BIOTROPIA ISSN: 0215-6334 | e-ISSN: 1907-770X
The Southeast Asian Journal of Tropical Biology

Vol. 34 No. 1, 2027: 58 - 70
DOI: 10.11598/btb.2027.34.1.2873

Research Paper

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VEGETATION STRUCTURE, DIVERSITY, AND STAND DYNAMICS IN AN ESG-MANAGED SUMATRAN SWAMP FOREST PATCH: IMPLICATIONS FOR CONSERVATION

Dwi Tyaningsih Adriyanti[1], Alnus Meinata[1*], Subeno[2], Frita Kusumawardani[2], Zyqro Milid Formandes[3], Syahrial Okzani[3]

[1]Department of Silviculture, Faculty of Forestry, Gadjah Mada University, Yogyakarta 55281, Indonesia

[2]Department of Conservation Forest Resource, Faculty of Forestry, Gadjah Mada Univesity, Yogyakarta 55281, Indonesia

[3]Pertamina International Refining II Dumai, Kota Dumai, Riau 28815, Indonesia

ARTICLE HIGLIGHTS

- Small peat swamp forest patch retained high plant diversity across life stages
- Surveys recorded 231 plant species, including many threatened tree species
- Species abundances were relatively even, with little dominance in regeneration
- Permanent plot monitoring showed more new recruits than deaths over four years
- Basal area gains after canopy gaps suggest active recovery in managed forest patch

Article Information

Received : 7 February 2026
Revised : 21 May 2026
Accepted : 8 June 2026
Available Online : 29 October 2026

***Corresponding author, e-mail:**
alnus.meinata@mail.ugm.ac.id

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ABSTRACT

Habitat fragmentation driven by agricultural expansion and urbanization, accelerated biodiversity loss across tropical landscapes. Small forest patches within production and concession matrices function as important refugia and stepping-stones for plant survival. In Indonesia, the conservation relevance of such patches is linked to corporate Environmental, Social, and Governance (ESG) commitments, where natural resource-based company should comply to ecological sustainability. This study evaluated vegetation structure, species diversity, and stand dynamics in a corporate-managed peat swamp forest patch. Vegetation surveys were conducted using systematic nested plots, while stand dynamics were assessed using a 1-ha permanent measurement plot monitored in 4 years. Analyses included the Importance Value Index (IVI), Shannon-Wiener diversity index (H'), species turnover, and basal area change over time. A total of 231 plant species representing 138 genera and 67 families were recorded, including 17 species categorized by the IUCN red list. Species diversity was high and relatively even across all growth stages, indicating the absence of strong dominance. Permanent plot revealed positive turnover with emergence generally exceeding mortality, and net basal area gains during the periods, suggesting active regeneration associated with canopy gap dynamics. Overall, these findings demonstrate that small peat swamp forest patches can retain high biodiversity and dynamic stand recovery, supporting their integration into landscape-scale conservation planning and ESG-oriented forest management in Sumatra.

Keywords: diversity, forest fragmentation, peat forest, stand dynamics, vegetation

INTRODUCTION

Nearly 83% of the Earth's land surface has been altered by human activities (Sanderson *et al.* 2002), leading to rapid ecological destruction and widespread fragmentation of terrestrial ecosystems (Jaureguiberry *et al.* 2022). In the tropical region, agriculture expansion and urbanization remain the main drivers of forest degradation and biodiversity loss (Laurance & Yensen 1991; Laurance *et al.* 2014). On a global scale, almost all ecosystems are now declining to extent and becoming more fragmented (Fischer & Lindenmayer 2007; Sunders *et al.* 1991). As a result, more fragmented landscapes have become a common feature worldwide, and in many regions fragmented forest patches represent the last remaining habitat for numerous species (Rojas *et al.* 2024; Saravia *et al.* 2025).

Conservation initiatives focused on large-scale ecosystems, such as protected area establishment and community-based incentive schemes, are widely implemented as major safeguarding approaches (Grieg-Gran 2008; Watson *et al.* 2014). These initiatives emphasize the role of large patches of vegetation in supporting habitat-dependent species survival (Andren 1999; Fischer *et al.* 2010). While the evidence supporting the protection of large forest blocks is strong, especially regarding species persistence, gene flow, and ecosystem functioning, a singular focus on large patches risks overlooking the conservation value of smaller forest remnants. Despite their ecological sensitivity, small forest patches are often the most vulnerable to clearing and land-use conversion (Stobbe *et al.* 2008). Yet these patches may act as refugia, stepping-stones, and reservoirs of genetic and functional diversity, particularly in highly human-modified landscapes (Herrera *et al.* 2017; Craven *et al.* 2016). Therefore, understanding their ecological role is crucial.

In Indonesia, the conservation of fragmented forest landscapes is increasingly linked to Environmental, Social, and Governance (ESG) commitments adopted by corporate and state-owned enterprises, particularly in sectors such as forestry, plantation agriculture, energy, and infrastructure development (Kopnina *et al.* 2024). National regulatory frameworks including sustainable forest management policies, and biodiversity safeguard encourage companies to integrate ecosystem protection into their operational and reporting frameworks (Talaat *et al.* 2012; Johansson & Keskitalo 2014). Under ESG-oriented approaches, maintaining ecosystem integrity, reducing deforestation risks, and conserving high conservation value (HCV) areas are now recognized as integral components of corporate environmental responsibility. Within this context, small and fragmented forests often embedded within production or concession landscapes become relevant as measurable indicators of environmental stewardship, scientific evidence on the ecological function of such patches is therefore essential to support credible ESG implementation, monitoring, and disclosure in Indonesia.

