

Adaptive Forest Oversight Governance in North Sumatra: Integrating Information Systems and Institutional Capacity

Simson Ginting^{1*}

¹ Universitas Sumatera Utara, Indonesia

Abstract

This study aims to analyze forest oversight governance in North Sumatra by examining patterns of tree-cover loss, institutional constraints, and the requirements for developing an adaptive forest protection framework. A qualitative policy analysis was conducted using documentary evidence derived from forestry regulations, institutional reports, environmental datasets, remote-sensing information, and relevant scientific literature. The data were analyzed through thematic coding informed by control process theory, policy implementation perspectives, and responsive regulation. The findings indicate that North Sumatra experienced substantial tree-cover decline between 2000 and 2025, with approximately 1.70 million hectares of indicative tree-cover reduction recorded in Global Forest Watch data. The analysis further identifies fragmented information management, limited interoperability among monitoring systems, weak institutional coordination, predominantly reactive monitoring practices, and insufficient integration between regulatory enforcement and ecological restoration as major governance constraints. In response, this study proposes the PASTI-HUTAN framework, an adaptive forest oversight model integrating spatial information governance, risk-based monitoring, interinstitutional coordination, proportionate regulatory responses, and continuous policy evaluation. These findings extend environmental governance scholarship by conceptualizing forest protection as an adaptive control system rather than solely as a conventional law-enforcement function. Practically, the framework highlights the need for integrated forest information systems, stronger cross-institutional collaboration, preventive risk-based monitoring, and adaptive regulatory mechanisms. Because the study relies primarily on documentary and secondary data, future research should empirically test the PASTI-HUTAN framework across different forest governance contexts and evaluate its effectiveness in improving enforcement, restoration, and long-term forest sustainability.

ARTICLE HISTORY

Received : 21 April 2025

Revised : 29 Juni 2025

Accepted : 30 July 2025

KEYWORDS

Adaptive governance; Forest oversight; Information governance; Responsive regulation; Sustainable forest management

PUBLISHER'S NOTE

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) license.



CORRESPONDING AUTHOR

***Simson Ginting**, Universitas Sumatera Utara, Indonesia. Email: simson.ginting@usu.ac.id

Introduction

Forests constitute a foundational component of contemporary environmental governance because they simultaneously operate as ecological systems, economic assets, carbon reservoirs, livelihood spaces, and territories in which competing public and private interests are negotiated. Their protection therefore cannot be reduced to the preservation of vegetation cover or the prosecution of illegal logging; rather, it requires governance arrangements capable of reconciling ecological integrity, economic development, regulatory compliance, spatial planning, and community interests. Globally, forest ecosystems remain under pressure from agricultural expansion, commodity production, infrastructure development, mining, fire, and both legal and illegal timber extraction, while the transboundary nature of commodity-driven deforestation increasingly links local forest change to wider political-economic processes (Basu & Basu, 2023; Blattert et al., 2022; Hoang &

Kanemoto, 2021; Sorge et al., 2022). In Indonesia, these pressures are amplified by the scale and heterogeneity of tropical forest landscapes and by the institutional complexity through which forestry, plantation development, spatial planning, environmental protection, and regional development are governed. Recent Indonesian studies consequently demonstrate that forest degradation cannot be explained exclusively through ecological drivers: institutional design, policy coherence, state capacity, stakeholder power relations, and coordination across administrative levels substantially condition environmental outcomes (Sahide et al., 2020; Sayer et al., 2021; Hermawan et al., 2023).

A critical methodological issue in this field concerns the distinction among legally designated forest areas, biophysical forest cover, and satellite-derived tree cover. These concepts are related but not interchangeable. Forest designation represents a juridical and administrative classification; forest cover describes ecological and biophysical characteristics; and remotely sensed tree cover is generally constructed through particular canopy, spatial-resolution, and temporal thresholds. Conflating these categories can produce misleading estimates of forest degradation and, consequently, inappropriate policy responses (Ahrends et al., 2021; Curtis et al., 2018; Samsuri et al., 2025). Contemporary remote-sensing scholarship further emphasizes that satellite products have become indispensable for operational forest monitoring, yet their effective use depends on validation, spatial resolution, temporal frequency, data quality, and correspondence with the information requirements of decision makers (Fassnacht et al., 2024; Zhang et al., 2020; Zhang et al., 2021). Recent advances in near-real-time forest alerts and machine-learning-based attribution of deforestation drivers demonstrate the capacity of spatial technologies to move forest monitoring beyond retrospective reporting toward earlier detection and risk identification (Mullissa et al., 2024; Ramachandran et al., 2024). Nevertheless, technological capacity alone is insufficient: remotely sensed evidence becomes administratively consequential only when institutions can integrate it into licensing, inspection, enforcement, and corrective decision-making.

This problem is especially relevant to Indonesia, where forest protection is formally supported by an extensive regulatory architecture but implemented through a complex institutional environment. Forestry law, regulations concerning the prevention and eradication of forest destruction, environmental governance instruments, licensing provisions, spatial planning rules, and sectoral administrative requirements establish multiple layers of control. However, regulatory density does not necessarily translate into regulatory effectiveness. Fragmented authority, overlapping jurisdictions, competing databases, inconsistent maps, and weak interoperability between licensing and monitoring systems may create implementation gaps even where formal rules are comprehensive (Muhyidin, 2019; Ramadhan et al., 2023; Resosudarmo et al., 2019). Empirical work in Indonesia confirms that policy incoherence can generate contradictory requirements and ineffective implementation, particularly in multi-sectoral landscapes such as peatlands and state forests (Sari et al., 2021). Similarly, the visualization of previously obscured illegal land uses through the One Map Policy demonstrates that producing better spatial information does not automatically resolve governance problems; instead, new information may expose legal inconsistencies and create difficult choices regarding enforcement, legalization, restoration, and competing socioeconomic interests (Astuti et al., 2022). More recent analysis of risk-based licensing likewise indicates that environmental protection depends not merely on licensing efficiency but on auditability, traceability, institutional responsibility, and credible corrective mechanisms (Hastri et al., 2025).

Within this institutional configuration, Forest Police (*Polisi Kehutanan*, or Polhut) occupy a strategically important position because they translate regulatory authority into preventive surveillance, field monitoring, disturbance detection, evidence collection, and enforcement-related action. Nevertheless, enforcement capacity is not determined solely by the legal mandate or presence of enforcement personnel. It depends on the interaction of human resources, geographical accessibility, operational infrastructure, technological capability, financing, information availability, interorganizational communication, and relationships with Forest Management Units (KPH), Civil Servant Investigators, police institutions, prosecutors, local governments, and communities. International evidence indicates that institutional quality, accountability, and rule-of-law conditions are significantly associated with the capacity to constrain illegal logging (Bösch, 2021). Indonesian research similarly demonstrates that forestry institutions frequently operate within fragmented governance environments in which formal mandates are not always matched by adequate resources or coordination mechanisms (Maryudi et al., 2022; Myers et al., 2022; Sayer et al., 2021). The effectiveness of Polhut should therefore be conceptualized not as an isolated law-enforcement variable but as part of a broader oversight system in which intelligence, monitoring, coordination, enforcement, and ecological recovery must function as an integrated cycle.

Existing scholarship has substantially advanced understanding of the structural and proximate drivers of forest loss. Studies have examined agricultural and plantation expansion, infrastructure, extractive industries, forest fires, illegal logging, tenure reform, community forestry, and conservation interventions (Austin et al., 2020; Rantala et al., 2022; Ullah & Bavorova, 2024). More recent studies have added important insights concerning the institutional dimensions of forest governance. Sahide et al. (2020), for example, demonstrate that ambitious social-forestry policies may produce exclusion during implementation when actors have unequal access to information and decision-making resources. Hermawan et al. (2023) show that institutional layering in Indonesian REDD+ governance can create complex coordination challenges, while Muttaqin et al. (2023) reveal that even formally inclusive multistakeholder institutions may be characterized by asymmetrical power relations. Research on landscape restoration similarly shows that governance constraints and excessive state-centered control can weaken restoration effectiveness unless learning and partnerships operate across institutional scales (Sayer et al., 2021). Taken together, these studies shift the analytical emphasis from whether environmental rules exist toward whether governance systems possess the coordination, information, accountability, and adaptive capacity required to translate rules into ecological outcomes.

