BIODIVERSITAS
Volume 25, Number 9, September 2024
Pages: 3320-3330

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250954

Species composition and diversity along the elevational gradient of a low tropical hill in Teramuo Hill, Bau, Sarawak, Malaysia

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Manuscript received: 2 July 2024. Revision accepted: 27 September 2024.

Abstract. *Noweg T, Grinang J, Nelson J, Philip B, Felix SE, Kalu M. 2024. Species composition and diversity along the elevational gradient of a low tropical hill in Teramuo Hill, Bau, Sarawak, Malaysia. Biodiversitas 25: 3320-3330.* Numerous efforts have been made to study the diversity pattern of trees in Nature Reserves in the Bau District of Sarawak, Malaysia. However, studies on tree diversity along the elevational gradient in the district's low tropical hills still need to be completed. This study sought to evaluate the composition and diversity of tree species on a low tropical rainforest hill in the Bau District of Sarawak. The study's specific objectives include: (i). Identifying the species composition at different elevations and (ii). Measuring the species diversity and richness across different elevational gradients. The study site was Teramuo Hill, a 9.2-hectare local recreational area in Bau District, Sarawak, belonging to a Bidayuh village community. The hill encompasses three forest types (primary, secondary, and agroforest) and has suffered degradation from both human activity and natural causes. A total of 28 sampling sites were arranged in six vertical lines along the elevational gradient, with the lowest elevation being below 45 meters above sea level (m asl.) and the highest about 100 m asl.. The study found that the species composition and species types dominating at different elevations varied. A distinct pattern emerged in species diversity and richness across the elevational gradient. Between 61 and 75 m asl., the mid-elevation zones exhibited the highest species diversity. These results suggest that the main influences are ecological factors and habitat physical variability at different elevations. The findings are essential for understanding how minor elevation changes affect tree communities in tropical forest environments. This knowledge can assist in planning targeted conservation programs and dictate community priorities in the Bau District of Sarawak, Malaysia.

Keywords: Borneo, community-managed, diversity, elevation, species composition

Abbreviations: ANOVA: Analysis of Variance; DBH: Diameter at Breast Height; FAO: Food and Agriculture Organization; IUCN: International Union for Conservation of Nature; JADC: Jagoi Area Development Committee; M ASL.: Meters Above Sea Level; PRF: Permanent Reserved Forest; SAC: Species Accumulation Curve; TPAs: Totally Protected Areas

INTRODUCTION

Tropical forests cover approximately 45% of the global forests (FAO 2020). It is home to between half and two-thirds of the world's approximately 64,000 taxonomically recognized tree species (Gatti et al. 2022). Approximately one-third of the known species of tropical trees are uncommon species, with extremely small populations and limited geographic distribution. Malaysia's forest is made up of 100% tropical forests, which cover approximately 55.5% of the total land area (FAO 2020). The forested areas are classified into three main categories, namely Permanent Reserved Forest (PRF), State Land Forest, and Totally Protected Areas (TPAs), which include the National Parks and Wildlife and Bird Sanctuary. Malaysia boasts a diverse forest landscape, encompassing at least 14 distinct forest types. Mixed dipterocarp, montane ericaceous, peat swamp, and mangrove forests are among the most prominent ecosystems in the country (Ruzman et al. 2021). There are more than 15,000 species of tree found in Malaysia's tropical forest (FAO 2020; Ruzman et al. 2021). Local research in the fields of forestry and environmental science has long focused on the diversity of plant species across various forest types, including hilly lowland forests (Mariam and Jivitra 2019), limestone forests (Kiew et al. 2019), mangrove forests (Azman et al. 2021), and urban forests (Majuakim et al. 2018).

Numerous local studies have identified significant research gaps warranting further investigation. A previous study by Kueh et al. (2017) examined tree species composition and diversity at 1,600 m asl. in Lawas, Sarawak. However, the study's scope was limited to five transect lines, potentially restricting its ability to capture species diversity at that elevation fully. Moreover, by focusing solely on trees with a Diameter at Breast Height (DBH) exceeding 10 centimeters, the study may have overlooked valuable data on smaller trees and saplings. Another study by Lepun and Heng (2020) assessed the floristic and forest structure of three hills in Bukit Kana National Park, Bintulu, Sarawak. While this study examined multiple hills, its reliance on a single transect line per hill and the exclusion of trees smaller than 20 centimeters DBH limited its ability to provide a comprehensive understanding of forest structure and composition. These studies faced limitations due to restricted sampling areas, focusing on specific elevation levels and excluding smaller trees.

Significant research gaps also exist within studies conducted in the Bau District. While successful efforts have been made to preserve tree diversity through the management and conservation of several low hills, the influence of elevational patterns on tree species composition and diversity remains understudied. For example, Pahon et al. (2016) examined tree diversity, composition, and distribution within the community-managed Gunung Serambu but did not explore how these factors varied with elevation. A more in-depth analysis of elevational gradients could provide valuable insights into the distribution of tree species in the region.

This current study sought to evaluate the composition and diversity of tree species on Teramuo Hill, a low tropical rainforest hill located in the Bau District of Sarawak. The study's specific goals include: 1. Identifying the species composition at different elevations and 2. Measuring the species diversity and richness across different elevational gradients. Therefore, to address these objectives, two hypotheses have been formulated: 1. Species composition varied along the elevational gradient, and 2. Species diversity observed along the elevational gradients is different.

This study investigates how tree diversity varies with elevation on a specific low tropical rainforest hill, unlike most of the research on Malaysian forests, which focuses on general forest types. This focused approach can help researchers better understand plant communities in similar tropical locations and how minor elevation changes can affect them. By identifying how elevation influences tree communities, this study can inform forest managers in developing specific and targeted conservation programs. Although the present study focuses on the understanding of the relationship of elevation to tree communities, it may also indirectly provide a contribution in the management of invasive alien plant species. Identifying the areas with a unique composition of tree species may suggest priorities for monitoring by forest managers who are looking for early warnings of potential threats from invasive species. This will prevent invasive plants from forming and multiplying, which is important to the overall health and biodiversity maintenance of the forest ecosystem. Understanding these patterns can also assist local communities in developing effective conservation efforts, such as reforestation, by recognizing tree species' suitability based on altitude.

MATERIALS AND METHODS

Study area

The study was conducted at Teramuo Hill in Kampung Stass in Bau District, Sarawak, southwest Borneo, Malaysia. The hill's coordinates are 1.388003° N and 109.992285° E (Figure 1, Table 1). This 9.20-hectare hill is managed as a local recreational area under the purview of the Stass Village Development and Security Committee and the Jagoi Area Development Committee (JADC). Established in 2007, the JADC, a community-based organization, was primarily formed to manage the nearby 1200-hectare Jagoi Heritage Forest (Sarok and Britin 2016). However, since Teramuo Hill is within its jurisdiction, the JADC also manages Teramuo Hill as part of its conservation and management efforts. Teramuo Hill comprises three forest types: Primary forest, old secondary forest, and agroforest (Felix 2022). From its prime state in the early 1900s, Teramuo Hill has somewhat deteriorated over time due to human activity and natural causes.

