DIVERSITY, DIAMETER STRUCTURE AND SPATIAL PATTERN OF TREES IN A SEMI-EVERGREEN RAIN FOREST ON LANGKAWI ISLAND, MALAYSIA

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KOHIRA, M., NINOMIYA, I., AHMED ZAINUDIN, I. & LATIFF, A. 2001. **Diversity, diameter structure and spatial pattern of trees in a semi-evergreen rain forest on Langkawi Island, Malaysia.** Species diversity, diameter structure and the spatial pattern of trees were studied in a 2.4-ha plot of the semi-evergreen rain forest at Machinchang Forest Reserve, Langkawi Island, Malaysia. The 3518 trees ≥ 5 cm dbh studied comprised 208 species from 45 families, including 156 species in 41 families for 1484 trees ≥ 10 cm dbh. Number of species per area was higher in trees 5 – < 10 cm dbh than in trees ≥ 10 cm dbh. The plot was dominated by Anacardiaceae, particularly *Swintonia floribunda*, which was the most frequent (11.1%) and displayed the greatest basal area (12.8%) of all trees. *Swintonia floribunda* was consistently dominant in all five dbh classes defined from the M-w relationship. Among 64 common species examined for spatial pattern, 2, 42 and 20 species exhibited uniform, random and clumped distribution respectively. The plot was characterised by lack of family dominance by Dipterocarpaceae.

Key words: Diversity - flora - semi-evergreen forests - Langkawi Island - Malaysia

KOHIRA, M., NINOMIYA, I., AHMED ZAINUDIN, I. & LATIFF, A. 2001. **Kepelbagaian, struktur garis pusat dan corak ruang pokok di hutan hujan separa malar hijau di Pulau Langkawi, Malaysia.** Kepelbagaian spesies, struktur garis pusat dan corak ruang pokok dikaji di petak 2.4-ha di hutan hujan separa malar hijau di Hutan Simpan Machinchang, Pulau Langkawi, Malaysia. Sebanyak 3518 pokok dengan garis pusat aras dada ≥ 5 cm dikaji dan ini mengandungi 208 spesies daripada 45 famili, termasuk 156 spesies daripada 41 famili bagi 1484 pokok bergaris pusat aras dada ≥ 10 cm. Bilangan spesies bagi setiap kawasan lebih tinggi bagi pokok bergaris pusat aras dada

5–<10 cm berbanding pokok bergaris pusat aras dada ≥10 cm. Petak tersebut didominasi oleh Anacardiaceae, khususnya *Swintonia floribunda*, iaitu yang paling kerap (11.1%) dan mempamerkan luas pangkal paling besar (12.8%) berbanding pokok-pokok lain. *Swintonia floribunda* mendominasi secara tetap di kesemua lima kelas garis pusat aras dada yang diperoleh daripada hubungan M-w. Dalam 64 spesies biasa yang duji untuk corak ruang, 2, 42 dan 20 spesies masing-masing mempamerkan taburan seragam, rawak dan serumpun. Petak dicirikan melalui kurangnya kedominanan oleh Dipterocarpaceae.

Introduction

Rain forests in lowland Southeast Asia, excluding mangrove forest, can be largely divided into two types, namely, evergreen and semi-evergreen rain forests (Whitmore 1984). Evergreen rain forest occurs in most parts of the Malesian floristic region (Whitmore 1984, Takhtajan 1986). Malesia is predominantly aseasonal without distinct dry periods. Seasonality prevails near the border and beyond the region. Semi-evergreen rain forest contains deciduous tree species and emerge where dry seasons occur. Parts of the Malesian, the Indochinese, and the north-east Australian floristic regions support this type of rain forest (Whitmore 1984, Takhtajan 1986). Semi-evergreen rain forest is vulnerable to fire during the dry seasons and is easily destroyed (Whitmore 1984, 1988).

In the Malay peninsula, semi-evergreen rain forest occurs near the Kra isthmus, a transitional zone where the Malesian and the Indochinese floristic regions meet (Steenis 1979, Whitmore 1984). Only a few studies have been reported on this forest (Congdon 1982, Latiff 1994).

We established a permanent ecological research plot in the area on Langkawi Island, Malaysia. The aim of this study was to describe baseline information on the tree species present in the island and to monitor long-term ecological processes of the forest community. This paper presents the results of the first census to discuss diversity, diameter structure and spatial distribution of tree species in the plot.

Materials and methods

Study area

Langkawi Island (6° 20' N, 99° 50' E; 939 km^2), the largest island of the Langkawi archipelago, lies approximately 30 km off the western coast of the Malay peninsula near the Thai-Malaysia border (Figure 1). Approximately two-thirds of the island are hilly and covered by semi-evergreen rain forest. Two mountain ranges occupy a major portion of the forest. The central part of the island is relatively flat with some lower hills.

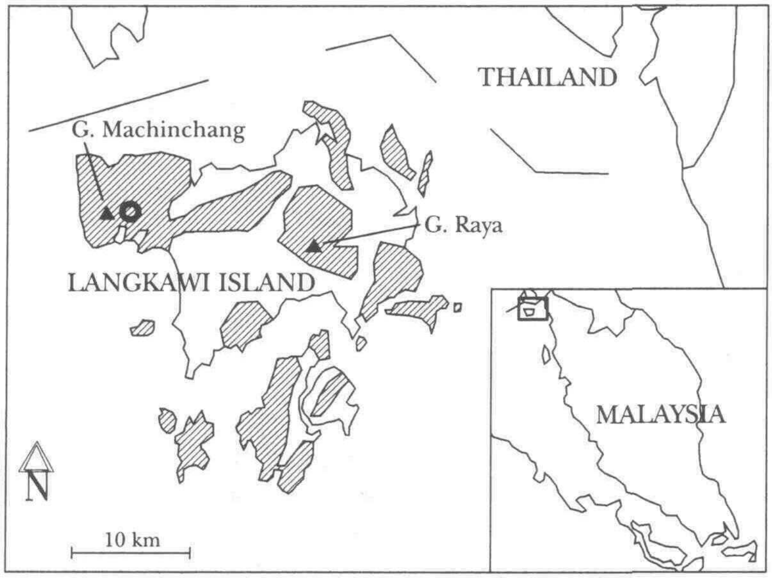

Figure 1 The open circle indicates the location of the study plot. Shaded area represents general extent of semi-evergreen rain forests excluding mangrove forests.

