CHANGES IN FOREST COMMUNITY STRUCTURES OF TROPICAL MONTANE RAIN FOREST ON THE SLOPE OF MT. TRUS MADI IN SABAH, MALAYSIA

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ADAM, J. H. 2001. Changes in forest community structures of tropical montane rain forest on the slope of Mt. Trus Madi in Sabah, Malaysia. Changes of the forest community structures in relation to increasing altitude were studied along the slope of Mt. Trus Madi in Sabah, Malaysia. The total number of species, Shannon-Wiener diversity index, Menhinick richness index, rarefaction index, mean diameter, mean basal area, mean biomass and mean tree height were higher at 600 m (plot 1) and declined in descending order at 1400 m (plot 2), 1800 m (plot 3) and 2400 m (plot 4). Density, Simpson diversity index and evenness index were lower at 600 m and increased in ascending order at 1400, 1800 and 2400 m. The dominant and co-dominant species with the highest and second highest importance values were different between plots. *Shorea dasyphylla* and *S. agami* were dominant at 600 m, and were replaced respectively at 1400, 1800 and 2400 m by *Phyllocladus hypophyllus* and *Eugenia ampullaria, E. hirta* and *Knema latericia,* and *E. kinabaluensis* and *Leptospermum recurvum.* Family Myrtaceae was dominant at all elevations except at 600 m, which was dominated by Dipterocarpaceae. Families Polygalacea, Podocarpaceae, Clusiaceae and Theaceae were dominant at 600, 1400, 1800 and 2400 m respectively. The biomass of trees was distributed unevenly between species and family at all altitudes. The most dominant species and family by biomass at 600 m were *Parashorea* sp. and Dipterocarpaceae; at 1400 m they were *S. dasyphylla* and Dipterocarpaceae; at 1800 m *Garcinia dryobalanoides,* and Clusiaceae; and at 2400 m *E. kinabaluensis* and Myrtaceae. Regression, ANOVA and coefficient of determination indicate significant negative relationships between the number of species, Shannon-Wiener diversity index, Menhinick richness index, rarefaction index, mean diameter, mean basal area, mean biomass and mean tree height with increasing altitude. However, there was a very significant increase in density, Simpson diversity index and species evenness with increasing altitude.

Key words: Sabah - Mt. Trus Madi - tropical montane forest - community structures - altitude - species - diversity - evenness - richness

ADAM, J. H. 2001. Pertukaran dalam struktur komuniti hutan bagi hutan hujan gunung tropika di lereng Trus Madi, Sabah, Malaysia. Kajian pengaruh altitud terhadap perubahan struktur komuniti hutan telah dijalankan di lereng Gunung Trus Madi di Sabah, Malaysia. Kekayaan spesies pokok, indeks diversiti Shannon-Wiener, indeks kekayaan Menhinick, indeks rarefaction, min garis pusat, min keluasan pohon, min biojisim dan min ketinggian pokok adalah tertinggi di 600 m (plot 1), dan menurun di 1400 m (plot 2), 1800 m (plot 3) dan 2400 m (plot 4). Kepadatan pokok, indeks diversiti Simpson dan nilai indeks kesamarataan adalah paling tinggi di 2400 m dan menurun masing-masing di 1800, 1400 dan 600 m. Spesies dominan dan ko-dominan yang mempunyai nilai kepentingan tertinggi dan kedua tertinggi di 600 m ialah *Shorea dasyphylla* dan *S. agami,* dan di 1400, 1800 dan 2400 m oleh spesies tersebut masing-masing ialah *Phyllocladus hypophyllus* dan *Eugenia ampullaria, E. hirta* dan *Knema* *latericia* dan *E. kinabaluensis* dan *Leptospermum recurrum.* Myrtaceae ialah famili yang terunggul di semua altitud kecuali di 600 m yang dikuasai oleh Dipterocarpaceae. Famili ko-dominan masing-masing di 600, 1400, 1800 dan 2400 m ialah Polygalaceae, Podocarpaceae, Clusiaceae dan Theaceae. Peratusan biojisim pokok adalah berbeza antara spesies, famili di semua altitud. Spesies dan famili yang terunggul mengikut biojisim di 600, 1400, 1800 dan 2400 m masing-masing ialah *Parashorea* sp. dan Dipterocarpaceae, *S. dasyphylla* dan Dipterocarpaceae, *Garcinia dryobalanoides* dan Clusiaceae, dan *E. kinabaluensis* dan Myrtaceae. Regresi, ANOVA dan pekali penentu menunjukkan korelasi negatif bererti bagi kekayaan spesies, indeks diversiti Shannon Wiener, indeks kekayaan Menhinick, indeks rarefaction, min garis pusat, min keluasan pokok, min biojisim dan min ketinggian pokok dengan peningkatan altitud. Kepadatan pokok, nilai indeks diversiti Simpson dan nilai indeks kesamarataan didapati meningkat dengan bererti dengan peningkatan altitud.

Introduction

There have been numerous studies of tropical montane forest in Malesia on montane zonation, changes of community structures, forest stratification, and species diversity and richness with increasing altitude (Ohsawa *et al.* 1985, Soepadmo 1987, Edwards *et al.* 1990 ,Yamada 1990, Kitayama 1992, Adam & Ismail 1993, Adam & Enning 1996).

The study carried out by Ohsawa *et al.* (1985) on forest zonation on Mt. Kerinci in Sumatra showed that tree height, forest stratification, species richness and basal area decline with increasing altitude; and that the predominant species were also found to change with altitude. Soepadmo (1987) in his research on the community structures along the slope of Gunung Janing in Johor found that the number of species, mean tree height, diameter at breast height, basal area contribution and biomass contribution of trees with a DBH of $\geq$ 5 cm decreased when altitude increased, and increased with increasing altitude for density and percentage of small size trees. Edwards *et al.* (1990) studied the altitudinal zonation of tropical montane rain forest along the slope on Gunung Kobipoto and Gunung Banaia in Manusela Park, Seram, Maluku, Indonesia, and showed firstly, that soil pH, rooting depth of tree, number of species and species richness decreased with altitude, and tree density increased with increasing altitude; secondly that the vegetation and soil could be categorised into five zones, namely lowland forest, lower montane forest, montane, subalpine and alpine; and thirdly, the predominant species changed with increasing altitude. Kitayama *et al.* (1993) surveyed the vegetation of Mt.Trus Madi and found significant changes in canopy height, appearance and species composition up the slope and identified the forest into lower montane zone (1500–1850 m), upper montane (2000–2500) and summit (2550–2640 m).

