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Institutional dimensions of remote sensing capacity for tropical forest monitoring

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Abstract

Remote sensing technologies are central to tropical forest monitoring, yet the institutional mechanisms constraining their adoption and operationalization within responsible organizations remain poorly understood. Drawing on thirty-eight semi-structured interviews with actors across the remote sensing value chain in Latin America, Africa, and Southeast Asia, we examine how institutional arrangements shape remote sensing capacity within organizations directly engaged in tropical forest monitoring and management. We distinguish between operational frictions, the practical obstacles practitioners encounter in day-to-day remote sensing work, and the institutional conditions that generate and sustain them, organized across four capacity dimensions: dependable data access, technical expertise, organizational support and mandate clarity, and equitable user-provider relations. Our findings show that capacity constraints are not primarily technical but institutional: external data ownership and governance structures, organizational instability, weak mandates, and asymmetric power within the remote sensing value chain interact and compound to undermine capacity even where technical resources are nominally available. These dynamics are especially pronounced for subnational governments, Indigenous organizations, and civil society actors at the periphery of the value chain, who face severe barriers and are frequently on the frontlines of deforestation. Our results suggest that capacity building efforts are more likely to yield durable results when they engage directly with the institutional contexts in which remote sensing is embedded, rather than focusing primarily on individual frictions, such as data access or technical skill development.

1. Introduction

Tropical ecosystems are critical for global biodiversity [1], carbon storage and sequestration [2], and human wellbeing for over one billion people [3, 4], making effective monitoring critical for their conservation and governance [5, 6]. Today, remote sensing data, products, and tools provide an increasing amount of environmental information [7–9] and are central to a range of monitoring and verification activities, including land use change monitoring [10], biodiversity conservation [11, 12], mapping of Indigenous territories [13, 14], policy design and carbon accounting [15, 16], supply chain monitoring [17, 18], and law enforcement [19].

Yet the availability of these tools and products does not automatically translate into operational use. Despite rapid advances in remote sensing technologies and data access [10, 20], capacity issues persist and institutional and organizational capacities remain unevenly developed and distributed [21, 22]. They are especially pronounced in tropical forest regions, where organizations often operate with limited budgets, weak institutional infrastructure, and under competing pressures between conservation objectives and development priorities [23, 24]. When remote sensing capacity is absent or fragile, the information needed to detect deforestation, enforce land rights, and account for carbon stocks may not reach decision-makers.

Monitoring and management of tropical ecosystems is carried out by a wide range of institutions, including national and subnational governments, semi-autonomous technical bodies, non-governmental organizations, international organizations, research institutions and think tanks, and hybrid organizations [25, 26]. Specific responsibilities vary by geography, the degree of administrative decentralization, and the resources and mandates of individual institutions. For example, in decentralized governance systems, these roles are often fulfilled by subnational governments, such as Mato Grosso's state-operated satellite monitoring system for deforestation alerts [27] or Pará's SeloVerde platform for deforestation-free supply-chain verification [28]. In more centralized systems, equivalent functions are carried out by national agencies, semi-autonomous technical bodies, or hybrid public non-governmental organizations, such as the Central African Forest Satellite Observatory and Gabonese Agency for Space Studies and Observations (AGEOS) [29, 30]. Increasingly, Indigenous peoples and customary communities are monitoring or co-monitoring their own territories, like in the community-based forest monitoring project in Peru co-designed by the regional Indigenous organization ORPIO [14, 31]. What these actors have in common is their responsibility for operationalizing remote sensing for public or quasi-public purposes and the translation of remote sensing information into formal decision-making processes operating under public or collective mandates.

Establishing remote sensing capacity within these diverse institutional contexts is challenging across multiple dimensions. Prior research has substantially advanced understanding of capacity barriers across functional domains, including data access, technical expertise, organizational support, and partnerships [32–35]. These challenges are accompanied by an increasingly complex value chain composed of a wide range of actors, including data providers, application developers, *in-situ* data collectors, donor agencies, consultants, and diverse end-users across geographies and organizations [36–38]. Complexity and documented barriers alone, however, do not fully account for why capacity gaps persist. Remote sensing technologies are also technically demanding, value-laden in their design and application [39], and embedded in existing rules, routines, and organizational practices, making their adoption contingent on institutional contexts that vary widely across actors and geographies [26, 40]. The critical remote sensing literature has been instrumental in surfacing questions of power, representation, and politics in an otherwise predominantly technical and functional remote sensing literature [39–41]. Yet even within this broadened literature, comparatively little attention has been paid to how capacity barriers emerge, interact, and persist as interconnected institutional arrangements, particularly for governance actors in tropical forest regions.

