

**STUDIES ON THE BIOGEOGRAPHY AND
EVOLUSION OF THE FLORA OF YUNNAN,
SOUTHWESTERN CHINA
SYMPOSIUM**

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**云南植物区系的生物地理及演化研究
论文集**

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(中国科学院西双版纳热带植物园)

介绍

云南是一个生物多样性高度富集的地区，它的植物种类占中国植物种类的一半以上，它几乎包含了欧亚大陆的各种主要植被类型，它的错综复杂的生物区系是如何起源与演化的，这个基本的问题尚未决解。本论文集合云南的历史地质事件，从植物区系地理学研究上对云南植物区系的起源与演化进行探讨。研究发现，云南植物区系具有一个远古的热带起源背景，在第三纪热带、亚热带性质的东亚植物区系的基础上，随着喜马拉雅的隆升，世界性和北温带植物区系成分在北部地区渗透、发生了迅速的物种形成，使北部地区演化为现今的以世界性和北温带分布的科和属占优势的温带植物区系；而在南部地区，因印度支那地质板块向东南亚的逃逸，热带亚洲成分渗透、发展，演化成以热带亚洲成分为主的热带植物区系；云南中部地区第三纪东亚植物区系成分有更多的保持与承袭。云南南部、中部和北部植物区系的系统发育关系（系统发育结构和 β 多样性格局）研究支持了植物区系地理学上提出推论。此外，思茅-兰坪地质板块自晚始新世以来发生了顺时针旋转可能导致了一些云南西北部与云南东南部的物种的对应分布格局的形成；云南南部与东南部热带地区的植物区系可能因具有不同的地质背景和演化历程而发生了显著的生物地理分异。

该论文集选择了作者发表的 15 篇英文研究论文，结合地质历史，分别从云南的不同区域、不同角度论述了云南的植物区系、生物地理分异、可能的起源与演化，为读者提供参考。

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9. Zhu, H. 2008. Advances in biogeography of the tropical rainforest in southern Yunnan, southwestern China. *Tropical Conservation Science* 1: 34-42. 103
10. Zhu, H., Wang, H., Li, B.G. 2006. Species composition and biogeography of tropical montane rain forest in southern Yunnan of China. *Gardens' Bull. Singapore* 58: 81-132. 112
11. Zhu, H., Cao, M. & Hu, H.B. 2006. Geological history, flora, and vegetation of Xishuangbanna, southern Yunnan, China. *Biotropica* 38(3): 310-317. 164
12. Zhu, H. 2004. Biogeographical implications of some plant species from a tropical montane rain forest in southern Yunnan. *Chinese Geographical Science* 14(3): 221-226. 172
13. Zhu, H., H. Wang, B. Li, P. Sirirugsa. 2003. Biogeography and floristic affinity of the limestone flora in southern Yunnan, China. *Annals of the Missouri Botanical Garden* 90: 444-465. 178
14. Zhu, H. & Yan Li-chun. 2002. A discussion on biogeographical lines of the tropical-subtropical Yunnan. *Chinese Geographical Science* 12(1): 90-96. 200
15. Zhu, H. 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *Journal of Biogeography* 24: 647-662. 207

SCIENTIFIC REPORTS

OPEN

A Phylogenetic Perspective on Biogeographical Divergence of the Flora in Yunnan, Southwestern China

Received: 04 September 2016

Accepted: 18 January 2017

Published: 21 February 2017

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In recent years, an increasing number of studies incorporated biogeography with phylogenetic analyses to reveal the origin and evolutionary history of specific floras. In this study, we constructed the mega-phylogeny of the floras of three representative regions across Yunnan, southwestern China. We analyzed the phylogenetic structure and beta diversity based on the presence/absence of species (genus or family) data to investigate the phylogenetic patterns of regional floras. We found conspicuous divergence at the genus and species level in the pattern of phylogenetic structures, which most likely related to historical biogeography. The flora of southern Yunnan was shaped by the strike-slip extrusion of Indochina and the regional climatic stability, while the flora of northwestern Yunnan was shaped by the uplift of the Himalaya-Tibetan Plateau and the oscillations of the glacial-interglacial periods. The flora of central Yunnan had nearly equal proportions of the northern and southern floras that may be derived from a common Tertiary tropical or subtropical flora. Geological events fit well with the floristic and phylogenetic patterns across Yunnan. This study highlighted the importance of linking phylogenetic analyses to biogeographic interpretations to improve our understanding of the origin, evolution and divergence of regional floras.

It is widely accepted that geological history, evolutionary events and processes, and current climatic conditions are significant factors in the formation of contemporary biogeographic patterns^{1,2}. A time-calibrated phylogeny contains information about the phylogenetic relationships among species and the timing of evolutionary processes, such as speciation, divergence, and extinction, and can therefore be used to extract information about the evolutionary history of biological communities or floras at different temporal and spatial scales³. Recently, the term ‘phylofloristics’ was introduced to describe an analytical approach that relates the compositional similarity between entire floras to spatial and environmental distances in order to phylogenetically investigate a floristic assembly⁴. Phylogenetic measures provide an estimate of how much of the evolutionary history is represented in a particular region, providing a novel research and analytical approach for biogeography and making it possible to infer the relative influence of various biogeographical events in the historical period on the phylogenetic patterns of floras^{4–6}. In this study, we applied this concept to investigate the contemporary pattern of floras and the associated geological events during the collision between India and Eurasia.

The collision between India and Eurasia, which began in the early Cenozoic, may be the largest active orogenic event on earth^{7,8}. This long-lasting and ongoing tectonic process triggered associated geological events ranging from the uplift of the Himalaya-Tibetan plateau to the lateral extrusion of the continental landmass^{9,10}. The associated orogenic and environmental effects (e.g., geomorphology and climate change), especially the later large-scale uplifts on or around the Himalaya-Tibetan Plateau¹¹ and the strike-slip extrusion of Indochina, were reported to have driven and influenced genetic discontinuities, speciation, and the evolution of numerous plant and animal groups, as well as generating the contemporary biotic distribution pattern^{7,12,13}. The species-based study on the biogeography of southern, central and northwestern Yunnan found that these three floras might be derived from a common flora, but the geological history of each region has influenced its flora, and they have

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remained divergent since the late Tertiary^{14–16}. However, this biogeographical hypothesis lacks the support of phylogenetic evidence at a regional scale. Phylofloristics give us new insight to use phylogenetic information to demonstrate that the multistage uplift of the Himalayas and the strike-slip extrusion of Indochina resulted in the contemporary patterns of biogeography or initiated the biogeographical divergence of floras at a regional scale.

In this study, we investigated the floristic phylogenetic patterns of three representative regions in southern, central, and northwestern Yunnan. The present study aimed to examine the significance of key geological events, particularly the plate collision-induced uplift of the Himalaya-Tibetan Plateau and the strike-slip extrusion of Indochina, on contemporary patterns of biogeography using a comprehensive method combining floristic geography with phylogenetic information. Several factors made these regions ideal for this research. First, the Yunnan region is located at a sutural zone between Laurasia and Gondwana in geological history^{17,18}, and an evident biogeographical divergence is believed to have occurred between these three regional floristic compositions in response to the uplift of Himalaya and extrusion of the Indochina block^{14–16}. Second, floristic inventories of angiosperms in these three areas are well documented^{15,19–21}. Third, the biogeography and divergence of these three floras were investigated on the basis of analyses of floristic geography^{14–16} without incorporating the phylogenetic patterns of these floras, which would allow the deduction of the influence of geological history on the floristic assembly with an evolutionary perspective.

We constructed mega-phylogenies of the regional floras and then analyzed the phylogenetic assemblage structure in each flora, as well as the phylogenetic beta diversity between floras from three taxonomical hierarchies (family, genus and species). These phylogenetic analyses were also conducted among different geographical elements (e.g., pantropic or tropical Asia genus, north temperate or temperate Asia genus) for more detailed phylogenetic investigations of these floras. Specifically, we addressed the following questions: (i) What is the pattern of the phylogenetic structure in three floras across Yunnan (i.e., southern, central and northwestern Yunnan)? (ii) What is the phylogenetic beta diversity between these floras? and (iii) Do the results integrated with phylogenetic information agree with previous biogeographic hypotheses in terms of the biogeographical divergence of the flora across Yunnan initiated by the uplift of Himalaya and extrusion of Indochina? Based on the biogeographic history described above and predicted patterns for community phylogenetic structure, we proposed three hypotheses. (i) The assemblages of flora in northwestern Yunnan are clustered, especially to temperate floristic elements, due to the quick speciation and divergence of abundant closely related taxa with the uplift of Himalaya. (ii) In contrast, the southern flora is more phylogenetically overdispersed, especially to tropical floristic elements, in response to the collision between India and Asia. This geological event resulted in southern Yunnan as a sutural zone, where distantly related taxa from Indo-Malesian flora (from Gondwana) and East Asia flora (from Laurasian) came together. (iii) The phylogenetic similarity between central and northwestern flora is nearly identical to the similarity between central and southern flora, which could derive from a common flora in geological time.

