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LONG-TERM DYNAMICS OF TROPICAL RAINFOREST LAND COVER IN LAWE GURAH RESORT, GUNUNG LEUSER NATIONAL PARK, 1990–2024

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Abstract

Long-term land-cover records are essential for evaluating ecological change at the operational scale of protected-area management. This study quantified land-cover dynamics in Lawe Gurah Resort, Gunung Leuser National Park, using nine harmonized GIS layers for 1990, 1996, 2000, 2006, 2011, 2016, 2021, 2023, and 2024. Area, percentage, absolute change, and mean annual change were calculated for each mapped class. Primary dryland forest declined from 51,349.34 ha in 1990 to 37,944.04 ha in 2024, a reduction of 13,405.30 ha (26.11%; 394.27 ha yr−1). Secondary dryland forest increased from 980.99 to 12,281.11 ha, while combined primary and secondary forest decreased more moderately from 52,330.33 to 50,225.15 ha (4.02%). Forest share therefore fell from 97.11% to 93.25%. Shrubland doubled to 1,654.67 ha, and mixed dryland agriculture reached 1,531.54 ha after first appearing in 2011. The results show a substantial shift in forest composition alongside a smaller net contraction of total forest. Management should prioritize recurrent mapping, field verification, and targeted surveillance of areas where secondary forest, shrubland, and mixed agriculture have expanded.

Keywords: conservation management; forest composition; GIS; land-cover change; protected area

INTRODUCTION

Tropical-forest protected areas are expected to retain habitat connectivity, hydrological functions, carbon storage, and biodiversity, yet their internal land-cover composition can change even when the administrative boundary remains fixed. Long time-series mapping is therefore more informative than a single-date inventory because it distinguishes persistent conditions from short-lived or recurrent changes. Landsat-era archives and modern geographic information systems (GIS) now support multi-decadal land-cover monitoring at increasingly fine spatial and temporal resolutions (Potapov et al., 2020; Song, 2023; Zhang et al., 2024).

Gunung Leuser National Park forms a central part of the Leuser Ecosystem in northern Sumatra. The landscape supports globally important populations of Sumatran megafauna and requires large, connected forest areas to sustain species occupancy and recovery (Lubis et al., 2023). Regional evidence indicates that protected status slows tropical-rainforest disturbance, but does not eliminate it (Condro et al., 2022). Within the national park, fire, access, and subsequent land-use expansion have also been associated with localized increases in non-forest cover (Thoha et al., 2022). These findings make management-unit-scale monitoring necessary, because broad park-level statistics can conceal where and when changes occur.

Lawe Gurah Resort is an operational management unit in the southeastern part of the park, in Aceh Tenggara Regency. The thesis dataset assembled for this area contains land-cover maps for nine observation years spanning 34 years. Initial inspection showed a decline in mapped primary dryland forest, an increase in secondary dryland forest, and the later appearance of mixed dryland agriculture, settlement, and water-body classes. The size and timing of these shifts have not previously been synthesized in a journal-format analysis at the resort scale.

This study therefore aimed to: (1) quantify the area and proportional composition of mapped land-cover classes from 1990 to 2024; (2) identify the long-term and interval-specific direction of change in the principal forest and non-forest classes; and (3) translate the observed patterns into cautious, evidence-based priorities for monitoring and conservation management. The analysis emphasizes what can be supported by the available area statistics and avoids treating aggregate class changes as proof of pixel-level conversion.

LITERATURE REVIEW

Land-cover change detection generally combines temporally comparable imagery or classified layers with spatial standardization, accuracy assessment, and post-classification comparison. Reviews of recent methods show rapid development in algorithms and data density, but also stress that apparent change may arise from class-definition differences, spectral confusion, geometric mismatch, or unequal validation quality (Cheng et al., 2024). Good-practice guidance therefore requires area estimates and accuracy evidence to be interpreted together, particularly when maps from several dates are compared (Olofsson et al., 2014).

For protected areas, the ecological meaning of a mapped class is as important as its area. A shift from primary to secondary forest may reflect disturbance, regeneration, or differences in image interpretation; shrubland and open land can represent either degradation stages or recovery pathways depending on spatial context. Land-cover changes can alter ecosystem-service values and watershed condition (Muche et al., 2023; Rahmawaty et al., 2022), while fragmentation can reduce connectivity even when total forest area remains high (Gunawan et al., 2024). Consequently, area trends should be used as an early-warning layer and followed by transition analysis, field verification, and landscape metrics.

