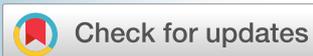**Research Article**

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Vegetation Structure and Species Composition Along a Canal-Distance Gradient Across Different Peatland Land Use Types

Sinta Haryati Silviana[1,2*], Bambang H. Saharjo[2], Sigit Sutikno[3], Yenni Vetrita[1]

[1]Research Center for Geoinformatics, National Research and Innovation Agency (BRIN), Bandung 40135, West Java, Indonesia
[2]Faculty of Forestry and Environment, IPB University, Bogor 16680, West Java, Indonesia
[3]Center for Peatland and Disaster Studies (CPDS), Department of Civil Engineering, University of Riau, Pekanbaru, Riau, Indonesia

ABSTRACT

Tropical peatlands are critical ecosystems that provide habitat for biodiversity and store large amounts of carbon, yet they are increasingly degraded due to land-use conversion, drainage, and recurrent fires. This study examined vegetation structure and species composition along a canal-distance gradient (10-350 m across three peatland land-use types: rubber plantation, secondary forest, and burned peatland. Vegetation surveys were conducted using 40 nested plots covering four growth strata (trees, poles, saplings/shrubs, and seedlings/herbs). Community structure was analyzed using the Importance Value Index (IVI), Shannon–Wiener diversity index (H′), Margalef's richness index (DMg), Pielou's evenness index (E), and Simpson's dominance index (C). Differences in environmental parameters among land-use types were tested using one-way ANOVA ($p<0.05$). Secondary forests exhibited the highest species richness and diversity with balanced structural complexity, whereas rubber plantations showed simplified communities dominated by *Hevea brasiliensis*. Burned peatlands were characterized by pioneer tree species and dense fern understorey, indicating successional arrest. Secondary forests had higher biodiversity than rubber plantations, which in turn had higher biodiversity than burned peatlands. These findings highlight that land-use intensity, canal proximity, and fire history jointly regulate vegetation dynamics in tropical peatlands and highlight the importance of forest conservation, plantation diversification, and restoration through rewetting and enrichment planting.

1. Introduction

Tropical peatlands are globally significant ecosystems because of their essential roles in biodiversity conservation, climate regulation, and hydrological balance. Their high water-holding capacity allows them to buffer seasonal fluctuations by storing water in wet seasons and gradually releasing it during dry seasons (Salimi *et al.* 2021). In their intact state, peat swamp forests are maintained by the interaction of three components—vegetation, peat, and hydrology—that regulate ecological processes and carbon balance (Darusman *et al.* 2022; Dharmawan *et al.* 2024).

Vegetation provides organic inputs, while decomposition processes regulate carbon release within the system (Akinbi *et al.* 2022; Li *et al.* 2024).

Land conversion and drainage canal construction have disrupted these processes by lowering water tables and altering hydrological regimes, thereby increasing peatland vulnerability to degradation (Word *et al.* 2022; Vilhar *et al.* 2022; Urzainki *et al.* 2023). Drainage canals accelerate groundwater drawdown and increase peat aeration, thereby enhancing human accessibility and intensifying ecological disturbance. Fires further intensify degradation, driving shifts from tree-dominated forests to landscapes dominated by ferns, grasses, and shrubs. This transition results in biodiversity decline, marked by a 58-98% reduction in tree density in Southeast Asian peatlands; although some regeneration

*Corresponding Author
E-mail Address: sintaharyatis@gmail.com

may occur, recurrent fires hinder long-term recovery (Harrison *et al.* 2024). Such disturbances accelerate carbon emissions, destroy vegetation biomass, and weaken ecological stability (Volkova *et al.* 2021). While secondary succession can support vegetation recovery (Konecny *et al.* 2016), repeated disturbances often lead to retrogressive succession, which necessitates active restoration interventions such as canal blocking and native species replanting (Smith *et al.* 2022; Hooijer *et al.* 2024).