Results

Patterns of phylogenetic structure. At the family level, the patterns of phylogenetic structure in these three regions were less divergent (Figures S1 and S2) but distinctly differed at the genus and species level. The genera and species of southern Yunnan exhibited a significant pattern of phylogenetic overdispersion across the entire tree (*NRI*), while genera and species in central and northwestern Yunnan were clustered (Fig. 1, ALL TAXA and Fig. 2). Genera that had a tropical distribution in southern Yunnan, which made up the majority of the genera (76.7% of the total), also showed significant overdispersion, particularly those with tropical Asia and tropical Asia to tropical Australia distributions. Interestingly, this pattern of overdispersion was also seen in the northwestern genera with a tropical distribution, which made up 43.5% of all genera (Fig. 1, ALL TRO-TA). However, northwestern genera with temperate distributions (45.8% of all genera) were highly clustered, especially those with old world temperate, temperate Asia and center Asia distributions (Figs 1 and 3, ALL TEM-CA). Moreover, with respect to the terminals (more recent divergences), the species and genera with a tropical distribution in southern Yunnan were clustered (Fig. 3, ALL TRO-TA and Fig. 2, *NTI*).

The *p*-values of all *NRI* and *NTI* measures and the taxonomic richness of these groups are available in the Supplementary Material (Table S1).

Phylogenetic beta diversity. The floras of the three regions at the family level were very similar (over 0.837), followed by those at the genus level (0.624–0.747), but fairly dissimilar at the species level (0.324–0.530) (Table 1). The phylogenetic similarities between the floras of central and southern Yunnan were similar to those between central and northwestern Yunnan at all taxonomic levels and geographic elements, implying that central Yunnan had nearly equal proportions of the southern and northwestern floras. Moreover, we found that the phylogenetic similarity scores of families or genera with tropical distributions were both notably higher than between temperate families or genera, which indicated a close phylogenetic relationship among tropical elements of these three floras. Additionally, higher positive values of *S.E.S. D_{nn}* in the tropical families and genera than temperate families and genera suggested that tropical and temperate taxa had smaller phylogenetic beta diversity than expected, and tropical taxa had a lower diversity than temperate taxa among these regions (Table 2).

Discussion

In this study, we extended traditional species-centric floristic analyses and phylogenetic analyses of certain taxa or local floras to incorporate phylogenetic information and focus on regional floras. We used presence/absence floristic data of regions in southern, central, and northwestern Yunnan to analyze the phylogenetic structure and beta diversity of the three regional floras to quantify how closely related pairs of taxa were within or between floras. Our results showed a conspicuous divergence at the genus and species level in the pattern of phylogenetic structures among the three representative floras. We integrated these results with the influence of geological historical events on the biogeographical divergence of regional floras to assist with interpretation.

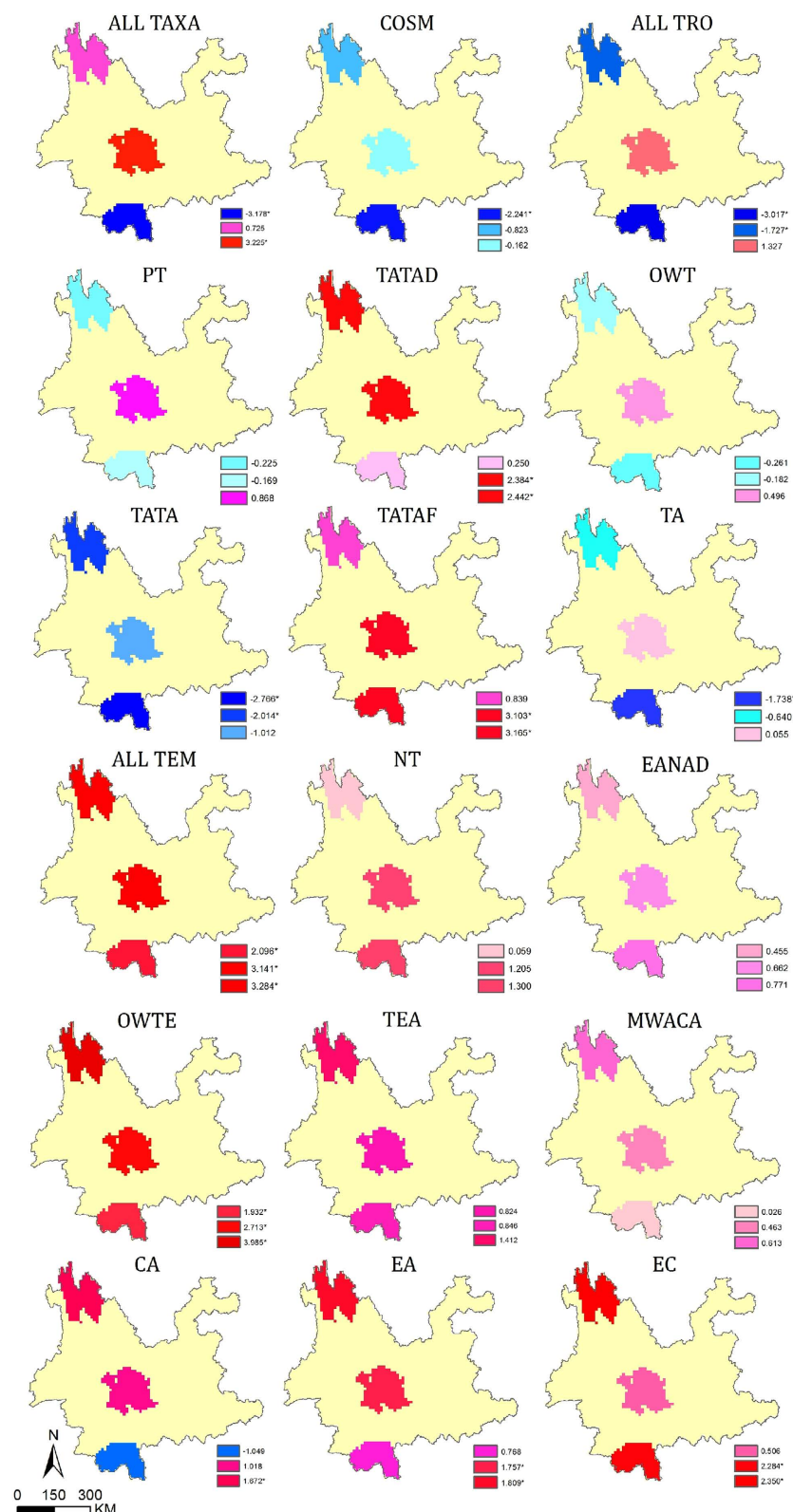


Figure 1. The net relatedness index (NRI) of the three floras at the genus level. *The p -values corresponding to NRI less than 0.05. ALL TAXA, all taxa at the generic level; COSM, cosmopolitan; ALL TRO, all taxa with tropical distributions; PT, pantropic; TATAD, tropical Asia and tropical America disjointed; OWT, old world tropic; TATA, tropical Asia to tropical Australia; TATAF, tropical Asia to tropical Africa; TA, tropical Asia; ALL TEM, all taxa with temperate distributions; NT, north temperate; EANAD, east Asia and North America disjointed; OWTE, old world temperate; TEA, temperate Asia; MWACA, Mediterranean, west Asia to center Asia; CA, center Asia; EA, east Asia; and EC, endemic to China. The map was generated using ArcGIS 10.2.2. (<http://www.esri.com>).

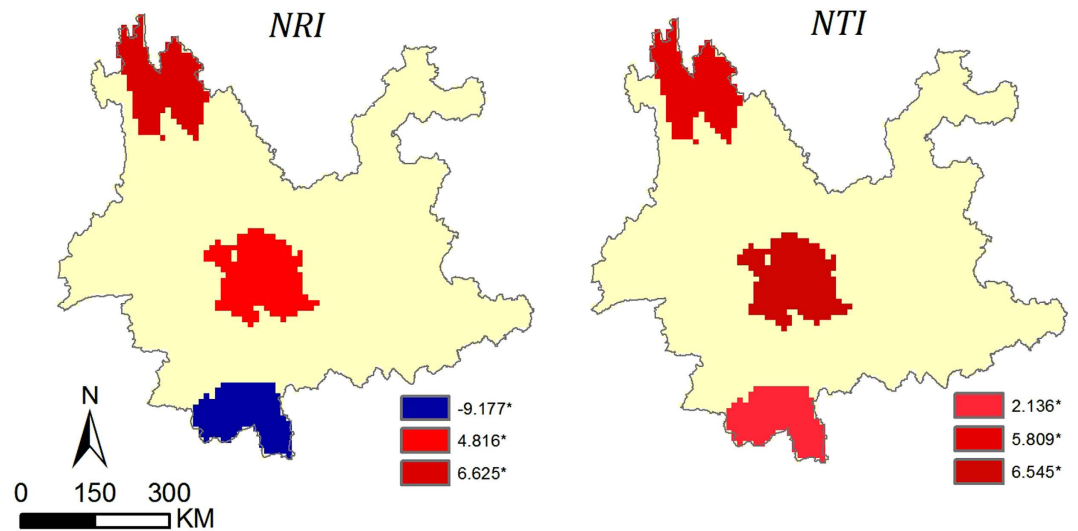


Figure 2. Phylogenetic structure of the three floras at the species level. *The p -values corresponding to NRI or NTI less than 0.05. NRI , the net relatedness index and NTI , the nearest taxon index. The map was generated using ArcGIS 10.2.2. (<http://www.esri.com>).

