STRUCTURE, COMPOSITION AND COMMERCIAL CHARACTERISTICS OF A PRIMARY DIPTEROCARP FOREST IN SABAH, MALAYSIA

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CEDERGREN, J., FALCK J., GARCIA, A., GOH, F. & HAGNER, M. 2002. Structure, composition and commercial characteristics of a primary dipterocarp forest in Sabah, Malaysia. A primary dipterocarp forest in Sabah, Malaysia, dominated by steep and broken terrain, was systematically sampled. A total of 88 clusters of four circular plots each (radius 10 m) were censussed for trees ≥ 10 cm dbh, climbers ≥ 2 cm dbh, and inclination over an area of approximately 600 ha. There was an average of about 400 stems ha^{-1} of which dipterocarps accounted for 27%. Red seraya was the most common dipterocarp group. Mean basal area was 28.4 m^2 ha^{-1}(dipterocarps 56%), and mean volume 399 m^3 ha^{-1} (dipterocarps 62%). Diameter distribution was negatively exponential. Of dipterocarps, 23% were of poor quality, as were 58% of the non-dipterocarps. There were 192 climbers ha^{-1} ≥ 2 cm dbh. One or more climbers were found on about 25% of the trees. Trees ≥ 10 cm dbh were significantly aggregated but approached a random distribution with increasing dbh. Dipterocarps ≥ 60 cm had a significantly uniform distribution. Stocking in general compares favourably to other parts of the region. Based on structure and composition data, diameter limit felling is cautioned against in favour of more elaborate selection systems.

Key words: Tropical rain forest - dipterocarp - harvesting - silviculture - stand dynamics

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CEDERGREN, J., FALCK, J., GARCIA, A., GOH, F. & HAGNER, M. 2002. Struktur, komposisi dan ciri-ciri komersial hutan dipterokarpa primer di Sabah, Malaysia. Hutan dipterokarpa primer di Sabah, Malaysia, yang banyak terdapat rupa bumi yang curam, diambil sampel secara sistematik. Sejumlah 88 kelompok yang setiap satu terdiri daripada empat plot bulat (jejari 10 m) dibanci untuk pokok berdiameter aras dada ≥ 10 cm, pepanjat berdiameter aras dada ≥ 2 cm, dan kecondongan di kawasan seluas kira-kira 600 ha. Terdapat purata kira-kira 400 batang ha^{-1} dan 27% daripadanya ialah dipterokarpa. Seraya merah merupakan kumpulan dipterokarpa yang paling biasa. Min luas pangkal ialah 28.4 m^2 ha^{-1} (56% dipterokarpa), dan isipadu min ialah 399 m^3 ha^{-1} (62% dipterokarpa). Taburan diameter adalah eksponen secara negatif. Bagi dipterokarpa, 23% berkualiti rendah, sementara bagi bukan dipterokarpa, jumlahnya ialah 58%. Terdapat 192 pepanjat ha^{-1} berdiameter aras dada ≥ 2 cm. Satu atau lebih pepanjat didapati pada kira-kira 25% pokok. Pokok berdiameter aras dada ≥ 10 cm menunjukkan taburan agregat secara bererti tetapi menghampiri taburan secara rawak dengan bertambahnya diameter aras dada. Dipterokarpa ≥ 60 cm mempunyai taburan seragam yang bererti. Penstokan secara umumnya adalah sama seperti kawasan lain di rantau ini. Berdasarkan data struktur dan komposisi, pengehadan tebangan berasaskan diameter perlu diawasi berbanding sistem pemilihan yang lebih teliti.

Introduction

Over the years, extensive and readily accessible areas of flat or gently undulating lowland forests in Malaysia have been converted to other forms of land use, or gazetted as national parks and reserves. As a result, forest operations have become increasingly confined to hilly and remote areas (Anonymous 1989, Appanah & Salleh 1991). Similar development is not unlikely in other parts of the tropics where pressure for land is high.

Differences between flat to gently undulating forests and hilly forests have been repeatedly stressed in reports from Peninsular Malaysia. There, hilly forests occupying elevations from about 320 to 760 m asl are often regarded as a separate forest type, that is, hill dipterocarp forest (see Symington (1943) for full description). Stocking has been found more irregular in hill dipterocarp forest than in lowland forest (Burgess 1970, Tang 1974, Lee 1982). Manokaran and Swaine (1994) reported poorer representation of Dipterocarpaceae, hence referred to as dipterocarps, in hill than in lowland forests. Stocking of hill dipterocarp forest is further influenced by topography, with the highest stocking on ridge tops and the poorest on lower slopes and valley bottoms (Burgess 1970, 1975). Differences in species composition between hill and lowland dipterocarp forest have also been found (Symington 1943, Manokaran & Swaine 1994, Wyatt-Smith 1995).

In Sabah, some differences have been pointed out between lowland and hill forests (e.g. Meijer & Wood 1964, Fox 1972, 1978, Nicholson 1979). According to Fox (1978), hill forests are characterised by total absence of *Eusideroxylon zwageri* and scarcity of *Dryobalanops lanceolata.* Otherwise differences are not much elaborated upon. A review of stocking data from Sabah (Nicholson 1979) indicated no major differences in terms of total stocking between lowland and hill forests.

However, as in Peninsular Malaysia, a lower share of dipterocarps was found in hill forests, particularly among trees bigger than 60 cm in diameter at breast height (dbh).