Both environmental and anthropogenic drivers influence vegetation dynamics in peatlands. Soil moisture, organic matter, pH, microtopography, and hydrological gradients strongly affect species establishment and community composition (Lampela *et al.* 2016; Guo *et al.* 2024). Plant traits, such as canopy density and bark characteristics, also regulate hydrological processes through rainfall interception, infiltration, and runoff (Livesley *et al.* 2014). At the same time, human activities such as intensive planting, logging, and land clearing alter vegetation density and structure, often simplifying plant communities (Zhang & Ye 2021; Fan *et al.* 2023). Canal proximity integrates these effects by simultaneously modifying hydroperiods and disturbance intensity, thereby shaping vegetation recovery and community trajectories (Dohong *et al.* 2018).

Given these challenges, a deeper understanding of vegetation structure and composition in relation to land-use history and canal proximity is required to support peatland management. This study aimed to analyze vegetation characteristics at varying distances from canals across three land-use types: secondary forests, rubber plantations, and burned peatlands. Vegetation was assessed using ecological indices, including Importance Value Index (IVI), Shannon-Wiener diversity index (H′), Simpson's dominance index (C), Pielou's evenness index (E), and Margalef's richness index (DMg), to evaluate how land-use history and canal-distance gradients interact in shaping tropical peatland vegetation communities.

2. Materials and Methods

2.1. Study Site

The study was conducted in May 2022 in Sungai Tohor Village, Tebingtinggi Timur Sub-district, Kepulauan Meranti Regency, Riau Province, Indonesia. This area represents a tropical lowland peatland ecosystem that has been subjected to various land-use practices. The study area is located at approximately 0°53′20.400″N 102°53′49.200″E.

2.2. Research Area

Three land-use types were selected for vegetation sampling:
1. Secondary forest, representing relatively undisturbed peatland.
2. Rubber plantation, representing community-managed land use.
3. Post-fire areas, consisting of two sites that were both affected by the 2015 fire event but currently exhibit different post-fire conditions.

2.3. Climate Characteristics

The study area has a humid tropical climate with a mean annual temperature of 26.6 °C and an average annual rainfall of 2,269 mm. Precipitation data from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) for 2012–2022 show that annual rainfall ranged between 1,775 and 3,206 mm, with the lowest value recorded in 2015 (coinciding with a major fire event) and the highest in 2022. Seasonally, rainfall peaks between November and January (230–330 mm/month) and reaches its minimum in February, June, and July (127–169 mm/month). Relative humidity remains high throughout the year (80–90%), while the southwest and northeast monsoons influence wind patterns.