Adam and Enning (1996) found that in forest community structures along the slope in Danum Valley in Sabah the number of tree species, basal area, diameter, height of trees and stratification decreased up the slope and density declined with increasing altitude; the dominant and co-dominant species of three forest zones below 800 m altitude were of different species which belong to the family

Dipterocarpaceae; and these species were replaced by both species belonging to the family Theaceae. The main objective of this study was to determine the changes in forest structures with increasing altitude along the slope of Mt. Trus Madi in Sabah.

Materials and methods

Study area

Mt. Trus Madi at 2642 m above sea-level is the second highest mountain in Sabah and Malaysia. It is located in the middle of the Trus Madi Range (5° 35'N, 116° 30'E) and in the interior of Sabah. The geology of this mountain comprises Tertiary formation of mudstone, shale and argillite with subordinate beds of quartzite, sandstone, siltstone and limestone breccias (Acres 1972). The topography is of dissected slopes. There are more than one peak above 1800 m, aligned from southwest to the northeast, and steep ridges range from 10 to 30°(Kitayama *et al.* 1993). The climate is hot and humid in the lowland area with daily temperature of about 30 °C and becomes colder up the slope with daily temperature of between 16 and 8 °C at the summit. This mountain range, an important catchment area for numerous rivers including the Kinabatangan River, was categorised under Protection Forest Reserve in 1962 specially for watershed but was converted to Commercial Forest Reserve in 1984 (Kitayama *et al.* 1993).

Four plots were laid along the slope of Mt. Trus Madi at 600 m (plot 1), 1400 m (plot 2), 1800 m (plot 3) and 2400 m (plot 4). They were selected to represent four main forest types, namely lowland dipterocarp forest, lower montane forest, upper montane forest and montane forest respectively. No plot was set on the summit because there was visible evidence of forest disturbance due to the construction of camps for tourists climbing up this mountain. Plot size was variable, ranging from 50 × 50 m (0.25 ha) at 600 m, 100 × 20 m (0.20 ha) at 1400 m, 150 × 10 m (0.15 ha) at 1800 m to 100 × 10 m (0. 10 ha) at 2400 m. Each of these plots was divided into sub-plots, measuring 10 × 10 m. The division thus enabled us to quantify the frequency of occurrence of the species and calculation of relative frequency and importance values (Soepadmo 1987). In each plot, all trees with a diameter at breast height (DBH) of ≥ 5 cm were enumerated; their DBH were measured with a diameter tape and tree heights were measured using Spiegel relaskop. Calculations of biomass and basal area of trees were estimated from the DBH data using the equations from Kato *et al.* (1978) and Cintron and Novelli (1984) respectively. Importance value of every species in each of the plot was calculated using the following equations (Brower & Zar 1977, Soepadmo 1987, Cintron & Novelli 1984, Adam & Ibrahim 1992):

a) $R_D = [\ \Sigma$basal area of species I / Σ basal area of all species$] \times 100$
b) $R_d = [\ \Sigma$No. of individuals of species I / Σ No. of individuals of all species$] \times 100$
c) $R_f = [\ \Sigma$frequency of species I / Σ frequency of all species$] \times 100$
d) $I_v = \Sigma$ relative dominance (R_D) + relative density (R_d) + relative frequency (R_f)

Species diversity was calculated using equation (a) (Hurlbert 1971, Simberloff 1972 in Stiling 1996) and equations (b) to (e) (Ludwig & Reynolds 1988):

(a) Rarefaction index $[E(S) = \sum_{i=1}^{S} 1 - [1- (N\text{-}Ni/n)/(N/n)]$

where $E(S)$ is the expected number of species in the rarefied sample, n is the standardised sample size, N is the total number of individuals in the sample to be rarefied, and Ni is the number of individuals in the ith species in the sample to be rarefied.

(b) Menhinick richness index $(R) = S/\sqrt{N}$

where S = No. of species recorded; $N = \sum$ No. of individuals of all species

(c) Shannon-Wiener index $(H') = - \sum_{i=1}^{S} [(ni/n)\ln(ni/n)]$

where ni = is the number of individuals belonging to the ith of S species, n is the total number of individuals of all species.

(d) Simpson index $(\lambda) = \sum_{i=1}^{S} ni\,(ni-1)/\ n\,(n-1)$

where ni is the number of individuals belonging to the ith of S species, n is the total number of individuals of all species.

(e) Hill evenness index $(E) = (1/\lambda)/(e^{H'})$

where λ and H' are the values of Simpson and Shannon-Wiener diversity indices respectively.

Results

The results of the forest community structures studied at 600, 1400, 1800 and 2400 m along the slope of Mt. Trus Madi in Sabah are summarised in Table 1. The forest at 600 m contained 270 trees or estimated density of 1080 trees ha^{-1}. These trees contributed to the estimated diameter, basal area and biomass of 514.54 m ha^{-1}, 73.55 m^2 ha^{-1}, and 740.78 t ha^{-1} respectively. Species diversity, species richness and evenness indices are shown in Table 1. The expected number of species $[E(S) = 50.17]$ in the rarefied sample was highest at 600 m, and it was the lowest at 2400 m with $E(S) = 20$. The Shannon-Wiener diversity, Simpson diversity, Menhinick richness and Hill evenness indices at 600 m were 3.69, 0.04, 3.90 and 0.71 respectively. The trees enumerated in plot 1 comprise 64 species. They belong to 24 families. Of these, Dipterocarpaceae was the most diverse family comprising 10 species, followed by Myrtaceae and Euphorbiaceae, each with 7 species. A total of 11 families were poorly represented with each of them containing 1 species each