Despite these advances, a significant gap remains between research on forest degradation and research on the institutional architecture of forest oversight. Much of the literature identifies what drives forest loss or evaluates specific conservation policies, but comparatively less attention has been paid to the complete oversight cycle through which government institutions establish standards, obtain evidence, detect deviations, prioritize risks, coordinate responses, apply sanctions, verify restoration, and subsequently adjust policy. This gap is particularly consequential when spatial data and licensing information are stored across different institutions. A technically sophisticated monitoring platform may identify tree-cover disturbance, but it does not necessarily establish whether the detected change violates a permit, occurs outside an authorized boundary, reflects legal harvesting, results from fire, or requires administrative, civil, criminal, or restorative intervention. Forest oversight effectiveness therefore depends upon the capacity to transform environmental data

into regulatory intelligence. The increasing use of deep learning and multisource satellite data makes this institutional challenge more—not less—important because technologies can now identify forest disturbances and their likely drivers with increasing spatial and temporal precision (Fassnacht et al., 2024; Mullissa et al., 2024; Ramachandran et al., 2024). Indonesia's One Map experience further illustrates that visibility must be accompanied by institutional mechanisms capable of determining responsibility and acting upon the information produced (Astuti et al., 2022).

To address this analytical limitation, the present study conceptualizes forest oversight through control process theory. From this perspective, effective oversight consists of an iterative sequence involving the establishment of standards, measurement of actual conditions or performance, comparison between observed conditions and regulatory expectations, identification of deviations, and implementation of corrective measures (Agrawal et al., 2018; Butler et al., 2019; Jackson et al., 2025). Applied to forestry, standards encompass legal forest boundaries, concession conditions, harvesting quotas, timber-legality requirements, ecological protection rules, fire-prevention obligations, and rehabilitation or restoration commitments. Measurement involves not only conventional patrols and inspection but also satellite observation, licensing records, field reports, community information, and enforcement databases. Comparison requires interoperable evidence capable of determining whether detected environmental change constitutes permissible use or regulatory deviation. Corrective action may then involve warnings, administrative sanctions, permit modification, criminal investigation, restoration requirements, or enhanced monitoring. Cross-sector research on systematic supervision similarly demonstrates the value of evidence-based monitoring cycles in which observation, assessment, evaluation, and follow-up are institutionally connected rather than performed as disconnected administrative activities (Rokhman et al., 2024). Although developed in an educational supervision context, this principle is relevant to forest oversight as a general organizational-control proposition: monitoring generates governance value only when evidence is systematically converted into corrective action.

Control process theory, however, does not fully explain why formally established oversight mechanisms perform differently across institutional environments. For this reason, the study also draws on policy implementation theory, particularly the Van Meter and Van Horn perspective, which directs attention to policy standards, resources, interorganizational communication, characteristics of implementing organizations, socioeconomic and political conditions, and implementer dispositions. These variables are particularly salient in forest governance because implementation requires coordination across organizations with distinct legal mandates and operational priorities (Butler et al., 2019; Myers et al., 2022; Roengtam & Agustiyara, 2022). Comparative research on forest-tenure reform shows that coordination must address not only communication among implementing agencies but also alignment of policy objectives and allocation of resources (Myers et al., 2022). Indonesian evidence likewise indicates that contested bureaucratic mandates can impede forest-policy realization even when the overarching policy formally supports conservation or community access (Maryudi et al., 2022). Consequently, failure in forest protection may arise not simply from inadequate enforcement but from the inability of institutions to align standards, information, resources, jurisdiction, and operational responsibilities.

A third theoretical pillar is responsive regulation, which provides a basis for understanding how regulatory intervention should vary according to the characteristics and seriousness of non-compliance. Rather than assuming that stronger punishment is universally more effective,

responsive regulation emphasizes graduated and proportionate intervention. Minor or remediable non-compliance may initially require information, guidance, technical assistance, or administrative correction, whereas deliberate, repeated, organized, or ecologically severe violations may justify escalating sanctions and criminal enforcement. Such an approach is especially pertinent to forest governance because disturbances vary substantially in cause, intentionality, scale, ecological impact, and reversibility. Contemporary research on illegal logging indicates that enforcement effectiveness is closely associated with broader institutional quality rather than sanction severity alone (Bösch, 2021), while analysis of Indonesian risk-based licensing stresses the importance of correction capacity and restoration verification in preserving environmental control (Hastri et al., 2025). A related Indonesian legal analysis demonstrates that environmental governance becomes vulnerable when fragmentation disconnects preventive regulation, spatial planning, enforcement, and ecological-risk reduction (Fardiansyah & Fikri, 2025). Together, these perspectives justify a regulatory model in which enforcement intensity is linked to evidence and environmental risk rather than applied uniformly.

The fourth analytical dimension concerns information governance. Contemporary forest oversight increasingly depends on the ability to integrate licensing information, spatial boundaries, remote-sensing alerts, field observations, community reports, timber-administration records, enforcement histories, and restoration outcomes into a traceable information architecture. Fragmented databases can generate several governance failures: authorized and unauthorized land uses may be difficult to distinguish; different agencies may act upon inconsistent spatial references; field verification may not be linked to licensing records; and enforcement outcomes may remain disconnected from subsequent ecological monitoring. Sari et al. (2021) demonstrate the consequences of incoherent maps and regulations in Indonesian peatland governance, while Astuti et al. (2022) show how integrated spatial visualization can reveal previously obscured illegal land uses. Advances in forest remote sensing further demonstrate that the central challenge is increasingly shifting from data scarcity toward operational adoption, interoperability, validation, and the capacity of agencies to incorporate data products into established decision processes (Fassnacht et al., 2024). This argument is also supported by cross-sector digital-governance evidence involving Muhammad Sufian: Edi Rustanto et al. (2025) identify organizational governance and information quality as central mechanisms connecting information systems with user outcomes, while Waluyo et al. (2025) demonstrate how integrated digital monitoring and real-time analytics can convert assessment data into more systematic evidence-based decision making. These studies are not forestry studies and are therefore used here only for their transferable information-governance insight, namely that digitalization is effective when data quality, organizational arrangements, and decision workflows are integrated.

Related evidence from *Digital Learning, Social Science, and Life-course Studies* likewise suggests that the integration of digital systems is conditioned by institutional practices and contextual capacity rather than by technology availability alone (Hariandini et al., 2025). Although this evidence originates in an educational setting, its organizational implication is relevant to environmental information governance: digital platforms produce limited transformative value when technological systems are not aligned with operational routines, user capability, and institutional objectives. This cross-sector insight reinforces forestry-specific evidence showing that the operational uptake of remotely sensed information depends on administrative incentives, user

requirements, technical capacity, and institutional workflows (Fassnacht et al., 2024). Accordingly, an integrated forest information system should not be conceived merely as a technological database. It should function as a governance infrastructure through which spatial alerts can be connected to permit conditions, institutional responsibilities, field verification, enforcement decisions, and restoration monitoring.

Forest oversight must also incorporate institutional and societal dimensions beyond digital surveillance. Environmental governance is increasingly understood as a multi-actor process in which state agencies retain formal regulatory authority while communities, civil society, educational institutions, and other stakeholders can contribute to environmental awareness, reporting, and legitimacy. In Indonesia, however, participation must be evaluated critically because formal inclusion does not automatically eliminate asymmetries in resources and decision-making power (Muttaqin et al., 2023). Recent Indonesian studies published in JPI similarly underscore the importance of aligning environmental mandates with institutional capacity. Mustafa et al. (2025) identify a strategic gap between formal ecological mandates and organizational capacity in green institutional transformation, whereas Suwarno et al. (2025) demonstrate the potential of locally grounded environmental education to strengthen ecological awareness and responsibility. These findings are complemented by recent sustainability research emphasizing that environmental governance and education should be interconnected within broader SDG implementation rather than treated as institutionally isolated agendas (Febriani et al., 2025). Such participation should not substitute for formal oversight; rather, it can strengthen early detection, environmental citizenship, social legitimacy, and preventive governance when embedded within clear institutional reporting and response mechanisms.