The pattern of phylogenetic structure in the flora of southern Yunnan was overdispersed. The assemblages of species (or genera) in southern Yunnan were more phylogenetically dispersed across the whole phylogeny (NRI), and the same was found for the tropical genera, especially with tropical Asia and tropical Asia to tropical Australia distributions (Fig. 1, ALL TAXA, ALL TRO, TATA, TA and Fig. 2, NRI). This pattern aligned with the geological and biogeological events, which was the collision between India and Asia that displaced Indochina southeastward along the Ailao Shan-Red River shear zone^{7,22}. The land and tropical climate of southern Yunnan, located at a sutural zone between Gondwana and Laurasia^{17,18}, were shaped during this geological event. Thus, the southern biome was conspicuously linked to the dispersal of distantly related species from Palaeotropic regions and South China. Our phylogenetic results illustrated that geological changes and the associated dispersal occurred in this region. This was generally compatible with the biogeographical hypothesis, which proposed that the flora of southern Yunnan evolved in concert with the extrusion of the Indochina block and was mainly influenced by tropical Asian elements since the later Tertiary¹⁶.

However, the NTI values indicated that, with respect to the more recent divergences, the species and tropical genera in southern Yunnan were clustered (Fig. 3, ALL TRO-TA and Fig. 2, NTI). This pattern may relate to the evolution and reproduction of species under a stable tropical climate. Phylogenetic clustering at a regional scale may result from the rapid speciation rates or slow extinction rates in evolutionary time^{23,24}. Tropical regions were expected to have relatively low rates of extinction and high rates of speciation^{14,25,26}. The different results of NRI and NTI were due to the different identification and measurements, which emphasized the importance of the simultaneous use of two indices providing diverse information from the whole phylogeny and the more recent divergences.

The floristic composition of northwestern Yunnan showed significant phylogenetic clustering. The species (or genera) in northwestern Yunnan were clustered across the entire phylogeny (NRI) and with respect to the more recent divergences (NTI), and the same was found for the temperate genera (Fig. 1, ALL TAXA, ALL TEM; Figs 2 and 3, ALL TAXA and ALL TEM). This pattern indicated the coexistence of substantial closely related species. This clustering was consistent with the biogeographical hypothesis, as the flora of northwestern Yunnan evolved with the uplift of the Himalayas and by the gradual proliferation of mainly cosmopolitan and north temperate floristic elements¹⁶. The plate collision-induced uplifting of the Himalayas-Tibetan Plateau began in the early Cenozoic and was relatively rapid and uniform, particularly during the Quaternary period^{27,28}. Taxa on the Himalaya-Tibetan Plateau became isolated from peripheral regions with the appearance of massive mountains and deep valleys. The continued uplift finally cut off the genetic exchange between the Himalayan range and the interior Tibetan Plateau⁷, promoting local speciation and hybridization of many closely related species, such as those in the genera *Saussurea*¹², *Pedicularis*¹³, and *Meconopsis*²⁹. The patterns of phylogenetic structure we observed in northwestern Yunnan reflected these geological and evolutionary processes.

We also observed that tropical genera of northwestern Yunnan, particularly those with tropical Asia and tropical Asia to tropical Australia distributions, were phylogenetically overdispersed across the whole phylogeny (NRI) (Fig. 1, ALL TRO, TATA, TA). The severe environments during the Quaternary may have filtered out many closely related tropical elements, leading to this overdispersed pattern. Another reason for such a pattern was that northwestern Yunnan may have acted as a refuge during glacial periods by providing diverse habitats in low, warm areas for plants distantly related to the local flora. This was consistent with an investigation of the Qinghai-Tibetan Plateau³⁰, which detected phylogenetic overdispersion at the junction of the eastern edge of the plateau due to shelters during glacial periods.

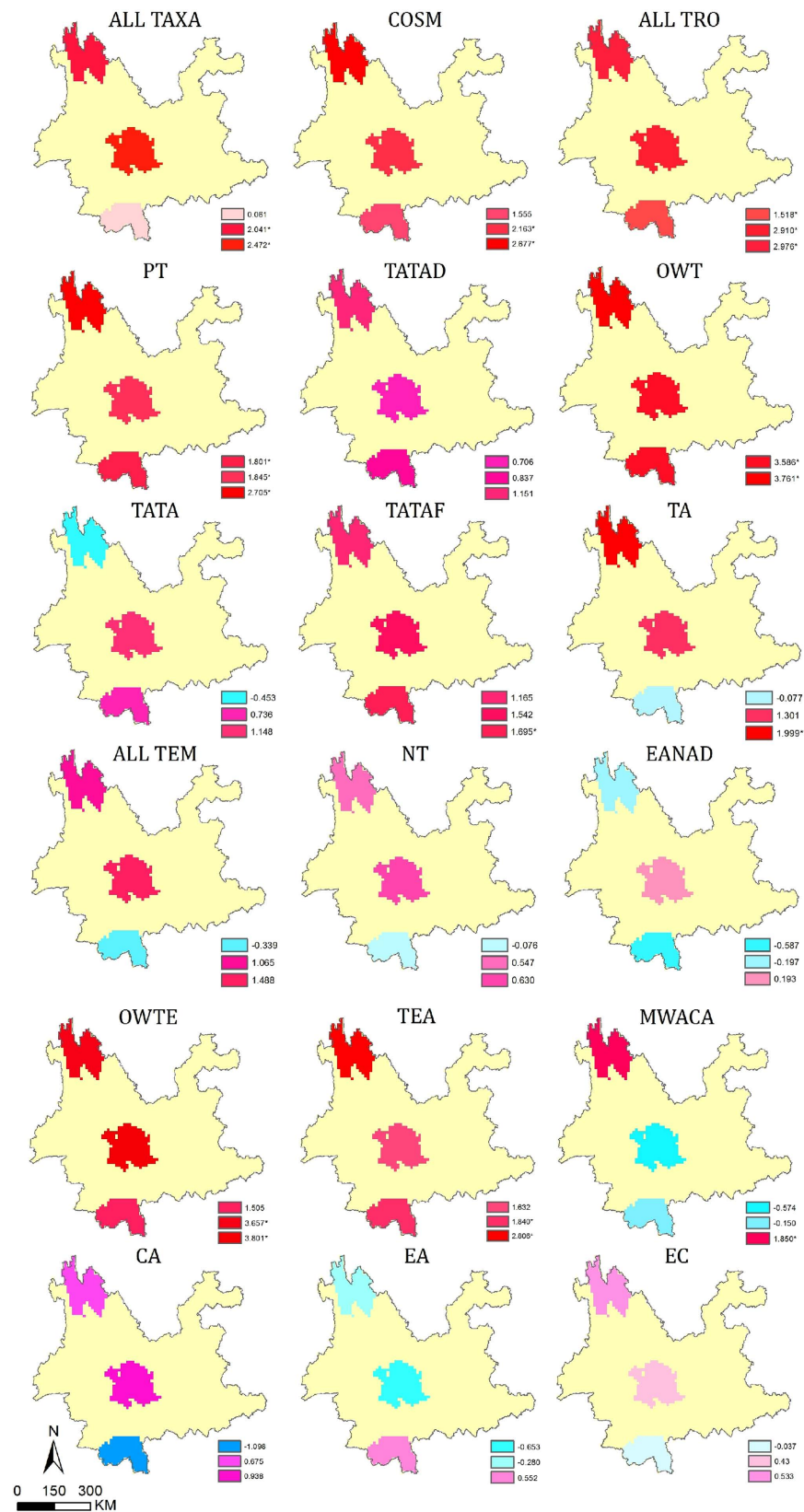


Figure 3. The nearest taxon index (NTI) of the three floras at the genus level. *The p -values corresponding to NTI less than 0.05. The map was generated using ArcGIS 10.2.2. (<http://www.esri.com>).