Differences between lowland and hill forests in Peninsular Malaysia contributed to a change in silvicultural system from Malayan Uniform System (MUS), and modifications thereof, to Selective Management System (SMS) (Appanah & Weinland 1990). SMS stipulates that, after a pre-felling inventory, forests are to be managed according to one of three procedures (Whitmore 1984): areas rich in intermediate-size trees under a polycyclic system; areas with no such trees under MUS; and areas with too few intermediate-size trees and with an inadequate stock of regeneration should be enriched by planting or converted to plantations. As practised, however, SMS has become a selective logging system based on diameter limits (Tang 1987). Cutting cycles of around 30 years are stipulated. Minimum felling diameters are 45 cm dbh for non-dipterocarps and 50 cm dbh for dipterocarps (Appanah & Weinland 1990). Thang (1987) specified standards for residual stocking to be left after harvesting.

In a review of SMS, Appanah and Weinland (1990) cautioned that diameter limit felling will only achieve sustainability where residual stands happen to be well-stocked. Forests managed under SMS could become depleted of dipterocarps, as residual trees with dbh of at least 30 cm may need decades before they can seed enough to regenerate the forest.

In Sabah the silvicultural system prevailing is a modified form of MUS (Anonymous 1972). Minimum felling diameter is 60 cm dbh. Since the adoption of modified MUS, harvesting operations have, as mentioned above, become more and more confined to hilly areas. Whether hilly forests of Sabah are so different from lowland forests that changes in silvicultural prescriptions along the lines of Peninsular Malaysia are warranted, is an issue that requires stand data for further resolution.

Logging damage receives much attention in Sabah (e.g. Chai & Udarbe 1992, Cedergren *et al.* 1994, Pinard 1994). If current efforts to reduce damage are successful, logged over forests will contain more healthy intermediate-size trees, thus improving prospects for polycyclic systems. Data from primary forest are, however, needed to analyse abundance and quality of intermediate-size trees in Sabah. In SMS, pre-felling climber cutting is prescribed to reduce harvesting damage to the residual crop (Appanah & Weinland 1990). This is also recommended in Sabah (Chai & Udarbe 1977). In an experimental evaluation in Peninsular Malaysia, climber cutting resulted in substantial reductions of felling damage (Appanah & Putz 1984). Being a costly treatment, Liew (1973) advocated spot treatment. Climber abundance and spatial distribution are thus of interest for discussions on silviculture in dipterocarp forests.

In 1991 an experiment to evaluate the effect of pre-felling climber cutting and directional felling was established in a dipterocarp forest in south-eastern Sabah. In this study pre-treatment stand data are analysed and used for a discussion on silviculture.

Materials and methods

The study was carried out in a logging compartment at Gunung Rara Forest Reserve, Sabah, Malaysia (4° 24' N, 116° 45' E). The forest was a primary dipterocarp forest of approximately 600 ha. Elevation ranged from 320 to 680 m asl. Soil was sampled in three pits at representative locations. Soil type was Orthic Acrisols (Nussbaum, pers. comm.).

A baseline was established parallel to the main direction of a logging road. The baseline was subjectively aligned to accommodate as much sampling area as possible. At a right angle to the baseline, 16 parallel transects, 30 m wide at a spacing of 160 m, were made through the experimental site. Starting point for the first baseline was randomised. For every transect, the first loggable tree, i.e. an apparently healthy tree of commercial species with a dbh of at least 60 cm and encountered 70 m from the baseline, was selected as centre point for sampling. After the first sampling point on a transect, consecutive centre points had a spacing of at least 140 m. Total number of centre points was 88, with one to ten per transect, i.e. as many as permitted by compartment boundaries. Around each centre point, clusters of four circular subplots, each with a radius of 10 m, were inventoried. Subplot centres were randomised, by angle and distance, within 50 m from each centre point with no overlapping of area. The sampling procedure is illustrated in Figure 1.

Within subplots all living trees with a dbh of at least 10 cm were recorded. Tree data recorded were species, dbh (measured with a diameter tape), health status (rotten or healthy), crown illumination (no direct light, mostly sidelight, some overhead light, full overhead light, emergent), log quality (reject, sawlog, veneer) and crown form (alive but no crown, mainly coppice, only a few branches, less than a half circle, half circular, broken circle, circular). For trees with buttresses higher than 1.3 m, dbh was measured 30 cm above buttresses.

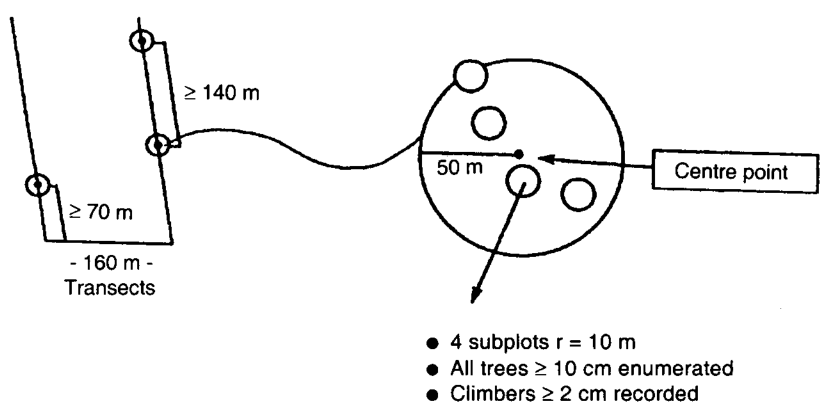

Figure 1 Design of plot alignment in the field. Note that the spacing of 140 m between sample points is a minimum spacing. Sample point pattern was therefore less regular than suggested by the figure.

Presence of fungi, unsound knots, bole cavities and bark damage were the most important evidence of rot. Log quality assessments were based on Anonymous (1980). For trees smaller than 60 cm dbh, log quality was an assessment of the quality expected when the tree reached 60 cm dbh. Crown form was assessed vertically.