The climate of the island generally follows that of the Malay peninsula at the same latitude. According to the 1987–1999 records of the meteorological station on the island, temperature is largely uniform throughout the year with an annual average of 27.6 °C. Annual rainfall during the same period averages 2360 mm with a mild dry period from December to March. The presence of the mild dry periods characterises the area as semi-seasonal.

Congdon (1982) argued that climate alone does not explain floristic transition between Thailand and Malaysia but edaphic factors also play an important role. The author showed that near the transitional zone, distribution of the Thai-type tree species generally coincide with limestone formation (namely, Tarutao Island), whereas the Malay-type tree species correspond with granite (namely, Adang Island). Langkawi Island has both types of rock formations, granite in the east and limestone in the west (Congdon 1982, Latiff 1994). Latiff (1994) reported that tree species of both floristic types are present on Langkawi Island. The study plot is at the west part of the island on limestone soils and expected to have close affinity with Thai-type tree species.

The 2.4-ha plot (120 × 200 m) has a relatively low relief, no discernible recent human disturbances, and has a continuous single vegetation type near Telaga Tujuh (Seven Wells) within the Gunung Machinchang Forest Reserve. The plot was established on an inconspicuous ridge descending southwards to Telaga Tujuh. Two streams run on the east and west sides of the ridge and unite at the southern base of the ridge.

Altitude of the plot varies between 174 and 220 m asl. A seasonal stream runs from near the north-east corner and exits the plot to the west. The stream was dry throughout the duration of study. The south-west part is the steepest with an approximate inclination of 30°. There was no sign of recent landslides within the plot.

Methodology

Fieldwork was conducted between December 1998 and April 1999. The study plot was aligned so that its longer axis (y-axis) corresponded with the magnetic N-S direction. Declination, a difference between the magnetic and true north, of the area was < 1° and considered negligible. We surveyed the topography of the plot and marked every horizontal distance of 10 m with tagged PVC pipes (75 cm long).

All freestanding trees ≥ 5 cm stem dbh including palms were measured, tagged with numbered plastic tags and mapped in the x-y coordinates to the nearest 10 cm. When a tree had multiple stems, only the thickest was measured. Buttressed trees were measured 0.3 m above the protrusions. Leaf specimens of trees were identified to species or morphospecies ("species" hereafter) and deposited in the herbarium at Universiti Kebangsaan Malaysia (UKM). Nomenclature of tree species followed *Tree Flora of Malaya* (Whitmore 1972, 1973, Ng 1978, 1989) and Ashton (1982), except where recent monographs were available.

Number of species and Fisher's index (Fisher *et al.* 1943, Rosenzweig 1995) were plotted against area and frequency (number of individuals) for all trees, trees ≥ 10 cm, and trees 5–< 10 cm dbh. Family and species were ranked by frequency and total basal area at dbh for all trees.

Stand structure was examined using the M-w diagram (Hozumi 1975). Analysis of the M-w diagram is a quantitative procedure to detect discontinuities in a frequency distribution. Mathematically, for all trees in a given area, weights of individual trees (w) distribute from w_{min} to w_{max}, or $w_0, w_1, w_2, \ldots, w_j, \ldots, w_n$ where $w_0 = w_{min}$ and $w_n = w_{max}$. For this distribution Hozumi *et al.* (1968) defined functions of N, Y and M as follows:

$$N(w_j) = \sum_{k=j}^{n} f(w_k),$$

$$Y(w_j) = \sum_{k=j}^{n} [f(w_k) * w_k] \text{ and}$$

$$M(w_j) \cong Y(w_j)/N(w_j),$$

where

$f(w_k)$ is the frequency distribution function showing the number of trees that weighs w_k,
$N(w_j)$ is the number of trees that ranges from w_j to w_{max},
$Y(w_j)$ is the biomass of trees for that range and
$M(w_j)$ is the mean weight of tree for that range.

An example for calculation of N, Y, and M is given in Table 1.

Table 1 Calculation of statistics for the M-w relationship. Data is from *Barringtonia macrostachya* (n = 51) found in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia.

dbh (cm)	w ($cm^{2.5}$)	f	f × w	Y = Σfw	N = Σf	M = Y/N
12.7	575	1	575	575	1	575.0
11.7	468	1	468	1043	2	521.5
10.5	357	1	357	1400	3	466.7
10.2	332	1	332	1732	4	433.0
9.7	293	1	293	2025	5	405.0
9.4	271	1	271	2296	6	382.7
9.2	257	1	257	2553	7	364.7
9.0	243	2	486	3039	9	337.7
8.9	236	1	236	3275	10	327.5
8.5	211	1	211	3486	11	316.9
8.2	193	1	193	3679	12	306.6
8.0	181	2	362	4041	14	288.6
7.8	170	1	170	4211	15	280.7
7.7	165	2	330	4541	17	267.1
7.6	159	1	159	4700	18	261.1
7.1	134	1	134	4834	19	254.4
6.8	121	1	121	4955	20	247.8
6.7	116	1	116	5071	21	241.5
6.6	112	1	112	5183	22	235.6
6.5	108	2	216	5399	24	225.0
6.4	104	1	104	5503	25	220.1
6.2	96	3	288	5791	28	206.8
6.0	88	5	440	6231	33	188.8
5.9	85	1	85	6316	34	185.8
5.8	81	1	81	6397	35	182.8
5.7	78	3	234	6631	38	174.5
5.6	74	4	296	6927	42	164.9
5.5	71	3	213	7140	45	158.7
5.4	68	1	68	7208	46	156.7
5.3	65	1	65	7273	47	154.7
5.2	62	1	62	7335	48	152.8
5.0	56	3	168	7503	51	147.1
Total		51	7503			

The M-w relationships can be generally approximated by a series of linear equations expressed as (Hozumi 1975)

$$M_i = A_i w + B_i \text{, for } i = 1, 2, 3, \ldots,$$

where

the subscript i represents the specific size class and
A_i and B_i are constants specific to each size class.

Adequacy of estimated values can be examined by comparing the observed and the estimated N(w)-w relationships (Hozumi 1975). We applied linear regression to determine the values of i, A_i and B_i that gave good estimates of N(w) with minimum i, the number of size classes (dbh classes for this study). Species were ranked by frequency for each dbh class. Hozumi (1963) also reported that allometric relationship between dbh and stem volume can be expressed for various forests as

$$(dbh)^{2.4} \leq V \leq (dbh)^{2.6}$$

Since the M-w relationship holds for other variables such as volume, basal area and dbh, following the method of Ninomiya and Ogino (1986), we used the 2.5th power of dbh, $(dbh)^{2.5}$, to represent w for this study.