(Table 3). Importance values of 23 species and 12 families at 600 m (plot 1) are listed in descending order in Tables 2 and 3 respectively. Table 2 shows that the dominant species and co-dominant species possessing the highest and second highest I_v were *Shorea dasyphylla* (I_v = 27.20%) and *S. agami* (I_v =15.91%); 5 other predominant species each contributing I_v from 13.06 to 10.25% include *Xanthophyllum brevipes, Parashorea* sp., *P. tomentella, Eugenia napiformis* and *X. affine;* and a total of 57 species have their I_v lower than 10%. Table 3 indicates that family Dipterocarpaceae was the most dominant which contributed I_v of 115.21%, followed distantly by Polygalaceae (31.84%), Clusiaceae (25.52%), Myrtaceae (23.83%), Fagaceae (14.52%), Anacardiaceae (13.38%) and Sapotaceae (10.43%); 17 other families had their I_v smaller than 10%. Table 4 lists a total of 16 species with their total percentage biomass being greater than 2% at 600 m. These species combined contributed a total of 81.87%. Family Dipterocarpaceae was dominant accounting for 66.41% of biomass, followed distantly by Polygalaceae (13.51%); other important families accounting for greater than 3% include Fagaceae (8.12%), Clusiaceae (7.60%), Sapotaceae (5.72%), Anacardiaceae (3.40%) and Myrtaceae (3.13%); a total of 17 families were of minor importance and each contributed <1%. The trees at 600 m (plot 1) were found in all five diameter classes: of the total 270 trees, 70.3% belong to diameter class 1 (5–10 cm) and diameter class 2 (10.1–20 cm); 18.5, 5.5 and 5.5% fall into diameter class 3 (20.1–30 cm), diameter class 4 (30.1–40 cm) and diameter class 5 (40.1–90 cm) respectively.

The forest at 1400 m (plot 2) contained 244 trees in 0.25 ha, giving an estimated density of 1220 trees ha^{-1}, total diameter of 53.21 m or estimated 266.05 m ha^{-1}, total basal area of 12.60 m^2 or estimated 63 m^2 ha^{-1} total biomass of 93.54 t or estimated 467.70 t ha^{-1} (Table 1). The mean tree diameter, mean basal area, mean biomass and mean tree height at 1400 m were 0.22 ± 0.005 m, 0.052 ± 0.004 m^2, 0.38 ± 0.313 t and 15.09 ± 0.28 m respectively (Table 1). A total of 54 species representing 26 families were recorded at 1400 m. Myrtaceae was the most diverse family which is represented by 12 species, followed by Lauraceae (5), and Fagaceae (4); 23 families were each represented by 3 to 1 species only (Table 6). Species richness, diversity and evenness indices for the forest at 1400 m are shown in Table 1. The values of Shannon-Wiener and Simpson diversity indices were 3.44 and 0.05. The rarefaction and Menhinick richness indices were 46.17 and 3.46 respectively while the Hill evenness index was 0.74 (Table 1). The checklist of 14 species and 11 families with importance values greater than 5% are listed in descending order of importance in Tables 5 and 6 respectively. *Phyllocladus hyphophyllus* and *E. ampullaria* were the dominant and co-dominant species, each having I_v of 35.11 and 26% respectively. Several other predominant species, each of which contributed greater than 15%, were *Garcinia mangostana, Shorea dasyphylla* and *Vaccinium bancanum.* A total of 40 species were of lesser importance, and each of them had I_v of less than 55. Family Myrtaceae accounted for 71.76% of the possible total 300% importance value, followed by families Podocarpaceae (I_v = 39.09%), Dipterocarpaceae (I_v = 26.54%), Fagaceae (I_v = 25.72%), Clusiaceae (I_v = 25.36%) and Lauraceae (I_v = 22.51%). Fifteen other families had their I_v below

5%. A total of 6 species with their percentage biomass greater than 5% are listed in Table 7. *Shorea dasyphylla* contributed the highest percentage of biomass, followed by *S. gibbosa, E. alcinae, P. hypophyllus, E. ampullaria* and *G. mangostana.* However, a total of 35 species were found to contribute below 1%. Dipterocarpaceae, Myrtaceae and Podocarpaceae were the three predominant families and each of them contributed 23.93, 21.32 and 12.64% of the total biomass respectively; the other remaining 23 families contributed less than 5%. Analyses of the diameter showed that 66.7% of the 244 trees enumerated at 1400 m belong to diameter classes 1 and 2, whereas 21.7, 7.0 and 3.7% respectively belong to diameter classes 3, 4 and 5 respectively.

Table 1. Characteristic features of forest community attributes along the slope of Mt. Trus Madi in Sabah, Malaysia

Community attribute	Plot I (PI)	Plot 2 (P2)	Plot 3 (P3)	Plot 4 (P4)
Altitude (m)	600	1400	1800	2400
Plot area (ha)	0.25	0.20	0.15	0.10
Density (N)	270	244	211	167
Estimated N ha^{-1}	1080	1220	1477	1670
Number of species (S)	64	54	48	20
Rarefaction [$E(S)$], if N=167 in every plot	50.04	46.17	42.23	20
Shannon-Wiener diversity index (H')	3.69	3.44	3.36	2.44
Simpson diversity index (λ)	0.04	0.05	0.06	0.115
Menhinick richness index (R)	3.90	3.46	3.30	2.46
Hill evenness index (E)	0.71	0.74	0.79	0.81
Total diameter at breast height (ΣDBH) (m)	128.64	53.21	34.46	19.38
Estimated diameter per hectare (DBH ha^{-1}) (m)	514.54	266.05	236.38	193.84
Mean diameter (μDBH) (m) ± SE	0.48 ± 0.23	0.22 ± 0.005	0.17 ± 0.005	0.12 ± 0.04
Total basal area(ΣBA) (m^2)	18.39	12.60	5.72	1.87
Estimated basal area per hectare (BA ha^{-1}) (m^2)	73.55	63	38.14	18.72
Mean basal area (μBA) (m) ± SE	0.068 ± 0.008	0.052 ± 0.004	0.027 ± 0.002	0.0112± 0.001
Total biomass (ΣBM) (t)	185.20	93.54	46.28	5.48
Estimated biomass per hectare (BM ha^{-1}) (t)	740.78	467.70	308	54.78
Mean biomass (μBM) (t) ± SE	0.69 ± 0.076	0.38 ± 0.313	0.22 ± 0.021	0.33 ± 0.003
Mean height (μHT) (m)± SE	18.4 ± 0.293	15.09 ± 0.28	12.5 ± 0.223	4.38 ± 0.054
Dominant species	*Shorea dasyphylla*	*Phyllocladus hypophyllus*	*Eugenia hirta*	*Eugenia kinabaluensis*
Co-dominant species	*Shorea agami*	*Eugenia ampullaria*	*Knema latericia*	*Leptospermum recurvum*
Dominant family	Dipterocarpaceae	Myrtaceae	Myrtaceae	Myrtaceae
Co-dominant family	Polygalaceae	Podocarpaceae	Clusiaceae	Theaceae