Climbers with a dbh of at least 2 cm attached to trees within subplots were recorded. Dbh of climbers was measured using callipers with their tips pointing to the subplot centre. General slope for all subplots was measured with a clinometer. Slopes were classified into mild slope (0 to 15° inclination), medium slope (15 to 35°) and steep slope (more than 35° inclination).

Tree species were identified by trained forest rangers. Vernacular names were used in the field. These were later converted to botanical names using Burgess (1966), Fox (1970) and Cockburn (1976). Non-dipterocarps that could not be identified were classified as Other Timbers (OT). For data analysis, trees were grouped into dipterocarps and non-dipterocarps, the main commercial groups in Sabah. Dipterocarps were grouped according to genus. The genus *Shorea* was subdivided into four sections according to Fox (1978): *Anthoshorea, Rubroshorea, Richetia* and *Shorea.* Trees were further grouped according to density into light, medium and heavy hardwoods following Burgess (1966).

Tree volumes were calculated according to the standing tree volume table for royalty assessment in Sabah (Anonymous 1981).

If not otherwise stated, data from the four subplots around each centre point were clumped together for analyses, and treated as one sample plot.

Analysis of crown illumination classes, log quality distribution and amount of rotten trees was done with the trees divided into three size classes: small trees (dbh from 10 to 29 cm), medium-size trees (30 to 59 cm dbh), and crop-size trees (60 cm dbh or more).

Spatial distribution of trees (s) was described with the variance-to-mean ratio (I) for the number of trees per cluster of four circular subplots (m) (Diggle 1983) and calculated as:

$$I = s^2/m \qquad (1)$$

For complete spatial randomness (sensu Diggle), $I = 1$. Significantly higher or lower values indicate aggregation and uniformity respectively. Statistical significance was tested by comparing I (n - 1) with the χ^2 distribution, where n is the number of sample plots.

A correlation analysis was conducted where abundance of small trees, medium-size trees and crop-size trees were correlated.

Differences in stocking, total and dipterocarps only, between slope classes were analysed using two sided t-test. Individual subplots were treated as independent units for this analysis.

Results

The tree population sampled comprised 4327 trees of 101 vernacular species of at least 59 genera and 33 families (Tables 1 and 2). The exact number of botanical species and genera cannot be determined as vernacular names may include more than one species or sometimes genus. Further, 44% of the trees were identified merely as non-dipterocarps.

Table 1 Vernacular name species composition in number of trees recorded (No.), basal area and volume (data collected on an area of 11.06 ha)

Fam.[1]	Vernacular name	Botanical name[2]	Wood density class[3]	No.	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})
24	Obah	*Eugenia* spp.	MHW	250	14.20	179.72
2	Karai	Annonaceae family	LMHW	186	4.42	49.06
13	Mempening	*Lithocarpus* & *Quercus* spp.	MHW	143	9.93	125.59
10	Seraya minyak	*Shorea oleosa*, ru	LHW	118	11.04	150.18
10	Seraya kuning	*Shorea* spp., ri	LHW	111	14.76	214.49
10	Keruing	*Dipterocarpus* spp.	MHW	106	13.01	183.16
10	Urat mata beludu	*Parashorea tomentella*	LHW	96	23.56	389.87
5	Kedondong	*Canarium, Dacryodes* & *Santiria* spp.	LHW	90	6.13	73.04
10	Kawang	*Shorea* spp., ru	LHW	81	10.11	145.26
12	Kunau kunau, Tampoi	*Baccaurea* spp.	LMHW	81	1.72	19.71
23	Darah darah	*Myristica* & *Hosfieldia* spp.	LHW	80	2.67	31
10	Kapur paji	*Dryobalanops lanceolata*	MHW	76	9.65	156.83
10	Selangan jangkang	*Hopea nervosa*	MHW	76	4.53	58
10	Seraya punai	*Shorea parvifolia*, ru	LHW	75	15.98	253.81
30	Nyatoh	Sapotaceae family	LMHHW	75	3.65	43.06
10	Seraya majau	*Shorea johorensis*, ru	LHW	69	15.10	253.74
10	Seraya kepong	*Shorea ovalis*, ru	LHW	64	7.55	108.13
10	Resak *V*	*atica* spp.	HHW	63	2.22	24.74
11	Kayu malam	*Diospyros* spp.	MHW	33	1.08	11.87
10	Melapi	*Shorea* spp., an	LHW	30	5.59	104.58
12	Magapayas	*Aporusa* spp.	Unidentified	28	0.46	4.85
31	Kembang	*Heritiera simplicifolia*	LHW	28	2.67	37.27
10	Selangan batu	*Shorea* spp., sh	HHW	24	5.08	73.91
10	Seraya kerukup	*Shorea almon*, ru	LHW	24	1.95	23.13
10	Oba suluk	*Shorea pauciflora*, ru	LHW	22	3.82	62.48
16	Medang	Lauraceae family	LHW	21	1.55	19.05
10	Seraya tembaga	*Shorea leprosula*, ru	LHW	20	3.99	64.55
10	Seraya melantai	*Shorea macroptera*, ru	LHW	19	2.09	30.25
22	Terap	*Artocarpus* & *Paraartocarpus* spp.	LHW	19	2.24	30.97
12	Telinga gajah	*Macaranga gigantifolia*	LHW	17	0.27	2.72
10	Seraya daun mas	*Shorea argentifolia*, ru	LHW	12	3.88	58.62
10	Urat mata daun licin	*Parashorea malaanonan*	LHW	12	2.43	35.84
15	Bintangor	*Calophyllum* spp.	LHW	11	0.26	2.87
10	Seraya kerangas	*Shorea venulosa*, ru	MHW	9	5.90	110.37
33	Takalis	*Pentace* spp.	Unidentified	9	0.28	3.5
10	Seraya langgai	*Shorea beccariana*, ru	LHW	8	1.79	27.76
12	Sedaman	*Macaranga* spp.	LHW	7	0.32	4.21
17	Tampalang	*Barringtonia* spp.	LHW	7	0.19	1.86
18	Keranji	*Dialium* spp.	MHW	7	0.37	4.13

continued

Table 1 (continued)