Spatial distributions were analysed using the index of spatial pattern, C (Ludwig & Reynolds 1988) based on T-square sampling (Besag & Gleaves 1973). For this study, we generated 50 T-square statistics to calculate the index of spatial pattern C for species that had at least 15 individuals in the plot. Departure from randomness ($C = 0.5$) was determined with the z-statistics (Ludwig & Reynolds 1988) using a significant level of 5%, and categorised as either uniform ($0 < C < 0.5$) or clumped ($C > 0.5$).

Results

Of the 3677 tagged trees, 58 trees were considered dead from the condition of inner bark and 72 were palms. Crowns of 29 trees were inaccessible for specimen collection. Excluding these 159 trees, 3518 trees comprising 208 species in 45 families were available for this study (Table 2).

For the 1484 trees ≥ 10 cm dbh, there were 156 species in 41 families. The remaining 2034 trees measuring 5– < 10 cm dbh consisted of 176 species in 43 families. Individuals of 32 species and 52 species occurred exclusively in the ≥ 10 cm and 5– < 10 cm dbh classes respectively. A complete list of tree species and their frequencies found in the plot is given in Appendix 1.

Three species-area curves for all trees, small (5– < 10 cm dbh) and large (≥ 10 cm dbh) classes, were generally similar in shape, but drew different trajectories (Figure 2). Number of species steeply rose as area increased to approximately 0.8 ha, then continued to increase at a slower but constant rate to 2.4 ha. The small dbh class had more species per area than the large dbh class, but their curves were almost parallel for the area > 1 ha. Fisher's α-area curves increased sharply at approximately 0.4 ha, fluctuated at 1.2–1.5 ha, then stabilised within a range of 40 to 50. For area of > 1.2 ha, the index of the small dbh class was slightly greater than that of the large dbh class.

Unlike the species-area relationship, the species-frequency curves were almost identical regardless of dbh class (Figure 3). Fisher's α for the small and large dbh classes appeared to stabilise for > 1000 trees, whereas the index for all trees became stable for > 1500–2000 trees.

In floristic composition for all trees, four families, namely, Anacardiaceae, Myrtaceae, Guttiferae and Dipterocarpaceae, were dominant and they represented 41.3% in frequency and 48.4% in basal area of all trees (Table 3). At species level, *S. floribunda* was the greatest for both criteria (Table 4).

Table 2 Summary of basic data on trees in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia. Total basal area is the sum of basal area for all tree species. Figures in parentheses are standardised to ha^{-1} for number of trees and total basal area.

Dbh (cm)	Number of trees	Number of species	Number of families	Total basal area (m^2)	Fisher's α
5– < 10 cm	2034 (848)	176	43	7.71 (3 21)	46.24
≥ 10 cm	1484 (618)	156	41	82.36 (34.32)	43.97
Total	3518 (1466)	208	45	90.07 (37.53)	48.37

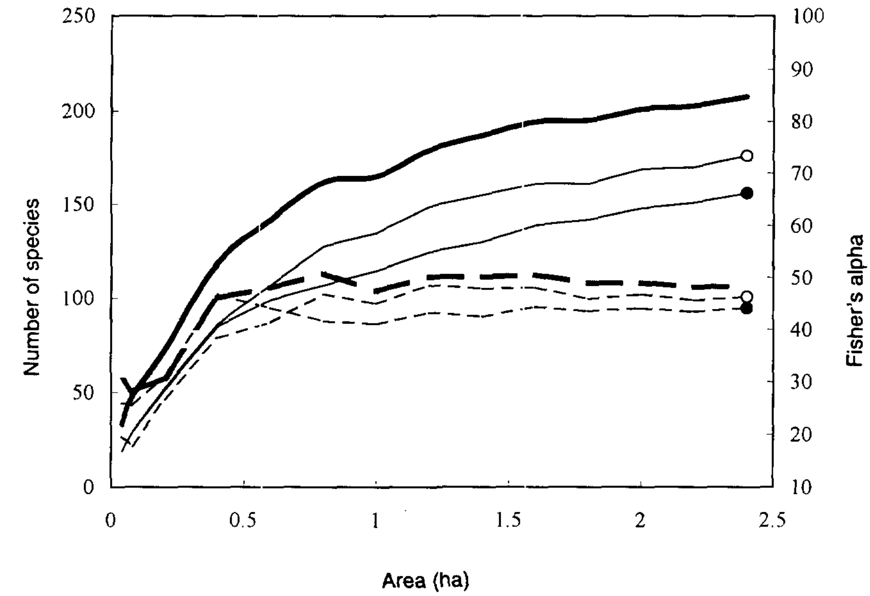

Figure 2 Species-area (solid) and Fisher's index-area (dashed) curves for trees in the 2.4-ha plot at Machinchang Forest Reserve, Malaysia. Thick lines are for all trees, lines with open circles are for trees 5– < 10 cm dbh and lines with closed circles are for trees ≥ 10 cm dbh.

The M-w relationship was approximated by five linear equations (Figure 4, Table 5). Among the five dbh classes, the second dbh class had the greatest basal area, whereas the smallest, the fifth dbh class, was most frequent. The diversity index was generally higher in the smaller dbh classes than the larger. *Swintonia floribunda* was the most frequent in four out of the five dbh classes and the second in the dbh class 2 (Table 6). Other common species included *Koompassia malaccensis* in classes 1 and 2, *Vatica* sp. 1 in classes 3, 4, and 5, *Garcinia eugeniaefolia* in classes 3 and 4, *Eurycoma longifolia* in classes 4 and 5, as well as *Diospyros ismailii* in classes 4 and 5.