Sumatra, as part of the Sundaland biodiversity hotspot together with Peninsular Malaysia, Borneo, and Java, harbors one of the richest floras in Southeast Asia (Latiff 2018). The plant diversity of Sumatra has historically been underestimated, with around 10,000 species reported by (Davis *et al.* 1995), further highlighting the need for updated and comprehensive documentation. Sumatra comprises 19 distinct subfloristic divisions (Laumonier 1990; Laumonier 1997), reflecting unique biogeographical and ecological gradients. However, rapid agricultural expansion, peatland conversion, logging, and urbanization continue to threaten the island's flora and associated ecological processes in Sumatra (Austin *et al.* 2019; Margono *et al.* 2012). The Sumatra peat swamp forest is one of the essential habitats that is currently having rapid loss due to agricultural expansion (Stibig *et al.* 2014). Peat swamp forest is one of the world's hotspots that shelters numerous living organisms (Wilcove *et al.* 2013; Myers 1988). As information on floral richness across the island remains limited, forest fragmentation and patch isolation intensify the risk of biodiversity loss, particularly for ecosystems such as peat-swamp forests and the emphasize of its protection is needed.

As the erosion and fragmentation of vegetated landscapes continue (Hansen *et al.* 2013), there is an urgent need to understand the ecological functions and conservation relevance of smaller forest patches, including their role in maintaining vegetation structure, diversity, and stand dynamics. Swamp forest patches in Sumatra may function as critical refuges for species persistence, hydrological regulation, and carbon storage, yet they remain among the least studied and most threatened habitats. Therefore, assessing vegetation diversity, stand structure, and dynamics in Sumatran swamp forest patches is fundamental to understanding their ecological significance as fragmented landscapes. Insights from such assessments can support more inclusive conservation frameworks

that value not only large forest blocks but also the ecological contributions of smaller, isolated forest patches that collectively sustain biodiversity across the landscape.

MATERIALS AND METHODS

Study Site

The research was conducted in August 2025 in the Eco-Edu Park Patra Seroja forest patch, owned by State Owned Oil Company, Pertamina International Refinery Unit II Dumai. The study area was located between 1°37'55.725" N and 1°39'40.779" N, and between 101°23'5.256" E and 101°25'46.024" E (Fig. 1). The area covers 94 ha and is located at an elevation of 50 meters above sea level (masl).

The establishment and maintenance of the forest patch represent one of the company's restoration initiatives aligned with Environmental, Social, and Governance (ESG) principles in Indonesia, particularly regarding environmental sustainability and ecosystem rehabilitation. Inside the forest patch, it is forbidden for any human activities such as dumping garbage, agricultural activities, and taking away trees, seedlings and seeds.

Investigation of stand dynamics was conducted in the permanent measurement plot located inside the Eco-Edu Park Patra Seroja Forest, encompassing an area of 1 ha, divided into smaller nested plots that have been established since 2021. The observation of the permanent plot was conducted in 2021; 2023, and 2025, all the observations were conducted between August and September. The area has 308,02 mm3 total precipitation with a total of 172 days of rain, relative humidity range of 60.75 – 99.42%, and mean air temperature between 22.8 °C and 34.7 °C (Statistic Department of Dumai 2024).

Vegetation Survey

Vegetation structure and diversity were assessed using a systematic sampling method, having distance of 200 m between each plot. Nested sampling was used to assess the list of different growth levels. A 20 x 20 m plot was used for assessing trees (> 20 cm diameter), a 10 x 10 m plot for poles (> 10 cm diameter), a 5 x 5 m plot for saplings (> 1.5 m height and < 10 cm diameter), and a 2 m x 2 m plot for seedlings and understory vegetation (< 1.5 m height).

To investigate the stand dynamic, a permanent plot was established inside the forest patch, at 100 x 100 m. Inside the permanent plot 25 subplots of 20 x 20 m were made and coded based on numerical order. Inside each subplot, the north-east side of the plot was designated as the initial plot to build the nested plot. Inside the nested plot, we labelled the seedlings inside the 2 x 2 m subplot, saplings in the 5 x 5 m subplot, poles in the 10 x 10 m subplot, and trees in the 20 x 20 m plot (Fig. 2).

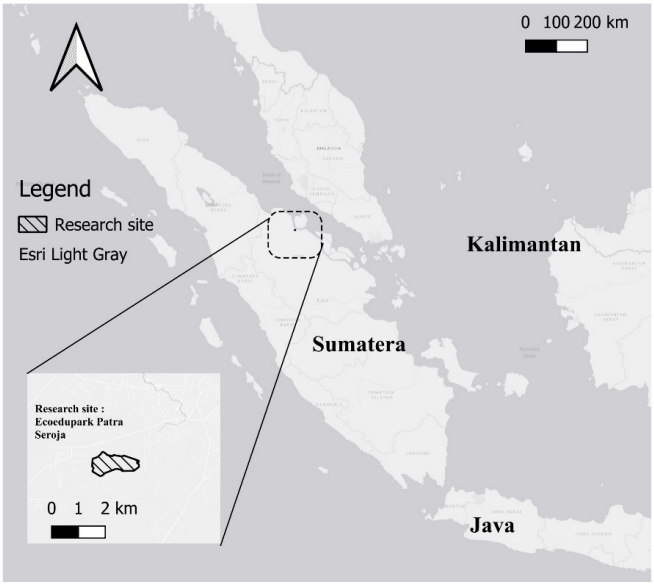


Figure 1 Location of the forest patches in the eastern part of Riau Province, Sumatra

