STRUCTURE, TREE SPECIES DIVERSITY AND COMPOSITION OF TROPICAL SEASONAL RAINFORESTS IN XISHUANGBANNA, SOUTH-WEST CHINA

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LÜ XT, YIN JX & TANG JW. 2010. Structure, tree species diversity and composition of tropical seasonal rainforests in Xishuangbanna, south-west China. We described the tree species diversity and floristic composition of a tropical seasonal rainforest located in Xishuangbanna, south-west China, based on a census of all trees with diameter at breast height (dbh) ≥ 10 cm in three 1-ha plots. A total of 1283 stems of 53 families, 125 genera and 207 species were recorded in these plots. Families with greatest importance value were Euphorbiaceae, Meliaceae, Sapindaceae, Lauraceae and Lecythidaceae. Lauraceae was the most species-rich family. Forest structure was marked by few tall emergent trees, such as *Pometia tomentosa* (Sapindaceae). The average number of large trees (dbh ≥ 70 cm) was 15 stems ha^{-1}. Beta diversity indices indicated that tree species composition differed greatly among the three plots. Our results revealed that species diversity of tropical seasonal rainforests in Xishuangbanna was lower than that of tropical lowland rainforest in South-East Asia. This may be due to lower annual precipitation, higher elevation and more distinct seasonality in Xishuangbanna. Additionally, tree species composition in our study area differs from that of the dipterocarp forests in South-East Asia. This study will help us to understand the patterns of tree species composition and diversity in the northern edge of tropical Asia.

Keywords: Alpha diversity, beta diversity, biodiversity index, floristic composition, mature forest, South-East Asia, species richness, tropical forest

LÜ XT, YIN JX & TANG JW. 2010. Struktur, kepelbagaian spesies pokok dan komposisi hutan hujan bermusim tropika di Xishuangbanna, barat daya China. Kami menerangkan kepelbagaian spesies pokok dan komposisi flora hutan hujan bermusim tropika di Xishuangbanna, barat daya China. Kajian kami berdasar bancian terhadap semua pokok yang berdiameter aras dada (dbh) ≥ 10 cm di tiga plot setiap satunya bersaiz 1 ha. Sejumlah 1283 batang daripada 53 famili, 125 genus dan 207 spesies dicerap di dalam ketiga-tiga plot ini. Famili yang penting di kawasan ini ialah Euphorbiaceae, Meliaceae, Sapindaceae, Lauraceae dan Lecythidaceae. Lauraceae merupakan famili yang mempunyai paling banyak spesies. Struktur hutan dicirikan oleh beberapa pokok tinggi seperti *Pometia tomentosa* (Sapindaceae). Purata bilangan pokok besar (dbh ≥ 70 cm) ialah 15 batang ha^{-1}. Indeks kepelbagaian beta menunjukkan bahawa komposisi spesies pokok sangat berbeza antara ketiga-ketiga plot. Keputusan kami menunjukkan bahawa kepelbagaian spesies hutan hujan bermusim tropika di Xishuangbanna adalah lebih rendah daripada hutan hujan tanah pamah tropika di Asia Tenggara. Ini mungkin disebabkan oleh jumlah hujan tahunan yang lebih rendah, kawasan yang lebih tinggi serta musim yang sangat ketara di Xishuangbanna. Tambahan pula, komposisi spesies pokok di kawasan kajian berbeza daripada hutan dipterokarpus di Asia Tenggara. Kajian ini dapat membantu kita memahami corak komposisi dan kepelbagaian spesies pokok di pinggir utara Asia tropika.

INTRODUCTION

Tropical rainforests harbour the world's most species-rich plant communities and are vulnerable to deforestation and forest degradation (LaFrankie *et al.* 2006). As an attempt to guide nature conservation efforts worldwide, Myers *et al.* (2000) emphasise the concept of hotspot, which considers regions with an exceptional concentration of endemic species and which experience high rates of habitat loss. These authors propose that priority of protection activities should focus on these spots. One of the 25 hotspots identified worldwide by Myers *et al.*

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(2000) is the Indu-Burma area, which includes the Xishuangbanna region in south-west China. Xishuangbanna contains over 5000 species of vascular plants comprising an estimated 16% of China's total plant diversity (Li *et al.* 1996, Cao & Zhang 1997, Myers *et al.* 2000). The expansion of rubber plantation throughout this region is threatening the existence of both primary and secondary forests, which may have unpredictable consequences for the sustainability of ecosystem functioning and services (Hu *et al.* 2008, Li *et al.* 2008, Ziegler *et al.* 2009). Thus, more attention is critically needed on the research and conservation of tropical forests in this area.