Human disturbances began in 1941, during the Japanese occupation period when the local community sought safety on the hill in a show of defiance against foreign interference in their culture and livelihoods. Many trees were felled during this period to construct shelters, and the foothill areas were farmed. This was one of the reasons for the remaining high forest being only 9.2 hectares. There was also an incident of a fire outbreak at the peak of the hill in the early 1990s, damaging the kerangas forest on the peak of the hill. As a result, the forest cover at the peak is so poor, being dominated by the shrubby *Cratoxylum glaucum* Korth and *Syzygium zeylanicum* L. (DC). Additionally, a landslide in 2020 has a sizeable amount of the hill's flora community being affected. A mixture of forests and planted fruit trees, some of which are privately owned, make up the lower foothill portion of the area. However, the rest of the hill (from an elevation of 70 meters and upwards) is a common property to the Stass Village community, and resources are shared. In the year 2000, harvesting of forest resources ceased as the area was declared as a community conservation and recreation area. Only the bottomland areas are still accessed by the villagers for the collection of fruits during the fruiting seasons.

Procedures

The sampling plots were distributed vertically along the elevational gradient (Figure 1). In order to provide a more representative sample of the hill's vegetation and elevation patterns, the vertical sampling lines were strategically distributed and positioned around the hill to represent the prevailing elevation patterns and thus guarantee that data is collected from various elevations. The primary plots measured 20 meters by 20 meters, and each containing a smaller one-meter by the one-meter mini-plot was established. Sampling was initiated at an elevation below 45 m above sea level, progressing to 46-60, 61-75, 76-90, and beyond 95 m asl. at the hill's peak. In total, there were six sampling lines, resulting in 28 primary plots and a combined sampling area of 1.12 hectares. Trees with DBH exceeding five centimeters were measured in the primary plots. In comparison, saplings and seedlings with a diameter of less than five centimeters were assessed in the mini-plots to evaluate species composition and diversity throughout the elevation gradient. The local knowledgeable informant was used to identify the trees according to their local names. After that, local tree identification keys, guides, and field manuals by Soepadmo et al. (2014), IUCN (2017), and Chai and Jawa (2023) were used as references for further species identification.

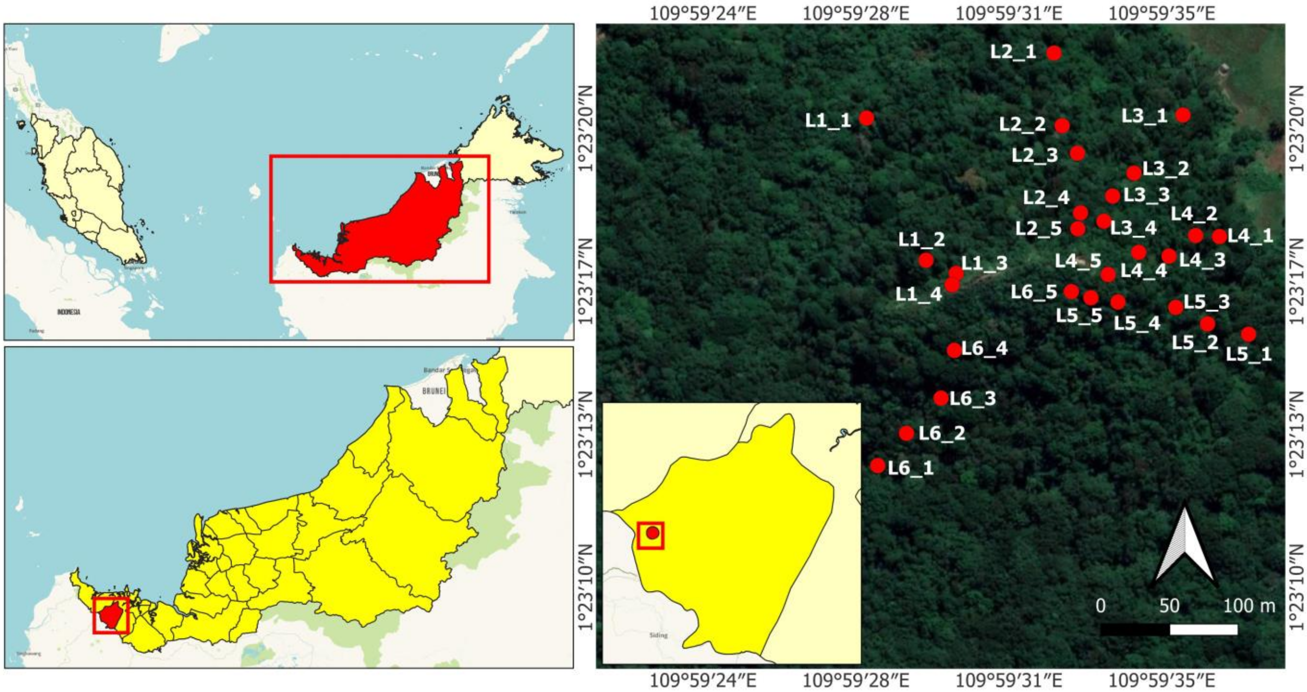

Figure 1. The map of sampling sites along the elevational gradient at Teramuo Hill, Bau District, Sarawak, Malaysia

Table 1. Coordinates of the sampling point in Teramuo Hill, Bau District, Sarawak, Malaysia

Plot ID	Coordinate	
L1_1	1.38907° N	109.99107° E
L1_2	1.38814° N	109.99146° E
L1_3	1.38806° N	109.99164° E
L1_4	1.38798° N	109.99163° E
L2_1	1.389495° N	109.992296° E
L2_2	1.38902° N	109.99235° E
L2_3	1.38884° N	109.99245° E
L2_4	1.38845° N	109.99247° E
L2_5	1.388333° N	109.992450° E
L3_1	1.38909° N	109.99314° E
L3_2	1.38871° N	109.99282° E
L3_3	1.38856° N	109.99268° E
L3_4	1.388394° N	109.992623° E
L4_1	1.388295° N	109.993379° E
L4_2	1.388302° N	109.993221° E
L4_3	1.388167° N	109.993049° E
L4_4	1.388192° N	109.992849° E
L4_5	1.388046° N	109.992651° E
L5_1	1.387656° N	109.993570° E
L5_2	1.387730° N	109.993277° E
L5_3	1.387825° N	109.993089° E
L5_4	1.387867° N	109.992715° E
L5_5	1.387895° N	109.992538° E
L6_1	1.386797° N	109.991144° E
L6_2	1.387050° N	109.991369° E
L6_3	1.38725° N	109.99157° E
L6_4	1.38757° N	109.99165° E
L6_5	1.387935° N	109.992410° E

Data analysis

Frequency analysis was used to determine the species composition along the elevational gradient. Frequency analysis is a statistical method applied to determine the relative abundance of different species in any given area or habitat. In this respect, frequency analysis aids in studies on species composition along an elevational gradient in respect to species dominance, species distribution, and elevation-related patterns. The frequency and percentage of species occurrence in each sampling plot at various elevations were shown in table form. The Species Accumulation Curve (SAC) was plotted to estimate the number of species along the elevational gradients. The shape of the curve determines the adequacy of sampling efforts (Deng et al. 2015). The sample is deemed sufficient when the end of the curve reaches a plateau.

