STAND PROFILE TOPOGRAPHY OF A PRIMARY HILL DIPTEROCARP FOREST IN PENINSULAR MALAYSIA

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A stratified systematic sampling along the gradient directed transect was conducted in a primary hill dipterocarp forest in Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia to study the variations of forest profiles in relation to topography. The structural variations are presented in 14 profile diagrams. Forest profiles showed 2–3 tree-canopy layers, depicting the mosaic of structural phases. The most distinguishing structural variation among the profiles was the higher canopy on gently sloping ridgetops with comparatively dense middle storey and scattered emergent trees. Another structural variation was the low stature of the forest on hillsides, with main canopy heights averaging to 22.8 m. Ridgetop profiles were generally vertically continuous, whereas on hillsides there were vertical discontinuities, mainly due to tree fall gaps. Structural pattern described in other studies elsewhere did not match the profiles of the study site, possibly due to the fact that previously published forest profiles were on level ground. As it appeared in the profiles of the study site, the presence of rare species is a contribution to the maintenance of forest structure. Thus the conservation of rare species should be a concern for the management.

Keywords: Forest profiles, emergent, canopy layer, understory, tree fall gap

INTRODUCTION

Natural forests in Malaysia are estimated to cover 19.26 million ha (58.6% of the total land area) (Anonymous 1992). The National Forestry Policy 1978 and the National Forestry Act 1984 designated 14.06 million ha of forest as permanent forest estate, which consists of production forest for timber production in perpetuity and protective forest for the sustenance of watersheds and the environment. The hill dipterocarp forest in Peninsular Malaysia is unique, extending from the extreme southeast of Thailand, with a forest formation differing from elsewhere. The dipterocarp forest in Peninsular Malaysia, on elevations of 300–750 m above sea level, is classified as hill dipterocarp forest (Whitmore 1984). Most of the dipterocarp forest left in Malaysia is hill dipterocarp forest, its terrain being hilly, rugged and difficult to access. The chief denoting feature of hill dipterocarp forest is the presence of Seraya (*Shorea curtisii*) tree stands with silvery or grayish crowns amongst other trees of the forest canopy. Seraya grows most frequently on hill ridges, as they are well adapted to dry conditions.

Literature shows a dearth of knowledge and information on the basic ecology and silviculture of hill dipterocarp forest (Burgess 1968, 1969, 1970, 1975). The hill dipterocarp forest in Malaysia constitute the bulk of productive permanent forest estate, due to the conversion of most lowland forest. However, the dearth of knowledge has further been compounded by the lack of research attention on rainforest stratification or layers in relation to local habitat types.

Tropical rainforests are often envisioned as being divided vertically into different height strata or layers, with vegetation organised into a vertical pattern from the top of the soil to the canopy (Bourgeron 1983). The vertical structure is generally three storied, i.e. emergent layer, main canopy layer and understorey layer. Topographic locations have profound influences on forest profiles (Saiful 2002). Richards (1996) elaborately described various forest profiles from mixed rain forests. Ashton and Hall (1992) constructed a number of stand profiles for different mixed dipterocarp forests in northwestern Borneo.

Constructing profile diagrams to scale from measurements of trees on narrow sample strips, though somewhat laborious, has proved to be an important method of describing and comparing forest types, differing in structure (Richards 1996). In terms of silviculture, the profiles provide better understanding of regeneration status and growing stock information for management decisions. However, Richards (1996) pointed out the potential biases in profiles selected subjectively. Ashton and Hall (1992) found that tall forests had more slender canopy trees compared to short forests, and vertical stratification were associated with the presence of emergent trees and their distribution. Pascal and Pelissier (1996), in a tropical evergreen forest in southwest India, found low structure on slopes with lack of emergents but with vertical continuity, and tall structures on raised and gently sloping areas with vertical discontinuity. Specht and Specht (1993) in Australian plant communities found that overstorey shading determined the species diversity and structure of the understorey. Whitmore (1990) and Kochummen (1997) reported that most members of Annonaceae, Ebenaceae, Guttiferae and Myristicaceae were represented by monopodial crown in the main and understorey canopy, with distinct horizontal branching.

Rainforests are dynamic and many changes affect the structure of the forest. The vertical structure of the forest cover is important for every aspect of the forest ecology. As concluded by Whitmore (1990), rainforest profile depicts the mosaic of structural phases, i.e. mature, building and regeneration phases. The construction of these structural phases is influenced by the light environment within a forest. Spatial patterning of the light environment on the forest floor occurs through complex interactions among canopy, subcanopy and understorey vegetation (Montgomery & Chazdon 2001). Openings in the forest canopy are widely recognised as important for the establishment, growth and maintenance of species diversity in a tropical forest (Denslow 1987, Denslow & Hartshorn 1994, Schnitzer 2001, Schnitzer & Carson 2001). Tree or branch falls of canopy or emergent trees with large, spreading crowns, cause complete gaps that extend from the forest floor to the canopy (Brokaw 1982, 1985, VanderMeer & Bongers 1996, Connell et al. 1997, Saiful 2002).

The present study was part of a larger research on effects of selective logging on tree species diversity, stand structure and physical environment of tropical hill dipterocarp forest of Peninsular Malaysia (Saiful 2002). The objective of the study was to describe the structural variations of forest profiles in an unlogged primary hill dipterocarp rainforest in relation to spatial habitats or topography, using systematically sampled study plots.

MATERIALS AND METHODS

Study area

The study was carried out in Sungai Weng Catchment, Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia (5° 50' N, 100° 55' E). The study site is located bordering Thailand at about 40 km northeast of Baling, Kedah and composed of five compartments i.e. C25, C26, C27, C28, and C29 (Figure 1 and Figure 2). The topography is characterised by a hilly and undulating terrain with moderately steep to very steep slopes (up to 45°). The elevation of the study site ranges from 340 to 600 m above sea level (Saiful 2002). The study site is characterised by four distinct habitat types such as streamside, hillside, ridge and ridgetop. The mean slope angle of the four habitats was significantly different (Saiful 2002). The ridgetop was entirely a different habitat with the lowest slope gradient (mean = 13.7°) than the ridge (mean = 22.4°). Hillside registered highest slope gradient (mean = 29.8°) and the streamside recorded 24.5° slope angle (Saiful 2002). At lower foot-slope, the ridges of the hills are wider but gradually become narrower when approaching to the ridgetops. In general, the width of the ridgetops varies from 20–25 m within the study area, but found to be even less in C25 with steep unstable hillsides. The climate is uniformly hot averaging 25 °C with plenty of rainfall throughout the year. The mean annual rainfall averaged 2869 mm. The forest is distinctive with continuing stream flows. The parent material is made up of quartzite and sandstone (RRIM 1988) giving rise to clayey and sandy texture. The soil is strongly acidic with pH ranging from 3.22–4.56 (Saiful 2002).

