DIVERSITY, COMPOSITION AND PHYSICAL STRUCTURE OF TROPICAL FOREST OVER LIMESTONE IN XISHUANGBANNA, SOUTH-WEST CHINA

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TANG JW, LÜ XT, YIN JX & QI JF. 2011. Diversity, composition and physical structure of tropical forest over limestone in Xishuangbanna, south-west China. This study presents an analysis of floristic composition patterns for limestone tropical forests in Xishuangbanna, which is located in the northern edge of tropical Asia. All trees in four 50 × 50 m plots with diameter at breast height (dbh, 1.3 m) ≥ 5 cm were measured and identified. A total of 998 individuals belonging to 100 species, 74 genera and 31 families were recorded in these plots. Species richness ranged from 18 to 46 species per plot. The most ecologically significant family as determined by basal area and stem density was Euphorbiaceae. *Cleistanthus sumatranus* and *Lasiococca comberi* were the dominant species. Total basal area was 33.5 m^2 in the four plots, ranging from 7.0 to 10.5 m^2 per plot. Comparing tropical forests in this area, this limestone forest showed lower species diversity and higher dominance by Euphorbiaceae. Results from this study will improve our understanding of the community composition of tropical limestone forests in the northern edge of tropical Asia.

Keywords: Community composition, community structure, karst, limestone forest, species diversity

TANG JW, LÜ XT, YIN JX & QI JF. 2011. Kepelbagaian, komposisi dan struktur fizikal hutan tropika di tapak batu kapur di Xishuangbanna, barat daya China. Kajian ini melaporkan analisis corak komposisi flora bagi hutan tropika batu kapur di Xishuangbanna yang terletak di pinggir utara Asia tropika. Semua pokok yang mempunyai diameter aras dada (dbh, 1.3 m) ≥ 5 cm dalam empat plot yang setiap satunya bersaiz 50 m × 50 m diukur dan dicam. Sejumlah 998 individu yang tergolong dalam 100 spesies, 74 genus dan 31 famili direkod di dalam keempat-empat plot tersebut. Kekayaan spesies berjulat antara 18 hingga 46 spesies setiap plot. Daripada luas pangkal pokok dan kepadatan batang, famili yang paling penting ialah Euphorbiaceae. *Cleistanthus sumatranus* dan *Lasiococca comberi* merupakan spesies yang dominan. Jumlah luas pangkal bagi keempat-empat plot ialah 33.5 m^2 iaitu antara 7.0 m^2 hingga 10.5 m^2 setiap plot. Berbanding hutan tropika di kawasan ini, hutan batu kapur menunjukkan kepelbagaian spesies yang lebih rendah tetapi kedominan Euphorbiaceae yang lebih tinggi. Keputusan kajian ini akan menambah pemahaman kita tentang komposisi komuniti hutan batu kapur tropika di pinggir utara Asia tropika.

INTRODUCTION

Biological diversity has great implications for nature conservation (Myers et al. 2000). Given that plant diversity is threatened by rapidly changing landuse patterns in tropical Asia (Sodhi et al. 2010), more effort should be made to document biodiversity in this area (Webb et al. 2010). In South-East Asia, limestone karsts cover an area of about 400 000 km^2, with geological ages ranging from the Cambrian to the Quaternary (Day & Urich 2000). Karsts are major foci for speciation and important biodiversity arks (Clements et al. 2006). However, limestone vegetation has been destroyed as much as other vegetation types even though these limestone areas are more difficult to access and farm. Limestone vegetation is also more vulnerable because it recovers much more slowly due to the relative dry habitat and shallow soils which sometimes are irreversible once damaged (Tuyet 2001).

Forests over limestone are widely distributed in the tropics, particularly in South-East Asia, northern Central America, south-eastern Brazil and the Greater Antilles. Limestone forests typically are rich in endemic flora and have

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high environmental heterogeneity due to large-scale variability in substrate solubility (Perez-Garcia et al. 2009). However, few studies have intensively investigated tropical forests over limestone partly due to the difficulty of working in tropical karst terrain (Kelly et al. 1988, Brewer et al. 2003). Given that the diversity of trees is fundamental to total tropical forest biodiversity (Novotny et al. 2006), inventory and monitoring of tree diversity and forest structure are key prerequisites for understanding and managing forest ecosystems.