Groups	At the family level			At the genus level			At the species level		
	BN-ZB	ZB-DQ	DQ-BN	BN-ZB	ZB-DQ	DQ-BN	BN-ZB	ZB-DQ	DQ-BN
All taxa	0.904	0.906	0.837	0.747	0.744	0.624	0.530	0.453	0.324
Cosmopolitan	0.944	0.976	0.955	0.872	0.862	0.821	—	—	—
tropical distributions	0.918	0.888	0.828	0.754	0.794	0.670	—	—	—
PT	0.948	0.876	0.852	0.828	0.855	0.777	—	—	—
TATAD	0.925	0.939	0.867	0.793	0.868	0.766	—	—	—
OWT	0.913	1.000	0.913	0.827	0.792	0.758	—	—	—
TATA	0.923	1.000	0.923	0.758	0.789	0.682	—	—	—
TATAF	0.614	—	—	0.755	0.836	0.688	—	—	—
TA	0.766	0.827	0.609	0.677	0.722	0.558	—	—	—
Temperate distributions	0.880	0.903	0.813	0.743	0.719	0.577	—	—	—
NT	0.899	0.962	0.861	0.731	0.800	0.605	—	—	—
EANAD	0.880	0.885	0.851	0.804	0.672	0.613	—	—	—
10. OWTE	—	—	—	0.687	0.657	0.527	—	—	—
TEA	—	—	—	0.814	0.497	0.405	—	—	—
MWACA	—	—	—	0.870	0.763	0.644	—	—	—
CA	—	—	—	0.380	0.357	0.392	—	—	—
EA	0.841	0.801	0.653	0.696	0.758	0.552	—	—	—
EC	1.000	0.437	0.437	0.543	0.415	0.265	—	—	—
ESHD	—	—	—	—	—	—	—	—	—

Table 1. Phylogenetic similarity (*PhyloSor*) among the three floras across Yunnan. BN, southern Yunnan; ZB, central Yunnan; and DQ, northwestern Yunnan.

Groups	At the family level			At the genus level			At the species level		
	BN-ZB	ZB-DQ	DQ-BN	BN-ZB	ZB-DQ	DQ-BN	BN-ZB	ZB-DQ	DQ-BN
All taxa	137.34	111.39	154.30	235.49	239.39	347.22	304.50	410.84	589.18
Cosmopolitan	26.82	27.82	27.00	28.23	30.62	30.63	—	—	—
tropical distributions	41.12	35.04	37.58	128.33	99.27	117.83	—	—	—
PT	33.16	28.45	29.60	54.69	52.65	54.37	—	—	—
TATAD	10.68	10.72	10.33	18.08	18.73	17.14	—	—	—
OWT	5.17	5.18	5.17	36.89	31.16	32.62	—	—	—
TATA	6.30	6.43	6.30	36.00	30.76	31.72	—	—	—
TATAF	0.08	—	—	27.36	25.31	25.63	—	—	—
TA	6.69	4.99	4.57	55.33	42.91	46.79	—	—	—
Temperate distributions	18.88	20.48	19.04	66.24	86.81	70.83	—	—	—
NT	14.83	16.61	14.94	34.73	48.26	36.51	—	—	—
EANAD	8.51	8.49	8.57	20.03	22.50	19.52	—	—	—
OWTE	—	—	—	20.48	26.32	20.26	—	—	—
TEA	—	—	—	6.92	6.96	6.04	—	—	—
MWACA	—	—	—	7.34	10.76	7.08	—	—	—
CA	—	—	—	0.70	3.60	2.47	—	—	—
EA	3.76	5.24	3.50	30.20	40.41	29.95	—	—	—
EC	—	0.33	0.33	8.67	11.03	8.07	—	—	—
ESHD	—	—	—	—	—	—	—	—	—

Table 2. The standardized effect sizes of phylogenetic beta diversity ($S.E.S. D_{nm}$) among the three floras across Yunnan. BN, southern Yunnan; ZB, central Yunnan; and DQ, northwestern Yunnan.

Lower phylogenetic beta diversity and closer phylogenetic relationships existed among the tropical elements in these three floras rather than among the temperate elements (Tables 1 and 2). In addition, the flora of central Yunnan had nearly equal proportions of the northern and southern floras, and the phylogenetic similarities of families among the three regions were very high, which may due to the possible common origin. However, the different geological and evolutionary histories after the Tertiary were most likely to have driven the biogeographical divergence, which explained the relatively low similarity of species in focused areas. The uplift of the mountains and the oscillations in the climate created severe living conditions during the Quaternary³¹ that acted as a barrier to dispersal, making it difficult for species from the lowlands to migrate to the northern area. Furthermore,

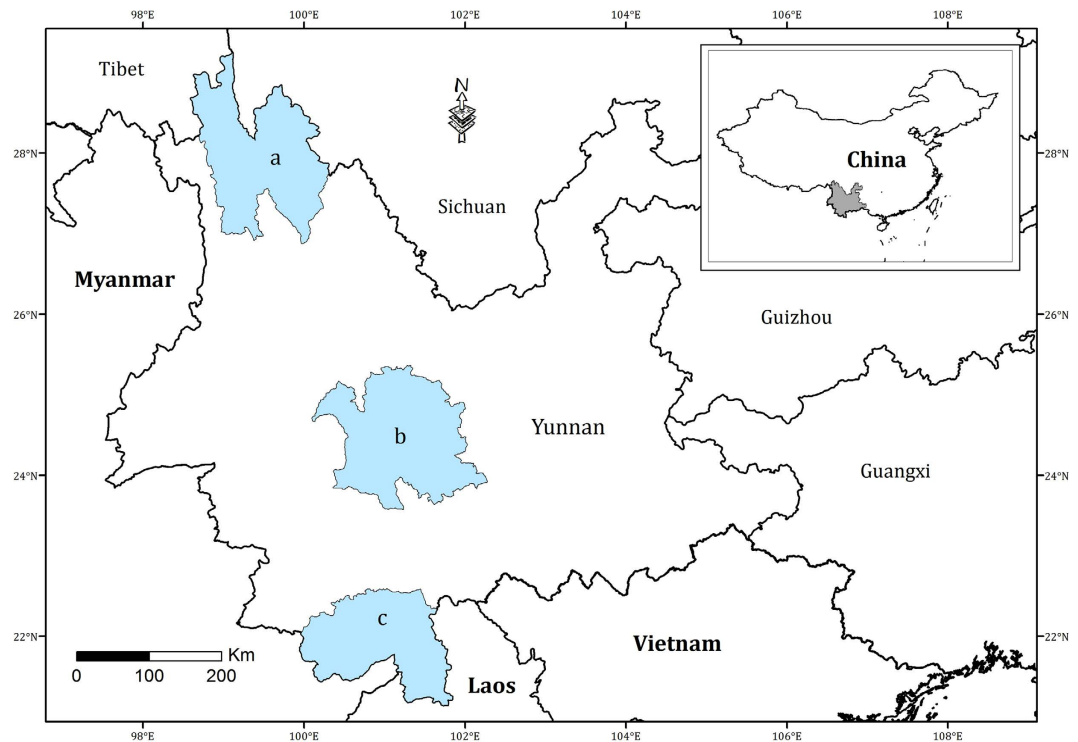


Figure 4. Location of the study regions. (a) Northwestern Yunnan; (b) central Yunnan; and (c) southern Yunnan. The map was generated using ArcGIS 10.2.2. (<http://www.esri.com>).

niche conservatism suggested that few clades crossed ecophysiological barriers to harsher environments^{32,33} due to the conserved ecological traits^{34–36}. This suggests that various tropical elements were present in northwestern Yunnan before the Quaternary period, which might explain such a close relationship among tropical elements. These results also supported the hypothesis that the floras of Yunnan were derived from a common Tertiary flora distributed in tropical or subtropical Asia¹⁶.

Taken together, the integration of floristic geography with phylogenetic information in our analyses provided clues that revealed the influence of geological events on the biogeographical divergence of regional floras, as well as evidences for biogeographical hypotheses about Yunnan. The uplift of the Himalayas and the extrusion of Indochina fit well with the phylogenetic patterns of regional floras across Yunnan. However, our results were no doubt coarser than would be found with a more refined supertree based on DNA sequences. The method used to build the phylogeny in this study was actually not ideal, especially when some genera or species were missing in the PhytoPhylo mega-phylogeny. In addition, we should be cautious about the limitations of using phylogenetic trees to date the timing of evolutionary processes because of the crucial role of fossils, especially when using these times to interpret the biological impacts of geological events^{37,38}. Thus, it is essential to improve the method of constructing a robust supertree, the ability of acquiring considerable DNA sequences and the study of plant fossils, which will help us reveal the origin, evolution and divergence of regional floras more objectively and truly.

Methods

Study area. Yunnan province is located in southwestern China, between 21°09'–29°15'N and 97°32'–106°12'E. The present analyses utilized the floras of three representative regions in southern, central and northwestern Yunnan (Fig. 4). Southern Yunnan (21°09'–22°36'N and 99°58'–101°50'E), which includes Xishuangbanna Dai Autonomous Prefecture, has a tropical monsoon climate and a low mountain-basin topography, with altitudes ranging from 475 m to 2,430 m across an area of 19,690 km². Its lowlands are often dominated by tropical rain-forest³⁹. Central Yunnan (23°53'–25°11'N and 100°32'–101°58'E), which includes 7 counties and incorporates the core regions of Mt. Wuliangshan and Mt. Ailaoshan, has a subtropical climate and a middle mountain-valley topography, with altitudes ranging from 422 m to 3,157 m (mainly 1,300 m to 2,200 m) across an area of 25,424 km². It is mostly covered by subtropical, evergreen broad-leaf forests and secondary *Pinus yunnanensis* forests. Northwestern Yunnan (27°10'–28°27'N and 98°53'–99°42'E), which includes 3 counties located at the center of the Hengduan Mountains, has a temperate climate and an alpine-deep valley topography, with altitudes ranging from 1,900 m to 6,740 m across an area of 23,870 km². Its main vegetation consists of temperate sclerophyllous oak forests and cold temperate coniferous forests¹⁶.