The vegetation is primarily hill dipterocarp forest, classified within the lowland evergreen rain forest formation (Whitmore 1984). The bio-physical characteristics of the study area also

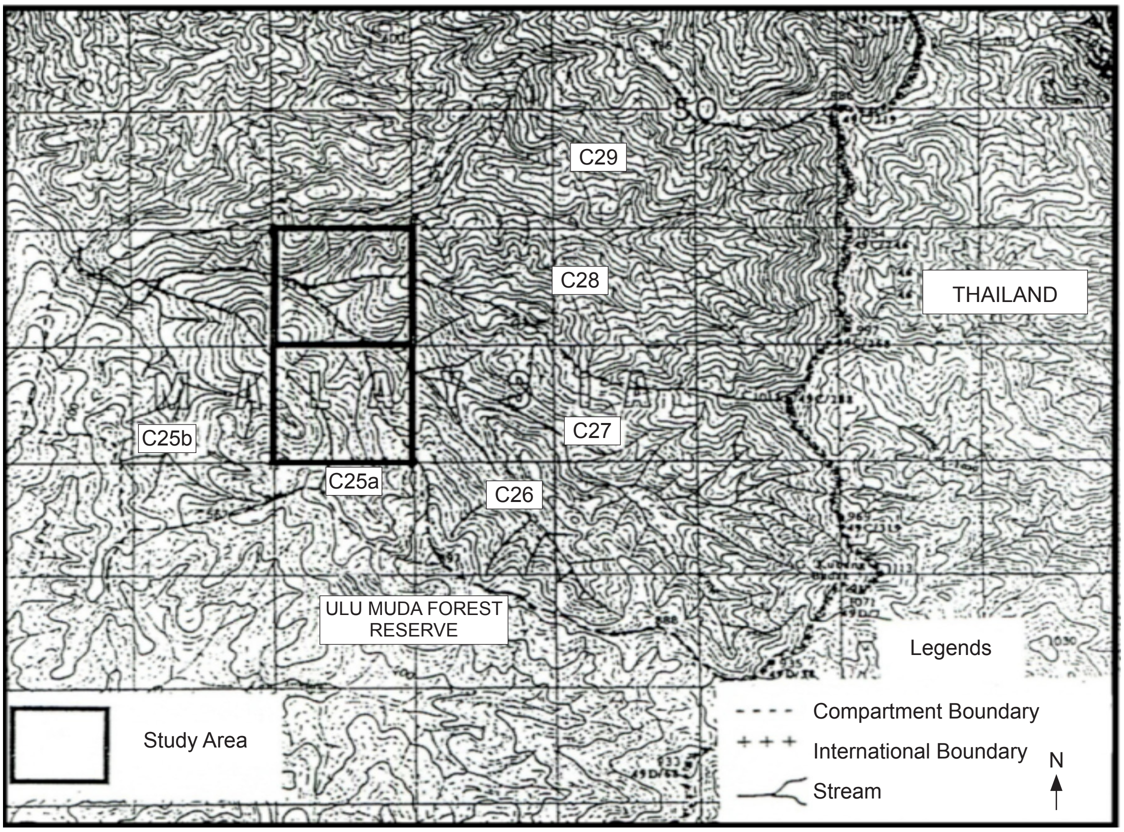

Figure 1 Topographic map (1: 50,000) of Ulu Muda Forest Reserve, Kedah, showing location of study area and compartments (c) (Saiful & Latiff 2014)

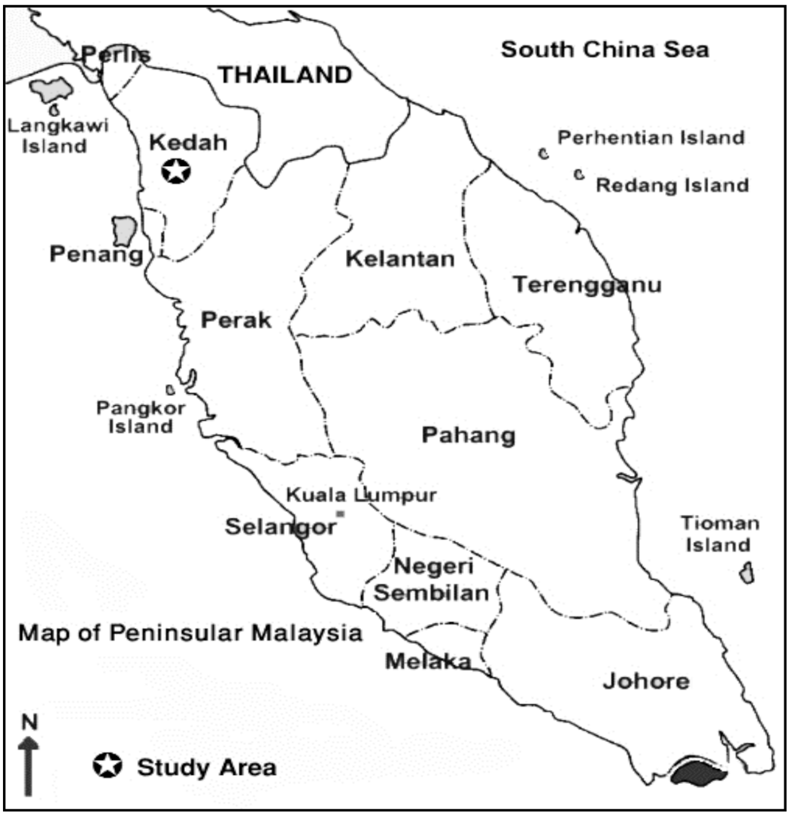

Figure 2 Map of Peninsular Malaysia showing the study location (Saiful & Latiff 2014)

indicate that the forest is 'primary' (Saiful 2002). The vegetation is characterised by small, medium and large-sized trees with scattered emergents, mostly of dipterocarp species. Due to rough and steep terrain, the study site is not adequately stocked with advanced growth compared to lowland dipterocarps. Apart from the tree crops, the ground layer vegetation consists of few common herbs, shrubs, climbers, creepers and bertam palms (*Eugeissona tristis*).