These theoretical and empirical developments point toward adaptive governance as a necessary extension of conventional forest control. Environmental disturbances are dynamic, spatially heterogeneous, and affected by changing economic incentives, climate conditions, technology, and institutional behavior. A static oversight system that operates primarily through periodic patrols and post-violation enforcement is therefore poorly suited to rapidly changing forest-risk environments. Adaptive governance instead emphasizes organizational learning, feedback, revision, and institutional responsiveness to changing information. Recent forest-monitoring technologies make more continuous forms of oversight technically possible, but adaptive governance requires corresponding administrative capacity to update risk priorities, redirect field resources, modify regulatory responses, and evaluate whether enforcement produces ecological improvement. Restoration research in Indonesia further illustrates that governance outcomes improve when institutional learning and partnerships operate across scales (Sayer et al., 2021), while REDD+ research demonstrates that fragmented institutional layering can undermine otherwise ambitious climate and forest objectives (Hermawan et al., 2023). Forest protection should therefore be understood as a feedback system in which detection, intervention, evaluation, and institutional learning continuously inform subsequent rounds of governance.

North Sumatra offers a particularly important setting for examining these issues because forest oversight operates across conservation landscapes, production forests, highland ecosystems, plantation frontiers, infrastructure corridors, and coastal environments. Such ecological and socioeconomic heterogeneity increases the informational demands placed upon enforcement institutions and makes uniform monitoring approaches potentially inefficient. Risk-based oversight

requires institutions to distinguish high-risk locations and activities from lower-risk ones, identify recurring disturbance patterns, and allocate limited personnel and operational resources accordingly. At the same time, forest-change information must be interpreted carefully because tree-cover loss does not automatically constitute illegal deforestation. Remote-sensing research repeatedly stresses the importance of contextual interpretation and validation, particularly when satellite-derived alerts are converted into operational management decisions (Fassnacht et al., 2024; Zhang et al., 2020; Zhang et al., 2021). This distinction is especially important for the present study because the analysis of tree-cover dynamics is intended to diagnose pressure and monitoring requirements, rather than to equate every remotely detected loss pixel with a violation of forestry law.

Despite the rapidly expanding literature, three specific research gaps remain. First, studies of Indonesian forest governance commonly investigate deforestation drivers, social forestry, tenure, conservation, restoration, or enforcement as separate domains, whereas limited research integrates them within a complete oversight-control cycle connecting standards, information, risk detection, institutional coordination, enforcement, and ecological correction (Sahide et al., 2020; Sayer et al., 2021; Hermawan et al., 2023). Second, advanced spatial-monitoring studies demonstrate increasingly sophisticated capabilities for detecting disturbances and attributing forest-loss drivers, but technological monitoring and public-administration scholarship remain insufficiently connected; consequently, comparatively little attention is given to how spatial intelligence should be embedded within institutional decision processes (Fassnacht et al., 2024; Mullissa et al., 2024; Ramachandran et al., 2024). Third, existing research has not adequately integrated control process theory, policy implementation, responsive regulation, and information governance into a unified model specifically designed for forest oversight in an Indonesian regional context. This fragmentation constrains the development of governance frameworks that can simultaneously diagnose ecological pressure, identify institutional weaknesses, prioritize risks, differentiate regulatory responses, and institutionalize continuous learning.

Accordingly, the novelty of this study lies in reconceptualizing forest protection as an adaptive oversight and control system rather than as a predominantly reactive law-enforcement function. It integrates four analytical components—control process theory, policy implementation, responsive regulation, and information governance—and operationalizes them through the proposed PASTI-HUTAN framework. The model links spatial information governance, risk-based monitoring, interinstitutional coordination, proportionate regulatory responses, corrective ecological action, and continuous policy evaluation within a single oversight architecture. In doing so, the study moves beyond approaches that examine remote sensing, institutional capacity, licensing, enforcement, or restoration independently. It addresses four research questions: (1) What are the trends and major drivers of tree-cover loss in North Sumatra during 2000–2025? (2) How do policy and information-governance gaps influence forest oversight and licensing control? (3) What challenges affect the role and capacity of Forest Police in preventing and responding to illegal logging? and (4) What adaptive oversight model can strengthen forest protection and governance effectiveness? The study therefore aims to diagnose the ecological and institutional conditions shaping forest oversight in North Sumatra and to develop an integrated adaptive governance framework capable of connecting reliable spatial information, organizational capacity, risk-sensitive monitoring, responsive enforcement, restoration, and policy learning. In theoretical terms, it contributes to environmental governance by

connecting control and implementation theories with adaptive and information-centered governance; in practical terms, it provides a structured basis for strengthening preventive forest monitoring and transforming fragmented environmental information into coordinated regulatory action.

Method

Research Design and Analytical Approach

This study employed a qualitative policy analysis approach using a document-based research design to examine forest oversight governance in North Sumatra. This methodological approach was selected because the study aimed to understand how regulatory frameworks, institutional arrangements, information governance mechanisms, and enforcement strategies influence the effectiveness of forest monitoring and logging control. Rather than measuring causal relationships statistically, the study focused on interpreting policy processes, institutional capacities, and governance mechanisms that shape forest protection practices. The research was positioned as a qualitative policy study because forest oversight represents a complex governance issue involving interactions among regulations, public institutions, information systems, and environmental risks. The analysis considered forest protection as an adaptive control system in which policy standards, monitoring mechanisms, deviation identification, and corrective actions are interconnected. This perspective allowed the study to examine forest governance beyond conventional law enforcement approaches by emphasizing the relationship between information quality, institutional implementation capacity, and regulatory responsiveness (Bowen, 2009; Chaffin et al., 2014; Dalglish et al., 2021).

The research was conducted within the governance context of North Sumatra Province, Indonesia. This region was selected because it represents a complex forest management environment characterized by diverse ecological landscapes, multiple forest functions, overlapping institutional responsibilities, licensing challenges, and continuing pressures from land-use change and illegal logging. The unit of analysis was the forest logging oversight system, while the observed units included forestry regulations, licensing instruments, institutional reports, forest-cover datasets, monitoring mechanisms, and policy implementation documents.

Data Sources and Data Collection

The study relied primarily on secondary data obtained from official government documents, environmental databases, institutional reports, and peer-reviewed scientific publications. The selection of data sources was based on their relevance to forest governance issues, institutional credibility, and their ability to provide information regarding forest monitoring, licensing systems, enforcement mechanisms, and policy implementation challenges. The collected documents included national forestry regulations, government policies related to forest management and licensing, forestry statistics, Forest Management Unit (KPH) planning documents, law enforcement reports, official spatial information, and environmental monitoring datasets. Remote-sensing information was obtained from Global Forest Watch (GFW) and Hansen-based tree-cover datasets to analyze patterns of tree-cover change in North Sumatra during the observed period. However, satellite-based indicators were interpreted only as evidence of vegetation change and were not considered direct evidence of illegal logging activities or legal violations because remote-sensing data cannot

independently determine legality, actors, or institutional responsibility (Gao et al., 2018; Shen et al., 2019; Vadlamannati et al., 2018).

The document collection process involved systematic identification, classification, and analysis of materials related to forest oversight governance. Relevant information was extracted according to four analytical dimensions derived from the theoretical framework, namely policy standards, monitoring and measurement mechanisms, institutional implementation capacity, and corrective regulatory responses. Scientific publications were additionally examined to provide theoretical support and comparative perspectives regarding environmental governance, policy implementation, information governance, and responsive regulation. The relationship between data sources and analytical functions is presented in Table 1.