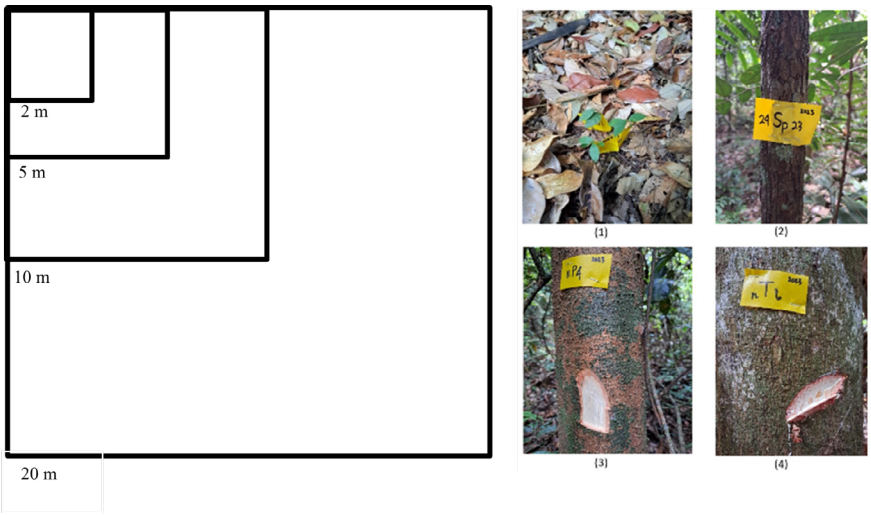


Figure 2 Sampling plot design for diversity analysis
Notes: Permanent plot monitoring (left); paper labels for permanent plot vegetation monitoring (right).

Plant images and samples were collected for identification purposes in the field. The unidentified materials were collected and identified at the Dendrology Laboratory in Gadjah Mada University by matching the dried sample with the description in the monograph and World Flora online Database for nomenclature reference (POWO 2021), as well as its conservation status according to IUCN (IUCN 2025). Tree measurements taken were height and stem diameter at breast height (DBH) of trees. For trees with buttresses, the diameter was measured at 20 cm above the buttress. In the permanent plot, the labels for observations were carefully placed. In 2021, each tree was initially labeled according to its growth stage. In subsequent years, the existing labels were carefully checked. Trees with missing labels or dead individuals were recorded as mortality. Trees with intact labels and remaining alive were classified as surviving, and those that progressed to the next growth stage were recorded as survivors and categorized according to their respective growth form during the observation year.

Data Analysis

Vegetation structure and diversity were analyzed by calculating their importance value index (IVI). The IVI measures the level of dominance of a species in a landscape as a percentage, the higher the value, the more dominant the species. IVI was calculated by adding up relative dominance (for trees and poles growth form), relative density and relative frequency which established as follows.

$$\text{Relative density (\%)} = \frac{\text{Number of individuals for a species}}{\text{total number of individuals for all species in the plot}} \times 100\%$$

$$\text{Relative frequency (\%)} = \frac{\text{Total frequency of a species}}{\text{Frequency of all species in the plot}} \times 100\%$$

$$\text{Relative dominance (\%)} = \frac{\text{total basal area of a species}}{\text{total basal area of all species in the plot}} \times 100\%$$

IVI= Relative frequency + Relative frequency + Relative dominance (tree and poles).

Lastly, the calculation on the stand's species diversity index (Shannon-Wiener index) was performed using the formula below:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where:
H' = Shannon-Wiener diversity index value
pi = the proportion of species in the community.

Stand dynamics were calculated as the species turnover, and the changes of basal area during the periods of 2021–2023 and 2023–2025 to see how the individual and basal area changes within the time.

RESULTS AND DISCUSSION

Plant Species Diversity

Based on the survey results from the Eco-Edu Park Patra Seroja Forest plot, we found 231 identified species representing 138 genera and 67 families. Among the identified species, 17 species are categorized as vulnerable (VU), near threatened (NT), endangered (EN), and critically endangered plant species (CR) (Table 1). The Shannon-Wiener diversity indices (H') were employed to quantify species diversity based on species richness and the distribution of individuals within

the community. Higher H' values indicate greater diversity (Shannon & Wiener 1948). Saplings had the highest diversity index (4.19), followed by poles (3.92), trees (3.84), and seedlings (3.64). The diversity of this forest fragment was higher than that previously reported for other forest patches in Sumatra (Ulfa *et al.* 2022; Solfiyeni *et al.* 2024). The high and relatively even diversity across growth stages suggests that there is no single species dominates the community, reflecting a dynamic and balanced forest ecosystem.

Based on the results of the analysis, plant species diversity across all growth stages in the forest patch was high according to the Shannon-Wiener diversity index (Fig. 3). Although large forest patches are generally expected to support high species diversity, this relationship is not universal. Small forest patches can also support high diversity, depending on the type and intensity of disturbance in the surrounding area.