Floristic data. Comprehensive synonymized inventories of the total angiosperms in southern, central and northwestern Yunnan were obtained based on checklists from several monographs^{15,19–21}, the Flora of Yunnan⁴⁰ and a database of angiosperms from the herbarium of the Kunming Institute of Botany, Chinese Academy of Sciences. Only native species were used in the study. All intraspecific taxa (e.g., subspecies, variety and forma)

were not included in the analyses. A total of 9,370 angiosperm species from 1,860 genera and 212 families were used in this study. We checked and standardized the spelling and nomenclature of species in the floras according to The Plant List version 1.1 (TPL, available at <http://www.theplantlist.org>), which is an international standard database for plant nomenclature. This process aimed to maximize the match between names in the local lists and those in the backbone phylogenetic hypothesis for construction of the phylogeny. All the names in the species list that were considered synonyms were replaced with their accepted names from the TPL. We assigned each species to a family using the R package 'plantlist'^{41,42} following the TPL database, in which the circumscription of angiosperm families was generally consistent with APG III⁴³.

Furthermore, to explore the phylogenetic information concerning taxa with different patterns of geographical distribution in the study areas, patterns of angiosperms distribution were quantified at the genus and family levels based on Wu⁴⁴ and Wu *et al.*^{45,46}. The distribution patterns of 6 families and 5 genera were unclear, so we excluded these taxa from the phylogenetic analysis of geographical elements. Across the three regions, a total of 13 types of geographical distribution at the family level and 15 types of geographical distribution at the generic level were included.

We built a presence/absence matrix at each level (i.e., species, genus and family) based on the presence or absence of each angiosperm in each region for the following calculation of phylogenetic structure and beta diversity.

Mega-phylogeny construction. We constructed phylogenies by grafting the families, genera and species included in the study onto a backbone phylogenetic hypothesis in the R package 'S. PhyloMaker'⁴⁷. The backbone of this supertree was the PhytoPhylo mega-phylogeny⁴⁷, an updated and expanded version of Zanne *et al.*'s species-level phylogeny³³, which included 30,771 seed plants and was time-calibrated for all branches using seven gene regions available in GenBank and fossil data. PhytoPhylo included all families of extant seed plants in the world⁴⁸ and had five times more genera and over 55 times more species than the newest angiosperm supertrees (i.e., R20120829)⁴⁷. Genera and species that were not found in the PhytoPhylo mega-phylogeny were handled by S. PhyloMaker in one of three ways: (1) adding genera or species as polytomies within their families or genera; (2) randomly adding genera or species within their families or genera; and (3) adding genera or species to their families or genera with the same approach used in the online software Phylomatic and BLADJ. Using these three approaches, three phylogenies were generated at each level of resolution (i.e., family, genus and species). The phylogenies with the first approach are available in the Supplementary Material (Figures S3, S4 and S5). However, we mainly reported results based on the first approach. The detailed results using the other approaches are available in the Supplementary Material (Tables S2 and S3).

Phylogenetic structure. The phylogenetic structure of each flora was quantified using two indices: the net relatedness index (*NRI*) and the nearest taxon index (*NTI*). In general, *NRI* is considered more sensitive to tree-wide patterns of phylogenetic clustering and overdispersion, while *NTI* is more sensitive to patterns of overdispersion and clustering closer to the tips of the phylogenetic tree⁴⁹. *NRI* and *NTI* are defined as the measure of standardized effect size of mean pairwise distance (*MPD*) and mean nearest taxon distance (*MNTD*), respectively. These indices describe the difference in phylogenetic distance (i.e., *MPD* or *MNTD*) between observed and null communities generated with some randomization methods divided by the standard deviation of phylogenetic distance in the null communities⁵⁰. They are computed as follows:

$$NRI = -1 \times \frac{MPD_{observed} - \text{mean}(MPD_{null})}{sd(MPD_{null})} \quad (1)$$

$$NTI = -1 \times \frac{MNTD_{observed} - \text{mean}(MNTD_{null})}{sd(MNTD_{null})} \quad (2)$$

where $MPD_{observed}$ (or $MNTD_{observed}$) is the observed *MPD* (or *MNTD*), $\text{mean}(MPD_{null})$ [or $\text{mean}(MNTD_{null})$] is the average *MPD* (or *MNTD*) of randomly generated assemblages, and $sd(MPD_{null})$ [or $sd(MNTD_{null})$] is the standard deviation of *MPD* (or *MNTD*) in the null assemblages. We randomly shuffled the tip labels of the constructed phylogeny 999 times to generate null communities. A positive *NRI* (or *NTI*) value indicated a smaller phylogenetic distance among co-occurring taxa than expected (i.e., phylogenetic clustering). Conversely, a negative *NRI* (or *NTI*) value indicated a greater phylogenetic distance among co-occurring taxa than expected (i.e., phylogenetic overdispersion).

In this study, we used all the species in the three floras as a species pool and each study area as a plant community at the regional scale.

Phylogenetic beta diversity. Phylogenetic beta diversity provides insights into the phylogenetic relationships between communities. Previous studies demonstrated that D_{pw} (mean pairwise phylogenetic distance) was unsuitable for large-scale studies, because it did not vary significantly along environmental and distance gradients⁵¹. Thus, the present analyses used *PhyloSor* (phylogenetic Sørensen index) and D_{nn} (nearest neighbor phylogenetic distance) to evaluate the phylogenetic relationships between floras. *PhyloSor* is defined as the ratio of branch length between shared taxa to the total branch length of all taxa in two ecological communities⁵². A larger *PhyloSor* value indicates closer community relationships⁵¹. D_{nn} is defined as the mean phylogenetic distance between a species in community A and its most-related species in community B. We used a null model analysis to test whether regional floras were more or less phylogenetically similar than expected by chance⁵³. Negative values indicated a higher than expected phylogenetic distance, and positive values indicated a lower than expected

phylogenetic distance. Specifically, the *PhyloSor* and the standardized effect size (S.E.S.) of D_{nn} can be quantified as follows:

$$PhyloSor_{ij} = 2 \times \frac{BL_{ij}}{BL_i + BL_j} \quad (3)$$

$$S.E.S. D_{nn} = -1 \times \frac{D_{n\text{observed}} - D_{n\text{null}}}{sd(D_{n\text{null}})} \quad (4)$$

where BL_{ij} is the branch length between taxa shared by two communities, and BL_i (or BL_j) is the branch length between all taxa of community i (or j). $D_{n\text{observed}}$ is the observed dissimilarity between floras. $D_{n\text{null}}$ is the mean of D_{nn} of the null distributions generated by randomly shuffling the tip labels of the phylogeny 999 times. $sd(D_{n\text{null}})$ is the standard deviation of D_{nn} in the null distributions.

Analyses of phylogenetic structure and beta diversity were performed using the R packages 'picante'⁴⁹ and 'vegan'⁵⁴. The results of the phylogenetic structure were mapped with ArcGIS 10.2.2.