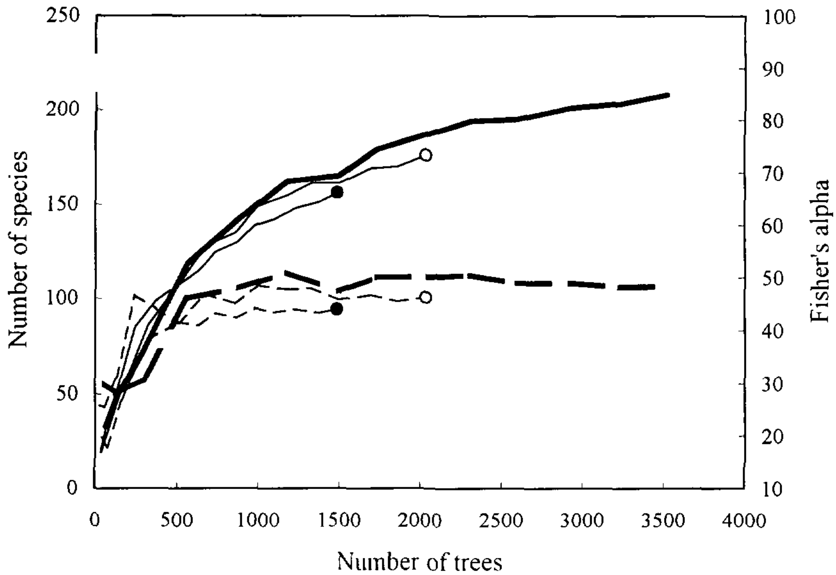

Figure 3 Species-frequency (solid) and Fisher's index- frequency (dashed) curves for trees in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia. Thick lines are for all trees, lines with open circles are for trees 5– < 10 cm dbh and lines with closed circles are for trees ≥ 10 cm dbh.

Table 3 Dominance of families for trees ≥ 5 cm dbh in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia. The 10 families highest in (a) frequency and (b) basal area are listed.

(a) Ranked by frequency			(b) Ranked by basal area		
Family	Number 2.4 ha^{-1}	%	Family	Area (m^2 2.4 ha^{-1})	%
Anacardiaceae	562	16.0	Anacardiaceae	14.83	16.5
Myrtaceae	321	9.1	Guttiferae	11.71	13.0
Guttiferae	313	8.9	Myrtaceae	10.63	11.8
Dipterocarpaceae	256	7.3	Leguminosae	6.41	7.1
Ebenaceae	192	5.4	Dipterocarpaceae	6.40	7.1
Simaroubaceae	151	4.3	Rubiaceae	5.59	6.2
Euphorbiaceae	142	4.0	Elaeocarpaceae	3.97	4.4
Myristicaceae	141	4.0	Celastraceae	2.64	2.9
Rubiaceae	129	3.7	Myristicaceae	2.44	2.7
Flacourtiaceae	123	3.5	Burseraceae	2.35	2.6
Others	1188	33.8	Others	23.10	25.7
Total	3518	100.0		90.07	100.0

Table 4 Dominance of species for trees ≥ 5 cm dbh in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia. The 10 species highest in (a) frequency and in (b) basal area are shown.

(a) Ranked by frequency

Species	Family	Number 2.4 ha^{-1}	%
Swintonia floribunda	Anacardiaceae	390	11.1
Eurycoma longifolia	Simaroubaceae	151	4.3
Vatica sp. 1	Dipterocarpaceae	138	3.9
Hydnocarpus curtisii	Flacourtiaceae	122	3.5
Diospyros ismailii	Ebenaceae	121	3.4
Mesua ferrea	Guttiferae	101	2.9
Garcinia eugeniaefolia	Guttiferae	80	2.3
Pentace floribunda	Tiliaceae	75	2.1
Memecylon amplexicaule	Melastomataceae	73	2.1
Diospyros buxifolia	Ebenaceae	65	1.8
Others		2202	62.6
Total		3518	100.0

(b) Ranked by basal area

Species	Family	Basal area m^2 2.4 ha^{-1}	%
Swintonia floribunda	Anacardiaceae	11.52	12.8
Mesua ferrea	Guttiferae	9.05	10.0
Koompassia malaccensis	Leguminosae	3.71	4.1
Elaeocarpus floribundus	Elaeocarpaceae	3.54	3.9
Pertusadina eurhyncha	Rubiaceae	2.43	2.7
Syzygium sp. 11	Myrtaceae	2.35	2.6
Kokoona reflexa	Celastraceae	2.19	2.4
Dipterocarpus sp. 1	Dipterocarpaceae	2.10	2.3
Hopea sp. 2	Dipterocarpaceae	1.91	2.1
Dysoxylum acutangulum	Meliaceae	1.85	2.1
Others		49.42	54.9
Total		90.07	100.0

Table 5 Statistics of stand components estimated from the M-w relationship for the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia

Dbh class (i)	Dbh range (cm)	n	A_i	B_i	R_i^2	Total basal area (m^2 2.4 ha^{-1})	S_i	S_i*	Fisher's α
1	91.0–133.7	8	0.60	83 344.9	0.981	7.44	6	208	8.39
2	27.4–90.3	309	1.44	14 348.5	0.994	50.90	76	202	32.19
3	15.7–27.3	463	3.04	6053.9	0.990	15.38	107	132	43.64
4	8.4–15.6	1073	5.86	2852.7	0.994	11.04	145	89	45.19
5	5.0–8.3	1665	11.73	1516.9	0.991	5.31	162	39	44.37
Total		3518				90.07			

A_i, B_i and R_i^2 are slope, y-intercept and the coefficient of determination respectively for the regression line of the i-th dbh class. S_i stands for the number of species observed in the i-th class, and S_i* represents the number of species that did not exceed the i-th class.

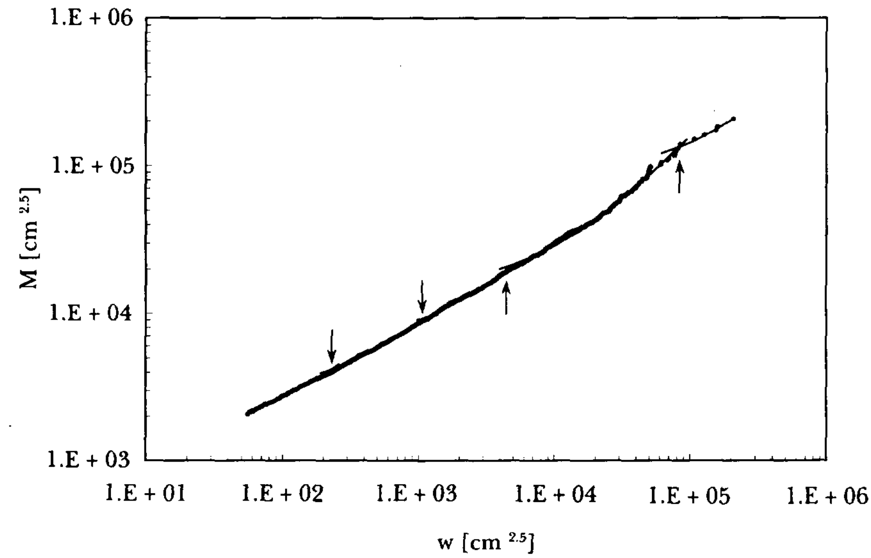

Figure 4 The M-w diagram for trees in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia. Arrows indicate divisions of the five dbh classes in the study.

