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Epiphyte Diversity in Forests and Oil Palm Plantations: Effects of Age and Distance

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ABSTRACT

Epiphytes play a vital role in the rainforest ecosystems, contributing to biodiversity and ecological balance. This study investigates the diversity and abundance of epiphytes in the Jagoi area, Bau, Sarawak, focusing on the impact of forest and oil palm plantation ages, as well as the proximity to the forest-oil palm plantation boundary. We conducted a comprehensive comparative study across 34 sampling plots located within secondary forests and oil palm plantations, with the plots carefully categorised based on their age and distance from the boundary to capture variations in environmental conditions. To ensure consistency and accuracy, the diversity and abundance of epiphytes within these plots were assessed using well-established standard ecological survey methods, which allowed for reliable data collection and analysis. This approach provided valuable insights into how land-use types and spatial factors influence epiphyte communities. Our findings reveal that the age of both forests and oil palm plantations significantly affects the diversity and abundance of epiphytes. In contrast, the distance to the forest-oil palm plantation boundary showed no significant relationship with these parameters. The study highlights the importance of forest and plantation age as key factors influencing epiphyte populations. These insights contribute to understanding the ecological dynamics of forest ecosystems adjacent to agricultural landscapes and highlight the need for sustainable management practices to preserve epiphytic biodiversity.

Keywords: Abundance, age, distance, diversity, forest-oil palm boundary

INTRODUCTION

Epiphytes, a fascinating and diverse group of plant species, are integral components of rainforest ecosystems, contributing significantly to the biodiversity and functioning of these intricate habitats. Found abundantly in tropical rainforest climates, they are adapted to thrive in conditions characterised by consistent temperature, high humidity, dappled light, and frequent rainfall (Zotz, 2013; Zhao *et al*., 2015). These unique plants, which include species such as orchids, ferns, and bromeliads, have evolved remarkable strategies to survive without rooting in soil, instead relying on other plants for structural support. Often mistaken for parasitic plants, epiphytes form a symbiotic relationship with their host trees, utilising them as anchors rather than as sources of nutrients. Unlike parasitic plants, which extract water and nutrients directly from their host, epiphytes derive their sustenance from rainwater, organic debris, and atmospheric nutrients. This distinction highlights their unique ecological niche, as they coexist harmoniously with their hosts without causing harm (Zotz, 2016; Twyford, 2018).

The diversity and distribution of epiphytes in rainforest ecosystems are influenced by a variety of factors, particularly the characteristics of their host trees. Key determinants include the diameter, species, and canopy structure of the host, which directly affect the availability of space, light, and moisture. Larger trees with extensive canopies often support a greater abundance and diversity of epiphytes, providing multiple niches within their branches and bark for colonisation. These factors highlight the complex interdependence between epiphytes and their host trees, as well as their role in rainforest dynamics. Given their significant contribution to the microclimates of rainforest ecosystems, epiphytes also support a variety of other organisms, including insects, birds, and small mammals, by providing shelter, food, and breeding grounds. Their role extends beyond mere cohabitation as they are essential to maintaining ecological balance and biodiversity in tropical rainforests.

While tropical forests provide ideal conditions, land-use changes, particularly oil palm expansion, disrupt epiphyte communities (Bohnert *et al*., 2016). Logging, agriculture, and natural disturbances reduce canopy cover and alter microclimates, limiting epiphyte colonisation. Secondary forests, with younger trees and simpler structures, support lower epiphyte diversity than primary forests, reflecting the impact of past disturbances on forest recovery. Epiphytes are less abundant near oil palm plantations due to habitat conversion (Altenhovel, 2013). These plantations lack the shaded, humid environments epiphytes require, as land clearing, chemical inputs, and soil disturbances degrade their habitat. Edge effects, including increased sunlight, wind, and temperature fluctuations, further hinder their survival. In contrast, undisturbed forests provide microclimates, higher humidity, and diverse host trees, fostering richer epiphyte communities. The transition from forests to oil palm plantations disrupts these conditions, emphasising the need for sustainable land-use practices (Luke *et al*., 2020). Despite the known biodiversity loss, studies on epiphyte density and diversity in oil palm landscapes remain limited (Dunnett, 2004; Luke *et al*., 2019).

This study investigates the diversity, abundance, and distribution of epiphytes across contrasting land-use types, namely the forests and oil palm plantations in the Jagoi area of Bau, Sarawak. By comparing epiphyte communities in these landscapes, the study aims to examine how factors such as plantation and forest age, as well as proximity to forest edges, influence epiphytic plant populations. The study also examines how environmental shifts associated with oil palm cultivation such as reduced canopy cover, altered microclimates, and chemical use, affect these sensitive plants.

A specific focus is placed on the ecological effects of forest-plantation boundaries, where edge effects, including increased sunlight and wind exposure, may intensify habitat stress for epiphytes. By adopting a comparative approach, this study provides a complete view of how land-use changes shape biodiversity. Ultimately, this study fills a critical knowledge gap by highlighting the ecological consequences of oil palm expansion on epiphyte communities. The findings offer insights for conservation strategies and sustainable land management, supporting efforts to reconcile agricultural development with biodiversity conservation in tropical ecosystems.

