ASIAN JOURNAL OF FORESTRY
Volume 10, Number 1, June 2026
Pages: 14

E-ISSN: 2580-2844
https://doi.org/10.13057/asianjfor/r100117

Socio-ecological perspective on forest encroachment and community adaptation in Mount Silanu, Indonesia

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Manuscript received: 27 July 2025. Revision accepted: 17 February 2026.

Abstract. *Mahmud M, Maulany RI, Paembonan SA, Millang S, Asja MA, Muchtar A. 2026. Socio-ecological perspective on forest encroachment and community adaptation in Mount Silanu, Indonesia. Asian J For 10 (1): r100117. https://doi.org/10.13057/asianjfor/r100117.* Forest encroachment poses a serious threat to ecological integrity and social stability in Indonesia's forest-edge landscapes, where livelihood dependence, tenure ambiguity, and weak governance intersect. This study examines forest encroachment dynamics and community adaptation strategies in Mount Silanu, South Sulawesi, a forest-edge area characterized by the overlap of community-managed forests (HKm), protected forest zones, and agricultural frontiers. This study draws on 32 semi-structured interviews and the focus group discussions conducted across three forest-edge villages, analyzed using NVivo-assisted thematic coding integrated with the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework. The coded qualitative findings indicate that socio-economic inequality, insecure or contested tenure, limited livelihood alternatives, and long-standing dependence on forest resources function as key drivers that translate into pressures such as agricultural plot clearing, informal forest product extraction, and small-scale infrastructure expansion. Participants consistently reported ecological state changes, including declining tree cover, forest fragmentation, and perceived declines in locally valued species, alongside impacts on disaster vulnerability and boundary-related conflicts. Community responses clustered into three empirically derived adaptation typologies: Collective stewardship (e.g., mixed cropping and controlled grazing), mixed reactive–survival strategies (short-term coping combined with livelihood diversification), and individual exploitative strategies (monoculture intensification and unilateral land expansion). Overall, the findings highlight forest-edge communities as active agents responding to structural constraints, rather than isolated rule violators. The study underscores the importance of tenure-sensitive and participatory co-management approaches to mitigate encroachment while supporting ecological resilience and locally viable livelihoods.

Keywords: Adaptive livelihood practices, ecological resilience, forest-edge communities, social forestry governance

INTRODUCTION

Forest encroachment is a complex socio-ecological phenomenon emerging from tensions between community livelihood needs and governance systems that remain largely unresponsive and non-adaptive (Yasmi et al. 2012; Jenke 2024). Globally, encroachment at tropical forest frontiers is closely linked to commodity expansion and uneven state capacity. In Indonesia, this issue is further complicated by a dual policy mandate to conserve biodiversity while sustaining forest-based livelihoods within rural economies. It continues to pose a persistent challenge across the country's tropical forest frontiers, where maintaining the delicate balance between environmental conservation and rural subsistence remains difficult. Encroachment is not merely a legal violation but reflects deeper structural constraints, including limited access to land (Pambudi 2020), restricted rural economic capacity (Patil et al. 2021; Nugroho et al. 2022), and institutional weaknesses in forest governance (Saha et al. 2018; Erbaugh et al. 2020). Recent evaluations of Forest Management Units (*Kesatuan Pemangkuan Hutan*, KPH) in Sulawesi have shown mixed outcomes, indicating minimal overall influence on deforestation rates but some positive effects during climatic stress periods and within early-established units (Chervier et al. 2025). These findings highlight the critical role of socio-economic drivers in shaping how communities engage with protected landscapes.

In practice, forest encroachment manifests in various forms, including agricultural land clearing, free-range livestock grazing, and the illegal extraction of forest products (FAO 2021; San et al. 2024; Njurumana et al. 2025). These activities are primarily undertaken by households whose livelihoods depend on forest-based resources for subsistence or income generation (Rochmayanto et al. 2023; Gunawan et al. 2024). The intensity and nature of encroachment vary among social groups (Sugandi and Hamdanah 2019; Jenke 2024), shaped by differences in income level, land tenure security, access to extension services, and livelihood diversification opportunities (Cloete et al. 2019; Kimengsi et al. 2020;

Sadeghi et al. 2023; Coronel-Chugden et al. 2025). Rather than constituting isolated acts of deviance, these variations reflect how structural constraints condition household land-use decisions at forest edges. Despite this growing body of literature, few studies in Indonesia have empirically examined how such structural conditions translate into everyday adaptation strategies or how distinct response patterns emerge with direct governance implications. Mount Silanu provides a relevant forest-edge context where socio-economic vulnerability intersects with ecological fragility and institutional (Nurhayati et al. 2025).

Mount Silanu represents a forest-edge landscape in Indonesia where socio-economic vulnerability intersects with ecological fragility and institutional ambiguity (Nurhayati et al. 2025). Ecologically, the site lies at a sensitive interface between community-managed forests (*Hutan Kemasyarakatan*, HKm) and state-protected zones, where incremental clearing and grazing contribute to habitat fragmentation. Socio-politically, overlapping administrative boundaries between villages and HKm areas create spatial ambiguities that blur permissible land use and increase the potential for conflict. Formally designated as a Social Forestry (HKm) zone in 2010 (Muthmainnah et al. 2022), the Mount Silanu landscape directly adjoins a state-protected forest, yet boundary overlaps between village territories and HKm areas have enabled unregulated forest expansion beyond designated zones. Over time, these conditions have contributed to progressive forest fragmentation and escalating resource extraction, reflecting broader structural challenges such as poverty, livelihood insecurity, and marginalization from formal governance systems. In the absence of secure tenure and viable livelihood alternatives, local communities often resort to unsustainable land-use practices as survival strategies under combined institutional and ecological constraints (Larson and Soto 2008; Aggarwal et al. 2021; Jagger et al. 2022; Larson et al. 2023).

The Drivers-Pressures-State-Impacts-Responses (DPSIR) framework is widely used to organize complex environmental problems by linking socio-economic drivers to ecological change and societal responses (Kim et al. 2021; Gunawan et al. 2024; Nyein et al. 2025). However, its application in forest governance research has often remained descriptive or indicator-based, with limited integration of systematically analyzed qualitative evidence. Recent scholarship highlights the need to strengthen DPSIR's analytical capacity by connecting empirical observations, community perceptions, and governance processes (Carnohan et al. 2023). Addressing this gap, the present study applies the DPSIR framework in combination with NVivo-assisted thematic analysis to link coded community narratives with drivers, pressures, impacts, and response patterns in a forest-edge context, an approach that remains relatively uncommon in social forestry research (Lawasi 2024).

Accordingly, the study aims to: (i) map how drivers translate into pressures and perceived ecological states using DPSIR, and (ii) derive community adaptation typologies and their governance implications. This study hypothesizes that forest encroachment in Mount Silanu in Indonesia is primarily driven by structural socio-economic and institutional constraints, particularly livelihood insecurity, tenure ambiguity, and limited access to extension services, which translate into differentiated land-use pressures and heterogeneous community response strategies ranging from collective stewardship to individual exploitative adaptation.