2.4. Plot Design and Vegetation Sampling

Vegetation data were collected using nested plots established at 10–350 m from drainage canals, with 10 plots per site distributed on both sides of the canal (Figure 1). Distances of 10–350 m were selected to represent a gradient of canal influence, with areas closer to canals experiencing stronger hydrological drawdown and greater human accessibility. At the same time, more distant plots reflect reduced drainage effects and lower disturbance intensity. In total, 40 plots were established, consisting of 10 plots per land-use type distributed along canal-distance gradients on both sides of the canal. Plants were classified into four growth strata: trees (DBH ≥ 20 cm), poles (DBH 10–19.9 cm), saplings and shrubs (DBH < 10 cm, height ≥ 1.5 m), and seedlings, small shrubs, and herbs (height < 1.5 m, including ground ferns).
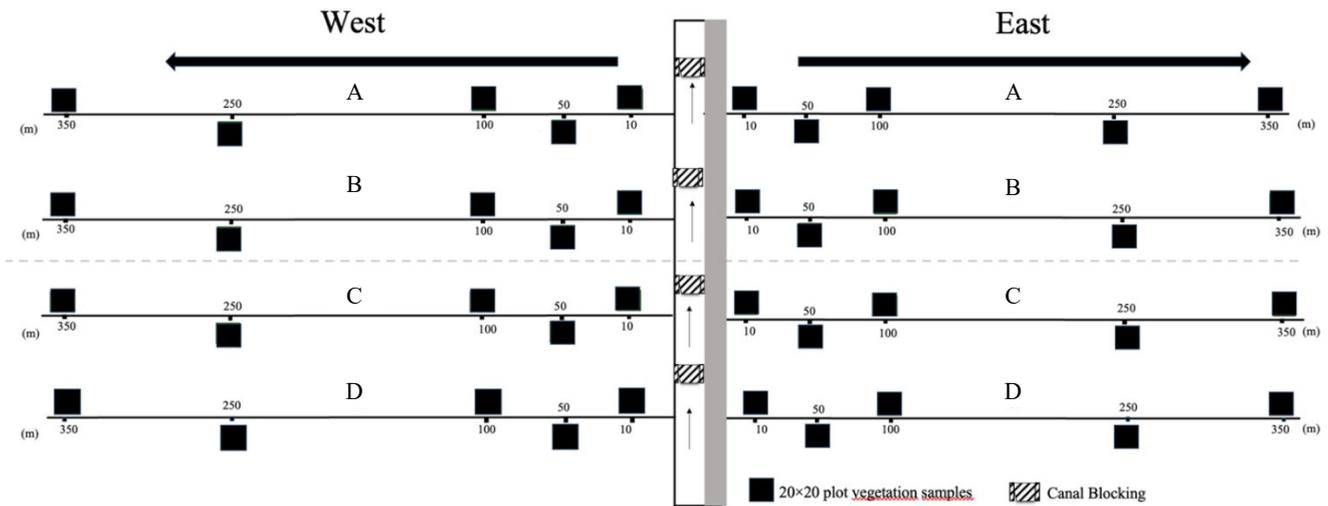
Figure 1. Vegetation sampling plot layout along drainage canals in Sungai Tohor Village, Riau, Indonesia. Plots were established perpendicular to the canal at 10–350 m on both western and eastern sides. Sub-figures show land-use types: (A) rubber plantation, (B) secondary forest, (C) burned area 1, and (D) burned area 2

2.5. Vegetation Inventory

Plot dimensions followed the standard method described by Soerianegara and Indrawan (1998) (Figure 2):

1. Trees (DBH ≥ 20 cm): 20 × 20 m plots.
2. Poles (DBH 10–19.9 cm): 10 × 10 m subplots.
3. Saplings and shrubs (height ≥ 1.5 m, DBH 5–9.9 cm): 5 × 5 m subplots.
4. Seedlings, small shrubs, and herbs (height < 1.5 m, DBH < 5 cm, including herbs): 2 × 2 m subplots.

2.6. Vegetation Data Collection

All plant species encountered in the plots were identified by their local and scientific names. For trees, the measured variables included DBH, height, species name, and number of individuals. Tree circumference (CBH) was measured at 1.3 m above ground level, and DBH was calculated using the formula:

$$DBH = \frac{CBH}{\pi}$$

2.7. Data Analysis

Vegetation community characteristics were quantified using a set of ecological indices, including the Importance Value Index (IVI), species richness (DMg), Shannon–Wiener diversity (H′), Pielou's evenness (E), and Simpson's dominance (C). The formulas, references, ecological meaning, and interpretation thresholds of
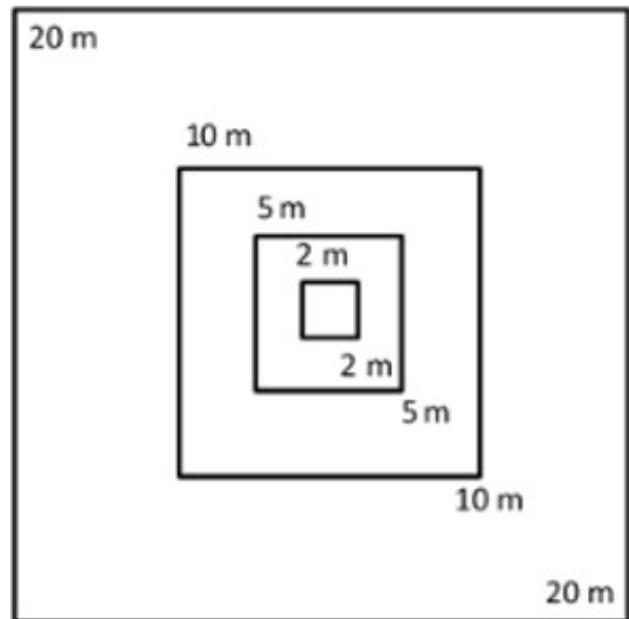
Figure 2. Nested plot design for vegetation inventory based on Soerianegara and Indrawan (1998), consisting of four growth strata: trees (20 × 20 m), poles (10 × 10 m), saplings and shrubs (5 × 5 m), and seedlings, small shrubs, and herbs (2 × 2 m)