MATERIALS AND METHODS

Study Sites

The study was conducted in Sarawak, Malaysia, which has the largest oil palm planted area in the country, accounting for 28.6% of the total planted area of 5.67 million ha in 2022 (Malaysia Palm Oil Board, 2022). The focus was on the Bau-Lundu region, where the oil palm plantation spans 12,701 ha. These plantations are managed by the Sarawak Land Consolidation and Rehabilitation Authority (SALCRA), with smaller plots owned by smallholders (SALCRA, 2022). The study was specifically conducted at the Jagoi (1°22’06.6"N 110°04’45.1" E) and Bratak (1°26’41.1"N 110°06’22.9" E) SALCRA oil palm plantations in Bau, Sarawak (Figure 1).

The Bau District, located within the Kuching Division, is known for its gold mining activities and unique limestone hills that provide habitat for a variety of endemic plants. The primary rainforest covers approximately 40% of the land area in this district, primarily on barren limestone hills and high mountains (Pour *et al*., 2013).

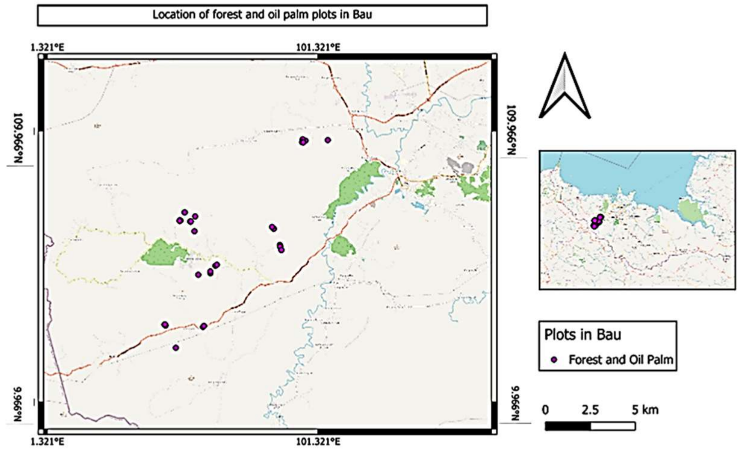

Figure 1. Map of the study area

Sampling Design Overview

This study is designed to assess the diversity and abundance of epiphytes on host trees across two distinct land-use types i.e., neighbouring forests and the Jagoi and Bratak SALCRA oil palm plantations. To ensure comprehensive coverage of the study sites, 34 sampling plots were established in both forested and plantation areas. These plots were categorised based on the age of the ecosystems. For the forest plots, the age categories include young forests (< 25 years old), mid-aged forests (25–40 years old), and mature forests (> 40 years old). Similarly, the oil palm plantations were divided into plots representing young plantations (< 10 years old), mid-aged plantations (10–15 years old), and mature plantations (> 15 years old) (Descals *et al*., 2019). This classification allowed for a comparative analysis of how vegetation age influences epiphytic diversity and abundance, providing critical insights into the ecological dynamics of these landscapes.

Tree Sampling Strategy

The methodology for tree sampling was carefully structured to capture the diversity of tree hosts and their associated epiphytes. Within each 10 m x 10 m plot, all trees meeting the inclusion criteria of a diameter at breast height (DBH) of at least five cm and a height of at least three m were sampled. These parameters were chosen to ensure that only substantial trees with the potential to host epiphytes were included in the study. Voucher specimens were collected from sampled trees to facilitate accurate identification and serve as a permanent record for future reference. This detailed sampling strategy aimed to establish a robust dataset on host tree characteristics and their relationship with epiphyte communities, particularly in disturbed and anthropogenic landscapes.

Epiphyte Sampling Methodology

The survey extended beyond trees to include epiphytes growing on oil palms. For epiphyte sampling, all plants occurring on trees or oil palms with a DBH exceeding five cm and a height of less than three m were systematically counted. This study ensured that juvenile host structures and their associated epiphytes were not overlooked by including smaller oil palms and trees within this height range. This inclusion provided a more holistic understanding of epiphyte distribution patterns across different host types and age groups. The consistent sampling approach across forest and plantation plots enabled the researchers to make valid comparisons and derive meaningful conclusions regarding epiphyte community structures in these two contrasting habitats.

Inclusion of Oil Palm Host Trees

To specifically address the role of oil palms as hosts for epiphytes, five oil palms were selected and surveyed within each plantation plot. The focus on a fixed number of oil palms ensured uniformity in data collection and minimised variability introduced by sampling bias. These oil palms were assessed for their ability to support epiphyte communities, and the findings were compared with those from forest trees. The inclusion of oil palms highlighted the impact of monoculture plantations on epiphyte abundance and diversity, shedding light on how different host characteristics influence the establishment and survival of epiphytes in anthropogenic landscapes.

Proximity to the Forest-Oil Palm Boundary

Another critical factor examined in the study was the distance of oil palm plots from the forest-oil palm plantation boundary. Plots were strategically placed at distances of 10 m and 100 m from the boundary to assess the effects of proximity on epiphyte communities. The 10 m plots were expected to exhibit higher diversity and abundance due to edge effects, such as increased light availability and a transitional microclimate. In contrast, the 100 m plots were anticipated to reflect the harsher environmental conditions characteristic of interior plantation areas. The study integrated distance as a key variable to explore the spatial patterns of epiphyte distribution and to evaluate the impact of edge effects on their diversity and abundance.