The Shannon-Wiener diversity index formula was used to measure the diversity of trees at five elevation gradients. The index was selected over Simpson's index because beta diversity (or species turn over) in a small hill like Teramou is presumed to be low with species dispersal by wind or animals can be evenly occurred across the hill. According to Daly et al. (2018), the Shannon-Wiener diversity index considers both the distribution of plant species in a particular area and the total number of species. The diversity values may change depending on where the transect is located. Sensitivity analysis was carried out by computing diversity indices independently for various groups of transect locations to mitigate the possible effects of various transect locations on diversity values (Kumar et al. 2022). The Shannon diversity value normally ranges from 1.5 to 3.5. The formula for the Shannon Diversity Index (H') is as follows:

$$\text{Diversity of a species } (H') = -\text{SUM}\,[(pi) \times \ln(pi)]$$

Where:

SUM: Summation

pi : Relative abundance of i^{th} species ($\frac{n_i}{N}$)

Species richness was also calculated to determine the number of different species in different elevations. Species richness is a simple measure that captures the total number of species in a sample, but it does not consider how many individuals of each species are present (abundance) or how those individuals are spread out (distribution) (Chao and Chiu 2016). A rarefaction curve with 50 bootstraps was generated to estimate species richness among the five elevational gradients, enabling comparisons between the sites (Chao et al. 2014, 2016). The variation in species richness was visualized using line graphs created in Microsoft Excel.

Last but not least, a One-way Analysis of Variance (ANOVA) was conducted to compare the mean differences of Shannon's diversity and richness among the five elevation gradients.

RESULTS AND DISCUSSION

Tree species composition at different elevation

A total of 2,151 tree individuals have been enumerated, with 218 in the elevation <45 m asl., 261 in the 46-60 m asl. range, 332 in the 61-75 m asl., 1,068 in the 76-90 m asl., and 272 in the >90 m asl.. The survey also recorded 229 tree species in the sampled area of Teramuo Hill. The species with the highest percentage of occurrence by elevation level are *Pimelodendron griffithianum* (Müll. Arg.) Benth. ex Hook. f. with 11.50% (for elevation band <45 m asl.), *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. with 9.60% for the elevation band of 46-60 m asl., *Syzygium hirtum* (Korth.) Merr. & L. M. Perry and *Baccaurea edulis* Merr. with 4.20% each from 61-75 m asl., *Hopea ferruginea* Parijs with 7.60% from 76-90 m asl., and *Whiteodendron moultonianum* (W. W. Sm.) Steenis with 14.00% for >90 m asl. (Table 2).

Tree species diversity along the elevational gradient

The Species Accumulation Curve (SAC) (Figure 2) shows a steep increase in the number of species from the lowest elevation (<45 m asl.) to mid-elevation (61-76 m asl.). The curve then increases slowly from the 61-76 m elevation band to the 76-90 m asl. and becomes asymptotic beyond 90 m asl.. This indicates that the sampling is sufficient and that species diversity can be calculated and compared between different elevation groups.

On the other hand, rarefaction curve shows species richness at elevation >90 m asl. is much lower than other sites (Figure 3) suggesting species richness varies with elevation. The results of the two analyses might have demonstrated the species richness changes with elevation. In contrast, the total abundance of trees seemed to be similar among elevation gradient because different species dominant at different elevation. For example (Table 2), at elevation <45 m asl., *P. griffithianum* was dominant, but at 46-60 m asl. was dominated by *H. brasiliensis*.

The ANOVA result for species diversity did not show a statistically significant effect of elevation (F(4, 23)) = 2.36, p = 0.08) (Table 3). This suggests that diversity may not differ significantly across the five elevation ranges. Similar to diversity, the ANOVA for richness did not yield a statistically significant effect of elevation (F(4, 23)) = 2.11, p = 0.11).

Next, a mixed-effects model was used with elevation as a fixed effect to capture any possible difference in diversity and richness between several locations of sampling units (Table 4). The model estimated a mean diversity of 2.82 with a standard deviation for the fixed effects of 0.61. This indicates that there is some variability in the estimates of diversity across different elevational gradients. It was also found that the mean value for the random effects is similar to the fixed effects (Mean = 2.82). The similarity of the mean values of random effects with fixed effects suggests that factors other than elevation, such as individual differences or site conditions, contribute to diversity variation.

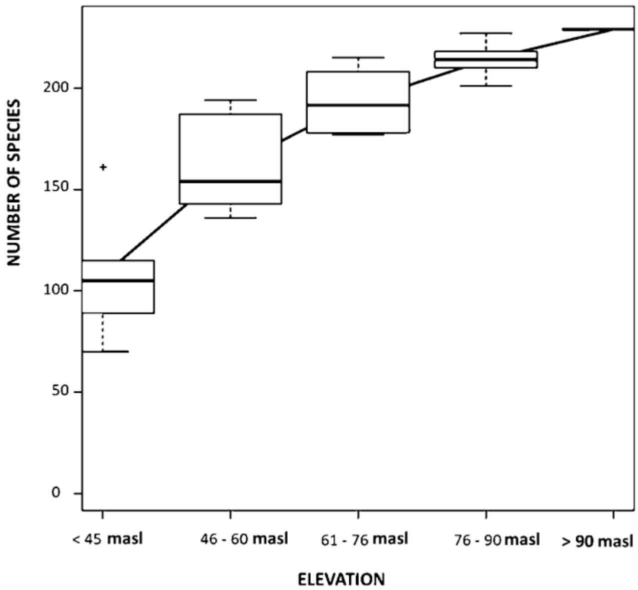

Figure 2. Species accumulation curve at Teramuo Hill, Bau District, Sarawak, Malaysia

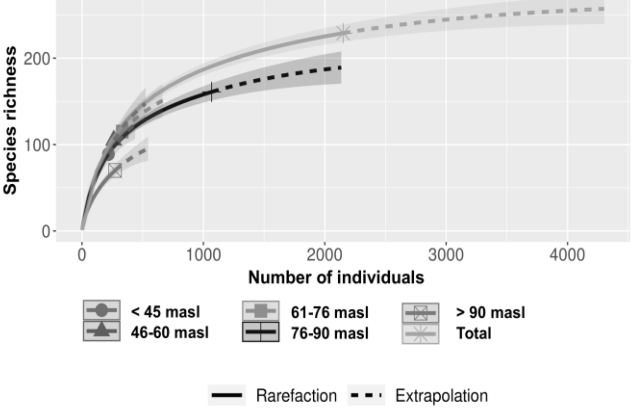

Figure 3. Diagram of rarefaction curve with 50 bootstraps shows species estimates and extrapolation for five elevational gradients

Table 2. Tree species composition in Teramuo Hill, Bau District, Sarawak, Malaysia