these indices are summarized in Table 1. Differences in environmental variables among land-use types and canal distances were tested using a one-way analysis of variance (ANOVA), followed by Tukey's HSD post hoc test, with significance set at $p < 0.05$.

Table 1. Ecological indices used to quantify vegetation community characteristics, their formulas, and interpretation

Index	Formula	Notes
Importance value index (IVI), Soerianegara & Indrawan (1998)	Trees: IVI = RD + RF + RDo Seedlings/shrubs/herbs: IVI = RD + RF With: • Density (D, ind/ha) = (number of individuals of a species) / (plot area, ha) • Frequency (F) = (number of plots containing the species) / (total plots) • Dominance (Do, m²/ha) = (total basal area of a species) / (plot area, ha) • Relative Density (RD, %) = (D of a species / ΣD) × 100 • Relative Frequency (RF, %) = (F of a species / ΣF) × 100 • Relative Dominance (RDo, %) = (Do of a species / ΣDo) × 100	Higher IVI = more dominant/important species
Species Richness (DMg), Margalef (1958)	$DMg = (S - 1) / \ln(N)$	<3.5 = low, 3.5–5.0 = moderate, >5.0 = high
Species Diversity (H′) Shannon-Wiener	$H' = -\sum (pi \ln pi)$ $pi = ni / N$	Higher H′ = more diverse community
Species Evenness (E) Pielou (1975)	$E = H' / \ln(S)$	<0.3 = low, 0.3–0.6 = moderate, >0.6 = high
Species Dominance (C) Simpson (1949)	$C = \sum (ni / N)^2$	0 ≈ no dominance, 1 ≈ single-species dominance

S: number of species, N: total number of individuals, ni = number of individuals of species i, pi: proportion of individuals of species i (ni/N), DBH: diameter at breast height (1.3 m), basal area: cross-sectional stem area from DBH

2.8. Environmental Data

Environmental variables measured in each plot included soil moisture, soil temperature, soil pH, air temperature, air humidity, and light intensity. Soil moisture, soil temperature, and soil pH were measured using a portable 4-in-1 soil analyzer; air temperature and relative humidity were recorded using a digital thermohygrometer; and light intensity was measured using a handheld lux meter. All instruments were commercially available field devices commonly used in ecological surveys and were calibrated according to manufacturer guidelines prior to measurements.

3. Results

3.1. Importance Value Index (IVI)

The Importance Value Index (IVI) highlighted strong contrasts in species dominance across land-use types. In rubber plantations, *Hevea brasiliensis* dominated the tree and pole strata at 10–250 m from the canal (IVI = 142–300%), whereas *Macaranga triloba* became dominant at 350 m. Understorey layers, including seedlings, small shrubs, and herbs, were consistently dominated by the fern *Nephrolepis biserrata* (IVI = 87–200%), indicating the prevalence of light-demanding species under relatively open canopies. Secondary forests exhibited multi-species dominance across all strata. Tree strata were dominated sequentially along the canal-distance gradient by *Sterculia gilva, Cratoxyllum glaucum, Euodia aromatica*, and *Macaranga triloba*. At the same time, pole and sapling/shrub layers included *Glochidion* sp., *Syzygium densiflorum, Sterculia coccinea,* and *Baccaurea bracteata*. Ferns occurred in the understorey but did not suppress woody regeneration, reflecting a more balanced community structure.