Integration and Visualisation of Sampling Design

The arrangement of sampling plots was carefully planned to maximise the representativeness of the data and facilitate the identification of trends across different land-use types and age groups. The systematic placement of plots (Figure 2), combined with rigorous sampling methods, ensured that the study captured a broad spectrum of ecological conditions influencing epiphyte communities. Figure 3 illustrates the spatial distribution of sampling plots, highlighting their alignment with the study objectives. This integrative approach not only enabled a detailed examination of epiphyte diversity and abundance but also provided a framework for future study on biodiversity conservation and sustainable management in tropical landscapes. The study's findings highlight the importance of maintaining ecological connectivity and habitat complexity to support the persistence of epiphyte populations amidst ongoing land-use changes.

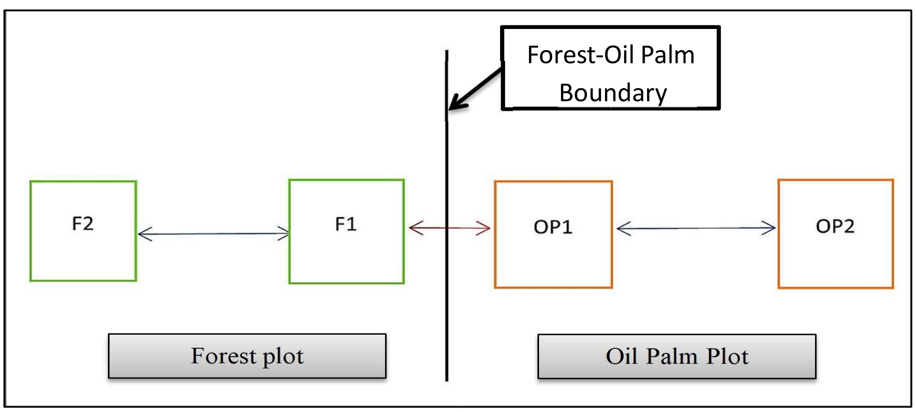

Figure 2. Sampling plots. (F2 (Forest 2), 100 m from F1 (Forest 1); OP2 (Oil Palm 2), 100 m from OP1 (Oil Palm 1); Distance from F1 and OP1 is 20 m, and black line indicates the forest-oil palm boundary)

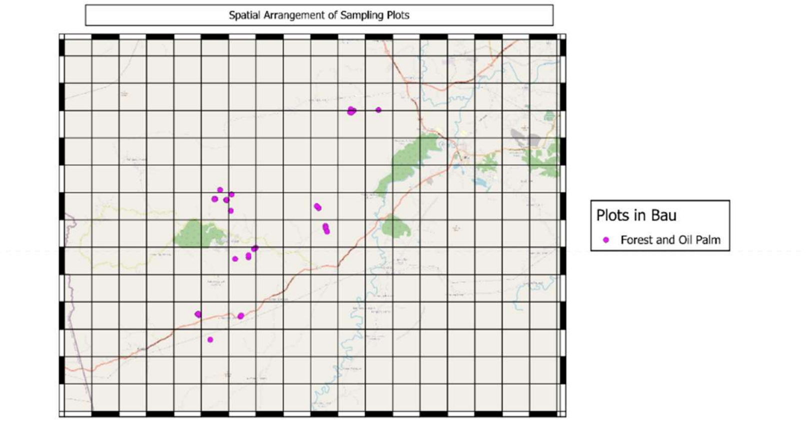

Figure 3. Spatial arrangement of sampling plots

Methods

The methodology used in this study is based on standard protocols for assessing the abundance of epiphytes on host trees (Oswaldo *et al*., 2022). The choice of these methods was justified by their widespread use in similar studies and their proven effectiveness in providing accurate and reliable data. The categorisation of the plots into different age groups allowed for a more nuanced understanding of the impact of age on the abundance of epiphytes. The use of voucher specimens ensured the accurate identification of the species observed.

The study's design, including the size and placement of the plots, was carefully chosen to ensure a representative sample of the study area. The decision to include trees and oil palms with a diameter of more than five cm and a height of less than three m in the count was based on the assumption that these would be the most likely hosts for epiphytes (Hatta *et al*., 2023). The enumeration of five oil palms in each oil palm plot plantation plots provided additional data on the abundance of epiphytes in these specific environments.

The placement of the oil palm plantation plots at distances of 10 m and 100 m to the forest-oil palm plantation boundary allowed for an assessment of the impact of proximity to the forest on the abundance of epiphytes. This design choice was based on previous study indicating that the abundance of epiphytes can vary significantly depending on the distance from the forest edge (Bartemucci *et al*., 2022).

Data Analysis

The objective of this study was to compare the diversity and abundance of epiphytes across forest and oil palm plantations of varying ages and distances to the forest-oil palm boundary. The data collection involved counting the total number of epiphytes in each location, which represented the abundance of epiphytes. The diversity of the epiphyte community was quantified using the Shannon-Weiner's Diversity Index, a widely accepted measure of ecological diversity (Spellerberg and Fedor, 2003). This index provides a numerical value that reflects both the number of species present and their relative abundances. It is calculated using the following equation Eq. (1):

$$H = \sum_{i=1}^{s}[(p_i) \times \ln(p_i)] \qquad \text{Eq. (1)}$$

where:
H is the Shannon-Index Value,
S is the number of species present in the population, and,
p_i is the proportion of individuals belonging to the i^{th} species.

