Pak. J. Bot., 58(1): 105-116, January 2026.

ARTICLE DOI: http://dx.doi.org/10.30848/PJB2026-1(9)

STAND STRUCTURE AND SPECIES COMPOSITION OF FRAGMENTED FORESTS IN SARAWAK, MALAYSIA

AFIFI NAZERI, ISMAIL JUSOH* AND MOHAMAD HASNUL BOLHASSAN

Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

*Corresponding author's email: ismailj.jusoh@gmail.com

Abstract

Forest disintegration is a major risk that challenges biodiversity conservation. The present study examined the stand structure, tree diversity, and tree distribution in two fragmented forests designated as areas of high conservation value within an oil palm plantation in Sarawak. The line transect sampling method was employed, where 25 quadrats in each study site were established. All Tree diameters of at least 10 cm in each quadrat were measured. The stand structure, importance value index and alpha diversity were evaluated. Morisita's dispersion index was determined to assess the relative dispersal pattern. The similarity of tree species composition of the two fragmented forests was determined using Jaccard's similarity coefficient. Generally, the stand characteristics between the two fragmented forests did not differ except for tree density. Tree diameters display a consistent reverse J-shape, demonstrating natural recovery is good in all study areas. Species distribution was uneven and the spatial dispersion of trees was random. Dipterocarpaceae is the dominant family and *Shorea* is the dominant genus. The fragmented forests exhibit high species diversity. The Jaccard's similarity coefficient was low, revealing that the species composition between the two forests varies. The fragmented forests appear to be undergoing self-sustaining forest recovery. Stand characteristics, floristic diversity and species distribution patterns have provided valuable insights into fragmented forests' ecological and health status. High conservation value areas in oil palm plantations are vital in conserving plant biodiversity.

Key words: Fragmented forests, High conservation value area, Forest structure, Species composition, Alpha diversity, Dispersion

Introduction

Borneo lowland rainforest is one of the world's oldest and most extensive forests that remains today. The Borneo lowlands ecozone was rated as the prime hotspot in the world and the only ecozone to exceed 10,000 plant species (Kier *et al*., 2005). This island is home to thousands of plants, including 15,000 different flowering plants and more than 3,000 species of trees, of which 267 species of trees are dipterocarps, and 155 of those are prevalent in Borneo (Rautner *et al*., 2005). The diversity of plant species promotes a wide array of ecosystem services and functions (Cardinale *et al*., 2012; Pasari *et al*., 2013; Cordonnier *et al*., 2018). It is vital to sustain the stability of the forest ecosystem (Brockerhoff *et al*., 2017). Borneo is occupied by Brunei Darussalam, Indonesia and Malaysia. The Malaysian region of Borneo is divided into two states, Sarawak and Sabah. Sarawak is the larger state of Borneo, covering a land mass of 12.4 Mha with 7.7 Mha covered with rainforest (Koh *et al*., 2023). Sarawak's forests encompass various types, including mixed dipterocarp, heath, peat swamp and mangrove forests.

Over the years, forest exploitation has caused major disturbances, resulting in the fragmentation of global tropical forests. The tremendous forest destruction is primarily caused by deforestation for settlement, timber production and plantations. There is a high correlation between the human population and the loss of forest regions (Pahari & Murai, 1999). Land transformation activities within the forest area include forestry, agriculture, infrastructure, and urbanization (Forman, 1995; Abdullah, 2016). These activities impacted the forest area, causing the breakage of continuous natural land cover or habitat into patches (Fahrig, 2003). The patchiness of the fragmented forest typically affects the ecosystem structure and function in tropical forests, such as habitat isolation, decreasing soil fertility and loss of biodiversity (Wade *et al*., 2003; Abdullah, 2016). Fragmentation substantially increases carbon emissions from tropical forests (Brinck *et al*., 2017). Fragmented areas exhibit reduced tree structure, altered species composition and diminished overall diversity (Alamgir *et al*., 2020). It experienced a notable decrease in species diversity, tree size and structural diversity (Hending *et al*., 2023).

Fragmented forests are normally more accessible to loggers, which relatively affects the forest configuration, tree species composition, and biodiversity. The decline of tree species' existence in the tropical rainforest over time is worrisome. The loss of tree species with large range sizes will increase the risk of catastrophic or range-wide losses to the biodiversity in the forest (Anon., 2022). This would negatively affect the ecosystem functions associated with biodiversity, such as animal habitation, soil anchoring, deterioration of clean air and water security. In the Roundtable on Sustainable Palm Oil (RSPO) criteria, the establishment of high conservation value (HCV) areas is required to safeguard the community's biodiversity, environment, social, economic and cultural attributes of forested areas. However, information on biodiversity conservation in HCV areas is still lacking (Edwards & Laurance, 2012; Senior *et al*., 2014; Kwatrina *et al*., 2018).

Received: 26-06-2024 | Revised: 25-03-2025 | Accepted: 18 04-2025 | Online: 02 09-2025

The identification of HCV areas in oil palm plantations in Sarawak is guided by the Malaysian National Interpretation of the Common Guidance on the Identification of High Conservation Values (HCV Malaysia Toolkit, 2018).

The forests of Sarawak, Malaysia, have witnessed extensive anthropogenic disturbances. It prompted a comprehensive examination of the ecological consequences of these changes. This alteration in the landscape has wide-ranging implications for these ecosystems' biodiversity, ecological processes and sustainability. It underlines the urgent need for an in-depth analysis to understand the extent of the impact on the overall health and resilience of Sarawak's fragmented forest areas.

This study aims to fill this knowledge gap by assessing the current status of fragmented forests situated within an oil palm plantation. This study was conducted with the objective of understanding the stand structure, tree species composition, alpha diversity, and tree dispersion in fragmented forests. The outcomes of this study will enhance understanding of the status of fragmented forests, contributing to better conservation planning and forest management in the study areas. Understanding species richness and structural features is integral to conserving forest diversity (Behera & Dash, 2017). Hence, it will help develop strategies to minimize forest degradation and biodiversity loss in forest ecosystems.

Materials and Methods

Study area: Two fragmented forests on the island of Borneo in Sarawak, Malaysia, were selected for this study. The first fragmented forest, Bukit Durang, is located at N3° 29′ 3.10″, E113° 49′ 15.60″ and the second was Division 5 at N3 34′ 3.45″, E113° 46′ 3.45″ with a span area of about 116 ha and 990 ha, respectively (Fig. 1). Oil palm plantations surround these forest fragments and they have been set aside as high conservation value (HCV) forests. The forest areas underwent selective logging 30 years in the past. Logging operations in the area have stopped since 1994. In Malaysia, selective logging is practice where only trees with DBH > 45 cm are harvested.