MATERIALS AND METHODS

Study area

This study was conducted in three forest-adjacent villages, Mount Silanu, Marayoka, and Kapita, located within the Bangkala Sub-district of Jeneponto District, South Sulawesi Province, Indonesia. These villages lie along the boundary of a designated Protected Forest Zone (*Hutan Lindung*), with portions of their land incorporated under Indonesia's Social Forestry scheme (HKm), which was established in 2010. The sites were selected because of active community engagement in forest-edge land uses, including subsistence agriculture, seasonal grazing, and forest resource extraction. The area represents a typical tropical forest–agroforestry mosaic in eastern Indonesia where community-managed forests interface directly with state-protected zones. Overlapping village and HKm boundaries create a complex land-use setting that is central to understanding local forest-livelihood interactions. This institutional and spatial configuration makes Mount Silanu an appropriate case for examining socio-ecological dynamics and their implications for forest governance.

Research design

A qualitative, exploratory case study design was adopted to examine forest encroachment dynamics among forest-edge communities. This design was selected to capture community narratives, lived experiences, and informal land-use practices that shape interactions between livelihoods, governance arrangements, and forest conditions. The study focuses on a bounded socio-spatial setting encompassing three forest-adjacent villages, allowing in-depth analysis of localized processes and cross-village comparison. The case study centered on the Mount Silanu area encompassing the three aforementioned villages, allowing for in-depth engagement within a specific socio-spatial setting and the integration of multiple data sources and stakeholder perspectives (Crowe et al. 2011). The overlap between social forestry and protected forest jurisdictions, coupled with a documented history of land-use change and visible degradation, made the Mount Silanu landscape an appropriate setting for exploring forest encroachment as an integrated social, ecological, and economic system (Tajuddin et al. 2019; Kyere-Boateng and Marek 2021; Syaban and Appiah-Opoku 2024).

The research design combined the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework with NVivo 12-assisted qualitative thematic analysis (Figure 1). In this study, the DPSIR framework is employed as an analytical structure to organize and interpret coded qualitative evidence, rather than as a purely conceptual model of

socio-ecological systems (Fischer 2018; Liu et al. 2023). DPSIR facilitates the systematic mapping of causal linkages from underlying drivers to observed pressure, perceived ecological states, impacts, and community responses (Quevedo et al. 2023). NVivo-assisted thematic analysis enhances transparency and pattern recognition by enabling the systematic coding and comparison of community narratives across social groups (Mortelmans 2025; Quan et al. 2025). By integrating DPSIR with qualitative coding, this approach supports the identification of empirically grounded adaptation typologies and the derivation of governance-relevant insights rooted in the lived experiences of forest-edge communities in Mount Silanu, Indonesia.

The study does not seek statistical generalization to all forest-edge communities in Indonesia, nor does it aim to produce biophysical measurements of ecological change. Instead, it pursues analytical generalization, whereby insights from Mount Silanu are used to refine conceptual understanding of forest encroachment dynamics and community adaptation within socio-ecological systems. Findings are therefore most applicable to contexts with similar institutional configurations and livelihood conditions, rather than being universally representative of all tropical forest frontiers.

Data collection

Participants were selected using a combination of purposive and convenience sampling strategies (Ahmed 2024). Purposive sampling was employed to identify information-rich individuals directly involved in forest-edge land-use practices and local governance, including village officials, forest farmer group (*Kelompok Tani Hutan*, KTH) representatives, customary leaders, and farming households. Convenience sampling was applied during field visits to include accessible households actively engaged in forest-related livelihoods, thereby capturing everyday practices that may be underrepresented in formal organizational roles. This combined approach was used to balance analytical depth with contextual diversity, enabling the inclusion of both institutional perspectives and household-level experiences. Representativeness was pursued in qualitative terms by ensuring variation across villages, gender, livelihood roles, and governance positions, rather than through statistical proportionality. In total, 32 respondents were involved in the preliminary interview phase across the three study villages, comprising village officials, community leaders, KTH representatives, and male and female farming households (Table 1). A subset of participants was subsequently engaged in in-depth interviews and focus group discussions to achieve thematic saturation and to triangulate perspectives across social groups. This sample size achieved information saturation and ensured diversity of perspectives, while unselected interviews and Focus Group Discussions (FGDs) were retained for triangulation.