Survey design

The study area, covering 150 ha, comprising of two adjacent blocks of 100 ha each (Figure 1), was selected for systematic sampling. Obtaining a representative sample of vegetation and stand parameters from a large area is highly dependent on sampling design and methodology. For this reason, topographic and gradient directed transect (Gillison & Brewer 1985, Austin & Heyligers 1989, Philip 1994) was applied to survey the bio-physical parameters, including information on forest profiles. The shape, size and positioning of plots were also determined based on reconnaissance survey of the study area. Within each forest stand (i.e. hill), a line transect of about 500–600 m was laid out originating from stream bank, following the centre of the ridge and finally ending at the ridge crest (Figure 3). Lateral transects were also established at

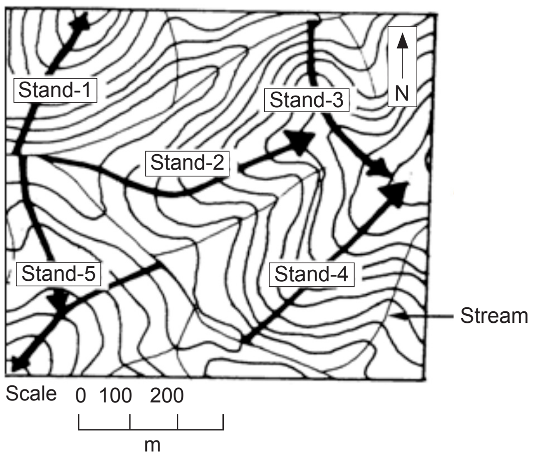

Figure 3 Topography of the study area showing direction of survey transects (indicated by arrow) following elevation gradient; lateral transects on hillsides are not shown, transects in one study block are shown, interval between isolines = 20 m; area = 100 ha (Saiful & Latiff 2014)

right angle to the main transect, alternately to sample hillsides and spaced systematically at 40 m distance. For construction of tree profile diagrams, 45 m × 10 m rectangular strips were established at a 40 m intervals on the transect line (Figure 4). To avoid subjective selection, the left side of the rectangular plot/strip was taken for profile diagram.

Data collection

Trees ≥ 5.0 cm diameter at breast height (DBH) were measured with a diameter tape at 1.3 m above ground level or just above the buttress. Tree seedling and saplings (regeneration phase) were not included in the profiles. Plant species other than trees (such as lianas) were also ignored. In the understorey, trees 5 to > 20 cm DBH and 7–15 m tall were taken into consideration for profile diagrams, and the main canopy layer was composed of trees > 20 cm DBH, 15–35 m height, with a few higher than 35 m. Each tree sampled was tagged with a unique identification code. Ground positions of individual trees, according to diameter, were mapped. Voucher specimens of individual trees were identified up to species level using keys and descriptions of Malaysian flora (Whitmore 1972, 1973, Ng 1978, 1989), and verified with collections at the herbarium of Forest Research Institute Malaysia (FRIM).

Since it was difficult to measure the tree height from the ground, tree heights and crown depths were estimated with the help of a tree climber aborigine using a 5 m pole and a meter tape. The estimated height was then compared with the height of fallen trees of various sizes in the study site. Crown width was measured with a meter tape by taking vertical crown projection down to ground level. A rough sketch diagram of each individual tree was drawn in the field book, including crown shape as well as bole and buttress form, and other detailed notes. Based on the ground plan of tree positions and notes taken in the field, a final profile diagram was constructed to scale. Species names were provided for canopy trees ≥ 20 cm DBH in the profile diagrams. Tree heights were measured and the recorded height measurements, in relation to DBH, were verified and found significant for every profile diagram (Figure 5). Altitude was recorded by altimeter and slope angle by Suunt' clinometer (Saiful 2002).

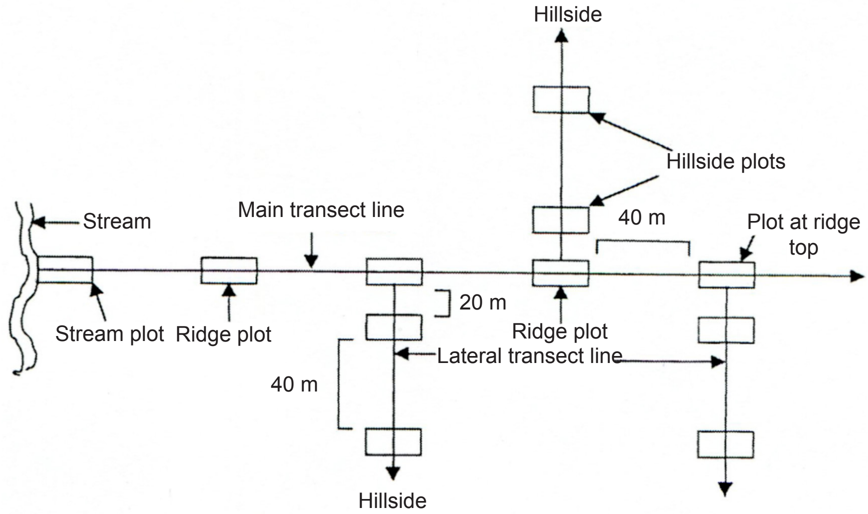

Figure 4 Diagram showing main and lateral transects and positioning of plots in a forest stand, lateral transects positioned alternately on either side of the main transect to sample hillside, study plots were regularly spaced on the transect line (Saiful & Latiff 2014)

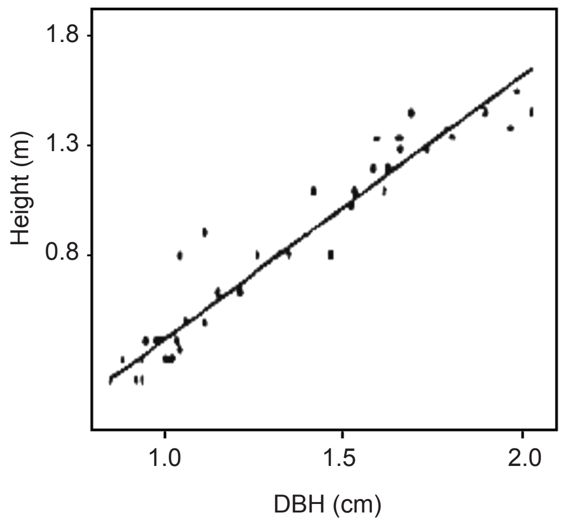

Figure 5 Relationship between diameter and height (log-transformed data) for trees ≥ 5.0 cm DBH recorded for profile diagram; tree height was estimated using 5.0 m pole; $r^2 = 0.92$, $p < 0.001$

RESULTS AND DISCUSSION

Hill dipterocarp forest is represented by 14 profile diagrams from different topographic locations (Figures 6–9). Of the four ridgetop profiles, only two had emergent trees (Figures 6a and b), and all other profiles showed two layers, main canopy and understorey. The canopy layer or middle strata was vertically variable and horizontally continuous, except in places of tree fall gaps or dead standing trees. Thus, the main effect of hill forest topography could be the disruption of canopy layering. The main canopy and understorey occasionally overlapped with each other, and only an arbitrary division could be made between them. The canopy layer (trees > 20 cm DBH) was dominated by Dipterocarpaceae followed distantly by Leguminosae, Myrtaceae, Burseraceae, Olacaceae, Anacardiaceae, Moraceae, Euphorbiaceae, Sapotaceae, Guttiferae, Linaceae, Meliaceae and Fagaceae. Most trees in the understorey layer (trees 5 to < 20 cm DBH) had narrow conical crowns usually deeper than wide, and sometimes overlapped the main canopy to some extent. As reported by Whitmore (1990) and Kochummen (1997) for other forests in Malaysia, many trees in this layer are members of Annonaceae, Ebenaceae, Guttiferae (Garcinia sp.) and Myristicaceae, represented by monopodial crowns in the understorey canopy with distinct horizontal branching. The dominant families of the study site (Saiful 2002, Saiful et al. 2008) represented the members of the understorey canopy.