Two subtypes of tropical rainforests were registered in Xishuangbanna, namely, tropical seasonal rainforest and tropical mountain rainforest (Wu *et al.* 1987, Zhu *et al.* 2006). The tropical seasonal rainforest occurs in lowlands (below 900 m asl), whereas tropical mountain rainforest is found at higher elevation. Tropical seasonal rainforests in Xishuangbanna are floristically dissimilar from other forests in the equatorial tropics as they contain tree species of both tropical and temperate regions (Cao & Zhang 1997). They are also different from the tropical rainforests in South-East Asia because they are not dominated by species of the Dipterocarpaceae family (Zhu *et al.* 2006). Apart from the few investigations performed in the tropical forests in Xishuangbanna (Cao & Zhang 1997, Cao *et al.* 2006, Zheng *et al.* 2006, Zhu 2008, Lü *et al.* 2009), there is little ecological information about these forests available for an international audience. One of the unexplored areas in Xishuangbanna is Mengla, where two of the three plots in this study are located. Our study is the first to document the woody species flora of Mengla. All forests occur in wet ravine habitats, having four indistinct tree layers and with emergent trees up to 45 m. The dominant canopy species of the region are *Pometia tomentosa* (Sapindaceae) and *Terminalia myriocarpa* (Combretaceae).

By analysing data from three 1-ha plots located in primary tropical seasonal rainforests in Xishuangbanna, this study was aimed at (1) providing baseline information about the current structure, floristic composition and woody species diversity of this region and (2) comparing the tropical forest of Xishuangbanna with other tropical Asian forests, including the dipterocarp forests of continental and insular South-East Asia.

MATERIALS AND METHODS

Study sites

The study sites are located in Xishuangbanna (21° 08'–22° 36' N and 99° 56'–101° 50' E), Yunnan Province, in south-western China. It borders Myanmar in the south-west and Laos in the south-east, and has mountainous topography, with mountain ridges running in a north–south direction, decreasing in elevation southward (Cao *et al.* 2006). Xishuangbanna has a typical monsoon climate with three distinct seasons, namely, a humid hot rainy season (May–October), a foggy cool-dry season (November–February), and a hot-dry season (March–April). Climate data (1959–2002) from the Xishuangbanna Tropical Rainforest Ecosystem Station (21° 55' N, 101° 15' E, 600 m asl) shows the following climatic characteristics: annual mean temperature, 21.7 °C; mean temperature for the hottest month (June), 25.7 °C; mean temperature for the coldest month (January), 15.9 °C; and mean annual precipitation, 1539 mm (of which 87% occurs in the rainy season and 13% in the dry season). During the dry season, fog occurs almost every day and is heaviest from midnight until mid-morning. The mean relative humidity is 87%. The soil is classified as latosol (pH 4.5–5.5) developed from purple sandstone.

Plot set-up and censuses

We established three 1-ha (100 × 100 m) plots at three different locations in Xishuangbanna (Figure 1). Each plot was divided into subplots of 10 × 10 m. Here we refer to these plots as Menglun (21° 57' N, 101° 12' E, 730 m asl), Mengla (21° 32' N, 101° 33' E, 581 m asl) and Manyang (21° 27' N, 101° 36' E, 643 m asl). The forests are all well conserved in these sites. Within each plot, trees with diameters at breast height (dbh) ≥ 2 cm were marked with aluminium tags. Their dbh were measured and species were identified according to the protocol of the Chinese Ecosystem Research Network (CERN). For buttressed trees the diameters were measured just above the buttress. Voucher specimens of most of the stems were collected and deposited at the Herbarium of Xishuangbanna Tropical Botanical Garden (XTBG). Stems, which could not be collected by a climber (some trees were too high), were identified by a local qualified