References

- Ricklefs, R. E. Community diversity: Relative roles of local and regional processes. *Science* **235**, 167–171 (1987).
- Hawkins, B. A. & Porter, E. E. Relative influence of current and historical factors on mammal and bird diversity patterns in deglaciated north America. *Glob. Ecol. Biogeogr.* **12**, 475–481 (2003).
- Pennington, R. T., Richardson, J. E. & Lavin, M. Insights into the historical construction of species-rich biomes from dated plant phylogenies, neutral ecological theory and phylogenetic community structure. *New Phytol.* **172**, 605–616 (2006).
- Swenson, N. G. & Umaña, M. N. Phylofloristics: An example from the Lesser Antilles. *J. Plant Ecol.* **7**, 166–175 (2014).
- Kooyman, R., Rossetto, M., Cornwell, W. & Westoby, M. Phylogenetic tests of community assembly across regional to continental scales in tropical and subtropical rain forests. *Global Ecol. Biogeogr.* **20**, 707–716 (2011).
- Thornhill, A. H. *et al.* Continental-scale spatial phylogenetics of Australian angiosperms provides insights into ecology, evolution and conservation. *J. Biogeogr.* **43**, 2085–2098 (2016).
- Che, J. *et al.* Spiny frogs (Paini) illuminate the history of the Himalayan region and Southeast Asia. *Proc. Natl. Acad. Sci. USA* **107**, 13765–13770 (2010).
- Jain, A. K. When did India-Asia collide and make the Himalaya? *Curr. Sci.* **106**, 254–266 (2014).
- Raymo, M. E. & Ruddiman, W. F. Tectonic forcing of late Cenozoic climate. *Nature* **359**, 117–122 (1992).
- Aikman, A. B., Harrison, T. M. & Lin, D. Evidence for early (>44 Ma) Himalayan crustal thickening, Tethyan Himalaya, southeastern Tibet. *Earth Planet. Sc. Lett.* **274**, 14–23 (2008).
- An, Z., Kutzbach, J., Prell, W. & Porter, S. Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan Plateau since late Miocene time. *Nature* **411**, 62–66 (2001).
- Wang, Y. J., Susanna, A., Raab-Straube, E. V., Milne, R. & Liu, J. Q. Island-like radiation of *Saussurea* (Asteraceae: Cardueae) triggered by uplifts of the Qinghai-Tibetan Plateau. *Bot. J. Linnean Soc.* **97**, 893–903 (2009).
- Yang, F. S., Li, Y. F., Ding, X. & Wang, X. Q. Extensive population expansion of *Pedicularis longiflora* (Orobanchaceae) on the Qinghai-Tibetan Plateau and its correlation with the Quaternary climate change. *Mol. Ecol.* **17**, 5135–5145 (2008).
- Zhu, H. The tropical flora of southern Yunnan, China, and its biogeographic affinities. *Ann. Mo. Bot. Gard.* **95**, 661–680 (2008).
- Zhu, H. Biogeography of Shangri-la flora in southwestern China. *Phytotaxa* **203**, 231–244 (2015).
- Zhu, H. Biogeographical divergence of the flora of Yunnan, southwestern China initiated by the uplift of Himalaya and extrusion of Indochina block. *Plos One* **7**, e45601 (2012).
- Jin, X. C. Permo-Carboniferous sequences of Gondwana affinity in southwest China and their paleogeographic implications. *J. Asian Earth Sci.* **20**, 633–646 (2002).
- Metcalfe, I. Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean peninsula in context. *Gondwana Res.* **9**, 24–46 (2006).
- Peng, H. *The seed plants from Mt. Wuliang in south-central Yunnan, China* (Yunnan Science and Technology Press, 1998).
- Zhu, H. & Yan, L. C. *List of seed plants in the Ailao Mts. of Yunnan province, China* (Yunnan Science and Technology Press, 2009).
- Zhu, H. & Yan, L. C. *Native seed plants in Xishuangbanna of Yunnan* (Science Press, 2012).
- Tapponnier, P. *et al.* The Ailao Shan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China. *Nature* **343**, 431–437 (1990).
- Cardillo, M. Phylogenetic structure of mammal assemblages at large geographical scales: Linking phylogenetic community ecology with macroecology. *Phil. Trans. R. Soc. B.* **366**, 2545–2553 (2011).
- Wiens, J. J. & Graham, C. H. Niche conservatism: Integrating evolution, ecology, and conservation biology. *Annu. Rev. Ecol. Evol. Syst.* **36**, 519–539 (2005).
- Kerkhoff, A. J., Moriarty, P. E. & Weiser, M. D. The latitudinal species richness gradient in New World woody angiosperms is consistent with the tropical conservatism hypothesis. *Proc. Natl. Acad. Sci. USA* **111**, 8125–8130 (2014).
- Matthew R. H., Thomas J. B., Christopher K. W. & Anthony R. I. Phylogenetic measures of biodiversity. *Am. Nat.* **169**, E68–E83 (2007).
- An, Y. Cenozoic tectonic evolution of Asia: A preliminary synthesis. *Tectonophysics* **488**, 293–325 (2010).
- Harrison, T. M., Copeland, P., Kidd, W. S. F. & Yin, A. Raising Tibet. *Science* **255**, 1663–1670 (1992).
- Yang, F. S., Qin, A. L., Li, Y. F. & Wang, X. Q. Great genetic differentiation among populations of *Meconopsis integrifolia* and its implication for plant speciation in the Qinghai-Tibetan Plateau. *Plos One* **7**, e37196 (2012).
- Yan, Y. J., Yang, X. & Tang, Z. Y. Patterns of species diversity and phylogenetic structure of vascular plants on the Qinghai-Tibetan Plateau. *Ecol. Evol.* **3**, 4584–4595 (2013).
- Liu, D. S., Zhang, X. S., Xiong, S. F. & Qin, X. G. Qinghai-Xizang Plateau glacial environment and global cooling. *Quat. Sci.* **19**, 385–396 (1999).
- Ricklefs, R. E. Evolutionary diversification and the origin of the diversity-environment relationship. *Ecology* **87**, S3–S13 (2006).
- Zanne, A. E. *et al.* Three keys to the radiation of angiosperms into freezing environments. *Nature* **506**, 89–92 (2014).
- Ackerly, D. D. Community assembly, niche conservatism, and adaptive evolution in changing environments. *Int. J. Plant Sci.* **164**, S165–S184 (2003).
- Donoghue, M. J. A phylogenetic perspective on the distribution of plant diversity. *Proc. Natl. Acad. Sci. USA* **105**, 11549–11555 (2008).
- Wiens, J. J. *et al.* Niche conservatism as an emerging principle in ecology and conservation biology. *Ecol. Lett.* **13**, 1310–1324 (2010).
- Sauquet, H. *et al.* Testing the impact of calibration on molecular divergence times using a fossil-rich group: The case of *Nothofagus* (Fagales). *Syst. Biol.* **61**, 289–313 (2012).

38. Wilf, P. & Escapa, I. H. Green Web or megabiased clock? Plant fossils from Gondwanan Patagonia speak on evolutionary radiations. *New Phytol.* **207**, 283–290 (2015).
39. Zhu, H. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *J. Biogeogr.* **24**, 647–662 (1997).
40. Wu, Z. Y. *Flora Yunnanica* Vol. 1–21 (Science Press, 1977–2006).
41. R Development Core Team. R: A language and environment for statistical computing. Available at: <http://www.R-project.org/>. (Date of access: 08/11/2015) (2012).
42. Zhang, J. L. Plantlist: Looking up families of higher plants. (2015) Available at: <http://R-Forge.R-project.org/projects/plantlist/>. (Date of access: 20/03/2016).
43. The Angiosperm Phylogeny Group. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Bot. J. Linnean Soc.* **161**, 105–121 (2009).
44. Wu, Z. Y. The areal-types of Chinese genera of seed plants. *Acta Bot. Yunnan. Supp.* **IV**, 1–139 (1991).
45. Wu, Z. Y., Zhou, Z. K., Li, D. Z., Peng, H. & Sun, H. The areal-types of the world families of seed plants. *Acta Bot. Yunnan.* **25**, 245–257 (2003).
46. Wu, Z. Y., Zhou, Z. K., Sun, H., Li, D. Z. & Peng, H. *The areal-types of seed plants and their origin and differentiation* (Yunnan Science and Technology Press, 2006).
47. Qian, H. & Jin, Y. An updated megaphylogeny of plants, a tool for generating plant phylogenies and an analysis of phylogenetic community structure. *J. Plant Ecol.* **9**, 233–239 (2015).
48. Qian, H. & Zhang, J. Using an updated time-calibrated family-level phylogeny of seed plants to test for non-random patterns of life forms across the phylogeny. *J. Syst. Evol.* **52**, 423–430 (2014).
49. Kembel, S. W. *et al.* Picante: R tools for integrating phylogenies and ecology. *Bioinformatics* **26**, 1463–1464 (2010).
50. Webb, C. O., Ackerly, D. D., McPeck, M. A. & Donoghue, M. J. Phylogenies and community ecology. *Annu. Rev. Ecol. Syst.* **33**, 475–505 (2002).
51. Feng, G. *et al.* Comparison of phylobetadiversity indices based on community data from Gutianshan forest plot. *Chin. Sci. Bull.* **57**, 623–630 (2011).
52. Bryant, J. A. *et al.* Microbes on mountainsides: Contrasting elevational patterns of bacterial and plant diversity. *Proc. Natl. Acad. Sci. USA* **105**, 11505–11511 (2008).
53. Webb, C. O., Ackerly, D. D. & Kembel, S. W. Phylocom: Software for the analysis of phylogenetic community structure and trait evolution. *Bioinformatics* **24**, 2098 (2008).
54. Oksanen, J. *et al.* Vegan: Community ecology package. Available at: <http://CRAN.R-project.org/package=vegan>. (Date of access: 02/11/2016) (2012).

Acknowledgements

This research was supported by the HPC platform, the public technology service center of Xishuangbanna tropical botanical garden (XTBG), CAS, China, the National Natural Science Foundation of China, No. 41471051, 41071040, 31170195, 31400362 and 31670442, the West Light Foundation of Chinese Academy of Sciences and the Chinese Academy of Sciences Youth Innovation Promotion Association (2016352). We also appreciate the reviewers for their helpful comments and suggestions to improve this manuscript.

Author Contributions

S.L., H.Z. and J.Y. conceived and designed the experiments. H.Z. provided the data. S.L. analyzed the data and wrote the first draft of the manuscript. S.L. and J.Y. contributed substantially to revisions.

Additional Information

Supplementary information accompanies this paper at <http://www.nature.com/srep>

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Liu, S. *et al.* A Phylogenetic Perspective on Biogeographical Divergence of the Flora in Yunnan, Southwestern China. *Sci. Rep.* **7**, 43032; doi: 10.1038/srep43032 (2017).