Fam.[1]	Vernacular name	Botanical name[2]	Wood density class[3]	No.	Basal area (m^2 ha^{-1})	Volume ($m^3 ha^{-1}$)
21	Limpaga	Meliaceae family	Unidentified	7	0.93	12.78
25	Bawang hutan	*Scorodocarpus borneensis*	MHW	7	0.66	8.69
1	Asam, Mangga	*Mangifera* spp.	LHW	6	0.91	13.53
1	Rengas	Anacardiaceae	MHW	6	0.23	2.85
9	Simpoh	*Dillenia* spp.	LHW	6	0.37	4.42
10	Kawang burong	*Shorea mecistopteryx*, ru	LHW	6	0.63	10.69
10	Selangan batu biabas	*Shorea leptoderma*, sh	HHW	6	0.72	9.73
10	Seraya merah	*Shorea* spp., ru	LHW	6	0.49	6.85
15	Manggis hutan	*Garcinia* spp.	Unidentified	6	0.18	2.07
16	Medang tiga urat	*Litsea* spp.	LHW	6	0.07	0.96
18	Impas	*Koompassia malaccensis*	MHHW	6	0.95	13.24
20	Sireh sireh	*Pternandra coerulescens*	Unidentified	6	0.08	0.96
1	Layang layang	*Parishia insignis*	Unidentified	5	0.06	0.8
4	Durian	*Durio* spp.	LHW	5	0.64	8.87
6	Perupok	*Lophopetalum* spp.	LHW	5	0.11	1.17
10	Urat mata batu	*Parashorea smytthiesii*	LHW	5	0.34	3.64
13	Berangan	*Castanopsis* spp.	MHW	5	0.24	2.69
21	Lantupak	*Dysoxylum* spp.	Unidentified	5	0.23	2.69
32	Karas	*Aquilaria malaccensis*	LHW	5	0.56	6.84
1	Bambangan	*Mangifera panjang*	LHW	4	0.07	0.64
9	Simpoh gajah	*Dillenia borneensis*	LHW	4	0.43	4.79
10	Kawang bukit	*Shorea amplexicalius*, ru	LHW	4	1.02	13.33
10	Selangan	*Hopea* spp.	MHW	4	0.15	1.75
10	Seraya bukit	*Shorea platyclados*, ru	LHW	4	1.43	19.54
12	Balek angin	*Mallutos* spp.	LHW	4	0.06	0.64
27	Merbatu	*Parinari oblongifolia*	MHW	4	0.75	9.86
28	Bangkal	*Nauclea* & *Neonauclea* spp.	LHW	4	0.04	0.64
31	Bayor	*Pterospermum* spp.	LHW	4	0.16	1.96
3	Pulai	*Alstonia* spp.	LHW	3	0.29	3.69
10	Banjutan	*Shorea multiflora*, ri	LHW	3	0.13	1.43
10	Keruing puteh	*Dipterocarpus caudiferus*	MHW	3	0.42	5.63
10	Seraya	*Shorea* spp, unidentified	LHW	3	0.28	2.74
10	Seraya kuning siput	*Shorea faguetiana*, ri	LHW	3	0.66	10.28
14	Giewei	*Ryparosa acuminata*	Unidentified	3	0.05	0.85
18	Mengaris	*Koompassia excelsa*	MHW	3	1.15	19.71
18	Sepetir	*Sindora irpicina*	LHW	3	1.03	13.62
19	Temasuk	*Fragraea* spp.	HHW	3	0.07	0.85
5	Kembayu	*Canarium odontophyllum*	LHW	2	0.06	0.69
7	Talisai	*Terminalia* spp.	LMHW	2	0.10	1.27
10	Gagil	*Hopea sangal*	MHW	2	0.35	4.36
10	Selangan batu merah	*Shorea guiso*, sh	HHW	2	0.04	0.32
10	Seraya kuning gajah	*Shorea gibbosa*, ri	LHW	2	3.79	92.05
10	Urat mata	*Parashorea* spp.	LHW	2	0.05	0.32
12	Ulas	*Mallotus miquelianus*	LHW	2	0.04	0.32
26	Tabarus	*Sarcotheca diversifolia*	Unidentified	2	0.02	0.32
29	Membuakat	*Paranephelium nitidum*	MHW	2	0.27	3.41
29	Meritam	*Nephelium mutabile*	MHW	2	0.04	0.32
29	Rambutan	*Nephelium* spp.	Unidentified	2	0.09	1.27
1	Ranggu	*Koordersiodendron pinnatum*	MHW	1	0.07	0.53
3	Jelutong	*Dyera* spp.	LHW	1	0.26	3.25
4	Durian monyet	*Neesia* spp.	LHW	1	0.01	0.16
8	Binuang	*Octomeles sumatrana*	LHW	1	0.02	0.16
10	Kapur gumpait	*Dryobalanops keithii*	MHW	1	0.21	3.25
10	Pengiran kesat	*Anisoptera costata*	LHW	1	0.02	0.16

continued

Table 1 (continued)

Fam.[1]	Vernacular name	Botanical name[2]	Wood density class[3]	No.	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})
10	Selangan batu daun halus	*Shorea superba*, sh	HHW	1	1.39	30.7
10	Selangan daun halus	*Hopea dyeri*	MHW	1	0.02	0.16
33	Takalis daun bulat	*Pentace adenophora*	Unidentified	1	0.08	1.11
34	OT	Non-dipterocarpaceae, unidentified	LMHHW	1908	72.37	853.45

[1] Family belonging (Fam.) is indicated by a number, referring to the number given to the family in Table 2.
[2] For species of *Shorea*, section belonging has been indicated by 'an' for *Anthoshorea*, 'ri' for *Richetia*, 'ru' for *Rubroshorea*, and 'sh' for *Shorea*.
[3] Wood density classes used are light hardwoods (LHW), medium hardwoods (MHW), heavy hardwoods (HHW), light to medium hardwoods (LMHW), medium to heavy hardwoods (MHHW), light to heavy hardwoods (LMHHW), and unidentified means that we were unable to find a class belonging.