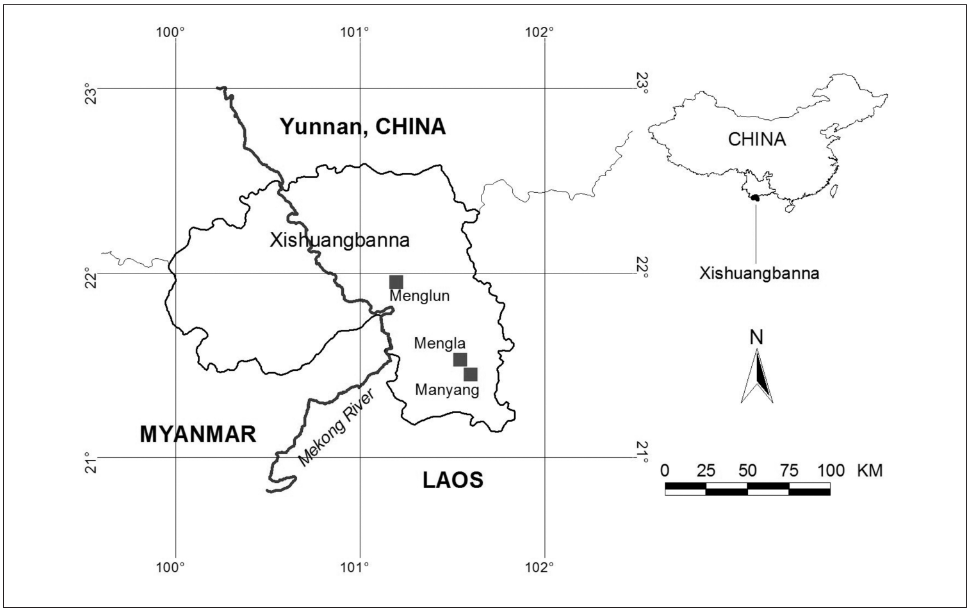

Figure 1 Map showing the location of the three plots of tropical seasonal rainforest in Xishuangbanna, south-west China

taxonomist from XTBG. Nomenclature follows *List of Plants in Xishuangbanna* (Li *et al.* 1996). All fieldwork was conducted between December 2004 and April 2005.

Data analysis

To facilitate comparisons with other tropical forests, we focused on trees with dbh ≥ 10 cm. We quantified basal area, relative density, relative frequency, relative dominance and importance value indices (IVI) following Curtis and Cottam (1962). In addition, family relative diversity, relative density, relative dominance and family-importance values (FIV) were calculated according to the formulae of Mori *et al.* (1983). Margalef's index, Fisher's alpha, Simpson's index, Shannon-Wiener index, Pielou's measure of evenness and Hill diversity numbers were calculated following Magurran (1988) and similarity between the plots was assessed using Jaccard's coefficient of similarity and Sorenson's coefficient of similarity (Magurran 1988, Small *et al.* 2004).

RESULTS

Overview of key characteristics of individual plots

Forest structure

A total of 1283 stems with dbh ≥ 10 cm were enumerated in the three plots (Table 1), which were represented by 207 tree species belonging to 53 families and 125 genera (Table 1).

In the Menglun plot, 393 stems with dbh ≥ 10 cm were recorded. There were 17 stems with dbh ≥ 70 cm and three stems with dbh ≥ 100 cm in this plot. The mean dbh of all stems was

Table 1 Numbers of stems, species, genera and families for trees with dbh ≥ 10 cm in three 1-ha plots of tropical seasonal rainforest of Xishuangbanna

	Menglun	Mengla	Manyang	Total	Mean
Stems	393	423	467	1283	428
Species	106	94	84	207	95
Genera	82	70	59	125	70
Families	42	39	34	53	38

25.2 cm and the largest stem was 146 cm belonging to *Terminalia myriocarpa*. All trees belonged to 42 families, 82 genera and 106 species.

Mengla plot had 423 stems, which was more than Menglun but fewer than Manyang. The total basal area of the plot was 39.7 m^2. The density of large trees (dbh ≥ 70 cm) in Mengla was the highest among the tree plots, accounting for 4.5% of the total density. Among these large trees, 40% were stems with dbh ≥ 100 cm. All trees (dbh ≥ 10 cm) belonged to 39 families, 70 genera and 94 species.

Manyang plot recorded 467 stems. Total basal area was 31.3 m^2. The density of large trees (10 stems) was also much lower than that of other plots. Mean dbh of all stems was 24.83 cm. Dbh of the largest tree recorded in this plot was 129 cm, much smaller than that of the largest trees found in other plots. All stems belonged to 34 families, 59 genera and 84 species.

Tree species composition

The most dominant families in all three plots were Sapindaceae, Meliaceae, Combretaceae, Lecythidaceae and Lauraceae (Table 2) and the most important species registered for all plots were *Pometia tomentosa*, *Barringtonia fusicarpa*, *T. myriocarpa*, *Garuga floribunda* and *Walsura robusta* (Table 3).

In the Menglun plot, Sapindaceae was the most important family with FIV of 36.6. This elevated value resulted from the fact that many Sapindaceae individuals were of large stature. The total basal area of Sapindaceae was 7.4 m^2, representing 24% of the entire basal area of this plot. The two most diverse families were Euphorbiaceae and Lauraceae, which were represented by 13 and 12 species respectively (Table 2). Lecythidaceae was most abundant (44 individuals) and was the fifth most important family. The 15 most important families constituted 75.7% of the total FIV. Twenty per cent of all families were represented by a single individual. The most important species was *P. tomentosa* (Table 3); its importance value accounted for 12.6% of the total IVI and most of this value was contributed by its relative dominance. Collectively, the five most important species constituted 33.2% and the top 15 species made up 52.3% of the total IVI (Table 3).

