challenges.

2.2 A collaborative research process

The authors initially convened in September 2021 during a workshop on community mapping on the Caribbean coast of Panama, which was organized by researchers, indigenous activists, and members of non-governmental organizations. As Geoindigena was recognized by indigenous authorities at the regional level, access to the field was facilitated (see Box 1). From 2021 to 2023, the team consistently visited indigenous territories together, beginning in Panama (Bribri, Wounaan, Naso, Emberá), before expanding their collaboration to Honduras (Miskito) and Nicaragua (Mayangna).

Data related to this article were collected at three points of the cartographic literacy process of the Miskito and Mayangna monitoring teams, allowing comparison over time. The nature of the data is entirely qualitative and refers to an ethnographic approach (interviews, observation notes, gray and academic literature). Thirty formal interviews were conducted with the participants (20) and traditional authorities (10). Several field observation sessions were conducted, particularly in Honduras (ranging from 7 days to 14 days). These iterative field excursions not only facilitated the establishment of intimate and trustful rapport with study participants but also intermittently provided access to the intricacies of their daily lives, enabling a nuanced understanding of the lived experiences concerning the socio-environmental challenges they faced. From these diverse elements, we derived diagnostics of territorial issues, the drivers and impediments of learning, and the practical applications of monitoring, as presented in Tables 1, 2, and 3. In the text, these tables are designed to synthesize the information according to the sections.

Box 1: Specifying Geoindigena's approach to Indigenous Forest Monitoring System (IFMS).

Previously reliant on foreign assistance for participatory mapping in the 1990s (Chapin et al., 2005), indigenous communities in Panama began employing local topographic experts to survey their ancestral lands in the 2000s (Voisin et al., 2022). By the 2010s, Panama became a pioneer candidate for implementing the UN-REDD mechanism, engaging indigenous trained experts in measuring carbon stocks within their territories (Holmes et al., 2017). Geoindigena arise from that period. Created in 2019, it is an indigenous organization, oriented to non-profit and digital activism in support of indigenous rights and sovereignty. It has forged connections with other indigenous organizations throughout the continent such as ACOFOP in Guatemala and AIDESEP in Peru and has worked on the elaboration and dissemination of an innovative monitoring device across Panama, Honduras and Nicaragua. Its primary objective was to establish small monitoring stations in all indigenous territories of Panama, manned by two or three individuals equipped with remote sensing tools. These stations provide uniform coverage, enabling communities to collect evidence of environmental damage and submit reports to relevant authorities or international organizations. Notably, indigenous monitors in Panama have been recognized for producing more accurate environmental information compared to government services (Moutinho, 2021). Additionally, Geoindigena has produced accurate maps of COVID-19 cases in remote indigenous territories during the pandemic helping international organization planning humanitarian aid. The organization was also involved in developing land management plans for various indigenous communities in Panama with the support of Rainforest Foundation US. Geoindigena's underlying philosophy value is that indigenous peoples, particularly technicians, should be capable of speaking the language of the state and major international organizations, to compel or urge them to uphold their responsibilities. Maps and geospatial data are understood as diplomatic tools and political levers.

Our shared research questions were oriented toward two points: whether the system can withstand different ecological and cultural contexts and how to conduct cartographic literacy while preserving indigenous sovereignty. The idea was not so much to compare before and after monitoring, but rather to decode (and narrate) the mechanisms associated with cartographic literacy by detailing the stages of medium-term appropriation. It is around these concerns that the data collection was organized. The insights presented in this paper have undergone multiple working meetings, including the co-definition of stakes, corrections, and precision of the general argument. These discussions were motivated by the guidelines and ethics of collaborative methodologies (Runk, 2014) and a decolonial approach to research design (Smith, 2021). The results presented here navigate a delicate balance between the anthropologist's practice, complemented by expertise and extensive field experience specific to the indigenous mapmaking domain. Free, prior and informed consent from the participants and communities where the mapping expeditions were conducted was obtained through agreements, sometimes formalized (with the communities) and sometimes oral (with the apprentice cartographers already involved in the study). The results of this study were communicated to the participants through an online presentation.