Table 1 Plant species identified in the study plot and categorized according to the IUCN red list status

Species	IUCN red list status
Aquilaria malaccensis Lam.	CR
Hopea griffithii Kurz	EN
Pterocarpus indicus Willd.	EN
Anthoshorea javanica (Koord. & Valeton) P.S.Ashton & J.Heck.	EN
Rubroshorea almon (Foxw.) P.S.Ashton & J.Heck.	NT
Artocarpus odoratissimus Blanco	NT
Rubroshorea pauciflora (King) P.S.Ashton & J.Heck.	NT
Rubroshorea leprosula (Miq.) P.S.Ashton & J.Heck.	NT
Artocarpus scortechinii King	NT
Semecarpus heterophyllus Blume	NT
Rubroshorea platyclados (Slooten ex Endert) P.S.Ashton & J.Heck.	NT
Rubroshorea stenoptera (Burck) P.S.Ashton & J.Heck.	NT
Dryobalanops aromatica C.F.Gaertn.	VU
Monocarpia euneura Miq.	VU
Aquilaria beccariana Tiegh.	VU
Artocarpus anisophyllus Miq.	VU
Shorea guiso (Blanco) Blume	VU

Notes: CR = Critically Endangered; EN = Endangered; NT = Nearly Threatened; and VU = Vulnerable.

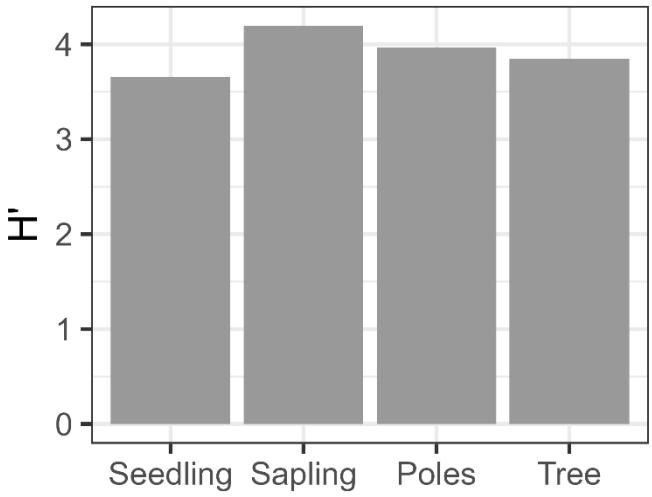


Figure 3 Shannon-Wiener diversity index across all growth stages in the study plot.

Previous studies have shown that small patches in highly fragmented forests can maintain high plant diversity (Arroyo-Rodríguez *et al.* 2009; Hernández-Ruedas *et al.* 2014; Watling *et al.* 2020). Similarly, a study of birds in Indonesia found that large forest patches located near human settlements may support lower bird diversity than smaller patches (Alghifari *et al.* 2021). Therefore, small forest patches should not be overlooked in conservation planning because they can serve as refuges for certain species, enhance landscape connectivity (Dunning *et al.* 1992), provide important ecosystem services (Bodin *et al.* 2006), and support diverse wildlife communities (Estrada & Coates-Estrada 2002; Benedick *et al.* 2006; Fischer & Lindenmayer 2007). Despite its small area, the forest patch examined in this study supports high plant diversity, including important species of conservation concern, highlighting its conservation value. Corporate compliance with environmental, social, and governance (ESG) commitments can support the conservation of biodiversity in swamp forest, as demonstrated by this study. Senanayake *et al.* (2026) reported an increasing trend in corporate biodiversity assessment and reporting in Indonesia, reflecting government initiatives to safeguard ecosystems by encouraging companies to integrate biodiversity conservation into their corporate sustainability commitments.

Stand Structure and Regeneration

The Importance Value Index (IVI) results indicate the species with the highest contribution at each growth stage (Fig. 4; Tables 2–5). At the seedling stage, *Nephrolepis biserrata* showed the highest IVI (15.6), followed closely by *Tetracera indica* (15.4). The gradual decline in IVI values among species, without marked differences, suggests the absence of strong dominance in seedling regeneration. A similar pattern was observed at the pole stage, where *Garcinia dioica* had the highest IVI (13.4), followed by *Psidium guajava* (11.4), with other species decreasing gradually in contribution. At the sapling stage, *Buchanania arborescens* exhibited the highest IVI (16.7), followed by *Blumeodendron tokbrai* (8.6), approximately half that of *B. arborescens*, indicating relatively stronger regeneration of *B. arborescens* compared to other species. Among tree-stage individuals, IVI values decreased gradually from *Macaranga gigantea* (33.6), followed by *Rubroshorea macrophylla* (24), and 13 additional species shown in Figure 4, suggesting no pronounced dominance despite the higher contribution of several species.