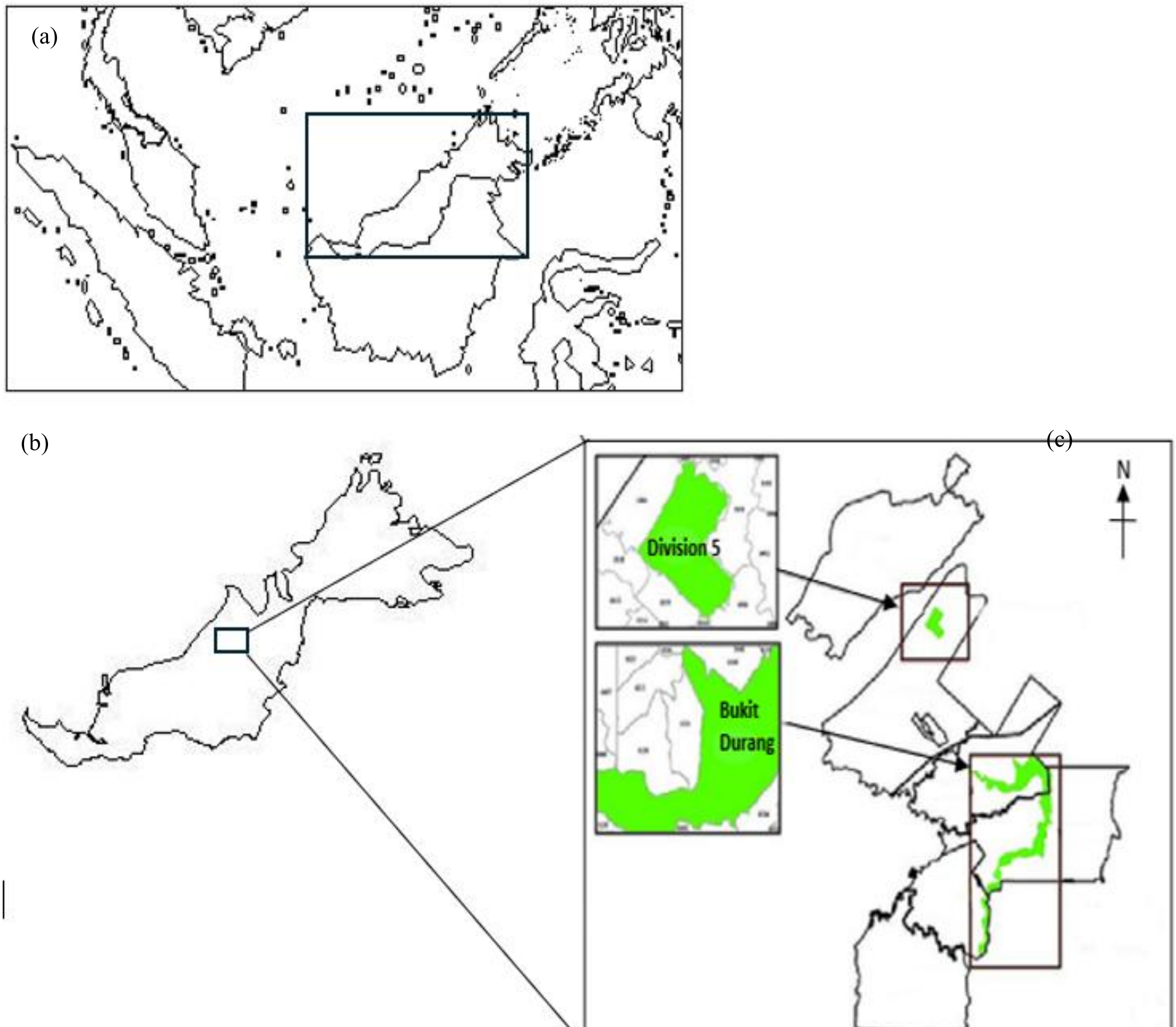

Fig. 1. (a) Outline map of Malaysia and Indonesia, (b) outline map of the Malaysian states of Sarawak and Sabah showing the study area, and (c) location of the sampling area (shaded) within the oil palm plantation in Sarawak, Malaysia.

Table 1. Equations used in the determination of importance value index, alpha diversity and dispersion indices.

Index	Equation
Importance value index (IVI)	Family importance value (FIV) index = Raf + RD + RS, where RAf = Relative abundance calculated as the number of individuals per family, RD = Relative dominance is the basal area per family, RS = Relative diversity is the proportion of species in a family (Gebeyehu *et al*., 2019) Species importance value (SIV) index = RA+RD+RF, where RA = Relative abundance calculated as the number of individuals per species, RD = Relative dominance is the basal area per species, RF = Relative frequency is the proportion of plots where the species occurred (Kacholi, 2014)
Alpha diversity	Shannon-Wiener diversity index (H') = $-\sum$ pi Ln (pi), where pi = proportion of individuals belonging to the species, Ln = natural logarithm Simpson's diversity index (D) = $1 - \frac{\sum n\,(n_i - 1)}{N\,(N-1)}$, where N = total number of individuals of all species, n_i = total number of individuals of a particular species (21) Pielou's evenness index (J) = $\frac{H'}{Ln(S)}$ (Magurran, 2021) Margalef Index (D_{Mg}) = $\frac{S-1}{Ln(S)}$ (Magurran, 2021)
Dispersion	Jaccard's similarity coefficient (C_J) = $\frac{a}{a+b+c}$, where a = number of species in both sites, b = number of species in Bukit Durang but not in Division 5, c = number of species in Division 5 but not Bukit Durang (Jaccard, 1912; Albatineh & Niewiadomska-Bugaj, 2011) Morisita Index (I_d) = $\left[\frac{\sum x^2 - N}{N\,(N-1)}\right]$, where n = number of quadrats, $\sum x^2$ = Sum of squares of the numbers of individuals per quadrat (Magurran, 2021)

Field sampling: Vegetation analysis in all study areas was performed to understand the forest stand characteristics, tree species diversity and species distribution. The line transect sampling method was employed. This method provides a convenient method of enumerating the tree population as more ground can be covered (Owusu, 2019). Twenty-five 20 m x 20 m sampling quadrats were set up within the sampling sites. The quadrats were laid out at 100 m intervals on five parallel 1000 m transect lines. All tree diameters over bark were taken at breast height (i.e. 1.30 m above ground level) and recorded to the nearest cm using a diameter tape. Only trees that are at DBH ≥10 cm were identified and enumerated. Tree species were identified based on their bark, slash, and leaf characteristics. Unknown tree species were recorded up to the genus level. Complete species recognition was carried out in the Forest Department Sarawak herbarium.

Determination of stand structure and important value index: To assess the stand structure, stand basal area, tree density, number of families and species were determined. To understand the ecological importance, the importance value index (IVI) by family and species was calculated (Table 1). It determines the tree dominance hierarchy of each family and species. The family important value (FIV) index describes and compares the family dominance within each study area, while the species important value (SIV) index describes and compares the species dominance within each study area (Kacholi, 2014). The value of FIV and SIV ranges between 0 and 300. The values indicate dominance, where large values denote that the family and species are dominant.

Determination of alpha diversity and dispersion index: The alpha diversity indices were calculated to assess tree diversity and richness. The alpha diversity indices calculated are the following: Shannon–Wiener index of species heterogeneity (H′), Simpson's Diversity Index (D), Pielou's evenness (E') and Margalef index (D_{Mg}). The Shannon diversity index is used to identify the richness and diversity of tree species, while the Simpson index is considered more as a dominance index of species (Stocker *et al.,* 1985; Kumar *et al.,* 2022). The species is evenly and unevenly distributed when the E' value is 1 and 0, respectively (Kumar *et al.,* 2022). The D_{MG} was used to explain species richness, which has no threshold value and depends on the species' quantity (Premavani *et al.,* 2017; Kumar *et al.,* 2022).

Spatial tree dispersion was determined by Morisita's index (Id) of dispersion. The Id determines plant dispersion and appraises the spatial distribution pattern into clustered, random, or dispersedly distributed (Hayes & Castillo, 2017). An Id value near 1.0 shows spatial random dispersion, less than 1.0 represents uniformity, and a large value indicates aggregate distribution (Amaral *et al*., 2015). The C_J is used to evaluate the similarity and dissimilarity of two data sets. The value of C_J was multiplied by 100 to convert the similarity of species composition between Bukit Durang and Division 5 to a percentage. The higher the percentage, the more similar the two populations. The equations used to calculate alpha diversity and dispersion indices are shown in Table 1.

Variation of tree structure, importance value and diversity: The independent samples T-test was used to determine the differences in tree structure attribute parameters (DBH, basal area, tree density) and IVI between the two fragmented forests. The statistical analysis was conducted using IBM Statistical Software for Social Science (SPSS) 2.0 for Windows Version 9.1. The significance level used was 0.05.

Results and Discussion

Stand structure: The average tree density across 25 quadrats of 20 x 20 m in both study areas differ (Table 2).

The tree density in Division 5 was higher than in Bukit Durang, with 820 trees ha^{-1}. The tree densities observed are comparable to past studies done in other tropical primary forests found in southern regions of Sarawak, such as the Semenggoh Nature Reserve (710 trees ha^{-1}) (Diway *et al*., 2009), Bako National Park (792 trees ha^{-1}) and Batang Ai National Park (813 trees ha^{-1}) (Ling & Julia, 2012). The tree densities of other disturbed forests were also comparable, for instance, Mina Wildlife Corridor, Bintulu (712 trees ha^{-1}) (Vilma *et al*., 2012) and Bukit Jugam, Bintulu logged-over forest (728 trees ha^{-1}) (Demies *et al*., 2019). The satisfactory tree density in fragmented forests also suggests that the study areas might be experiencing favourable conditions for regrowth or could have a different composition of tree species that are more resilient to the disturbance factors present. This depicts the forest's recovery despite the historical disturbance within the fragmented forests. Understanding the potential for forest recovery in fragmented forests is crucial because it can guide forest managers in strategies for promoting regeneration and restoration in degraded forests (Nunes *et al*., 2021; Mills *et al.*, 2023).

Table 2. Structural characteristics of Bukit Durang and Division 5 with DBH ≥ 10.