Pioneer species strongly dominated burned areas. In Burned Area-1, *Macaranga caladiifolia* and *Euodia ridleyi* alternated as dominant tree species, whereas in Burned Area-2, *E. ridleyi* consistently dominated tree and pole strata across most distances. Understorey vegetation in both burned areas was dominated by ferns, particularly *Stenochlaena palustris, Dicranopteris linearis*, and *Nephrolepis biserrata*. These patterns indicate simplified vegetation structure and limited species turnover across strata, characteristic of successional arrest in post-fire peatlands. Detailed IVI values for each species, vegetation stratum, land-use type, and canal distance are presented in Tables 2 and 3.

Table 2. Dominant plant species (highest IVI) in unburned peatlands by land use and distance from the canal

Plant category	Distance from the canal (m)	Land use			
		Rubber plantation		Secondary forest	
		Species name	IVI (%)	Species name	IVI (%)
Tree	10	*Hevea brasiliensis*	300	*Sterculia gilva*	80.31
	50	*Hevea brasiliensis*	184.75	*Cratoxyllum glaucum*	51.03
	100	*Hevea brasiliensis*	231.13	*Euodia aromatica*	35.88
	250	*Hevea brasiliensis*	142.63	*Euodia aromatica*	30.42
	350	*Macaranga triloba*	157.05	*Macaranga triloba*	47.89
Pole	10	*Hevea brasiliensis*	300	*Glochidion SP*	72.75
	50	*Macaranga triloba*	165.37	*Euodia aromatica*	118.36
	100	*Hevea brasiliensis*	121.88	*Eugenia clariflora*	32.53
	250	*Macaranga triloba*	94.91	*Syzygium densiflorum*	81.93
	350	*Macaranga triloba*	195.74	*Macaranga triloba*	81.23
Sapling and shrub	10	*Melastoma malabathricum*	103.33	*Euodia aromatica*	36.15
	50	*Macaranga triloba*	70.00	*Syzygium densiflorum*	55.56
	100	*Macaranga triloba*	70.00	*Sterculia coccinea*	86.11
	250	*Macaranga triloba; Melastoma malabathricum*	100.00	*Baccaurea bracteata*	48.71
	350	-	-	*Baccaurea bracteata*	40.80
Seedling, small shrub, and herb	10	*Nephrolepis biserrata*	87.21	*Nephrolepis biserrata*	130.56
	50	*Nephrolepis biserrata*	130.56	*Nephrolepis biserrata*	131.96
	100	*Nephrolepis biserrata*	131.69	*Nephrolepis biserrata*	80.12
	250	*Nephrolepis biserrata*	200.00	*Nephrolepis biserrata*	99.24
	350	*Nephrolepis biserrata*	90.91	*Nephrolepis biserrata*	103.65

Table 3. Dominant plant species (highest IVI) in burned peatlands by land use and distance from the canal