Previous studies have highlighted the importance of investigations directed to improve our understanding of tree diversity in tropical limestone forests, especially those in Central and South America (Kelly et al. 1988, Brewer et al. 2003, Felfili et al. 2007, Perez-Garcia et al. 2009). Yet information is still scarce regarding even such basic aspects as the range of environmental conditions in which they grow and the levels and patterns of species diversity of such ecosystems all over the world. Xishuangbanna, well-known for its tropical climate and biodiversity in China, is included in the Indo-Burma biodiversity hotspots (Myers at al. 2000). Tropical forest over limestone is one of the four main forest types in Xishuangbanna; the other three types are tropical seasonal rain forest, tropical montane rain forest and evergreen broad-leaved forest (Cao & Zhang 1997). Compared with tropical forests in non-limestone soils in this area (Cao & Zhang 1997, Lü et al. 2009, Lü & Tang 2010, Lü et al. 2010a, b), we still know little about the species composition and diversity of tropical forest over limestone; the few studies available include Zhu et al. (1998 & 2003). Given the special characteristics with respect to climate, geography and soil (Cao et al. 2006), it is important to analyse the community structure and composition of tropical forest over limestone in Xishuangbanna.

The aim of this study was to evaluate the physical structure and floristic composition of tropical limestone forests in Xishuangbanna. As part of a biodiversity conservation project in this region, this study will provide a botanical reference for future ecological research and conservation efforts in the Xishuangbanna National Nature Reserve. Subsequently, this will extend the botanical and ecological knowledge about limestone forests in the tropical Asia.

METHODS AND MATERIALS

This study was carried out in Xishuangbanna (21° 09'– 22° 36' N, 99° 58'–101° 50' E), which is located in northern tropical Asia and borders Myanmar in the south-west and Laos in the south-east. This region experiences a typical tropical monsoon climate with a rainy season from May till October and a dry season between November and April. Mean annual temperature is 21.7 °C and mean annual precipitation is about 1500 mm. More than 80% of the precipitation occurs during the rainy season. The limestone occurs mainly in the south-eastern part of Xishuangbanna, with a total area of 3650 km^2. Two types of limestone topography can be found in this area, namely, typical karst hills (600–1200 m) which is partially covered by thin soil and frequent limestone outcrops, and large mountains (600–1600 m) which is covered by thick soil and few limestone outcrops (Zhu et al. 1998). Soils are derived from limestone substrate of Permian origin with a pH of 6.75 (Cao et al. 2006).

Four permanent plots (50 × 50 m each, total 1 ha) were established in the tropical forest over limestone in different locations of Xishuangbanna in 2005 till 2006 (Table 1). All plots were located in the natural reserve and were well protected. Plots 1, 2 and 3 were established on slopes covered by thick soil whereas Plot 4, on a typical karst hill with thin soil. These four plots represent community characteristics of tropical limestone forests in Xishuangbanna. Mean soil depths in Plots 1, 2, 3 and 4 were 40, 30, 70 and 20 cm respectively. Each plot was divided into 25 subplots, each 10 × 10 m, for the convenience of field inventory. All living trees with diameter at breast height (dbh, 1.3 m) ≥ 5 cm in each plot were recorded by species and marked with aluminium tags. The dbh values of trees with buttresses were measured just above the buttress. Voucher specimens were collected and deposited at the herbarium of Xishuangbanna Tropical Botanical Garden. Nomenclature followed *List of Plants in Xishuangbanna* (Li et al. 1996).

Species diversity was quantified by species richness, Shannon index H', Simpson index λ, evenness index E and Fisher's α (Magurran 1988). Given the problems associated with the use of importance value index (Mueller-Dombois & Ellenberg 1974), basal area was used to evaluate the importance of each species and family in the plots.