Forest of the study site depict the mosaic of structural phases (i.e. mature, building and regeneration phases) as described by Whitmore (1990) for tropical rain forest, but differed from profiles presented by Richards (1952, 1983, 1996), Ashton (1964) and Ashton & Hall (1992). The most distinguishing structural variations among the topographic locations were the higher canopy on the flat or gently sloping ridgetops with comparatively dense canopy trees in the middle storey, forming more or less laterally continuous canopy (Figures 6a, b and d). This was mainly because the ridgetop had significantly higher number of canopy trees than other topographic locations (Saiful 2002). The profiles of the ridgetop (Figures 6a, b and d) comprised of mature phase forest, represented by the full-sized dense canopy trees, and the building phase, by a thin layer of pole-sized trees. Another structural variation in the profiles was the low stature of the hillside forests, averaging to only 22.8 m tall (Figure 8). This association between forest height and topographic position was described by Ashton & Hall (1992) and Pascal & Pelissier (1996), but the latter authors reported low

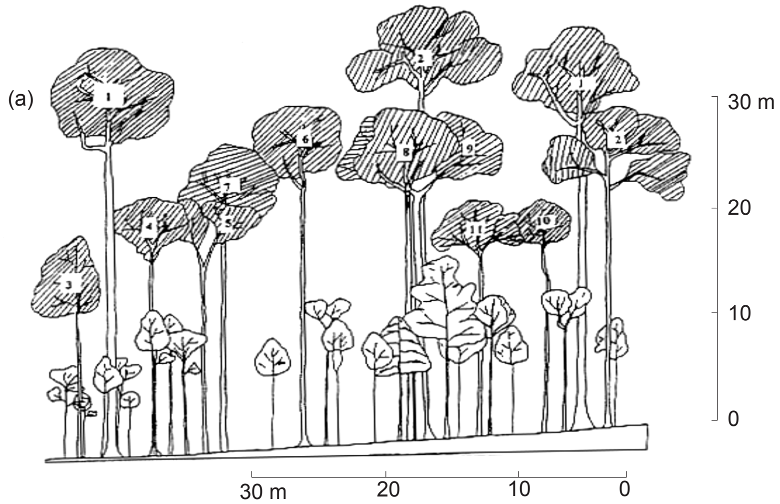

Figure 6(a) Profile diagram of primary hill dipterocarp rainforest, Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia, a strip of forest on ridge-top 45 m × 10 m (elevation 500 m asl, slope angle 15.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH with was one single large tree as emergent above the main canopy layer, main canopy was laterally continuous; ☐ = understorey trees, vertically well separated from the main canopy layer; key to species for A (≥ 20 cm DBH): 1 = *Swintonia floribunda,* 2 = *Shorea curtisii, 3* = *Syzygium prainiana,* 4 = *Litsea firma,* 5 = *Psydrax sp.,* 6 = *Lithocarpus ewyckii,* 7 = *Mastixia pentandra,* 8 = *Xanthophyllum affine,* 9 = *Archidendron bubalinum,* 10 = *Syzygium duthieana,* 11 = *Horsfieldia punctatifolia*

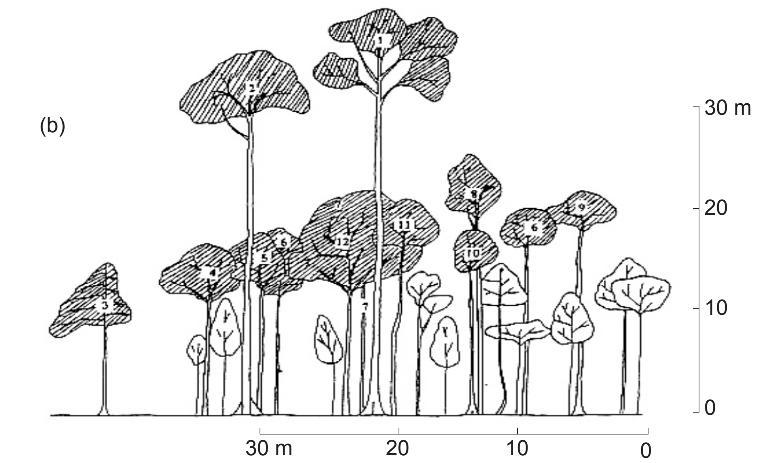

Figure 6(b) Profile diagram of a strip of forest on ridge-top 45 m × 10 m (elevation 520 m asl, slope angle 12.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, the emergent trees were fairly well separated vertically from the main canopy layer, the main canopy was laterally more or less continuous; ☐ = understorey trees, vertically separated from the main canopy layer; key to species for B (trees ≥ 20.0 cm DBH): 1 = *Shorea curtisii,* 2 = *Dacryodes incurvata,* 3 = *Garcinia parvifolia,* 4 = *Canarium littorale,* 5 = *Brackenridgea hookeri,* 6 = *Syzygium prainiana,* 7 = *Cinnamomum sintoc,* 8 = *Dillenia grandifolia,* 9 = *Palaquium rostratum,* 10 = *Cyathocalyx pruniferus,* 11 = *Styrax benzoin,* 12 = *Endospermum diadenum*

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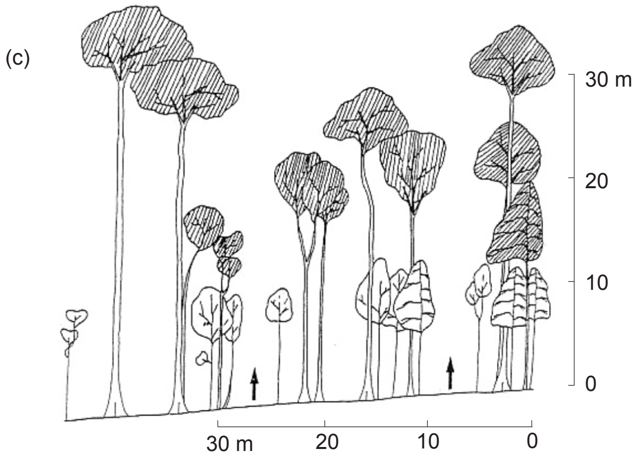

Figure 6(c) Profile diagram of a strip of forest on ridge-top 45 m × 10 m (elevation 525 m asl, slope angle 13.5°), all trees ≥ 5.0 cm DBH are shown; = canopy trees ≥ 20 cm DBH, main canopy layer was laterally interrupted by tree fall gaps (↑); = understorey trees, less dense and vertically separated from the main canopy layer; species names were not provided due to lack of voucher specimens