Plant category	Distance from the canal (m)	Land use			
		Burned area-1		Burned area-2	
		Species name	IVI (%)	Species name	IVI (%)
Tree	10	*Macaranga caladiifolia*	300.00	*Macaranga triloba*	129.53
	50	*Macaranga caladiifolia*	200.77	*Euodia ridleyi*	166.38
	100	*Melastoma malabathricum*	136.52	*Stemonurus secundiflorus*	63.00
	250	*Macaranga caladiifolia*	300.00	*Macaranga triloba*	120.35
	350	*Macaranga caladiifolia*	85.86	*Euodia ridleyi*	114.66
Pole	10	*Macaranga triloba*	151.76	*Euodia ridleyi*	153.49
	50	*Euodia ridleyi*	138.63	*Euodia ridleyi*	183.05
	100	*Macaranga caladiifolia*	118.12	*Euodia ridleyi*	178.59
	250	*Euodia ridleyi*	160.87	*Euodia ridleyi*	123.16
	350	*Maranthes corymbosa*	141.30	*Euodia ridleyi*	300.00
Sapling and shrub	10	*Euodia redleyi; Hevea brasiliensis*	100.00	*Euodia ridleyi*	54.29
	50	*Melastoma malabathricum*	125.00	*Euodia ridleyi*	108.33
	100	*Euodia ridleyi*	100.00	*Euodia ridleyi*	200.00
	250	*Euodia ridleyi*	200.00	*Macaranga triloba*	113.33
	350	-	-	*Euodia ridleyi*	
Seedling, small shrub, and herb	10	*Stenochlaena palustris*	84.06	*Stenochlaena palustris*	54.86
	50	*Dicranopteris linearis*	48.01	*Nephrolepis biserrata*	49.09
	100	*Nephrolepis biserrata*	52.47	*Stenochlaena palustris*	68.93
	250	*Dicranopteris linearis*	80.30	*Nephrolepis biserrata*	115.25
	350	*Nephrolepis biserrata*	96.85	*Nephrolepis biserrata*	96.61

3.2. Diversity, Richness, Evenness, and Dominance

Vegetation indices reinforced the patterns revealed by IVI. Rubber plantations exhibited the lowest diversity and richness, especially in plots near the canal (H′ = 0.00–1.14; DMg = 0.77–5.74 for trees). Evenness was generally low (E = 0.00–0.71), and dominance was high (C = 0.42–1.00), reflecting strong monodominance by H. brasiliensis. In contrast, secondary forests maintained the highest values across all indices. Tree diversity reached H′ = 2.26–3.14, species richness (DMg) increased up to 31.77, evenness was high (E = 0.80–0.94), and dominance remained low (C = 0.06–0.28), indicating multi-species co-dominance, structural complexity, and stable recruitment across strata.

Burned areas showed generally low diversity and richness (H′ < 1.0; DMg rarely exceeding 3.0), with variable evenness and generally high dominance values (C up to 1.00). These patterns are consistent with vegetation communities dominated by pioneer tree species and dense fern understorey. Occasionally, high richness or diversity values observed in seedling and herb layers represent short-term colonization events by pioneer species rather than stable forest recovery, as woody recruitment remained limited and dominance remained high. A summary of diversity (H′), richness (DMg), evenness (E), and dominance (C) indices across land-use types and canal distances is presented in Table 4.

3.3. Environmental Parameters

Soil moisture and light intensity varied among land-use types. Secondary forests exhibited the highest soil moisture (75–79%) and the lowest light intensity, while burned areas showed the lowest soil moisture (74–76%) and the highest light intensity due to open canopy conditions. Statistical analysis indicated significant differences in soil moisture and light intensity among land-use types (one-way ANOVA, p<0.05). In contrast, West–East differences within land-use types were generally not significant. These environmental patterns corresponded with observed vegetation structures across land-use types (Table 5).

Table 4. Summary of vegetation indices (H′, DMg, E, C) across land-use types and distances from the canal

Plant category	Land-use type	Distance from canal (m)	H′	DMg	E	C
Tree	Rubber plantation	10–250	0.00–1.14	0.77–5.74	0.00–0.71	0.42–1.00
	Secondary forest	10–100	2.26–3.14	4.46–31.77	0.80–0.94	0.06–0.20
	Burned areas	10–350	0.00–1.85	0.00–7.68	0.00–0.95	0.10–1.00
Pole	Rubber plantation	10–250	0.00–1.71	0.56–7.68	0.00–0.99	0.25–1.00
	Secondary forest	50–250	1.49–2.71	5.72–18.74	0.83–0.92	0.08–0.28
	Burned areas	10–350	0.50–1.12	0.58–3.58	0.00–0.95	0.38–0.68
Sapling/shrub	Rubber plantation	10–350	0.00–1.04	0.00–2.28	0.00–1.00	0.00–0.56
	Secondary forest	10–350	1.06–1.83	1.68–8.76	0.48–0.91	0.19–1.00
	Burned areas	10–350	0.00–1.55	0.00–3.38	0.00–1.00	0.28–1.00
Seedling/herb	Rubber plantation	10–350	0.00–0.74	0.79–5.76	0.00–0.46	0.60–1.00
	Secondary forest	10–100	0.07–1.00	1.79–7.79	0.10–0.48	0.00–0.95
	Burned areas	10–350	0.61–1.48	1.79–6.81	0.25–0.95	0.25–0.72