Table 1 Plot characteristics of tropical forest over limestone in Xishuangbanna

Plot	Latitude (N)	Longitude (E)	Altitude (m)	Aspect	Slope	Soil depth (cm)
1	21° 54'	101° 16'	664	SW	15°–20°	40
2	21° 54'	101° 17'	620	NW	30°–35°	30
3	21° 53'	101° 18'	560	NW	10°–25°	70
4	21° 43'	101° 23'	800	N	15°–20°	20

RESULTS

Species diversity

A total of 998 stems were recorded across the four plots of tropical forest over limestone in Xishuangbanna, representing 100 species, 74 genera in 31 families (Table 2). Plot 3 was the most species rich between the four plots with 46 species in 38 genera and 19 families. Only 18 species representing 17 genera and 11 families were found in Plot 4. Among the four plots, Plot 3 had the highest H', λ, E and Fisher's α values. Plot 1 had the lowest H', λ and E values while Plot 4, the lowest Fisher's α values (Table 2). The H', λ, E and Fisher's α values for the total 1 ha were 2.56, 0.80, 0.56 and 27.70 respectively.

Floristic composition and physical structure

In the four plots Euphorbiaceae was the most abundant and species-rich family with 761 stems and 16 species (Table 3). Euphorbiaceae, accounting for 46% of the total basal area, was the most important family. Based on basal area, Ulmaceae, Meliaceae, Sapindaceae and Moraceae were the second to the fifth most important family respectively (Table 3). Basal area for stems with dbh ≥ 5 cm across all four plots was 33.54 m^2, ranging from 6.98 (Plot 2) to 10.46 m^2 (Plot 3) in each individual plot.

Plot 1 was dominated by *Cleistanthus sumatranus* which took up 71% of the stem density and 43% of the total basal area in this plot (Table 4). There was no other species with > 10% of the total basal area in this plot. The top five important species accounted for 71% of the total basal area in Plot 1. Plot 2 was codominated by *C. sumatranus* and *Lasiococca comberi*, accounting for 30 and 29% of the total basal area respectively. However, the stem density of *C. sumatranus* was much higher than *L. comberi*. More than 80% of the total basal area in Plot 2 was taken up by the top five most important species. The two most important species in Plot 3 were *L. comberi* and *Ficus maclellandii*, with basal areas of 2.1 and 1.8 m^2 respectively. The most abundant species was *Sumbaviopsis albicans* with 41 stems enumerated. The five most important species only accounted for about 13% of the total basal area in Plot 3. There were three species that, individually, had more than 10% of the total basal area in Plot 4; *L. comberi* was the most important species, accounting for 39% of the total basal area. Due to its large stature, the one *Pometia tomentosa* recorded was the third most important species in Plot 4. The top five important species accounted for 86% of the total basal area in Plot 4.

Plot 1 had the highest density with 382 stems in an area of 0.25 ha and Plot 3 was the least dense with 181 stems. More individuals were distributed in small dbh classes in Plot 1 than in the rest of the plots (Figure 1). About 90% of the individual trees in Plot 1 had stems with dbh < 20 cm. In contrast, dbh of 70% individuals were < 20 cm in the other three plots. The curves of rank/abundance of the four plots displayed different distribution patterns (Figure 2). The percentage of single individual species ranged from 42 (Plot 2) to 50% (Plots 3 and 4). Meanwhile, the percentage of species with one or two stems ranged from 58 (Plots 2) to 70% (Plot 3). The initial value of the curve displayed by Plot 1 was higher than those of other plots, indicating that Plot 1 was more dominated by one species in comparison with the other three plots.