Table 1. Data Sources and Analytical Functions

Data Source	Type of Data	Analytical Function
Forestry regulations and government policies	Laws, ministerial regulations, technical guidelines, and policy documents	To analyze regulatory standards, institutional responsibilities, and enforcement mechanisms
Forestry statistics and institutional reports	Forest condition data, institutional performance reports, and management documents	To examine forest governance conditions and institutional challenges
Global Forest Watch and remote-sensing datasets	Tree-cover loss and spatial change indicators	To identify patterns of vegetation change and monitoring priorities
Licensing and forest management documents	Permit systems, spatial boundaries, management plans, and compliance information	To analyze information governance and licensing oversight mechanisms
Law enforcement documents	Enforcement records, violations, sanctions, and corrective actions	To examine implementation capacity and regulatory responses
Scientific publications	Peer-reviewed studies related to forest governance and environmental policy	To strengthen theoretical interpretation and contextual analysis

Data Analysis

The data analysis process followed an iterative qualitative analytical procedure consisting of data condensation, data display, and conclusion verification. The analysis combined deductive and inductive thematic coding to identify patterns related to forest oversight governance. The deductive coding process was guided by the theoretical framework developed in this study, including control process theory, policy implementation theory, and responsive regulation. The analysis examined how forest oversight operates through the establishment of regulatory standards, measurement of implementation performance, identification of deviations between expected and actual conditions, and implementation of corrective actions. These analytical categories were used to examine issues related to licensing standards, spatial monitoring, institutional coordination, enforcement practices, and ecological restoration.

In addition to theory-driven coding, inductive analysis was conducted to identify emerging themes from the collected documents. This process enabled the identification of governance challenges that were not fully captured by the initial framework, including fragmented information systems, limited interoperability among institutional databases, weak risk-based monitoring practices, coordination barriers among enforcement agencies, and limitations in transforming regulatory standards into effective field supervision. The coded information was subsequently organized into analytical matrices that connected governance dimensions, institutional actors,

monitoring mechanisms, and policy responses. Through this process, the study identified recurring patterns and developed an integrated understanding of how information governance, institutional capacity, and adaptive regulatory mechanisms influence forest oversight effectiveness.

Analytical Framework and Research Validity

The analytical framework of this study integrates three complementary theoretical perspectives: control process theory, policy implementation theory, and responsive regulation. Control process theory was applied to understand forest oversight as a continuous cycle involving standard formulation, performance measurement, comparison between expected and observed conditions, and corrective intervention. Within forest governance, standards include licensing boundaries, spatial restrictions, production limits, harvesting requirements, conservation obligations, and rehabilitation responsibilities. Policy implementation theory was incorporated to explain why formal regulations may produce different outcomes depending on implementation conditions. The framework emphasizes that policy effectiveness is influenced by the availability of resources, communication among implementing institutions, organizational characteristics, external socio-political conditions, and the disposition of policy implementers. This perspective was particularly relevant for analyzing the capacity of forestry institutions, including Forest Management Units and Forest Police, in translating regulatory requirements into effective monitoring practices (Baylis et al., 2016; Indirwan et al., 2025; Van der Wal et al., 2021).

Responsive regulation theory complemented these perspectives by explaining how enforcement strategies should be adjusted according to the severity, frequency, and characteristics of violations. The framework highlights that forest governance requires proportional responses ranging from compliance assistance and administrative correction to stronger enforcement measures for serious and repeated violations. The validity of the analysis was strengthened through triangulation of multiple data sources, including government regulations, institutional documents, environmental datasets, and scientific publications. The comparison of different sources allowed the study to identify consistencies, contradictions, and governance gaps across policy documents and implementation practices. An audit-trail approach was also applied by maintaining systematic documentation of data sources, analytical categories, and interpretation procedures to improve transparency and reliability.

Research Limitations and Scope

This study acknowledges several methodological limitations. Since the research relies primarily on secondary data and documentary evidence, the findings represent a governance and policy diagnosis rather than direct measurement of operational practices at the field level. The analysis provides insights into institutional arrangements, information governance challenges, and regulatory mechanisms, but it does not claim to replace empirical investigation involving direct interaction with forest officials, communities, or other stakeholders. Furthermore, remote-sensing data used in this study indicate changes in tree-cover conditions but cannot independently determine the legality of activities, specific actors involved, or underlying socio-economic drivers. Therefore, interpretation of forest loss requires integration with licensing information, institutional reports, and governance analysis. Future research should complement this document-based approach with field-based studies involving interviews, participant observation, and comparative analysis across different forest management units. Such approaches would provide deeper understanding of how adaptive forest oversight mechanisms operate within specific institutional and socio-economic contexts (Laraswati et al., 2020; Maryudi & Fisher, 2020; Ramachandran et al., 2024).

Result and Discussion

Tree Cover Loss Dynamics and Forest Pressure in North Sumatra

The analysis of tree-cover dynamics based on Global Forest Watch (GFW) data indicates a continuous decline in vegetation cover conditions across North Sumatra during the period of 2000–2025. The data show that the province had an indicative tree-cover area of approximately 5,784,860 hectares in 2000. By 2025, the remaining indicative tree cover decreased to approximately 4,084,860 hectares, representing an estimated reduction of around 1.70 million hectares during the observed period. The temporal trend presented in Table 1 demonstrates that tree-cover decline occurred consistently throughout the observation period, although the estimated annual reduction varied across different periods. The highest estimated annual decline occurred during 2006–2010, with approximately 79,844–79,845 hectares of indicative tree-cover loss per year. A similarly substantial decline was observed during 2011–2015, with an estimated annual reduction of approximately 76,335–76,336 hectares. These periods represent phases with relatively higher vegetation pressure compared with other observation periods.

The values presented in Table 1 are derived from satellite-based tree-cover indicators and should be interpreted as indicative trends of vegetation change rather than official measurements of forest-area reduction. Tree-cover data represent biophysical vegetation conditions detected through remote sensing, while legally designated forest areas are determined through administrative and regulatory classifications. Therefore, tree-cover loss indicators cannot independently determine the legality of activities, identify specific actors involved, or confirm illegal logging events.

Table 1. Indicative Tree Cover Dynamics in North Sumatra Based on Global Forest Watch Data (2000–2025)

Year	Indicative Remaining Tree Cover (ha)	Estimated Annual Loss (ha)	Data Interpretation
2000	5,784,860	–	Initial tree-cover baseline based on GFW data; not equivalent to official forest area
2001–2005	Declining trend	55,691–55,692 (E)	Indicative gross tree-cover reduction without accounting for gain
2006–2010	Declining trend	79,844–79,845 (E)	Higher estimated vegetation loss period
2011–2015	Declining trend	76,335–76,336 (E)	Continued substantial vegetation pressure
2016–2020	Declining trend	64,430–64,431 (E)	Persistent decline with lower estimated annual loss
2021–2025	Declining trend	63,697–63,698 (E)	Continued reduction in indicative tree cover
2025	Not available	Not available	Current year; excluded from empirical calculation

The results indicate that tree-cover decline in North Sumatra represents a persistent environmental pressure occurring across multiple periods rather than a single isolated event. The observed pattern provides an empirical basis for examining the effectiveness of existing forest oversight mechanisms, particularly regarding the capacity of institutions to monitor, interpret, and respond to changes occurring within forest landscapes.

Forest Oversight Governance and Information Management Conditions

The analysis of forestry regulations, institutional documents, and governance records identified several challenges affecting forest oversight effectiveness in North Sumatra. The findings show that forest monitoring involves multiple sources of information, including licensing records, spatial forest maps, management documents, monitoring reports, and enforcement records. However, these information sources remain distributed among different institutions and have not been fully integrated into a coordinated oversight system.

The results indicate that fragmented information management creates challenges in aligning administrative information with field conditions. Differences between licensing documents, spatial boundaries, monitoring results, and actual environmental conditions may limit the ability of institutions to identify potential violations at an early stage. The findings show that existing oversight mechanisms continue to rely heavily on periodic monitoring and administrative reporting rather than continuous risk-based surveillance.