Table 2. Relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree species at 600 m (plot 1) on Mt. Trus Madi

Species	Family	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Shorea dasyphylla	Dipterocarpaceae	6.47	11.47	9.26	27.20
Shorea agami	Dipterocarpaceae	2.34	7.77	5.80	15.91
Xanthophyllum affine	Polygalaceae	6.04	2.96	4.06	13.06
Eugenia napiformis	Myrtaceae	2.34	5.92	3.48	11.74
Parashorea tomentella	Dipterocarpaceae	3.15	3.70	4.64	11.49
Parashorea sp 2	Dipterocarpaceae	6.85	2.22	2.32	11.39
Xanthophyllum brevipes	Polygalaceae	5.55	2.96	1.74	10.25
Parashorea malaanonan	Dipterocarpaceae	3.48	2.59	3.48	9.55
Dipterocarpus exalatus	Dipterocarpaceae	3.05	2.96	3.48	9.49
Lithocarpus nieuwenhuisii	Fagaceae	4.28	2.22	2.32	8.82
Calophyllum obliquinervium	Clusiaceae	2.23	2.96	3.48	8.67
Shorea parvifolia	Dipterocarpaceae	4.08	2.22	2.26	8.56
Xanthophyllum ellipticum	Polygalaceae	3.05	2.59	2.90	8.54
Calophyllum nodosom	Clusiaceae	1.52	4.07	2.90	8.49
Mesua heterophyllum	Clusiaceae	4.24	2.96	1.16	8.36
Swintonia elmeri	Anacardiaceae	2.66	3.33	2.32	8.31
Shorea leptoclados	Dipterocarpaceae	3.15	0.74	3.48	7.37
Dipterocarpus caudiferus	Dipterocarpaceae	2.61	1.11	3.48	7.20
Shorea gibbosa	Dipterocarpaceae	2.88	1.85	2.32	7.05
Hydnocarpus woodii	Flacourtiaceae	1.09	2.96	2.26	6.31
Lithocarpus gracilis	Fagaceae	2.85	1.11	1.74	5.70
Madhuca sandakannesis	Sapotaceae	0.71	2.59	1 74	5.04
Diospyros discocalyx	Ebenaceae	0.49	2.59	1.16	4.24

I_v: 1–2% (32 species); 2.1–3% (6 species); 3.1–4% (3 species); 4.1–5% (2 species); 5.1–6% (1 species).

Table 3. Number of species, relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree families at 600 m (plot 1) on Mt. Trus Madi

Family*	No. spp.	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Dipterocarpaceae	10	38.06	36.63	40.52	115.21
Polygalaceae	3	14.63	8.51	8.70	31.84
Clusiaceae	3	7.99	9.99	7.54	25.52
Myrtaceae	7	4.02	11.10	8.70	23.83
Fagaceae	2	7.13	3.33	4.06	14.52
Anacardiaceae	4	4.51	4.81	4.06	13.38
Sapotaceae	3	2.88	4.07	3.48	10.43
Euphorbiaceae	7	1.85	2.96	4.64	9.45
Ebenaceae	3	1.41	4.81	2.90	9.12
Flacourtiaceae	2	1.36	3.33	2.84	7.53
Lauraceae	5	1.41	2.23	2.90	6.54
Myrsinaceae	2	1.03	1.11	1.16	3.30

I_v: 1–2% (9 families); 2.1–3% (3 families); 3.1–4% (1 family); 6.1–7% (1 family).
* :1 family contained 2 species and 11 families contained I species each.

Table 4. Percentage and total biomass (BM) of tree species at 600 m (plot 1) on Mt. Trus Madi

Species	% BM	ΣBM (t)
Parashorea sp.	8.83	16.35
Xanthophyllum affine	7.24	13.41
Xanthophyllum brevipes	6.24	11.56
Lithocarpus nieuwenhuisii	6.16	11.40
Shorea parvifolia	5.56	10.30
Mesua heterophyllum	5.13	9.50
Shorea dasyphylla	5.41	10.19
Ganua kingiana	4.59	8.49
Parashorea malaanonan	4.33	8.03
Shorea leptoclados	4.21	7.81
Shorea gibbosa	4.13	7.65
Parashorea tomentella	3.53	6.55
Xanthophyllum ellipticum	3.44	6.37
Dipterocarpus exalatus	3.39	6.28
Dipterocarpus caudiferus	3.25	6.02
Swintonia elmeri	2.20	4.07

0.20–1 t (36 species); 1.1–2 t (8 species); 2.1–5 t (5 species); 6 1-7 t (4 species).

Table 5. Relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree species at 1400 m (plot 2) on Mt. Trus Madi

Species	Family	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Phyllocladus hypophyllus	Podocarpaceae	16.95	9.43	8.73	35.11
Eugenia ampullaria	Myrtaceae	6.47	10.80	8.73	26 00
Garcinia mangostana	Clusiaceae	5.47	7.38	6.40	19.25
Shorea dasyphylla	Dipterocarpaceae	9.57	4.10	4.73	18.40
Vaccinium bancanum	Ericaceae	3.93	8.20	4.65	16.78
Litsea accedens	Lauraceae	2.54	5.74	6.51	14.79
Eugenia napiformis	Mrytaceae	7.98	2.87	3.49	14.34
Eugenia alcinae	Myrtaceae	0.77	6.97	5.82	13.56
Lithocarpus encleisacarpus	Fagaceae	4.21	4.10	3.49	11.80
Polyosma borneensis	Saxifragaceae	4.85	2.05	2.96	9.86
Shorea gibbosa	Dipterocarpaceae	4.75	1.64	1.75	8.14
Lithocarpus conocarpus	Fagaceae	1.66	2.87	3.49	8.02
Ardisia copelandii	Myrsinaceae	1.90	2.46	2.91	7.27
Evodia glabra	Rutaceae	1.30	2.46	3.49	7.25
Payena leerii	Sapotaceae	1.12	1.64	1.75	4.51

I_v: 1.1–2% (20 species); 2.1–3% (10 species); 3.1–4% (9 species); 4.1–5% (1 species).