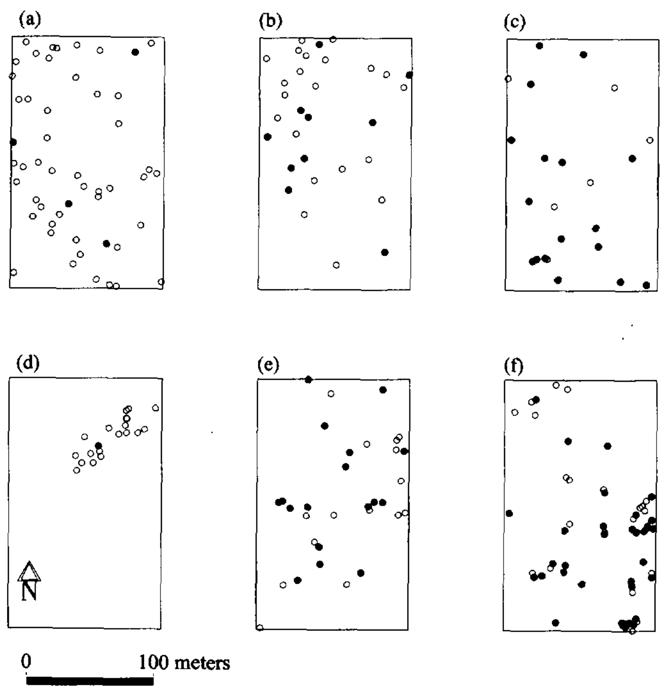

Figure 5 Distributions of tree species in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia showing random for (a) *Barringtonia macrostachya*, uniform for (b) *Hopea* sp. 1 and (c) *Dysoxylum acutangulum* as well as clumped patterns for (d) *Agrostistachys gaudichaudii*, (e) *Pternandra coerulescens* and (f) *Teijsmanniodendron coriaceum*. Open and closed circles represent trees 5– <10 cm and ≥ 10 cm dbh respectively.

Table 6 The top five frequent species for the five dbh classes of trees in the 2.4-ha study plot at Machinchang Forest Reserve, Malaysia

dbh class	Species	Family	Number (2.4 ha^{-1})
i = 1	*Swintonia floribunda*	Anacardiaceae	2
	Pertusadina eurhyncha	Rubiaceae	2
	Hopea sp. 2	Dipterocarpaceae	1
	Elaeocarpus floribundus	Elaeocarpaceae	1
	Koompassia malaccensis	Leguminosae	1
	Others		1
		Subtotal	8
i = 2	*Mesua ferrea*	Guttiferae	36
	Swintonia floribunda	Anacardiaceae	35
	Koompassia malaccensis	Leguminosae	14
	Dipterocarpus sp. 1	Dipterocarpaceae	11
	Leguminosae sp. 1	Leguminosae	11
	Others		202
		Subtotal	309
i = 3	*Swintonia floribunda*	Anacardiaceae	31
	Gymnacranthera eugenlifolia	Myristicaceae	17
	Vatica sp. 1	Dipterocarpaceae	15
	Pentace floribunda	Tiliaceae	15
	Garcinia eugeniaefolia	Guttiferae	13
	Others		372
		Subtotal	463
i = 4	*Swintonia floribunda*	Anacardiaceae	112
	Eurycoma longifolia	Simaroubaceae	59
	Vatica sp. 1	Dipterocarpaceae	42
	Diospyros ismailii	Ebenaceae	41
	Garcinia eugeniaefolia	Guttiferae	33
	Others		786
		Subtotal	1073
i = 5	*Swintonia floribunda*	Anacardiaceae	210
	Hydnocarpus curtisii	Flacourtiaceae	121
	Eurycoma longifolia	Simaroubaceae	90
	Diospyros ismailii	Ebenaceae	78
	Vatica sp. 1	Dipterocarpaceae	77
	Others		1089
		Subtotal	1665
		Total	3518

Of the 64 species that had at least 15 individuals in the plot, T-square index of spatial pattern indicated that 42 species displayed random distribution. Two and 20 species showed uniform and clumped patterns respectively. *Barringtonia macrostachya* (Figure 5(a), $n = 51$) showed random distribution with $C = 0.47$ ($z = 0.72$, $p > 0.05$). The two species showing uniform patterns were *Hopea* sp. 1 (Figure 5(b), $n = 31$, $C = 0.36$, $z = 3.52$, $p < 0.001$) and *Dysoxylum acutangulum* (Figure 5(c), $n = 23$, $C = 0.42$, $z = 2.03$, $p < 0.05$). *Agrostistachys gaudichaudii* (Figure 5(d), $n = 21$, $C = 0.95$, $z = 11.01$, $p < 0.001$), *Pternandra coerulescens* (Figure 5(e), $n = 32$, $C = 0.61$,

$z = 2.69$, $p < 0.01$) and *Teijsmanniodendron coriaccum* (Figure 5(f), $n = 57$, $C = 0.68$, $z = 4.49$, $p < 0.001$) were examples of species showing clumped distributions.

Discussion

The species-area curves for the plot did not reach an asymptote, whereas Fisher's α was fairly stable for the area larger than 1 ha. Fisher's α is a constant for a given community and known to be robust against increases in sample size (Rosenzweig 1995, Condit *et al.* 1996). The results of this study showed that the tree community can be homogenous within the plot.

The difference between dbh classes observed in the species-area curves was almost negligible in the species-frequency curves. This suggested that the higher richness per area observed for the small dbh class can be explained by the greater number of small trees per area. The slight differences that were apparent in the index-frequency curves were obviously due to species that did not attain large dbh class. Although at a much smaller scale, the independence in species-frequency relationship in dbh classes obtained in this study is consistent with the finding of Condit *et al.* (1996) who examined tree diversity of three 50-ha plots in Panama, Malaysia and India.