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A BIOGEOGRAPHICAL COMPARISON BETWEEN YUNNAN, SOUTHWEST CHINA, AND TAIWAN, SOUTHEAST CHINA, WITH IMPLICATIONS FOR THE EVOLUTIONARY HISTORY OF THE EAST ASIAN FLORA¹

Hua Zhu²

ABSTRACT

Located in southwestern and southeastern China, respectively, Yunnan and Taiwan are of biogeographical significance for the floristic diversity and evolution of the East Asian flora. A total of 13,253 seed plant species in 2140 genera and 225 families are recognized from Yunnan, while 3411 species in 1234 genera and 190 families are recognized from Taiwan. Although the flora of Yunnan is much more diverse than the flora of Taiwan, it is conspicuously similar in floristic composition and biogeographical elements. Yunnan and Taiwan share many of the same species-rich families in their floras. In both areas, families of tropical distribution contribute 52.4% and 50.5% of the total families in Yunnan and Taiwan, respectively, and the genera of tropical distribution contribute 57.3% of the flora in Yunnan and 60.9% of the flora in Taiwan. Yunnan and Taiwan have floristic similarities of 96.3% at the family level and 84.7% at the generic level. These similarities indicate that Yunnan and Taiwan have close floristic affinities. However, the floras of Yunnan and Taiwan have diverged to some extent. Yunnan has eight East Asian families and two Chinese endemic families, of which only two East Asian families are shared with Taiwan. Of the 12 tropical Asian families in Yunnan, 10 are not seen in Taiwan. Compared to Taiwan, Yunnan has 474 genera of tropical Asian distribution, which contribute 22.1% of its total genera, while Taiwan has 165 genera of tropical Asian distribution, contributing only 13.4% of its total genera. Furthermore, the patterns of geographical elements indicate that genera with transcontinental distributions, such as pantropic, Old World tropic, north temperate, or East Asia and North America disjunctions, are more likely to be shared by Yunnan and Taiwan, while those genera with distributions of tropical Asia, Old World temperate, temperate Asia, Mediterranean and western to central Asia, East Asia, and Chinese endemic are more often represented only in Yunnan. The flora of Yunnan might be derived from a Tertiary subtropical East Asian flora and has been diversified in its biogeographical elements following tectonic events since the Late Tertiary: northwestern Yunnan has evolved a temperate-featured flora with the uplift of the Himalayas, and southern Yunnan has evolved a tropical Asian flora with extrusion of the Indochina block. The flora of Taiwan could mainly derive from the East Asian flora with uplifting to an island after the Late Tertiary, and could have a relatively unsophisticated evolutionary history compared to Yunnan.

Key words: Biogeography, China, East Asian flora, floristics, Taiwan, Yunnan.

In his floristic regionalization of the world, Takhtajan (1978) delineated the Eastern Asiatic floristic region. Later, Wu and Wu (1996) raised this floristic region to kingdom level, the Eastern Asiatic Kingdom, considering its uniqueness with more than 30 endemic families and an exceptionally large number of endemic genera. The Eastern Asiatic Kingdom was further divided into Sino-Himalayan (with 144 endemic genera) and Sino-Japanese (with 104 endemic genera) subkingdoms (Wu & Wu, 1996). The Eastern Asiatic Kingdom was supposed to be one of the major centers for the evolution of higher seed plants, as the floristic

kingdom is especially rich in gymnosperms and primitive angiosperms (Wu & Wu, 1996). It is important for botanists who study the history of the temperate floras of the Northern Hemisphere and the tropical flora of southeastern Asia to deeply understand Eastern Asiatic flora. Yunnan and Taiwan comprise the southwestern and southeastern wings, respectively, of the Eastern Asiatic floristic region (Takhtajan, 1978), although their southernmost parts were in the northern margin of the Paleotropical kingdom, and Taiwan, as a whole, was later moved to the Paleotropical kingdom by Wu and Wu (1996). Yunnan and Taiwan are of

¹ This project was funded by The National Natural Science Foundation of China (41071040, 41471051, 31170195). The database was made by Yan Lichun from Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences. Prof. Li Zhenji from Xiamen University offered the plant list from Fujian Province. I also thank Dr. Richard Corlett for his help with English.

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doi: 10.3417/20111037

important biogeographical significance for the East Asian flora; they are at similar latitudes and have similar geography and vegetation. Comparing their floras may lead to a better understanding of the geological history, floristic variation, and evolution of East Asian floras.

The flora of Yunnan was primarily studied by Li and Walker (1986). Further research revealed that southern Yunnan has a tropical flora of Malaysian affinity (Zhu, 1997, 2008a; Zhu & Yan, 2009); central Yunnan is largely characterized by a subtropical East Asian flora (Yan et al., 2009), while northwestern Yunnan has a temperate Himalayan flora (Zhu, 2015). Floristic relationships between Taiwan and mainland China have been discussed previously (Ying & Hsu, 2002), and paleobotanical comparisons between Taiwan and mainland China have also been made (Song & Huang, 2004). These studies have shown that both the present flora and the palynoflora of Taiwan have close affinities to those of mainland China. It has also been observed that some taxa in Taiwan are related to taxa from southwestern China and the Himalayas, e.g., *Taiwania* Hayata, which is disjunctively distributed in northern Myanmar, the Hengduan Mountains of Yunnan, Hubei in central China, and Taiwan (Yu, 1995). Ying and Hsu (2002) recorded 15 genera of seed plants in Taiwan with Chinese-Himalayan distributions. While it has been observed that the gymnosperms of Taiwan have a closer affinity to southwestern China than to southeastern Asia (Ying & Hsu, 2002), the floristic relationships between southwestern China and Taiwan are understudied.

In this article, I compare the floras of Yunnan and Taiwan and their biogeographical affinities, to contribute to our understanding of geological history and the floristic evolution and variation of East Asia.

GEOGRAPHY

Yunnan Province is in southwestern China between 21°09' to 29°15'N and 97°32' to 106°12'E and occupies an area of 394,100 km². It has a mountainous topography with mountain ridges generally running in a north-south direction, decreasing in elevation southward from 6740 m at the highest mountain summit in the northwest to 76.4 m at the lowest valley bottom in the southeast (Red River). The general climatic pattern is: (1) tropical wet climates in the southern lowlands, (2) tropical dry climates in deep valleys below 1000 m, due to the foehn effect, (3) subtropical climates on the central plateau, and (4) temperate to cold temperate climates in the northern high mountains. It has a roughly annual precipitation of less than 1000 mm in the

northern mountains, 1000–1250 mm on the central plateau, and 1250–2250 mm in the south except in the deep dry valleys. Yunnan is a region with tropical areas at the horizontal base because almost all areas of lower elevation are tropical in nature regardless of their latitudinal location (Zhu, 2008b).

Taiwan is in southeastern China, at similar latitudes to Yunnan. It is a large (35,989 km²) continental island and lies between 21°45' to 25°56'N and 119°18' to 124°34'E. It also has a mountainous topography with mountain ridges in the center, running in a north-south direction. Its elevation ranges from sea level to 3997 m on the highest mountain summit in Yushan (Huang, 1993). Taiwan shows a transition from a tropical monsoon climate with an annual temperature of 23°–24°C in the south to a southern subtropical climate with an annual temperature of ca. 21°C in the north. It has an annual precipitation that exceeds 1500 mm across the island. Taiwan is also a region with tropical areas at its horizontal base.

VEGETATION

Yunnan supports a rich biodiversity and various vegetation types, making it a key area in biogeography and a hotspot for biodiversity (Myers, 1998). The vegetation types of Yunnan include tropical rainforest, subtropical evergreen broad-leaved forest, warm-temperate deciduous broad-leaved forest, temperate coniferous and broad-leaved mixed forest, cold temperate coniferous forest, alpine shrubs and meadows, as well as thorny shrubs and savanna in dry-hot valleys (Wu, 1987). The variety in these vegetation types shows a more or less mosaic distribution pattern, which occurs in response to the extremely diverse topography in Yunnan. It is conspicuous that the vegetation distribution of Yunnan corresponds more to elevation than latitude (Zhu, 2008b).

Taiwan has very similar vegetation types to those of Yunnan. It has tropical rainforest and monsoon forest in the lowlands; subtropical evergreen broad-leaved forest, which is the main vegetation type in Taiwan, in the lower montane zone; temperate coniferous–broad-leaved mixed forest and evergreen-deciduous mixed forest in the upper montane zone; and cold temperate *Picea* A. Dietr.–*Abies* Mill. forest at altitudes above 3000 m (Huang, 1993; Song & Xu, 2003).