Table 2 All trees sampled grouped according to families

Family	Number	Basal area (m^2)	Volume (m^3)
Anacardiaceae	22	1.34	18.35
Annonaceae	186	4.42	49.06
Apocynaceae	4	0.55	6.94
Bombacaceae	6	0.65	9.03
Burseraceae	92	6.19	73.73
Celastraceae	5	0.11	1.17
Combretaceae	2	0.10	1.27
Datiscaceae	1	0.02	0.16
Dilleniaceae	10	0.79	9.21
Dipterocarpaceae	1177	176.32	2748.06
Ebenaceae	33	1.08	11.87
Euphorbiaceae	139	2.88	32.45
Fagaceae	148	10.17	128.28
Flacourtiaceae	3	0.05	0.85
Guttiferae	17	0.44	4.94
Lauraceae	27	1.63	20.01
Lecythidaceae	8	0.21	2.02
Leguminosae	19	3.50	50.7
Loganiaceae	3	0.07	0.85
Melastomataceae	6	0.08	0.96
Meliaceae	13	1.19	15.63
Moraceae	19	2.24	30.97
Myristicaceae	80	2.67	31
Myrtaceae	251	14.56	184.66
Olacaceae	7	0.66	8.69
Oxalidaceae	2	0.02	0.32
Rosaceae	4	0.75	9.86
Rubiaceae	6	0.13	1.33
Sapindaceae	6	0.40	5
Sapotaceae	75	3.65	43.06
Sterculiaceae	33	2.97	41.28
Thymelaeaceae	5	0.56	6.84
Tiliaceae	10	0.36	4.61
Misc.	1908	72.37	853.45

(Misc. refers to trees merely identified as Non-Dipterocarpaceae)

The ten most common families, in terms of number of trees, accounted for 51% of the trees, 72% of the basal area and 76% of the volume. Dipterocarps, present with 42 vernacular species of seven genera, accounted for 27% of the trees, 56% of the basal area and 62% of the volume. Of non-dipterocarp families, Myrtaceae was the most abundant (Table 2).

The ten most common vernacular species accounted for 29% of the trees and 35% of the basal area and volume. Of these species, five were dipterocarps (Table 1). *Shorea* was the most common dipterocarp genus, with *Rubroshorea* being the most common section.

Among non-dipterocarps, heavy hardwoods were rare (Tables 1 and 3) and were represented by only one species, *Fragraea* sp. The biggest tree recorded was a *Shorea gibbosa* (section *Richetia*) of 165 cm dbh. The biggest non-dipterocarp was an *Eugenia* sp. of 114 cm dbh.

Average stocking per hactare was 391 trees with a basal area of 28 m^2 and a volume of 398 m^3. Eleven subplot clusters had basal areas below 20 m^2 ha^{-1}, 62 were in the range between 20 and 40 m^2 ha^{-1}, and 15 exceeded 40 m^2 ha^{-1}.

Diameter distribution was negatively exponential for dipterocarps as well as for non-dipterocarps (Figure 2), with about 300 small trees, 70 medium-size, and 23 crop-size trees ha^{-1}.

In total, signs of rot were found on 6% of the trees. Five, eight and eleven per cent of the small, medium-size and crop-size trees respectively showed signs of being rotten.

Dipterocarps were generally better illuminated than non-dipterocarps (Figure 3). In all size classes, a large proportion of the trees received at least some overhead light.

Table 3 All trees assorted in dipterocarp species groups and in wood density classes for non-dipterocarps

Family	Species group	Stems ha^{-1}	Basal area m^2 ha^{-1}	Volume m^3 ha^{-1}
Dipterocarpaceae	Red seraya	58	8.6	133
	White seraya	10	2.4	39
	Yellow seraya	18	2.2	35
	Keruing	10	1.2	17
	Kapur	7	0.9	15
	Selangan batu	3	0.7	10
Non-dipterocarpaceae	OT	285	12.4	150
Total		391	28.4	399

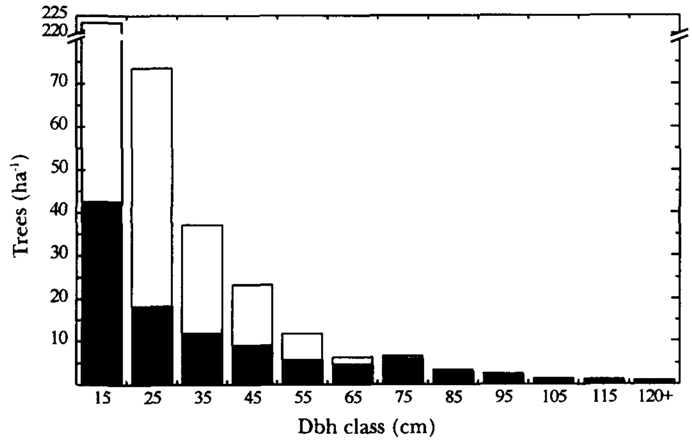

Figure 2 Diameter distribution of dipterocarp (filled columns) and non-dipterocarp (unfilled columns) trees. Class midpoints given. Observe that the column for small trees is interrupted.