Being a semi-evergreen rain forest, our plot was dominated strongly by a single species, namely, *S. floribunda*, from the family Anacardiaceae (Table 4). At family level, Dipterocarpaceae was relatively inconspicuous (Table 3). These are in contrast to evergreen rain forests in Malesia where, in general, most species occur in low density but Dipterocarpaceae dominates at family level (Ashton 1982, Whitmore 1984, Kochummen *et al.* 1990, Richards 1996). The floristic composition clearly differentiated our plot from other evergreen rain forests. We cannot conclude, however, if the observed dominance of *S. floribunda* characterised the tree community of Machinchang Forest Reserve until replicate plots are examined.

Among the five dbh classes defined from the M-w relationship, the second and third classes represented most of the total basal area, whereas the forth and fifth dbh classes were more frequent and diverse. The dbh classes 2 and 3 roughly corresponded to the canopy layer whereas classes 4 and 5, the subcanopy layer. The strong dominance of *S. floribunda* in all the dbh classes could be attributed to stable recruitment and shade tolerance of the species. Conversely, species that appeared only in the large dbh class such as *Mesua ferrea* and *K. malaccensis*, possibly had irregular recruitment or a markedly different growth pattern.

Analysis of spatial distribution suggested that the clumped distribution had two patterns. In one pattern, trees were restricted to a certain part of the plot (e.g., *A. gaudichaudii*, Figure 5(d)), and in the other, trees were scattered in clusters or patches (e.g., *T. coriaceum*, Figure 5(f)). Distributions of the former were likely to be related to habitat gradients and that of the latter might be reflecting their dispersal pattern and tolerance to conspecifics. Species such as *T. coriaceum* is considered as "clump syndrome" (Howe 1990), the term applied to species that are animal-dispersed, deposited in clumps and also adapted to growing among conspecifics or near parent trees.

The above examples are of course simplifications. Spatial distribution of species must be a complex consequence of factors such as soil, light, species interaction and seed dispersal. Since these factors change over time and space, it is conceivable that the current cohort of young trees may experience markedly different pressure of natural selection from that of adult trees and change the distribution accordingly. Such temporal changes in spatial pattern could be an interesting aspect in understanding and conserving long-term dynamics of a tree community.

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References

ASHTON, P. S. 1982. Dipterocarpaceae. *Flora Malesiana* 9(2): 237–552.

BESAG, J. & GLEAVES, J. T. 1973. On the detection of spatial pattern in plant communities. *Bulletin of the International Statistical Institute* 45: 153–158.

CONDIT, R., HUBBEL, S. P., LAFRANKIE, J. V., SUKUMAR, R., MANOKARAN, N., FOSTER, R. B. & ASTON, P. S. 1996. Species-area and species-individual relationships for tropical trees: a comparison of three 50-ha plots. *Journal of Ecology* 84: 549–562.

CONGDON, G. 1982. The vegetation of Tarutao National Park. *The Natural History Bulletin of the Siam Society* 30: 135–198.

FISHER, R. A., CORBET, A. S. & WILLIAMS, C. B. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *Journal of Animal Ecology* 12: 42–58.

HOWE, H. F. 1990. Seed dispersal by birds and mammals: implications for seedling demography. Pp. 191–218 in Bawa, K. S. & Hadley, M. (Eds.) *Reproductive Ecology of Tropical Forest Plants: Man and Biosphere Series 7.* UNESCO, Paris.

HOZUMI, K. 1963. Allometry of the higher plant. 2. Allometry of trees–especially in allometric relation of stem diameter at breast height. *Seicho* 2: 1–18.

HOZUMI, K. 1975. Studies on the frequency distribution of the weight of individual trees in a forest stand. V. The M-w diagram for various types of forest stands. *Japanese Journal of Ecology* 25: 123–131.

HOZUMI, K., SHINOZAKI, K. & TADAKI, Y. 1968. Studies on the frequency distribution of the weight of individual trees in a forest stand. I. A new approach toward the analysis of the distribution function and the -3/2th power distribution. *Japanese Journal of Ecology* 18: 10–20.

KOCHUMMEN, K. M., LAFRANKIE, J. V. & MANOKARAN, N. 1990. Floristic composition of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science* 3(1):1–13.

LATIFF, A. 1994. Species and habitat diversity of Langkawi archipelago, Malaysia. Pp. 111–122 in Peng, C. I. & Chou, C. H. (Eds.) *Biodiversity and Terrestrial Ecosystems.* Institute of Botany, Academia Sinica Monograph Series No.14, Taipei.

LUDWIG, J. A. & REYNOLDS, J. F. 1988. *Statistical Ecology.* John Wiley & Sons, Inc., New York. 337 pp.

NG, F. S. P. (Ed.) 1978. *Tree Flora of Malaya.* Volume 3. Longman, Kuala Lumpur. 339 pp.

NG, F. S. P. (Ed.) 1989. *Tree Flora of Malaya.* Volume 4. Longman, Kuala Lumpur. 549 pp.

NINOMIYA, I. & OGINO, K. 1986. Size structure analysis by M-w diagram. Pp. 17–27 in Hotta, M. (Ed.) *Diversity and Dynamics of Plant Life in Sumatra.* Kyoto University, Kyoto.

RICHARDS, P. W. 1996. *The Tropical Rain Forest.* 2nd edition. Cambridge University Press, Cambridge. 575 pp.

ROSENZWEIG, M. L. 1995. *Species Diversity in Space and Time.* Cambridge University Press, New York. 436 pp.

STEENIS, C. G. G. J. VAN. 1979. Plant geography of east Malesia. *Botanical Journal of the Linnean Society of London* 79: 97–178.

TAKHTAJAN, A. 1986. *Floristic Regions of the World.* University of California Press, California. 522 pp.

WHITMORE, T. C. (Ed.) 1972. *Tree Flora of Malaya.* Volume 1. Longman, Kuala Lumpur. 473 pp.

WHITMORE, T. C. (Ed.) 1973. *Tree Flora of Malaya.* Volume 2. Longman, Kuala Lumpur. 444 pp.

WHITMORE, T. C. 1984. *Tropical Rain Forests of the Far East.* Oxford University Press, Oxford. 352 pp.

WHITMORE, T. C. 1988. Forest types and forest zonation. Pp. 20–30 in Earl of Cranbrook (Ed.) *Malaysia.* Pergamon Press, Oxford.

Appendix 1 Species List

Free standing tree species except palms found in the 2.4-ha study plot at Machinchang Forest Reserve, Langkawi Island, Malaysia are listed below. Fourteen morphospecies (18 individuals) could not be identified even at the family level. Number of all trees, and trees ≥ 10 cm dbh among them (in parentheses), are given.