Variable	Bukit Durang	Division 5
Tree density (No. of trees per ha)	725^{a*}	820^{b}
Basal area (m^2/ha)	29^{a}	30^{a}
Number of families	47^{a}	52^{a}
Number of genera	93^{a}	106^{a}
Number of species	232^{a}	226^{a}

* Statistically significant differences between Bukit Durang and Division 5 are indicated by different letters

The average basal area of both sites was similar. The average basal area ranged from 29 to 30 m^2 ha^{-1}. Basal area (BA) is the average cross-sectional area of trees expressed as square per unit of land area. It was an important measurement in forestry practices because it provides the stocking of trees in an area. The BA of tree species depended upon the density and size of the tree, where DBH and tree density contributed to the total area occupied by particular species. The mean BA of lowland tropical forests below 600 m is generally in the range of 28 to 52 m² ha^{-1} (Swaine *et al*., 1987), which concurs with this study. The mean BA is comparable with that of the logged forest (29 m^2 ha^{-1}) of Sungkai, Perak, Malaysia (Suratman *et al*., 2007). A lower BA (DBH ≥ 10 cm; 27 m^2 ha^{-1}) was recorded for Pasoh Forest Reserve, Malaysia, after 41 years of logging (Okuda *et al*., 2003). The BA of this study is on the low side compared to some Malaysian primary forests. Ling & Julia (2012) and Proctor *et al*., (1983) reported 43 m²ha^{-1} in Semenggoh Arboretum and Gunung Mulu National Park, Sarawak, respectively.

The low basal area observed in both fragmented forests, influencing tree growth and establishment, could be attributed to past anthropogenic disturbances. A recent study in Western Himalaya showed that tree basal area decreases with increased disturbance intensities (Singh, 2021). Ramirez-Marcial *et al*., (2001) also reported that basal area declined with greater intensity of montane rainforests in Chiapas, Mexico. It was found that the basal area was lowest in the most disturbed dry tropical forest of Northern India (Sagar *et al*., 2003). According to Mori & Takeda (2004), the variability in spatial and temporal disturbances in historically disturbed forests significantly impacts the regeneration, dominance and long-term survival of woody species within a forest ecosystem. Whitman *et al*., (1997) stated that the forest areas that had undergone logging activities in the past, which typically involved significant use of heavy equipment have resulted in soil compaction and hindered the recruitment and growth of seedlings in certain forest areas.

The composition of tree species also remarkably influences the basal area. A forest dominated by a high density of wooded tree species usually will possess a greater mass of big trees and have a greater basal area (Baker *et al*., 2004; Malhi *et al*., 2006). Both study areas showed a prominent presence of tree species belonging to the Dipterocarpaceae family. This family also had the highest basal area contribution in the tropical forest (Gobilik, 2016). Some of the trees in this family grow large and tall and often reach emergent or upper canopy heights. Our results demonstrated that numerous large *Shorea* trees among the Diterocarpaceae family contributed to the high basal area values, which include *S. pubistyla, S. parvifolia, S. beccariana, S. leprosula, S. macroptera,* and *S. subcylindrical.* Big *Elasteriospermum tapos* trees from the family Euphorbiaceae were the other notable species responsible for the high basal area. Their ability to attain substantial sizes over long periods contributes to their higher representation in the basal area of the forest.

The present study recorded a high species number per hectare in the HCV areas - nonetheless, it is comparable to those in primary tropical forests. According to MacKinnon *et al*., (1997), the intact tropical rainforest is typically rich in tree species diversity, which can be up to 240 different plant species within one ha. The number of species recorded is higher than Semenggoh Arboretum (Ling & Julia, 2012), Kuala Keniam, Pahang National Park, Pahang (Suratman, 2012), and Batang Ai National Park (Diway *et al*., 2009).

Tree size distribution by diameter class: Figures 2 and 3 represent the number of enumerated tree stems categorized into different diameter classes. Following the reverse-J distribution pattern, the quantity of stems declined with the rising tree size. The pattern also shows that the smallest diameter class contains the highest number of trees. Tree diameter at breast height varies significantly among species (King, 1996; Paoli *et al*., 2008; Feldpausch *et al*., 2011). The reverse-J distribution pattern in the present study concurs with other studies (Hayat & Abd Kudus, 2010; Ling & Julia, 2012; Dar *et al*., 2019). Good regenerating forests usually exhibit an inverted J-shaped curve (Gonçalves *et al*., 2017), indicating a natural progression of tree growth and development (Westphal *et al.,* 2006). The DBH variation of forest stems varies depending on the specific species configuration, forest age and degree of disturbance.

The low density of big trees resulted from the previous logging that created canopy gaps. For instance, about 40% of stems were in the 5 to 10 cm DBH class, while the larger DBH classes were represented by a few individuals (Figs. 2 and 3). The large-sized diameter class (> 45cm) accounted for only 3.5 to 6 %. The canopy gaps enable more light penetration into the forest floor, stimulating the development of small, fast-growing trees (Numata *et al*.,

2006) and providing room for seedlings and young trees to develop (Manokaran & LaFrankie, 1990). The smaller, more shade-tolerant tree species may have a competitive advantage in gap environments and establish themselves more quickly and effectively, preventing the regeneration of larger tree species (Hossain & Olson, 2023). Genetic variations within the forest can also contribute to varying sizes and structures (Potter & Riitters, 2021). Hence, certain species exhibit rapid growth, while others follow a slower growth pattern. Disturbances like storms, fires and pest outbreaks can also affect tree growth. Some species might be more resilient to certain disturbances and can maintain or recover their DBH more effectively. Thus, a combination of biological, ecological and environmental factors influences the growth and development of trees. Tree species that possess greater adaptability to varying soil conditions and light availability may lead to a larger DBH. The weather conditions can also influence tree growth, with tree size and species contributing to this effect, and these factors may interact with each other (Nabeshima *et al*., 2010). Pumijumnong *et al*., (2023) stated that temperature and rainfall are essential drivers of tree growth in tropical regions. The forest's environmental conditions shape the growth patterns of trees, resulting in tree diameter variations.

Floristic composition and dominance: The top ten family important value (FIV) indices are presented in Table 3. The Dipterocarpaceae was the commonest family, followed by Euphorbiaceae, at both sites. There were 217 or 29.9%, and 227 or 27.7%, total Dipterocarp trees recorded in Bukit Durang and Division 5, respectively. The number of Euphorbiaceae trees was represented by 136 (18.8%) in Bukit Durang and 56 (6.8%) in Division 5. In Bukit Durang, the Myristicaceae, Burseraceae, and Anacardiaceae families were ranked third, fourth, and fifth as dominant families. Conversely, Sapotaceae, Myrtaceae and Moraceae ranked third, fourth, and fifth in Division 5.

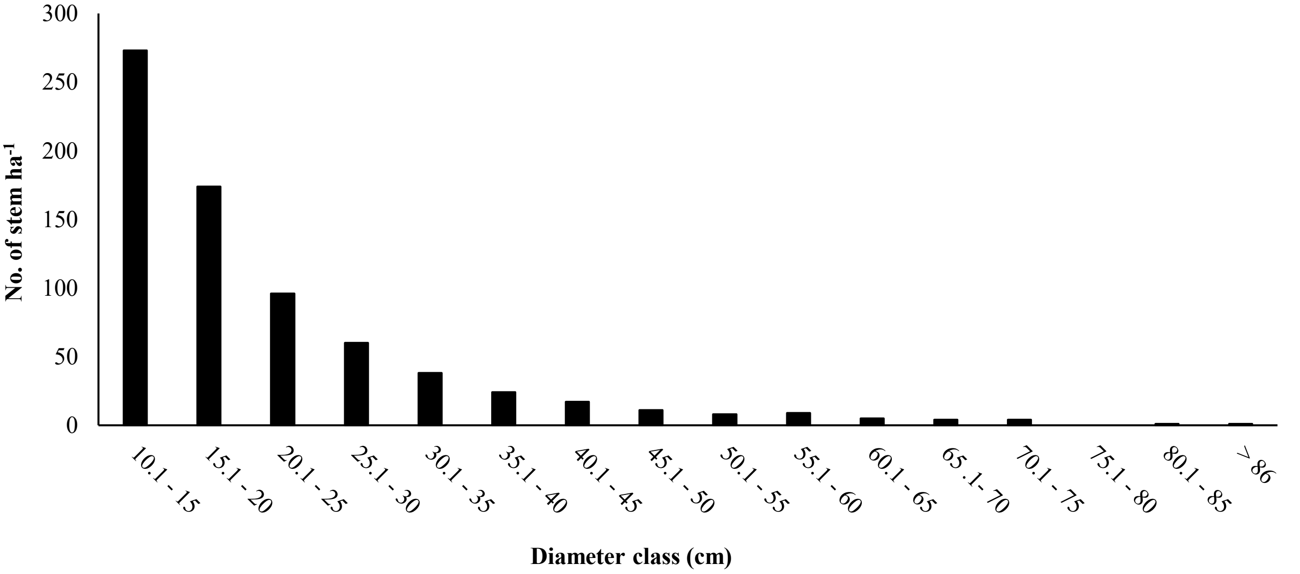

Fig. 2. Tree distribution by diameter classes in Bukit Durang.