Here, we seek to advance understanding of how institutional arrangements shape remote sensing capacity and its everyday practice within organizations directly engaged in tropical forest monitoring and management, drawing on perspectives from across the remote sensing value chain. Through first-hand accounts from key operational users (OUs), data producers and developers, intermediaries and enablers (IEs), and civil society and research actors, we analyze how capacity constraints manifest as operational frictions, the practical obstacles encountered in the course of operationalizing remote sensing and how these constraints are rooted in broader institutional arrangements. In doing so, we offer an institutional lens for understanding how remote sensing capacity is constrained within critical organizations, with implications for how capacity building efforts are designed and targeted.

2. Methods

We conducted thirty-eight semi-structured interviews with remote sensing actors across three tropical regions, Latin America, Africa, and Southeast Asia (table 1). We categorized actors by their functional role in the remote sensing value chain. Operaional users (OU) are civil servants or personnel embedded in public agencies or organizations working with government institutions who directly employ remote sensing data and tools for forest monitoring, land use planning, and environmental management. Data providers and technology developers (DP) generate, process, and/or maintain Earth observation data, analytical products, and technical platforms and include private companies, space agencies, and research-oriented organizations. IEs support the production and use of remote sensing through funding, coordination, technical assistance, or capacity building and include development agencies, donor programs, nonprofit organizations, and space agency initiatives. Civil society and research actors (CS) apply remote sensing for advocacy, accountability, and research. Boundaries between these categories may be fuzzy and actors can occupy multiple roles simultaneously. Participants are based in one of the three tropical regions or the Global North, reflecting the broad geographic distribution of actors within the remote sensing ecosystem.

We employed purposive and snowball sampling and participants met pre-defined criteria: (i) they

Table 1. Overview of interviewees.

Functional role in the remote sensing value chain	ID	Organization of interviewee	Role of interviewee	Continent interviewee is based in
Data producers & technology developers	DP-1	Forest monitoring platform	Research analyst	North America
	DP-2	Forest monitoring platform	Research associate	Europe
	DP-3	Earth imaging company	Senior director forests and land use program	North America
	DP-4	Geographic information system company	Manager for national government sector business development	North America
	DP-5	Venture capital firm	Founder and managing director	North America
Intermediaries & enablers	IE-1	Space agency program	Lead regional science coordinator	North America
	IE-2	Development agency	Geographic information system and forestry advisor	Asia
	IE-3	Foreign relations agency	Environment officer	Asia
	IE-4	Development agency	Head of private sector engagement	South America
	IE-5	Development bank	Senior advisor	Europe
	IE-6	Development agency	Senior adviser	Europe
	IE-7	Space agency program	Science and data lead	Asia
	IE-8	Space agency program	Land cover and ecosystem theme lead	Asia
Operational users	OU-1	Subnational environmental government agency	Secretary for the environment	South America
	OU-2	Subnational environmental government agency	Environmental management technician	South America
	OU-3	Subnational environmental government agency	Specialist in cartography	South America
	OU-4	Subnational environmental government agency	Director of research and technology for land management	South America
	OU-5	Subnational environmental government agency	President	South America
	OU-6	Subnational environmental government agency	Forestry civil servant	Asia
	OU-7	Subnational environmental government agency	Territorial planning specialist	South America
	OU-8	National space agency	Remote sensing & GIS engineer	Africa
	OU-9	National climate change observatory	Director	Africa
	OU-10	National climate change observatory	Head of geomatics department	Africa
	OU-11	Regional intergovernmental entity	Regional project coordinator	Africa
	OU-12	Domestically operating environmental advocacy organization	Spatial data analyst for Indigenous and local lands and forest policy	Asia
	OU-13	Indigenous government and knowledge-sharing platform	Congressional member; co-founder	Central America
	OU-14	Secretary for tribal affairs in subnational government	Director for Indigenous people of Acre[a]	South America
	OU-15	Secretary for tribal affairs in subnational government	Civil servant	South America
	OU-16	Indigenous and customary people advocacy organization	Data scientist	Asia

(Continued.)