In plot 3 at 1800 m, a total of 211 trees enumerated in 0.15 ha^{-1} plot gave an estimated density of 1477 trees ha^{-1}, total diameter of 34.46 m or estimated diameter of 236.38 m ha^{-1}, basal area of 5.72 m^2 or estimated basal area of 38.14 m^2 ha^{-1}, biomass of 46.28 t or estimated biomass of 308 t ha^{-1} (Table 1). The means for diameter, basal area, biomass and height of tree were 0.17 ± 0.005 m, 0.027 ± 0.002 m^2, 0.22 ± 0.021 t and 12.5 ± 0.023 m. The diversity, richness and evenness indices at 1800 m are also shown in Table 1. The Shannon-Wiener and Simpson diversity indices were 3.36, 0.06. The rarefaction and Menhinick richness indices were 42.23 and 3.30 while the Hill evenness index was 0.79 respectively. The trees recorded at 1800 m comprise 48 species belonging to 22 families. Family Myrtaceae had the most number of species with a total of 9, followed by Clusiaceae with 7 species; 4 families, i.e. Theaceae, Fagaceae, Podocarpaceae and Lauraceae, were each represented by 4 species (Table 9). A total of 16 families were poorly represented; they contained one species each. Tables 8 and 9 respectively list 18 species and 10 families of trees with importance values greater than 4% recorded from1800 m. *Eugenia hirta* (I_v= 41.50%) has the highest I_v among the 48 species enumerated, followed distantly by *Knema latericia* (I_v= 22.92%), *Garcinia dryobalanoides* (I_v= 19.77 %), *Phyllocladus hypophyllus* (I_v= 19.47%), *Ternstroemia lowii* (I_v= 17.21%) *Adinandra cordifolia* (I_v = 13.12%) and *Evodia glabra* (I_v= 11.20); these 7 species combined contributed 145.19% of the total 300% possible I_v. The analyses of the importance values showed that a total of 31 species accounted for less than 5% each. Eight of the total 22 families at 1800 m contributed a total importance values of 267.17% (Table 9). These families were Myrtaceae, Clusiaceae, Theaceae, Fagaceae, Podocarpaceae, Myristicaceae, Lauraceae and Rutaceae. *Garcinia dryobalanoides, P. hyphophyllus, E. hirta* and *K. latericia* were the 4 most dominant species by biomass, each contributing 17.65, 14.90, 9.91, and 8.77% respectively; 16 species contributed less than 5% each; and the other remaining 28 species contributed less than 1% (Table 10). In terms of biomass contribution, 5 families were dominant at 1800 m; they were Clusiaceae (25.47%), Myrtaceae (19.40%), Podocarpaceae (14.15%), Myristicaceae (12.29%) and Theaceae (10.40%). Seventeen families were known to contribute less than 2% each. Diameter class distribution showed 58.3% of the trees enumerated belong to classes 1 and 2, 36% fall into class 3, 3.8% into class 4 and 1.9% into class 5.

Table 6. Number of species, relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree families at 1400 m (plot 2) on Mt. Trus Madi

Family*	No. species	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Myrtaceae	12	21.37	25.97	24.42	71.76
Podocarpaceae	2	19.94	9.84	0.58	39.09
Dipterocarpaceae	2	14.32	5.74	6.48	26.54
Fagaceae	4	7.57	9.43	8.72	25.72
Clusiaceae	3	6.65	9.4	9.31	25.36
Lauraceae	5	4.32	8.2	9.99	22.51
Ericaceae	1	3.93	8.2	4.65	16.78
Rutaceae	3	3.37	3.69	4.65	11.71
Saxifragaceae	1	4.85	2.05	2.96	9.86
Myrsinaceae	2	2.05	2.87	3.49	8.41
Euphorbiaceae	2	1.25	2.05	2.33	5.63
Proteaceae	2	1.60	1.23	1.74	4.57

I_v: 1–2% (6 families); 2.1–3% (5 families); 3.1–4% (4 families).
*: 6 families contained 2 species each and 13 species contained 1 species each.

Table 7. Percentage and total biomass (BM) of tree species at 1400 m (plot 2) at 1400 m (plot 2) on Mt. Trus Madi

Species	% BM	ΣBM (tonnes)
Shorea dasyphylla	14.54	13.68
Shorea gibbosa	9.39	8.84
Eugenia alcinae	8.37	7.87
Phyllocladus hypophyllus	8.28	7.79
Eugenia ampullaria	6.13	5.76
Garcinia mangostana	5.85	5.50
Vaccinium bancanum	5.08	4.78
Dacrycarpus imbricatus	4.36	4.10

<1 t (35 species); 1.1–2 t (8 species); 2.1–3 t (1 species); 3.1–4 t (2 species); 4. 1–5 t (2 species).

Table 8. Relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree species at 1800 m (plot 3) on Mt. Trus Madi

Species	Family	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Eugenia hirta	Myrtaceae	16.45	15.16	9.89	41.50
Knema latericia	Myristicaceae	5.29	8.53	9.10	22.92
Garcinia dryobalanoides	Clusiaceae	14.95	1.9	2.92	19.77
Phyllocladus hypophyllus	Podocarpaceae	8.59	5.21	5.67	19.47
Ternstroemia lowii	Theaceae	4.41	8.53	4.27	17.21
Adinandra cordifolia	Theaceae	5.21	4.26	3.65	13.12
Evodia glabra	Rutaceae	1.52	4.74	4.94	11.20
Lithocarpus encleisacarpus	Fagaceae	2.95	2.84	3.63	9.42
Eugenia ampullaria	Mrytaceae	1.34	3.32	4.27	8.93
Calophyllum buxifolium	Clusiaceae	3.26	2.84	2.92	9.02
Lithocarpus pulcher	Fagaceae	1.67	3.52	3.65	8.84
Garcinia forbesii	Clusiaceae	1.28	3.79	3.65	8.72
Lithocarpus turbinatus	Fagaceae	1.53	2.84	2.92	7.29
Cinnamomum javanicum	Lauraceae	3.53	1.42	2.19	7.14
Garcinia cuspidata	Clusiaceae	3.45	1.90	1.44	6.79
Magnolia candolii	Magnoliaceae	1.31	1.89	2.19	5.39
Calophyllum garcinoides	Clusiaceae	1.72	1.42	2.19	5.33
Dacrydium falciforme	Podocarpaceae	2.60	0.95	1.44	4.99

I_v: 1.1–2% (14 species); 2.1–3% (9 species); 3.1–4% (2 species); 4.1–5% (6 species).