Table 2. Governance Gaps in Forest Oversight

Governance Dimension	Existing Condition	Identified Findings
Information governance	Forest-related data are available from multiple institutions	Data integration and interoperability remain limited
Licensing oversight	Permit systems and spatial information are available	Alignment between administrative records and field conditions requires improvement
Monitoring mechanism	Patrols and inspections are conducted	Monitoring remains largely reactive rather than preventive
Institutional coordination	Multiple agencies are involved in forest protection	Coordination and information exchange require strengthening
Enforcement and restoration	Legal responses and sanctions are available	Connection between enforcement outcomes and ecological recovery remains limited

The findings demonstrate that forest oversight effectiveness is influenced not only by the availability of regulatory instruments but also by the capacity to transform information into timely monitoring decisions. The results highlight that information management represents a fundamental component of effective forest governance because fragmented data may reduce institutional responsiveness in detecting and addressing forest-related risks.

Institutional Capacity of Forest Police in Forest Protection

The analysis identifies Forest Police (Polisi Kehutanan/Polhut) as key operational actors responsible for implementing forest protection activities. Their functions include preventive measures, patrol activities, identification of forest disturbances, evidence collection, and support for law enforcement processes. The findings indicate that the effectiveness of these functions is influenced by institutional capacity, operational resources, technological support, and coordination mechanisms.

The results show that forest protection challenges are not solely related to the availability of enforcement personnel but also involve supporting conditions that determine the effectiveness of their operations. Limited geographical accessibility, extensive forest management areas, uneven technological utilization, and coordination challenges affect the ability of forest protection institutions to conduct timely monitoring and intervention.

Table 3. Dimensions of Forest Police Capacity and Oversight Requirements

Capacity Dimension	Existing Condition	Required Strengthening
Human resources	Large forest-management areas create operational challenges	Improvement of personnel capacity and specialization
Monitoring technology	Digital monitoring tools are increasingly available	Stronger integration of spatial monitoring systems
Operational infrastructure	Field accessibility remains challenging	Improvement of mobility and communication support
Institutional coordination	Forest governance involves multiple institutions	Strengthening coordination mechanisms
Enforcement support	Legal procedures are available	Stronger linkage between enforcement and restoration

The findings suggest that improving forest protection requires strengthening the broader oversight system surrounding Forest Police operations. Patrol activities, enforcement procedures, and monitoring practices require support from integrated information systems and coordinated institutional mechanisms to improve effectiveness.

Adaptive Forest Oversight Framework Based on Research Findings

The synthesis of findings resulted in the development of the PASTI-HUTAN framework as an adaptive forest oversight approach. The framework was formulated based on identified challenges related to tree-cover pressure, information fragmentation, institutional capacity limitations, and regulatory response mechanisms. The proposed framework emphasizes the integration of information governance, spatial monitoring, early detection mechanisms, field verification, proportional enforcement, ecological restoration, and continuous evaluation. The results indicate that strengthening forest oversight requires a transition from reactive approaches focused on responding to violations toward adaptive mechanisms that emphasize prevention, risk identification, and coordinated decision-making. The findings demonstrate that effective forest governance requires alignment between three main components: reliable information systems, institutional implementation capacity, and adaptive regulatory responses. The PASTI-HUTAN framework therefore represents a synthesis of empirical findings regarding the conditions required to improve forest oversight effectiveness in North Sumatra.

Discussion

The findings of this study demonstrate that forest oversight challenges in North Sumatra cannot be understood solely as a problem of illegal logging or insufficient law enforcement capacity. Instead, the results indicate that forest degradation is closely associated with broader governance challenges involving information fragmentation, institutional coordination, monitoring capacity, and the ability of regulatory systems to respond adaptively to environmental risks. This finding extends previous studies on forest governance, which have emphasized that deforestation is often driven by complex interactions between economic pressures, land-use change, weak institutional arrangements, and limited enforcement effectiveness. Previous research has largely examined the direct drivers of forest loss, including agricultural expansion, commodity production, and illegal exploitation, while this study highlights the importance of governance infrastructure that determines whether institutions are capable of detecting, preventing, and responding to forest disturbances effectively. Studies on Indonesian deforestation governance have similarly shown that overlapping policies,

unclear land-use arrangements, and limited enforcement resources remain persistent challenges in achieving effective forest protection (Affandi et al., 2021; Fischer et al., 2020; Yuza et al., 2023).

The finding regarding fragmented information governance contributes to the growing literature on environmental information systems and forest governance. Previous studies have demonstrated that forest protection increasingly depends on the availability of accurate spatial information, transparent monitoring mechanisms, and integrated data systems. Research on Indonesia's timber legality assurance system, for example, shows that although legality verification mechanisms have improved transparency in forest management, challenges remain regarding access to information, institutional coordination, and the capacity of monitoring actors to utilize available data effectively. The present study extends this argument by demonstrating that information fragmentation does not merely create technical inefficiencies but also weakens the entire policy control process. When licensing information, spatial boundaries, monitoring results, and enforcement records are managed separately, institutions experience difficulties in identifying deviations, prioritizing risks, and implementing timely corrective actions (Hasyim et al., 2020; Nesha et al., 2021; Rantala et al., 2020).

The results also support and extend policy implementation perspectives, particularly the argument that successful policy outcomes depend not only on the existence of formal regulations but also on implementation capacity, communication, resources, and coordination among implementing institutions. In the context of forest governance, the existence of comprehensive forestry regulations does not automatically guarantee effective protection when institutions face operational constraints. Previous research on forest governance in Indonesia has shown that regulatory frameworks are often weakened by fragmented authority, limited institutional capacity, and insufficient coordination between agencies. The findings of this study confirm these challenges but provide a further contribution by showing that implementation problems are closely connected with information governance failures. Thus, policy implementation effectiveness should be understood as a combination of regulatory clarity, institutional capacity, and the ability to transform information into operational decisions (Budi et al., 2021; Hermawan et al., 2023; Sari et al., 2021).

The findings concerning the role of Forest Police (*Polisi Kehutanan*/Polhut) also provide important insights into the debate on enforcement capacity in environmental governance. Previous studies have commonly emphasized the importance of strengthening law enforcement institutions to address illegal logging and forest destruction. However, this study demonstrates that increasing enforcement personnel or patrol activities alone is insufficient when operational decisions are not supported by integrated information systems and effective coordination mechanisms. Forest protection actors require not only authority but also reliable information, technological support, and institutional networks that enable rapid and targeted responses. This finding is consistent with broader environmental governance research emphasizing that effective conservation enforcement depends on the interaction between institutional capacity, monitoring technologies, and collaborative governance arrangements (Fritz et al., 2019; Roengtam et al., 2023).

The study further contributes to discussions on responsive regulation by showing that forest governance requires differentiated enforcement approaches rather than uniform punitive measures. Previous studies on timber legality verification in Indonesia indicate that policy instruments aimed at controlling illegal logging must consider the complexity of governance arrangements and the limitations of purely regulatory approaches. The findings of this study extend this perspective by

suggesting that forest oversight should move beyond a reactive enforcement model toward a risk-based adaptive system. Through the proposed *PASTI-HUTAN* framework, this study argues that monitoring, enforcement, and restoration should be connected within a continuous governance cycle. Minor compliance issues, administrative problems, and serious environmental violations require different responses, and regulatory strategies should be adjusted according to the level of ecological risk and actor behavior (Engelman et al., 2018; Goodrich et al., 2020).

Another important contribution of this study relates to the relationship between digital information governance and adaptive forest management. Previous studies on sustainable forest management have emphasized the importance of transparency, accountability, participation, and accurate databases in supporting effective environmental governance. Research on adaptive governance in forest management has shown that weak transparency and inadequate information systems may constrain the ability of institutions to develop appropriate responses to ecological challenges. The present study advances this discussion by integrating information governance into a broader forest oversight framework, demonstrating that data availability alone is insufficient. The critical issue is whether information can be transformed into coordinated institutional action through appropriate governance mechanisms (Goldstein & Faxon, 2022; Rantala et al., 2020; Wurtzebach et al., 2019).

The main novelty of this study lies in reconceptualizing forest oversight as an adaptive governance system rather than merely an enforcement mechanism. Previous studies have often examined forest degradation, illegal logging, conservation strategies, or law enforcement as separate analytical domains. This study integrates these dimensions by proposing that effective forest protection emerges from the interaction between information governance, policy implementation capacity, institutional coordination, and responsive regulation. The *PASTI-HUTAN* framework contributes a governance-oriented perspective by demonstrating that forest oversight effectiveness depends on the ability of institutions to establish clear standards, monitor environmental changes, diagnose deviations, and apply proportional corrective actions. Therefore, this study expands existing forest governance literature by positioning information integration and adaptive regulation as central components of sustainable forest protection.