Table 1. (Continued.)

Functional role in the remote sensing value chain	ID	Organization of interviewee	Role of interviewee	Continent interviewee is based in
Civil society and research actors	CS-1	Domestically operating environmental advocacy organization	Senior manager conservation planning	Asia
	CS-2	Investigative journalism initiative	Director of environmental investigations	South America
	CS-3	Internationally operating environmental advocacy organization	Senior geospatial analyst	North America
	CS-4	Research-focused conservation organization	Senior researcher	South America
	CS-5	Environmental advocacy organization with focus on Indigenous peoples' rights	Senior advisor; founder	South America
	CS-6	Non-profit environmental consultancy	Deputy director responsible sourcing	Africa
	CS-7	National forestry school	Lecturer	Africa
	CS-8	Research University	Researcher specialized in participatory mapping	Europe
	CS-9	Research university	Researcher specialized in participatory mapping	Europe

[a] The interviewee requested explicit mention of their state.

were directly engaged in the use, facilitation, or provision of remote sensing for tropical forest governance (including both local practitioners and international professionals working on tropical forest issues), and (ii) held roles enabling them to speak to organizational practices or constraints. Interviews were held online or in-person.

Interview questions focused on operational constraints, their institutional drivers, and implications for practice and were adapted where necessary. The study is approved by the University of California, Los Angeles Institutional Review Board (protocol ID IRB#23-000850). Recordings were transcribed manually or with Otter.ai and manually corrected. For data analysis, we employed thematic analysis to identify and analyze key themes [42, 43], utilizing the Taguette tool for coding. Coding was conducted inductively, with themes derived iteratively from interview transcripts and refined across multiple passes.

3. Results

Across interviews, we identified recurring operational frictions and the institutional conditions that give rise to them. We distinguish between these two levels because they require different responses: operational frictions are the day-to-day impediments practitioners face, while institutional conditions are the deeper structural arrangements that generate and sustain them. Both levels interacted and constrained four determinants of remote sensing capacity: dependable access to adequate data, institutional technical expertise, organizational support and mandate clarity, and equitable and durable partnerships (figure 1).

3.1. Dependable access to adequate data

Dependable access to adequate data is shaped by two institutional conditions related to *external data ownership and governance* and *resource and infrastructure constraints*. Interview respondents described a reliance on remote sensing data that is generated, owned, and governed by external actors, including commercial providers, international organizations, and foreign research institutions (OU-2, OU-9). Commercial data contracts were frequently cited as a particular source of tension, as licensing terms may include audit rights, restrictions on downstream use, requirements to demonstrate compliance with provider-defined purposes, or stipulations that legal disputes be handled in the provider's country of origin (IE-2, IE-6). Interviewees raised related concerns around data sovereignty and security, with agencies questioning whether uploading sensitive datasets to cloud platforms such as Google Earth Engine might violate data ownership or privacy obligations (IE-2). These governance challenges are compounded by resource and infrastructure constraints. Interviewees described insufficient budgets to procure data, maintain storage, or invest in reliable internet connectivity, hardware, and office space (OU-8, OU-10, OU-13). Even modest recurring costs, for example cloud-based data storage or platform access, were reported to exceed available budgets (IE-1).