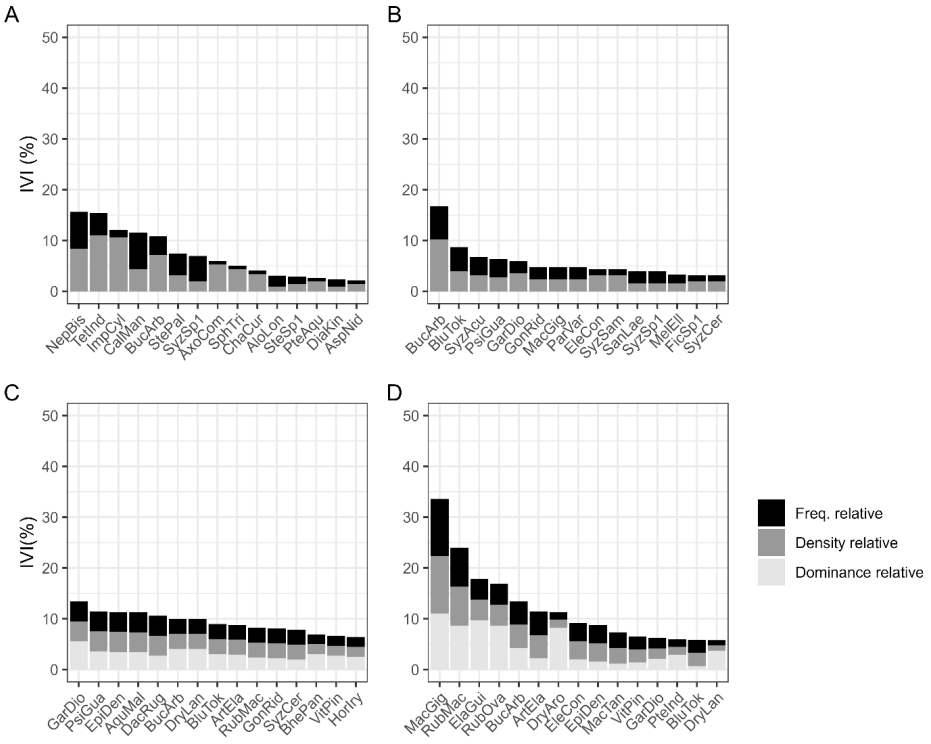


Figure 4 Fifteen plant species having the highest Important Value Index at each growth stage
Notes: the top 10 plant species are mentioned in each growth stage; A = seedlings; B = saplings; C = poles; D = trees.

Table 2 Top 10 important value index, relative density, frequency and dominance for seedling stage

Species code	Species	Density	Frequency	Dominance	Relative density (%)	Relative frequency (%)	IVI
NepBis	*Nephrolepis biserrata* (Sw.) Schott	35	10	0.00	8.43	7.19	15.63
TetInd	*Tetracera indica* (Christm. & Panz.) Merr.	46	6	0.00	11.08	4.32	15.40
ImpCyl	*Imperata cylindrica* (L.) Raeusch.	44	2	0.00	10.60	1.44	12.04
CalMan	*Calamus manan* Miq.	18	10	0.00	4.34	7.19	11.53
BucArb	*Buchanania arborescens* Blume	30	5	0.00	7.23	3.60	10.83
StePal	*Stenochlaena palustris* (Burm.) Bedd.	13	6	0.00	3.13	4.32	7.45
SyzSp1	*Syzygium* sp1	8	7	0.00	1.93	5.04	6.96
AxoCom	*Axonopus compressus* (Sw.) P.Beauv.	22	1	0.00	5.30	0.72	6.02
SphTri	*Sphagneticola trilobata* (L.) Pruski	18	1	0.00	4.34	0.72	5.06
ChaCur	*Chassalia curviflora* (Wall.) Thwaites	14	1	0.00	3.37	0.72	4.09

Table 3 Top 10 important value index, relative density, frequency and dominance for sapling stage

Species code	Species	Density	Frequency	Dominance	Relative density (%)	Relative frequency (%)	IVI
BucArb	*Buchanania arborescens* Blume	26	11	0.00	10.28	6.51	16.79
BluTok	*Blumeodendron tokbrai* Kurz	10	8	0.00	3.95	4.73	8.69
SyzAcu	*Syzygium* acuminatissimum (Blume) DC.	8	6	0.00	3.16	3.55	6.71
PsiGua	*Psidium guajava* L.	7	6	0.00	2.77	3.55	6.32
GarDio	*Garcinia dioica* Blume	9	4	0.00	3.56	2.37	5.92
GonRid	*Goniothalamus ridleyi* King	6	4	0.00	2.37	2.37	4.74
MacGig	*Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg.	6	4	0.00	2.37	2.37	4.74
ParVar	*Paropsia vareciformis* Mast.	6	4	0.00	2.37	2.37	4.74
EleCon	*Eleiodoxa conferta* (Griff.) Burret	8	2	0.00	3.16	1.18	4.35
SyzSam	*Syzygium samarangense* (Blume) Merr. & L.M.Perry	8	2	0.00	3.16	1.18	4.35

Table 4 Top 10 important value index, relative density, frequency and dominance for pole stage

Species code	Species	Density	Frequency	Dominance	Relative density (%)	Relative frequency (%)	Relative Dominance (%)	IVI
GarDio	*Garcinia dioica* Blume	4	4	0.09	3.92	3.92	5.57	13.42
PsiGua	*Psidium guajava* L.	4	4	0.06	3.92	3.92	3.59	11.43
EpiDen	*Epicharis densiflora* Blume	4	4	0.06	3.92	3.92	3.48	11.32
AquMal	*Aquilaria malaccensis* Lam.	4	4	0.06	3.92	3.92	3.44	11.28
DacRug	*Dacryodes rugosa* (Blume) H.J.Lam	4	4	0.05	3.92	3.92	2.74	10.58
BucArb	*Buchanania arborescens* Blume	3	3	0.07	2.94	2.94	4.06	9.94
DryLan	*Dryobalanops lanceolata* Burck	3	3	0.07	2.94	2.94	4.05	9.94
BluTok	*Blumeodendron tokbrai* Kurz	3	3	0.05	2.94	2.94	3.09	8.97
ArtEla	*Artocarpus elasticus* Reinw.	3	3	0.05	2.94	2.94	2.95	8.83
RubMac	*Rubroshorea macroptera* (Dyer) P.S.Ashton & J.Heck.	3	3	0.04	2.94	2.94	2.35	8.23