The contribution of this study is contextual and operational rather than algorithmic. It uses nine observation dates—more than a simple start–end comparison—to reveal phase changes at a resort management scale. This scale is relevant for patrol planning, rehabilitation, and local engagement, while the long series enables unusually large class oscillations to be recognized and reported as a data-quality issue rather than converted directly into ecological claims.

METHOD

Study area and analytical dataset

The study was conducted in Lawe Gurah Resort, a management unit of Gunung Leuser National Park in Aceh Tenggara Regency, Aceh Province, Indonesia (Figure 1). The mapped resort extends over approximately 53,860–53,888 ha across the annual layers. The location is predominantly mountainous tropical forest and is positioned near settlements and access corridors on the eastern side of the park.

The analytical dataset comprised nine pre-existing land-cover layers and their attribute-area tables for 1990, 1996, 2000, 2006, 2011, 2016, 2021, 2023, and 2024. The thesis workflow standardized coordinate reference, spatial extent, attribute structure, and class nomenclature before clipping all layers to the resort boundary. Eleven classes occurred in at least one year: primary dryland forest, secondary dryland forest, shrubland, open land, dryland agriculture, mixed dryland agriculture, plantation, planted forest, savanna/grassland, water body, and settlement. A value of zero indicates that a class was not identified in that year's mapped layer; it should not automatically be interpreted as confirmed ecological absence.

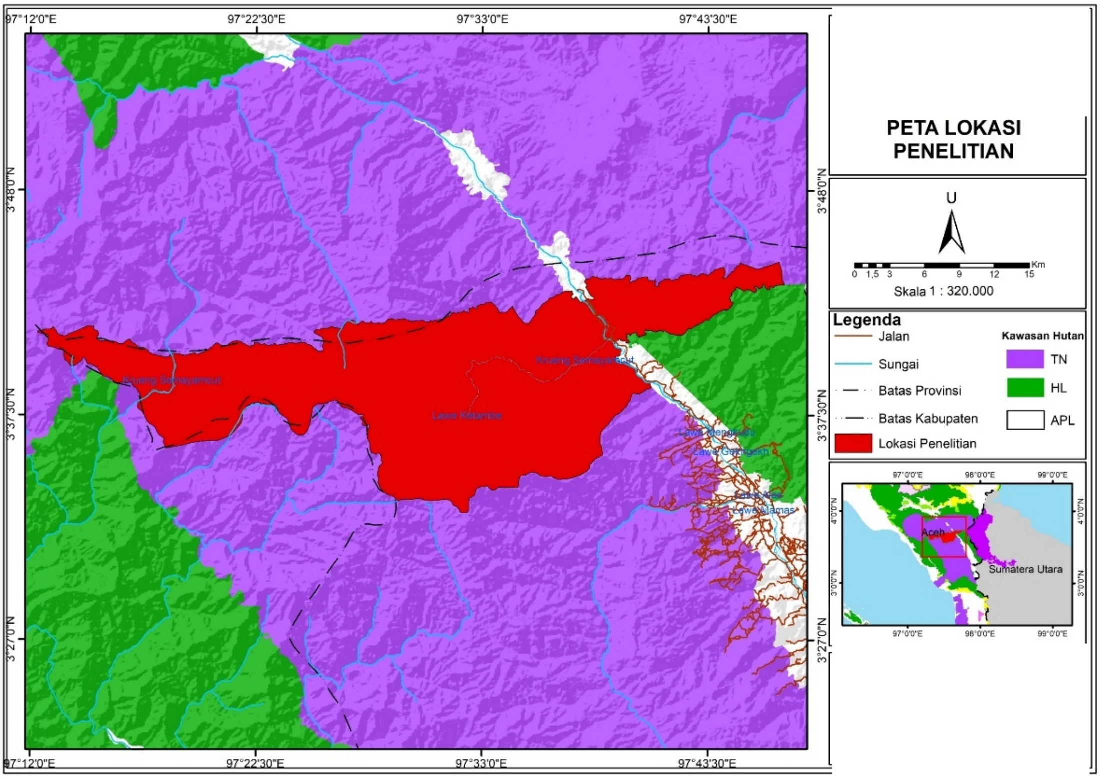

Figure 1. Location of Lawe Gurah Resort within Gunung Leuser National Park and northern Sumatra.