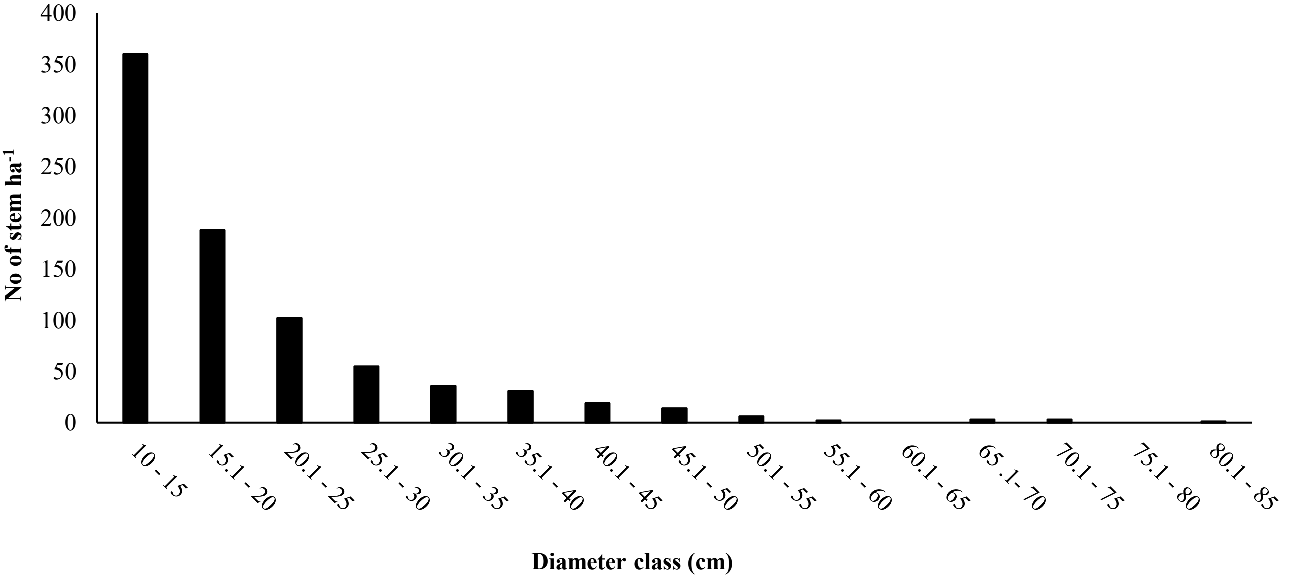

Fig. 3. Tree distribution by diameter classes in Division 5.

Table 3. Ten most dominant families and their Family Importance Value (FIV) at Bukit Durang and Division 5 with DBH ≥ 10 cm.

No.	Family	Bukit Durang					
		No. of stem	RAf (%)		RS (%)	RD (%)	FIV
1.	Dipterocarpaceae	217	29.9	217	21.6	34.0	28.5
2.	Euphorbiaceae	136	18.8	136	11.9	17.7	16.1
3	Myristicaceae	52	7.2		9.4	4.7	7.1
4.	Burseraceae	22	3.1		4.5	5.2	4.3
5.	Anacardiaceae	24	3.3		4.0	3.2	3.5
6.	Phyllanthaceae	20	2.8		2.9	4.6	3.4
7.	Moraceae	17	2.4		3.2	3.6	3.1
8.	Myrtaceae	21	2.9		3.8	2.2	3.0
9.	Annonnaceae	21	2.9		4.0	1.9	3.0
10.	Fagaceae	13	1.8		2.5	4.5	2.9
No.	**Family**	**Division 5**					
		No. of stem	**RAf (%)**		**RS (%)**	**RD (%)**	**FIV**
1.	Dipterocarpaceae	227	27.7		21.0	27.3	25.3
2.	Euphorbiaceae	56	6.8		8.0	6.7	9.4
3.	Sapotaceae	51	6.2		6.2	4.0	5.5
4.	Myrtaceae	39	4.8		5.7	4.8	5.1
5.	Moraceae	32	3.9		4.7	6.4	5.0
6.	Lauraceae	36	4.4		4.2	5.2	4.6
7.	Anacardiaceae	41	5		4.2	3.9	4.4
8.	Myristicaceae	28	3.4		4.2	2.8	3.5
9.	Burseraceae	23	2.8		3.5	3.2	3.2
10.	Polygalaceae	21	2.6		3.0	3.1	2.9

Table 4. Ten most dominant tree species based on Species Importance Value (SIV) at Bukit Durang and Division 5 with DBH ≥ 10 cm.

No.	Species	Bukit Durang				
		No. of stem	RA (%)	RF (%)	RD (%)	SIV
1.	*Macaranga triloba*	51	7.1	3.6	6.1	5.6
2.	*Elateriospermum tapos*	35	4.8	3.2	5.5	4.5
3.	*Shorea parvifolia*	28	3.9	1.8	4.5	3.4
4.	*Shorea pubistyla*	23	3.2	2.0	4.9	3.4
5.	*Shorea subcylindrical*	30	4.2	2.0	2.6	2.9
6.	*Gironniera nervosa*	15	2.0	2.3	0.6	1.6
7.	*Shorea leprosula*	9	1.3	0.9	2.6	1.6
8.	*Shorea beccariana*	7	1.0	0.2	3.4	1.5
9.	*Shorea ovata*	13	1.8	1.1	1.6	1.5
10.	*Xanthophyllum amoenum*	10	1.4	1.4	1.7	1.5
No.	**Species**	**Division 5**				
		No. of stem	**RA (%)**	**RF (%)**	**RD (%)**	**SIV**
1.	*Shorea macroptera*	46	5.6	2.7	5.4	4.5
2.	*Elateriospermum tapos*	12	1.5	1.7	1.8	1.7
3.	*Shorea beccariana*	14	1.7	1.7	1.8	1.6
4.	*Shorea amplexicaulis*	14	1.7	0.8	2.0	1.5
5.	*Palaquium pseudorostratum*	13	1.6	1.8	1.0	1.5
6.	*Semecarpus heterophylla*	15	1.8	1.3	1.2	1.4
7.	*Litsea accedens*	13	1.6	1.2	1.5	1.4
8.	*Macaranga triloba*	11	1.3	1.5	1.4	1.4
9.	*Shorea parvifolia*	10	1.2	0.8	2.2	1.4
10.	*Shorea multiflora*	18	2.2	0.7	1.3	1.4

The species relative dominance differs between the study areas. Bukit Durang and Division 5 were dominated by *Macaranga triloba* (51 stems) and *Shorea macroptera* (46 stems), respectively (Table 4). In both sites, *Elateriospermum tapos* was the second major species. Dipterocarpaceae represented the third and fourth dominant species from the genus *Shorea*. Notably, Shorea species predominate among the top 10 dominant species at both sites.

Dipterocarpaceae is the main family in Bukit Durang and Division 5 forests, representing 29.9% and 27.7% of the total trees recorded. The high domination of Dipterocarpaceae aligns with findings from previous studies on tropical forests. Most Malaysian lowland dipterocarp forests show an abundance of trees in the family of Dipterocarpaceae regardless of any degree of disturbances (Matius *et al*., 2000; Sakai *et al*., 2022). Based on the previous works, the comparative contribution of dipterocarp trees is generally within the range of 8−18% of stem number (Proctor *et al*., 1983; Kochummen *et al*., 1990; Newbery *et al*., 1992; Davies & Becker, 1996; Lee *et al*., 2002; Ganivet *et al*., 2020). A comprehensive study by Slik (2005) reported that Dipterocarpaceae was typical, with 21.9% of the total trees he inventoried belonging to this family. In Berau, East Kalimantan's primary forest recorded 25% of the trees were Dipterocarpaceae (Sist & Saridan 1999). Dipterocarpaceae trees comprised 20.2% of Barito Ulu, Central Kalimantan primary forest (Brearley *et al*., 2004). According to MacKinnon *et al*. (1997), dipterocarp trees may dominate the forests of Malaysia, accounting for up to 85% of the forest areas. Other tree common families in this study include Euphorbiaceae, Myristicaceae, Anacardiaceae, Moraceae, and Myrtaceae. This observation parallels the study recorded in other Malaysian forests, including Semenggoh Nature Reserve (Ling & Julia, 2012), Mina Wildlife Corridor, Bintulu (Vilma *et al*., 2012) and Sungai Udang Forest Reserve, Malacca, Peninsular Malaysia (Razak & Haron, 2015).