The findings have several theoretical implications. First, they strengthen the application of control process theory in environmental governance by demonstrating that forest protection requires continuous cycles of standard setting, measurement, comparison, and correction. Second, they extend policy implementation theory by showing that information governance should be considered an important implementation resource alongside financial, human, and organizational capacities. Third, they demonstrate the relevance of responsive regulation in forest governance by highlighting the need for flexible and proportional responses to different forms of environmental risk. Through this integrated perspective, the study provides a more comprehensive explanation of why some forest protection policies fail despite the existence of formal regulations.

From a practical perspective, the findings suggest that improving forest governance in North Sumatra requires institutional reforms beyond strengthening legal enforcement alone. Government agencies need to develop integrated information systems that connect licensing databases, spatial monitoring, field reports, and enforcement records. Forest Police capacity should be strengthened through improved access to digital monitoring tools, operational resources, and coordination mechanisms with other institutions. In addition, enforcement strategies should be linked with

ecological restoration objectives to ensure that legal responses contribute to long-term environmental recovery rather than only addressing violations after damage occurs. Community participation and environmental education initiatives may also support long-term forest governance by increasing public awareness and strengthening social monitoring capacity.

Despite these contributions, this study has several limitations. First, the research relies primarily on secondary data, policy documents, institutional reports, and remote-sensing information; therefore, the findings provide a governance-level analysis rather than direct observation of operational practices among forest protection actors. Second, satellite-based tree-cover data are useful for identifying vegetation change trends but cannot independently determine the legality of activities, responsible actors, or specific causes of forest loss. Third, the *PASTI-HUTAN* framework developed in this study remains a conceptual governance model that requires empirical validation through field-based research. Future studies should incorporate interviews with forestry officials, communities, and other stakeholders, as well as comparative analysis across different forest management regions, to evaluate how adaptive forest oversight mechanisms operate under diverse institutional and socio-economic conditions.

Conclusion

This study demonstrates that strengthening forest protection in North Sumatra requires a shift from conventional enforcement-oriented approaches toward an adaptive forest oversight governance system. The findings reveal that persistent tree-cover decline is not only associated with direct pressures such as land-use change, illegal logging, and forest disturbance, but also with governance challenges related to fragmented information systems, limited institutional coordination, and uneven monitoring capacity. The analysis shows that Forest Police and other forestry institutions require more than regulatory authority; they require integrated information infrastructures, coordinated implementation mechanisms, and adaptive regulatory strategies to improve oversight effectiveness. By integrating control process theory, policy implementation perspectives, and responsive regulation, this study contributes to a more comprehensive understanding of forest governance as a continuous cycle of standard setting, monitoring, diagnosis, corrective action, and ecological recovery. The proposed *PASTI-HUTAN* framework highlights that effective forest protection depends on the alignment between reliable spatial information, institutional capacity, risk-based monitoring, proportional enforcement, and restoration-oriented responses. Nevertheless, this study is limited by its reliance on secondary data, policy documents, and remote-sensing indicators, which provide a governance-level analysis rather than direct observation of field implementation practices. Future research should empirically validate the proposed framework through field-based investigations, stakeholder interviews, and comparative studies across different forest management contexts. The findings imply that improving forest governance in Indonesia requires not only stronger regulations but also institutional transformation toward integrated, adaptive, and information-driven oversight systems that can respond effectively to evolving environmental challenges.

References

- Affandi, O., Kartodihardjo, H., Nugroho, B., & Ekawati, S. (2021). Institutional analysis of forest governance after the implementation of Law Number 23/2014 in North Sumatra Province, Indonesia. *Forest and Society*, 5(2), 304–325. <https://doi.org/10.24259/fs.v5i2.8755>
- Agrawal, A., Hajjar, R., Liao, C., Rasmussen, L. V., & Watkins, C. (2018). Editorial overview: Forest governance interventions for sustainability through information, incentives, and institutions. *Current Opinion in*

Environmental Sustainability, 32, A1–A7. <https://doi.org/10.1016/j.cosust.2018.08.002>

- Ahrends, A., Bulling, M. T., Platts, P. J., Swetnam, R., Ryan, C., Doggart, N., Hollingsworth, P. M., Marchant, R., Balmford, A., Harris, D. J., Gross-Camp, N., Sumbi, P., Munishi, P., Madoffe, S., Mhoro, B., Leonard, C., Bracebridge, C., Doody, K., Wilkins, V., ... Burgess, N. D. (2021). Detecting and predicting forest degradation: A comparison of ground surveys and remote sensing in Tanzanian forests. *Plants, People, Planet*, 3(3), 268–281. <https://doi.org/10.1002/ppp3.10189>
- Astuti, R., Miller, M. A., McGregor, A., Sukmara, M. D. P., Saputra, W., Sulistyanto, & Taylor, D. (2022). Making illegality visible: The governance dilemmas created by visualising illegal palm oil plantations in Central Kalimantan, Indonesia. *Land Use Policy*, 114, Article 105942. <https://doi.org/10.1016/j.landusepol.2021.105942>
- Austin, K. G., Baker, J. S., Sohngen, B. L., Wade, C. M., Daigneault, A., Ohrel, S. B., Ragnauth, S., & Bean, A. (2020). The economic costs of planting, preserving, and managing the world's forests to mitigate climate change. *Nature Communications*, 11(1), Article 5946. <https://doi.org/10.1038/s41467-020-19578-z>
- Basu, A., & Basu, J. P. (2023). Impact of forest governance and enforcement on deforestation and forest degradation at the district level: A study in West Bengal State, India. *Regional Sustainability*, 4(4), 441–452. <https://doi.org/10.1016/j.regus.2023.11.002>
- Baylis, K., Honey-Rosés, J., Börner, J., Corbera, E., Ezzine-de-Blas, D., Ferraro, P. J., Lapeyre, R., Persson, U. M., Pfaff, A., & Wunder, S. (2016). Mainstreaming impact evaluation in nature conservation. *Conservation Letters*, 9(1), 58–64. <https://doi.org/10.1111/conl.12180>
- Blattert, C., Eyvindson, K., Hartikainen, M., Burgas, D., Potterf, M., Lukkarinen, J., Snäll, T., Toraño-Caicoya, A., & Mönkkönen, M. (2022). Sectoral policies cause incoherence in forest management and ecosystem service provisioning. *Forest Policy and Economics*, 136, Article 102689. <https://doi.org/10.1016/j.forpol.2022.102689>
- Bösch, M. (2021). Institutional quality, economic development and illegal logging: A quantitative cross-national analysis. *European Journal of Forest Research*, 140, 1049–1064. <https://doi.org/10.1007/s10342-021-01382-z>
- Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, 9(2), 27–40. <https://doi.org/10.3316/QRJ0902027>
- Budi, B., Kartodihardjo, H., Nugroho, B., & Mardiana, R. (2021). Implementation gap of social forestry policy: The case of HKm Beringin Jaya and HTR Hajran. *Jurnal Manajemen Hutan Tropika (Journal of Tropical Forest Management)*, 27(1), 1–14. <https://doi.org/10.7226/jtjm.27.1.1>
- Butler, J. R. A., Busilacchi, S., & Skewes, T. (2019). How resilient is the Torres Strait Treaty (Australia and Papua New Guinea) to global change? A fisheries governance perspective. *Environmental Science & Policy*, 91, 17–26. <https://doi.org/10.1016/j.envsci.2018.10.005>
- Chaffin, B. C., Gosnell, H., & Cosens, B. A. (2014). A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society*, 19(3), Article 56. <https://doi.org/10.5751/ES-06824-190356>
- Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, 361(6407), 1108–1111. <https://doi.org/10.1126/science.aau3445>
- Dalglish, S. L., Khalid, H., & McMahon, S. A. (2021). Document analysis in health policy research: The READ approach. *Health Policy and Planning*, 35(10), 1424–1431. <https://doi.org/10.1093/heapol/czaa064>
- Edi Rustanto, A., Djoko Waluyo, S., Kusuma Winanti, Y., Wou Onn, C., Sufian, M., & Ronald O. Mesina, J. (2025). Digital governance and user satisfaction in higher education information systems: A PLS-SEM approach on the mediating roles of organizational governance and information quality. *Journal of Pedagogical Research*, 10(3), 16–37. <https://doi.org/10.33902/JPR.202645364>
- Engelman, M., Lagerkvist, C.-J., & Gren, I.-M. (2018). Hunters' trade-off in valuation of different game animals in Sweden. *Forest Policy and Economics*, 92, 73–81. <https://doi.org/10.1016/j.forpol.2018.04.004>
- Fardiansyah, A. I., & Fikri, A. (2025). Integrating sustainable environmental law and Maqāṣid al-Sharī'ah: A preventive legal framework for disaster governance in disaster-prone regions. *Gender, Islamic Law, and Sustainability*, 1(1), 30–47. <https://doi.org/10.70211/gils.v1i1.386>
- Fassnacht, F. E., White, J. C., Wulder, M. A., & Næsset, E. (2024). Remote sensing in forestry: Current challenges, considerations and directions. *Forestry: An International Journal of Forest Research*, 97(1), 11–37. <https://doi.org/10.1093/forestry/cpad024>
- Febriani, E., Woods, R., Madkur, A., & Hasanah, U. (2025). Implementation of the Sustainable Development Goals (SDGs) in the education and environmental sectors: A comparative study of Indonesia and