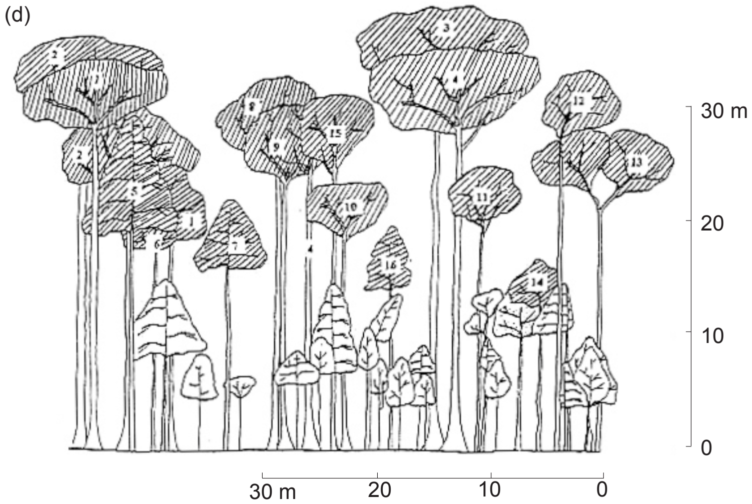

Figure 6(d) Profile diagram of a strip of forest on ridge-top 45 m × 10 m (elevation 600 m asl, slope angle 10.5°), all trees ≥ 5.0 cm DBH are shown; = canopy trees ≥ 20 cm DBH, main canopy layer was laterally more or less continuous; = understorey trees, vertically separated from the main canopy layer; key to species for D (trees ≥ 20.0 cm DBH) : 1 = *Shorea curtisii,* 2 = *Michelia koordersiana,* 3 = *Swintonia schwenkii,* 4 = *Millettia atropurpurea,* 5 = *Alphonsea curtisii,* 6 = *Horsfieldia polyspherula,* 7 = *Xanthophyllum affine,* 8 = *Shorea macroptera,* 9 = *Aporusa falcifera,* 10 = *Hopea glaucescens,* 11 = *Mezzettia parvifolia,* 12 = *Mastixia pentandra,* 13 = *Castanopsis nephelioides,* 14 = *Palaquium hervey,* 15 = *Aporusa nervosa,* 16 = *Gironniera subaequalis*

canopies on slopes with lack of emergent trees but with vertical continuity, and tall structures on raised and gently sloping areas with vertical discontinuities. In fact, in the study site, there were vertical discontinuities in the hillsides due to tree fall gaps (Figures 8a, b and c), and the profiles thus showed few trees of mature phase along with pole-sized young trees of building phase, derived from regeneration niches. Like hillsides, the main canopy layer of ridge and streamside (Figures 7a–d, Figures 9a and b) was also vertically and laterally discontinuous, i.e. not well represented by canopy trees. As such, tree fall gaps are one phase in a forest regeneration cycle. Colonisation and growth in the gap phase lead to building mature phases, in which tree fall renew the cycle (Whitmore 1975).

Most of the canopy gaps were associated with the death of single trees, falling by uprooting. About 90% of trees > 20.0 cm DBH that fell in gaps were uprooted. Green (1996) reported that in Christmas Island 59% of trees of similar diameter class found in gaps were uprooted, and the remainder were snapped off. In the study site, ridgetops with gentle slope had significantly lower number of tree fall than other topographic locations (Saiful 2002). In Costa Rican tropical rain forest, gaps were more common on steep

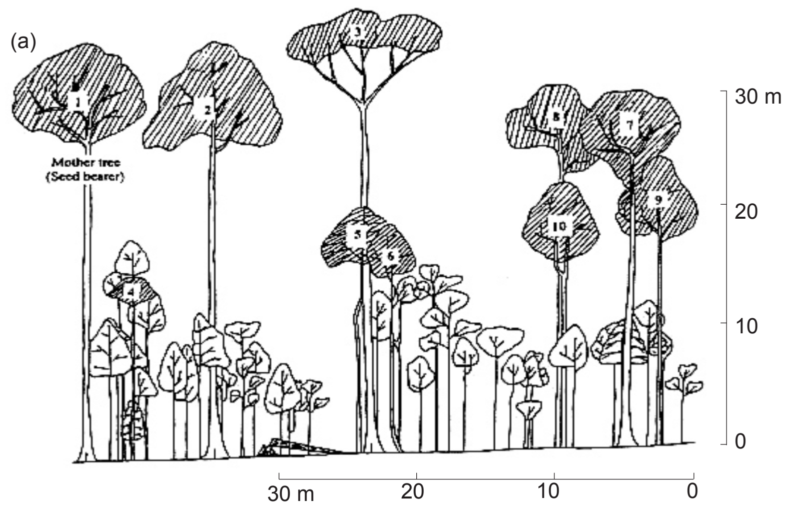

Figure 7(a) Profile diagram of a strip of forest on ridge 45 m × 10 m (elevation 440 m asl, slope angle 18.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally discontinuous and interrupted by tree fall gaps; ☐ = understorey trees, not vertically well separated from the main canopy layer; key to species for A (trees ≥ 20.0 cm DBH): 1 = *Shorea macroptera,* 2 = *Ctenolophon parvifolius,* 3 = *Irvingia malayana,* 4 = *Durio griffithii,* 5 = *Monocarpia marginalis,* 6 = *Archidendron bubalinum,* 7 = *Dacryodes costata,* 8 = *Syzygium dyeriana,* 9 = *Caulaya atropurpurea,* 10 = *Ochanostachys amentacea*

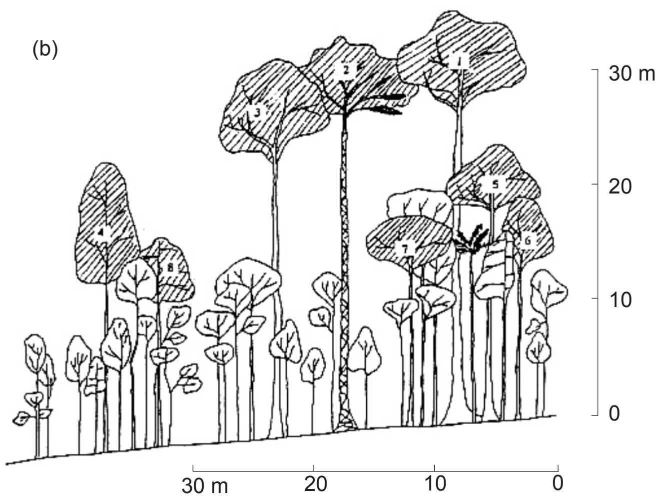

Figure 7(b) Profile diagram of a strip of forest on ridge 45 m × 10 m (elevation 460 m asl, slope angle 20.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally discontinuous; ☐ = understorey trees, not vertically well separated from the main canopy layer; key to species for B (tees ≥ 20.0 cm DBH): 1 = *Shorea parvifolia,* 2 =*Nephelium subfalcatum* (strangling fig and its host tree), 3 = *Syzygium duthieana,* 4 = *Dialium platysepalum,* 5 = *Neoschortechinia forbesii,* 6 = *Ochanostachys amentacea,* 7 = *Trigoniastrum hypoleucum,* 8 = *Aglaia odoratissima*

