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INSTITUTIONAL RECLASSIFICATION AND FOREST RECOVERY TRAJECTORIES IN A TROPICAL PROTECTED AREA: EVIDENCE FROM GUNUNG HALIMUN SALAK NATIONAL PARK INDONESIA

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Abstract

Protected areas are widely recognized as key instruments for biodiversity conservation and forest protection; however, the long-term ecological outcomes of institutional changes in protected area management remain insufficiently understood. This study evaluated land-cover dynamics in Gunung Halimun Salak National Park (TNGHS), Indonesia, following major institutional transformations associated with park expansion and boundary reclassification. Land-cover datasets for 2003, 2009, 2014, 2019, and 2024 obtained from the Indonesian Ministry of Forestry were analyzed using Geographic Information Systems (GIS), transition matrices, and intensity analysis. Land-cover transitions were decomposed into persistence, gains, losses, net change, and swap components to identify underlying landscape dynamics beyond conventional net-change assessments. The results revealed a positive long-term trajectory of forest recovery. Forest cover increased from 67,100 ha (76.5%) in 2003 to 73,078 ha (83.3%) in 2024, resulting in a net forest gain of approximately 5,978 ha. Secondary forest exhibited the largest expansion, largely through transitions from plantation forests and agricultural land. Transition analysis indicated that forest gains (9,113 ha) substantially exceeded forest losses (3,135 ha). However, a considerable swap component (6,270 ha) demonstrated that forest recovery and forest loss occurred simultaneously in different locations, indicating ongoing spatial redistribution of land-cover change within the park. These findings suggest that institutional reclassification and conservation-oriented management have contributed to forest recovery in TNGHS, supporting the Forest Transition Theory and evidence on protected area effectiveness. The study demonstrates that transition-based approaches provide a more comprehensive assessment of conservation outcomes than net-change statistics alone and underscores the importance of governance capacity, tenure certainty, and long-term monitoring in sustaining forest recovery within tropical protected areas

Keywords: Forest Transition; Institutional Change; Land-Cover Change; Protected Area Effectiveness; Transition Matrix

INTRODUCTION

Protected areas are widely recognized as one of the most important policy instruments for biodiversity conservation and ecosystem service maintenance. Globally, the expansion of protected-area networks has become a central strategy for reducing biodiversity loss, maintaining ecosystem functions, and supporting climate-change mitigation efforts (Eklund and Cabeza, 2017; Joppa and Pfaff, 2010). Nevertheless, the effectiveness of protected areas in preventing forest loss and promoting ecosystem recovery remains highly variable across regions, particularly in tropical countries where conservation landscapes frequently overlap with long-established human land-use systems. Increasing evidence suggests that legal protection alone does not automatically guarantee positive conservation outcomes because land-cover dynamics are influenced by complex interactions among governance arrangements, tenure systems, socio-economic pressures, and biophysical conditions (Eklund and Cabeza, 2017). Indonesia has experienced substantial forest-cover change during recent decades as a result of agricultural expansion, infrastructure development, population growth, and competing land-use interests. In response, the government has expanded and reclassified numerous protected areas to strengthen biodiversity conservation and ecosystem management. However, empirical evidence regarding the long-term ecological consequences of such institutional changes remains limited. While many studies have documented patterns of deforestation and forest recovery, fewer studies have explicitly examined how changes in conservation governance influence long-term landscape trajectories. Understanding this relationship is important because the effectiveness of conservation interventions depends not only on formal designation but also on governance quality, management effectiveness, and the capacity to address anthropogenic pressures (Eklund and Cabeza, 2017; Joppa and Pfaff, 2010). Gunung Halimun Salak National Park (TNGHS) provides an important case for examining the ecological consequences of institutional change in a tropical conservation landscape. As the largest remaining montane rainforest ecosystem on Java Island, TNGHS functions as a biodiversity refuge, a critical watershed, and an important provider of ecosystem services for surrounding communities. Since its establishment, the park has undergone several major institutional transformations. Initially designated as a national park covering approximately 40,000 ha in 1992, the area was substantially expanded in 2003 through the incorporation of former production and protection forests, increasing its extent to approximately 113,357 ha. Subsequently, the park boundary was revised in 2016, resulting in a legally recognized area of approximately 87,699 ha.