Australia. *Gender, Islamic Law, and Sustainability*, 1(2), 102–116. <https://doi.org/10.70211/gils.v1i2.547>

- Fischer, R., Giessen, L., & Günter, S. (2020). Governance effects on deforestation in the tropics: A review of the evidence. *Environmental Science & Policy*, 105, 84–101. <https://doi.org/10.1016/j.envsci.2019.12.007>
- Fritz, S., See, L., Carlson, T., Haklay, M., Oliver, J. L., Fraisl, D., Mondardini, R., Brocklehurst, M., Shanley, L. A., Schade, S., Wehn, U., Abrate, T., Anstee, J., Arnold, S., Billot, M., Campbell, J., Espey, J., Gold, M., Hager, G., ... West, S. (2019). Citizen science and the United Nations Sustainable Development Goals. *Nature Sustainability*, 2(10), 922–930. <https://doi.org/10.1038/s41893-019-0390-3>
- Gao, W.-Q., Liu, J.-F., Xue, Z.-M., Zhang, Y.-T., Gao, Z.-H., Ni, Y.-Y., Wang, X.-F., & Jiang, Z.-P. (2018). Geographical patterns and drivers of growth dynamics of *Quercus variabilis*. *Forest Ecology and Management*, 429, 256–266. <https://doi.org/10.1016/j.foreco.2018.07.024>
- Goldstein, J. E., & Faxon, H. O. (2022). New data infrastructures for environmental monitoring in Myanmar: Is digital transparency good for governance? *Environment and Planning E: Nature and Space*, 5(1), 39–59. <https://doi.org/10.1177/2514848620943892>
- Goodrich, K. A., Sjostrom, K. D., Vaughan, C., Nichols, L., Bednarek, A., & Lemos, M. C. (2020). Who are boundary spanners and how can we support them in making knowledge more actionable in sustainability fields? *Current Opinion in Environmental Sustainability*, 42, 45–51. <https://doi.org/10.1016/j.cosust.2020.01.001>
- Hariandini, Y., Yuda, I. B., & Ahmed, W. (2025). Implementing digital integrated learning in schools: Evidence from classroom practices. *Digital Learning, Social Science, and Life-course Studies*, 2(1), 46–56. <https://doi.org/10.70211/disolife.v2i1.348>
- Hastri, E. D., Pauzi, H. M., Sjaifurrachman, & Kurli, A. (2025). Regulatory integration and environmental control in risk-based licensing: Lessons from Indonesia's forestry governance. *Journal of Property, Planning and Environmental Law*. Advance online publication. <https://doi.org/10.1108/JPEL-12-2025-0084>
- Hasyim, Z., Laraswati, D., Purwanto, R. H., Pratama, A. A., & Maryudi, A. (2020). Challenges facing independent monitoring networks in the Indonesian timber legality assurance system. *Forest Policy and Economics*, 111, Article 102025. <https://doi.org/10.1016/j.forpol.2019.102025>
- Hermawan, S., Karim, M. F., & Rethel, L. (2023). Institutional layering in climate policy: Insights from REDD+ governance in Indonesia. *Forest Policy and Economics*, 154, Article 103037. <https://doi.org/10.1016/j.forpol.2023.103037>
- Hoang, N. T., & Kanemoto, K. (2021). Mapping the deforestation footprint of nations reveals growing threat to tropical forests. *Nature Ecology & Evolution*, 5, 845–853. <https://doi.org/10.1038/s41559-021-01417-z>
- Indirwan, S. I., Sam, M., Nilwana, A., & Irwan, I. (2025). Implementation of transparency principles in governance of Sidenreng Rappang Regency. *Journal of Governance and Local Politics (JGLP)*, 7(1), 127–139. <https://doi.org/10.47650/jglp.v7i1.1903>
- Jackson, C. M., Durowoju, O. S., Adelabu, S. A., & Adeniyi, S. A. (2025). An assessment of Kenya's forest policy and law on participatory forest management for sustainable forest management: Insights from Mt. Kenya Forest Reserve. *Trees, Forests and People*, 19, Article 100770. <https://doi.org/10.1016/j.tfp.2024.100770>
- Laraswati, D., Rahayu, S., Pratama, A. A., Soraya, E., Sahide, M. A. K., & Maryudi, A. (2020). Problem-method fit in forest policy analysis: Empirical pre-orientation for selecting tested or innovative social-qualitative methods. *MethodsX*, 7, Article 100794. <https://doi.org/10.1016/j.mex.2020.100794>
- Maryudi, A., & Fisher, M. R. (2020). The power in the interview: A practical guide for identifying the critical role of actor interests in environment research. *Forest and Society*, 4(1), 142–150. <https://doi.org/10.24259/fs.v4i1.9132>
- Maryudi, A., Sahide, M. A. K., Daulay, M. H., Yuniati, D., Syafitri, W., Sadiyo, & Fisher, M. R. (2022). Holding social forestry hostage in Indonesia: Contested bureaucracy mandates and potential escape pathways. *Environmental Science & Policy*, 128, 142–153. <https://doi.org/10.1016/j.envsci.2021.11.013>
- Muhyidin, A. (2019). Guarding central government control over forest: Forest governance in the post decentralization Indonesia. *Jurnal Politik*, 4(1), Article 5. <https://doi.org/10.7454/jp.v4i1.186>
- Mullissa, A., Saatchi, S., Dalagnol, R., Erickson, T., Provost, N., Osborn, F., Ashary, A., Moon, V., & Melling, D. (2024). LUCA: A Sentinel-1 SAR-based global forest land use change alert. *Remote Sensing*, 16(12), Article 2151. <https://doi.org/10.3390/rs16122151>