We wish to draw the reader's attention to the fact that this study employs a fully qualitative methodology and that its scope is focused on characterizing specific practices. These results are localized and, as such, have limitations.

2.3 Two case studies in Central America

Our paper follows the circulation of the device in two distinct (but neighboring) ecological and cultural contexts: the Miskito territory of southern Honduras and the Mayangna territory in northern Nicaragua. These two territories are situated within the Central American Biological Corridor (see Box 2 and Box 3). They overlap with la Moskitia, one of the last remaining great forests of Mesoamerica (AMPB, 2021). Encompassing solid climate and ecological concerns on an international level, this specific location is attracting external funding regarding development and conservation initiatives (Finley-Brook, 2007a; Holland, 2012). Geoindigena's capacity-building project (that forms the material for our case studies) was supported by the Ford Foundation and the Mesoamerican Alliance of Peoples and Forests (AMPB). The aim of the project was to train a select group of young indigenous participants to establish the foundations of a territorial monitoring system.

Box 2: Exploring historical and socio-ecological characteristics of the Mayangna's case study.

In Nicaragua, the Mayangna territory spans approximately 1,600 km², and is primarily covered by tropical forests. Despite considerable distances, conducting surveys on foot remain feasible. Territorial struggles have persisted since the early days of colonization, stemming from interactions with the Miskitos. Having forged alliances with the British Crown, they compelled the Mayangna to abandon the plains and seek refuge in the mountains due to escalating interethnic tensions. Years later, the region became a 'corridor of confrontation' during the conflict between the Sandinistas and the Contras. Today, the Mayangna territory faces the challenges of neo-extractivism (Finley-Brook, 2007b). According to our interviews, various actors collaborate to appropriate and exploit the Mayangna territory, which is strategically located within the mining triangle, renowned for its gold reserves. In recent years, infrastructure developments, such as the completion of a road project by the state, have opened the area to truck traffic and attracted mestizo laborers from the west, primarily engaged in cattle ranching (Stocks et al., 2007). Consequently, the territory now houses more colonists than the Mayangna themselves. These destructive forces that encroach upon indigenous worlds are further compounded by the impacts of climate change. In 2020, Hurricanes ETA and IOTA devastated the forests, facilitating the expansion of ranching. Similarly, dry season fires have exacerbated this issue. In summary, the survival of Mayangna culture is under threat, and ecological, historical, and sociopolitical dimensions have become increasingly intertwined.

Box 3: Exploring historical and socio-ecological characteristics of the Miskito's case study.

Situated in eastern Honduras, La Mosquitia is significantly larger and ecologically more diverse than the Mayangna territory, which is located just on the other side of the Coco River (see Table 1). La Mosquitia features tropical forests adjacent to pine savannahs, mangroves, and lagoons. It is evident that monitoring activities represent a more complex challenge in this nearly 17,000 km² territory. The use of motorized vehicles, such as 4x4s or boats, is thus necessary, resulting in additional logistical costs for surveillance operations. There are approximately 300 villages in the area, and while the Miskito are the most numerous, the Pech, Garifuna, and Tawahka indigenous peoples also inhabit the region (Herlihy & Tappan, 2019). It was reported that this context made it difficult to obtain Free Prior and Informed Consent (FPIC) approval for villages where forest monitoring activities were conducted, and it is not yet clear how these other indigenous groups will be integrated into the monitoring network. Historically, the Miskito people have a long tradition of interaction and negotiation with colonial institutions. Their incorporation into the Honduran state in the 17th century implied a guarantee for the indigenous people's possession of their ancestral lands (Nietschmann, 1991). However, these commitments are far from being respected, and numerous territorial problems affect these territories. Farming fronts are encroaching on tropical forests, and intense illegal and extractive activities have been reported by local authorities and researchers throughout the region (McSweeney et al., 2018). Due to a variety of factors, including corruption, clientelism, and threats, many traditional authorities are involved in land trafficking and in agreements with settlers and criminal groups for the exploitation of Mosquitia's resources. Forest fires are also prevalent in these areas, especially during the dry season, and climate change has only exacerbated the situation (Vida, 2020).