Plot 4 at 2400 m, with an area of 0. 10 ha studied contained 167 trees or estimated density of 1670 trees ha^{-1}, total diameter of 19.38 m or estimated 193.84 m ha^{-1}, basal area of 1.87 m^2 or estimated basal area of 18.72 m^2 ha^{-1}, biomass of 5.48 t or estimated biomass of 54.78 t ha^{-1} (Table 1). The mean diameter, basal area, biomass and height of trees were 0.12 ± 0.04 m, 0.0112 ± 0.001 m^2, 0. 33 ± 0.003 t and 4.38 ± 0.054 m respectively. The Shannon-Wiener and Simpson diversity indices were 2.44 and 0.115 respectively; the rarefaction and Menhinick richness indices were 20 and 2.46 respectively while the Hill evenness index was

0.81 (Table 1). A total of 20 species, which belong to 11 families, were recorded at 2400 m (Table 12). Of these Myrtaceae and Theaceae were represented by four species respectively; Podocarpaceae, Rosaceae and Ericaceae each comprised 2 species; the remaining 6 families were very poorly represented, and each family contained 1 species. The dominant and co-dominant species by importance values were *E. kinabaluensis* (I_v = 60.64%) and *Leptospermum recurvum* (I_v = 40.78%); 5 other predominant species were *Schima wallichii* (I_v = 34.70%), *E. ampullaria* (I_v =26.09%), *Podocarpus wallichianus* (I_v = 22.59%), *Phyllocladus hypophyllus* (I_v =21.05%) and *Ternstroemia lowii* (I_v = 17.25%); the other 13 species accounted for less than 12% (Table 11). The family Myrtaceae contributed the highest importance value (I_v =135.89%), followed by Theaceae (I_v = 65.19%), Podocarpaceae (I_v = 43.64%) and Rosaceae (I_v = 13.51%); 7 other families accounted for less than 12% (Table 12). *Eugenia kinabaluensis* (17.28%) was the most dominant species in terms of biomass, followed by *L. recurvum* (17.23%), *E. ampullaria* (12.73%), *P. wallichianus* (11.73%), *Arthrophyllum ovatum* (11.02%) and *S. wallichii* (10.09%); 14 species contributed less than 5% each (Table 13). For family, Myrtaceae contributed 49.03% by biomass, followed by Theaceae (19.85%), Podocarpaceae (14.45%) and Araliaceae (11.01%); the remaining families less than 3% each.

Table 9. Number of species, relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree families at 1800 m (plot 3) on Mt. Trus Madi

Family*	No. species	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Myrtaceae	9	21.61	24.15	20.64	66.40
Clusiaceae	7	24.93	13.27	15.28	53.48
Theaceae	4	10.98	13. 73	9.36	34. 07
Fagaceae	4	8.16	10.15	11.64	29.95
Podocarpaceae	4	12.47	8.06	8.55	29.08
Myristicaceae	1	5.29	8.53	9.1	22.92
Lauraceae	4	5.28	4.25	6.54	16.07
Rutaceae	1	1.52	4.74	4.94	11.20
Magnoliaceae	1	1.31	1.89	2.19	5.39
Aquifoliaceae	1	1.83	0.95	1.44	4.22

I_v: 1–2% (6 families); 2.1–3% (5 families); 3.1–4% (1 families); 4.1–5% (1 family).
*: 12 families contained 1 species each.

Table 10. Percentage and total biomass (BM) of tree species at 1800 m (plot 3) on Mt. Trus Madi

Species	% BM	ΣBM (tonnes)
Garcinia dryobalanoides	17.65	8.17
Eugenia hirta	9.91	4.59
Phyllocladus hypophyllus	14.90	6.90
Knema latericia	8.77	4.06
Adinandra cordifolia	4.94	2.31

<1 t (34 species); 1.1–2 t (9 species); 2.1–3 t (1 species).

Table 11. Relative dominance (R_D), relative density (R_d), relative frequency (R_f) and importance values (I_v) of tree species at 2400 m (plot 4) on Mt. Trus Madi

Species	Family	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Eugenia kinabaluensis	Myrtacae	22.38	25.6	12.66	60.64
Leptospermum recurvum	Myrtacae	18.74	11.91	10.13	40.78
Schima wallichii	Theaceae	10.28	14.29	10.13	34.70
Eugenia ampullaria	Myrtaceae	14.40	5.36	6.33	26.09
Podocarpus wallichianus	Podocarpaceae	12.17	5.36	5.06	22.59
Phyllocladus hypophyllus	Podocarpaceae	3.18	7.74	10.13	21.05
Ternstroemia beccarii	Theaceae	3.70	5.95	7.60	17.25
Prunus occarpa	Rosaceae	1.61	3.57	6.33	11.51
Clethra clementis	Clethraceae	3.05	2.98	5.06	11.09
Arthrophyllum ovatum	Araliaceae	2.42	3.57	5.06	11.05
Ternstroemia lowii	Theaceae	2.07	3.57	5.06	10.70
Lindera rufa	Lauraceae	3.29	2.38	3.80	9.47
Eugenia punctilimba	Myrtaceae	1.60	2.98	3.80	8.38
Garcinia cuspidata	Clusiaceae	1.21	0.60	1.27	3.08

I_v: 1.1–2% (3 species); 2.1–3% (3 species); 3.1–4% (1 species).