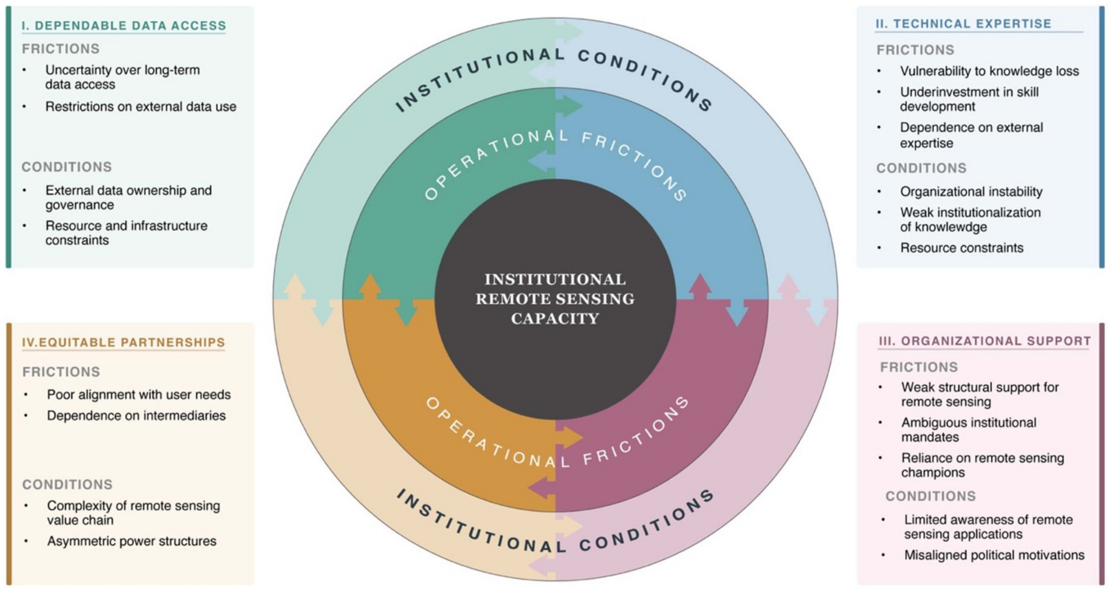

Figure 1. Institutional determinants of remote sensing capacity for tropical forest monitoring. Remote sensing capacity (center) is constrained by operational frictions (inner ring) rooted in broader institutional conditions (outer ring), organized across four interrelated capacity dimensions: dependable data access, technical expertise, organizational support and mandates, and equitable and durable partnerships. Frictions and conditions interact across all four dimensions.

Together, these conditions gave rise to interrelated and compounding operational frictions. First, reliance on externally owned data introduces *uncertainty over long-term access*. Interviewees were concerned that free or subsidized datasets might become unavailable or unaffordable over time, exposing institutions to sudden disruptions (DP-2, OU-5). As one intermediary noted, institutions were reluctant to build long-term public systems on the '[…] basis of some one-off goodwill thing that maybe lasts two years' (IE-6). Second, this uncertainty created vulnerability to external decisions, including changes in pricing, licensing terms, or political sensitivities. Resource constraints exacerbated this vulnerability by limiting institutions' capacity to pay for continued access, negotiate contracts, or develop alternative data pipelines. Some governments responded by imposing *restrictions on the use of external sources*. While this approach addressed sovereignty concerns, it introduced new constraints (figure 2). In Indonesia, for example, stipulations that only centrally produced data could be used for official purposes introduced data access delays (IE-2), leaving provincial-level civil servants waiting for official land cover data and relying on outdated information: 'We cannot get the data real-time. […] The bureaucracy is just taking too much time' (OU-6).

3.2. Institutional technical expertise

Technical expertise was described by respondents not only as the sum of individual competencies but as an institutional capacity enabled by staffing stability, resource availability, and internal knowledge retention. Limitations in technical expertise were associated with three interconnected institutional conditions. First, formal organizations such as government agencies were constrained by *organizational instability* in the form of high staff turnover, frequent reassignment, and uncertainty regarding the continuity of technical work (OU-2, OU-3). In public entities, turnover was linked to political cycles, elections, and changes in leadership (OU-1, OU-6) while in both public and civil society organizations trained staff were also reported to leave for more stable or better-paid positions in the private sector (CS-7; IE-5, IE-7). Second, these dynamics were compounded by *weak institutionalization of knowledge*, where processes for retaining and transferring technical knowledge, such as standardized documentation, onboarding procedures, or internal training were absent or poorly developed and workflows were highly dependent on the expertise of individuals (OU-3). Third, *resource constraints* exacerbated these issues, limiting the ability to offer competitive salaries, maintain stable staffing, or invest in knowledge retention mechanisms. Respondents highlighted that budget constraints restricted hiring, curtailed training opportunities, and reduced the feasibility of sustained skill development, as exemplified by one facilitator's observation: 'If I train people in the analysis and interpretation of satellite data, then in many countries they will change quite quickly to the private sector' (IE-5). Perceived resource availability varied substantially across contexts: while civil servants in some Brazilian states