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Area-based change analysis

For each year, class area was summarized in hectares and divided by the corresponding mapped total to calculate percentage composition. Long-term absolute change was calculated as the 2024 area minus the 1990 area, and mean annual absolute change was calculated over the 34-year interval. Combined forest was defined as the sum of primary and secondary dryland forest. The principal calculations were:

$$P_i = (A_i / A_t) \times 100\% \tag{1}$$

$$L_i = (A_{i,2} - A_{i,1}) / (t_2 - t_1) \tag{2}$$

where P_i is the percentage of class i, A_i is its area, A_t is the mapped total, and L_i is mean annual absolute change. Annual mapped totals differed by only 28.34 ha between the maximum and minimum layers (0.053% of the 1990 total), so the original annual totals were retained rather than forced to a single value.

Interpretive safeguards

The available thesis results contained class-area statistics and maps, but not the completed pixel-level transition matrices, independent validation samples, or classification-accuracy values described in the broader research plan. This article therefore reports compositional and temporal patterns rather than asserting direct conversion from one class to another. Abrupt reciprocal changes between primary and secondary forest were treated as signals requiring spatial overlay and validation, consistent with recommended change-detection and accuracy-assessment practice (Olofsson et al., 2014; Cheng et al., 2024).

RESULTS AND DISCUSSION

Temporal pattern of the principal classes

Primary dryland forest dominated every mapped year, but its trajectory was not monotonic. The class was essentially stable at about 51,349–51,351 ha from 1990 to 2006 and remained similar in 2011 (51,340.53 ha). It then fell to 42,784.18 ha in 2016, rose to 49,259.10 ha in 2021, and declined sharply to 37,951.28 ha in 2023 before changing only slightly in 2024. Secondary dryland forest displayed an approximately reciprocal pattern after 2011: 578.96 ha in 2011, 8,618.39 ha in 2016, 1,082.18 ha in 2021, and 12,294.22 ha in 2023. These large alternations are visible in both the maps and the time series (Table 1; Figures 2–3).

Table 1. Principal land-cover areas in Lawe Gurah Resort, 1990–2024 (ha)

Year	Primary forest	Secondary forest	Total forest	Shrubland	Mixed dryland agriculture
1990	51,349.34	980.99	52,330.33	809.73	0.00
1996	51,350.79	981.24	52,332.03	809.73	0.00
2000	51,349.34	981.16	52,330.50	809.73	0.00
2006	51,349.34	981.16	52,330.50	809.73	0.00
2011	51,340.53	578.96	51,919.49	1,052.05	167.07
2016	42,784.18	8,618.39	51,402.57	740.01	352.54
2021	49,259.10	1,082.18	50,341.28	1,194.32	1,446.86
2023	37,951.28	12,294.22	50,245.50	1,645.01	1,531.54
2024	37,944.04	12,281.11	50,225.15	1,654.67	1,531.54

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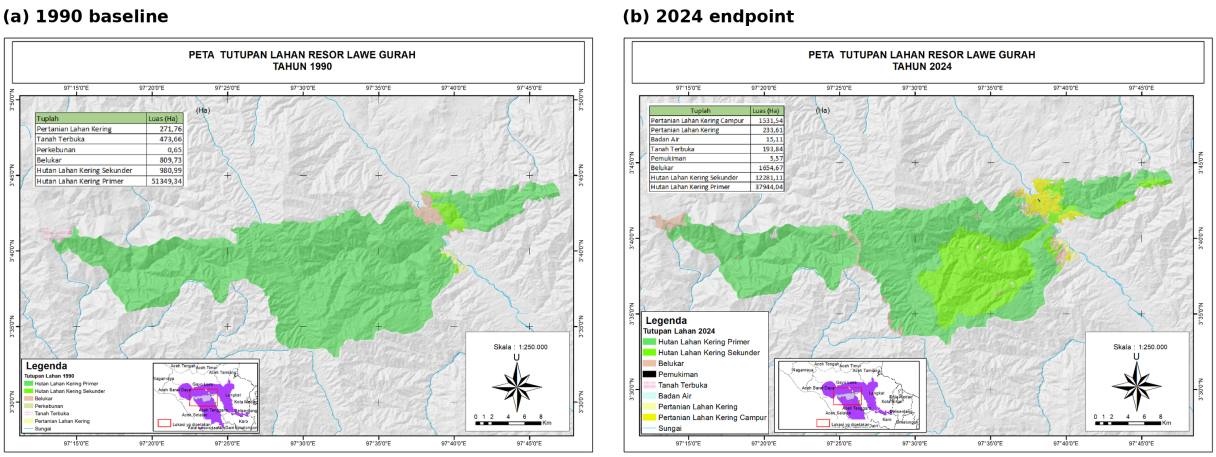

Figure 2. Mapped land-cover composition at the 1990 baseline and 2024 endpoint.