Table 5 Top 10 important value index, relative density, frequency and dominance for tree stage

Species code	Species	Density	Frequency	Dominance	Relative density (%)	Relative frequency (%)	Relative Dominance (%)	IVI
MacGig	*Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg.	22	22	3.01	11.28	11.28	11.03	33.59
RubMac	*Rubroshorea macroptera* (Dyer) P.S.Ashton & J.Heck.	15	15	2.36	7.69	7.69	8.63	24.02
ElaGui	*Elaeis guineensis* Jacq.	8	8	2.65	4.10	4.10	9.69	17.89
RubOva	*Rubroshorea ovalis* (Korth.) P.S.Ashton & J.Heck.	8	8	2.37	4.10	4.10	8.66	16.87
BucArb	*Buchanania arborescens* Blume	9	9	1.16	4.62	4.62	4.23	13.46
ArtEla	*Artocarpus elasticus* Reinw.	9	9	0.60	4.62	4.62	2.19	11.42
DryAro	*Dryobalanops aromatica* C.F.Gaertn.	3	3	2.26	1.54	1.54	8.29	11.36
EleCon	*Eleiodoxa conferta* (Griff.) Burret	7	7	0.56	3.59	3.59	2.03	9.21
EpiDen	*Epicharis densiflora* Blume	7	7	0.44	3.59	3.59	1.61	8.79
MacTan	*Macaranga tanarius* Müll.Arg.	6	6	0.33	3.08	3.08	1.21	7.37

The Important Value Index results for each growth stage level in the study area showed that there was no species dominating in the forest plot. The highest IVI differences are within sapling growth level, with *B. arborescens* being dominant in the saplings growth level. In the tree level, overall species found belong to Sumatra native plant, however, the presence of *Elaaeis guinensis* (palm oil) should be further investigated whether it is just because of the recent disturbance or only the past history of agricultural activity before the area is carefully managed. Palm oil is one agricultural crop that play role in shifting forest to agricultural practice, especially in Indonesia (Austin *et al.* 2019). Another species that should be considered is *Macaranga tanarius*, *Macaranga gigantea*. John (1989) documented the dominance of wind-dispersed pioneer species, such a *Macaranga* spp., which are responsive to forest disturbance. Their seeds can remain dormant until a subsequent disturbance triggers germination (John 1989; Fiala 1996). The occurrence of *Macaranga* spp. in the area should be carefully evaluated to determine whether management intervention is necessary. If native species in the surrounding area can outcompete *Macaranga* regeneration, management intervention should be minimized. Otherwise, enrichment planting may be an option for restoring the floristic composition (Shono *et al.* 2007). Our results showed that two high-conservation-value species, *Rubroshorea macrophylla* and *Dryobalanops aromatic*, were among the 15 species with the highest Important Value Index (IVI),. This finding indicates that the forest supports species of high conservation value and should therefore, be managed carefully to maintain ecosystem balance.

Stand Dynamics in Permanent Measurement Plot

Measurements obtained in 2021, 2023, and 2025, showed an overall increasing trend in the total number of individuals across all growth stages (Fig. 5). The number of seedlings increased from 72 in 2021 to 81 in 2023 and 217 in 2025, representing an approximately threefold increase between 2023 and 2025 and indicating successful seedling establishment. The number of saplings also increased, from 281 in 2021 to 285 in 2023 and 374 in 2025. The number of poles decreased from 86 in 2021 to 73 in 2023 but increased to 94 in 2025. Similarly, the number of trees increased from 93 in 2021 to 96 in 2023 and 130 in 2025. The increase in tree abundance may indicate progression of individuals from the pole to the tree stage between 2023 and 2025.

In terms of species turnover, the overall number of new individuals entering each growth stage exceeded mortality. Mortality was generally lower than the number of individuals establishing at a new growth stage. During 2021–2023, recruitment consistently exceeded mortality across all growth form (Fig. 6).