These successive changes altered not only administrative boundaries but also management objectives, governance arrangements, and patterns of resource access across the landscape. Previous studies in TNGHS have primarily focused on conservation governance, land-tenure conflicts, community access, and institutional arrangements associated with protected-area management. These studies have demonstrated that the transition from production-oriented forest management to conservation-based management generated complex interactions among local communities, government agencies, and conservation objectives. However, despite extensive discussion of governance challenges, empirical assessments linking institutional changes to long-term land-cover outcomes remain scarce. Existing research has rarely evaluated whether conservation reclassification has been associated with forest recovery, continued land-use pressure, or spatial redistribution of land-cover change within the park landscape. Furthermore, many studies assessing conservation effectiveness rely primarily on net-change statistics, which may obscure the underlying processes driving landscape transformation. Similar levels of net forest gain may emerge from fundamentally different dynamics, including widespread forest regeneration, localized forest loss, or simultaneous gains and losses occurring in different locations. Recent advances in land-change science emphasize the importance of transition-based approaches that distinguish persistence, gains, losses, and spatial swaps in order to better understand the mechanisms underlying landscape change (Pontius et al., 2004; Aldwaik and Pontius, 2012). This study addresses these knowledge gaps by examining land-cover dynamics within TNGHS during the period 2003–2024 using a transition matrix framework that decomposes land-cover change into persistence, gains, losses, net change, and swap components. Specifically, this study aims to: (1) quantify long-term land-cover dynamics in TNGHS between 2003 and 2024; (2) identify dominant land-cover transitions and distinguish between persistence, gains, losses, and spatial swaps; and (3) evaluate the implications of these dynamics for conservation management and protected-area governance.

METHOD

Study Area

This study was conducted in Gunung Halimun Salak National Park (TNGHS), located in West Java and Banten Provinces, Indonesia. The park extends across Bogor and Sukabumi Regencies in West Java Province and Lebak Regency in Banten Province. TNGHS represents the largest remaining montane tropical rainforest landscape on Java Island and constitutes an important biodiversity conservation area as well as a critical watershed supplying ecosystem services to densely populated downstream regions. The analysis employed the legally recognized park boundary established under Ministerial Decree No. SK.327/Menlhk/Setjen/PLA.2/4/2016, covering approximately 87,699 ha (Figure 1). Applying a consistent boundary across all observation years ensured comparability of land-cover conditions and minimized bias associated with administrative boundary changes.

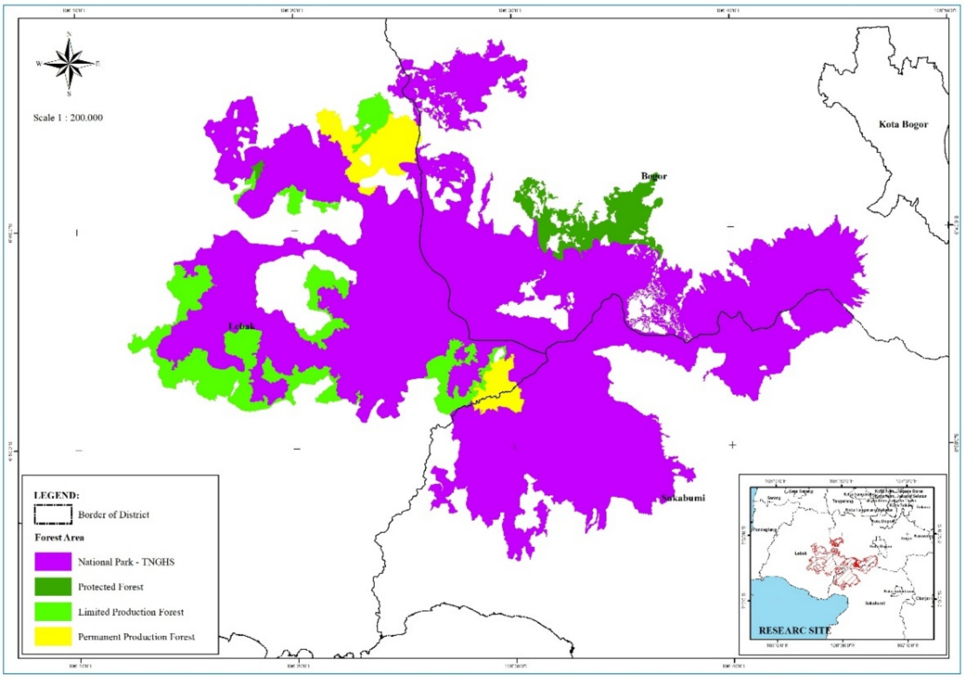

Figure 1. Study area of Gunung Halimun Salak National Park (TNGHS) based on Decree SK.327/2016