Tree species	Elevations (m asl.)										Total	
	< 45		46-60		61-75		76-90		> 90			
	n	%	n	%	n	%	n	%	n	%	n	%
Actinodaphne sp. Nees	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Adinandra sp. Jack	1	0.50	2	0.80	2	0.60	1	0.10	0	0.00	6	0.30
Aetoxylon sympetalum (Steenis & Domke) Airy Shaw	0	0.00	1	0.40	3	0.90	2	0.20	0	0.00	6	0.30
Aglaia sp. 1 Lour.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Aglaia sp. 2	0	0.00	3	1.10	0	0.00	4	0.40	0	0.00	7	0.30
Agrostistachys sp. Dalzell	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Alangium sp. Lam.	1	0.50	0	0.00	2	0.60	6	0.60	1	0.40	10	0.50
Albizia sp. Durazz.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Alseodaphne sp. Nees	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Alstonia sp. R. Br.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Anisophyllea curtisii King	0	0.00	0	0.00	5	1.50	15	1.40	2	0.70	22	1.00
Anisophyllea disticha (Jack) Baill.	0	0.00	0	0.00	3	0.90	3	0.30	0	0.00	6	0.30
Anisoptera sp. Korth.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Aporosa sp. Blume	1	0.50	1	0.40	0	0.00	0	0.00	0	0.00	2	0.10
Aquilaria beccariana Tiegh.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Aquilaria macrocarpa Baill.	0	0.00	3	1.10	0	0.00	0	0.00	0	0.00	3	0.10
Archidendron jiringa (Jack) I. C. Nielsen	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Ardisia sp. Sw.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Artocarpus anisophyllus Miq.	3	1.40	4	1.50	4	1.20	0	0.00	0	0.00	11	0.50
Artocarpus dadah Miq.	1	0.50	1	0.40	1	0.30	0	0.00	0	0.00	3	0.10
Artocarpus elasticus Reinw. ex Blume	3	1.40	1	0.40	3	0.90	5	0.50	2	0.70	14	0.70
Artocarpus integer (Thunb.) Merr.	3	1.40	1	0.40	2	0.60	1	0.10	0	0.00	7	0.30
Artocarpus kemando Miq.	2	0.90	2	0.80	1	0.30	4	0.40	1	0.40	10	0.50
Artocarpus nitidus Trécul	1	0.50	1	0.40	0	0.00	11	1.00	1	0.40	14	0.70
Artocarpus sarawakensis F. M. Jarrettt	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Artocarpus tamaran Becc.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Baccaurea angulata Merr.	2	0.90	1	0.40	2	0.60	2	0.20	0	0.00	7	0.30
Baccaurea costulata (Miq.) Müll. Arg.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Baccaurea edulis Merr.	5	2.30	5	1.90	14	4.20	18	1.70	1	0.40	43	2.00
Baccaurea hookeri Gage	0	0.00	1	0.40	3	0.90	5	0.50	2	0.70	11	0.50
Baccaurea lanceolata (Miq.) Müll. Arg.	0	0.00	2	0.80	1	0.30	3	0.30	0	0.00	6	0.30
Baccaurea macrocarpa (Miq.) Müll. Arg.	1	0.50	0	0.00	2	0.60	17	1.60	1	0.40	21	1.00
Baccaurea maingayi Hook.f.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Bellucia pentamera Naudin	0	0.00	1	0.40	1	0.30	1	0.10	0	0.00	3	0.10
Bhesa sp. Buch. -Ham. ex Arn.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Bouea oppositifolia (Roxb.) Meisn.	0	0.00	0	0.00	0	0.00	1	0.10	1	0.40	2	0.10
Brackenridgea sp. A. Gray	0	0.00	0	0.00	0	0.00	0	0.00	1	0.40	1	0.00
Breynia racemosa (Blume) Müll. Arg.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Breynia sp. J. R. Forst. & G. Forst.	0	0.00	1	0.40	0	0.00	1	0.10	0	0.00	2	0.10
Brownlowia sp. Roxb.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Caesalpinia sp. Plum. ex L.	0	0.00	0	0.00	0	0.00	2	0.20	2	0.70	4	0.20
Callicarpa sp. L.	0	0.00	0	0.00	0	0.00	4	0.40	0	0.00	4	0.20
Calophyllum sp. L.	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Calophyllum woodii P. F. Stevens	0	0.00	0	0.00	0	0.00	5	0.50	1	0.40	6	0.30
Campnosperma auriculatum (Blume) Hook. f.	0	0.00	0	0.00	2	0.60	3	0.30	1	0.40	6	0.30
Campnosperma coriaceum (Jack) Hallier f.	2	0.90	1	0.40	5	1.50	9	0.80	1	0.40	18	0.80
Canarium sp. L.	2	0.90	0	0.00	11	3.30	32	3.00	0	0.00	45	2.10
Canthium umbelligerum Miq.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Cantleya corniculata (Becc.) R. A. Howardd	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Castanopsis motleyana King	1	0.50	0	0.00	3	0.90	2	0.20	0	0.00	6	0.30
Cinnamomum sp. Schaeff.	1	0.50	1	0.40	1	0.30	0	0.00	0	0.00	3	0.10
Cleistanthus sp. Hook. f. ex Planch.	2	0.90	1	0.40	0	0.00	0	0.00	0	0.00	3	0.10
Clerodendrum sp. L.	1	0.50	0	0.00	1	0.30	0	0.00	0	0.00	2	0.10
Cratoxylum arborescens (Vahl) Blume	0	0.00	0	0.00	1	0.30	18	1.70	2	0.70	21	1.00
Cratoxylum formosum (Jack) Benth. & Hook. f. ex Dyer	0	0.00	0	0.00	2	0.60	20	1.90	18	6.60	40	1.90
Cratoxylum glaucum Korth.	0	0.00	1	0.40	0	0.00	7	0.70	24	8.80	32	1.50
Cratoxylum sp. Blume	0	0.00	0	0.00	0	0.00	4	0.40	4	1.50	8	0.40
Cryptocarya rugulosa Hook.f.	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Dacryodes edulis G. Don	0	0.00	1	0.40	0	0.00	4	0.40	2	0.70	7	0.30
Dacryodes rostrata (Blume) H. J. Lam	3	1.40	0	0.00	2	0.60	7	0.70	0	0.00	12	0.60
Decussocarpus sp. de Laub.	1	0.50	0	0.00	2	0.60	2	0.20	0	0.00	5	0.20
Dialium indum L.	0	0.00	0	0.00	1	0.30	2	0.20	1	0.40	4	0.20