Table 5. Soil moisture, light intensity, and ecological characteristics across different land cover types

Land cover type	Distance from canal (m)	Light intensity (lm/m^2)	Ecological notes
Rubber Plantation	76–78% (no sig. West–East differences)	Moderate–high; significantly higher than secondary forest at 10 m and 50 m	Stable moisture but high light promoted fern invasion and suppressed tree regeneration.
Secondary Forest	75–79% (highest; no sig. differences)	Lowest significant West–East differences at 10 m and 50 m	Balanced IVI and favorable microclimate supported natural regeneration and resilience.
Burned Area 1	74–76% (lowest)	Highest; open-canopy, no sig. differences	Fire reduced soil water retention and canopy cover, enabling pioneer–fern dominance.
Burned Area 2	74–75%	Very high; no sig. differences	Severe disturbance locked the system into the fern-pioneer stage with minimal r

Differences among land-use types were tested using one-way analysis of variance (ANOVA) followed by Tukey's HSD post-hoc test. Differences were considered significant at p<0.05

4. Discussion

The results of the Importance Value Index (IVI) highlighted clear contrasts among rubber plantations, secondary forests, and burned areas. Rubber plantations were strongly dominated by *Hevea brasiliensis*, whereas secondary forests supported multiple co-dominant species across strata, and burned areas exhibited simplified structures dominated by pioneer species. These differences were closely associated with micro-environmental gradients. Soil moisture was highest in secondary forests (75–79%) and lowest in burned areas (74–76%). At the same time, light intensity followed an inverse pattern: dense canopies in secondary forests reduced understorey illumination, while open canopies in plantations and burned lands allowed greater light penetration. Such conditions shaped regeneration dynamics, favoring shade-tolerant species under closed canopies and light-demanding pioneers and ferns in more open environments (Owusu *et al.* 2022; Berhanu *et al.* 2023).

In rubber plantations, *H. brasiliensis* dominated the tree strata, particularly at distances of 10–100 m from canals, before declining at greater distances where pioneer species such as *Macaranga triloba* became more prominent. This pattern reflects a coupled hydrological–disturbance gradient associated with canal proximity, in which areas closer to canals experience stronger drainage effects and greater human accessibility. Light intensity, rather than soil moisture (76–78%), was the primary factor promoting pioneer and fern expansion in these plantations. *Nephrolepis biserrata* reached high IVI values in the understorey, consistent with previous findings that canopy openness favors fern proliferation (Sedayu *et al.* 2022). Although ferns can inhibit woody seedling establishment, they may also contribute to soil stabilization and nutrient cycling (Richardson *et al.* 2012; Lu *et al.* 2023; Azevedo-Schmidt *et al.* 2024). Socio-economic influences, such as smallholder management with limited silvicultural intervention, likely reinforced these patterns; however, this interpretation is based on field observations and supported by comparable studies rather than direct socio-economic measurements (Amare & Simane 2017; Ward *et al.* 2021). Similar patterns reported from rubber agroforestry systems in Lampung suggest that accessibility and low-intensity management facilitate pioneer invasion and the formation of a semi-natural mosaic (Guillaume *et al.* 2016; Wong *et al.* 2020; Febryano *et al.* 2024).