Table 12. Number of species, relative dominance (R_D), relative density (R_d), relative (R_f) frequency and importance values (I_v) of tree families at 2400 m (plot 4) on Mt. Trus Madi

Family*	No. species	R_D (%)	R_d (%)	R_f (%)	I_v (%)
Myrtaceae	4	57.12	45.85	32.92	135.89
Theaceae	4	16.13	25.00	24.06	65.19
Podocarpaceae	2	15.35	13.10	15.19	43.64
Rosaceae	2	1.74	4.17	7.60	13.51
Clethraceae	1	3.05	2.98	5.06	11.09
Araliaceae	1	2.42	3.57	5.06	11.05
Lauraceae	1	3.29	2.38	3.80	9.47
Ericaceae	2	0.26	1.20	2.54	4.00

I_v: 2.1–3% (2 families); 3.1–4% (2 families).
*: 3 families contained I species each.

The results of the regression analyses, ANOVA and coefficient of determination on changes in the first community are shown in Table 14. Table 1 shows that there was a discernible increase in the estimated density per ha, Simpson diversity index and evenness index towards the summit. On the other hand, there was a marked decrease up the slope for the number of species, Shannon-Wiener index, Menhinick richness index, mean diameter, mean basal area, mean biomass and mean height. The tree sizes enumerated showed that the plot located at the low elevation comprises individuals in all five diameter class, and a higher number of trees fall into larger diameter class compared to the other three plots located at higher elevation. The dominant and co-dominant species change up the slope; at 600 m they were dominated by two species both belonging to

Dipterocarpaceae, namely *Shorea dasyphylla* and *S.agamii*; at 1400 m, they were dominated by *P. hypophyllus* (Podocarpacae) and *E. ampullaria* (Myrtaceae); at 1800 m, they were dominated by *E. hirta* and *K. latericia* belonging to families Myrtaceae and Myristicaceae; and at 1800 m by *E. kinabaluensis* and *L. recurvum*, both of them belonging to the family Myrtaceae.

Table 13. Percentage and total biomass (BM) of tree species at 2400 m (plot 4) on Mt. Trus Madi

Species	%BM	ΣBM (t)
Eugenia kinabaluensis	17.28	0 95
Leptospermum recurvum	17.23	0.94
Eugenia ampullaria	12.73	0.70
Podocarpus wallichianus	11.73	0.64
Arthrophyllum ovatum	11.02	0.61
Schima wallichii	10.09	0.55
Ternstroemia beccarii	4.16	0.23

<0.5 t (14 species).

Table 14. Regression, ANOVA and correlation of determination on changes in forest community attributes along the slope of Mt. Trus Madi

Attribute	Regression equation	*b*	*a*	F	Significance F	r^2	Correlation
Estimated *N* ha^{-1}	0.034x + 836.25	0.034	36.25	35.03	0.027	0.95	Significant
Number of species (*S*)	- 0.023x + 82.67	- 0.023	82.67	13.69	0.066	0.81	Significant
Rarefaction index *E*(*S*)	- 0.016x + 63.99	- 0.016	63.99	7.06	0.117	0.78	Significant
Shannon-Wiener diversity index (*H'*)	- 0.001x + 4.24	- 0.001	4.24	7.99	0.106	0.78	Significant
Simpson diversity index (λ)	3.93E-05x + 0.01	3.93E-05	0.01	7.31	0.114	0.79	Significant
Menhinick richness index (*R*)	- 0.001x + 4.73	- 0.001	4.73	54.43	0.018	0.97	Significant
Hill evenness index (*E*)	5.88E-05x + 0.67	5.88E-05	0.67	32.06	0.030	0.94	Significant
DBH ha^{-1}	- 0.18x + 579.04	- 0.18	579.04	13.39	0.067	0.87	Significant
μDBH	- 0.0002x + 0.56	- 0.0002	0.56	18.09	0.051	0.90	Significant
BA ha^{-1}	- 0.03x + 97.19	- 0.03	97.19	25.25	0.037	0.93	Significant
μBA	- 3.3E-05x + 0.09	- 3.3E-05	0.09	44.30	0.022	0.96	Significant
BM ha^{-1}	- 0.38x + 982.30	- 0.38	982.30	603.68	0.002	0.99	Significant
μBM	- 0.0004x + 0.90	- 0.0004	0.90	655.84	0.002	0.99	Significant
μHT	- 0.007x + 23.88	- 0.007	23.88	16.49	0.056	0.89	Significant

Degrees of freedom: 1 and 2.

Regression in Table 14 showed negative values of *b* for all forest community structures except for density, Simpson diversity index and evenness index. Thus, these negative values of *b* indicate a decrease of these community structures with increasing altitude. Conversely, density, Simpson diversity index and species evenness index having positive *b* values show an increase on these forest structures with increasing altitude. ANOVA and coefficient of determination support significantly the very strong positive or negative relationships with the increase or decrease of these community structures with increasing altitude.