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Figure 7 (continued)

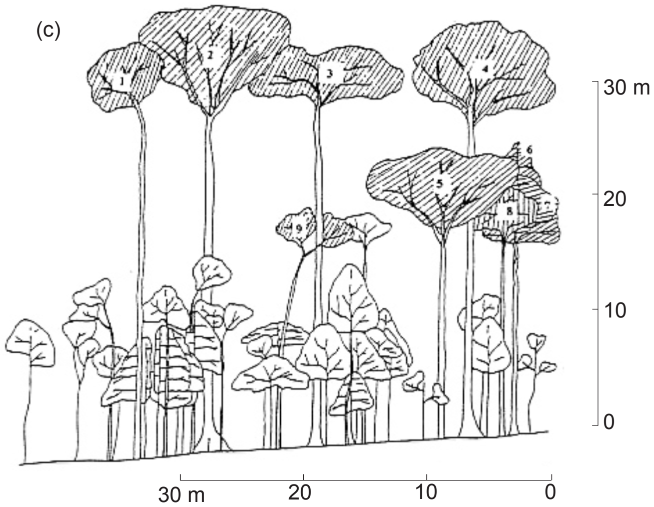

Figure 7(c) Profile diagram of a strip of forest on ridge 45 m × 10 m (elevation 535m asl, slope angle 25.0°), all trees ≥ 5.0 cm DBH are shown; = canopy trees ≥ 20 cm DBH, main canopy was laterally discontinuous; = understorey trees, vertically well separated from the main canopy layer; key to species for C (trees ≥ 20.0 cm DBH): 1 = *Neesia synandra,* 2 = *Koompassia malaccensis,* 3 = *Blumeodendron subrotundifolium,* 4 = *Dysoxylum acutangulum,* 5 = *Diospyros buxifolia,* 6 = *Quercus argentata,* 7 = *Anisoptera scaphula,* 8 = *Syzygium pseudosubtilis,* 9 = *Gonystylus affinis*

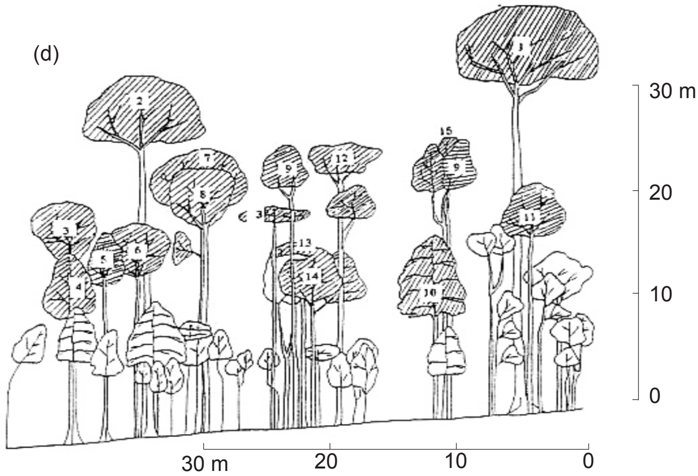

Figure 7(d) Profile diagram of a strip of forest on ridge 45 m × 10 m (elevation 460 m asl, slope angle 24.0°), all trees ≥ 5.0 cm DBH are shown; = canopy trees ≥ 20 cm DBH, main canopy layer was laterally continuous, with occasional gaps; = understorey trees, vertically well separated from the main canopy layer; key to species for D (trees ≥ 20.0 cm DBH): 1 = *Shorea macroptera,* 2 = *Palaquium herveyi,* 3 = *Xanthophyllum affine,* 4 = *Syzygium rugosa,* 5 = *Gymnacranthera eugenifolia,* 6 = *Shorea parvifolia,* 7 = *Garcinia pyrifera,* 8 = *Canarium patentinervium,* 9 = *Gonystylus affinis,* 10 = *Myristica malaccesis,* 11 = *Neoscortechinia kingii,* 12 = *Palaquium hexandrum,* 13 = *Shorea lapidota,* 14 = *Nephelium subfalcatum*

slopes than gentle slopes (Clark et al. 1996). High precipitation in tropical rain forest has been said to be associated with both frequency and magnitude of tree fall, particularly on hillslopes due to structurally unstable soil (Huston 1994). In the study site, most gaps were small in size (median = 10.05 m^2), indicating primary forest condition for climax species to regenerate (Saiful 2002). In large gaps (for example in logged forest), pioneers appear only after the gap is formed and colonised in large numbers.

It was also revealed that probably due to creation of canopy gaps and injury caused by tree fall, many trees, particularly in the understorey, developed asymmetric one-sided branching, and the tree boles below the crown tended to be forked and leaned. Besides, the understorey was closely packed beneath the canopy open areas or tall canopy trees, but apparently less dense in places under the shade of overstorey canopy (Figures 7–9). The effect of shading by overstorey canopy was particularly noticeable among the understorey saplings (1.5 m height to < 5.0 cm DBH) of the ridgetops, and their low density showed increased horizontal visibility compared to other topographic locations (Saiful 2002). Ashton and Hall (1992) identified canopy characteristics, determining forest structure and

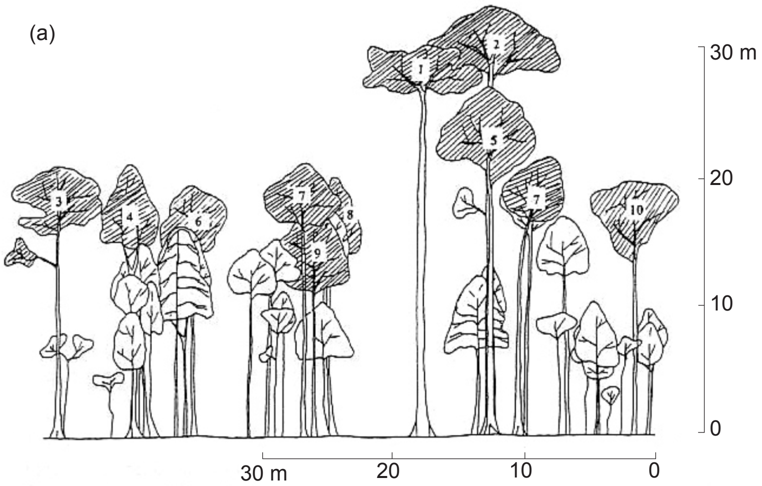

Figure 8(a) Profile diagram of a strip of forest on hillside 45 m × 10 m (elevation 400 m asl, slope angle 22.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally continuous with occasional gaps; ☐ = understorey trees, not vertically well separated from the main canopy layer; key to species for A (trees ≥ 20.0 cm DBH): 1 = *Shorea macroptera,* 2 = *Shorea curtisii,* 3 = *Macaranga gigantea,* 4 = *Ixonanthes icosandra,* 5 = *Endospermum diadenum,* 6 = *Aporusa falcifera,* 7 = *Monocarpia marginalis,* 8 = *Knema cinerea,* 9 = *Alseodaphne wrayi,* 10 = *Gironniera subaequalis*