DISCUSSION

A total of 100 tree species (dbh ≥ 5 cm) belonging to 74 genera and 31 families were recorded in the four 0.25-ha plots in tropical forest over limestone in Xishuangbanna. Species richness of tropical forests in South-East Asia ranged from 60 to 250 species ha^{-1} (Losos & Leigh 2004). Thus, species richness of tropical forest over limestone of Xishuangbanna is in the lower end of the range of tree species richness in tropical

Table 2 Summary of stem density (N), basal area (m^2), species richness (S) and floristic diversity for tree with dbh ≥ 5 cm from four 0.25-ha plots in tropical forest over limestone in Xishuangbanna, SW China

Plot	N	Basal area (m^2)	S	Number of genera	Number of families	H'	λ	E	α
1	382	7.01	37	30	14	1.49	0.49	0.41	10.11
2	241	6.98	24	22	15	1.76	0.70	0.55	6.63
3	181	10.46	46	38	19	3.01	0.90	0.78	19.89
4	194	9.09	18	17	11	1.78	0.76	0.61	4.84
Total	998	33.54	100	74	31	2.56	0.80	0.56	27.70
Mean	249	8.39	31	27	15	-	-	-	-

H' = Shannon-Wiener index = $-\sum(n_i/N_i)\ln(n_i/N_i)$, λ = Simpson's concentration index = $1 - \sum(n_i/N_i)^2$, E = Pielou's evenness index = H'/lnS, α = Fisher's α index of diversity, S = $\alpha \ln(1 + N/\alpha)$

Table 3 Ten families with the largest basal area value recorded for combined 1-ha plot (four plots, each 0.25 ha) in tropical forest over limestone in Xishuangbanna

Family	No. species	Density	Basal area (m^2)
Euphorbiaceae	16	761	15.3
Ulmaceae	4	48	3.4
Meliaceae	12	33	2.7
Sapindaceae	4	15	2.2
Moraceae	6	12	2.0
Lythraceae	2	7	1.6
Buseraceae	3	4	1.3
Lauraceae	8	12	1.2
Annonaceae	8	29	0.8
Myristicaceae	4	14	0.5

Asia. In the tropical limestone forests in Sarawak, Malaysia, 129 tree species with dbh ≥ 5 cm were encountered within an area of 0.75 ha (Adam & Mamat 2005) and 75 tree species with dbh ≥ 10 cm were recorded in a 1-ha plot (Proctor et al. 1983). In this study, tree species richness in each plot ranged from 18 to 46. In contrast, the species richness in limestone forest in Malaysia ranged from 51 to 70 per 0.25 ha (Adam & Mamat 2005). The authors also reported that H' values ranged from 3.0 to 3.7 and E, from 0.72 to 0.87. Both these values are higher than values in this study. The lower tree species diversity in Xishuangbanna may result from lower rainfall and greater seasonality compared with Malaysia (Zhu et al. 2006). These are the main factors accounting for gradients in tropical tree diversity (Givnish 1999). In a seasonally dry forest on limestone outcrops in central Brazil, an area of 400 m^2 had 39 tree species with dbh ≥ 5 cm and the Fisher's α value for the total 1-ha plot was 8.8 (Felfili et al. 2007). The Fisher's α in the present study was 27.7. It seemed that tree species diversity in the tropical limestone forests was higher in Xishuangbanna than that in central Brazil. We assumed that soil depth and fertility may account for the differences in tree species diversity between forests in Xishuangbanna and central Brazil. In the latter, rocky cover was > 75% for most plots and many trees of all species grew on rocks or in fissures (Felfili et al. 2007). The mean soil depth of plots in this study was 0.4 m (range 0.2 to 0.7 m). These comparisons indicated that tree species diversity of tropical forests over limestone varies greatly in different areas.

In the present study, we found that Euphorbiaceae was the most important family with the highest stem density, species diversity and basal area in the tropical forest over limestone in Xishuangbanna. Similarly, Euphorbiaceae was also the most important family in limestone forests in Sarawak (Adam & Mamat 2005). However, in a forest over limestone in Gunung Mulu National Park, Sarawak, Dipterocarpaceae was the most important family and Euphorbiaceae, the second in terms of basal area and stem density (Proctor et al. 1983). Results from this study and those in Malaysia indicated that Euphorbiaceae played an important role in the sustainability of diversity and ecosystem assembly of tropical forests over limestone in tropical Asia. In contrast, the legume family is usually found to be dominant in neo-tropical limestone forests (Pennington et al. 2000, Felfili et al. 2007).