Land-Cover Data

Land-cover data were obtained from the Directorate of Forest Resource Inventory and Monitoring (IPSDH), Ministry of Forestry, Indonesia, for five observation years: 2003, 2009, 2014, 2019, and 2024. These datasets represent official national land-cover inventories derived primarily from Landsat satellite imagery through visual interpretation and standardized national classification procedures. The year 2003 was selected as the baseline because it coincided with the major expansion of TNGHS, while 2024 represents the most recent available condition. For analytical purposes, individual classes were aggregated into forest and non-forest categories; forest categories included primary dryland forest, secondary dryland forest, and plantation forest, whereas all remaining categories were classified as non-forest.

Land-Cover Transition and Intensity Analysis

All spatial datasets were projected into a common coordinate reference system and clipped to the 2016 TNGHS boundary before analysis using Geographic Information System (GIS) techniques. Land-cover transition matrices were developed by cross-tabulating land-cover categories between 2003 and 2024. Following Pontius et al. (2004), five components were quantified: persistence (P), gain (G), loss (L), net change (NC), and swap change (SC), where swap change was calculated as $SC = 2 \times \min(G, L)$. This decomposition distinguishes genuine expansion or contraction of a class from spatial redistribution that remains hidden when only net change is considered. To determine whether transitions occurred systematically or randomly, intensity analysis was applied following Aldwaik and Pontius (2012) at the interval, category, and transition levels.

Limitations and Uncertainty

This study relied on official land-cover datasets produced through national monitoring programs; consequently, classification accuracy depended on the interpretation procedures and quality-control protocols of the Ministry of Forestry rather than independent classification by the authors. Potential uncertainties may arise from differences in image quality, interpretation consistency, and temporal intervals among observation years. Therefore, the results should be interpreted primarily as indicators of broad landscape trajectories rather than precise measurements of ecological processes at individual sites.

RESULTS AND DISCUSSION

Temporal Dynamics of Forest and Non-Forest Cover

Forest cover within TNGHS increased from 67,100 ha (76.51%) in 2003 to 73,078 ha (83.33%) in 2024 (Table 1; Figure 2). The increase was not linear: forest cover declined slightly during 2003–2009 (from 76.51% to 75.91%), remained relatively stable in 2014 (76.09%), and subsequently increased to 78.94% in 2019 and 83.33% in 2024. In contrast, non-forest cover decreased from 20,598 ha (23.49%) to 14,620 ha (16.67%), yielding a net forest gain of 5,978 ha over the 21-year period.

Table 1. Area and proportion of forest and non-forest cover in TNGHS, 2003–2024

Year	Forest (ha)	Forest (%)	Non-Forest (ha)	Non-Forest (%)
2003	67,099.9	76.51	20,598	23.49
2009	66,570	75.91	21,127.9	24.09
2014	66,732.8	76.09	20,965.1	23.91
2019	69,231.2	78.94	18,466.7	21.06
2024	73,077.8	83.33	14,620	16.67

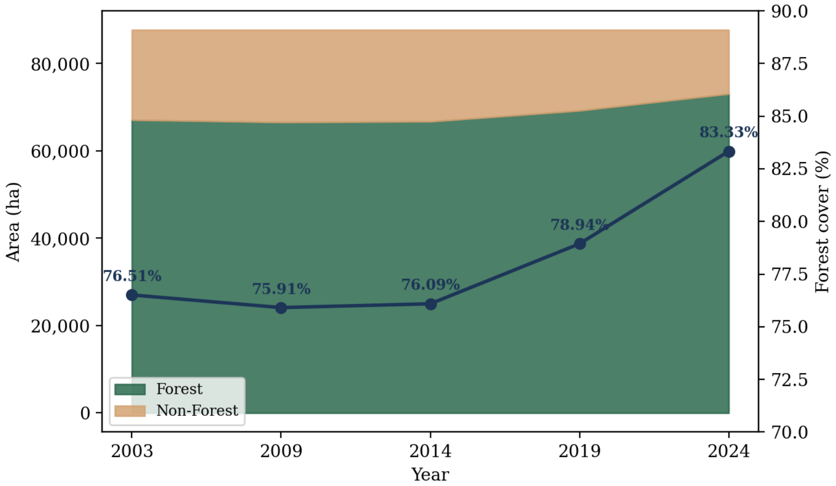

Figure 2. Trends in forest and non-forest area and forest cover percentage in TNGHS, 2003–2024