In 2021, the Mayangna traditional authorities undertook participant selection in their territories (n=10), whereas the Miskito traditional authorities, in collaboration with AMPB, selected participants from their ethnic group (n=12). The selection criteria vary each time. For the former, the focus was on engaging individuals with specific political connections (leaders) or those already possessing technical knowledge (like engineers, professors, and other professionals). In the latter case, the goal was to impart technical knowledge to future leaders, primarily (though not exclusively) young people chosen through local congresses to actively engage in local indigenous politics. Nonetheless, the knowledge and skills gained during these programs are not solely intended for the participants themselves; they are designed for replication. It is important to mention that the initial significant step in incorporating indigenous perspectives into this specific form of social-ecological monitoring relates to participant selection. This decision should rest with traditional authorities, as they understand the community's cultural context. External entities, like NGOs or regional activist organizations, may unintentionally impose external priorities that don't align with the community's needs.

For both groups, traditional authorities and monitors have identified various territorial problems during the initial stages of the capacity-building process. These issues encompass illegal logging, illegal mining activities, the presence of settlers, armed violence, land trafficking, and drug dealing. These problems affect both ancestral territories but differ in intensity. They play a central role in shaping the motivations driving the local implementation of the system, while also being pivotal in the collection of geographical data. The table below provides a summary of these elements for both teams (Table 1).

Table 1: Local contexts and participants.

	Mayangna team	Miskito team
Socio-Environmental characteristics of the territory	Mayangna Sauni Arungka Territory 1,638.10 km² Rainforest area Total population 4750 (2022) 1 Biosphere reserve 100% demarcated and titled territory	Department of Gracias a Dios 16,997 km² Rainforest, spine savannas, mangrove and coastal areas Total population 104 261 (2020) 1 Biosphere reserve 90% titled territory (IUCN)
Number of indigenous monitors selected	10	12
The selection process	Traditional authorities	AMPB leadership school in coordination with 12 territorial councils (leaders of future leaders)
Territorial problems identified	Illegal mining (intense) Illegal logging (intense) Wild and anthropogenic fires Effects of climate change Presence of settlers (intense) Armed violence (intense) Land trafficking (intense) Drug trafficking	Illegal mining (moderate) Illegal logging (intense) Wild and anthropogenic fires Effects of climate change Presence of settlers (moderate) Armed violence (moderate) Land trafficking (moderate) Drug trafficking

3. Results

In this section, we first provide detailed information on the learning steps and mapping techniques on each stage of appropriation (Section 3.1.). We then explore the idiosyncrasies associated with disseminating the toolkit in the Mayangna and Miskito contexts, emphasizing the challenges (levers and obstacles) of implementation (Section 3.2). Then, we reflexively describe the way in which we demonstrate how, despite the diversity of cultural and ecological contexts across the case studies, the sociotechnical system proved to be particularly robust, while effective implementation responded to different logics. The first training session occurred in 2021 within the traditional territories of the participants in Honduras and Nicaragua (October for the Miskito team and November for the Mayangna team). Subsequently, in 2022, two workshops were conducted, uniting the two teams in the city of Puerto Lempira, Honduras. Continuing into 2023, a workshop brought together selected participants in Panama, fostering sessions that connected them with young Naso and Emberá monitors (see Figure 2).