Dillenia borneensis Hoogland	0	0.00	0	0.00	2	0.60	1	0.10	0	0.00	3	0.10
Dillenia excelsa (Jack) Gilg	0	0.00	3	1.10	0	0.00	2	0.20	0	0.00	5	0.20
Dillenia suffruticosa (Griff. ex Hook.f. & Thomson) Martelli	1	0.50	5	1.90	0	0.00	5	0.50	0	0.00	11	0.50
Diospyros foxworthyi Bakh.	0	0.00	0	0.00	0	0.00	10	0.90	1	0.40	11	0.50
Diospyros hermaphroditica (Zoll.) Bakh. ex Steenis	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Diospyros piscicapa Ridl.	0	0.00	0	0.00	3	0.90	2	0.20	0	0.00	5	0.20
Diospyros sp. L.	6	2.80	1	0.40	5	1.50	10	0.90	3	1.10	25	1.20
Dipterocarpus kunstleri King	1	0.50	0	0.00	1	0.30	0	0.00	0	0.00	2	0.10
Dipterocarpus obtusifolius Teijsm. ex Miq.	0	0.00	0	0.00	0	0.00	1	0.10	1	0.40	2	0.10
Dipterocarpus sp. C. F. Gaertn.	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Drimycarpus sp. Hook. f.	0	0.00	0	0.00	1	0.30	2	0.20	0	0.00	3	0.10
Dryobalanops beccarii Dyer	4	1.80	7	2.70	11	3.30	75	7.00	21	7.70	118	5.50
Durio testudinarius Becc.	0	0.00	0	0.00	0	0.00	2	0.20	0	0.00	2	0.10
Durio zibethinus L.	11	5.00	10	3.80	3	0.90	18	1.70	0	0.00	42	2.00
Dyera costulata (Miq.) Hook. f.	0	0.00	1	0.40	1	0.30	9	0.80	0	0.00	11	0.50
Elaeocarpus sp. Burm. ex L.	1	0.50	0	0.00	1	0.30	2	0.20	0	0.00	4	0.20
Elaeocarpus sphaeroblastus Stapf ex Ridl.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Elateriospermum tapos Blume	0	0.00	1	0.40	4	1.20	7	0.70	0	0.00	12	0.60
Endospermum diadenum (Miq.) Airy Shaw	1	0.50	2	0.80	2	0.60	1	0.10	0	0.00	6	0.30
Eusideroxylon zwageri Teijsm. & Binn.	1	0.50	2	0.80	4	1.20	8	0.70	0	0.00	15	0.70
Ficus aurata (Miq.) Miq.	0	0.00	1	0.40	1	0.30	4	0.40	0	0.00	6	0.30
Ficus brunneoaurata Corner	0	0.00	2	0.80	0	0.00	0	0.00	0	0.00	2	0.10
Ficus geocharis Corner	1	0.50	4	1.50	0	0.00	4	0.40	0	0.00	9	0.40
Ficus grossularioides Burm.f.	0	0.00	1	0.40	0	0.00	1	0.10	0	0.00	2	0.10
Flacourtia jangomas (Lour.) Raeusch.	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Flacourtia rukam Zoll. & Moritzi	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Fordia splendidissima (Blume ex Miq.) Buijsen	1	0.50	2	0.80	7	2.10	6	0.60	0	0.00	16	0.70
Garcinia cuspidata King	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Garcinia mangostana L.	1	0.50	0	0.00	0	0.00	1	0.10	0	0.00	2	0.10
Garcinia parvifolia (Miq.) Miq.	1	0.50	5	1.90	2	0.60	4	0.40	1	0.40	13	0.60
Garcinia petiolaris Pierre	0	0.00	1	0.40	0	0.00	9	0.80	0	0.00	10	0.50
Gironniera nervosa Planch.	0	0.00	0	0.00	4	1.20	1	0.10	1	0.40	6	0.30
Gironniera sp. Gaudich.	5	2.30	1	0.40	0	0.00	0	0.00	0	0.00	6	0.30
Gluta sp. L.	0	0.00	1	0.40	0	0.00	0	0.00	3	1.10	4	0.20
Gnetum gnemon L.	0	0.00	0	0.00	3	0.90	14	1.30	0	0.00	17	0.80
Goniothalamus malayanus Hook.f. & Thomson	0	0.00	1	0.40	1	0.30	0	0.00	0	0.00	2	0.10
Goniothalamus suaveolens Becc.	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Goniothalamus velutinus Airy Shaw	2	0.90	1	0.40	1	0.30	3	0.30	0	0.00	7	0.30
Gymnacranthera bancana (Miq.) J. Sinclair	0	0.00	3	1.10	1	0.30	1	0.10	1	0.40	6	0.30
Gymnacranthera sp. (A.DC.) Warb.	0	0.00	0	0.00	0	0.00	2	0.20	0	0.00	2	0.10
Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg.	11	5.00	25	9.60	6	1.80	14	1.30	0	0.00	56	2.60
Hopea ferruginea Parijs	1	0.50	13	5.00	11	3.30	81	7.60	10	3.70	116	5.40
Hopea kerangasensis P. S. Ashton	0	0.00	2	0.80	3	0.90	7	0.70	3	1.10	15	0.70
Hopea sarawakensis F. Heim	1	0.50	16	6.10	0	0.00	0	0.00	0	0.00	17	0.80
Horsfieldia sp. 1 Willd.	3	1.40	1	0.40	4	1.20	15	1.40	2	0.70	25	1.20
Horsfieldia sp. 2	2	0.90	0	0.00	0	0.00	2	0.20	0	0.00	4	0.20
Horsfieldia sp. 3	0	0.00	1	0.40	5	1.50	8	0.70	5	1.80	19	0.90
Horsfieldia sp. 4	0	0.00	0	0.00	2	0.60	0	0.00	0	0.00	2	0.10
Horsfieldia crassifolia sp. 5Hook.f. & Thoms. (Warb.)	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
*Horsfieldi*a grandis (Hook.f.) Warb.*a* sp. 6	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Ilex hypoglauca (Miq.) Loes.	3	1.40	1	0.40	1	0.30	1	0.10	0	0.00	6	0.30
Intsia sp. Thouars	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Ixonanthes sp. Jack	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Ixora sp. L.	0	0.00	0	0.00	1	0.30	4	0.40	4	1.50	9	0.40
Knema latifolia Warb.	0	0.00	0	0.00	1	0.30	4	0.40	1	0.40	6	0.30
Knema sp. Lour.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Koompassia malaccensis Maingay	2	0.90	0	0.00	4	1.20	7	0.70	0	0.00	13	0.60
Kopsia sp. Blume	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Lansium domesticum Corrêa	4	1.80	4	1.50	10	3.00	18	1.70	0	0.00	36	1.70
Leea indica (Burm.f.) Merr.	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Lindera sp. Thunb.	0	0.00	0	0.00	2	0.60	1	0.10	0	0.00	3	0.10
Lithocarpus echinifer (Merr.) A. Camus	0	0.00	0	0.00	0	0.00	7	0.70	0	0.00	7	0.30
Lithocarpus ewyckii (Korth.) Rehder	3	1.40	1	0.40	7	2.10	7	0.70	0	0.00	18	0.80
Lithocarpus leptogyne (Korth.) Soepadmo	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Lithocarpus pseudokunstleri A. Camus	3	1.40	1	0.40	0	0.00	0	0.00	0	0.00	4	0.20
Lithocarpus sp. Blume	0	0.00	1	0.40	2	0.60	0	0.00	0	0.00	3	0.10
Lithocarpus turbinatus (Stapf) Forman	1	0.50	0	0.00	1	0.30	0	0.00	0	0.00	2	0.10