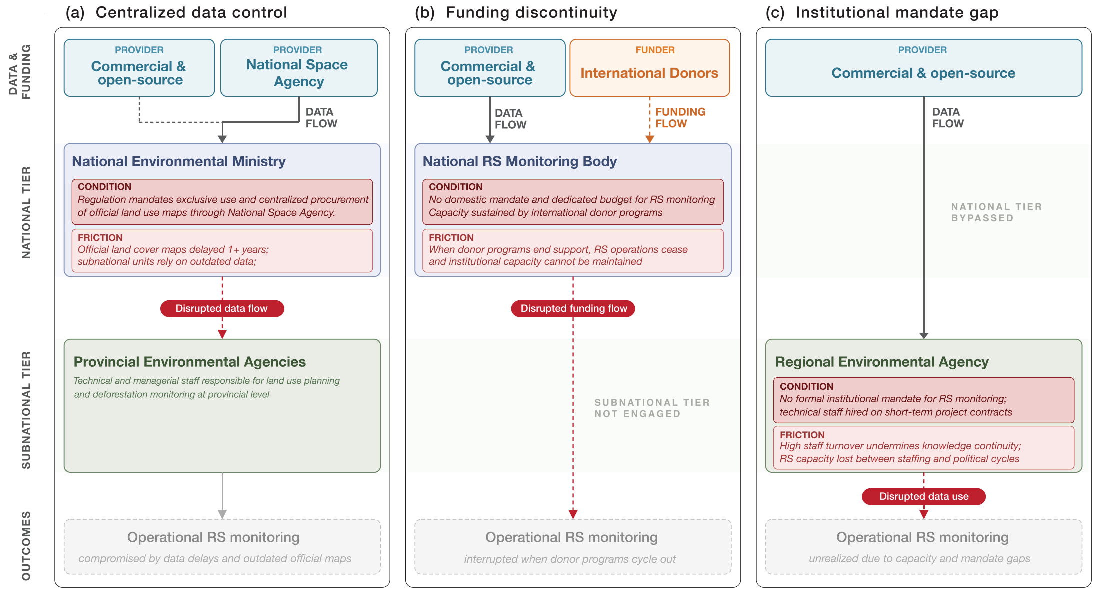

Figure 2. Institutional conditions and operational frictions across the remote sensing (RS) value chain. The cases highlight that value chain flows are context specific and show how a specific institutional condition (dark red) produces an operational friction (light red) that disrupts the effective use of remote sensing for forest governance.

reported comparatively fewer constraints, interviewees from other locations described severe limitations, including insufficient access to basic infrastructure like electricity, internet, and computer hardware (CS-7, OU-13, OU-10).

These conditions gave rise to *vulnerability to knowledge loss*, whereby staff turnover or individual departures could have an outsized impact in organizations with small teams and poorly institutionalized knowledge structures (figure 2). Interviewees described agencies with only one or two GIS specialists, where the loss of a single technical champion could lead to the abandonment of remote sensing systems entirely (OU-6, IE-1, OU-7). Similarly, budgetary limitations frequently resulted in *underinvestment in sustained skill development*, manifested as training being delivered as one-off workshops rather than as continuous learning processes, or the absence of training altogether (IE-5).

The projectization of remote sensing also created a *dependence on external expertise*, whereby institutions relied on consultants, donor-funded programs, or temporarily embedded staff to perform core remote sensing functions. Interviewees emphasized that such arrangements were often tied to short-term projects with narrowly defined deliverables, in which explicit knowledge transfer was not prioritized (DP-5, IE-7). As one government user from Cameroon noted, repeated reliance on consultants leaves local actors and organizations as 'spectators,' unable to independently reproduce the work after the external experts leave (OU-9). Consultancies were described as 'black boxes', deliberately limiting transparency around data, models, or workflows, thereby reinforcing dependence (IE-7). While respondents acknowledged that external expertise is often a necessary entry point, projectization without internal skill development perpetuated dependencies (CS-7, IE-8).

3.3. Organizational support and mandate clarity

In the absence of clear institutional mandates and support, organizations struggled to embed remote sensing into routine practice, resulting in uncertainty over responsibility, authority, and sustained support. Two institutional conditions underpinned these dynamics. First, a *limited awareness of remote sensing applications* at decision-making levels, where interviewees described situations in which senior officials lacked a clear understanding of how remote sensing can inform decision-making processes (OU-3, OU-4). This was attributed less to technical complexity than to weak communication between technical staff and leadership, resulting in remote sensing being perceived as optional or experimental rather than as a core operational tool (IE-1, CS-1). Second, *misaligned political motivations* impacted whether remote sensing initiatives were prioritized and sustained. Respondents noted that political incentives might favor activities with more immediate visibility or personal benefit, resulting in situations where politicians '[…] instead of going by what's needed they go by their own personal interest' (OU-3).