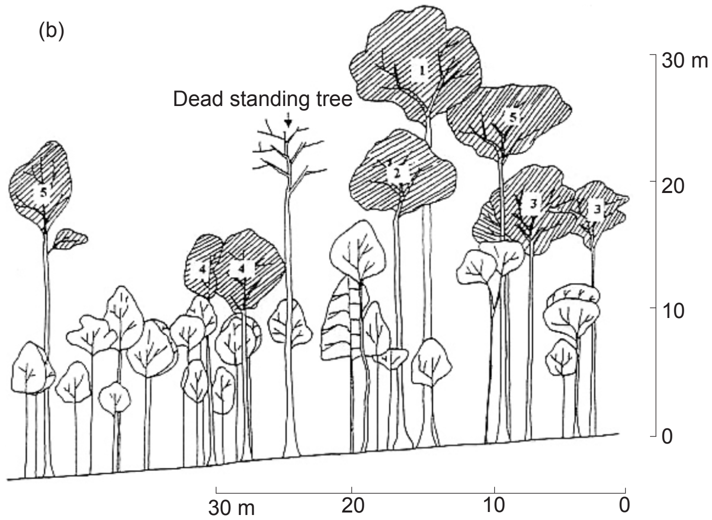

Figure 8(b) Profile diagram of a strip of forest on hillside 45 m × 10 m (elevation 420 m asl, slope angle 30.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally discontinuous and interrupted by dead standing tree and tree fall gaps; ☐ = understorey trees, vertically separated from the main canopy layer; key to species for B (trees ≥ 20.0 cm DBH): 1 = *Dialium platysepalum,* 2 = *Aporusa prainiana,* 3 = *Mallotus kingii,* 4 = *Ochanostachys amentacea,* 5 = *Xanthophyllum affine*

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Figure 8 (continued)

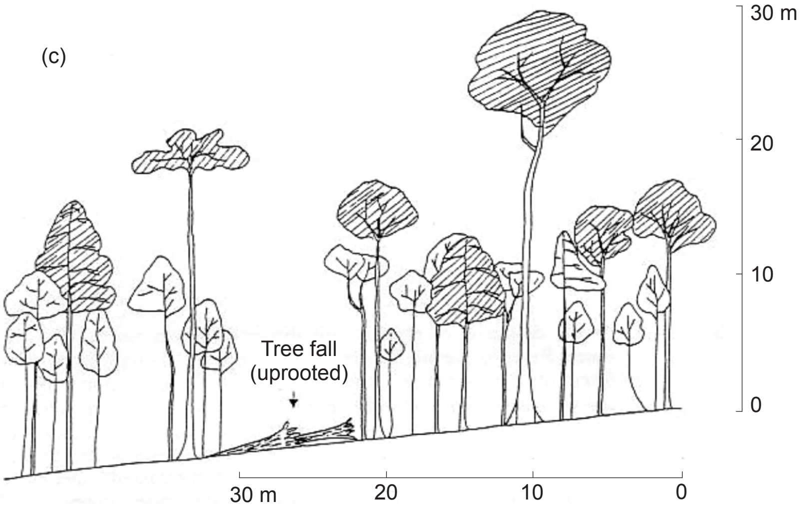

Figure 8(c) Profile diagram of a strip of forest on hillside 45 m × 10 m (elevation 485 m asl, slope angle 30.5°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally discontinuous by tree fall gaps; ☐ = understorey layer, tending to overlap the main storey to some extent; key to species (trees ≥ 20.0 cm DBH) was not provided due to lack of voucher specimens; trees with monopodial crowns in the main storey

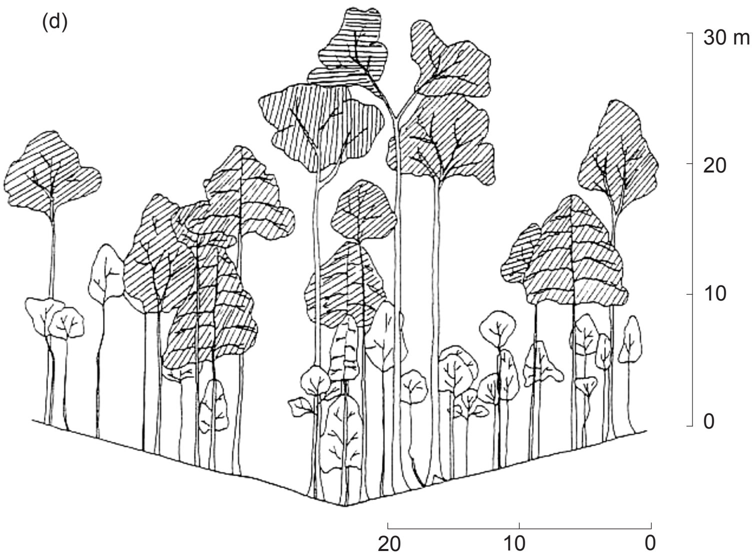

Figure 8(d) Profile diagram of a strip of forest on hillside (gully) 45 m × 10 m (elevation 480 m asl, slope angle 35.0°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally continuous with occasional gaps; ☐ = understorey trees, tending to overlap the main storey to some extent; key to species (trees ≥ 20.0 cm DBH) was not provided due to lack of voucher specimens; trees with monopodial crowns in the main storey

subcanopy stand density. It was also shown that overstorey shading determined the understorey species diversity (Specht & Specht 1993). The positioning of study plots differed in different studies. Richards (1996) described the stand profiles of primary rainforest on level ground instead of undulating terrain or steep slopes. Ashton & Hall (1992) established all their plots within mature phase forest. However, similar to the current study, their plots were also located at different habitat types, except streamside. Furthermore, most of their plots were at elevations < 300 m, whereas in this study, elevations started at 340 m above sea level.