No family in the Mengla plot made up more than 10% of the total FIV (Table 2). Meliaceae, with the highest stem density, had the highest FIV. The third most important family was Combretaceae, with 24% of the total basal area. As in the Menglun plot, the most diverse family was Euphorbiaceae, with 10 species and 37 individuals. The top 5 and 15 families accounted for 35.4 and 74.2% of the total FIV respectively, whereas 8 families were each represented by a single individual. At the species level, *T. myriocarpa*, with only six individuals and 1.4% of total stems, had the highest IVI of 21.1 (Table 3). The most abundant species was *Diospyros xishuangbannaensis*, with 33 individuals and a relative frequency of 7.1%. *Diospyros xishuangbannaensis* had the second highest IVI of 17.3. More than 44% of species were represented by only one individual. The top 5 and top 15 species comprised 27.4 and 62.1% of the total IVI respectively, and both of these proportions were the lowest compared with the other plots.

Lauraceae and Lecythidaceae were the two most important families in Manyang plot (FIV 44.4 and 40.8 respectively). Lauraceae ranked first in species richness, second in basal area and third in stem density. Lecythidaceae was represented by a single species and 104 individuals and was thus the most abundant family. The other families in the top 5 were Meliaceae, Myristicaceae and Euphorbiaceae, each of them made up about 6% of the total FIV. More than 50% of the total FIV was accounted for by the top 5 families, and the top 15 families contributed 84.1%. *Barringtonia macrostachya* (Lecythidaceae) was the most dominant species followed by *Myristica yunnanensis* (Table 3). Other relatively important species found in this plot included *Gironniera subaequalis*, *Cinnamomum bejolghota*, *G. floribunda* and *Dysoxylum binecteriferum*, and each of these species accounted for more than 3% of the total IVI (Table 3). Together, these six species constituted 44.5% of the total IVI and the top 15 species, 63.7%.

Comparison of key characteristics between plots

Forest structure

Menglun plot recorded the highest density of stems with dbh ≥ 2 cm (results not shown), but lowest stems of dbh ≥ 10 cm among the three plots (Table 1). Mengla plot held the highest stem basal area in this study; this value was mainly

Table 2 Families with the highest importance value in three plots in Xishuangbanna, south-west China

Plot	Family	NS	NI	BA	RDi	RDe	RDo	FIV
Menglun	Sapindaceaes	3	37	7.35	2.83	9.41	24.40	36.64
	Euphorbiaceae	13	32	1.42	12.26	8.14	4.72	25.13
	Lauraceae	12	26	1.80	11.32	6.62	5.97	23.91
	Meliaceae	8	30	2.49	7.55	7.63	8.27	23.45
	Lecythidaceae	1	44	2.46	0.94	11.20	8.17	20.31
	Elaeocarpaceae	5	21	2.16	4.72	5.34	7.18	17.24
	Ulmaceae	2	30	1.25	1.89	7.63	4.14	13.66
	Annonaceae	4	24	0.91	3.77	6.11	3.02	12.90
	Combretaceae	2	4	2.09	1.89	1.02	6.94	9.84
	Fagaceae	3	8	1.00	2.83	2.04	3.31	8.17
	Sterculiaceae	3	6	1.12	2.83	1.53	3.70	8.06
	Burseraceae	2	7	1.17	1.89	1.78	3.90	7.57
	Myristicaceae	4	8	0.35	3.77	2.04	1.17	6.98
	Moraceae	3	13	0.23	2.83	3.31	0.78	6.91
	Rubiaceae	4	7	0.21	3.77	1.78	0.69	6.24
Mengla	Meliaceae	7	38	4.26	7.45	8.98	10.74	27.17
	Euphorbiaceae	10	37	1.10	10.64	8.75	2.78	22.17
	Combretaceae	1	6	7.20	1.06	1.42	18.14	20.62
	Sapindaceae	4	27	2.97	4.26	6.38	7.48	18.11
	Rubiaceae	2	27	3.80	2.13	6.38	9.57	18.08
	Ebenaceae	3	45	1.24	3.19	10.64	3.12	16.95
	Annonaceae	4	27	1.4	4.26	6.38	3.53	14.17
	Lauraceae	8	14	0.84	8.51	3.31	2.11	13.93
	Guttiferae	3	27	1.66	3.19	6.38	4.19	13.77
	Burseraceae	4	13	2.47	4.26	3.07	6.21	13.54
	Anacardiaceae	1	26	1.05	1.06	6.15	2.64	9.85
	Myristicaceae	2	15	1.53	2.13	3.55	3.86	9.53
	Bignoniaceae	5	7	0.67	5.32	1.65	1.70	8.67
	Lecythidaceae	1	21	0.99	1.06	4.96	2.48	8.51
	Moraceae	4	10	0.32	4.26	2.36	0.81	7.43
Manyang	Lauraceae	14	51	5.26	16.67	10.92	16.79	44.38
	Lecythidaceae	1	104	5.43	1.19	22.27	17.35	40.81
	Meliaceae	7	45	3.94	8.33	9.64	12.57	30.54
	Myristicaceae	2	61	1.81	2.38	13.06	5.78	21.22
	Euphorbiaceae	7	16	2.08	8.33	3.43	6.64	18.40
	Sapindaceae	4	16	2.20	4.76	3.42	7.01	15.20
	Ulmaceae	1	33	2.04	1.19	7.06	6.50	14.76
	Burseraceae	3	10	2.02	3.57	2.14	6.46	12.17
	Moraceae	5	15	0.87	5.95	3.21	2.77	11.94
	Annonaceae	3	25	0.58	3.57	5.35	1.86	10.79
	Guttiferae	4	11	0.35	4.76	2.36	1.13	8.25
	Rubiaceae	4	7	0.13	4.76	1.50	0.40	6.66
	Juglandaceae	2	5	0.92	2.38	1.07	2.95	6.40
	Xanthophyllaceae	1	9	0.82	1.19	1.92	2.62	5.73
	Proteaceae	3	5	0.11	3.57	1.07	0.36	5.00