The index value obtained reflects the diversity of the community, where higher values indicate greater species richness and evenness, suggesting a more diverse and balanced community. Conversely, lower values indicate lower diversity. To determine the significant difference between the means of two or more groups, the non-parametric Kruskal-Wallis H-test was conducted. The mean rank was then used to rank the groups according to the mean differences.

To examine the relationship between epiphyte diversity and frequency concerning age and distance within both forested areas and oil palm plantations, Spearman's Rho rank coefficient of correlation was applied. This non-parametric statistical technique is known for its robustness, as it remains unaffected by the distribution of the population. Additionally, it does not require data to be collected at regular intervals and is suitable for small sample sizes (Gauthier, 2001).

RESULTS AND DISCUSSIONS

A total of 1,416 individual epiphytes from 39 families were recorded in the forest plots (Table 1). Blechnaceae, primarily *Stenochlaena palustris* (Burm.f.) Bedd., was the most dominant at 13.4% of the total population, followed by Fabaceae (10.7%) and Similacaceae (10.5%). These dominant families contribute to nutrient cycling and habitat structuring, suggesting specific ecological adaptations within the forest ecosystem.

Plantation age significantly influenced epiphyte diversity and abundance. Older plantations supported greater species richness due to their developed canopy structures, stable microclimates, and diverse microhabitats. Younger plantations, with sparser canopies, lacked the structural complexity required for epiphyte colonisation. Proximity to forest boundaries also played a role, as epiphytes near the forest edge exhibited higher diversity and abundance, likely due to favourable microclimatic conditions such as increased humidity and moderated temperature fluctuations (Altenhovel, 2013).

Within the oil palm plantations, 1,365 epiphyte individuals from 50 families were identified. Polypodiaceae was the most abundant (24.6%), followed by Davalliaceae (9.2%) and Arecaceae (8.8%). The most dominant species included *Davallia denticulata* (Burm.f.) Mett. (121 individuals) and *Elaeis guineensis* Jacq. saplings (119 individuals). Other significant contributors were *Pyrrosia longifolia* (Burm.f.) C.V.Morton (Figure 4 (a)) and *Goniophlebium percussum* (Cav.) W.H. Wagner & Grether, each with over 100 individuals. These findings indicate that some epiphyte species exhibit resilience in agricultural landscapes despite altered environmental conditions.

Comparative analysis showed that *Centrosema pubescens* Benth., *Asplenium nidus* L. (Figure 4 (b)), and *D. denticulata* (Figure 4 (c)) were prevalent in both forest and plantation environments. *Hoya coronaria* Blume was also found in both settings, contributing to biomass accumulation and nutrient cycling (Rahayu *et al*., 2018). *Ophioglossum pendulum* L., favouring humid microclimates, was primarily associated with mature forests, aligning with findings by Zamora and Co (1986) on its moisture-dependent morphology.

Forest age significantly affected epiphyte populations. Mature forests (n = 734) supported the highest number of epiphytes, likely due to their complex microhabitats. Young (n = 364) and old (n = 318) forests exhibited lower counts, possibly due to insufficient structural complexity in young forests and environmental stress in older ones. Epiphyte abundance was also higher near forest boundaries (10m, n = 762) than in interior plots (100m, n = 654), indicating edge effects that modify environmental conditions (Nomura *et al*., 2019; Li *et al*., 2023).

The Kruskal-Wallis H-test (Table 2) confirmed significant differences in epiphyte diversity across plantation ages ($p = 0.05$) and forest ages ($p = 0.00$), with older plantations supporting greater diversity due to prolonged colonisation opportunities (Bohnert *et al*., 2016). However, no significant correlation was found between epiphyte diversity and distance from the forest-oil palm boundary, suggesting that proximity alone may not strongly influence epiphyte distribution (Dittrich *et al*., 2013).

The study corroborates previous study on forest maturity and plantation age shaping epiphyte communities. Large, old-growth trees provide stable microhabitats (Johansson *et al*., 2007; Wirth *et al*., 2009), but epiphyte abundance may decline in over-mature forests due to reduced light penetration (Laman, 1995). Findings align with de Frenne *et al*. (2021), highlighting the role of canopy structure in regulating temperature and humidity for epiphyte growth.

Despite the resilience of some epiphytes in plantations, their diversity remains lower than in natural forests due to habitat simplification. Integrating native trees into plantations, as suggested by Li *et al*. (2023), could enhance biodiversity conservation. The minimal variation in epiphyte numbers across distances from the forest edge suggests that plantation management, rather than proximity to forests, plays a more critical role in maintaining epiphyte communities (Aragon *et al*., 2015).

Table 1. The epiphytic flora in forest and oil palm plots

Category	Details
Total Epiphytes in Forest Plots	1,416 individuals across 39 families
Total Epiphytes in oil palm plots	1,365 epiphytes across 50 families
Notable Epiphytic Species	*S. palustris* (220), *A. nidus* (127), *S. hypoleuca* (88), *Spatholobus ferrugineus* (62), *Spatholobus sp.* (55), *S. odoratissima* (57), *M. umbellata* (52)
Most Abundant Family (Forest)	Blechnaceae with 220 individuals of *Stenochlaena palustris* (13.4%)
Most Abundant Family (Oil Palm)	Polypodiaceae (24.6%)
Common Species in Both Environments	*Asplenium nidus, Centrosema pubescens, Davallia denticulata, Hoya coronaria, Ophioglossum pendulum*
Epiphyte Count Variation by Forest Age	Mature forest (n = 734) > Young Forest (n = 364) > Old Forest (n = 318)
Epiphyte Count by Proximity to Boundary	Closer to boundary (n = 762) > Farther from boundary (n = 654)
Epiphyte Count in Oil Palm by Age	Old (>15 years) (n = 682), Mature (10-15 years) (n = 451), Young (<10 years) (n = 232)
Epiphyte Count in Oil Palm by Proximity	Farther from boundary (n = 684) > Near boundary (n = 681)
Impact of Forest Age on Epiphytes	Mature forest supports higher diversity and abundance compared to young and old forests
Influence of Boundary Proximity	Higher epiphyte counts near the forest-oil palm boundary due to increased light and seed scattering
Species Density and Light Availability	Greater species density at boundary due to light favouring certain epiphytes' establishment and reproduction