Changes in Land-Cover Composition

Changes in land-cover composition varied considerably among classes (Figure 3). Secondary dryland forest exhibited the largest increase, expanding from 48,431 ha in 2003 to 57,174 ha in 2024, while plantation forest decreased from 16,096 ha to 13,409 ha. Among non-forest classes, paddy fields decreased substantially from 5,272 ha to 1,832 ha and shrubland declined from 3,424 ha to 406 ha, whereas plantation areas increased from 1,146 ha to 2,305 ha. Agricultural land also showed substantial transitions toward forest categories.

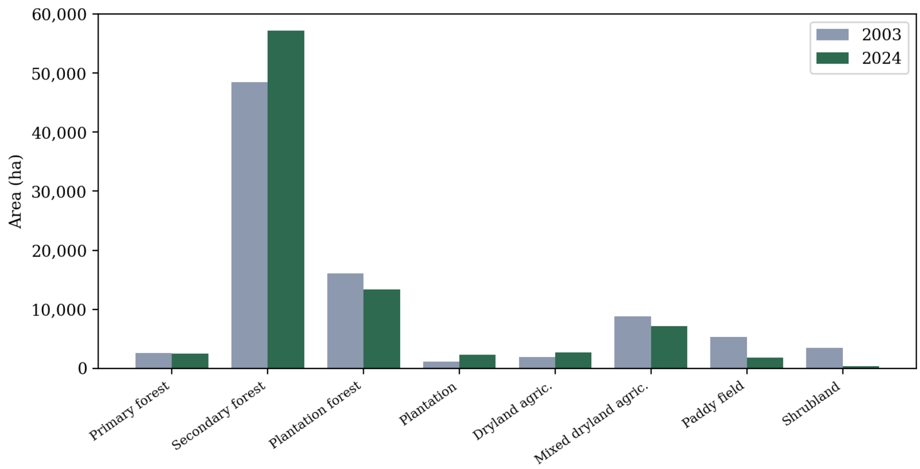

Figure 3. Comparison of major land-cover class areas in TNGHS, 2003 and 2024

Land-Cover Transition Dynamics

The transition matrix revealed substantial land-cover dynamics despite the overall increase in forest cover (Table 2). Approximately 63,917 ha (72.9%) remained in the same category (persistence), whereas 23,781 ha (27.1%) experienced class transitions. At the aggregated forest–non-forest level, forest classes gained 9,113 ha from non-forest categories and lost 3,135 ha to non-forest categories, resulting in a net gain of 5,978 ha. The swap component reached 6,270 ha, indicating substantial simultaneous gains and losses occurring in different locations. The largest individual transition was from plantation forest to secondary dryland forest (approximately 5,100 ha), followed by conversions from agricultural land and paddy fields to secondary forest.

Table 2. Land-cover transition matrix of TNGHS, 2003 (rows) → 2024 (columns), in hectares

2003 ↓ / 2024 →	Prim. for.	Sec. for.	Plant. for.	Plantation	Agric.	Paddy	Shrub/Other
Prim. for.	2,492	9	0	0	64	7	0
Sec. for.	0	47,121	658	26	373	92	160
Plant. for.	0	5,100	8,584	23	2,026	150	214
Plantation	0	135	73	593	343	0	1
Agric.	2	2,609	2,900	988	3,847	258	57
Paddy	0	656	811	19	2,413	1,246	127
Shrub/Other	0	1,545	382	657	823	79	34

Note: shaded diagonal cells denote persistence (areas remaining in the same class).

Spatial Distribution of Forest Recovery

Forest-cover gains occurred across all administrative regions within TNGHS (Table 3). The largest increase was observed in Bogor Regency (+3,702 ha), followed by Lebak Regency (+1,524 ha) and Sukabumi Regency (+751 ha). Spatial distribution maps indicate that forest recovery was concentrated primarily within former plantation forest areas and selected agricultural mosaics, whereas forest loss remained localized and scattered throughout the landscape (Figures 4–6).