The fragmented forests are dominated by *Shorea*, which comprises more than half of the population of the dipterocarp trees. This parallels a study stating that *Shorea* is highly distributed in Bornean dipterocarp forests (Indrioko & Wicaksono, 2021). *Shorea* is one of the genera within Dipterocarpaceae with the most species. In Bornean dipterocarp forests, the highest habitat for *Shorea* tree distribution comprises of 102 species (Purwaningsih & Kintamani, 2018). The dominance of *Shorea* suggests a high degree of adaptation to the local environmental conditions in the study areas. This adaptation could include tolerance to specific soil types, climatic factors or disturbance regimes favouring *Shorea* over other dipterocarp genera. The dominance of *Shorea macroptera* Division 5 forest was attributed to its high abundance, frequency and basal area. The SIV of other species was uniformly low, which is characteristic of the mixed forest type (Richard, 1996). This contrasts markedly with the Bukit Durang forest, where the dominant species was *Macaranga triloba*. Notably, the top 10 dominant species were different except for *Elateriospermum tapos*.

Macaranga triloba is a light-demanding or pioneer species that dominates forest gaps, signifying disturbance. The greater the disturbance, the higher the diversity of pioneer species. The diversity of pioneer species appeared similar between Bukit Durang and Division 5; however, Bukit Durang recorded a higher abundance. For example, there were 56 widely scattered trees of *Macaranga triloba* in Bukit Durang as opposed to only 14 in Division 5; a total of 16 *Macaranga hosei* trees in Bukit Durang but only seven in Division 5; a total of six *Macaranga conifera* trees and only one in Division 5. Due to this, Bukit Durang forest probably has more canopy gaps than Division 5. However, more studies and data are needed before any conclusion can be made in this regard.

Macaranga triloba and *Glochidion obscurum* are typically found in abundance in tropical forests (Whitmore, 1990; Davies *et al*., 1998). These fast-growing tree species frequently dominate disturbed forests (Demies *et al*., 2019). The planted forest zone in Mina Wildlife Corridor, Bintulu dominated by *M. hypoleuca*, the secondary forest of Universiti Teknologi Malaysia Recreational Forest, Skudai, was dominated by *M. gigantea* (Vilma *et al*., 2012; Isa *et al*., 2015) and in Ulu Muda Forest Reserve, Kedah, was dominated by *M. hosei* (Mardan *et al*., 2013). Sheil and Bongers (2020) stated that a forest that experiences a disturbance like timber cutting results in canopy openings, providing a chance for fast-growing pioneer species to establish themselves and usually contribute to the increase in species diversity and overall volume growth within the forest.

Species diversity and dispersion: The alpha diversity indices presented in Table 5 showed that neither site differed. The richness and abundance of the tree community in the study areas are high, as shown by Shannon-Weiner, Simpson's and Margalef indices. Species distribution is uneven, as indicated by the small Pielou's index. Calculation of the Morisita dispersion index gives a value of close to 1.0 for both sites (Table 5). This indicates that the spatial dispersion of tree species is generally randomly distributed, which implies that the occurrence of a tree species has the same probability of occurring and that the existence of the tree individuals in the study sites does not influence the distribution of others. Species compositional similarity (C_J) was only 18%, suggesting substantial differences in species composition between the two sites.

The alpha diversity indices are slightly higher than those reported in other studies. As a comparison, mixed dipterocarp forests in Lambir Hills National Park H' values ranged from 4.1 to 4.3 (Takeuchi *et al*., 2017). The H′ species diversity in Keniam forest, Pahang National Park, was 3.4−4.0 (Suratman, 2012). Riparian and lowland dipterocarp forests in Taman Negara Pahang had H′ values of 3.4 and 4.8, respectively (Zani *et al*., 2013). The logged forest in Anap Muput, Bintulu, had an H' of 3.4 (Demeis *et al*., 2019). The Planted Forest Zone (PFZ) of Sarawak and Semenggoh Arboretum recorded to have an H' of 4.1 and 4.3, respectively (Ganivet *et al*., 2020).

Table 5. Alpha diversity and dispersion index.

	Index	Bukit Durang	Division 5
Alpha diversity	Shannon-Weiner Diversity Index (H')	5.05	5.07
	Simpson's Diversity Index (D)	0.99	0.99
	Pielou's evenness (E′)	0.18	0.18
	Margalef (D_{Mg})	35.55	38.83
Dispersion	Morisita's Index (Id)	1.09	1.05
	Jaccard's similarity coefficient (C_J)	18%	

Simpson's diversity index (D) also showed a high value, indicating that the species within the study areas are rich and abundant. Species richness supports carbon capture and enhances greater stand productivity (Liu *et al*., 2018). The previous study by Jana and Jusoh (2021) on the forest fringes of a forest fragment at Suai, Sarawak, found that the D was also high (0.99). Hayat & Abd Kudus (2010) recorded that the D in Pasir Tengkorak Forest Reserve, Langkawi Island, Malaysia, was 0.96.

Pielou's evenness (E') index showed very small values (E' = 0.18−0.20). This indicates an uneven distribution of species; very few species dominate a particular site. The assessment of the floristic composition of Kilim Geoforest Park, Langkawi, Malaysia, reported that the species evenness in the study area was also low (0.1−0.2) (Nabila *et al*., 2012). In Keniam Forest, Taman Negara, Pahang, a low E' at 0.14 was observed (Ruziman *et al*., 2022). The Margalef index showed that tree species richness was comparable. This corresponds to the similar number of species, as shown in Table 2. The value of Margalef's index is highly sensitive to sample size thus, interpreting it must be cautious (Magurran, 2021). Therefore, the data set's sampling areas must be the same (Gamito, 2010). The variations in species richness are influenced by tree age, climate and human interference (Mishra & Das, 2019). Species richness varies with forest characteristics and anthropogenic actions (Kessler *et al*., 2005).

Morisita's dispersion index used in this study is to quantify the extent of spatial dispersion within a population to analyze its distribution patterns (Morisita, 1962; Amaral *et al*., 2015). The community structure of plant species is influenced by habitat, ecological circumstances and the existing species (Tassadduq *et al*., 2022). Identifying patterns is the first step to understanding ecological processes (Fortin *et al*., 2016).

The present study observed that the species dispersion within the study area is randomly distributed. This randomness suggests that the way species are spread in the region does not follow a clear pattern. Instead, their presence seems more random or by chance. Factors such as environmental heterogeneity or chance dispersal events could contribute to this randomness in the distribution of genera in the study area (Spiegel & Nathan, 2010; Salazar-Tortosa *et al*., 2019).

Jaccard's coefficient of similarity between the two forest types was 18%. Only 83 species are recorded in both forests out of the 458 species combined. The low similarity index indicates that tree communities contrast in species composition. It depicts the species spread in the two sites as independent of each other. Consequently, similar stand appearance or characteristics do not necessarily imply that species composition is comparable. Site microclimate and the local species pool may affect similarities and differences in successional pathways between forest areas (Dent *et al*., 2013). A similarity index of > 50% is considered highly similar (Barbour *et al*. 1998). A high similarity index indicates two forest communities have similar species composition.

The present study showed that the fragmented forests, also HCV areas, retain native species and maintain natural regeneration after more than 30 years of logging. It also indicated that the HCV areas provide the necessary environment for preserving plant diversity in oil palm plantations. The HCV areas studied have a role in maintaining the diversity of plant species in oil palm plantations.

Conclusion

This study demonstrated that the stand structures of trees DBH ≥ 10 cm among Bukit Durang and Division 5 are comparable in basal area, number of families, number of genera and number of species, except for tree density. The fragmented forests exhibited the classic features of lowland tropical rainforests. The tree communities are rich, very diverse, unevenly distributed, and have a random spatial distribution. Dipterocarpaceae and its genus *Shorea* dominated both study areas. Generally, the family Euphorbiaceae are found in abundance in the study areas. Regeneration and species recruitment are satisfactory, suggesting both forests are generally healthy. Thus, fragmented forests in this study appear to be undergoing self-sustaining forest recovery, which is reflected in their forest structure, species diversity, and composition.

The present study has provided valuable insights into the variation of forest structure, tree species composition and diversity within the fragmented forests. To evaluate the effectiveness of HCV areas for species conservation, more fragmented forests in oil palm plantations should be considered. Future studies should consider the inclusion of additional factors, such as tree height, biomass, soil properties and edge factors. Including these variables can offer a more comprehensive understanding of the intricate dynamics within forest ecosystems.

The establishment of HCV areas will assist the oil palm industry in complying with the sustainability standards required by certifications and prospering in the global markets. In this regard, all parties, including the government, oil palm companies, local communities, the general public, and businesses dealing with palm oil products, must recognize that the HCV designation is crucial for sustainable production and accreditation, facilitating exports, and maintaining ecological balance.