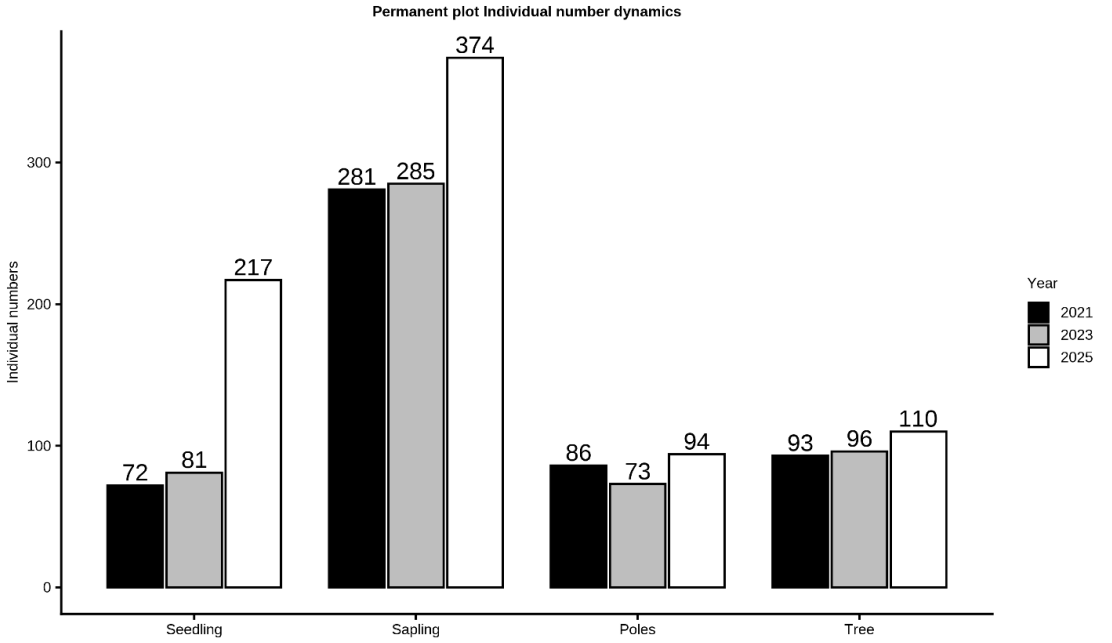


Figure 5 Individual dynamic in each growth stage in the permanent plot between 2021-2025

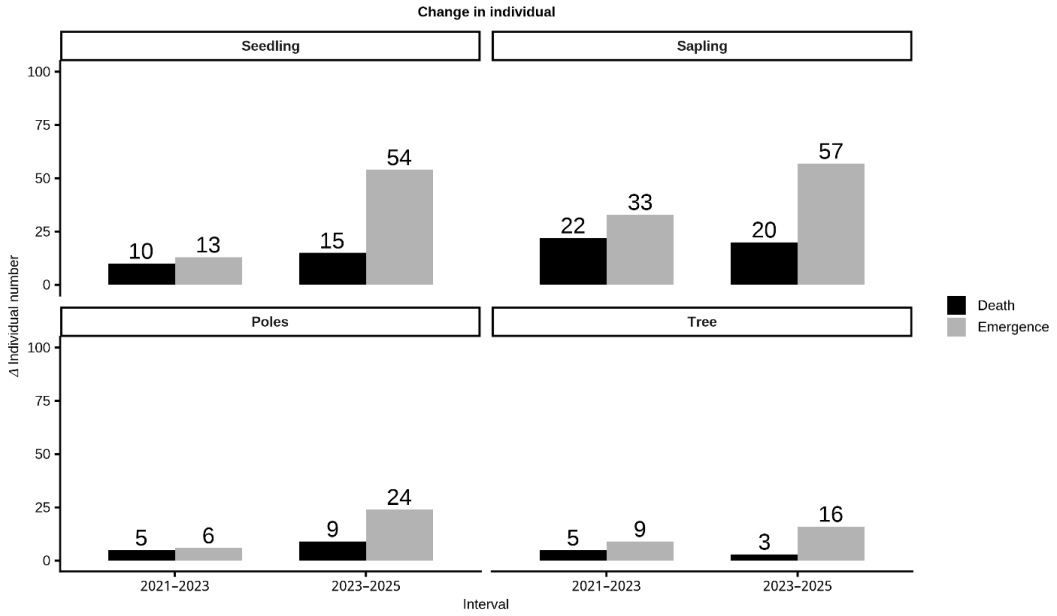


Figure 6 Changes in the number of individuals at each growth stage
Notes: Black bars indicate mortality; Gray bars indicate newly established individuals.