Table 4 Tree species composition in four 0.25-ha plots of tropical forest over limestone in Xishuangbanna, SW China

Species	Plot 1		Plot 2		Plot 3		Plot 4	
	D	BA	D	BA	D	BA	D	BA
Adenanthera pavonina	1	0.074						
Aglaia odorata					1	0.003		
Aglaia parviridia					1	0.003		
Albizia bracteata	1	0.019						
Albizia odoratissima	1	0.065						
Alphonsea mollis	1	0.006						
Alphonsea monogyna	3	0.151						
Amoora calcicola	1	0.134					1	0.364
Amoora tetrapetala							1	0.003
Antiaris toxicaria					3	0.055		
Antidesma montanum					1	0.012		
Aphananthe cuspidata	1	0.102						
Baccaurea ramiflora					2	0.021		
Barringtonia racemosa					1	0.104		
Bauhinia erythropoda	1	0.001						
Beilschmiedia brachythyrsa	1	0.224						
Beilschmiedia pauciflora	1	0.135						
Beilschmiedia purpurascens			1	0.005				
Beilschmiedia robusta	1	0.047						
Bridelia tomentosa					3	0.037		
Canarium album					1	0.014		
Casearia kurzii							1	0.201
Celtis wightii	10	0.618	7	0.299			23	2.256
Chisocheton paniculatus					5	0.028		
Chisocheton siamensis					2	0.059		
Chukrasia tabularia					1	0.715		
Cinnamomum bejolghota					1	0.004		
Cinnamomum tamala					1	0.252		
Cipadessa baccifara	2	0.041						
Clausena excavata	1	0.002						
Cleidion brevipetiolatum			15	0.064	6	0.043		
Cleidion spiciflorum	3	0.013					51	0.318
Cleistanthus sumatranus	271	2.986	111	2.101	1	0.002		
Cordia dichotoma			1	0.131				
Croton euryphyllus			1	0.102			3	0.096
Croton yanhuii	1	0.013						
Cryptocarya calcicola	4	0.493						
Dendrocnide sinuata							2	0.014
Dichapetalum gelonioides					1	0.002		
Diospyros atrotricha	7	0.205						
Diospyros yunnanensis			1	0.021				
Dolichandrone stipulata							1	0.117
Drypetes hoaensis					2	0.339		
Drypetes perreticulata					1	0.311		
Dysoxylum binecteriferum					13	0.988	2	0.181
Dysoxylum densiflorum					1	0.079		
Dysoxylum lenticellatum					1	0.010		
Elaeocarpus rugosus					2	0.107		
Ficus cyrtophylla							1	0.046
Ficus fistulosa					2	0.015		
Ficus maclellandii					1	1.797		
Ficus tinctoria			4	0.028				
Garcinia cowa					5	0.034		

(continued)

Table 4 (continued)

Garuga floribunda					1	1.091	1	0.056
Garuga pierrei			1	0.150				
Glycosmis craibii	1	0.008						
Glycosmis ovoidea	3	0.010						
Gomphandra tetrandra					2	0.035		
Goniothalamus griffithii					1	0.002		
Harpullia cupanioides								
Homalium laoticum	1	0.054						
Horsfieldia pandurifolia					1	0.335		
Horsfieldia tetratepala					1	0.121		
Knema furfuracea					8	0.024		
Lageatroemia tomentosa	3	0.551	3	0.898				
Lagerstroemia intermedia			1	0.121				
Lasiococca comberi	25	0.341	68	2.020	30	2.145	71	3.540
Lepisanthes senegalensis	1	0.003						
Litsea baviensis					2	0.023		
Mallotus philippinensis	3	0.054						
Mallotus repandus	4	0.067						
Mayodendron igneum	2	0.067	1	0.003				
Memecylon cyanocarpum					1	0.116		
Miliusa velutina							5	0.036
Millettia pulchra					2	0.011		
Mitrephora maingayi			3	0.371	1	0.006		
Mitrephora thorelii	2	0.014						
Morus macroura							1	0.056
Murraya paniculata			1	0.004				
Myristica yunnanensis					4	0.058		
Nephelium chryseu					1	0.016		
Pistacia weinmannifolia	1	0.022						
Polyalthia cheliensis	3	0.057	1	0.008	5	0.108	1	0.003
Polyalthia litseifolia			3	0.080				
Pometia tomentosa					10	0.821	1	1.307
Pterospermum menglunense					4	0.093		
Pygeum latifolium					1	0.002		
Semecarpus reticulata					2	0.054		
Spondias lokouensis	2	0.215						
Spondias pinnata	1	0.004						
Stereospermum tetragonum	2	0.045	2	0.201				
Sumbaviopsis albicans			6	0.041	41	0.349	26	0.289
Syzygium latilimbum					1	0.002		
Toona ciliata			1	0.055				
Trema nitida	6	0.127						
Trigonostemon lutescens			3	0.007				
Trigonostemon bonianus	9	0.023						
Trigonostemon thyrsoideum					3	0.016		
Ulmus lanceaefolia	1	0.012						
Vitex quinata			2	0.106			2	0.206
Wrightia pubescens			2	0.136				