Number of families for each plot = 15; NS = number of species; NI= number of individuals in a family, BA = basal area (m^2), RDi = relative diversity, RDe = relative density, RDo = relative dominance, FIV = family importance value; families in each plot were ranked by their FIVs.

Table 3 Comparison of the 15 most important species (dbh ≥ 10 cm) in three tropical seasonal rain forest plots in Xishuangbanna, south-west China

Plot	Species	D	BA	RDe	RF	RDo	IVI
Menglun	*Pometia tomentosa*	30	6.91	7.63	7.04	22.97	37.65
	Barringtonia macrostachya	44	2.46	11.20	9.01	8.18	28.38
	Gironniera subaequalis	29	1.1	7.38	6.48	3.66	17.51
	Chisocheton siamensis	13	0.46	3.31	3.66	1.54	8.51
	Ardisia tenera	14	0.20	3.56	3.38	0.66	7.60
	Sloanea cheliensis	7	1.02	1.78	1.69	3.39	6.86
	Garuga floribunda	6	1.05	1.53	1.69	3.48	6.70
	Terminalia myriocarpa	1	1.69	0.25	0.28	5.60	6.13
	Mezzettiopsis creaghii	9	0.39	2.29	2.54	1.30	6.12
	Elaeocarpus prunifolioides	8	0.24	2.04	2.25	0.80	5.08
	Ficus langkokensis	9	0.13	2.29	1.97	0.44	4.70
	Cleidion spiciflorum	7	0.28	1.78	1.69	0.94	4.41
	Baccaurea ramiflora	7	0.19	1.78	1.97	0.63	4.38
	Elaeocarpus varunua	4	0.67	1.02	1.13	2.24	4.37
	Walsura robusta	7	0.27	1.78	1.69	0.89	4.35
Mengla	*Terminalia myriocarpa*	6	7.20	1.42	1.57	18.14	21.13
	Diospyros xishuangbannaensis	33	0.97	7.80	7.08	2.44	17.32
	Anthocephalus chinensis	20	2.39	4.73	4.46	6.02	15.21
	Pometia tomentosa	16	2.62	3.78	3.94	6.59	14.31
	Pseuduvaria indochinensis	24	1.22	5.57	5.51	3.08	14.27
	Semecarpus reticulata	26	1.05	6.15	5.25	2.64	14.03
	Baccaurea ramiflora	26	0.68	6.15	5.25	1.71	13.11
	Garcinia cowa	19	1.43	4.49	4.72	3.60	12.81
	Barringtonia macrostachya	21	0.99	4.96	4.72	2.48	12.17
	Dysoxylum lenticellatum	11	2.27	2.60	2.62	5.71	10.94
	Walsura robusta	18	0.74	4.26	4.46	1.87	10.58
	Garuga floribunda	9	1.77	2.13	2.10	4.46	8.69
	Horsfieldia pandurifolia	11	1.31	2.60	2.36	3.30	8.27
	Metadina trichotoma	7	1.41	1.65	1.84	3.54	7.03
	Pouteria grandiflora	6	1.31	1.42	1.57	3.29	6.28
Manyang	*Barringtonia macrostachya*	104	5.43	22.27	15.26	17.35	54.88
	Myristica yunnanensis	60	1.79	12.85	10.63	5.73	29.21
	Gironniera subaequalis.	33	2.04	7.07	7.36	6.50	20.92
	Cinnamomum bejolghota	17	0.66	3.64	4.09	2.10	9.83
	Garuga floribunda	7	1.98	1.50	1.63	6.34	9.47
	Dysoxylum binecteriferum	9	1.79	1.92	1.63	5.72	9.28
	Miliusa sinensis	16	0.40	3.43	3.54	1.28	8.25
	Walsura robusta	14	0.53	3.00	3.27	1.69	7.96
	Xanthophyllum siamensis	9	0.82	1.92	2.45	2.62	6.99
	Litchi chinensis Sonn.	10	0.54	2.14	2.72	1.72	6.59
	Pometia tomentosa	4	1.45	0.85	1.09	4.64	6.58
	Sapium baccatum	2	1.61	0.43	0.54	5.13	6.10
	Chisocheton siamensis	8	0.49	1.71	1.91	1.57	5.19
	Litsea panamonja	7	0.62	1.50	1.63	1.99	5.13
	Engelhardtia spicata	4	0.85	0.86	1.09	2.70	4.65