Table 3. Change in forest cover area in TNGHS by regency, 2003–2024

Regency	Forest 2003 (ha)	Forest 2024 (ha)	Change (ha)
Bogor	20,838.3	24,540.5	+3,702.2
Lebak	24,397.9	25,922.2	+1,524.3
Sukabumi	21,863.7	22,615.1	+751.4

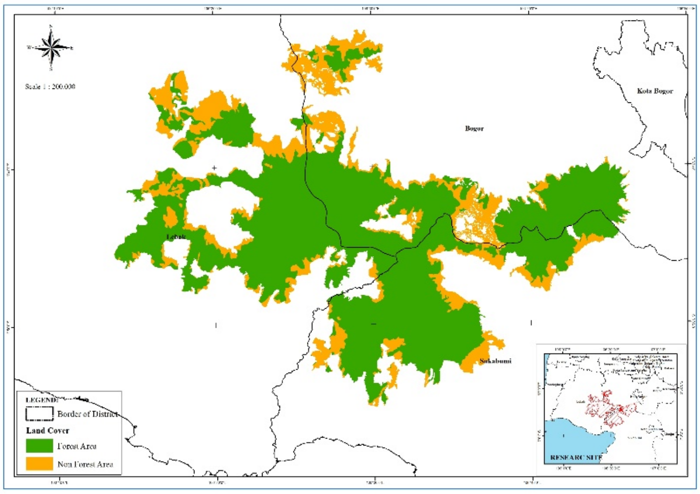

Figure 4. Land-cover map of TNGHS in 2003

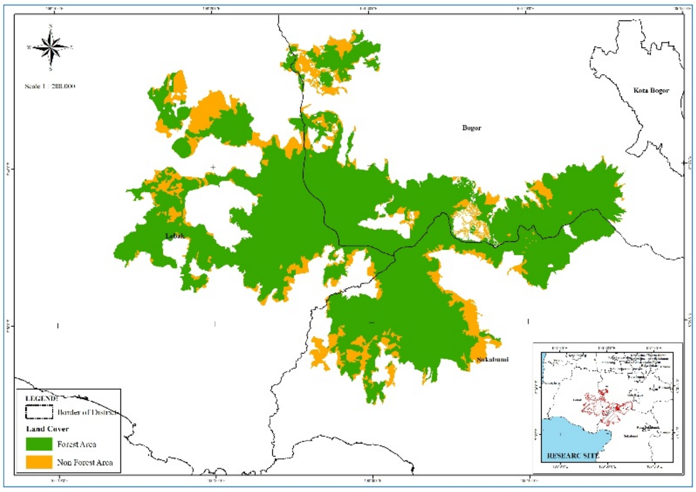

Figure 5. Land-cover map of TNGHS in 2024

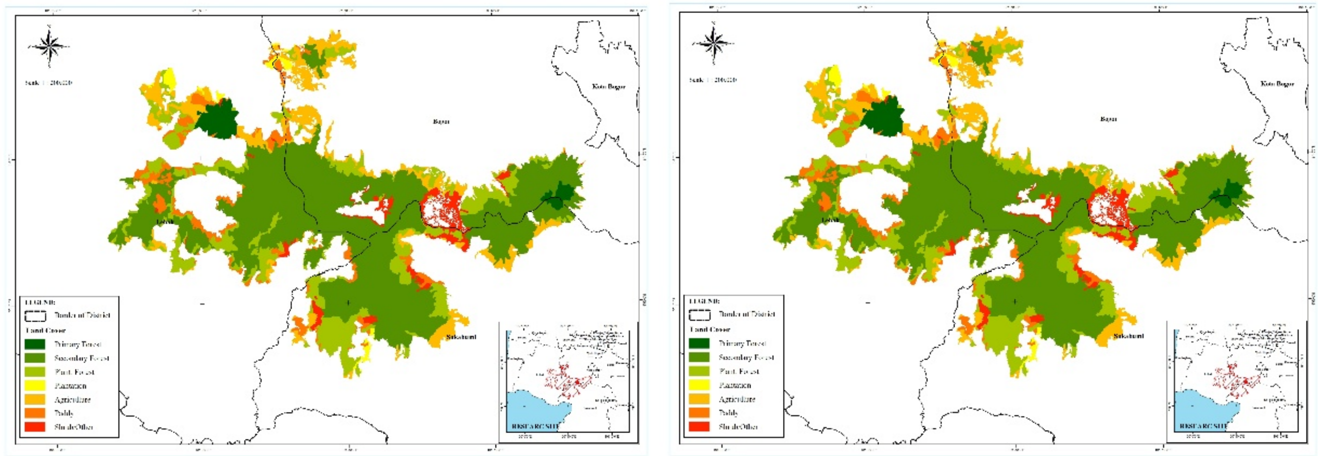

Figure 6. Land-cover change map of TNGHS, 2003–2024

Forest Recovery and the Effectiveness of Protected Areas

The observed increase in forest cover from 76.5% in 2003 to 83.3% in 2024 indicates a positive long-term trajectory of forest recovery within TNGHS following major institutional changes. This finding is broadly consistent with the protected-area effectiveness framework, which argues that protected areas can reduce deforestation and facilitate ecosystem recovery when legal protection is accompanied by effective governance and management interventions (Joppa and Pfaff, 2010; Geldmann et al., 2019). The substantial increase in secondary forest indicates ongoing successional processes within previously disturbed landscapes, similar to recovery trajectories reported in other tropical protected areas where strengthened management reduced anthropogenic disturbance (Nelson and Chomitz, 2011). Nevertheless, protected-area effectiveness should not be interpreted solely through net forest gains, as conservation outcomes also depend on governance quality, enforcement capacity, and local compliance (Eklund and Cabeza, 2017).

Evidence of Forest Transition Following Institutional Reclassification

The substantial expansion of secondary forest and the decline of several non-forest classes suggest that TNGHS has experienced a process consistent with Forest Transition Theory, whereby landscapes shift from net forest loss to net recovery as institutional arrangements and land-use systems evolve (Mather, 1992; Rudel et al., 2005). Historically, large portions of the expanded area were managed under production-oriented systems; following reclassification and stricter conservation management, the trajectory shifted toward increasing forest cover through natural regeneration and succession. However, the dominance of secondary rather than mature forest indicates that ecological recovery is still underway, representing an early-to-intermediate stage rather than full ecosystem restoration (Chazdon, 2014).

Simultaneous Recovery and Ongoing Land-Use Pressure