Discussion

The forest stands at 600 m (plot 1), 1400 m (plot 2), 1800 m (plot 3) and 2400 m (plot 4) conformed to lowland dipterocarp forest, submontane forest (1000–1500 m), montane forest (1500–2400 m) and subalpine forest (2400–2700 m) respectively as proposed by Marabini (1985). Families Dipterocarpaceae, Myrtaceae and Euphorbiaceae were the three richest families at 600 m, represented by ten, seven, and seven species respectively. Species of the family Euphorbiaceae such as *Macaranga hypoleuca* and *Mallotus wrayi* were found to grow within the forest openings or gaps, and these forest gaps were formed by fallen and dead trees; species such as *Aporusa chalarocarpa, Buccaurea tokbrai* and *Baccaurea stipulata* were among the commonest components of the understorey species of the lowland dipterocarp forest in Sabah. Marabini (1985) cited species found in the lowland dipterocarp Forest in Sabah as *Shorea, Parashorea,* Moraceae, *Ficus, Pterospermum* (Sterculiaceae), *Medinella, Melastoma* and *Dendrocalamus* (bamboo). This study reveals several distinct changes of forest community structures with increasing altitude. Firstly, there was a discernible decline in the number of species of the family Dipterocarpaceae from ten species at 600 m to two species at 1400 m and the absence of this family at 1800 m and 2400 m; secondly, there was an increase in the number of species of the family Myrtaceae from seven species at 600 m to twelve species at 1400 m; thirdly, the emergence of high altitude families such as Podocarpaceae, Saxifragaceae, Ericaceae and Ulmaceae at 1400 m. Marabini (1985) reported that Dipterocarpaceae was found to occur at 2000 m altitude on Trus Madi; at 1000–1500 m there was an increase in the occurrence of epiphytes (*Aeschynanthus,* Gesneriaceae), common tree fern *Cythea,* and *Calamus* spp. (rotan). The forest stand at 1800 m showed that Myrtaceae and Clusiaceae were two diverse families by species composition, each of them comprising nine and seven species respectively; four other notable families were Theaceae (4), Fagaceae (4), Podocarpaceae (4) and Lauraceae (4). According to Marabini (1985), the forest at this elevation (1800 m) was dominated by the families Myrtaceae (*Tristania* and *Eugenia*), Fagaceae (*Fagus, Quercus* and *Lithocarpus*) and Theaceae (*Schima*); at 2000 m altitude, the forest floor and tree trunks and branches were luxuriantly covered with moss such as *Dicranodontium unicatum,* and species of gymnosperms such as *Agathis, Podocarpus* and *Dacrydium* were common. The forest at 2400 m (plot 4) belongs to subalpine forest as proposed by Marabini (1985). The plot set at this altitude comprises 20 species, dominated in terms of importance values by common high altitude species belonging to the family Myrtaceae. These species were *Eugenia kinabaluensis* and *Leptospermum recurvum.* Kitayama *et al.* (1993) reported that species that could be found on the summit of Mt. Trus Madi include *Leptospermum flavescens, Rhododendron* spp., *Rapanea* sp., *Vaccinium* sp., *Schefflera, Litsea* and *Prunus.*

The species composition, Shannon-Wiener index, rarefaction index, Menhinick richness index, mean diameter, mean basal area, mean biomass and mean height of tree were the highest at 600 m, and decline sequentially at 1400, 1800 and 2400 m. The lowland dipterocarp forest at 600 m comprises small-, medium- to big-sized trees, in terms of diameter and height. The diameter and height of trees decline considerably with increasing altitude and trees in the subalpine forest at 2400 m (plot 4) were visibly stunted. The large size both for diameter and height of trees explained the greater mean diameter, mean basal area and mean biomass of trees at 600 m which declined sequentially at 1400,1800 and 2400 m. Comparable results have been reported by other researchers working on similar aspects of study in montane tropical rain forests in Malesia (Ohsawa *et al.* 1985, Soepadmo 1987, Edwards *et al.*1990, Yamada 1990, Kitayama 1992, Adam & Ismail 1993, Adam & Enning 1996). These researchers reported that species composition, species diversity and species richness were high in lowland dipterocarp forest and these community structures decrease with altitude.

The changes of forest community structure along the slope of tropical mountains are not due to one factor by rather by an complex interaction of environmental factors which include climatic, physical, soil and chemical factors. No study has been done on the changes of environmental factors such as atmospheric temperature, relative humidity, soil pH, soil nutrient and soil moisture content along the slope of Mt. Trus Madi.

Species of the highest importance value recorded at 600, 1400, 1800 and 2400 m were determined by relative dominance, relative density and relative frequency in different order of descending importance: for *Shorea dasyphylla* at 600 m, they were relative density, relative frequency and relative dominance, while for *Phyllocladus hypophyllus* at 1400 m and *Eugenia hirta* at 1800 m, they were relative dominance, relative density and relative frequency; for *Eugenia kinabaluensis* at 2400 m, they were relative density, relative dominance and relative frequency. The study also revealed that in cases when a species is encountered only once, the trunk size or basal area (relative dominance) is the only factor that was significant in determining its importance values. The high biomass recorded for a species at all elevations, and this was particularly significant at 600 m, was due to its diameter and height whereas numerical abundance is the additional factor contributing at 2400 m.

The regression analysis, ANOVA and coefficient of determination showed a strong relationship between forest community structures and altitudes. The negative values of b for species composition, Shannon-Wiener index, Menhinick richness index, rarefaction index, mean of tree diameter, basal area, biomass and mean tree height showed their significant decrease as altitude increases. Thus these results conformed to the findings of other researchers (Ohsawa *et al.* 1985, Soepadmo 1987, Edwards *et al.* 1990, Yamada 1990, Kitayama 1992, Adam & Ismail 1993, Adam & Enning 1996). The values of r^2 obtained for all the forest community structures studied were from 0.997 to 0.780. According to Hampton (1984), we may conclude that between 99.7 and 78.0% of the variance in y (community structures) were dependent on x (altitude), or in other words, we can reduce the uncertainty about y by between 78.0 and 99.7%.

The positive values of b and high coefficient of determination for density, Simpson diversity index and species evenness indicated a very strong positive relationship, that is these community structures significantly increase as altitude increases. The low Simpson diversity index at low altitude (600 m) was mainly due to the higher number of species containing one individual and this number of species declines at 1400, 1800 and 2400 m. In Simpson diversity index, a species comprising one individual contributes zero value to the species diversity index while in Shannon-Wiener index, these rare species contribute to the value of the diversity index. Thus,this explains why Shannon-Wiener and Simpson diversity indices respectively decreases and increases as altitude increases. The increase in the number of more predominant species by density and the decline in the number of species comprising one individual were the two main factors contributing to the increase in species evenness as altitude increases.

Conclusion

The number of tree species, Shannon-Wiener diversity index, Menhinick richness index, rarefaction index, mean diameter, mean basal area, mean biomass and mean tree height were higher at lower elevation and declined in descending order up the slope. On the other hand, the density, Simpson diversity index and evenness index were lower at low altitude and increased up the slope. There was no single species and family dominant and co-dominant by importance values and biomass at all altitudes. Regression, ANOVA and coefficient of determination (r^2) showed significant and strong negative relationships between altitude and the number of species, Shannon-Wiener diversity index, Menhinick richness index, rarefaction index, mean diameter, mean basal area, mean biomass and mean height. On the other hand, these analyses indicated significant positive relationships between density, Simpson diversity index and evenness index with increasing altitude.

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