Acknowledgements

We would like to express our gratitude to PPB Oil Palms for its supportive assistance throughout the study. We are thankful to Universiti Malaysia Sarawak and the Ministry of Higher Education for providing the necessary facilities. This work was supported by the Danish Technological Institute (Grant No: 05-FA070900-0706-0021 (GL/F07/DTI/2019)).

References

Abdullah, S.A. 2016. Quantifying forest fragmentation spatial process in the developing State of Selangor, Peninsular Malaysia. *J. Land Use Sci.*, 11(3): 294-309.

Alamgir, M., M.J. Campbell, S. Sloan, J. Engert, J. Word and W.F. Laurance. 2020. Emerging challenges for sustainable development and forest conservation in Sarawak, Borneo. *PloS One*, 15(3): e0229614.

Albatineh, A.N. and M. Niewiadomska-Bugaj. 2011. Correcting Jaccard and other similarity indices for chance agreement in cluster analysis. *Adv. Data Anal. Classif.*, 5: 179-200.

Amaral, M.D., S. Pellico Netto, C. Lingnau and A.F. Filho. 2015. Evaluation of the Morisita index for determination of the spatial distribution of species in a fragment of *Araucaria* forest. *Appl. Ecol. Environ. Res.*, 13(2): 361-372.

Anonymous. 2022. The IUCN Red List of Threatened Species. Version 2022-1.

Baker, T.R., O.L. Phillips, Y. Malhi, S. Almeida, L. Arroyo, A.D. Fiore, T.J. Killeen, S.G. Laurance, W.F. Laurance, S.L. Lewis, J. Lloyd, A. Monteagudo, D.A. Neill, S. Patino, N.C.A. Pitman, S.J.N. Macedo and M.R. Vasquez. 2004. Variation in wood density determines spatial patterns in Amazonian forest biomass. *Glob. Chang. Biol.*, 10(5): 545-562.

Barbour, M.G., J.H. Burk and W.D. Pitts. 1998. *Terrestrial plant ecology*. 3rd edition. Reading, Maine: The Benjamin/Cummings Publishing Company, Inc.

Behera S.R. and D.P. Dash. 2017. The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region. *Renewable & Sustainable Energy Reviews*, 70: 96-106.

Brearley, F.Q., S. Prajadinata, P.S. Kidd, J. Proctor and Suriantata. 2004. Structure and floristics of an old secondary rain forest in Central Kalimantan, Indonesia, and a comparison with adjacent primary forest. *For. Ecol. Manag.*, 195(3): 385-397.

Brinck, K., R. Fischer, J. Groeneveld, S. Lehmann, M.D. De Paula, S. Pütz, J.O. Sexton, D. Song and A. Huth. 2017. High resolution analysis of tropical forest fragmentation and its impact on the global carbon cycle. *Nat. Commun.*, 8: 14855.

Brockerhoff, E.G., L. Barbaro, B. Castagneyrol, D.I. Forrester, B. Gardiner, J.R. González-Olabarria, P.O. Lyver, N. Meurisse, A. Oxbrough, H. Taki, I.D. Thompson, F. van der Plas and H. Jactel. 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. *Biodivers. Conser.*, 26: 3005-3035.

Cardinale, B.J., J.E. Duffy, A. Gonzalez, D.U. Hooper, C. Perrings, P. Venail, A. Narwani, G.M. Mace, D. Tilman, D.A. Wardle, A.P Kinziq, C.G. Daily, M. Loreau, J.B. Grace, A. Larigauderie, D.S. Srivastava and S. Naeem. 2012. Biodiversity loss and its impact on humanity. Biodiversity loss and its impact on humanity. *Nature*, 486(7401): 59-67.

Cordonnier, T., G. Kunstler, B. Courbaud and X. Morin. 2018. Managing tree species diversity and ecosystem functions through coexistence mechanisms. *Ann. For. Sci.*, 75: 1-11.

Dar, J.A., K. Subashree, D. Raha, A. Kumar, K.P. Khare and L.M. Khan. 2019. Tree Diversity, Biomass, and Carbon Storage in Sacred Groves of Central India. *Environ. Sci. and Pollut. R.*, 26(36): 37212-37227.

Davies, S.J. and P. Becker. 1996. Floristic composition and stand structure of mixed dipterocarp and heath forests in Brunei Darussalam. *J. Trop. For. Sci.*, 542-569.

Davies, S.J., P.A. Palmiotto, P.S. Ashton, H.S. Lee and J.V. Lafrankie. 1998. Comparative ecology of 11 sympatric species of Macaranga in Borneo: tree distribution in relation to horizontal and vertical resource heterogeneity. *J. of Ecol.*, 86(4): 662-673.

Demies, M., H. Samejima, A.K. Sayok and G.T. Noweg. 2019. Tree diversity, forest structure and species composition in a logged-over mixed dipterocarp forest, Bintulu, Sarawak, Malaysia. *Transactions on Science & Technology*, 6(1-2): 102-110.

Dent, D.H., S.J. DeWalt and J.S. Denslow. 2013. Secondary forests of central Panama increase in similarity to old-growth forest over time in shade tolerance but not species composition. *J. Veg. Sci.*, 23(3): 530-542.

Diway, B.M., P.K. Chai and M. Blum. 2009. A study on the vegetation of Batang Ai National Park, Sarawak, Malaysia (Part 2). *In:* ITTO Project PD 288/04 Rev. 2 (F) *Development of Lanjak Entimau Wildlife Sanctuary as a totally protected area, Phase IV* (Final Phase). International Tropical Timber Organisation, Forest Department Sarawak & Sarawak Forestry Corporation. 47 pp.

Edwards, D.P. and S.G. Laurance. 2012. Green labelling, sustainability and the expansion of tropical agriculture: Critical issues for certification schemes. *Biol. Conserv.*, 151: 60-64.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. *Annu. Rev. Ecol. Evol. Syst.*, 34(1): 487-515.

Feldpausch, T.R., L. Banin, O.L. Phillips, T.R. Baker, S.L. Lewis, C.A. Quesada, K. Affum-Baffoe, E.J.M.M. Arets, N.J. Berry, M. Bird, E.S. Brondizio, P. de Camargo, J. Chave, G. Djagbletey, T.F. Domingues, M. Drescher, P.M. Fearnside, M.B. França, N.M. Fyllas, G. Lopez-Gonzalez, A. Hladik, N. Higuchi, M.O. Hunter, Y. Iida, K.A. Salim, A.R. Kassim, M. Keller, J. Kemp, D.A. King, J.C. Lovett, B.S. Marimon, B.H. Marimon-Junior, E. Lenza, A.R. Marshall, D.J. Metcalfe, E.T.A. Mitchard, E.F. Moran, B.W. Nelson, R. Nilus, E.M. Nogueira, M. Palace, S. Patiño, K.S.-H. Peh, M.T. Raventos, J.M. Reitsma, G. Saiz, F. Schrodt, B. Sonké, H.E. Taedoumg, S. Tan, L. White and H. Wölland J. Lloyd. 2011. Height-diameter allometry of tropical forest trees. *Biogeosciences*, 8(5): 1081-1106.

Forman, R.T. 1995. Some general principles of landscape and regional ecology. *Landsc. Ecol.*, 10(3): 133-142.

Fortin, M.J., M.R.T. Dale and J.M. Ver Hoef. 2016. Spatial analysis in ecology. In: *Wiley StatsRef: Statistics Reference Online*, 1-13. John Wiley & Sons, Ltd.

Gamito, S. 2010. Caution is Needed When Applying Margalef Diversity Index. *Ecol. Indic.*, 10(2): 550-551.

Ganivet, E., J. Unggang, V. Bodos, M. Demies, C.Y. Ling, J. Sang and M. Bloomberg. 2020. Assessing tree species diversity and structure of mixed dipterocarp forest remnants in a fragmented landscape of north-western Borneo, Sarawak, Malaysia. *Ecol. Indic.*, 112: 106117.

Gebeyehu, G., T. Soromessa, T. Bekele and D. Teketay. 2019. Species composition, stand structure, and regeneration status of tree species in dry Afromontane forests of Awi Zone, northwestern Ethiopia. *Ecosyst. Health Sust.*, 5(1): 199-215.

Gobilik, J. 2016. Stand structure and tree composition of Timbah Virgin Jungle Reserve, Sabah, Malaysia. *J.T.B.C.*, 4(1): 55-66.

Gonçalves, F.M., R. Revermann, A.L. Gomes, M.P. Aidar, M. Finckh and N. Juergens. 2017. Tree species diversity and composition of Miombo woodlands in South-Central Angola: A chronosequence of forest recovery after shifting cultivation. *Int. J. For. Res.*, 2017: 1-13.