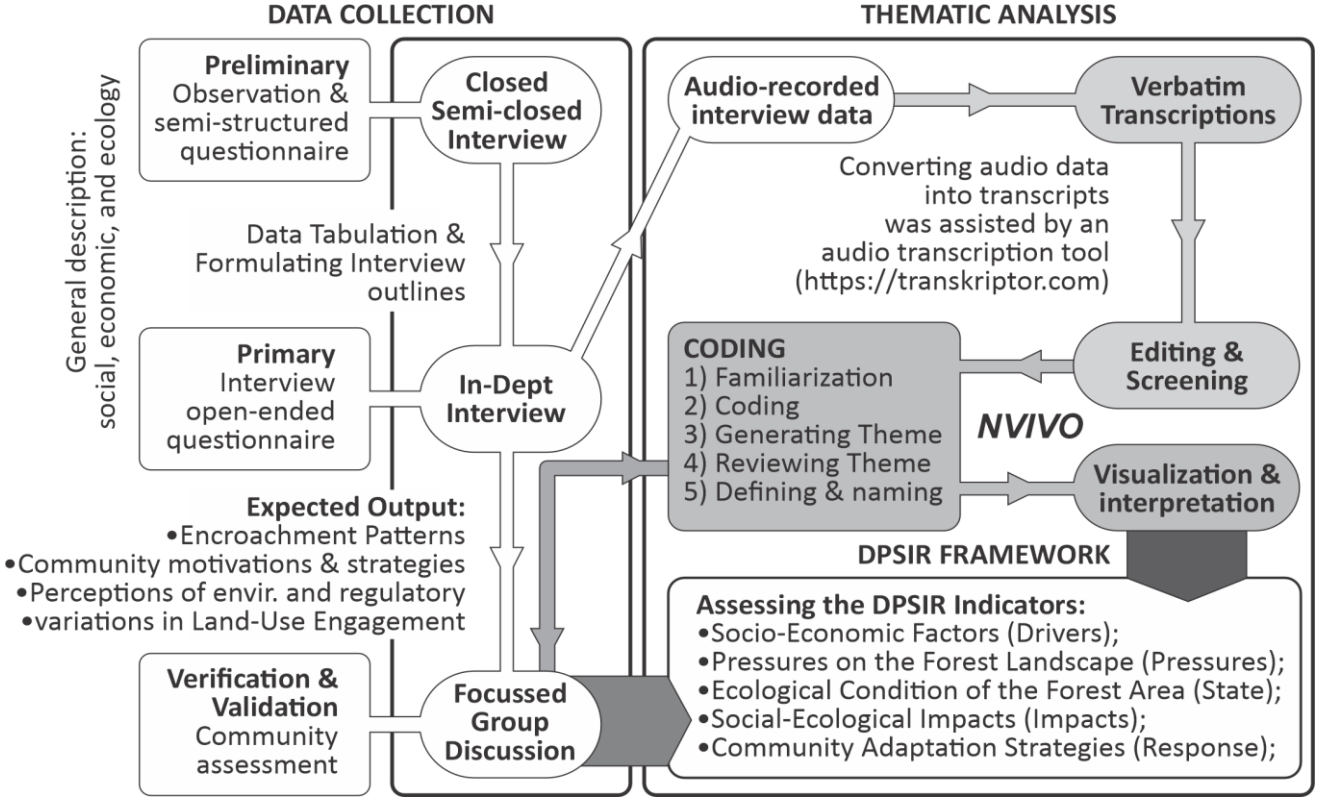

Figure 1. Flowchart of research design integrating qualitative data collection, NVivo-based thematic analysis, and DPSIR framework application

Table 1. Distribution of respondents in the preliminary interview phase by category, gender, and proportional representation

Respondent category	Gender	Count (n)	Proportion (%)
Community Leaders	Male	3	9.38
Village Government Representatives	Male	2	6.25
	Female	1	3.13
KTH Representatives	Male	4	12.50
Male Farmers	Male	17	53.13
Female Farmers	Female	5	15.63
Total		32	100.00

FGDs were later conducted with the original 32 respondents. Additional community members, including active farmers and representatives of local social groups, were invited to participate to enrich the range of perspectives. Audio recordings of interviews and FGDs were transcribed using an AI-assisted platform (Transkriptor, https://transkriptor.com) and manually verified line by line by two researchers to ensure accuracy. An AI-assisted transcription platform was used to improve efficiency and consistency, particularly for multi-speaker recordings in Indonesian. All automated transcripts were manually checked and corrected to ensure accuracy and reliability for subsequent analysis. Discrepancies were resolved through consensus, and a timestamped audit trail was maintained. All transcripts were anonymized prior to analysis and stored on restricted-access drives in accordance with institutional data protection policies. Ethical approval was granted by the Universitas Hasanuddin Ethical Board (Approval No. 2350/UN4.14.1/TP.01.02/2025). Before participation, respondents were informed, both verbally and in writing, about the purpose, procedures, potential risks and benefits, confidentiality, and recording protocols of the study.

The use of convenience sampling may have introduced selection bias toward more accessible participants, potentially underrepresenting more marginalized community members; therefore, findings should be interpreted as context-specific rather than fully representative of all households.

Data processing and familiarization

The first stage of data analysis involved the preparation, transcription, and initial familiarization of qualitative data to ensure contextual consistency and analytical readiness for NVivo-assisted thematic coding. Audio recordings from interviews and focus group discussions were transcribed verbatim and systematically organized according to respondent identity and interview context to maintain data traceability throughout the analysis process. Transcripts were manually reviewed and corrected to preserve linguistic accuracy and contextual meaning. A familiarization process was then conducted through repeated reading of transcripts to support immersion in community narratives and the identification of preliminary patterns related to forest use, encroachment practices, and governance perceptions. The initial stage of data analysis involved the preparation, transcription, and early exploration of qualitative data to ensure consistency, contextual depth, and analytical readiness for NVivo-assisted thematic coding.

The process began with the management of audio-recorded interviews and FGD data. Each recording was segmented and labeled based on the respondent's identity and interview context (e.g., individual interview, group discussion, thematic focus). This step was essential for organizing the data corpus and enabling accurate tracking during the analysis phase.

Audio files were then transcribed using an online automated transcription tool (Transcriptor: https://transkriptor.com; and/or https://transcriptor.ai). The tool produced verbatim transcripts, which were subsequently reviewed and corrected manually to ensure linguistic accuracy and the preservation of context-specific meanings.

The finalized transcripts underwent two refinement phases. The first retained respondents' original phrasing, dialects, and narrative flow to preserve sociocultural nuance. The second involved light editing to prepare the data for visual text analysis in NVivo, such as word clouds and word trees. This included simplifying fragmented sentences, removing non-thematic fillers (e.g., "and," "so"), and emphasizing recurring terms like poverty, inequality, land, and access.

While not used for coding, these visual tools supported the familiarization phase by highlighting common speech patterns and key vocabulary related to forest use, encroachment, and governance perceptions. This phase served as a conceptual bridge between raw data and structured analysis. It enabled immersion in community narratives, identification of linguistic markers, and preparation for systematic coding and theme development aligned with the DPSIR framework.

Coding and thematic analysis

Qualitative data analysis was conducted using NVivo 12 through an inductive and iterative coding process designed to derive themes grounded in participants' narratives and structured within the DPSIR framework. Coding followed an inductive, iterative process designed to capture actions, perceptions, and experiences related to forest use, livelihood strategies, land tenure, and adaptation at the forest edge. Initial coding generated a set of open codes derived directly from the transcripts. These codes were then iteratively compared, refined, and grouped into higher-order conceptual categories based on semantic similarity, shared causal logic, and relevance to DPSIR dimensions. Through this process, 116 open codes were synthesized into 20 conceptual categories, which constitute the analytical basis for thematic interpretation and DPSIR mapping (Table 2). Following the familiarization phase, the transcripts were systematically analyzed through a two-stage coding process using NVivo 12 software: open coding and spindle coding. These stages allowed the

researcher to inductively extract meaning from the data and progressively build a structured thematic framework (Allsop et al. 2022).

Open coding was carried out line-by-line on the verbatim transcripts of in-depth interviews. This initial phase focused on identifying discrete units of meaning, including actions, perceptions, motives, and observed phenomena, by assigning descriptive labels (codes) directly to text segments. NVivo's free nodes function was employed to store these open codes, each supported by multiple direct quotes from participants. This stage was intentionally inductive: no predetermined codes were applied. Instead, coding decisions were grounded in the language and lived experiences of the respondents (Cassell and Bishop 2019), especially concerning their interaction with forest resources, livelihood practices, land tenure challenges, and adaptation strategies. Memos were created in parallel to document interpretive reasoning and emerging analytical insights.