D = density, BA = basal area (m^2)

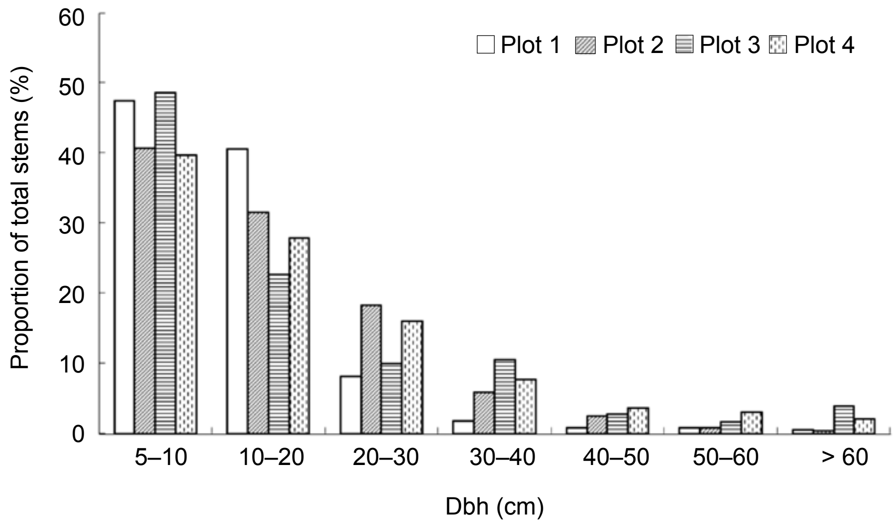

Figure 1 Tree distribution by dbh intervals as a percentage of total stem density within each plot in tropical forest over limestone in Xishuangbanna, SW China

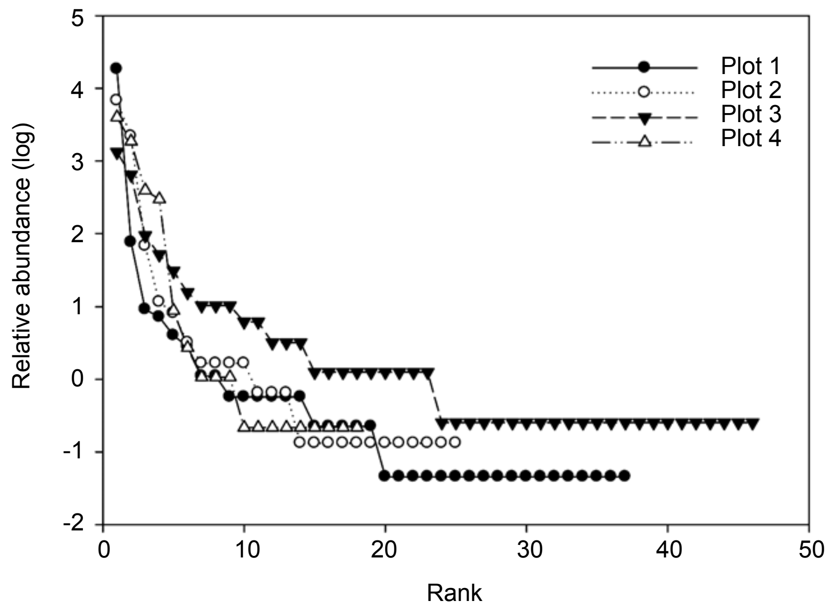

Figure 2 Tree species rank/abundance curves for the four 0.25-ha plots in tropical forest over limestone in Xishungbanna, SW China