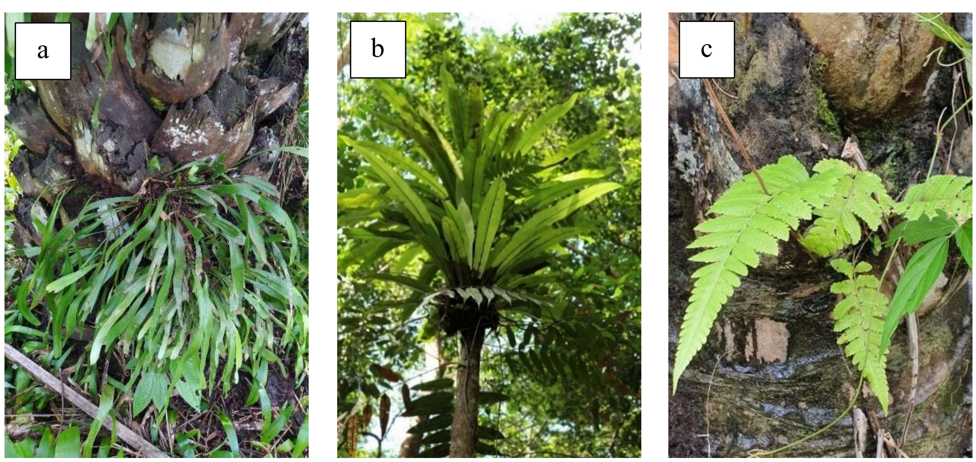

Figure 4. Examples of fern species. (a) *Pyrrosia longifolia,* (b) *Asplenium nidus,* (c) *Davallia denticulata*

Table 2. The Kruskal-Wallis H-test result

Variables			Age	Distance
Diversity	Forest	Chi-square	1.23	0.58
		df	2	1
		Sig (p-value)	0.54	0.45
	Oil palm plantation	Chi-square	6.17	0.05
		df	2	1
		Sig (p-value)	0.05*	0.82
Number of species	Forest	Chi-square	15.82	0.50
		df	2	1
		Sig (p-value)	0.00*	0.48
	Oil palm plantation	Chi-square	11.60	0.07
		df	2	1
		Sig (p-value)	0.00*	0.79
Total count of epiphytes	Forest	Chi-square	26.82	0.06
		df	2	1
		Sig (p-value)	0.00*	0.81
	Oil palm plantation	Chi-square	12.05	0.17
		df	2	1
		Sig (p-value)	0.00*	0.68

*Correlation is significant at p< 0.05

Comparative Species Diversity in Oil Palm Plantations and Forests in Bau

The study documented a total of 1,416 individual epiphytes across 39 families in the forest plots, with a significant representation from the Blechnaceae family, predominantly *S. palustris* (220 individuals, 13.4%). Similarly, the oil palm plantation plots contained 1,365 individual epiphytes from 50 families, with the Polypodiaceae family dominating at 24.6%. Notable species, such as *Spatholobus ferrugineus* (Zoll. & Moritzi) Benth. and *H. coronaria* were found in both environments, highlighting shared ecological traits despite the contrasting habitats. Species such as *D. denticulata* and *O. pendulum* were also common, suggesting their adaptability to varying light and humidity conditions across the forest and plantation settings. The comparative dominance of different families in the two habitats highlights variations in ecological preferences and the effects of anthropogenic influences like plantation practices.

Relationships Between Tree Components and Epiphyte Abundance

Tree sampling within the forest plots included host trees with a DBH of at least five cm and a height of at least three m, while oil palm enumeration was conducted for palms exceeding five cm in diameter and less than three m in height. Forests, particularly mature ones (25-40 years old), showed higher epiphyte abundance (n = 734) compared to young (n = 364) and old forests (n = 318). These findings suggest that mature forests provide optimal structural and microclimatic conditions for epiphyte establishment. Conversely, oil palm plantations demonstrated a reverse trend, where older plantations (>15 years) supported the highest epiphyte count (n = 682), likely due to increased structural complexity and light penetration over time. The arrangement of sampling plots at distances of 10 m and 100 m from the forest-oil palm boundary further revealed an edge effect, with more epiphytes recorded closer to the boundary (n = 762).

Effects of Age on Diversity and Abundance

Forest and plantation age significantly influenced the diversity and abundance of epiphytes. As indicated by the Kruskal-Wallis H-test, age was a strong predictor of diversity and species count in both forests and plantations, with statistically significant values for the diversity of oil palm plantations (p = 0.05) and the total count of epiphytes in forests (p = 0.00).