D = density (trees ha^{-1}); BA = basal area (m^2), RDe = relative density, RDo = relative dominance, IVI = importance value index contributed by the average stem size (27 cm) rather than the absolute stem density. The total basal area of Manyang plot was a little greater than that of Menglun, but much lower than that of Mengla. This was mainly caused by the relatively lower density of stems of large stature in this plot. For example, stems with dbh ≥ 50 cm contributed only 7% of the total stem density, whereas this figure was 9% for Menglun and 11% for Mengla. Additionally, Manyang plot held the lowest mean dbh of stems in this study, suggesting that most of the stems were concentrated in the smaller dbh classes. In fact, stems of dbh ≤ 30 cm made up 74% of the total density, which is the highest in the three plots.

Tree species composition, tree alpha and beta diversity

The tree species composition varied greatly among the three plots. Menglun plot held the highest number of families, genera and species, whereas Manyang plot held the lowest (Table 1). Euphorbiaceae was the most diverse family in both Menglun and Mengla plots, while Lauraceae was the most diverse one in Manyang plot. Lecythidaceae held the most stems in Menglun and Manyang plots. Different families held the highest basal area in each plot, with Sapindaceae in Menglun, Combretaceae in Mengla and Lecythidaceae in Manyang (Table 2). Consequently, the importance value of each family differed greatly among the three plots. Similarly, the relative density, relative frequency and relative dominance and, thus, the importance value of a particular tree species also varied considerably among these plots (Table 3).

Several widely used diversity indices, which vary essentially with respect to their contribution to properties of species richness, abundance and evenness, were calculated to compare the alpha diversity of different plots (Table 4). The Menglun plot was the richest (106 species) while Manyang plot was poorest (84 species) in view of species richness. The S/N index showed that there were more species with the same number of trees recorded in Menglun plot compared with other plots (Table 4). All indices except Simpson's concentration index (λ) showed Menglun as the most diverse plot and Manyang as the least diverse. The Simpson's index (λ) considers the probability of two stems selected at random will be of the same species and puts more emphasis on the abundances of the most common species. By this measure, the Mengla plot got the minimum value (0.0316) and could be seen as the most diverse. The Manyang plot was the least diverse because the most common species in this plot are more dominant than in other plots, e.g. *B. macrostachya* with an IVI of 54.9.

The curves of species–abundance of all the three plots displayed the same distribution pattern (Figure 2), which is similar to primary forests with high species diversity. The percentage of single individual species ranged from 38.6 (Menglun) to 45.2% (Manyang) (Figure 2). Meanwhile, the number of species with 1–2 individuals ranged from 57.1 (Manyang) to 64.9% (Mengla). The number of species with a density of > 10 individuals ranged from 5 species (4.7%) at Menglun to 11 species (11.7%) at Mengla. The curve displayed by Manyang was much higher than that of Menglun and Mengla and this suggested that the former plot was

Table 4 Tree species diversity indices for stems of dbh ≥ 10 cm in the three 1-ha forest plots in Xishuangbanna

Plot	SR	S/N	M	α	λ	H´	N1	N2	E
Menglun	106	0.28	18.21	50.28	0.0325	4.08	59.42	30.77	0.87
Mengla	94	0.23	16.48	41.48	0.0316	3.93	50.78	31.68	0.85
Manyang	84	0.19	14.29	32.43	0.0779	3.45	31.48	12.85	0.78

SR = tree species richness of each plot; N = number of individuals registered; S = total number of species censused; S/N = rate of species increase per individual recorded; M = Margalef's index of species richness, $M = (S - 1)/\ln N$; α = Fisher's index of diversity, $S = \alpha \ln(1 + N/\alpha)$; λ = Simpson's concentration index, $\lambda = \sum(n_i/N_i)^2$; H´ = Shannon-Wiener index, $H' = -\sum(n_i/N_i)\ln(n_i/N_i)$; N1 = Number 1 of Hill diversity indices, $N1 = e^{H'}$; N2 = Number 2 of Hill diversity indices, $N2 = 1/\lambda$; E = Pielou's evenness index, $E = H'/\ln S$