One of the core principles behind these sessions is to initiate a cross-cultural and peer-to-peer learning dynamic around high technologies. Within these transitory monitoring laboratories, established for a brief duration (spanning from 4 to 10 days), emphasis is placed on accommodating a limited number of participants (up to a maximum of ten per facilitator), thereby ensuring enhanced guidance. The underlying philosophy of every workshop revolves around experiential learning, grounded in the immersive process of comprehending and actively interacting with technology. The pedagogy of learning through practical engagement fosters a sense of confidence and reliance between young monitors and technical objects, which is a prerequisite for the correct process of sociotechnical appropriation. The transition from formal presentations on cartographic theory swiftly yields hands-on practical application and fieldwork within these workshops.

Figure 2: Indigenous monitors in the field and ephemeral monitoring labs (Source: Yann Voisin).

3.1 Workshops descriptions

For Geoindigena, the implementation of IFMS across diverse indigenous territories necessitates pedagogical expertise and know-how that demonstrate relative uniformity across cases. The training curriculum has evolved through numerous replications, each with distinct successes and failures, ultimately achieving a degree of robustness over the years. The fundamental choice of the organization is to conduct the learning sessions in situ and build ephemeral monitoring labs within the territories. Visiting the communities that are the subjects of the mapping and monitoring processes not only allows to cut down on logistics costs and to identify territorial issues more accurately, but also to effectively communicate the operations and goals of the monitoring to the locals. Wherever the workshops were held, all participants and facilitators (Carlos and Eliceo) were introduced to the hosting community. Initially, introductions and training were conducted in Spanish (the lingua franca) and subsequently translated into the local language (Mayangna and Miskitu) to ensure better comprehension among the elders. Implementation occurs gradually, aligning with the pace of community agreements, and follows an approach that respects the principles of free and informed consent.

During this initial phase (preceding the first workshop), participants draft an initial map highlighting socio-ecological issues, territorial concerns, and prerequisites for documenting and advancing monitoring endeavors. In addition, in this phase, participants are encouraged to identify the national authorities and institutions with which they might engage. The central idea of this form of monitoring is that indigenous peoples, particularly technicians, should be capable of speaking the language of the state and major international organizations to compel or urge them to uphold their responsibilities. Therefore, the goal is to establish a form of direct communication with stakeholders that is centered around the language of maps and geospatial data. In our two case studies, this preliminary phase proved invaluable, fostering discussions on the state of ancestral territories (territorial recognition, human rights observance, ecological situations). Participants shared perspectives on commonalities and distinctions in their local struggles, thereby establishing a foundation for unity and camaraderie despite their varied cultural backgrounds.

The initial workshop (1) was dedicated to getting familiar with the LocusMap software on a mobile phone. LocusMap is a free application for Android that introduces young monitors to the production of geospatial data (GPS, track recording, and georeferenced photos). It enables the export of collected elements in various formats (KML, KMZ, GPX) suitable for further processing on other digital devices. Easily usable, it is typically employed in the field and while walking. Its use relies directly on local geographic knowledge and the specific skills of indigenous walkers in these tropical environments. During the workshops, we discussed how it can be used to locate species of wildlife, identify resources, settler installations, or illegal activities, and measure deforested areas or various types of pollution. According to the trainers from Geoindigena, it serves as the first step toward visualizing specific territorial issues within the modeling material (map, sketch, report).

The subsequent workshop (2) afforded the Mayangna and Miskito communities an opportunity to embark upon the domain of GIS. For a substantial portion of the participants, this marks their inaugural immersion into the realm of laptop computing. Attendees acquaint themselves with diverse categories of geospatial data in the QGIS software (such as points, lines, polygons), georeferencing systems, spatial strata, and cartographic projections. Elementary exercises are undertaken using data procured through LocusMap; for instance, crafting village sketches entailing the identification of dwellings and pathways. Additional exercises may pertain to demarcation within the ancestral territory, including farms, hunting grounds, timber harvesting areas, stringent conservation zones, or sacred sites. The introduction of analytical procedures is a culminating facet of the learning process.