Table 2. Nodal levels and coding number reflecting the current situation of community interactions and encroachment dynamics in forest-edge areas

Primary nodes (based on interview context)	Secondary nodes (spindle coding)	Number of nodes (open nodes)	Coding examples
Types and patterns of encroachment activities (theme 1)	Land encroachment for agriculture/ livestock	7	clear land; rainy season comes; grass for livestock; no fixed boundaries; can still be cultivated
	Unauthorized forest product extraction	6	We collect firewood and rattan whenever we need; no one asks for permits here.
	Uncontrolled livestock grazing	5	Cattle are left to forage freely, and they often enter other people's land or protected zones.
	Collective expansion without governance	6	We usually clear land together as a group. There's no written agreement; just mutual understanding.
	Seasonal intensification and unsustainable cropping patterns	6	We plant repeatedly during each season. It's mostly monoculture; corn, corn, and corn again.
Community motivations and strategies in utilizing forest land (theme 2)	Socio-economic inequality	6	Assistance usually goes to those close to village officials. People like us are always left behind.
	Lack of livelihood alternatives	4	There's no other option; we rely on this land to survive
	Community dependence on unsustainable practices	6	Even if it's illegal, we keep using the forest. It's the only way to feed our families.
Perceptions of environmental pressures and regulations (theme 3)	Weak land tenure security	5	We don't have certificates. We know our parents have used this land for years.
	Limited access to extension services and conservation information	5	We've never been trained. No one comes to explain how to protect the forest or what's allowed.
Variations across villages or groups in land-use engagement (theme 4)	Mixed cropping, grazing in designated plots	8	We grow different crops and only allow livestock to graze in agreed parts of the land.
	Forest product diversification, shifting cultivation, and seasonal adaptation	6	When corn fails, we switch to tubers or collect honey and bamboo from the forest.
	Monoculture intensification, land expansion without agreement, and open-access forest use	6	Some expand land without telling others; everyone clears what they can, wherever it's still empty.
Additional Information (theme 5)	Historical dependency on forest resources	6	Our ancestors did this long before any rules. It's part of our way of life.
	Small-scale community infrastructure development	5	We built a small hut and dug a water hole for dry-season farming
	Declining tree cover	6	There used to be big trees here. Now it's just shrubs and exposed soil
	Landscape fragmentation	6	The paths, farming plots, and livestock trails have cut up the forest; it's no longer continuous.
	Declining biodiversity	5	It's rare to hear birds anymore. We don't see wild pigs or deer like we used to
	Progressive landscape degradation and community vulnerability to ecological hazards	6	The slopes are bare and fragile. We fear landslides during every rainy season.
	Emergence of social conflicts over forest boundaries	6	Some people argue over plots. Without maps or boundaries, conflicts are common during the planting season.
Total Nodes		116	

Spindle coding, open codes were grouped and reorganized using spindle coding (a process similar to axial coding), where patterns and connections between codes were explored to form conceptual categories. Related codes were merged, reclassified, or refined into hierarchical relationships (parent and child nodes in NVivo) to capture broader social, ecological, and economic dynamics. This stage also involved iterative comparison across cases to reveal commonalities and divergences among respondents, both within and across the three study villages. Through this process, the coding structure evolved from a flat list of labels into an interconnected map of core themes, providing the foundation for selective coding and theme generation. As a result, a total of 116 detailed open codes were developed, which were subsequently organized into 20 higher-order conceptual categories as spindle coding results (Table 2). These categories served as secondary nodes and provided the fundamental structure for thematic classification and the DPSIR-based analysis in the next stage.

Thematic analysis was subsequently employed to identify, interpret, and synthesize patterns of meaning across the data (Braun and Clarke 2006). This method was particularly suited to the narrative and contextual depth of qualitative data obtained from interviews and FGDs (Malek and Abdul Rahim 2022). NVivo 12 supported the structured organization of codes, theme generation, and the analysis of relationships between nodes using tools such as word frequency queries, matrix coding, and word trees (Zamawe 2015). The six analytical phases outlined by Braun and Clarke (2006), familiarization, coding, theme generation, theme review, theme definition and naming, and writing, guided the entire thematic process.

DPSIR framework

The Drivers-Pressures-State-Impacts-Responses (DPSIR) framework provided a structured analytical lens for linking socio-economic activities to environmental outcomes (Smeets and Weterings 1999). The DPSIR components interact through feedback loops rather than operating as a linear sequence. Tenure-related Drivers intensify Pressures, while perceived ecological State changes shape community Responses, which in turn modify future Drivers and Pressures. This highlights tensions between collective stewardship and unresolved tenure ambiguity, demonstrating that encroachment is an evolving socio-ecological process rather than a simple cause–and–effect chain.

In this study, the DPSIR model conceptualized forest encroachment as an outcome of intertwined socio-economic, ecological, and institutional processes (Maxim et al. 2009; Gari et al. 2015). This hierarchical structure was effective for examining deforestation and fragmentation dynamics and understanding how social drivers translate into ecological impacts (Kyere-Boateng and Marek 2021; Mosaffaie et al. 2021; Gunawan et al. 2024). The coding process adhered to grounded theory principles, employing open, axial (spindle), and selective coding to identify and link thematic elements, drivers, and responses (Mortelmans 2025). The final 20 conceptual categories derived from spindle coding were systematically mapped onto the five DPSIR components. Figure 1 presents the overall research design flow, illustrating the integration of data collection, coding, and DPSIR-based analysis.

Validity and reliability

Methodological rigor was ensured through multiple strategies commonly applied in qualitative research. Data triangulation was achieved by drawing on multiple sources, including semi-structured interviews, focus group discussions, and diverse respondent categories (village officials, community leaders, and farming households), enabling cross-validation of emerging themes across perspectives and villages. To enhance analytical reliability, coding was conducted iteratively with continuous comparison across transcripts, villages, and respondent groups. Analytical memos and audit trails were maintained throughout the coding process to document interpretive decisions and category development. While formal intercoder reliability statistics were not applied, coding consistency was reinforced through repeated review of code definitions and category boundaries during the synthesis of open codes into higher-order categories. Bias mitigation was addressed through reflexive analysis, including critical examination of the researchers' positionality and assumptions during interpretation, as well as systematic reliance on verbatim quotations to anchor themes in participants' narratives. Together, these procedures strengthen the credibility, dependability, and transparency of the qualitative findings.

RESULTS AND DISCUSSION

To provide a coherent interpretation of forest encroachment dynamics, the 20 secondary nodes derived from spindle coding were systematically reclassified within the DPSIR framework. This categorization enables a structured causal analysis, tracing the progression from socio-economic and institutional drivers to land-use pressures, ecological transformations, resultant impacts, and community-level adaptive responses (Table 3). Figure 2 illustrates these interconnections, presenting a schematic overview of how the thematic dimensions interact across the DPSIR components as observed in Mount Silanu.

Driving forces of forest encroachment

The primary drivers of forest encroachment in Mount Silanu reflect the combined effects of structural inequality, institutional disconnection, and persistent livelihood dependence. Drawing from five secondary nodes, socio-economic inequality, limited livelihood alternatives, weak land tenure security, limited extension access, and historical reliance on forest resources, this section examines the foundational forces shaping encroachment behavior and land-use decisions (Table 3).