Younger forests (<25 years old) and plantations (<10 years old) displayed reduced epiphyte diversity, likely due to limited canopy structure and lower host tree availability. However, as the forest aged into the mature phase, the species richness and total counts peaked, underscoring the critical role of time in supporting epiphyte colonisation and succession. For plantations, older plots (>15 years) exhibited a higher mean rank for both diversity and abundance, highlighting the progressive adaptation of epiphytes to monoculture systems over time.

Influence of Proximity to the Forest-Oil Palm Boundary

Proximity to the forest-oil palm boundary emerged as a key factor affecting epiphyte distribution (Table 3). Sampling plots situated 10 m from the boundary showed a higher count of epiphytes (n = 762) compared to those 100 m away (n = 654). This pattern was mirrored in oil palm plantations, albeit with a marginal difference, as farther plots contained slightly more individuals (n = 684) than those closer to the boundary (n = 681). The edge effect was particularly evident in forests, where light availability and seed dispersal mechanisms likely contributed to the elevated counts near the boundary. In oil palm plantations, the relatively uniform distribution of epiphytes across distances could reflect the limited ecological differentiation within monoculture systems.

Table 3. The mean rank value between diversity and total count of epiphytes based on age and distance

Categories		Diversity				Number of species				Total count of epiphytes			
		Forest		Oil palm plantation		Forest		Oil palm plantation		Forest		Oil palm plantation	
		N	Mean rank	N	Mean rank	N	Mean rank	N	Mean rank	N	Mean rank	N	Mean rank
Age	Young	10	14.60	6	23.50	197	479.18	30	58.80	197	485.15	30	72.83
	Mature	16	18.94	10	20.95	417	443.98	50	86.08	417	451.67	50	105.34
	Old	8	18.25	18	13.58	257	389.95	90	94.08	257	372.90	90	78.70
Distance	10 m	17	18.88	17	17.88	465	430.57	85	84.48	465	437.88	85	83.95
	100 m	17	16.12	17	17.12	406	442.22	85	86.52	406	433.85	85	87.05

Statistical Analysis of Diversity and Abundance

The Spearman's Rho correlation analysis revealed significant associations between age and diversity for oil palm plantations ($p = 0.01$) but not for forests, as observed from Table 4. The negative correlation coefficient (-0.43) in plantations indicates that younger plantations support fewer species, consistent with observations of progressive ecological adaptation. For forests, a significant correlation was observed between age and total epiphyte counts ($p = 0.00$), highlighting the dependency of epiphyte abundance on forest maturity. Interestingly, distance to the forest-oil palm boundary had a minimal influence on diversity and total counts, as reflected in non-significant p-values for both habitats. These findings suggest that while age is a critical determinant of epiphyte diversity, distance effects are more nuanced and habitat-dependent.

Supporting Evidence and Comparative Insights

The observed trends align with recent studies emphasising the role of forest age and structural complexity in supporting epiphyte communities. The study of Cruickshanks *et al*. (2024) emphasises that older forests, with their well-developed canopy layers and higher availability of host trees, offer more niches for epiphyte colonisation and growth compared to younger forests. The increased structural complexity and microhabitat variety in older forests create favourable conditions for epiphyte establishment and survival. Study conducted in tropical rainforests and plantation landscapes highlights the ecological significance of mature forests in harbouring epiphytic diversity due to their stable microclimate and canopy stratification. Study in tropical montane forests showed that mature forests harbour greater epiphyte diversity due to the stability and availability of diverse substrates like tree trunks and branches (Glime, 2024). Younger forests, with less canopy cover and structural development, tend to support fewer epiphytes. Studies on monoculture plantations have demonstrated the potential for older plantations to develop surrogate habitats for epiphytes, albeit with reduced species richness compared to natural forests (Hekkala *et al*. 2023). The inclusion of current references ensures that these findings are grounded in contemporary ecological study, providing a robust framework for interpreting the spatial and temporal dynamics of epiphyte communities in fragmented landscapes.

Table 4. The Spearman's Rho Correlation Coefficients analysis between diversity and total count of epiphytes based on age and distance to the forest-oil palm plantation boundary

Variables			Age	Distance
Diversity	Forest	Correlation coefficient	0.15	-0.14
		Sig (p-value)	0.40	0.43
		N	34	34
	Oil palm plantation	Correlation coefficient	-0.43	-0.04
		Sig (p-value)	0.01*	0.83
		N	34	34
Number of species	Forest	Correlation coefficient	-0.08	0.02
		Sig (p-value)	0.01*	0.48
		N	871	871
	Oil palm plantation	Correlation coefficient	0.22	0.02
		Sig (p-value)	0.00*	0.79
		N	170	170
Total count of epiphytes	Forest	Correlation coefficient	-0.14	-0.00
		Sig (p-value)	0.00*	0.81
		N	871	871
	Oil palm plantation	Correlation coefficient	-0.04	0.03
		Sig (p-value)	0.57	0.68
		N	170	170