Secondary forests exhibited balanced IVI distributions and high species turnover across distances. Dominant species varied among strata, including *Sterculia gilva, Cratoxyllum glaucum, Euodia aromatica*, and *Macaranga triloba*, reflecting natural successional processes influenced by canopy structure, soil fertility, and micro-topography (Lampela *et al.* 2016; Astiani *et al.* 2021). High diversity (H′ up to 3.14) and richness (DMg up to 31.77) confirmed the presence of structural complexity and continuous recruitment across strata (Poorter *et al.* 2021). Although *N. biserrata* was commonly present, closed canopies limited its competitive dominance, allowing woody regeneration to persist (Satriawan *et al.* 2021; Sibarani *et al.* 2024). Favorable hydrological conditions, characterized by higher soil moisture and lower light intensity, buffered microclimatic extremes and enhanced ecosystem resilience (Lenk *et al.* 2024; Greiser *et al.* 2024). Human disturbance in these forests was minimal, consisting mainly of selective logging and non-timber forest product collection, which created small canopy gaps that increased heterogeneity without substantially reducing canopy integrity (Jakovac *et al.* 2021; Havrdová *et al.* 2023).

Burned areas represented the most degraded conditions, with vegetation dominated by *Macaranga caladiifolia, Euodia ridleyi*, and *Melastoma malabathricum*, accompanied by dense fern mats (*Stenochlaena palustris, Dicranopteris linearis, N. biserrata*). Species diversity was consistently low (H′ < 1.0), and richness rarely exceeded DMg = 3.0. Reduced soil moisture and high light reflected canopy loss and fire-induced peat degradation. These conditions favor pioneer species and ferns and contribute to ecological lock-in, in which feedbacks among vegetation structure, microclimate, and peat properties constrain successional progression (Mueller-Dombois 2000). Occasional increases in diversity within lower strata likely represent short-term recruitment pulses rather than stable recovery, consistent with observations from long-term post-fire peatland studies in Southeast Asia (Vozbrannaya *et al.* 2023).

Patterns of diversity, richness, evenness, and dominance further reinforced these ecological gradients. Rubber plantations exhibited pronounced ecological simplification driven by *H. brasiliensis* monodominance, whereas secondary forests maintained high diversity, richness, and evenness, indicating structurally complex and resilient communities. Burned peatlands remained impoverished with high dominance

values reflecting persistent pioneer–fern assemblages. These patterns demonstrate that vegetation structure in peatlands is shaped by the interaction of land-use type, disturbance history, and canal proximity, while also being influenced by additional factors such as fire severity, peat depth variability, and past management history, which may contribute to site-specific variation.

In conclusion, Land-use type, disturbance history, and distance from canals strongly shape peatland vegetation dynamics. Rubber plantations were dominated by *Hevea brasiliensis* and understorey ferns, particularly in areas closer to canals, resulting in low diversity, richness, and evenness. Secondary forests exhibited multi-species co-dominance, high diversity and richness, and balanced evenness, reflecting structurally complex and resilient communities. Burned peatlands were dominated by pioneer species and ferns, with low diversity and high dominance, suggesting simplified communities and arrested succession. This study demonstrates that canal proximity is an important driver of vegetation patterns by simultaneously lowering water tables and increasing access to disturbance. These effects interact with land-use history and fire disturbance, shaping vegetation composition and structure across peatland landscapes. Management implications of these findings indicate that canal blocking is most effective in burned peatlands, where rewetting can restore hydrological conditions, reduce fire risk, and promote successional recovery. In rubber plantations, canal blocking alone is unlikely to substantially enhance biodiversity. It should be combined with enrichment planting and diversification of tree species to improve structural complexity and ecosystem resilience. Protecting remaining secondary forests is essential, as they function as biodiversity reservoirs and reference ecosystems for peatland restoration.

Data Availability Statement

The dataset analyzed in this study was generated from original field surveys conducted in May 2022 and has not been published elsewhere. The data are available from the corresponding author upon reasonable request.

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Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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