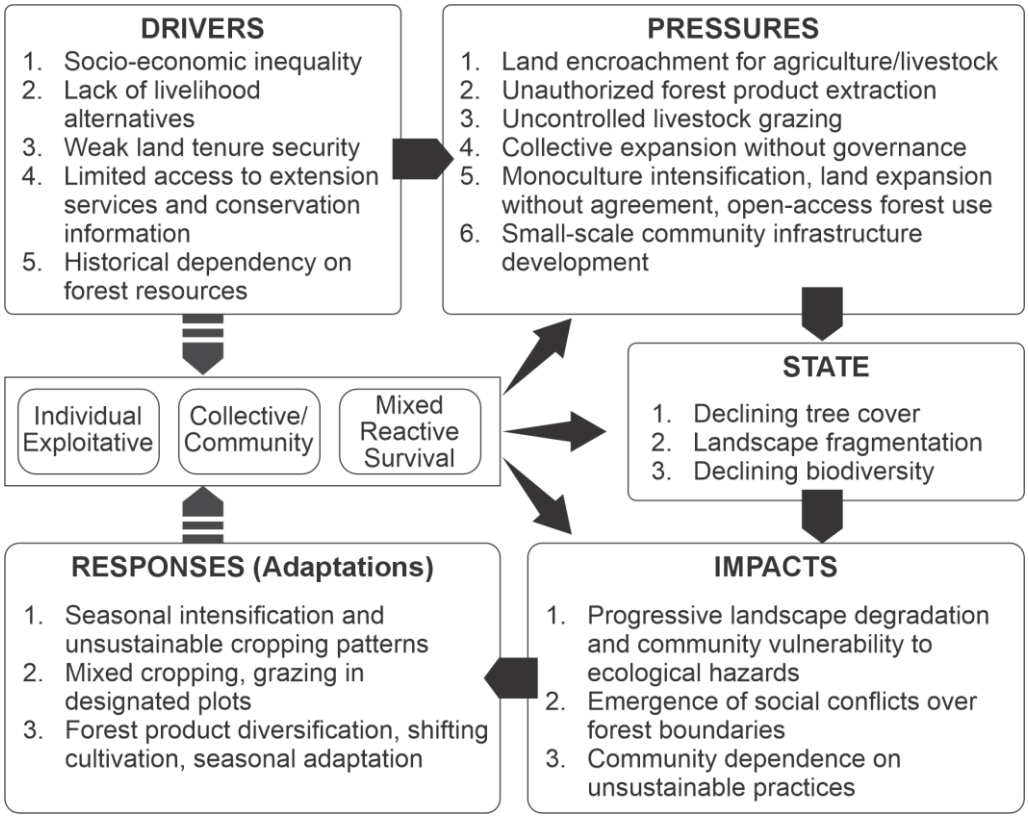

Figure 2. Schematic mapping of forest encroachment dynamics in Mount Silanu using the DPSIR framework

Socio-economic inequality emerged as a major factor, particularly in access to government assistance. Households in remote or peripheral areas reported being excluded from social support schemes that favored groups closer to village authorities. One respondent noted,

"*Assistance usually goes to those close to village officials. People like us are always left behind, even though our needs are just as urgent*."

This exclusion sustains dependence on forest-based strategies, particularly among poorer households. Consistent with Jagger et al. (2022), forests often function as safety nets when viable alternatives are lacking. Across interviews, limited livelihood opportunities were repeatedly linked to land clearing and extraction undertaken for subsistence rather than profit. This dependence is further reinforced by weak tenure security, where customary land use lacks formal recognition or legal rights. Respondents described unclear boundaries and the absence of land titles as sources of uncertainty that intensified competition for access and undermined trust in regulatory institutions. These empirical patterns are consistent with observations from other forest-edge contexts, where legal ambiguity has been shown to heighten tensions between subsistence needs and conservation objectives. Aggarwal et al. (2021) similarly observed that legal ambiguity can heighten tensions between subsistence needs and conservation goals.

Limited access to extension services and conservation information further perpetuates these dynamics. Respondents consistently stated that the absence of forestry outreach and communication regarding regulations has resulted in continued reliance on unmanaged, unsustainable land-use practices. As one participant explained,

"*We've never been trained. No one comes to explain how to protect the forest or what's allowed*."

This finding aligns with Sunderlin et al. (2008) and Wang et al. (2023), who link low institutional engagement with poor community compliance and ecological awareness. Historical dependence is also culturally embedded, where present-day practices continue ancestral traditions. As one elder remarked,

"*Our ancestors did this long before any rules; it's how we live*."

Participants commonly associated this long-standing reliance with limited understanding of formal land-use regulations and unclear territorial boundaries, conditions that sustained uncertainty over permissible practices. Despite the presence of local agency interventions, respondents perceived that inequality and tenure ambiguity remained largely unresolved at the community level. Mau and Naatonis (2024) note that forest encroachment often intersects with land claims, unclear territorial boundaries, and a limited understanding of legal or ecological designations. Despite local agency interventions, inequality and tenure ambiguity remain unresolved. Addressing encroachment, therefore, requires targeting these underlying socio-economic and institutional gaps. Key priorities include clarifying tenure and boundaries, ensuring pro-poor targeting of social assistance, and providing regular extension programs that translate regulations into practicable local guidance.

Table 3. Reclassification of spindle-coded secondary nodes into the DPSIR framework based on thematic origin and node frequency

DPSIR	Reclassification of secondary nodes into DPSIR framework	Theme and nodes
Drivers	Socio-economic inequality	theme 2; 6 nodes
	Lack of livelihood alternatives	theme 2; 4 nodes
	Weak land tenure security	theme 3; 5 nodes
	Limited access to extension services and conservation information	theme 3; 5 nodes
	Historical dependency on forest resources	theme 5; 6 nodes
Pressures	Land encroachment for agriculture/livestock	theme 1; 7 nodes
	Unauthorized forest product extraction	theme 1; 6 nodes
	Uncontrolled livestock grazing	theme 1; 5 nodes
	Collective expansion without governance	theme 1; 6 nodes
	Monoculture intensification, land expansion without agreement, and open-access forest use	theme 4; 6 nodes
	Small-scale community infrastructure development	theme 5; 5 nodes
States	Declining tree cover	theme 5; 6 nodes
	Landscape fragmentation	theme 5; 6 nodes
	Declining biodiversity	theme 5; 5 nodes
Impact	Progressive landscape degradation and community vulnerability to ecological hazards	theme 5; 6 nodes
	Emergence of social conflicts over forest boundaries	theme 5; 6 nodes
	Community dependence on unsustainable practices	theme 2; 6 nodes
Responds	Seasonal intensification and unsustainable cropping patterns	theme 1; 6 nodes
	Mixed cropping, grazing in designated plots	theme 4; 8 nodes
	Forest product diversification, shifting cultivation, and seasonal adaptation	theme 4; 6 nodes

Pressures: Encroachment behaviors and land use practices

Encroachment behaviors in Mount Silanu reflect direct manifestations of the above drivers through unsustainable land-use practices. Six major pressures were identified: (i) agricultural and livestock land encroachment, (ii) unauthorized extraction of forest products, (iii) uncontrolled grazing, (iv) collective land clearing without governance, (v) monoculture intensification and open-access use, and (vi) small-scale infrastructure development (Table 3). These activities represent immediate ecological disturbances within the landscape.