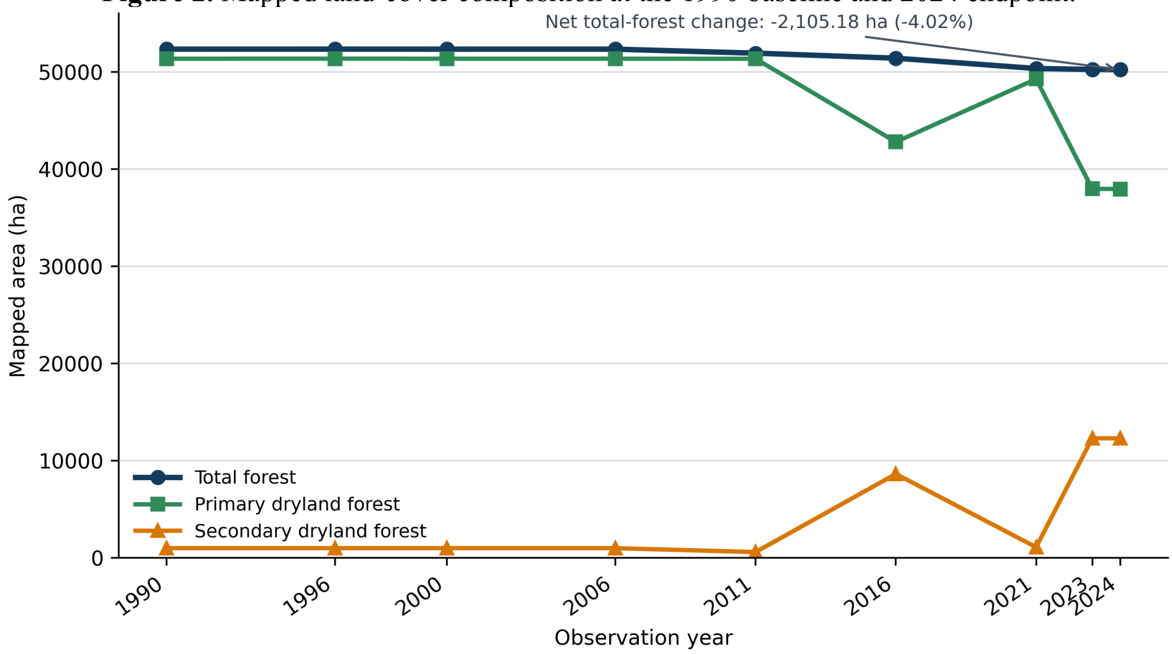

Figure 3. Mapped primary, secondary, and combined forest area across nine observation years.

The combined forest series provides a more stable ecological screening indicator than either forest subclass alone. Total mapped forest declined from 52,330.33 ha in 1990 to 50,225.15 ha in 2024, a net loss of 2,105.18 ha (4.02%) or an average of 61.92 ha yr−1. Its share of the mapped resort fell from 97.11% to 93.25%. Unlike the large primary–secondary oscillations, combined forest decreased in every interval after 1996, reaching 51,919.49 ha in 2011, 51,402.57 ha in 2016, 50,341.28 ha in 2021, and 50,245.50 ha in 2023. The endpoint maps accordingly show that forest remained extensive but was compositionally more heterogeneous in 2024.

Magnitude of long-term change

Table 2. Long-term change in mapped land-cover area, 1990–2024

Class	1990 (ha)	2024 (ha)	Change (ha)	Change (%)	Mean annual change (ha yr−1)
Total forest	52,330.33	50,225.15	-2,105.18	-4.02	-61.92
Primary dryland forest	51,349.34	37,944.04	-13,405.30	-26.11	-394.27
Secondary dryland forest	980.99	12,281.11	+11,300.12	+1151.91	+332.36
Shrubland	809.73	1,654.67	+844.94	+104.35	+24.85
Open land	473.66	193.84	-279.82	-59.08	-8.23
Dryland agriculture	271.76	233.61	-38.15	-14.04	-1.12
Mixed dryland agriculture	0.00	1,531.54	+1,531.54	n.a.	+45.05
Water body	0.00	15.11	+15.11	n.a.	+0.44
Settlement	0.00	5.57	+5.57	n.a.	+0.16

The largest gross subclass change was the 13,405.30-ha decline in primary dryland forest, equivalent to 26.11% of its 1990 area and an average reduction of 394.27 ha yr−1. Secondary dryland forest increased by 11,300.12 ha, or 332.36 ha yr−1. Because these values partly offset within the combined forest series, they indicate a major change in mapped forest composition, but do not by themselves prove that 11,300 ha converted directly from primary to secondary forest. A transition matrix and validation evidence are required for that claim.