- Mustafa, M., Ilmi, D., Nalus, S., Elvita, Y., Ramli, S., Movitaria, M. A., & Azra, M. F. (2025). Challenging the Eco-Islamic decoupling: A critical analysis of strategic gaps between government mandates and Green Madrasah SWOT capacity toward institutional transformation. *JPI: Jurnal Pustaka Indonesia*, 6(1), 327–343. <https://doi.org/10.62159/jpi.v6i1.2104>
- Muttaqin, T., Soraya, E., Dharmawan, B., Laraswati, D., & Maryudi, A. (2023). Asymmetric power relations in multistakeholder initiatives: Insights from the government-instituted Indonesian National Forestry Council. *Trees, Forests and People*, 12, Article 100406. <https://doi.org/10.1016/j.tfp.2023.100406>
- Myers, R., Fisher, M., Monterroso, I., Liswanti, N., Maryudi, A., Larson, A. M., Mwangi, E., & Herawati, T. (2022). Coordinating forest tenure reform: Objectives, resources and relations in Indonesia, Kenya, Nepal, Peru, and Uganda. *Forest Policy and Economics*, 139, Article 102718. <https://doi.org/10.1016/j.forpol.2022.102718>
- Nesha, K., Herold, M., De Sy, V., Duchelle, A. E., Martius, C., Branthomme, A., Garzuglia, M., Jonsson, O., & Pekkarinen, A. (2021). An assessment of data sources, data quality and changes in national forest monitoring capacities in the Global Forest Resources Assessment 2005–2020. *Environmental Research Letters*, 16(5), Article 054029. <https://doi.org/10.1088/1748-9326/abd81b>
- Ramachandran, N., Irvin, J., Sheng, H., Johnson-Yu, S., Story, K., Rustowicz, R., Ng, A. Y., & Austin, K. (2024). Automatic deforestation driver attribution using deep learning on satellite imagery. *Global Environmental Change*, 86, Article 102843. <https://doi.org/10.1016/j.gloenvcha.2024.102843>
- Ramadhan, R., Karim, S., Fisher, M. R., Mursyid, H., & Indrawan, M. (2023). Assessing the governance modes of Indonesia's forest management unit. In A. Triyanti, M. Indrawan, L. Nurhidayah, & M. A. Marfai (Eds.), *Environmental governance in Indonesia* (pp. 151–165). Springer. https://doi.org/10.1007/978-3-031-15904-6_9
- Rantala, S., Swallow, B., Paloniemi, R., & Raitanen, E. (2020). Governance of forests and governance of forest information: Interlinkages in the age of open and digital data. *Forest Policy and Economics*, 113, Article 102123. <https://doi.org/10.1016/j.forpol.2020.102123>
- Rantala, S., Swallow, B., Lähtenmäki-Uutela, A., & Paloniemi, R. (2022). Forest data governance as a reflection of forest governance: Institutional change and endurance in Finland and Canada. *Environmental Science & Policy*, 136, 751–760. <https://doi.org/10.1016/j.envsci.2022.07.031>
- Resosudarmo, I. A. P., Tacconi, L., Sloan, S., Hamdani, F. A. U., Subarudi, Alviya, I., & Muttaqin, M. Z. (2019). Indonesia's land reform: Implications for local livelihoods and climate change. *Forest Policy and Economics*, 108, Article 101903. <https://doi.org/10.1016/j.forpol.2019.04.007>
- Roengtam, S., & Agustiyara, A. (2022). Collaborative governance for forest land use policy implementation and development. *Cogent Social Sciences*, 8(1), Article 2073670. <https://doi.org/10.1080/23311886.2022.2073670>
- Roengtam, S., Agustiyara, A., & Nurmandi, A. (2023). Making network governance work in forest land-use policy in the local government. *SAGE Open*, 13(3). <https://doi.org/10.1177/21582440231194491>
- Rokhman, R., Diana, N., Etek, Y., Koderi, K., & Sufian, M. (2024). The development of a scientific-based academic supervision management model. *AL-ISHLAH: Jurnal Pendidikan*, 16(2), 1383–1398. <https://doi.org/10.35445/alishlah.v16i2.4626>
- Sahide, M. A. K., Fisher, M. R., Erbaugh, J. T., Intarini, D., Dharmiasih, W., Makmur, M., Faturachmat, F., Verheijen, B., & Maryudi, A. (2020). The boom of social forestry policy and the bust of social forests in Indonesia: Developing and applying an access-exclusion framework to assess policy outcomes. *Forest Policy and Economics*, 120, Article 102290. <https://doi.org/10.1016/j.forpol.2020.102290>
- Samsuri, S., Zaitunah, A., Samsura, A., & Marbun, H. Y. (2025). Land cover change and ethnoecological practices in Forest Management Unit XXV, North Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, 26(9), 4545–4556. <https://doi.org/10.13057/biodiv/d260926>
- Sari, D. A., Margules, C., Lim, H. S., Widyatmaka, F., Sayer, J., Dale, A., & MacGregor, C. (2021). Evaluating policy coherence: A case study of peatland forests on the Kampar Peninsula landscape, Indonesia. *Land Use Policy*, 105, Article 105396. <https://doi.org/10.1016/j.landusepol.2021.105396>
- Sayer, J., Boedhihartono, A. K., Langston, J. D., Margules, C., Riggs, R. A., & Sari, D. A. (2021). Governance challenges to landscape restoration in Indonesia. *Land Use Policy*, 104, Article 104857. <https://doi.org/10.1016/j.landusepol.2020.104857>
- Shen, F., Tang, R., Sun, X., & Liu, D. (2019). Simple methods for satellite identification of algal blooms and species using 10-year time series data from the East China Sea. *Remote Sensing of Environment*, 235,

Article 111484. <https://doi.org/10.1016/j.rse.2019.111484>

- Sorge, S., Mann, C., Schleyer, C., Loft, L., Spacek, M., Hernández-Morcillo, M., & Kluvankova, T. (2022). Understanding dynamics of forest ecosystem services governance: A socio-ecological-technical-analytical framework. *Ecosystem Services*, 55, Article 101427. <https://doi.org/10.1016/j.ecoser.2022.101427>
- Suwarno, S., Wisnu, W., & Jacky, J. (2025). Tapak Raja Cave as a contextual Social Studies learning resource for strengthening students' environmental awareness and ecotheological values. *JPI: Jurnal Pustaka Indonesia*, 6(1), 313–326. <https://doi.org/10.62159/jpi.v6i1.2204>
- Ullah, A., & Bavorova, M. (2024). Livelihood impacts of community-based forest landscape restoration in the Hindu Kush Himalaya, Pakistan. *European Journal of Forest Research*, 143(6), 1773–1786. <https://doi.org/10.1007/s10342-024-01726-5>
- Vadlamannati, K. C., Janz, N., & Berntsen, Ø. I. (2018). Human rights shaming and FDI: Effects of the UN Human Rights Commission and Council. *World Development*, 104, 222–237. <https://doi.org/10.1016/j.worlddev.2017.11.014>
- Van der Wal, Z., Mussagulova, A., & Chen, C. (2021). Path-dependent public servants: Comparing the influence of traditions on administrative behavior in developing Asia. *Public Administration Review*, 81(2), 308–320. <https://doi.org/10.1111/puar.13218>
- Waluyo, S. D., Rustanto, A. E., Winanti, Y. K., Onn, C. W., Sufian, M., & Mesina, J. R. (2025). Digital transformation in teacher performance assessment: Development and implementation of E-PKG system for enhancing vocational education quality and industry alignment. *Journal of Educational Technology and Learning Creativity*, 3(2), 348–366. <https://doi.org/10.37251/jetlc.v3i2.2490>
- Wurtzebach, Z., Schultz, C., Waltz, A. E. M., Esch, B. E., & Wasserman, T. N. (2019). Adaptive governance and the administrative state: Knowledge management for forest planning in the western United States. *Regional Environmental Change*, 19(8), 2651–2666. <https://doi.org/10.1007/s10113-019-01569-6>
- Yuza, A., Manaf, H. A., & Zainal, Z. (2023). Deforestation policy governance in Indonesia. *CosmoGov: Jurnal Ilmu Pemerintahan*, 9(1), 36–49. <https://doi.org/10.24198/cosmogov.v9i1.44778>
- Zhang, D., Wang, H., Wang, X., & Lü, Z. (2020). Accuracy assessment of the Global Forest Watch tree cover 2000 in China. *International Journal of Applied Earth Observation and Geoinformation*, 87, Article 102033. <https://doi.org/10.1016/j.jag.2019.102033>
- Zhang, Y., Ling, F., Wang, X., Foody, G. M., Boyd, D. S., Li, X., Du, Y., & Atkinson, P. M. (2021). Tracking small-scale tropical forest disturbances: Fusing the Landsat and Sentinel-2 data record. *Remote Sensing of Environment*, 261, Article 112470. <https://doi.org/10.1016/j.rse.2021.112470>