Litsea nidularis Gamble	1	0.50	0	0.00	1	0.30	2	0.20	1	0.40	5	0.20
Litsea sp. Lam.	0	0.00	4	1.50	0	0.00	9	0.80	0	0.00	13	0.60
Litsea accedens (Blume) Boerl	0	0.00	0	0.00	3	0.90	0	0.00	0	0.00	3	0.10
Lophopetalum sp. Wight ex Arn.	2	0.90	0	0.00	0	0.00	7	0.70	1	0.40	10	0.50
Macaranga caladiifolia Becc.	1	0.50	4	1.50	7	2.10	8	0.70	0	0.00	20	0.90
Macaranga gigantea (Rchb.f. & Zoll.) Müll. Arg.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Macaranga pruinosa (Miq.) Müll. Arg.	0	0.00	3	1.10	0	0.00	9	0.80	0	0.00	12	0.60
Mallotus repandus (Rottler) Müll. Arg.	0	0.00	2	0.80	0	0.00	2	0.20	0	0.00	4	0.20
Mallotus sp. Lour.	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Mangifera caesia Jack	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Mangifera pajang Kosterm.	1	0.50	0	0.00	1	0.30	0	0.00	0	0.00	2	0.10
Memecylon borneense Merr.	0	0.00	0	0.00	3	0.90	5	0.50	1	0.40	9	0.40
Memecylon edule Roxb.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Mesua calophylloides (Ridl.) Kosterm.	1	0.50	0	0.00	1	0.30	0	0.00	0	0.00	2	0.10
Mesua sp. L.	0	0.00	1	0.40	0	0.00	3	0.30	3	1.10	7	0.30
Myristica elliptica Wall. ex Hook. f. & Thomson	3	1.40	0	0.00	0	0.00	3	0.30	0	0.00	6	0.30
Myristica villosa Warb.	0	0.00	1	0.40	4	1.20	12	1.10	0	0.00	17	0.80
Nauclea sp. L.	1	0.50	1	0.40	1	0.30	2	0.20	1	0.40	6	0.30
Neoscortechinii sp.	1	0.50	0	0.00	3	0.90	4	0.40	3	1.10	11	0.50
Nephelium cuspidatum Blume	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Nephelium lappaceum L.	5	2.30	2	0.80	0	0.00	5	0.50	0	0.00	12	0.60
Nephelium maingayi Hiern	0	0.00	2	0.80	2	0.60	1	0.10	0	0.00	5	0.20
Nephelium ramboutan-ake (Labill.) Leenh.	0	0.00	2	0.80	0	0.00	0	0.00	0	0.00	2	0.10
Nephelium sp. L.	0	0.00	0	0.00	1	0.30	1	0.10	0	0.00	2	0.10
Norrisia major Soler.	1	0.50	4	1.50	0	0.00	3	0.30	0	0.00	8	0.40
Ochanostachys amentacea Mast.	0	0.00	1	0.40	2	0.60	2	0.20	0	0.00	5	0.20
Palaquium gutta (Hook.) Baill.	4	1.80	2	0.80	6	1.80	10	0.90	3	1.10	25	1.20
Palaquium obovatum (Griff.) Engl.	0	0.00	0	0.00	0	0.00	4	0.40	0	0.00	4	0.20
Parashorea sp. Kurz	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Parastemon grandifructus Prance	0	0.00	0	0.00	0	0.00	4	0.40	5	1.80	9	0.40
Parastemon urophyllus (Wall. ex A. DC.) A. DC.	0	0.00	3	1.10	0	0.00	2	0.20	0	0.00	5	0.20
Parishia sp. Hook. f.	0	0.00	0	0.00	0	0.00	1	0.10	3	1.10	4	0.20
Parkia speciosa Hassk.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Pentace sp. Hassk.	0	0.00	0	0.00	1	0.30	1	0.10	0	0.00	2	0.10
Pimelodendron griffithianum (Müll. Arg.) Benth. ex Hook.f.	25	11.50	1	0.40	10	3.00	16	1.50	3	1.10	55	2.60
Pimelodendron sp. Hassk.	3	1.40	0	0.00	1	0.30	4	0.40	0	0.00	8	0.40
Pittosporum sp. Banks ex Gaertn.	0	0.00	3	1.10	0	0.00	0	0.00	0	0.00	3	0.10
Polyalthia borneensis Merr.	4	1.80	0	0.00	0	0.00	4	0.40	1	0.40	9	0.40
Polyalthia cauliflora Hook.f. & Thomson	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Polyalthia curtisii Ridl.	0	0.00	2	0.80	3	0.90	16	1.50	0	0.00	21	1.00
Polyalthia glauca (Hassk.) F. Muell.	0	0.00	2	0.80	0	0.00	4	0.40	1	0.40	7	0.30
Pometia pinnata J. R. Forst. & G. Forst.	0	0.00	2	0.80	3	0.90	5	0.50	1	0.40	11	0.50
Psychotria malayana Jack	0	0.00	0	0.00	0	0.00	6	0.60	0	0.00	6	0.30
Psychotria viridiflora Reinw. ex Blume	0	0.00	7	2.70	1	0.30	10	0.90	0	0.00	18	0.80
Pternandra echinate Jack	0	0.00	0	0.00	0	0.00	2	0.20	0	0.00	2	0.10
Pterospermum sp. Schreb.	0	0.00	0	0.00	0	0.00	2	0.20	0	0.00	2	0.10
Sandoricum koetjape (Burm.f.) Merr.	1	0.50	0	0.00	0	0.00	2	0.20	0	0.00	3	0.10
Santiria laevigata Blume	2	0.90	2	0.80	3	0.90	9	0.80	2	0.70	18	0.80
Santiria rubiginosa Blume	0	0.00	6	2.30	0	0.00	6	0.60	0	0.00	12	0.60
Santiria sp. Blume	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Saraca sp. L.	0	0.00	1	0.40	1	0.30	0	0.00	0	0.00	2	0.10
Scaphium sp.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Scorodocarpus borneensis (Baill.) Becc.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Rubroshorea bullata (P. S. Ashton) P. S. Ashton & J. Heck.	0	0.00	0	0.00	0	0.00	1	0.10	1	0.40	2	0.10
Rubroshorea coriacea (Burck) P. S. Ashton & J. Heck.	0	0.00	0	0.00	0	0.00	4	0.40	0	0.00	4	0.20
Rubroshorea macrophylla (de Vriese) P. S. Ashton & J. Heck.	11	5.00	3	1.10	1	0.30	5	0.50	0	0.00	20	0.90
Rubroshorea macroptera (Dyer) P. S. Ashton & J. Heck.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Rubroshorea ovata (Dyer ex Brandis) P. S. Ashton & J. Heck.	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Rubroshorea palembanica (Miq.) P. S. Ashton & J. Heck.	0	0.00	1	0.40	1	0.30	2	0.20	0	0.00	4	0.20
Rubroshorea splendida (de Vriese) P. S. Ashton & J. Heck.	0	0.00	0	0.00	1	0.30	0	0.00	0	0.00	1	0.00
Shorea ladiana P.S Ashton	0	0.00	0	0.00	3	0.90	13	1.20	0	0.00	16	0.70
Shorea sp. 1 Roxb. ex C.F. Gaertn.	0	0.00	2	0.80	13	3.90	2	0.20	1	0.40	18	0.80
Shorea sp. 2	1	0.50	1	0.40	0	0.00	1	0.10	1	0.40	4	0.20
Shorea sp. 3	0	0.00	5	1.90	1	0.30	17	1.60	3	1.10	26	1.20
Shorea sp. 4	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Shorea sp. 5	0	0.00	0	0.00	2	0.60	15	1.40	5	1.80	22	1.00
Shorea sp. 6	0	0.00	0	0.00	1	0.30	12	1.10	1	0.40	14	0.70