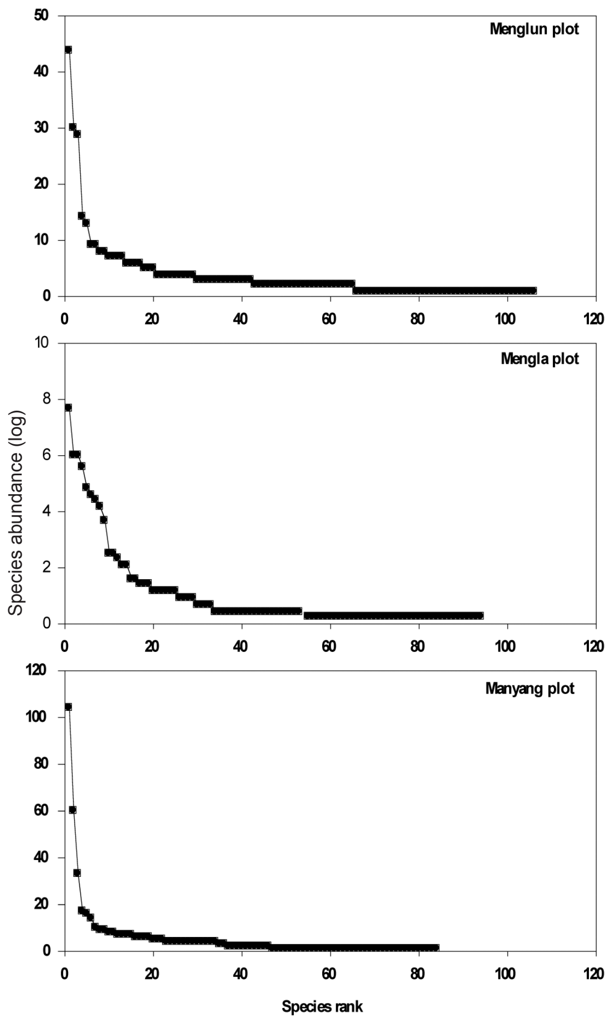

Figure 2 Rank/abundance diagrams for the three plots in tropical seasonal rainforest in Xishuangbanna, south-west China

dominated by limited species in comparison with the other two.

There were only moderate similarities between the three plots at family level. Menglun and Mengla plots were more similar than any other two plots of the three (Table 5). At genera level, Menglun and Manyang plots were also the most similar within the three pairs. In brief, the species composition of the three plots in this study was about 85% different from one another, suggesting that the species composition of different plots in Xishuangbanna varied greatly.

DISCUSSION

Results from this study showed that tropical seasonal rainforest in Xishuangbanna has its singular characteristics that are different from the tropical forests in other areas of South-East Asia. On average, 428 stems were encountered in each 1-ha plot studied. All the trees belonged to 38 families, 70 genera and 95 species averaged among the three plots. Floristic compositions varied considerably among three plots at both family and species levels, indicating that general inferences could not be made about the stand structure and species composition of a wide ranging forest in regional scale from only one plot.

When three plots were considered together, Lecythidaceae with 169 stems ranked first in terms of stem density followed by Meliaceae, Lauraceae, Euphorbiaceae and Myristicaceae. Together, these five families comprised 42.2% of the total number of individuals. These five families except Lecythidaceae appeared among the top 10 abundant families in the tropical forest of Doi Inthanon, Thailand (Kanzaki *et al.* 2004). Similarly to tropical rainforests in some sites of South-East Asia (Proctor *et al.* 1983, Hamann *et al.* 1999. Small *et al.* 2004, Kessler *et al.* 2005), the most dominant families observed in our three plots were Moraceae, Meliaceae, Lauraceae and Euphorbiaceae. In Xishuangbanna, however, Sapindaceae was the most dominant family. It is different from the typical dipterocarp forests in South-East Asia, which are dominated by Dipterocarpaceae. Similar to forests in Vietnam (Blanc *et al.* 2000), Lauraceae, Euphorbiaceae and Meliaceae were the most diverse families in our three plots. All these results suggest that floristic composition of tropical seasonal rainforest in Xishuangbanna is similar to tropical forests in Vietnam and Thailand but different from most of the forests in Malaysia and Indonesia.