Hayat, M.A. and K. Abd Kudus. 2010. Assessment of plant species diversity at Pasir Tengkorak forest reserve, Langkawi Island, Malaysia. *J. of Agric. Sci*., 2(1): 31-38.

Hayes, J.J. and O. Castillo. 2017. A new approach for interpreting the Morisita index of aggregation through quadrat size. *ISPRS Int. J. Geo-Inf*., 6(10): 296.

HCV Malaysia Toolkit. 2018. *Malaysian National Interpretation for the Identification of High Conservation Values*. Kuala Lumpur, Malaysia.

Hending, D., H. Randrianarison, N.N.M. Andriamavosoloarisoa, C. Ranohatra-Hending, M. Holderie d, G. McCabe and S. Cotton. 2023. Forest fragmentation and its associated edge-effects reduce tree species diversity, size, and structural diversity in Madagascar's transitional forests. *Biodivers. Conser*., 32: 3329-3353.

Hossain, S.M. and M.G. Olson. 2023. The lateral growth of branches into small canopy gaps: implications for competition between canopy trees. *Forest*, 14(7):1350.

Indrioko, S. and B.A. Wicaksono. 2021. The adaptability of six introduced Shorea spp. to the community forest in Sleman, Yogyakarta. *Advances in Biological Sciences Research*, 14: 200-204.

Isa, N.N.M., I. Said and M.N.M. Reba. 2015. Community structure, diversity and total aboveground biomass of four pioneer species at Universiti Teknologi Malaysia Secondary Forest. *Amer. J. Environ. Eng*., 5(3A): 26-32.

Jaccard, P. 1912. The distribution of the flora in the alpine zone. *New Phytol.*, 11(2): 37-50.

Jana, C.L. and I. Jusoh. 2021. Structure and tree species composition of forest fringe of a forest fragment in an oil palm plantation at Suai, Sarawak, Malaysian Borneo. *Biodiversitas*, 22(7): 3013-3019.

Kacholi, D.S. 2014. Analysis of structure and diversity of the Kilengwe Forest in the Morogoro Region, Tanzania. *Int. J. Biodivers.*, 2014(516840): 1-8.

Kessler, M., P.J.A. Keßler, S.R. Gradstein, K. Bach, M. Schmull and R. Pitopang. 2005. Tree Diversity in Primary Forest and Different Land Use Systems in Central Sulawesi, Indonesia. *Biodivers. Conserv.*, 14(3): 547-560.

Kier, G., J. Mutke, E. Dinerstein, T.H. Ricketts, W. Küper, H. Kreft and W. Barthlott. 2005. Global patterns of plant diversity and floristic knowledge. *J. Biogeogr*., 32: 1107-1116.

King, D.A. 1996. Allometry and life history of tropical trees. *J. Trop. Ecol*., 12(1): 25-44.

Kochummen, K.M., J.V. LaFrankie Jr. and N. Manokaran. 1990. Floristic composition of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *J. Trop. For. Sci*., 3(1): 1-13.

Koh, J., S. Johari, A. Shuib, M.L. Siow and N.K. Matthew. 2023. Malaysia's Forest Pledges and The Bornean State of Sarawak: A Policy Perspective. *Sustainability*, 15: 1385.

Kumar, P., M. Dobriyal, A. Kale, A.K. Pandey, R.S. Tomar and E. Thounaojam. 2022. Calculating forest species diversity with information-theory based indices using Sentinel-2A sensor's of Mahavir Swami Wildlife Sanctuary. *PLoS One*, *17*(5): e0268018.

Kwatrina, R.T., Y. Santosoa, M. Bismark and N. Santoso. 2018. Tropical Plant Diversity of Borneo: The Role of High Conservation Value Area on Species Conservation in an Oil Palm Plantation. *AIP Conf. Proc.*, 2019(1): 040012.

Lee, H.S., S.J. Davies, J.V. LaFrankie Jr., S. Tan, T. Yamakura, A. Itoh, T. Ohkubo and P.S. Ashton. 2002. Floristic and structural diversity of mixed dipterocarp forest in Lambir Hills National Park, Sarawak, Malaysia. *Trop. For. Sci*., 14(3): 379-400.

Ling, C.Y. and S. Julia. 2012. Diversity of the tree flora in Semenggoh Arboretum, Sarawak, Borneo. *Gard. Bull. Singapore*, 64(1): 139-169.

Liu, X., S. Trogisch, J.S. He, P.A. Niklaus, H. Bruelheide, Z. Tang, A. Erfmeier, M. Scherer-Lorenzen, K.A. Pietsch, B. Yang, P. Kuhn, T. Scholten, Y. Huang, C. Wang, M. Staab, K.N. Leppert, C. Wirth, B. Schmid and K. Ma. 2018. Tree species richness increases ecosystem carbon storage in subtropical forests. *Proc. R. Soc. B*., 285(1885): 20181240.

MacKinnon, K., G. Hatta, H. Halim and A. Mangalik. 1997. *The ecology of Kalimantan*. Oxford University Press.

Magurran, A.E. 2021. Measuring biological diversity. *Curr. Biol*., 31(19): R1174-R1177.

Malhi, Y., D. Wood, T.R. Baker, J. Wright, O.L. Phillips, T. Cochrane, P. Meir, J. Chave, S. Almeida, L. Arroyo, N. Higuchi, T.J. Killeen, S.G. Laurance, W.F. Laurance, S.L. Lewis, A. Monteagudo, D.A. Neill, P.N. Vargas, N.C.A. Pitman, C.A. Quesada, R. Salomão, J.N.M. Silva, A.T. Lezama, J. Terborgh, R.V. Martínez and B. Vinceti. 2006. The regional variation of aboveground live biomass in old-growth Amazonian forests. *Glob. Chang. Biol*., 12(7): 1107-1138.

Manokaran, N. and J.V. LaFrankie Jr. 1990. Stand structure of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *J. Trop. For. Sci*., 3(1): 14-24.

Mardan, M.N., K.R. Hakeem, I. Faridah-Hanum and N.S. Saari. 2013. Tree species composition and diversity in one ha forest, Ulu Muda Forest Reserve, Kedah. *Sains Malays*., 42(10): 1409-1424.

Matius, P., T. Toma and M. Sutisna. 2000. Tree species composition of a burned lowland dipterocarp forest in Bukit Soeharto, East Kalimantan. In: (Eds.): Guhardja, E., M. Fatawi, M. Sutisna, T. Mori, S. Ohta. *Rainforest Ecosystems of East Kalimantan: El Niño, Drought, Fire and Human Impacts*. Tokyo, Springer Japan, pp. 99-106.

Mills, M.B., Y. Malhi, R.M. Ewers, L.K. Kho, Y.A. The, S. Both, D.F.R.P. Burslem, N. Majalap, R. Nilus, W. Huaraca Huasco, R. Cruz, M.M. Pillco, E.C. Turner, G. Reynolds and T. Riutta. 2023. Tropical forests post-logging is a persistent net carbon source to the atmosphere. *Proc. Natl. Acad. Sci*., 120(3): e2214462120.

Mishra, G. and P.K. Das. 2019. Comparative study on tree diversity and population structure in two forest types of Nagaland, India. *Proc. Natl. Acad. Sci. India Sect. B: Biol. Sci.*, 89: 1305-1310.

Mori, A. and H. Takeda. 2004. Effects of undisturbed canopy structure on population structure and species coexistence in an old-growth subalpine forest in central Japan. *For. Ecol. Manag*., 200(1-3): 89-100.

Morisita, M. 1962. I σ-Index, a measure of dispersion of individuals. *Res. Popul. Ecol*., 4: 1-7.

Nabeshima, E., T. Kubo and T. Hiura. 2010. Variation in tree diameter growth in response to the weather conditions and tree size in deciduous broad-leaved trees. *For. Ecol. Manag*., 259(6): 1055-1066.

Nabila, G.F., I. Faridah-Hanum, K. Abd Kudus and M. Nazre. 2012. Assessment of Floristic Composition of Kilim Geoforest Park, Langkawi, Malaysia. *J. Agric. Sci*., 4(3): 23-34.

Newbery, D.M., E.J.F. Campbell, Y.F. Lee, C.E. Ridsdale and M.J. Still. 1992. Primary lowland dipterocarp forest at Danum Valley, Sabah, Malaysia: Structure, relative abundance and family composition. *Philos. Trans. R. Soc. Lond.*, *B*, *Biol. Sci*., 335(1275): 341-356.