Shorea sp. 7	0	0.00	0	0.00	0	0.00	3	0.30	0	0.00	3	0.10
Stemonurus sp. Blume	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Symplocos sp. 1 Jacq.	0	0.00	1	0.40	0	0.00	1	0.10	0	0.00	2	0.10
Symplocos sp. 2	1	0.50	2	0.80	0	0.00	1	0.10	0	0.00	4	0.20
Syzygium acuminatissimum (Blume) DC.	0	0.00	1	0.40	3	0.90	3	0.30	0	0.00	7	0.30
Syzygium anthicoides P.S. Ashton	0	0.00	0	0.00	0	0.00	4	0.40	2	0.70	6	0.30
Syzygium bakoense P. S. Ashton	1	0.50	1	0.40	0	0.00	0	0.00	0	0.00	2	0.10
Syzygium faciflorum P. S. Ashton	0	0.00	1	0.40	0	0.00	7	0.70	4	1.50	12	0.60
Syzygium fulvotomentosum P. S. Ashton	2	0.90	0	0.00	0	0.00	0	0.00	0	0.00	2	0.10
Syzygium grande (Wight) Walp.	0	0.00	0	0.00	0	0.00	1	0.10	1	0.40	2	0.10
Syzygium hirtum (Korth.) Merr. & L. M. Perry	8	3.70	5	1.90	14	4.20	58	5.40	21	7.70	106	4.90
Syzygium monticola Merr. & L. M. Perry	0	0.00	1	0.40	7	2.10	12	1.10	1	0.40	21	1.00
Syzygium polyanthum (Wight) Walp.	1	0.50	1	0.40	1	0.30	13	1.20	6	2.20	22	1.00
Syzygium zeylanicum (L.) DC.	1	0.50	1	0.40	0	0.00	1	0.10	0	0.00	3	0.10
Tabernaemontana macrocarpa Jack	0	0.00	0	0.00	1	0.30	0	0.00	2	0.70	3	0.10
Timonius flavescens (Jack) Baker	0	0.00	1	0.40	1	0.30	0	0.00	1	0.40	3	0.10
Timonius lasianthoides Valeton	3	1.40	5	1.90	4	1.20	8	0.70	0	0.00	20	0.90
Tristaniopsis beccarii (Ridl.) Peter G. Wilson & J. T. Waterh.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Tristaniopsis obovata (Benn.) Peter G. Wilson & J. T. Waterh.	0	0.00	0	0.00	0	0.00	23	2.20	21	7.70	44	2.00
Tristaniopsis whiteana (Griff.) Peter G. Wilson & J. T. Waterh.	0	0.00	1	0.40	0	0.00	1	0.10	1	0.40	3	0.10
Unknown 1	0	0.00	0	0.00	0	0.00	4	0.40	2	0.70	6	0.30
Unknown 2	0	0.00	0	0.00	0	0.00	5	0.50	0	0.00	5	0.20
Unknown 3	0	0.00	0	0.00	0	0.00	1	0.10	1	0.40	2	0.10
Unknown 4	0	0.00	1	0.40	0	0.00	5	0.50	0	0.00	6	0.30
*Vatica borneensis*sp. L.	0	0.00	0	0.00	1	0.30	7	0.70	1	0.40	9	0.40
Vernonia arborea Buch. -Ham.	0	0.00	0	0.00	0	0.00	0	0.00	1	0.40	1	0.00
Vitex pubescens Vahl	0	0.00	1	0.40	0	0.00	0	0.00	0	0.00	1	0.00
Vitex sp. L.	0	0.00	1	0.40	2	0.60	1	0.10	0	0.00	4	0.20
Whiteodendron moultonianum (W. W. Sm.) Steenis	0	0.00	3	1.10	0	0.00	18	1.70	38	14.00	59	2.70
Xanthophyllum affine Korth. ex Miq.	0	0.00	1	0.40	3	0.90	0	0.00	0	0.00	4	0.20
Xanthophyllum amoenum Chodat	1	0.50	0	0.00	1	0.30	1	0.10	0	0.00	3	0.10
Xanthophyllum borneense Miq.	0	0.00	0	0.00	3	0.90	13	1.20	2	0.70	18	0.80
Xylopia ferruginea (Hook. f. & Thomson) Baill.	0	0.00	0	0.00	0	0.00	1	0.10	0	0.00	1	0.00
Total	218	100.00	261	100.00	332	100.00	1068	100.00	272	100.00	2151	100.00

Note: Unknown species were identified only up to the local name

Table 3. Comparison analysis of species diversity and richness variance

	Diversity			Richness		
	Between groups	Within groups	Total	Between groups	Within groups	Total
Sum of squares	3.51	8.56	12.07	8.21	22.40	30.61
df	4	23	27	4	23	27
Mean square	0.88	0.37		2.05	0.97	
F	2.36			2.11		
Significance	0.08			0.11		

Note: *Significant at 0.05 level

Table 4. Mixed-effects model results for tree diversity and richness

		Diversity		Richness	
		Fixed effects	Random effects	Fixed effects	Random effects
Standard deviation		0.61		0.99	
Standard error		0.12	0.18	0.19	0.27
95% Confidence interval for mean	Lower bound	2.58	2.33	3.04	2.67
	Upper bound	3.06	3.31	3.81	4.18
Between- component			0.09		0.19

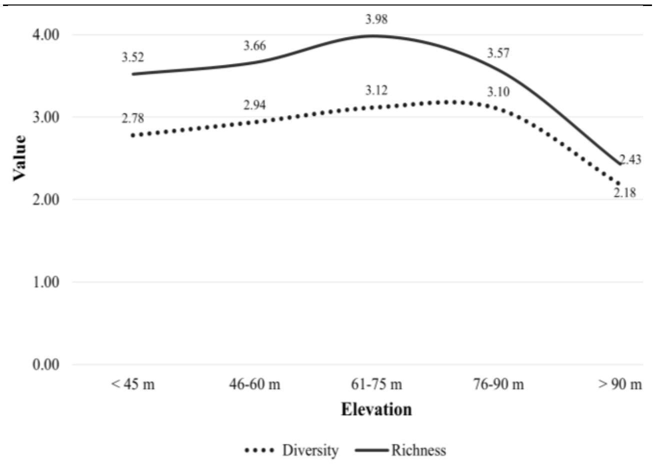

Figure 4. Species diversity and richness along the elevational gradient

Similar to diversity estimates, the model estimated a mean richness of 3.43 with a fixed effects standard deviation of 0.99. It was also found that the mean value for the random effects is similar to the fixed effects (Mean = 3.43). The results of the mixed-effects model, following the equality of mean fixed effects and random effects, suggest that there is minimal variability in species richness along the elevational gradients. This may be due to low variation across the sample units, low predictive ability of elevation, or both. On the other hand, the low variance of random effects can also result in type II error, implying that more variation in richness could actually be present but not detected due to a lack of statistical power.