The most dominant pressure identified across the study villages was land clearing for agriculture and livestock, often undertaken without prior ecological planning. Respondents described clearing small plots for seasonal crops (typically maize or upland rice) based on rainfall cycles and proximity to accessible forest edges. These practices were generally incremental and oriented toward subsistence rather than commercial expansion. One respondent explained that land was opened as needed, following seasonal demands rather than long-term land-use planning. Such unplanned conversion has been associated with soil degradation, erosion, and vegetation loss in comparable contexts (AbdelRahman 2023).

Unauthorized extraction of forest products, including firewood and honey, also emerged as a widespread pressure. Respondents emphasized that these activities were largely unregulated and embedded in everyday livelihood practices. As one participant stated,

"*We collect whatever we need—there is no permit system, and no one comes to check.*"

Weak enforcement was perceived to facilitate continued extraction, contributing to the gradual degradation of forest structure and habitats, as similarly observed by AbdelRahman (2023).

Uncontrolled grazing constituted another significant pressure on forest-edge ecosystems. Farmers acknowledged that free-ranging livestock frequently grazed within forest areas, causing trampling, soil compaction, and disruption of ecological corridors. Such practices were described as routine and difficult to regulate at the community level. Comparable impacts of grazing on forest integrity and wildlife movement have been documented in protected areas elsewhere (Soofi et al. 2018). In addition, some communities reported engaging in collective land clearing activities without formal governance mechanisms. Although framed locally as cooperative efforts, these practices reflected institutional weaknesses in land-use regulation, particularly in contexts of unclear tenure arrangements and limited participatory spatial planning (Persson and Prowse 2017).

Monoculture intensification emerged as a related but distinct pressure following land conversion, shaping how cleared areas were subsequently managed. Respondents described continuous single-crop cultivation on converted plots as a common survival strategy under conditions of population pressure and land scarcity. This practice intensified ecological stress within already cleared areas rather than expanding forest boundaries further. Limited technical support and extension services were perceived to exacerbate soil nutrient depletion and reduce ecosystem resilience. Alongside agricultural intensification, small-scale infrastructure development—such as dirt paths, water catchments, and temporary shelters—was also reported. Although modest in scale, respondents noted that the cumulative expansion of such structures fragmented the landscape and disrupted ecological connectivity. Similar patterns of localized infrastructure contributing to broader

ecological degradation have been documented in other forest-edge settings (Alamgir et al. 2019; Santika et al. 2019; da Silva et al. 2023).

State: Ecological changes observed

Community narratives indicate clear perceptions of ecological change associated with forest encroachment, particularly vegetation loss, habitat fragmentation, and declining availability of wildlife and forest products, representing the "State" component within the DPSIR framework (Table 3). Landscape fragmentation emerged as a prominent condition, accounting for 31.2% of coded references. Respondents repeatedly described the forest as "disconnected," "cut through," and "no longer continuous," noting visible breaks in forest cover caused by agricultural plots and informal paths. Several participants observed that forest areas that were previously contiguous are now separated into smaller patches, making it more difficult for wildlife to move across the landscape. These locally observed conditions are consistent with broader ecological understandings of fragmentation and its implications for habitat continuity (Haddad et al. 2015; Gunawan et al. 2024).

Declining biodiversity, representing 26.3% of coded responses, was another frequently cited ecological condition. Participants consistently referred to the reduced presence of wildlife and useful plant species in areas near settlements and cultivated land. As one respondent remarked,

"*Animals have disappeared, birds no longer sing, and useful plants are rarely found*."

Such statements reflect perceived changes in species abundance and everyday ecological encounters rather than formal species inventories. Similar observations have been noted in contexts where forest condition is shaped by intensive land use and limited ecological management (Youn 2009; Langridge et al. 2023).

More broadly, respondents associated these ecological changes with the cumulative effects of agricultural expansion and unregulated land use at the forest edge. While participants did not quantify ecological change, their accounts consistently emphasized observable alterations in forest structure and species presence. Comparable tensions between conservation objectives and production-oriented land use have been reported in other protected landscapes, including Dadia National Park in Greece (Poirazidis et al. 2011), highlighting how unmanaged pressures can reshape ecological conditions over time.

Impacts: Social and environmental consequences

The ecological changes observed by respondents were reported to translate into tangible social and environmental impacts at the community level, including reduced ecosystem services, increased vulnerability to environmental hazards, and the emergence of social conflict (Table 3). Analysis of interview and focus group data identified three dominant impact themes: (i) progressive environmental degradation and disaster vulnerability, (ii) boundary-related social conflict, and (iii) continued dependence on unsustainable livelihood practices.

Communities consistently reported physical signs of environmental degradation, such as unstable slopes, soil erosion, and disrupted water regulation, particularly during the rainy season. These conditions were described as directly affecting agricultural safety and productivity. As one farmer observed,

"*The land erodes during every heavy rain. It's no longer safe for planting*."

Respondents associated these impacts with changes in land cover and farming practices near forest edges. Similar linkages between upland land-use change, erosion, and hydrological instability have been documented in other Southeast Asian contexts (Ziegler et al. 2007; He et al. 2023).

Boundary-related social conflict emerged as another prominent impact, primarily linked to unclear tenure arrangements and expanding cultivation into forest-edge areas. Participants described frequent disputes over land boundaries, often occurring between neighboring households or between communities and state authorities. One respondent noted,

"*People argue over land because no one knows exactly where the boundary is.*" Another added, "*Without clear maps or agreements, everyone just claims what they can.*"

These accounts indicate that conflict was commonly perceived as a consequence of institutional ambiguity rather than interpersonal hostility. Comparable patterns of conflict driven by unclear governance arrangements have been observed in other forest contexts (Lund 2015).

A third impact involved continued dependence on unsustainable practices as a coping response to declining productivity and limited livelihood options. Respondents acknowledged that reduced yields and restricted access to alternative income sources encouraged intensified extraction of forest resources. As one participant admitted,

"*We keep harvesting even if it's not allowed, because we have no other choice.*"

Such dependence reflects a self-reinforcing cycle in which ecological degradation and livelihood insecurity mutually exacerbate one another, a dynamic also reported in forest-dependent communities elsewhere (Angelsen et al. 2014; Bennett et al. 2019).

Responses: Local strategies and adaptive actions

Under the DPSIR framework, "responses" denote formal or informal actions by individuals, communities, or institutions to mitigate or adapt to environmental degradation. In Mount Silanu, three adaptive strategies were identified: (i) seasonal intensification and unsustainable cropping, (ii) mixed cropping and localized grazing, and (iii) forest product diversification and shifting cultivation (Figure 2). These strategies varied in their frequency, depth of narrative detail, and distribution across villages, forming the empirical basis for the adaptation typology presented in this study.