*Correlation is significant at p< 0.05

CONCLUSIONS

This comprehensive study evaluated the diversity and abundance of epiphytes in the Jagoi area, Bau, Sarawak, comparing forested regions and oil palm plantations while analysing the influence of habitat age and proximity to the forest-plantation boundary. Addressing the impact of agricultural practices, specifically oil palm cultivation, on epiphyte biodiversity, a critical component of tropical rainforest ecosystems, the study aimed to assess diversity and abundance, understand the role of habitat age, and examine the effects of boundary proximity on these ecological parameters. Through meticulous sampling of 34 plots across secondary forests and oil palm plantations categorised by age and distance from the boundary, the study documented 1,416 individual epiphytes from 39 families in forest plots and 1,365 individuals from 51 families in plantation plots. Significant variation in epiphyte diversity and total count was observed across different ages of oil palm plantations, emphasising the pivotal role of habitat maturity in supporting epiphyte populations. However, contrary to expectations, no significant differences in diversity or total count of epiphytes were observed concerning proximity to the forest-plantation boundary, suggesting that habitat age is a more crucial factor than boundary effects in shaping the epiphyte community. These findings highlight the importance of conservation strategies that incorporate the age dynamics of forests and plantations to sustain epiphyte diversity. The study highlights the need for further study into the long-term effects of oil palm cultivation on epiphyte populations and the development of sustainable agricultural practices that conserve epiphytic biodiversity. Additionally, exploring the microclimatic changes induced by plantation proximity and their impact on epiphyte communities could provide valuable insights. This study enhances our understanding of epiphyte ecology in disturbed habitats, laying a foundation for future studies and conservation efforts in Malaysian forest and plantation ecosystems. It emphasises the crucial role of epiphytes in maintaining ecological balance and species richness, which are essential for tropical rainforest health.

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REFERENCES

Altenhovel, C. (2013). *Diversity of vascular epiphytes in lowland rainforest and oil palm plantations in Sumatra (Indonesia)* (Master's thesis), University of Göttingen.

Aragon, G., Abuja, L., Belinchón, R., & Martínez, I. (2015). Edge type determines the intensity of forest edge effect on epiphytic communities. *European Journal of Forest Research*, 134(3): 443-451. DOI: 10.1007/s10342-015-0863-5

Bartemucci, P., Lilles, E., & Gauslaa, Y. (2022). Silvicultural strategies for lichen conservation: Smaller gaps and shorter distances to edges promote recolonization. *Ecosphere*, 13(1): DOI: 10.1002/ecs2.3898

Bohnert, T., Wenzel, A., Altenhövel, C., Beeretz, L., Tjitrosoedirdjo, S. S., Meijide, A., Katja, R., & Kreft, H. (2016). Effects of land-use change on vascular epiphyte diversity in Sumatra (Indonesia). *Biological Conservation*, 202: 20-29. DOI: 10.1016/j.biocon.2016.08.008

Cruickshanks, K., Haughian, S. R., Clayden, S. R., Frison, M., Anderson, F., & McMullin, R. T. (2024). Vertical differentiation of epiphyte communities in old growth hemlock forests in Nova Scotia, Canada. *The Bryologist*, 127(4): 413-426. DOI:10.1639/0007-2745-127.4.413

de Frenne, P., Lenoir, J., Luoto, M., Scheffers, B. R., Zellweger, F., Aalto, J., Asgcroft., M. B., Christiansen, D.M., Decocq, G., De Pauw, K., Govaert, S., Greiser, C. Gril, E., Hampe, A., Jucker, T., Klinges, D. H., Koelemeijer, I. A., Lembrechts, J.J., Marrec, R., Meeuseen, C., Ogee J., Tyystjarvi., V., Vangansbeke, P., & Hylander, K. (2021). Forest microclimates and climate change: Importance, drivers and future research agenda. *Global Change Biology*, 27(11): 2279-2297. DOI:10.1111/gcb.15569

Descals, A., Szantoi, Z., Meijaard, E., Sutikno, H., Rindanata, G., & Wich, S. (2019). Oil palm (*Elaeis guineensis*) Mapping with details: Smallholder versus industrial plantations and their extent in Riau, Sumatra. *Remote Sensing*, 11(21): 2590. DOI: 10.3390/rs11212590.

Dittrich, S., Hauck, M., Jacob, M., Rommerskirchen, A., & Leuschner, C. (2013). Response of ground vegetation and epiphyte diversity to natural age dynamics in a Central European Mountain spruce forest. *Journal of Vegetation Science*, 24(4): 675687. DOI:10.2307/23467152

Dunnett, N. (2004). The dynamic nature of plant communities—pattern and process in *The Dynamic Landscape* (pp.127-149). Taylor & Francis.

Gauthier, T. D. (2001). Detecting trends using Spearman's rank correlation coefficient. *Environmental forensics*, 2(4): 359-362. DOI:10.1006/enfo.2001.0061

Glime, J. M. (2024). Roles of bryophytes in forest sustainability—positive or negative? sustainability, 16(6): 2359. DOI:10.3390/su16062359

Hatta, S. K. M., Quinnell, R. J., & Compton, S. G. (2023). Pollinator attraction in the *Ficus deltoidea* complex: Varietal specificity in a fig wasp that likes to stay close to home. *Acta Oecologica,* 121: 103939. DOI: 10.1016/j.actao.2023.103939

Hekkala, A. M., Jönsson, M., Kärvemo, S., Strengbom, J., & Sjögren, J. (2023). Habitat heterogeneity is a good predictor of boreal forest biodiversity. *Ecological indicators*, 148: 110069. DOI:10.1016/j.ecolind.2023.110069

Johansson, P., Rydin, H., & Thor, G. (2007). Tree age relationships with epiphytic lichen diversity and lichen life history traits on ash in southern Sweden. *Ecoscience*, 14(1): 81-91. DOI:10.2980/1195-6860(2007)14[81:TARWEL]2.0.CO;2