The descriptive analysis of the species diversity and richness then shows a small difference in the pattern along the elevational gradient. The species diversity pattern shows a hump-shape (Figure 4), in which there is a small increase from the lower elevation of below 45 m asl. (H' = 2.78), then reaching its peak at mid-elevation between 61-75 m (H' = 3.12). However, the species diversity drops to 2.18 beyond the 90 m asl.. A similar pattern is found in species richness when assessed by the total number of species. The highest richness recorded (3.98) is found in the 61-75 m asl., followed by a decrease at higher elevations (>90 m asl.).

Discussion

The study affirmed that the composition of tree species varied throughout Teramuo Hill's elevational gradient. Additionally, the study discovered a hump-shaped relationship between elevation and species diversity, often associated with mid-elevation peaks. Thus, both null hypotheses are rejected, and the alternative hypotheses are accepted, which support the initial preposition that there are differences in species composition and diversity along the elevational gradient. These differences may be attributed to topographic and edaphic factors, as suggested by Hulshof and Spasojevic (2020). These factors directly influence how various tree species are dispersed (Latt and Park 2022), and it was established. Variations in terrain characteristics, including slope, aspect, and soil composition, can create distinct microenvironments that favor specific species adaptations. For instance, mid-elevation peaks in species diversity may result from an optimal balance of ecological conditions that support a broader range of species. This emphasizes the importance of taking topography and edaphic factors into account when analyzing patterns of species diversity. Zhu et al. (2019) also found this notion of species diversity pattern in a tropical forest on China's Diaoluo Mountain. The study found that, in contrast to the predicted pattern of decline with elevation, the highest points of tree abundance, richness, and phylogenetic diversity were all followed by a decrease. This high diversity and richness point represents an ideal range of climatic conditions for tree diversification, probably because mid-elevations have abundant resources, such as moisture and temperature.

In the northwest Himalayas, Wani et al. (2022) also investigated plant diversity along an elevation gradient. They also found a similar result with the current study in which the species richness peaked at mid- and lower elevations before declining at higher altitudes. Several techniques, such as examining the distribution of plant species across various elevation ranges, were used to validate this trend. The study also demonstrated that, rather than a loss of species at higher elevations, this species shift is primarily caused by species turnover, i.e., different species residing at different altitudes.

A review of 118 studies also discovered that a hump-shaped pattern was displayed by most studies (57%), with the greatest variety seen in the medium elevations and a drop at both higher and lower elevations (Dani et al. 2023). This trend was present in all plant families and in both hemispheres. According to the study, the shape of this pattern can be influenced by a species' elevation range, with larger ranges favoring longer hump lengths.

Another similar study by de Andrade Kamimura et al. (2022) on the effects of elevation on plant diversity in Brazil's Atlantic Rainforest also discovered that both the variety of evolutionary lineages (phylogenetic diversity) and the number of unique species (species turnover) increased with elevation before declining at the highest elevations. The mid-elevations were the apex for overall species diversity. This implies that distinct plant families flourish at varying elevations, resulting in a patchwork pattern of diversity across the rainforest. This study emphasizes the importance of both the ecological and evolutionary aspects when planning conservation efforts and assessing biodiversity.

In addition to finding that elevation significantly impacted species diversity, distribution, and stand structure in the Harego Mountain Forest, Worku et al. (2023) also found that environmental factors and anthropogenic disturbances, such as unlawful stem cutting and grazing pressure, influenced these patterns. Disturbances were most severe at the lower elevation, moderate at the upper elevation, and least pronounced at the middle elevation. Variations in environmental conditions across different elevations also contributed to the observed differences in species composition and structure. Also, according to Lugo et al. (2020), some of the factors contributing to the variations are past land use and human disturbances in the forest region. Understanding the observed patterns of species diversity over elevation gradients requires considering both natural and human-related factors. These factors are most likely to alter the ecological circumstances and the fit of habitat at various elevations.

A study by Yano et al. (2021) then found that logging activities decrease both alpha and beta diversity in the Bornean tropical forest of Sabah. In particular, species richness declined at both lower and higher elevations as logging activity increased. Furthermore, severely logged regions have much lower variation in species composition between elevations (beta diversity). The substitution of pioneer species, which have a greater elevation range, for late-successional tree species is what the researchers blamed for the drop in beta diversity. This implies that the loss of biodiversity results from logging's homogenization of the forest structure. In essence, logging has a detrimental effect on biodiversity in the area; hence, attempts to manage tropical forests sustainably should put a high priority on preserving species diversity at all elevations. In contrast, a study conducted in Eastern Usambara, Tanzania, by Lolila et al. (2023) found that environmental factors such as elevation, temperature, nutrient levels, and soil acidity were more influential in determining tree species distribution than anthropogenic disturbances. The study emphasizes the critical role of environmental factors in shaping forest communities and underscores the need for targeted conservation efforts to protect these invaluable ecosystems. In addition, research conducted by Ni and Vellend (2024) in southern Quebec, Canada, discovered soil conditions significantly influence plant growth at different elevations. This suggests that plant growth is more limited at higher elevations due to soil restriction. Thus, species diversity and richness are lower at higher elevations.

In conclusion, this study aimed to identify the species composition at various elevations and measure species diversity at different altitude gradients. It has been found that there is a difference in species composition and dominant species found at various elevations. The study also found a distinct pattern in species diversity and richness across the elevational gradients, with the mid-elevation zone, between 61 and 75 m asl., standing out with the highest species diversity. These results suggest that the main influences are ecological factors and habitat suitability at different altitudes. This study paves the way for further research, and these valuable contributions are integral to advancing our understanding of biodiversity.

However, it is essential to acknowledge the limitations of the current study. Future research should broaden its geographic scope, incorporating higher elevations to unveil more pronounced differences and gain a more comprehensive understanding of species composition and diversity. In addition, future research should consider adding a more comprehensive range of variables that can affect species diversity and composition over elevation gradients. To better understand how various factors affect patterns of species composition and diversity, factors like climate, anthropogenic activities, natural disturbances, and soil characteristics should be included in the research framework.

The assessment of conservation and sustainable forestry practices requires that forest management techniques consider the unique biological dynamics at various elevations. It is critical to adjust forest management practices, considering how climate change is causing habitat displacement and changes in ecological conditions. Given the ever-changing natural landscape, conservation efforts and sustainable management techniques can benefit from an understanding of how variables such as climate and human activity impact species variety. This study advances ecological understanding while having real-world applications to protect biodiversity and maintain forests efficiently in a changing global environment.

ACKNOWLEDGEMENTS

The study is supported by Shell Chair Grant I01/SHC/1981/2020. The authors would like to express their gratitude to everyone who helped make this project a success, especially Hasri Al-Hafiz Bin Haba, Ms Rahah Binti Mohamad Yakup from the Institute of Biodiversity and Environmental Conservation (IBEC), and Rakow Siden, the local field guide. We would also like to thank the editors and anonymous reviewers whose suggestions have significantly raised the caliber of this work.

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