The following workshop (3) was dedicated to initiating satellite monitoring. This constitutes a pivotal phase within the pedagogy, bridging the initial surveying knowledge with the informational capacities of satellites, which capture landscape and forest transformations from a spaceborne perspective. Data sourced from open-access satellite initiatives (such as Planet Labs, Global Forest Watch, NASA, etc.) is integrated into the knowledge base of upcoming indigenous monitors. Primarily, this data equips them to pinpoint deforested areas or instances of forest fires. Certain programs even provide the functionality of alerts (nearly in real time) that can be received on mobile devices (e.g., Landsat, Glad Alert), affording participants an unparalleled speed in reaching the scene, verifying the situation, and subsequently submitting reports (Slough et al., 2021).

The concluding workshop (4) focused on the use of quadcopter drones. These devices can capture georeferenced photographs and videos that encompass extensive land expanses. Their utility becomes particularly pronounced in the documentation and measurement of deforested regions or fire-affected areas, which can be complemented by accurate altitude measurements. Nevertheless, it should be noted that this instrument generates data of substantial weight and complexity, demanding intricate analytical procedures. Consequently, drones will predominantly serve as sensors and enhancers of visibility, prioritizing these roles over functioning as geomatic analysis tools. A low-cost digital library known as 'Internet-in-a-Box' (including a wireless access point with storage capabilities accessible to nearby users) facilitated the sharing of documents, datasets, presentations, and instructional materials. A noteworthy innovation is that it allowed participants to engage in closed-circuit learning, meaning that they can learn without requiring connectivity to the global internet network. This innovation enabled the establishment of these workshops within remote territories, thereby enhancing the speed and quality of the adoption of monitoring techniques.

3.2 Current challenges and outcomes

While monitoring is a relatively stable set of knowledge and practices, as described in the description of the workshops, its actual implementation in the Mayangna and Miskito territories results from quite different processes and logics. Here we detail information regarding the levers and obstacles that determine the degree of appropriation of the IFMS. The data used for this section are primarily derived from the interviews we conducted with participants and authorities. Our results show that these issues are much more than just a technical story, and that they are embedded with different parameters such as the local geography, state of relationships with national authorities, external funding possibilities, history of participatory mapping projects (see Box 4 below), and local context regarding violence against indigenous monitors.

For the Mayangna people, the workshops arrived in a troubled context (see Box 1). They already had their local surveillance initiative and had established their forest rangers in 2017. These individuals are armed and continuously patrol the territory to identify and report various territorial violations. One of the main goals of the monitoring workshops was to disseminate technical knowledge among this collective. The underlying concept is to pacify indigenous territorial defense strategies, which are undergoing transformation in the digital realm, while institutionalizing these forms of control for traditional authorities. However, this desire for pacification does not shield the monitors from threats to their lives. While no indigenous cartographer has been killed to date, one of the group's members was murdered by a settler after a monitoring session. During interviews, monitors reported facing challenges due to the growing influence of dictatorial practices within traditional governance structures. They observed that Nicaragua's national government has taken control of communication channels—radio, television, and social networks—restricting the publication of content on land issues. Many expressed concerns about the significant risk of criminalization they now face as a result. This element posed significant problems during the workshops, as some members were suspected of having overly close ties to the State. Consequently, the workshops were conducted with great diplomacy, and many of the informal discussions initiated by the Miskito and Panamanian facilitators aimed to deconstruct and critique the excessively close relationship between certain Mayangna leaders and the state. These discussions encouraged the continued politicization of geographic information despite state pressure to control indigenous territorial resistance strategies.

Box 4: Contemporary and historical dynamics of geospatial and cartographic indigenous practices in our study area.