These conditions resulted in *weak structural support for remote sensing*, manifested in the absence of dedicated budget lines, permanent staff positions, institutional units, or formal workflows. Remote sensing activities were often treated as peripheral to core mandates, relying on ad hoc funding or short-term projects (OU-3, OU-7, IE-8). An interviewee from Central Africa described how limited awareness among senior decision-makers that remote sensing can identify areas at high risk of post-deforestation mudslidesled to a proposed monitoring initiative not being funded. When mudslides later occurred, response efforts were delayed as a result (OU-10). Interviewees emphasized that sustained remote sensing capacity required explicit prioritization from leadership as without 'top cover,' technical staff lacked both the mandate and protection to advance remote sensing initiatives (IE-3, DP-5).

Closely linked to weak structural support were *ambiguous institutional mandates*, where responsibility for remote sensing was unclear and authority over systems and data was fragmented. In such contexts, remote sensing activities might be deprioritized in budgeting, staffing, and procurement decisions (figure 2). Interviewees from Southeast Asia noted that governments had to triage budgets, deprioritizing remote sensing in favor of health, education, and economic development (IE-7). This leads to situations where civil servants face uncertainty about the continuity of their program even when their direct superiors strongly support remote sensing initiatives (IE-8). Guyana provides a contrasting example: despite limited initial resources, clear mandates across agencies, consistent high-level support, and retention of skilled personnel enabled the development of a robust land-use change monitoring system (IE-6, see also [44]). However, such long-term, institutionally embedded approaches were perceived as less attractive to external funders seeking short-term, high-visibility interventions (IE-6).

In the absence of clear mandates and structural support, organizations might be forced to *rely on remote sensing champions*, individuals or small groups who advocate for remote sensing adoption, mobilize resources, and create enabling environments (IE-3, IE-5, OU-9). At the same time, such dependence on individuals introduced fragility: when champions leave or lose influence, momentum could fade quickly, particularly where no institutional structures exist to sustain progress (DP-5).

3.4. Equitable user-provider relations

Within the complex remote sensing value chain, our interviewees described *asymmetric power structures* that concentrate agenda-setting authority upstream. The absence of co-design pathways, understood here as structured processes through which end users contribute directly to the development, adaptation, and evaluation of remote sensing products and tools, limited opportunities for users to engage meaningfully in the design, implementation, and adaptation of remote sensing tools and products (IE-1, OU-11, IE-5). For example, in a subnational government in Peru, monitoring responsibilities were formally assigned to a dedicated unit yet control over the data required to carry out those tasks resided with an upstream unit, so that 'the unit itself has no way to access the information that it needs' (OU-7). As a result, opportunities to develop remote sensing products that reflect users' knowledge of local ecosystems and land use patterns were limited, despite the importance of such contextual knowledge for outputs ranging from accurate biomass estimation to biodiversity assessment to land cover mapping (CS-2).

A second friction was *poor alignment of data and tools with user needs*, even when data access and technical capacity were nominally present. For example, an official from a state agency for Indigenous affairs noted that rigid funding and contract timelines often clashed with local administrative procedures, causing teams to miss contractual or project deadlines even when resources were available (OU-14). Interviewees also noted that central authorities and local users often had different ideas about what should be mapped, resulting in data that was technically accurate but failed to capture how communities actually understand and use the land (CS-5).

A third friction is *dependence on intermediaries* for information, data, tools, and training, which was particularly pronounced for organizations with limited in-house expertise or prior exposure to remote sensing (IE-5, OU-4, CS-2). Intermediaries were common in two settings. One, intra-organizational where users communicate to providers and/or facilitators via individuals or institutional entities within their organization, for example a federal-level ministry, or a high-ranking decision-maker (OU-15). Two, inter-organizational, where external actors such as consultants, NGOs, or development agencies mediate interactions between users and providers. While in many cases intermediaries were necessary for translation, introduction, and initialization of remote sensing tools and capacity, over-dependence introduced the risk of losing access to data and knowledge once the intermediaries or external consultants leave (CS-7, OU-9). Additionally, intermediaries themselves might require training on how to effectively consult with Indigenous communities, adding further complexity (CS-9).