Seasonal intensification and unsustainable cropping emerged as a reactive strategy primarily associated with land scarcity and declining productivity. This category was

characterized by frequent references to repeated planting cycles, monoculture reliance, and short-term yield maximization, particularly among households with limited land access. One farmer explained,

"*We plant again and again, even if the yield is low. We have no other land.*"

Such responses were commonly coded across all villages and reflected short-term coping rather than coordinated adaptation, with implications for soil fertility and long-term sustainability (Yengoh et al. 2016; Santika et al. 2019).

In contrast, mixed cropping and rotational grazing represented a more locally coordinated and lower-impact form of adaptation. This strategy was supported by fewer but more detailed narrative accounts, often emphasizing deliberate crop diversity and controlled livestock movement. Respondents described practices aimed at reducing disturbance and maintaining land productivity, as illustrated by one participant:

"*We grow maize and cassava together and only graze animals where it's allowed."*

These practices were unevenly distributed across villages but tended to cluster in areas with stronger customary norms and informal coordination, reflecting elements of collective action in resource management (Ostrom 2009).

Forest product diversification and mobile cultivation systems formed the third adaptation category. This strategy was identified through recurrent references to supplementing farming with non-timber forest products or rotating cultivation sites in response to seasonal conditions. One participant noted,

"If we can't harvest from the land, we collect honey or bamboo."

Although less frequent than seasonal intensification, these codes exhibited greater thematic depth and were often linked to households with broader livelihood portfolios. Similar adaptive patterns have been documented in forest-dependent contexts where diversification enhances short-term resilience (Kimengsi et al. 2020; Rochmayanto et al. 2023; Sadeghi et al. 2023).

While these responses display local ingenuity, they also expose structural constraints such as insecure tenure, weak institutional support, and limited extension services. Without enabling conditions, such as agroecological training, legal recognition of customary systems, and participatory planning, these adaptations remain fragmented. De Boon et al. (2024) argue that effective adaptation requires institutional flexibility and multi-level governance to achieve transformative outcomes.

Beyond exploitative strategies, the Word Tree visualization (Figure 3) illustrates a rich repertoire of collective norms and emerging ecological awareness, expressed through phrases like "mixed farming," "not grazing randomly," and "preserving large trees." These practices, often guided by customary leaders, reveal informal governance structures that regulate behavior and sustain local stewardship.

Field data identified three adaptation typologies (Table 4 and Figure 3): (i) Collective community-based adaptation, marked by shared norms and locally enforced stewardship (Bennett et al. 2018; Bennett and Satterfield 2018). (ii) Mixed reactive–resilient adaptation, encompassing short-term diversification and shifting cultivation with limited coordination (Alem et al. 2023; Behera and Rout 2025). (iii) Individual exploitative adaptation, characterized by monoculture intensification and open-access resource extraction driven by immediate need (Byerlee et al. 2014; Juniyanti et al. 2021).

The three adaptation pathways, collective stewardship, mixed reactive–survival, and individual exploitative strategies, should be understood as descriptive typologies derived from participants' narratives rather than prescriptive models of "good" or "bad" behavior. Each pathway reflects how households navigate specific combinations of tenure conditions, livelihood constraints, and governance relations at the forest edge. The analysis, therefore, focuses on differences in coordination, risk exposure, and land-use logic, rather than ranking strategies in terms of environmental desirability. As Berkes and Folke (1998) note, such local responses embody accumulated ecological knowledge and resilience. They represent grassroots expressions of what Adger et al. (2005) define as social resilience, the capacity to reorganize and persist amid change. Moreover, these community-driven responses illustrate socio-ecological innovation that often compensates for the absence of formal institutional support (Nordberg et al. 2020; Gupta et al. 2022; Shemshad et al. 2025). Strengthening such endogenous practices is therefore essential for designing adaptive co-management systems that are both ecologically sustainable and socially legitimate. Recognizing the plurality of adaptation pathways available to forest-edge communities is vital. Rather than dismissing these as informal or marginal, they should serve as entry points for co-developing community-based interventions that align with local realities and enhance long-term sustainability.

The findings suggest that encroachment in Mount Silanu reflects institutional misalignment rather than simple rule-breaking. Differentiated adaptation pathways highlight tenure as a central governance pivot, the need to reconceptualize participation as co-production of norms, and the importance of adaptive governance that can respond to dynamic forest-edge conditions. The case, therefore, advances social forestry theory by showing that effective governance depends on aligning formal rules with local livelihoods, tenure realities, and evolving socio-ecological interactions.

The Mount Silanu findings have direct implications for forest management and social forestry policy in Indonesia. First, they underscore that forest management effectiveness depends less on stricter enforcement and more on tenure clarity. Ambiguous boundaries between HKm areas and protected forest zones generate persistent pressures, even where communities show willingness to cooperate. Strengthening tenure mediation, through clearer boundary delineation, participatory mapping, and conflict-resolution mechanisms, should therefore be a priority in forest-edge landscapes.

Table 4. Indicative typology of community adaptation strategies based on thematic coding of local responses to forest degradation

Typology of adaptation strategies	Strategy characteristics	Supporting social structure	Adaptation orientation
Collective Community-Based Adaptation	Mixed cropping, controlled grazing on designated land	Deliberation, active farmer groups, involvement of customary leaders, and informal consensus	Collective, preventive, grounded in local norms
Mixed Reactive-Survival Adaptation	Diversification of forest products, shifting cultivation, and seasonal mobility	Loose group structures, household-dominated decision-making	Reactive, responsive to local stressors
Individual Exploitative Adaptation	Monoculture intensification, land expansion without agreement, and open-access resource extraction	Weak social coordination, strong individual influence	Individual, short-term oriented, ecologically high-risk