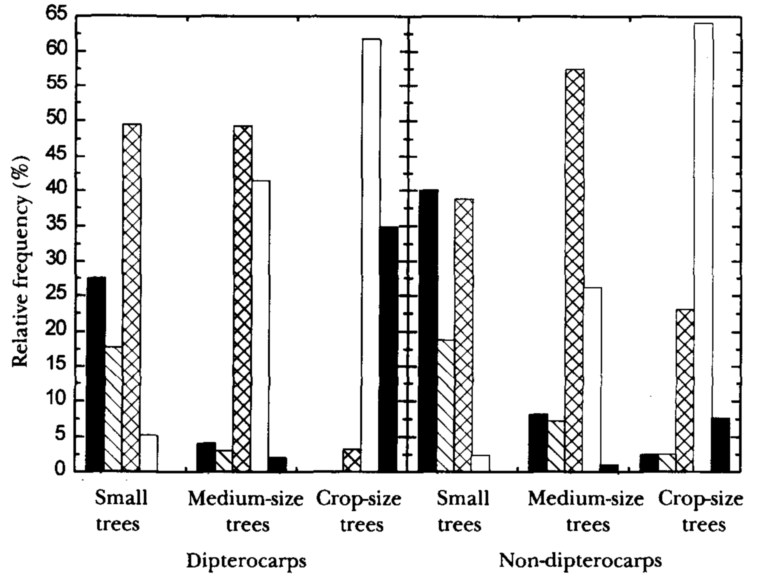

Figure 3 Crown illumination class distribution within tree size classes. Small trees denotes trees with dbh of 10 to 29 cm, medium-size trees 30 to 59 cm, and crop-size trees at least 60 cm dbh. Black, hatched, double hatched, open and grey columns denote trees receiving no direct light, mostly sidelight, some overhead light, full overhead light, and emergent trees respectively.

Dipterocarp boles were generally found to be of higher timber quality than non-dipterocarps (Figure 4). Proportion of veneer quality boles increased with tree size for dipterocarps. Most medium-size trees of all quality classes received at least some overhead light (Figure 5).

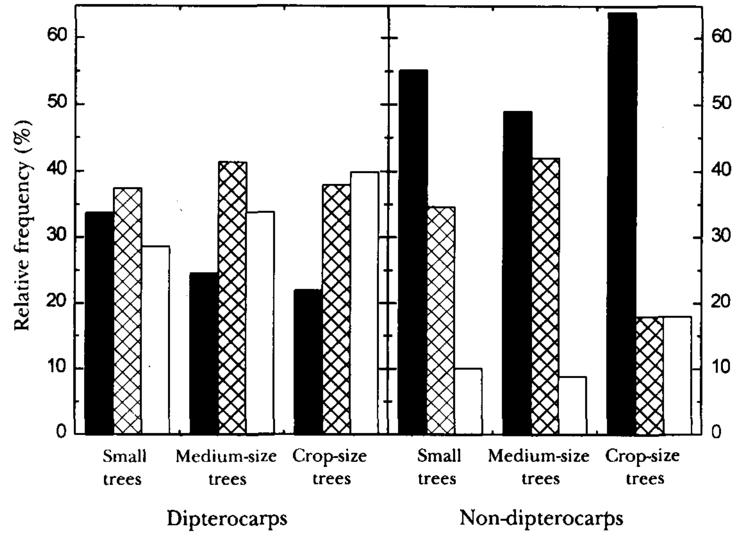

Figure 4 Quality class distribution within tree size classes. Black, double hatched and open columns denote reject, sawlog and veneer quality respectively. Trees divided into dipterocarps and non-dipterocarps. Tree size classes according to Figure 3.

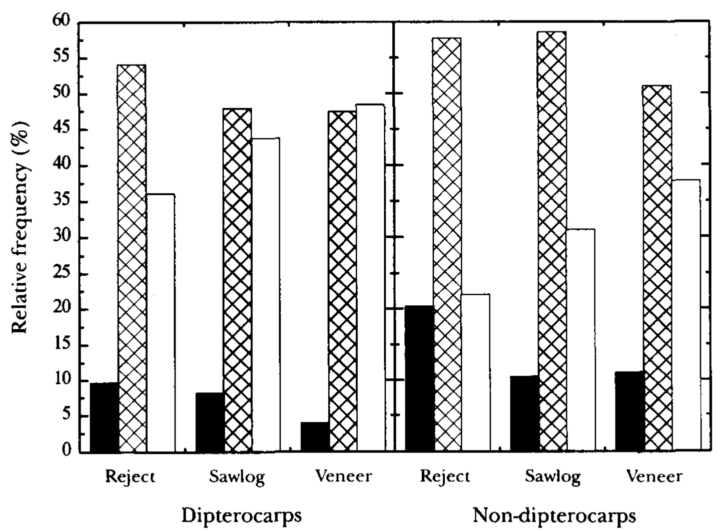

Figure 5 Crown illumination class distribution within the different quality classes for medium-size trees. Black columns denote no direct light or mostly sidelight, double hatched columns some overhead light, and unfilled columns full overhead light and emergent.

Dipterocarps generally had better crown form than non-dipterocarps (Figure 6). Among medium-size trees, circular or broken circular crowns dominated in all quality classes (Figure 7).