Participatory mapping practices are not new in this region. The Honduran Mosquitia was the subject of one of the most important pioneering on-land community mapping projects in the early 1990s (Chapin et al., 2005; Herlihy & Tappan, 2019). There have been projects associated with Garifuna and Miskito in the 2000s (Mollett, 2013), as well as projects focusing on marine regions (Nietschmann, 1995). In Nicaragua, the Mayangna territory also holds a distinctive place in the global history of indigenous counter-mapping (Peluso, 1995) as it constituted one of the initial instances to establish a legal precedent in Latin America regarding indigenous cartographic production during negotiations with the State (Alvardo, 2007; Anaya & Grossman, 2002). These stories are far from inconsequential and serve to illustrate the present-day potential for adopting monitoring technologies. Several members of our case study teams, as well as individuals from the traditional authorities closely engaged in these projects, had previous involvement in these initiatives and effectively leveraging their experiences during the workshops.

MASTA , in collaboration with the AMPB Leadership School (Mesoamerican Alliance of Peoples and Forests), has made a clear choice to train future indigenous leaders in monitoring techniques. While the Miskito are recognized as having a robust organization and representation on a national and regional scale (see Box 3, the articulations of these political networks with local traditional authorities are less obvious (Galeana, 2020). The underlying motivations stem from a desire to address internal local political issues and gradually decentralize the application of monitoring methods to tailor them to the specific socio-ecological challenges faced by local councils. Among the motivations most emphasized by the participants were better control and management of natural resources, as well as the organization of the expulsion and/or regularization of settler presence. One major issue identified during the investigation was the selection of participants. Some of the young people selected were also involved in other professional activities, such as teaching or studying, which means that they did not necessarily encounter specific problems in their territories or were disconnected from them. Additionally, some participants preferred to use geospatial technologies for personal purposes, such as titling private property. While the top-down selection process for participants within indigenous governance ensures some oversight, it can also hinder the development of a fully functional monitoring network. A more microlocalized selection process, involving broader community input, could better reflect the real needs on the ground and enhance the network's effectiveness.

By the concluding phases of our survey process, the two teams of apprentice monitors had attained promising outcomes (see Table 2 for a summary of these elements). The Miskito, for instance, established a monitoring collective with the appointment of a president, secretary, and treasurer. The Mayangna successfully enhanced their land use plan proposals. While both teams have achieved a relatively satisfactory level of technological appropriation, common problems have emerged from our survey process, particularly concerning hardware, specifically the quantity and processing power of computers (see Table 3 for a summary of these elements). This aspect allows us to address an inherent obstacle to the sustainability of a monitoring network: external funding. Despite acquiring new skills in the use of geospatial technologies, these groups lack training in writing projects and funding applications. In contexts where the state does not actively support these initiatives, or even opposes or criminalizes them, there is a dependency on cooperation. This creates an inherent contradiction within these autonomous groups, as their sustainability often relies on the goodwill of foreign donors and their ability to engage with them.

The results of the ethnographic study indicate that, contrary to a prevalent idea in the literature, knowledge does not "dialogue" with one another. This notion is not quite accurate, as there is no dynamic and egalitarian interaction between different epistemic systems (Ruddle, 2000). At first glance, we noted that local knowledge

Table 2: Key outcomes and needs identified by workshop participants.

	Mayangna team	Miskito team
Cartographic responses	Reinforcing the land zoning and proposing a strategy for organizing communal property	Creation of a monitoring collective with a president, a secretary, and a treasurer Some visits to isolated territories with the state armed forces
Limits/needs identified	Lack of computers as a limit to sustainable implementation of the device	Lack of computers as a limit to sustainable implementation of the device material Drone capacity-building missing

Table 3: Levels of technological appropriation and challenges in cartographical literacy.