4. Discussion

Operational frictions and the institutional conditions that produce them require fundamentally different responses as addressing frictions without engaging the underlying conditions does not resolve the root cause and may reproduce the same friction elsewhere or at a later time. Consistent with the observation that functional capacities are difficult to develop relative to technical ones [45], we show that these frictions interact and compound.

For example, when addressing issues of technical expertise, enablers and intermediaries may identify limited expertise among civil servants as a key bottleneck and respond by providing training. However, such training may not yield long-term benefits if high staff turnover and insufficient onboarding processes are not also addressed. This illustrates a broader pattern: operational frictions such as limited expertise, weak structural support, or asymmetric agenda-setting are often symptoms of deeper institutional conditions, including organizational instability, limited awareness of remote sensing applications, lack of high-level mandates, external data ownership, and lack of co-design pathways. These findings call into question a tendency in the remote sensing literature to treat democratizing access to data and computational tools as the primary pathway to broader remote sensing capacity [23, 46, 47].

Our results suggest that institutional conditions represent fundamental constraints that technological advancements alone cannot resolve. This echoes Olbrich's [48] finding that across three waves of NGO enthusiasm for remote sensing technology, each period of optimism was followed by a confrontation with the institutional work required to sustain it, consistent with Sætra's [49] observations that techno-solutionist approaches tend to address symptoms while leaving political and organizational root causes unaddressed.

The operational frictions and institutional conditions constraining these four dimensions interact and compound. For instance, organizational support and mandate clarity tends to be a prerequisite for sustained technical expertise: without high-level commitment and clear mandates, investments in training and staffing are unlikely to stick [45]. User-provider relations similarly affect outcomes across all other dimensions, as authority concentrated upstream can render data and tools effectively inaccessible to end users, regardless of their nominal availability [24, 41, 50]. Applying an institutional lens that distinguishes conditions from frictions reveals why targeted interventions frequently yield only temporary results: training without addressing turnover, consultancy without knowledge transfer, and data provision without governance reform each address a friction while leaving the underlying institutional condition intact [48, 51, 52]. This suggests the primary locus of intervention should shift from operational symptoms to the institutional arrangements that produce them.

Where institutional foundations are weak or absent, organizations often rely on external intermediaries and individual champions to substitute institutional support. While intermediaries and champions can be instrumental in initiating remote sensing activities, they can also introduce fragility, prevent internalization of skills, and leave progress vulnerable to individual departures or external disengagement [52, 53]. These dynamics reflect a broader pattern documented in the literature that technology-intensive projects often remain highly dependent on external expertise and cannot be considered truly empowering as a result [54]. Such dependencies can reproduce themselves in the absence of institutionalized support such as clear mandates, documentation, and shared ownership, so that knowledge remains with individuals and external actors rather than embedded in organizational practice. Addressing this requires what González and Kröger [50] describe as genuine redistribution of difficult tasks to local actors, rather than delivery of outputs on their behalf, an approach consistent with calls for more ethical and empowering practices in remote sensing [55].

Consequently, actors seeking to support remote sensing capacity development must move beyond standardized, scalable interventions and instead engage in careful diagnosis of the institutional mechanisms producing specific pain points within specific organizational environments. This requires sustained engagement with target organizations and direct interaction with key actors which might exceed the capacities or strategic priorities of many facilitating organizations. Interviewees suggested that international facilitators, particularly those in the Global North, might find it less advantageous or even outside of their remit to address institutional barriers, consistent with observations from the literature that donors and external stakeholders disengage once a project moves into a phase of consistent institutional maintenance [48, 51]. Compounding factors are that explicit knowledge transfer is seldom required as an outcome of research proposals [32] and that remote sensing systems are designed and funded through institutional visions that rarely prioritize the needs of under-resourced users [26]. Capacity building efforts that recognize institutional conditions as the root of practical frictions are more likely to yield effective and durable results [24, 45]. This is especially true for actors at the periphery of the value chain, such as Indigenous groups and public entities, who often face the most severe barriers to remote sensing adoption yet are frequently on the frontlines of deforestation monitoring and management.