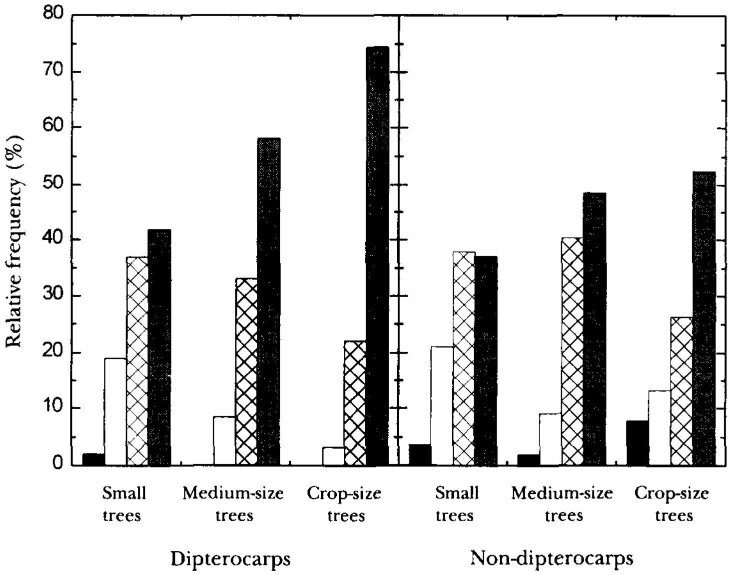

Figure 6 Distribution of crown form classes within tree size classes and species groups. Black columns denote alive but no crown or mainly coppice, unfilled columns only a few branches or less than half a circle, double hatched columns half circular, and grey columns broken circular or circular. Tree size classes according to Figure 3.

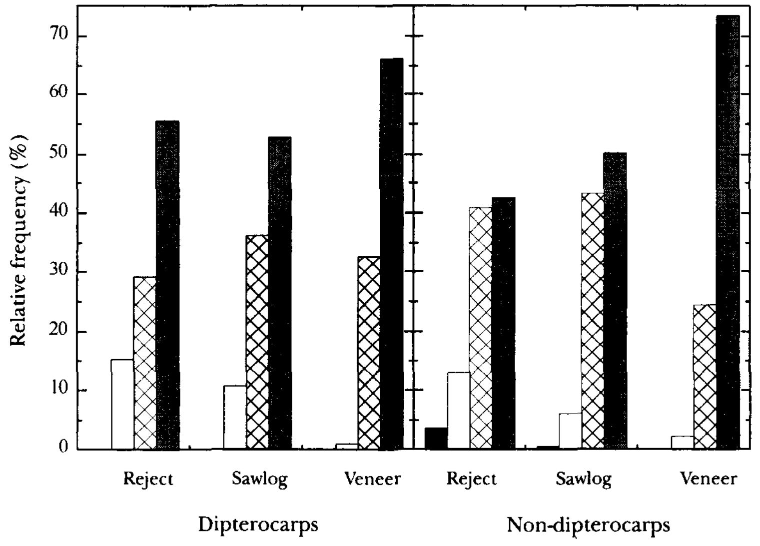

Figure 7 Crown form class distribution within the different quality classes for medium-size trees. Black, unfilled, double hatched and grey columns denote alive but no crown and mainly coppice only a few branches or less than half a circle half circular broken circular or circular respectively.

General climber density was 189 ha^{-1} (SD 93), with a dbh of up to 32 cm. Most trees (73%) were without climbers, 17% had one climber and about 2% had five or more climbers. Crop-size trees accounted for 54% of the trees with five or more climbers.

Trees in the study area were generally aggregated (Table 4). The tendency among crown illumination classes was that the more overhead light the less evident the aggregation, although all classes were significantly aggregated. Spatial distribution for small and medium-size trees was aggregated whereas distribution of crop-size trees did not differ significantly from random (Table 5). Dipterocarp crop-size trees even showed a uniform deviation from random.

Table 4 Spatial distribution expressed as variance-to-mean ratio (I) for trees with a dbh $\geq$ 10 cm

Tree group	I
All trees	2.24***
Dipterocarps	2.33***
Non-dipterocarps	2.16***
Rotten trees	1.67***
Climber-holding trees	1.75***
No direct light	4.36***
Mostly sidelight	3.75***
Some overhead light	2.93***
Full overhead light	1.48**
Emergent and full overhead light	1.38*

I calculated with equation 1. Values larger than 1 indicate aggregated deviation from random, and values smaller than 1 uniform deviation.

Table 5 Spatial distribution within subplot clusters of different size classes, expressed through variance-to-mean ratio (I)

	Small trees	Medium-size trees	Crop-size trees
All	2.02***	1.59***	0.77
Dipterocarps	2.49***	1.73***	0.66**
Non-dipterocarps	1.73***	1.33*	.

I calculated with equation 1. Values larger than 1 indicate aggregated deviation from random, and values smaller than 1 uniform deviation. Size classes are defined in Figure 3.

There was a significantly positive correlation ($r = 0.25$, $p < 0.05$) between frequency in the number of small and medium-size trees. Correlation between small trees and crop-size trees was 0.02 and the correlation between medium-size and crop-size trees was 0.12, neither of which was statistically significant.

Of the subplots 42% were found on mild slopes, 44% on medium, and 14% on steep slopes. There were significantly ($p < 0.05$) fewer trees on steep slopes than on mild and medium slopes. Steep slopes had an average of 339 trees ha^{-1} while mild and medium slopes had 399 and 403 trees ha^{-1} respectively. Apart from that, no significant differences in stocking between slope classes were detected, neither for total stocking nor for dipterocarp stocking.