Among persistent non-forest classes, shrubland increased from 809.73 to 1,654.67 ha, a gain of 844.94 ha (104.35%). Mixed dryland agriculture was first mapped in 2011 at 167.07 ha, rose to 352.54 ha in 2016 and 1,446.86 ha in 2021, and reached 1,531.54 ha in 2023–2024. Together, shrubland and mixed dryland agriculture occupied 5.91% of the 2024 mapped area. Open land, by contrast, declined by 279.82 ha (59.08%), while dryland agriculture decreased by 38.15 ha. Settlement and water body were each first identified in 2021 and remained small and stable through 2024.

The 2024 composition—70.45% primary forest, 22.80% secondary forest, 3.07% shrubland, and 2.84% mixed dryland agriculture—shows that the resort remained predominantly forested. Nevertheless, a high aggregate forest percentage should not be treated as evidence that ecological condition is unchanged. Indonesian forest-fragmentation research emphasizes that configuration, edge effects, and connectivity can deteriorate without proportionate loss of total forest area (Gunawan et al., 2024). For Sumatra's megafauna, habitat configuration and the spatial distribution of disturbance are directly relevant to recovery planning (Lubis et al., 2023).

Interpretation in the Leuser conservation context

The observed contraction of combined forest and expansion of shrubland and mixed agriculture are consistent with the broader need for continued vigilance inside the Leuser landscape. Protected areas in the ecosystem have been shown to reduce rainforest disturbance relative to comparable unprotected areas, yet residual disturbance remains (Condro et al., 2022). Research in Gunung Leuser National Park has also documented how fire-affected and newly accessible sites can develop into non-forest land uses over time (Thoha et al., 2022). The present area series does not identify drivers, but it indicates where management questions should be tested through patrol records, field checks, and community-level evidence.

Operationally, three priorities emerge. First, the spatial clusters represented as secondary forest in 2016 and 2023 should be overlaid with the preceding maps and verified in the field to distinguish actual structural change from classification inconsistency. Second, sites where shrubland and mixed dryland agriculture recur after 2011 should be screened against access routes, resort patrol findings, tenure history, and restoration records. Local land-use decisions around Gunung Leuser are socially differentiated, so management responses should combine enforcement with locally grounded engagement rather than infer a single driver from mapped cover alone (Prayitno et al., 2025). Third, a repeatable monitoring protocol should retain consistent class definitions, training data, reference samples, and uncertainty reporting across years.

These safeguards are essential because the strongest year-to-year signal in the dataset is not net forest loss but alternating assignment between primary and secondary forest. The pattern may include real degradation and regeneration, but its magnitude also points to inter-date classification sensitivity. Modern long-term products use dense observations, temporal-consistency rules, and large validation samples precisely to suppress false changes (Zhang et al., 2024). Future resort-scale work should therefore pair the existing maps with a pixel-based transition matrix, stratified accuracy assessment, and landscape metrics before estimating conversion pathways or causal impacts.

Study limitations

This article is limited to the maps and area tables available in the thesis dataset. Satellite sensor specifications, image dates, classification algorithm, reference-sample design, class-specific accuracy, and completed transition matrices were not reported in the available results. The analysis therefore supports comparison of mapped composition, not an independent accuracy claim or a causal attribution of change. The small variation in annual mapped total and the intermittent appearance of plantation, planted forest, and savanna classes also indicate that minor classes should be interpreted conservatively. These limitations do not invalidate the documented area series; they define the level of inference that can responsibly be drawn from it.

CONCLUSION

Across nine observation years from 1990 to 2024, Lawe Gurah Resort remained predominantly forested, but its mapped composition changed substantially. Primary dryland forest declined by 13,405.30 ha, secondary dryland forest increased by 11,300.12 ha, and combined forest declined by 2,105.18 ha (4.02%). Shrubland more than doubled, while mixed dryland agriculture expanded to 1,531.54 ha after 2011. The central management implication is therefore not only to prevent further net forest loss, but also to investigate where forest subclasses have shifted and where persistent non-forest classes are expanding. Consistent reclassification, independent accuracy assessment, spatial transition analysis, and field verification are required before the strong primary–secondary oscillations can be interpreted as ecological degradation or recovery. At the resort scale, the present series provides a defensible screening basis for targeted patrols, rehabilitation checks, and a repeatable monitoring program.

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