In a previous study, Cao and Zhang (1997) compared the tree species diversity of different tropical forest types in Xishuangbanna. However, the comparison was not straightforward due to different sampling intensities of the various forest types, e.g. 0.25-ha plots for tropical seasonal rain forest, 0.16 ha for tropical montane rain forest, 0.12 ha for evergreen broad-leaved forest and 0.04 ha for monsoon forest over limestone. In Xishuangbanna, the stem density per quadrat of 0.04 ha ranged from 142 stems in a limestone forest to 308 stems in a tropical seasonal rain forest (Cao & Zhang 1997). With the same area (0.25 ha), species richness of trees with dbh ≥ 5 cm in limestone forests in this study was lower than that recorded by Cao and Zhang (1997) in tropical seasonal rain forests (ranged from 43 to 77 species per 0.25 ha) but their tree density was similar. Furthermore, H' index (range 1.49–3.01), E index (0.41–0.78) and Fisher's α index (4.8–19.9) of tropical limestone forests were much lower than those of tropical seasonal rainforests (3.02–3.89, 0.74–0.90, 22–37 respectively). These comparisons suggested that despite the similar stem densities, tree species diversity of tropical limestone forests was much lower than that of tropical seasonal rainforests in Xishuangbanna. Similarly, species richness of tropical forest over limestone (39 species ha^{-1}) was lower than that of tropical seasonal forests on non-limestone substrate (50–70 species ha^{-1}) in central Brazil (Felfili 1995, Felfili et al. 2007). However, Kelly et al. (1988) found no difference in species richness between limestone forests in Jamaica and forests on other Caribbean islands.

In terms of stem density, tropical forest over limestone in Xishuangbanna was much lower than limestone forest in Sarawak. We enumerated 998 individuals with dbh ≥ 5 cm within an area of 1 ha, whereas a total of 1682 stems were recorded in an area of 0.75 ha in Sarawak (Adam & Mamat 2005). Moreover, the stem density of trees with dbh ≥ 10 cm in this study was 554 ha^{-1} while in Sarawak it was 644 (Proctor et al. 1983). The basal area of tropical forest over limestone in Xishuangbanna (33.5 m^2 ha^{-1}) was comparable with forests in Bau Hill (28 m^2 ha^{-1}) and Gunung Mulu National Park (37 m^2 ha^{-1}) in Sarawak (Proctor et al. 1983, Adam & Mamat 2005). On individual plot (0.25 ha) basis, basal area of all four plots in this study (7.0–10.5 m^2) were either higher or lower than values (4.2–12.1 m^2) reported by Adam and Mamat (2005). The differences in basal area among these plots could be partly attributed to diameter distribution patterns and the different stem density of trees with large dbh. For example, less than 50% of individuals in this study fell into the diameter class of 5–10 cm in each plot. In contrast, dbh of more than 60% and as high as 87% of stems were less than 10 cm in Bau Hill of Sarawak (Adam & Mamat 2005).

Tropical forest over limestone in Xishuangbanna differed significantly in floristic composition and structure as indicated by species composition (Table 4) and species rank/abundance curve (Figure 2), although Euphorbiaceae was generally dominant in terms of basal area, stem density and species richness. The high dissimilarity of tropical forest over limestone among different locations in Xishuangbanna suggests that this tropical limestone forest may exhibit high beta diversity in this area. Greater replications of plots are needed to more accurately assess the degree to which high species turnover among the four study plots is representative of beta-diversity in this study area. Further research and conservation initiatives on these vulnerable ecosystems are needed if we are to better understand how to manage and conserve these forests resources.

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