ANACARDIACEAE	
Bouea oppositifolia (Roxb.) Meisn.	27(14)
Buchanania sessifolia Bl.	31(18)
Drimycarpus luridus (Hk. f.) Ding Hou	24(8)
Gluta elegans (Wall.) Hk. f	4(23)
Melanochyla caesia (Bl.) Ding Hou	56(17)
Swintonia floribunda Griff.	390(132)
Subtotal	562(212)
ANNONACEAE	
Anaxagorea javinica Bl.	1(1)
Platymitra siamensis Craib	7(3)
Polyalthia cinnamomea Hk. f. & Thoms.	16(9)
Polyalthia sp. 1	4(1)
Xylopia sp. 1	16(1)
Annonaceae sp. 1	1(0)
Subtotal	45(15)
APOCYNACEAE	
Alstonia angustiloba Miq.	1(0)
Dyera costulata (Miq.) Hk. f.	1(1)
Apocynaceae sp. 1	3(3)
Subtotal	5(4)
BURSERACEAE	
Dacryodes costata (Benn.) Lam	32(19)
Dacryodes rostrata (Bl.) Lam	41(21)
Santiria laevigata Bl.	15(9)
Triomma malaccensis Hk. f.	8(6)
Burseraceae sp. 1	1(1)
Burseraceae sp. 2	1(0)
Subtotal	98(56)
CELASTRACEAE	
Bhesa robusta (Roxb.) Hou	4(3)
Euonymus javanicus Bl.	3(1)
Kokoona reflexa (Laws.) Hou	42(23)
Lophopetalum javanicum (Zoll.) Turcz.	8(4)
Microtropis sp. 1	2(2)
Subtotal	59(33)
CORNACEAE	
Mastixia pentandra Bl. ssp. *scortechinii* (King) Mathew	1(1)
DILLENIACEAE	
Dillenia grandifolia Wall. ex Hk. f. & Thoms.	1(1)
DIPTEROCARPACEAE	
Anisoptera curtisii Dyer ex King	2(0)
Anisoptera scaphulla (Roxb.) Kurz	1(0)
Dipterocarpus sp. 1	55(33)
Hopea sp. 1	31(10)
Hopea sp. 2	5(5)
Hopea sp. 3	3(2)
Hopea sp. 4	2(0)
Hopea sp. 5	1(1)
Shorea sp. 1	6(1)
Vatica bella Sloot	5(2)
Vatica sp. 1	138(47)
Vatica sp. 2	6(5)
Vatica sp. 3	1(0)
Subtotal	256(106)
EBENACEAE	
Diospyros cf. bibracteata Bakh.	3(0)
Diospyros buxifolia (Bl.) Hiern	65(25)
Diospyros ismailii Ng	121 (25)
Diospyros pilosanthera Blanco var. *oblonga* (Wall. ex G. Don) Ng	2(0)
Diospyros tristis K. & G.	1(0)
Subtotal	192(50)
ELAEOCARPACEAE	
Elaeocarpus floribundus Bl.	15(13)
Elaeocarpus petiolatus (Jack) Wall.	11(7)
Elaeocarpus sp. 1	1(0)
Elaeocarpus sp. 2	1(1)
Subtotal	28(21)
EUPHORBIACEAE	
Actephila exelsa (Dalz.) M. A. *var. javanica* (Miq.) P. & H.	10(0)
Agrostistachys gaudichaudii M. A.	21(1)
Antidesma sp. 1	2(0)
Antidesma sp. 2	1(1)
Aporusa falcifera Hk. f.	40(21)
Baccaurea kunstleri King ex Gage	6(3)
Baccaurea minor Hk. f.	24(12)
Chaetocarpus castanocarpus (Roxb.) Thw.	1(1)
Mallotus sp. 1	5(0)
Mallotus sp. 2	1(1)
Euphorbiaceae sp. 1	31(11)
Subtotal	142 (51)
FAGACEAE	
Castanopsis schefferiana Hance	2(2)
Lithocarpus curtisii (King ex Hk. f.) A. Camus	2(0)
Lithocarpus falconeri (Kurz) Rehd.	3(1)
Lithocarpus sundaicus (Bl.) Rehd.	11(9)
Quercus gemelliflora Bl.	14 (11)
Quercus sp. 1	1(1)
Subtotal	33 (24)

continued

Appendix 1 - (continued)