Discussion

Most species encountered in the area studied were those found typical for both lowland and hill forests by Meijer and Wood (1964) and Fox (1970). A striking feature of the species composition was the total absence of *Eusideroxylon zwageri,* a species typical of the lowlands of Sabah, up to 450 m asl (Burgess 1966). Combined with the relative scarcity of *Dryobalanops lanceolata,* this is in agreement with observations by Keith (1935) (referred to by Fox (1978)) on hill forests in Sabah. However, when establishing another experiment in primary forest about 3 km from the present area, *Eusideroxylon zwageri* was observed by the author to be a common species.

Composition data are largely in agreement with Fox's (1967) study of a lowland forest in Sabah, except that white serayas (*Parashorea* spp.) accounted for a larger share of the stocking in Fox's study. In fact the commonness of white serayas is regarded as a typical trait of the dipterocarp forests in Sabah (Anonymous 1989). Data from the present area do not support this.

There were no major differences in stocking between the present area and those reviewed by Nicholson (1979), although stocking of crop-size trees with a dbh of at least 87 cm seems lower in the present area. Data from East Kalimantan (Nicholson 1979) seem similar to the present study. Data from Peninsular Malaysia, from hill and lowland forests (Nicholson 1979, Manokaran & Swaine 1994), show higher number of trees but a lower share of dipterocarps than in the present study. Data from Philippines and Sarawak indicated larger number of trees and higher proportion of dipterocarps (Nicholson 1979). What seems to distinguish dipterocarp forests in Sabah is the comparatively high number of dipterocarp medium-size trees present, especially compared with hill forests in Peninsular Malaysia. Part of the explanation for differences in stocking between hill forests in Peninsular Malaysia and the present area may be that, in the present study, no stratification of the area into ridge tops, hill sides or valley bottoms was made. Further, choosing the nearest tree to a point as a centre point for sampling introduces a systematic error, as trees growing in dense groups have less probability of being chosen as centre points. However, as data originate from groups of four randomly displaced circular plots within a 50-m radius from the sampling points, this error is probably minor.

Differences in stocking compared with other forests studied in Sabah are small enough to render silvicultural discussions based on the present area generally interesting for Sabah. Compared with studies of dipterocarp forests outside Sabah, differences are big enough to warrant caution.

Medium-size trees need not only be of merchantable quality to form part of the next crop; they must also be able to respond to release. Trees with large and monopodial crowns are those that respond best to release (Appanah & Weinland 1990). When medium-size trees with circular or broken circular crowns are assumed to have large monopodial crowns, and thus ability to respond to release, we would have some 25 medium-size trees ha^{-1} that can be counted on for future harvests (Figure 6). This should be enough to replace trees harvested and to produce a sufficient number of crop trees for future harvests. Very few of these trees were suppressed for light (Figure 5). Should trees with half circular crowns be included, the number increases to about 40, almost half of them dipterocarps.

Climber abundance per ha was about half that recorded by Appanah and Putz (1984) in Peninsular Malaysia, and about a third of that recorded by Pinard *et al.*(1995). Proportion of climber-holding trees was about half that found by Campbell and Newberry (1993) in Sabah. Climbers in Sabah have been found most abundant in low lying areas (Fox 1972), i.e. areas not much represented in this study. This does not warrant a recommendation against pre-felling climber cutting but its effect on felling damage would, most likely, be more modest. The aggregated distribution of climber-holding trees (Table 4) supports spot treatment suggested by Liew (1973) and Chai (1991).

When studying results on spatial distribution (Tables 2 and 3) it should be stressed that the results are affected by plot size. Had plots been larger or smaller, another picture would have emerged. Detailed analysis of spatial structures at different scales requires that all trees be mapped within fairly large areas. A trend found in this study was that as trees grow bigger, distribution pattern goes from aggregated to random, or even uniform. One possible explanation for this is that trees are established in randomly distributed groups, which over time are self-thinned. The fact that most trees of all size classes receive at least some overhead light (Figure 3), i.e. are not overshadowed, could be seen as supporting gap phase dynamics (cf. Doyle 1981, Shugart 1984). However, the low positive correlation in frequency between number of small trees and number of crop-size trees on the sample plots, and the significantly positive correlation between number of small and medium-size trees indicates that forces other than gap dynamics were present in the regeneration and ingrowth process. This warrants further study.

If gap dynamics are of overriding importance, diameter limit felling could be a viable basis for silviculture, provided that big gaps created through the fall of big trees are of greater importance than small gaps created by gradual degeneration of trees in upper storeys. As there is evidence of other forces being present in the area, and as stocking is not uniformly distributed, strict diameter limit fellings could alter the natural regeneration processes, and consequently also, future stand development.

Lack of significant differences in stocking between slope classes in this study can possibly be ascribed to the fact that only general inclination was recorded, not subplot position on slope nor altitude above sea level. Topography has earlier been found important for composition and growth of tropical rain forest (cf. reviews by Richards 1952, Basnet 1992). Harvesting slopes steeper than 35° is not permitted in Sabah. As the primary forest estate shrinks in size, the question of whether or not to harvest at least parts of steep slopes may arise. Research on environmentally sound harvesting methods for steep areas is therefore justified.

Given current forest structure and efforts in Sabah to control harvesting damage, it would seem profitable to rely on medium-size trees for future harvests. Silvicultural systems resembling single-tree selection could have a potential in areas like the present, and the concept is not new to Malaysia (Arnot & Landon 1937). Setting different diameter limits for different species, or groups thereof, has been suggested as a measure to adapt silviculture to local stand conditions (Vanclay 1989). Harvesting regulations should be founded on more sophisticated rules than minimum felling diameter (Roach 1974, Appanah & Weinland 1990), and cutting cycles be determined by what is left in the stands, not by what was harvested (Kraft 1892). Growth data, as local as possible, should be used to determine what volumes to harvest per unit area, how big areas to harvest per year, and, as a consequence of that, the cutting cycles.

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