Remote sensing products and findings are shaped and used by systems and actors with heterogeneous, normative views and goals that—while beyond the empirical scope of this study—must be considered to fully understand the implications of capacity considerations at the organization level. First, remote sensing-derived information is situated within broader political, economic, and governance systems. Empirical descriptions of land cover change including deforestation may be politically sensitive and certain actors or sections within governments may have incentives to conceal, resist, delay, or ignore data that are at odds with economic or political priorities. Such dynamics are well-documented in the critical remote sensing literature [39, 56].

Second, strong technical capacity does not ensure that remote sensing information is objectively used for decision-making: the translation of monitoring data to inform policy and support enforcement requires political will, an adequate regulatory framework, coordination across institutions, and sufficient capacity and resources within the institutions responsible for acting on it [19, 57, 58]. Finally, remote sensing data products themselves are not neutral representations of physical reality. They, too, are shaped by choices about how key terms are defined, methodological conventions, and institutional priorities of the actors who commission, fund, generate, and distribute them. For example, global forest datasets frequently disagree on how forests are defined and measured, leading to substantial variation in the estimates for carbon storage, habitat availability, and number of forest proximate people, thereby introducing considerable uncertainties for global sustainability and development efforts [59].

Moreover, our findings should be interpreted in light of several study limitations. They are based on qualitative interviews with a purposive sample, which introduces participation and sample bias; perspectives from actors who declined to participate or who were not reached may differ. The sampling strategy also does not allow for systematic triangulation across interviewee roles and organizations. Future research could explicitly structure sampling to enable cross-validation of perspectives. Remote sensing capacity is also highly context-dependent, shaped by local political, institutional, and ecological conditions, and findings from our sample cannot be fully generalized. We nonetheless consider the institutional dynamics identified here to be broadly transferable, given the diversity of organizations, geographies, and value chain positions represented. Furthermore, while our sample prioritizes actors directly engaged with tropical forest governance, the majority of providers and intermediaries in our sample are headquartered in the Global North, which is broadly representative of the sector, but may introduce asymmetries in perspective.

5. Conclusion

Remote sensing capacity for tropical forest monitoring is shaped by institutional conditions that generate recurring operational frictions within organizations responsible for monitoring and managing tropical ecosystems. Distinguishing between these two levels helps explain why capacity deficits persist despite rapid technological advances and ongoing capacity building efforts. Our results suggest that capacity building is more likely to succeed if it considers the institutional contexts in which remote sensing is embedded, with implications for actors across the value chain seeking to strengthen such capacities. Capacity-building organizations should move beyond standardized tool and training provision toward a sustained and institutionally embedded approach that also aims at improving institutional mandates, retaining institutional knowledge, and generates leadership buy-in. Such approaches challenge how success is defined, since a focus on short project cycles and high-visibility deliverables may not be conducive to building the long-term support required for building durable and resilient capacity. Because the conditions and frictions we describe are distributed across the value chain, effective responses must be tailored to the specific interests and capacities of the actors involved. Governments can support such efforts by embedding it within stable institutional structures with dependable annual funding and permanent staff positions, rather than relying on project-based or champion-driven arrangements. These changes require financial investment in remote sensing infrastructure and the governance structures surrounding it. Whether these are funded domestically through dedicated budgets or fiscal transfers or externally through sustained reliance on project funding and donor contributions depends on the specific needs and conditions of each government. Regardless of the financing pathway, such investments may require a critical rethinking of current priorities and joint efforts by all actors along the remote sensing value chain, from producers and developers to IEs, as well as civil society and research actors.

Future inquiry into remote sensing capacity building could examine two complementary questions: how initiatives that explicitly embed institutional conditions into their approaches perform over time relative to interventions focused primarily on data access or skill development; and how geopolitical factors, including the origins of data providers, funding agencies, and technical partners, shape which tools are adopted, which partnerships are prioritized, and whose agendas are advanced. Recognizing and engaging with these institutional dimensions is not peripheral to remote sensing capacity development but a necessary condition for making capacity durable and robust.

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Data availability statement

The data cannot be made publicly available upon publication because they are not available in a format that is sufficiently accessible or reusable by other researchers. The data that support the findings of this study are available upon reasonable request from the authors.

Conflict of interest

The authors declare no competing interests.

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