Although net forest cover increased substantially, transition analysis revealed considerable swap dynamics, indicating that forest gains and losses occurred simultaneously in different locations. From a land sparing perspective (Phalan et al., 2011), conservation benefits appear concentrated in specific areas while land-use pressures persist elsewhere. The relatively large swap component highlights the limitations of relying solely on net-change indicators: had only net forest gain been considered, localized forest losses and continuing pressures would have remained largely invisible. Transition-based approaches therefore provide a more nuanced assessment by revealing the coexistence of recovery and degradation within the same protected area.

Institutional Change and Implications for Management

The findings provide empirical support for Institutional Change Theory, which argues that changes in formal institutions alter resource-use behavior and environmental outcomes by modifying rules, incentives, and governance structures (North, 1990; Ostrom, 2009). The reclassification of former production forests into a national park changed management objectives from extraction toward conservation, likely contributing to the observed increase in forest cover. However, formal policy changes do not automatically generate desired outcomes; their effectiveness depends on implementation capacity, legitimacy, and stakeholder acceptance (Oldekop et al., 2016; Sahide et al., 2019). The persistence of localized forest loss suggests that strengthening boundary governance, resolving tenure conflicts, and enhancing collaboration with local communities are as important as maintaining formal legal protection.

CONCLUSION

Land-cover dynamics within TNGHS during 2003–2024 were characterized by an overall trajectory of forest recovery following major institutional changes in park management and boundary designation. Forest cover increased substantially, primarily through the expansion of secondary forest and the transition of former plantation and agricultural areas toward forested classes. However, transition matrix analysis revealed that the recovery was accompanied by continuing land-use dynamics: while forest gains (9,113 ha) exceeded losses (3,135 ha), a considerable swap component (6,270 ha) indicated that recovery and pressure coexisted within the park. These findings demonstrate that net forest gain alone does not fully capture landscape dynamics and may obscure localized degradation. The study underscores the importance of strengthening protected-area governance, improving boundary certainty, and enhancing long-term monitoring capable of detecting both forest recovery and forest loss. Future research should integrate landscape metrics, field verification, and spatially explicit analyses of biophysical and socio-institutional drivers.

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