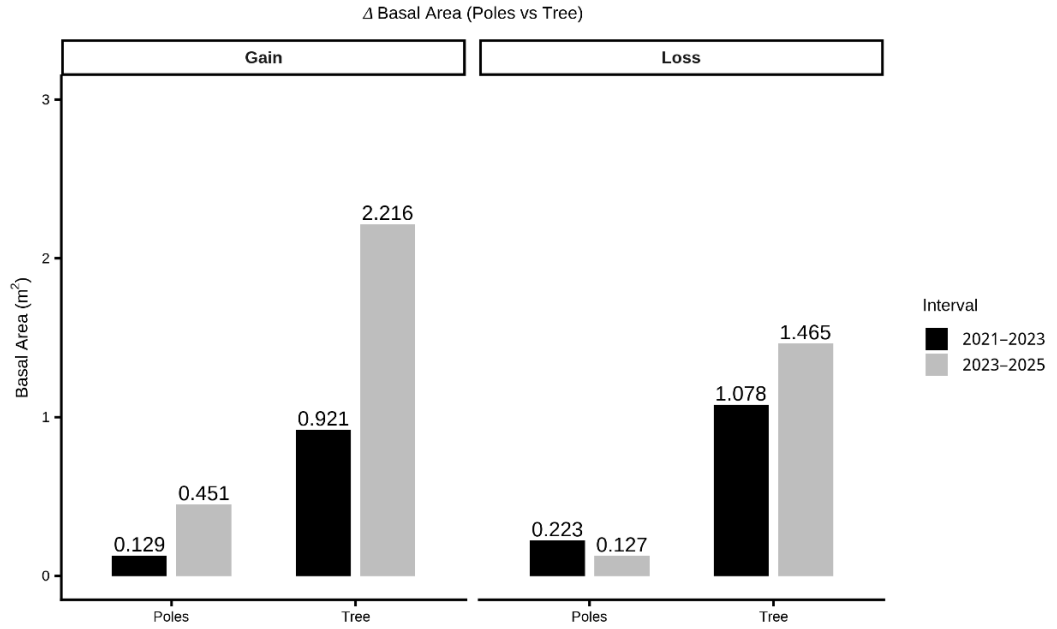


Figure 7 Changes in basal area of poles and trees during the observation period

We also assessed changes in basal area and observed a balance between losses and gains in poles and tree basal areas (Fig. 7). For poles, basal area loss exceeded gain during 2021–2023, resulting in a net decrease of 0.094 m^2. In contrast, during 2023–2025, basal area gain exceeded loss, resulting in a net increase of 0.324 m^2. A similar pattern was observed for trees, with a net basal area decrease of 0.157 m^2 during 2021–2023 and an increase of 0.751 m^2 during 2023–2025. These results indicate an overall increase in basal area during the most recent observation period.

Based on the number of species recorded across all growth stages, an overall increasing trend in individual abundance was observed. However, the identities of species contributing to this increase should be documented in subsequent observation. The increase in seedling and sapling individuals from 2023 to 2025 was likely associated with canopy gaps created by tree and pole mortality. This interpretation is supported by the basal area date, which showed a loss during 2021–2023, potentially indicating tree falls that created light gaps and facilitated the germination and

establishment of new propagules. Although tree abundance also increased from 2021 to 2023, the increase was relatively small and may have resulted from poles progressing to the tree stage. The increasing abundance shown in Figure 5 is further supported by Figure 6, which illustrates mortality and recruitment among seedlings and saplings. Recruitment was greater during 2023–2025 than during 2021–2023. Light is a key factor influencing plant turnover in vegetation communities (Fan *et al.* 2023). Overall, the four-year observations indicate a positive trend in forest patch dynamic, suggesting a degree of ecosystem balance based on species and individual turnover. However, continued monitoring of the permanent plots is needed to assess ecosystem resilience and determine whether disturbance effects diminish over time.

Implication for Conservation

The findings suggest that company-managed forest patches established under sustainability or Environmental, Social, and Governance (ESG) commitments may contribute to biodiversity conservation. Although biodiversity is not consistently operationalized within many corporate ESG strategies, protected or restored forest patches may provide tangible environmental benefits beyond regulatory compliance. The observed vegetation diversity and stand dynamics in the monitored swamp forest indicate that long-term management and monitoring can help maintain ecological functions and provide measurable outcomes relevant to the environmental dimension of ESG performance.

Although the studied forest fragment is relatively small compared with the large protected forests traditionally prioritized for conservation (Kukkala & Moilanen 2013), this study demonstrated substantial ecological value. Small forest patches are highly vulnerable to anthropogenic disturbance, while habitat loss and reduced landscape connectivity remain major drivers of biodiversity decline (Fahrig 2017; Newbold *et al.* 2015). Inadequate management of these patches can accelerate species loss, whereas effective management may promote biodiversity persistence. Although the extent to which small patches can maintain viable populations remains uncertain, strategically managed forest fragments can function as refugia, stepping stones, and dispersal corridors that facilitate movement of plants and animals among habitats, thereby enhancing connectivity among subpopulations (Saura *et al.* 2017). These ecological functions are particularly important in fragmented tropical landscapes, including Sumatra, where agricultural expansion and land-use change continue to reduce continuous forest cover.

Therefore, conservation-oriented management supported by ESG commitments, restoration programs, and biodiversity-related policies may provide opportunities to maintain ecological integrity in fragmented landscapes. Integrating long-term ecological monitoring, biodiversity indicators, and measurable conservation targets into ESG implementation could strengthen accountability and help ensure that sustainability commitments generate tangible biodiversity outcomes rather than disclosure alone.

CONCLUSION

Habitat fragmentation remains a major challenge for biodiversity conservation due to increasing risks of habitat loss, isolation, and species decline. Within the monitored peat swamp forest patch, relatively high plant diversity across growth stages, the presence of threatened species, and positive short-term regeneration trends indicate that this site retains substantial ecological value despite its limited size. Observations from 2021 to 2025 indicate ongoing recruitment and balanced stand dynamics; however, longer-term monitoring is needed to evaluate ecosystem resilience. These findings suggest that company-managed forest patches established through restoration or ESG-related environmental commitments may contribute to maintaining biodiversity and ecological processes at the local scales. Although findings from a single forest patch should be interpreted cautiously and may not be representative of other fragmented landscapes, this study provides site-specific evidence that small peat swamp forest patches can retain conservation value. Continued ecological monitoring and the integration of measurable biodiversity indicators into ESG implementation may strengthen conservation outcomes in fragmented landscapes of Sumatra.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Pertamina International Refinery Unit II Dumai and its staff for their financial and logistical support during the fieldwork. We also thank Mr Bukhori Akhmad, technical staff of UGM, for his invaluable contribution to the project management. We further acknowledge all field officers and individuals who assisted with this research.

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