The significant association of *S. curtisii* (Dipterocarpaceae) in the ridgetop profiles

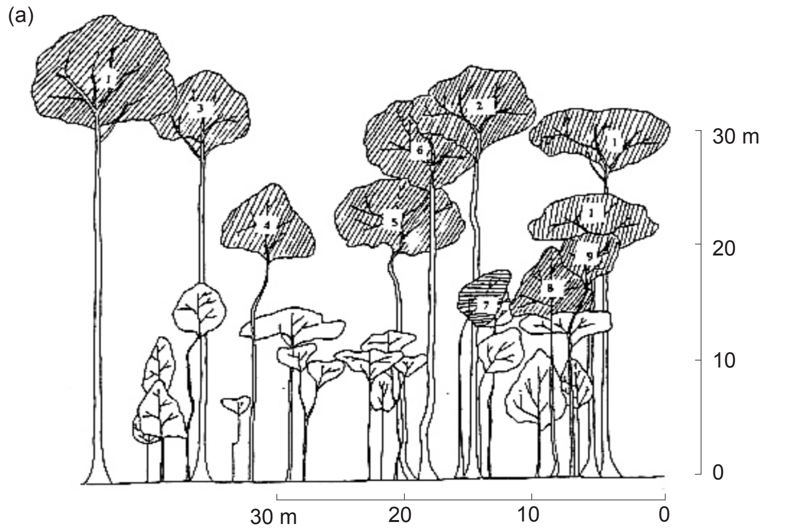

Figure 9(a) Profile diagram of a strip of forest on streamside 45 m × 10 m (elevation 340 m asl, slope angle 22.6°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally continuous; ☐ = understorey trees, almost vertically well separated from the main storey; key to species for A (trees ≥ 20.0 cm DBH): 1 = *Shorea parvifolia,* 2 = *Shorea lapidota,* 3 = *Dillenia grandifolia,* 4 = *Artocarpus nitidus,* 5 = *Endosprmum diadenum,* 6 = *Lithocarpus encleisacarpus,* 7 = *Lithocarpus cantleyanus,* 8 = *Lithocarpus ewyckii,* 9 = *Macaranga hypoleuca*

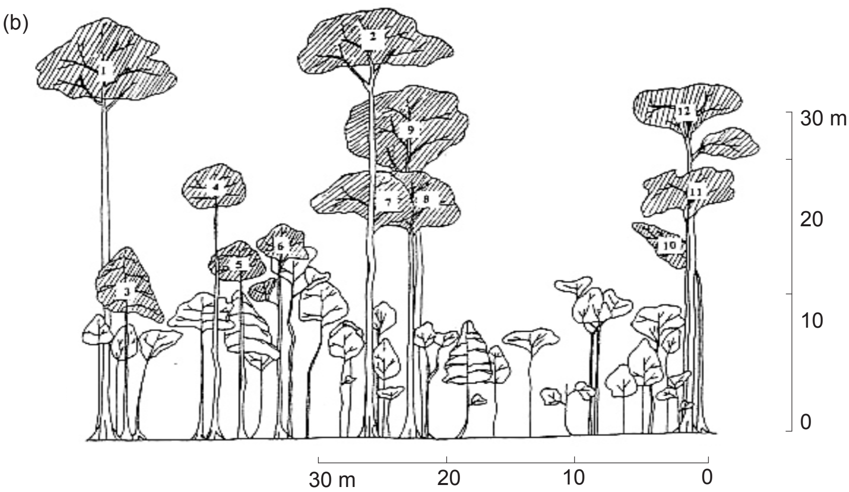

Figure 9(b) Profile diagram of a strip of forest on streamside 45 m × 10 m (elevation 360 m asl, slope angle 23.4°), all trees ≥ 5.0 cm DBH are shown; ▨ = canopy trees ≥ 20 cm DBH, main canopy layer was laterally discontinuous; ☐ = understorey tress, laterally continuous and vertically defined; key to species for B (trees ≥ 20.0 cm DBH): 1 = *Shorea assamica,* 2 = *Shorea pauciflora,* 3 = *Chisocheton pauciflorus,* 4 = *Xylopia malayana,* 5 = *Memecylon excelsum,* 6 = *Blumeodendron kurzii,* 7 = *Nephelium cuspidatum,* 8 = *Hydnocarpus castanea,* 9 = *Endiandra kingiana,* 10 = *Rinorea sclerocarpa,* 11 = *Baccaurea macrophylla,* 12 = *Alangium ridleyi*

supports the low percentage moisture content or dry edaphic environment (Saiful 2002, Saiful et al. 2010). It also appears from the profiles that the rare species (species with very low individuals), particularly in the overstorey, contributed to the maintenance of forest structure as the dominant species, except on streamsides where forest structure was largely dependent on rare species. As such, conservation of rare species in the study site is imperative, particularly for streamside vegetation. As this study was restricted to elevation between 340 m to 600 m above sea level, there was a positive linear relationship between diameter and the measured height growth of trees ≥ 5.0 cm DBH in all studied profiles (see Figure 5). However, in Peninsular Malaysia, beyond 600 m elevation, the tree heights gradually decreased with the increase of elevation (e.g. lower montane and upper montane forest formation) (Whitmore 1984). In a study carried out by Clark et al. (2015) in rain forest of Costa Rica, wood species diversity, stem density and forest and crown height peaked at 400–600 m elevation, but decreased substantially at higher elevation.

The forest structure has been documented by means of profile diagrams, properly constrained by statistical limitations. In the absence of quantitative description of a forest profile, qualitative explanation was the only way to describe the variation of the profiles with respect of topography. While inclusion of more profiles in each category of topography could have been more appropriate, but in a species rich and diverse forest ecosystem such as hill dipterocarp forest with rough and steep terrain, data recording for construction of a series of profiles was an enormous task. However, construction of these 14 profile diagrams has shown comparative structural variation among the topographic locations of the study site, but further research is needed to obtain information on forest differing in structure as well as for management decisions.

CONCLUSIONS

Constructing profile diagram has proved to be an important method for describing and comparing forest types, differing in structure. They also provided better understanding of regeneration status and growing stock information for management decisions. However, there are potential biases in profiles selected subjectively. Rainforests are dynamic and many changes affect the structure of the forest. The structural phases are influenced by the light environment within a forest, due to formation of canopy gaps of different sizes. Openings in the forest canopy by tree fall are widely recognised as important for the establishment, growth and maintenance of species diversity in a tropical forest. The structure of the studied forest varied substantially with topography. Both ridgetop and hillside forests were different in slope, the former with gentle undulation and the latter with steep to very steep gradient. The higher canopy on flat or gently sloping ridgtops, with dense canopy trees in the middle storey, was the most distinguishing structural variations among the topographic locations. A structural variation in the profiles was the low stature of the hillside forests. Further, as opposed to ridgetops, the main canopy layer of hillside, ridge and streamside was vertically and laterally discontinuous, i.e. not well represented by canopy trees due to tree fall gaps.

However, the profiles of the study site were different from profiles described elsewhere from lowland rain forest (Ashton & Hall 1992, Pascal & Pelissier 1996). Rare species contributed to the maintenance of forest structure, and conservation of these species should be a concern for the management. While inclusion of more profiles in each category of topography could have been more appropriate, construction of 14 profile diagrams has shown comparative structural variation among the topographic locations.

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