	Mayangna team	Miskito team
Technological appropriation	Good mobile appropriation (LocusMap)	Good mobile appropriation (LocusMap)
	GIS appropriation (QGIS)	GIS appropriation (QGIS)
		Satellite imagery (LandSat)
	Drone capacity building in a Panama camp-type workshop	Lack of drone capacity building
	Impossibility of conducting virtual workshops	Possibility of conducting virtual workshops
	Replication of knowledge	
Intended objectives	Monitoring focused on one ancestral territory	Monitoring focused on several ancestral territories
	Organize sanitation (non-indigenous settlers' expulsion)	Organize sanitation (non-indigenous settlers' expulsion)
	Zoning and the genuine organization of communal property	
		Better control and management of natural resources
	Training leaders and professionals with technical knowledge	Training leaders and future leaders with technical knowledge
	Replicate knowledge to indigenous forest rangers	Replicate knowledge to community members and indigenous youth
	Counteracting an illegal tenure system that overlaps with indigenous communal rights	
Difficulties	Gender issues	Gender issues
	No possibility to conducting virtual workshops	FPIC respect during mapping exercises
	Criminalization by the State	
	Threat to monitor safety	
		Huge territories to cover
	Too few computers	Too few computers
		Computers not powerful enough to support Geographic Information System programs
		Lack of communication among participants

about the forest (e.g., vernacular categories of plants and animals, medicinal knowledge from oral traditions, or spiritual knowledge) seemed incompatible with the framework of geospatial technologies. However, non-verbal knowledge derived from experience—closer to the body in motion within the forest—was used to operate geospatial technologies (we discuss this idea in the Section 4.2.). We noted that the knowledge that interacts within our IFMS combines in ways that focus more on integration than on dialogue. In doing so, it secures the data collection process, enhances its speed and accuracy, and provides valuable information on remote areas that are difficult for Westerners to access. This includes facilitating movement through dense vegetation, knowledge of venomous plants or animals, anticipation of abrupt weather changes, generic survival skills, orientation, and more. Additionally, it encompasses hunting knowledge that helps prevent prey or intruders from detecting the cartographic activity related to them.

4. Discussion

In this final section, we defend the idea that the toolkit we presented is particularly innovative from a socio-technical standpoint as it successfully integrates « satellites » to « boots » (in other words, technology to indigenous forest practices and knowledge) in a context where indigenous communities are becoming increasingly scrutinized for their role as forest sentinels (FAO & FILAC, 2021; Sheil et al. 2015). First, we will briefly revisit the global parameters prompting indigenous peoples to assert control over the production of geospatial data in the forested areas of Latin America (Section 4.1). Then, in Section 4.2, we will delve into the issue of a dialog between technologies and indigenous practices, discussing the system's propensity to root itself in indigenous space epistemologies through practice (Dei et al., 2022).

4.1 Forest monitoring and indigenous data sovereignty

In Latin America and the Caribbean, indigenous peoples assert their presence over approximately 35% of forested territories (Fa et al., 2020; Saatchi et al., 2011; Walker et al., 2020). In Central America, half of the forests remain in indigenous lands (Chapin, 2016). The recognition of these actors as essential contributors to addressing global forest-related challenges is now indisputable, with local monitoring strategies viewed as crucial for achieving these objectives. The propensity of these territories to serve as reservoirs of biodiversity and carbon sinks has significantly influenced discussions within global environmental governance to underscore the protection of territorial rights as fundamental for combating climate change (FAO & FILAC, 2021; Reed et al., 2020). The proliferation of forest monitoring projects with indigenous participation has surged since the 2010s, particularly through the UN-REDD and REDD+ programs. Community-based monitoring, which is more cost-effective than engineer-led programs, has become integral to the successful implementation of climatic global policies (Holmes et al., 2017; Palmer Fry, 2011). This first institutionalization of monitoring is deeply rooted in discussions on the commons (Ostrom & Nagendra, 2006).