FLACOURTIACEAE	
Flacourtia rukam Zoll. & Mor.	1(0)
Hydnocarpus curtisii King	122(0)
Subtotal	123(0)
GUTTIFERAE	
Calophyllum depressinervosum Hend. & Wyatt-Smith	9(3)
Calophyllum kunstleri King	10(7)
Calophyllum symingtonianum Hend. & Wyatt-Smith	35(25)
Garcinia eugeniaefolia Wall. ex T. Anders.	80(42)
Garcinia nigrolineata Planch. ex T. Anders.	8(4)
Garcinia parvifolia (Miq.) Miq.	39(17)
Garcinia scortechinii King	31(13)
Mesua ferrea L.	101(66)
Subtotal	313(177)
ICACINACEAE	
Platea latifolia Bl.	13(9)
Stemonurus malaccensis (Mast.) Sleum.	11(5)
Subtotal	24(14)
ILLICIACEAE	
Illicium tenuifolium (Ridl.) A. C. Smith	9(6)
IXONANTHACEAE	
Ixonanthes reticulata Jack	12(9)
LAURACEAE	
Actinodaphne sesquipedalis Hk. f. & Th. var. *sesquipedalis*	1(0)
Actinodaphne sp. 1	20(1)
Beilschmiedia lucidula (Miq.) Kosterm.	3(1)
Cinnamomum sintoc Bl.	14(6)
Cryptocarya scortechinii Gamb.	1(1)
Lauraceae sp. 1	7(2)
Lauraceae sp. 2	6(2)
Lauraceae sp. 3	2(0)
Lauraceae sp. 4	6(5)
Lauraceae sp. 5	10(6)
Lauraceae sp. 6	6(2)
Lauraceae sp. 7	18(8)
Lauraceae sp. 8	8(4)
Lauraceae sp. 9	2(0)
Subtotal	104(38)
LECYTHIDACEAE	
Barringtonia macrostachya (Jack) Kurz	51(4)
LEGUMINOSAE	
Adenanthera bicolor Moon	2(1)
Albizia splendens Miq.	9(8)
Archidendron contortum (Martelli) Nielsen	4(0)
Callerya atropurpurea (Wall.) Schot	2(2)
Crudia lanceolata Ridl.	2(0)
Koompassia malaccensis Maing. ex Benth.	26(20)
Leguminosae sp. 1	51(22)
Leguminosae sp. 2	1(0)
Leguminosae sp. 3	1(1)
Subtotal	98(54)
LOGANIACEAE	
Loganiaceae sp. 1	1(0)
MELASTOMATACEAE	
Memecylon amplexicaule Roxb.	73(4)
Memecylon campanulatum Cl.	18(10)
Pternandra coerulescens Jack	32(17)
Subtotal	123(31)
MELIACEAE	
Aglaia sp. 1	8(2)
Aglaia sp. 2	5(2)
Aglaia sp. 3	3(0)
Chisocheton sp. 1	2(0)
Dysoxylum acutangulum Miq.	23(17)
Dysoxylum rugulosum King	4(3)
Meliaceae sp. 1	1(0)
Meliaceae sp. 2	1(0)
Subtotal	47(24)
MORACEAE	
Artocarpus sp. 1	3(1)
Ficus sp. 1	1(0)
Moraceae sp. 1	1(0)
Subtotal	5(1)
MYRISTICACEAE	
Gymnacranthera eugeniifolia (A. DC.) Sinclair	40(37)
Horsfieldia macrocoma (Miq.) Warb.	6(4)
Horsfieldia wallichii (Hk. f. & Thoms.) Warb.	4(3)
Horsfieldia sp. 1	1(1)
Horsfieldia sp. 2	1(0)
Knemofurfuracea (Hk. f. & Thoms.) Warb.	54(8)
Knema kunstleri (King) Warb.	9(1)
Knema laurina (Bl.) Warb.	23(9)
Myristicaceae sp. 1	1(0)
Myristicaceae sp. 2	2(1)
Subtotal	141(64)
MYRSINACEAE	
Ardisia spec. 01	17(0)
Rapanea porteriana Wall. ex A. DC.	2(1)
Subtotal	19(1)
MYRTACEAE	
Rhodamnia cinerea Jack	25(12)
Syzygium sp. 1	27(14)
Syzygium sp. 2	25(7)
Syzygium sp. 3	4(4)
Syzygium sp. 4	13(9)

continued

Appendix 1 - (continued)

Syzygium sp. 5	2(0)
Syzygium sp. 6	4(0)
Syzygium sp. 7	1(1)
Syzygium sp. 8	17(9)
Syzygium sp. 9	17(14)
Syzygium sp. 10	33(21)
Syzygium sp. 11	29(17)
Syzygium sp. 12	52(23)
Syzygium sp. 13	20(3)
Syzygium sp. 14	48(20)
Syzygium sp. 15	4(3)
Subtotal	321(157)
OCHNACEAE	
Brackenridgea hookeri (Planch.) A. Gray	19(10)
Gomphia serrata (Gaertn.) Kanis	35(11)
Subtotal	54(21)
PODOCARPACEAE (GYMNOSPERMAE)	
Podocarpus polystachyus R. Br. ex Mirb.	2(1)
Podocarpus wallichianus Presl.	11(4)
Subtotal	13(5)
POLYGALACEAE	
Xanthophyllum griffithii Hk. f.	2(0)
PROTEACEAE	
Helicia attenuata (Jack) Bl.	6(1)
RHIZOPHORACEAE	
Gynotroches axillaris Bl.	22(14)
ROSACEAE	
Licania splendens (Korth.) Prance	7(5)
Rosaceae sp. 1	14(10)
Subtotal	21(15)
RUBIACEAE	
Aidia wallichiana Tirveng.	19(10)
Gardeniopsis longifolia Miq.	4(0)
Greenea corymbosa (Jack) Schum.	2(0)
Psydrax sp. 5*	13(10)
Psydrax sp. 8*	5(2)
Psydrax sp. 10*	9(6)
Pertusadina eurhyncha (Miq.) Ridsd.	8(7)
Saprosma sp. 1	6(4)
Timonius sp. 1	30(20)
Rubiaceae sp. 1	6(0)
Rubiaceae sp. 2	7(7)
Rubiaceae sp. 3	3(1)
Rubiaceae sp. 4	3(0)
Rubiaceae sp. 5	12(7)
Rubiaceae sp. 6	1(1)
Rubiaceae sp. 7	1(1)
Subtotal	129(76)
RUTACEAE	
Acronychia laurifolia Bl.	7(5)
Tetractomia tetrandra (Roxb.) Craib	13(5)
Subtotal	20(10)
SAPINDACEAE	
Sapindaceae sp. 1	1(0)
Sapindaceae sp. 2	1(0)
Subtotal	2(0)
SAPOTACEAE	
Chrysophyllum lanceolatum (Bl.) DC.	3(0)
Planchonella maingayi (Clarke) van Royen	10(3)
Palaquium oxleyanum Pierre	2(2)
Sapotaceae sp. 1	16(4)
Subtotal	31(9)
SIMAROUBACEAE	
Eurycoma longifolia Jack	151(39)
STERCULIACEAE	
Heritiera javanica (Bl.) Kosterm.	1(1)
Sterculia sp. 1	1(0)
Subtotal	2(1)
SYMPLOCACEAE	
Symplocos cochinchinensis (Lour.) Moore	8(4)
Symplocos sp. 1	25(16)
Symplocos sp. 2	1(0)
Symplocos sp. 3	1(1)
Symplocos sp. 4	15(4)
Subtotal	50(25)
THEACEAE	
Eurya acuminata DC.	3(2)
THYMELEACEAE	
Aquilaria malaccensis Lamk.	17(11)
TILIACEAE	
Pentace floribunda King	75(34)
ULMACEAE	
Gironniera subaequalis Planch.	32(27)
VERBENACEAE	
Teijsmanniodendron coriaceum (Clarke) Kosterm.	57(33)
UNKNOWN	
sp. 1	2(0)
sp. 2	4(1)
sp. 3	1(0)
sp. 4	1(1)
sp. 5	1(0)
sp. 6	1(0)
sp. 7	1(1)
sp. 8	1(1)
sp. 9	1(1)
sp. 10	1(1)
sp. 11	1(0)
sp. 12	1(0)
sp. 13	1(0)
sp. 14	1(1)
Subtotal	18(7)
TOTAL	3518(1484)

* as described in *Tree Flora of Malaya* Volume 4 (Ng 1989: 399-404)