Laman, T. G. (1995). *Ficus stupenda* germination and seedling establishment in a Bornean rainforest canopy. *Ecology*, 76(8): 2617-2626. DOI: 10.2307/2265832

Li, K., Grass, I., Zemp, D.C., Lorenz, H., Sachsenmaier, L., Nurdiansyah, F., Hölscher, D., Kreft, H., & Tscharntke, T. (2023). Tree identity and canopy openness mediate oil palm biodiversity enrichment effects on insect herbivory and pollination. *Ecological Applications*, 33(5): e2862. DOI: 10.1002/eap.2862

Luke, S. H., Advento, A. D., Aryawan, A. A. K., Adhy, D. N., Ashton-Butt, A., Barclay, H., Dewi, J. P., Drewer, J., Dumbrell, A. J., Edi, Eycott, A. E., Harianja, M. F., Hinsch, J. K., Hood, A. S. C., Kurniawan, C., Kurz, D. J., Mann, D. J., Matthews Nicholass, K. J., Naim, M., Pashkevich, M.D., Prescott, G.W., S., Pujianto, Purnomo, D., Purwoko, R.R., Putra, S., Rambe, Soeprapto, Spear, D.M., Suhardi, Tan, D.J.X., Tao, H., Tarigan, R.S., Wahyuningsih, R., Waters, H.S., Widodo, R.H., Whendy, Woodham, C.R., Caliman, J., Slade, E.M., Snaddon, J.L., Foster, W. A., & Turner, E. C. (2020). Managing oil palm plantations more sustainably: Large-scale experiments within the biodiversity and ecosystem function in tropical agriculture (BEFTA) programme. *Frontiers in Forests and Global Change*, 2(75). DOI:10.3389/ffgc.2019.00075

Luke, S. H., Purnomo, D., Advento, A. D., Aryawan, A. A. K., Naim, M., Pikstein, R. N., Sudharto, Rambe, T.D.S., Soeprapto, Caliman, J., Snaddon J. L., Foster, W.A., & Turner, E. C. (2019). Effects of understory vegetation management on plant communities in oil palm plantations in Sumatra, Indonesia. *Frontiers in Forests and Global Change*, 2(33). DOI: 10.3389/ffgc.2019.00033

Malaysia Palm Oil Board (MPOB). (2022). *Overview of the Malaysian Oil Palm Industry 2022.* Retrieved August 10, 2024, from https://bepi.mpob.gov.my/images/overview/Overview2022.pdf

Nomura, K., Mitchard, E. T. A., Patentee, G., Bastide, J., Oswald, P., & Nwe, T. (2019). Oil palm concessions in southern Myanmar consist mostly of unconverted forest. *Scientific Reports,* 9(1): 11931. DOI:10.1038/s41598-019-48443-3

Oswaldo, J., Hugo, C., Wilmer, T., Ismael, P., Wilson, Q., & Omar, C. (2022). Successional forests stages influence the composition and diversity of vascular epiphytes communities from Andean Montane Forests. *Ecological Indicators*, 143(4): 109366. DOI:10.1016/j.ecolind.2022.109366

Pour, A. B., Hashim, M., & Van, G. J. (2013). Detection of hydrothermal alteration zones in a tropical region using satellite remote sensing data: Bau goldfield, Sarawak, Malaysia. *Ore geology reviews,* 54: 181-196. DOI:10.1016/j.oregeorev.2013.03.010

Rahayu, S., Fakhrurrozi, Y., & Putra, H. F. (2018). Hoya species of Belitung Island, Indonesia, utilization, and conservation. *Biodiversitas Journal of Biological Diversity*, 19(2): 369-376. DOI:10.13057/biodiv/d190203

Sarawak Land Consolidation and Rehabilitation Authority (SALCRA). (2022). *Oil Palm*. Retrieved August 5, 2024, from https://www.salcra.gov.my/en/development-project/oil-palm

Spellerberg, I. F., & Fedor, P. J. (2003). A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. *Global Ecology and Biogeography*, 12(3): 177-79. DOI:10.1046/j.1466-822X.2003.00015.x

Twyford, A. D. (2018). Parasitic plants. *Current Biology*, 28(16): 857-859. DOI: 10.1016/j.cub.2018.06.030

Wirth, C., Gleixner, G., & Heimann, M. (2009). *Old-growth forests: Function, fate, and value–an overview* (pp. 3-10). Springer.

Zamora, P. M., & Co, L. (1986). *Guide to Philippine flora and fauna: Economic ferns, endemic ferns, gymnosperms* (Vol. II). Natural Resources Management Center, Ministry of Natural Resources, Philippines and University of the Philippines.

Zhao, M., Geekiyanage, N., Xu, J., Khin, M. M., Nurdiana, D. R., Paudel, E., & Harrison, R. D. (2015). Structure of the epiphyte community in a tropical montane forest in SW China. *PLOS One*, 10(4): e0122. DOI:10.1371/journal.pone.0122210

Zotz, G. (2013). The systematic distribution of vascular epiphytes—a critical update. *Botanical Journal of the Linnean Society*, 171: 453–481. DOI:10.1111/boj.12010

Zotz, G. (2016). Plants on plants—the biology of vascular epiphytes. Switzerland: Springer International Publishing.