The 2020s will witness a notable acceleration toward the digitization of indigenous monitoring, concurrent with the emergence of a new era of indigenous data production (González & Kröger, 2023). Technologies such as databases, drones, spatial imagery, and geographic information systems (GIS) have become new intermediaries in creating common ground between conservationists and indigenous people (Macdonald et al., 2018). States increasingly engage as stakeholders in these monitoring initiatives, while new actors enter this domain. Notably, NASA has initiated an Indigenous People Pilot program to facilitate Earth observation (Neugebauer et al., 2021). Indigenous-led initiatives like the Geo Indigenous Alliance and the Global Indigenous Data Alliance are championing autonomous data production for socio-environmental monitoring worldwide. Large-scale environmental monitoring projects involving indigenous peoples, particularly in the Amazon basin, are gaining prominence (Slough et al., 2021). Indigenous data sovereignty has emerged as a critical factor in determining the recognition, empowerment, and autonomy of these actors (Lovett et al., 2019; Walter et al., 2021; Williamson et al., 2023). The coordination of diverse stakeholders necessitates an increasingly heightened demand for interoperability and enhanced communicative capacities. The standardization of geographic data and data production systems is evolving into an imperative for indigenous organizations, constituting a pivotal milestone and paradigm shift for collective action and geo-activism (Gutierrez, 2019).

4.2 Grounding digital tools in indigenous contexts: a boots-on-the-ground approach

The methodological ingenuity of the toolkit we present lies in its ability to integrate a diverse range of technical elements and coordinate their collaborative operation in practice. From an indigenous perspective, walking is not merely a means of transportation, but rather a pathway through which a distinct understanding of the landscape is developed (Ingold & Vergunst, 2008). In practice, durations of monitoring sessions varies, ranging from several hours to several days, or in some cases, extending over weeks, depending on the size of the territory being traversed. Recognizing that the distribution of geographical knowledge on ancestral territories is not uniform among community members, it is customary for younger instructors to be accompanied by seasoned elders or skilled hunters who possess an intimate familiarity with the area and can anticipate potential challenges within the landscape. In addition, individuals skilled in the use of machetes are often integral members of these expeditions, responsible for forging paths, trails, or passages through dense vegetation. During longer journeys, cooks and porters, who provide indispensable logistical support for the mapping endeavor, may also join the collective.

While young cartographers often navigate these sessions guided by the principles of cardinal points and GPS coordinates, their older companions rely on a reservoir of senses, techniques, know-how, and memories to move through the forest. The combination of these two distinct cognitive frameworks in the field engenders dialogs, negotiations, and at times, conflicts within the collective, and we noted that these particular moments contribute to the integration of digital tools at the community level. After closely studying monitoring sessions in Panama, Honduras, and Nicaragua, it became evident that surveying the forests with digital instruments also served as an opportunity to revise and update the collective memory of the territory. This process involved discussions about the presence of spiritual entities, discovery of archaeological artifacts, and deciphering of traces indicative of ancestral occupation, such as specific medicinal plants and changes in vegetation structure. Consequently, forest monitoring has also emerged as a means of reconstructing and perpetuating indigenous relations with the forest.

5. Conclusion

Combining digital technologies and indigenous perspectives is not an easy task. This article endeavors to elucidate the intricacies associated with the process of appropriating geospatial technologies. Our case studies with the Mayangna and Miskito people showed that this process entails a form of socio-technical integration that manifests itself through dynamic interactions among various forms of knowledge and tools.

Beginning with the portrayal of a simple and cost-effective device designed for easy use by populations unaccustomed to digital mapping tools, our goal was to demonstrate the possibility of establishing IFMS independent of western involvement. The exportable dimension of the device we presented resides not only in its intrinsic characteristics that make it suited for less literate populations but also in the possibility for indigenous geographical knowledge and territorial practices to integrate with the system.

Grounding technology is imperative for an effective device, and linking satellites to boots in indigenous tropical lands enables the production of particularly valuable geodata in areas that are becoming increasingly valued in climatic and environmental terms. Despite the significant challenges and obstacles that continue to surround the future of indigenous forest monitoring, we believe that the prospects for scaling up are feasible. Future challenges thus reside not only in the external provision of support for these ongoing transformations but also in a particular emphasis on safeguarding the principles of sovereignty and the preservation of the intellectual property rights of indigenous geodata.

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