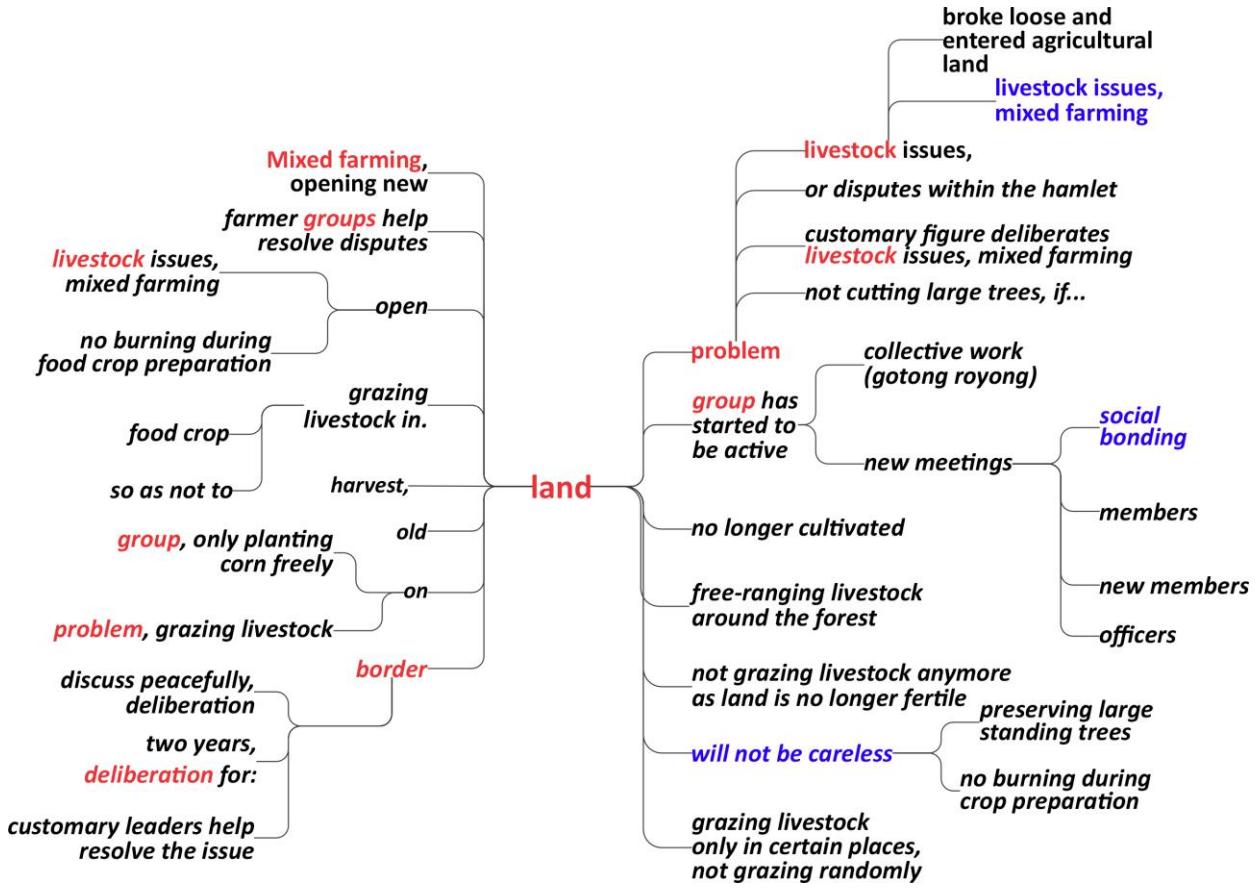

Figure 3. Word tree visualization of keywords reflecting local survival strategies and adaptive practices among forest-edge communities

Second, the differentiated adaptation pathways suggest that one-size-fits-all management prescriptions are unlikely to work. Households engage with forests in diverse ways depending on their risk exposure, coordination capacity, and livelihood options. Forest agencies should therefore adopt context-sensitive management approaches that recognize multiple legitimate livelihood strategies rather than treating all encroachment as uniform illegality.

Third, the results support a shift from compliance-centered governance toward co-management arrangements in which communities, HKm groups, and state actors jointly negotiate rules for grazing, burning, and land use at the forest margin. Such arrangements can align local practices with conservation objectives while maintaining livelihood viability.

Finally, the recursive interactions among Drivers, Pressures, State, Impacts, and Responses highlight the need for adaptive forest governance, including iterative learning, joint monitoring of ecological conditions and livelihood outcomes, and flexible rule adjustment, rather than static boundary-based regulation.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the research adopts a qualitative, single-case design centered on three villages in Mount Silanu; consequently, the results

are not intended for statistical generalization to all forest-edge communities in Indonesia. Instead, the study offers analytically transferable insights that are most relevant to contexts with similar institutional configurations (e.g., HKm–protected forest interfaces) and livelihood conditions. Second, ecological "State" and associated impacts are based entirely on community perceptions and lived experience, not on remote sensing or biophysical measurements of forest change. While these perceptions provide valuable insight into how people interpret environmental change, they do not constitute quantified assessments of degradation or biodiversity loss. Third, the use of a combination of purposive and convenience sampling may have favored more accessible or socially connected participants, potentially underrepresenting more marginalized groups within the villages. As a result, the findings should be understood as context-specific patterns rather than comprehensive representations of all households in the study area.

In conclusion, this study examined forest encroachment dynamics in Mount Silanu through the DPSIR framework, drawing on interview and focus group data analyzed using NVivo-assisted thematic analysis. Based on qualitative evidence from 32 interviews and focus group discussions across three forest-edge villages, a total of 116 open codes were synthesized into 20 secondary thematic categories, which were subsequently reclassified into the five DPSIR components. These results show that forest encroachment is driven primarily by socio-economic inequality (6 coded nodes), historical dependence on forest resources (6 nodes), weak land tenure security (5 nodes), limited access to extension services (5 nodes), and lack of livelihood alternatives (4 nodes). These drivers translate into direct pressures dominated by agricultural and livestock land encroachment (7 nodes), unauthorized forest product extraction (6 nodes), uncontrolled grazing (5 nodes), and monoculture intensification and open-access land use (6 nodes). Communities consistently perceived ecological state changes characterized by declining tree cover (6 nodes), landscape fragmentation (6 nodes), and declining biodiversity (5 nodes). These changes were associated with tangible impacts, including increased vulnerability to environmental hazards (6 nodes) and escalating boundary-related social conflicts (6 nodes).

In response, communities exhibited three dominant adaptation pathways: (i) individual exploitative strategies characterized by reactive intensification and open-access resource use; (ii) mixed reactive–resilient strategies combining short-term diversification with limited coordination; and (iii) collective community-based adaptations grounded in shared norms and localized stewardship. These pathways varied in frequency and coordination across villages, reflecting differing capacities for collective action and access to institutional support.

Based on these findings, site-specific implications for Mount Silanu include the need to clarify forest and village boundaries, strengthen locally accessible extension services focused on agroecological practices, and recognize existing community-based stewardship norms within formal co-management arrangements. Such measures directly address the structural drivers and pressures identified by respondents and build on locally observed adaptation practices, rather than imposing externally defined solutions. This study is limited by its context-specific focus on three villages and its reliance on qualitative, perception-based data, which does not allow statistical generalization or direct ecological measurement. Future research should integrate longitudinal designs, spatial or remote-sensing data, and quantitative ecological indicators to assess the long-term impacts of identified encroachment pressures and adaptation strategies. Comparative studies across multiple forest-edge regions would further strengthen understanding of how governance arrangements and livelihood diversification influence forest outcomes at broader scales.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Local Government of Jeneponto District, Indonesia, and the Forestry Service of South Sulawesi Province, along with the relevant local authorities, for providing field access and coordination support. Sincere thanks are also extended to the Faculty of Forestry, Universitas Hasanuddin, South Sulawesi, for their logistical assistance and institutional support. This research was approved by the Ethical Clearance Board of Universitas Hasanuddin (Approval No. 2350/UN4.14.1/TP.01.02/2025).

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