Tree density can be affected by natural and anthropogenic disturbance or soil conditions (Richard 1952). The stand density (393–467 stems ha^{-1}, Table 1) of tropical seasonal rainforests in Xishuangbanna falls well within the range (245–859 stems ha^{-1}) recorded for various tropical forests (Campbell *et al.* 1992). The average density (428 stems ha^{-1}) encountered in this study was similar to Borneo rainforest (Small *et al.* 2004) which contained 422 stems ha^{-1} for the same dbh range but was much lower than that of the primary forest in Indonesia (544 stems ha^{-1}, Kessler *et al.* 2005) and dipterocarp forest in Lambir, Malaysia (637 stems ha^{-1}, Lee *et al.* 2004). The mean basal area of 33.7 m^2 ha^{-1} of tropical

Table 5 Sorensen Index (SI) and Jaccard's Coefficient (J) between pair of plots of the three tropical seasonal rain forest plots in Xishuangbanna, south-west China

Plots	Family level		Genera level		Species level	
	SI	J	SI	J	SI	J
Menglun plot–Mengla plot	0.383	0.620	0.224	0.288	0.145	0.170
Menglun plot –Manyang plot	0.355	0.551	0.255	0.343	0.163	0.195
Mengla plot –Manyang plot	0.329	0.490	0.248	0.330	0.157	0.187

seasonal rainforest is greater than the pantropical average of 32.0 m^2 ha^{-1} (Dawkins 1959) and 32.30 m^2 ha^{-1} (Small *et al.* 2004) reported for the forests of Borneo, but much lower than that of a primary forest in Indonesia (139.7 m^2 ha^{-1}, Kessler *et al.* 2005), which is among the highest values ever recorded in tropical forests.

The number of tree species of 84–106 species ha^{-1} in this study is well within the range of mature tropical forest from South-East Asia (62–247 species ha^{-1}, Losos & Leigh 2004). The species richness of tropical seasonal rainforest is also comparable with submontane tropical rainforest in Philippines (92 species, Hamann *et al.* 1999) but higher than the mature lowland dense forest in Vietnam (81 species, Blanc *et al.* 2000) and the tropical montane forest in Doi Inthanon of Thailand (67 species, Kanzaki *et al.* 2004). The differences of tree species richness among these forest types may be accounted for by the different length of time they were subjected to catastrophic. Although the lowland dense forest in Vietnam can be considered as mature forest, it is in the process of community succession (Blanc *et al.* 2000). In contrast, the submontane tropical rainforest in Philippines and tropical seasonal rainforest in Xishuangbanna are old growth forests (Hamann *et al.* 1999). The lower species richness in Doi Inthanon may be related to its higher altitude (1700 m). The alpha diversity of tropical seasonal rainforests of Xishuangbanna is lower than that of the lowland dipterocarp forest (Proctor *et al.* 1983) and lowland mixed dipterocarp forest (Small *et al.* 2004), with approximately half of the species richness found in these forests (214 species and 197 species respectively). The lower species richness and alpha diversity may be caused by the lower rainfall, greater seasonality and higher elevation compared with the lowland forests in Malaysia. All three factors are well known to be causes of gradients in tropical tree diversity (Givnish 1999).

A few species were exceedingly important in tropical seasonal rainforest. For example, with an IVI value 37.6, *P. tomentosa* ranked first in Menglun plot while *B. macrostachya* was most important in Manyang plot (54.9). Tropical forests are usually characterised by an abundance of species with a low frequency of occurrence (Pitman *et al.* 1999, Small *et al.* 2004). In this study, more than 40% of species were represented by singletons and more than 60% of species were represented by only one or two individuals.

Large trees (dbh ≥ 70 cm) play an important role in carbon storage and disturbance regimes in the tropical forests and are more tightly coupled to weather and climate conditions (Clark & Clark 1996). However, we know little about the large trees in tropical forests of South-East Asia. Our study showed that the density of large trees ranged from 10 to 19 stems ha^{-1} with a mean of 15 stems ha^{-1}, accounting for 3.5% of the total stems. In a Neotropical lowland rainforest, large trees accounted for 2% of stems (Clark & Clark 1996), whereas they accounted for 4.5% of total stems in Tanzanian tropical forests (Huang *et al.* 2003). More large trees were registered in our three plots, indicating that the forests were at a mature stage.

In summary, the present study revealed that both species richness and stem density of the tropical seasonal rainforests in Xishuangbanna were lower than most of the South-East Asia tropical rainforests, especially in comparison with the dipterocarp forest. The species composition was also different from that of the dipterocarp forest. The basal area was similar to that of other tropical forests of South-East Asia and this may be due to the higher density of large trees in this study. Although our research area is located in a region where nature conservation is given high priority, in the process of our inventory, we found that mining, logging, agricultural colonisation and especially the plantation of rubber trees have a degrading impact on the rainforest cover of this area. Based on this observation as well as on the findings presented here, we strongly recommend that effective and timely actions on the conservation of the tropical seasonal rainforest of Xishuangbanna be taken.

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