Numata, S., M. Yasuda, T. Okuda, N. Kachi and M.N. Supardi. 2006. Canopy gap dynamics of two different forest stands in a Malaysian lowland rain forest. *J. Trop. For. Sci*., 18(2): 109-116.

Nunes, M.H., T. Jucker, T. Riutta, M. Svátek, J. Kvasnica, M. Rejžek, R. Matula, N. Majalap, R.M. Ewers, T. Swinfield, R. Valbuena, N.R. Vaughn, G.P. Asner and D.A. Coomes. 2021. Recovery of logged forest fragments in a human-modified tropical landscape during the 2015-16 El Niño. *Nat. Commun.,* 12: 1526.

Okuda, T., H. Nor Azman, N. Manokaran, M. Suzuki, N. Adachi and S.Q. Eng. 2003. Effective of selective logging on canopy and stand structure and tree species composition in a lowland dipterocarp forest in Peninsular Malaysia. *For. Ecol. Manag*., 175: 297-320.

Owusu, B. 2019. An introduction to line transect sampling and its applications. Department of Mathematical Sciences Montana State University, Bozeman.

Pahari, K. and S. Murai. 1999. Modelling for prediction of global deforestation based on the growth of human population. *ISPRS J. Photogramm. Remote Sens*, 54(5-6): 317-324.

Paoli, G.D., L.M. Curran and J.W.F. Slik. 2008. Soil nutrients affect spatial patterns of aboveground biomass and emergent tree density in southwestern Borneo. *Oecologia*, 155(2): 287-299.

Pasari, J.R., T. Levi, E.S. Zavaleta and D. Tilman. 2013. Several scales of biodiversity affect ecosystem multifunctionality. *Proc. Natl. Acad. Sci. USA*. 110(25): 10219-10222.

Potter, K.M. and K. Riitters. 2021. A national multi-scale assessment of regeneration deficit as an indicator of potential risk of forest genetic variation loss. *Forests*, 13(1): 19.

Premavani, D., M.T. Naidu, O.A. Kumar and M. Venkaiah. 2017. Diversity and distribution of tree species in tropical forests of Northcentral Eastern Ghats, India. *Asian J. For.*, 1(1): 27-32.

Proctor, J., J. Anderson, P. Chai and H. Vallack. 1983. Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak. I. Forest environment, structure and floristics. *J. Ecol*., 71: 237-260.

Pumijumnong, N., C. Muangsong, S. Buajan, P. Songtrirat, R. Chatwatthana and U. Chareonwong. 2023. Factors affecting cambial growth periodicity and wood formation in tropical forest trees: A Review. *Forests*, 14(5): 1025.

Purwaningsih and E. Kintamani. 2018. The diversity of *Shorea* spp. (Meranti) at some habitats in Indonesia. *IOP Conf. Ser.: Earth Environ. Sci.*, 197: 012034.

Ramirez-Marcial, N., M. Gonzalez-Espinosa and G. Williams-Linera. 2001. Anthropogenic disturbance and tree diversity in montane rain forests in Chiapas, Mexico. *For. Ecol. Manag*., 154: 311-326.

Rautner, M., M. Hardiono and J.R. Alfred. 2005. *Borneo: Treasure Island at Risk*: *Status of Forest, Wildlife and related Threats on the Island of Borneo*. WWF Germany.

Razak, S.A. and N.W. Haron. 2015. Phytosociology of Aquilaria Malaccensis Lamk. and its communities from a tropical forest reserve in peninsular Malaysia. *Pak. J. Bot*., 47(6): 2143-2150.

Richards P.W. 1996. *The Tropical Rain Forest*. Second edition. Cambridge: Cambridge University Press.

Ruziman, H.H., A. Ismail, K.A. Radzun, N.S. Ishak, A.F. Zohari, M. Kusin and F. Pardi. 2022. Tree species diversity and conservation status of Keniam Forest, Taman Negara, Pahang. *IOP Conference Series: Earth and Environmental Science*, 1019: 012014.

Sagar, R., A.S. Raghubanshi and J.S. Singh. 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *For. Ecol. Manag.*, 186 (2003): 61-71.

Sakai, A., A. Arbain, S. Sugiarto, K. Rahmawati, E. Mirmanto, M. Takahashi and A. Ueda. 2022. Composition and diversity of tree species after fire disturbance in a lowland tropical forest in East Kalimantan, Indonesia. *Biodiversitas*, 23(3): 1576-1587.

Salazar-Tortosa, D., B. Saladin, N.E. Zimmermann, J. Castro and R.R. de Casas. 2019. The evolution of seed dispersal is associated with environmental heterogeneity in Pinus. *Perspect. Plant Ecol. Evol. Syst.*, 41: 125464.

Senior, M.J. M., E. Brown, P. Villalpando and J.K. Hill. 2014. Increasing the Scientific Evidence Base in the "High Conservation Value" (HCV) Approach for Biodiversity Conservation in Managed Tropical Landscapes. *Conserv. Lett*., 8 (5): 361-367.

Sheil, D. and F. Bongers. 2020. Interpreting forest diversity-productivity relationships: volume values, disturbance histories and alternative inferences. *For. Ecosyst*., 7(1): 6.

Singh, S. 2021. Low to moderate-level forest disturbance effects on plant functional traits and associated soil microbial diversity in western Himalaya. *Front. For. Glob. Change*, 4: 710658.

Sist, P. and A. Saridan. 1999. Stand structure and floristic composition of a primary lowland dipterocarp forest in East Kalimantan. *J. of Trop. For*., 11 (4): 1-11.

Slik, J.W.F. 2005. Assessing tropical lowland forest disturbance using plant morphological and ecological attributes. *For. Ecol. Manag*., 205: 241-250.

Spiegel, O. and R. Nathan. 2010. Incorporating density dependence into the directed-dispersal hypothesis. *Ecology*, 91(5): 1538-1548.

Stocker, G.C., G.L. Unwin and P.W. West. 1985. Measures of richness, evenness and diversity in tropical rainforest. *Aust. J. Bot*., 33(2): 131-137.

Suratman, M.N. 2012. Tree species diversity and forest stand structure of Pahang National Park, Malaysia. In: (Ed.): Lameed, G.A. *Biodiversity Enrichment in a Diverse World*. In-Tech. 18: 473-492.

Suratman, M.N., M. Kusin and S.A.K. Yamani. 2007. Study of tree species composition in Sungkai Forest. Paper presented at the National Biodiversity Seminar, Department of Wildlife and National Parks. 20-21 Nov. 2007, Seremban.

Swaine, M.D., D. Lieberman and F.E. Putz. 1987. The Dynamics of Tree Populations in Tropical Forest. A review. *J. Trop. Ecol*., 3(4): 359-366.

Takeuchi, Y., R. Soda, B. Diway, T. A. Kuda, M. Nakagawa, H. Nagamasu and T. Nakashizuka. 2017. Biodiversity conservation values of fragmented communally reserved forests, managed by indigenous people, in a human-modified landscape in Borneo. *PLoS One*, 12(11): e0187273.

Tassadduq, S.S., S. Akhtar, M. Waheed, N. Bangash, D. Nayab, M. Majeed, S. Abbasi, M. Muhammad, A. Alataway, A.Z. Dewidar, H.O. Elansary and K. Yessoufou. 2022. Ecological Distribution Patterns of Wild Grasses and Abiotic Factors. *Sustainability*, 14(18): 11117.

Vilma, B., M. Demies, S. Julia and J. Unggang. 2012. Tree Diversity in Mina Wildlife Corridor, Bintulu, Sarawak, Malaysia. International Symposium of Forestry & Forest Products. 5-7 October, 2010, Kuala Lumpur, Malaysia.

Wade, T.G., K.H. Riitters, J.D. Wickham and K.B. Jones. 2003. Distribution and causes of global forest fragmentation. *Conserv. Ecol*., 7(2): 7.

Westphal, C., N. Tremer, G. von Oheimb, J. Hansen, K. von Gadow and W. Härdtle. 2006. Is the reverse J-shaped diameter distribution universally applicable in European virgin beech forests? *Forest Ecol. Manag*., 223(1-3): 75-83.

Whitman, A.A., N.V. Brokaw and J.M. Hagan. 1997. Forest damage caused by selection logging of mahogany (*Swietenia macrophylla*) in northern Belize. *Forest Ecol. Manag*., 92(1-3): 87-96.

Whitmore, T.C. 1990. *An introduction to tropical rain forests*. Clarendon Press.

Zani, N.F., M.N. Suratman and F. Khalid. 2013. June Floristic composition and diversity in lowland dipterocarp and riparian forests of Taman Negara Pahang. Presented at the IEEE Symposium on Humanities, Science and Engineering Research (SHUSER 2013), pp. 23-26.