MATERIALS AND METHODS

In the *Flora of Taiwan* (Huang & Editorial Committee of the Flora of Taiwan, 1994), which incorporated the newest checklist of vascular plants

of Taiwan (Boufford et al., 2003), excluding cultivated, introduced, and invasive species, and rectifying the circumscription of families that followed APG III (Chase & Reveal, 2009; APG III, 2009), and species following the nomenclature and classification as presented in Tropicos® of the Missouri Botanical Garden (<http://www.tropicos.org>), an updated list of native seed plants in Taiwan was completed, with a total of 3411 species in 1234 genera and 190 families. A similar circumscription of families and species was obtained, using the *Flora of Yunnan* (Wu, 1977–2006) and Tropicos®, with a total of 13,253 native seed plant species in 2140 genera and 225 families. Complete lists of families and genera with species numbers for Yunnan and Taiwan are given in Appendix 1. Floristic and geographical attributes of the floras of Yunnan and Taiwan were then analyzed. Patterns of seed plant distribution of these floras were quantified at the generic level based on documentation from Wu (1991) and Wu et al. (2006) and at the family level according to Wu et al. (2003). Comparisons of both floristic composition and geographical elements were made to assess the floristic similarity and variation as well as biogeographical affinities between these two regions.

RESULTS

FLORISTIC COMPOSITION OF THE FLORAS IN YUNNAN AND TAIWAN

A total of 13,253 native seed plant species in 2140 genera and 225 families were recognized from Yunnan. The families with high species richness include Poaceae (874 species), Asteraceae (787), Orchidaceae (774), Fabaceae (637), Rosaceae (460), Lamiaceae (446), Rubiaceae (365), Ericaceae (360), Ranunculaceae (310), Cyperaceae (273), Umbelliferae (250), Euphorbiaceae (226), Primulaceae (221), Lauraceae (205), and Gentianaceae (202). A total of 3411 species in 1234 genera and 190 families were recognized from Taiwan. Similar to the flora of Yunnan, the families with high species richness in Taiwan include Orchidaceae (334 species), Poaceae (317), Asteraceae (204), Fabaceae (195), Cyperaceae (159), Lamiaceae (103), Rubiaceae (97), Rosaceae (90), Euphorbiaceae (78), Urticaceae (61), and Lauraceae (57). The total number of native seed plant species in Yunnan is more than four times the total species in Taiwan.

The top 50 families ranking in species richness from both Yunnan and Taiwan are compared in Table 1. The dominant 50 families in Yunnan include a total of 10,447 species, contributing to 78.8% of its total flora (13,253 species), while the

dominant 50 families in Taiwan have a total of 2696 species, contributing to 79.0% of the total flora (3411 species). The floras of Yunnan and Taiwan are conspicuously similar in their species-rich families. Thirty-nine of the dominant 50 families in Yunnan are shared by Taiwan. The other 11 dominant families in Yunnan are Balsaminaceae, Begoniaceae, Berberidaceae, Campanulaceae, Fumariaceae, Gesneriaceae, Orobanchaceae, Primulaceae, Salicaceae, Sapindaceae, and Saxifragaceae; most of them are species-rich families in the Himalayas, while Gesneriaceae has high species diversity in southwestern China, especially in limestone habitats.

GEOGRAPHICAL ELEMENTS

Geographical elements of the floras of Yunnan and Taiwan at the family level are enumerated in Table 2. Families with tropical distribution dominate both, contributing to 52.4% and 50.5% of the total families in Yunnan and Taiwan, respectively, with those of pantropical distribution (e.g., Acanthaceae, Anacardiaceae, Annonaceae, Apocynaceae, Araceae, Arecaceae, Clusiaceae, Combretaceae, Icacinaceae, Myristicaceae, and Sapotaceae), making up 34.2% in Yunnan and 37.9% in Taiwan. Excluding cosmopolitan families with little geographical significance, those of north temperate distribution (e.g., Adoxaceae, Betulaceae, Caprifoliaceae, Cornaceae, Fagaceae, Fumariaceae, Hamamelidaceae, Orobanchaceae, and Salicaceae) rank second, contributing to 12.4% and 14.2% of their total floras, respectively. The flora of Yunnan includes 12 families of tropical Asian distribution (e.g., Crypteroniaceae, Escalloniaceae, Ixonanthaceae, Pentaphragmataceae, Pentaphylacaceae, Rafflesiaceae, Sabiaceae, and Sladeniaceae), eight families of East Asian distribution (e.g., Cercidiphyllaceae, Circaeasteraceae, Dipentodontaceae, Eupteleaceae, Stachyuraceae, and Tetracentraceae), and two families endemic to China (Eucommiaceae and Ginkgoaceae). The flora of Taiwan, in contrast, includes only two tropical Asian families (Akaniaaceae, Sabiaceae), three East Asian families (Cephalotaxaceae, Stachyuraceae, and Trochodendraceae), and no Chinese endemic families.

Geographical elements at the generic level are enumerated in Table 3. The genera of tropical distribution contribute to 57.3% of the flora of Yunnan and 60.9% of the flora of Taiwan. The genera of tropical Asian distribution make up the highest proportion of the total genera of Yunnan (22.1%), while the genera of pantropical distribution constitute the highest proportion of the total genera of

Table 1. Dominant 50 families with high species richness among the floras of Yunnan (making up a total of 10,447 species, 78.8% of the total flora) and Taiwan (making up a total of 2696 species, 79.0% of the total flora).

Flora of Yunnan			Flora of Taiwan		
Family	No. of species	Species (%)	Family	No. of species	Species (%)
Poaceae	874	6.6	Orchidaceae	334	9.8
Asteraceae	787	5.9	Poaceae	317	9.3
Orchidaceae	774	5.8	Asteraceae	204	6.0
Fabaceae	637	4.8	Fabaceae	195	5.7
Rosaceae	460	3.5	Cyperaceae	159	4.7
Lamiaceae	446	3.4	Lamiaceae	103	3.0
Rubiaceae	365	2.8	Rubiaceae	97	2.8
Ericaceae	360	2.7	Rosaceae	91	2.7
Ranunculaceae	310	2.3	Euphorbiaceae	78	2.3
Cyperaceae	273	2.1	Urticaceae	61	1.8
Umbelliferae	250	1.9	Lauraceae	57	1.7
Euphorbiaceae	226	1.7	Fagaceae	48	1.4
Primulaceae	221	1.7	Convolvulaceae	44	1.3
Lauraceae	205	1.5	Polygonaceae	42	1.2
Gentianaceae	202	1.5	Ranunculaceae	38	1.1
Gesneriaceae	194	1.5	Ericaceae	36	1.1
Apocynaceae	192	1.4	Araceae	33	1.0
Urticaceae	190	1.4	Umbelliferae	33	1.0
Liliaceae	181	1.4	Theaceae	32	0.9
Acanthaceae	175	1.3	Acanthaceae	31	0.9
Orobanchaceae	161	1.2	Apocynaceae	31	0.9
Saxifragaceae	145	1.1	Moraceae	31	0.9
Fagaceae	142	1.1	Rutaceae	31	0.9
Caryophyllaceae	139	1.0	Liliaceae	30	0.9
Zingiberaceae	139	1.0	Plantaginaceae	29	0.9
Celastraceae	126	1.0	Cruciferae	28	0.8
Theaceae	120	0.9	Symplocaceae	26	0.8
Araliaceae	117	0.9	Caryophyllaceae	25	0.7
Berberidaceae	116	0.9	Solanaceae	25	0.7
Cruciferae	115	0.9	Boraginaceae	23	0.7
Balsaminaceae	112	0.8	Gentianaceae	23	0.7
Salicaceae	111	0.8	Malvaceae	23	0.7
Polygonaceae	108	0.8	Cucurbitaceae	22	0.6
Moraceae	103	0.8	Aquifoliaceae	21	0.6
Rutaceae	102	0.8	Smilacaceae	21	0.6
Araceae	99	0.7	Celastraceae	20	0.6
Cucurbitaceae	99	0.7	Myrsinaceae	20	0.6
Vitaceae	96	0.7	Commelinaceae	19	0.6
Rhamnaceae	93	0.7	Crassulaceae	19	0.6
Begoniaceae	92	0.7	Linderniaceae	19	0.6
Oleaceae	90	0.7	Oleaceae	19	0.6
Campanulaceae	85	0.6	Vitaceae	19	0.6
Caprifoliaceae	84	0.6	Zingiberaceae	19	0.6
Sapindaceae	81	0.6	Caprifoliaceae	18	0.5
Aquifoliaceae	79	0.6	Hydrocharitaceae	18	0.5
Fumariaceae	79	0.6	Amaranthaceae	17	0.5
Convolvulaceae	74	0.6	Loranthaceae	17	0.5
Crassulaceae	74	0.6	Melastomataceae	17	0.5
Melastomataceae	73	0.6	Rhamnaceae	17	0.5
Boraginaceae	71	0.5	Araliaceae	16	0.5

Table 2. Biogeographical elements of seed plants at the family level in the floras of Yunnan (Southwest China) and Taiwan (Southeast China).

Biogeographical elements at family level	Yunnan		Taiwan	
	No. of families	%*	No. of families	%*
Cosmopolitan	58	25.8	58	30.5
Pantropic	77	34.2	72	37.9
Tropical Asia and tropical America disjunct	16	7.1	12	6.3
Old World tropic	5	2.2	4	2.1
Tropical Asia to tropical Australia	6	2.7	5	2.6
Tropical Asia to tropical Africa	2	0.9	1	0.5
Tropical Asia	12	5.3	2	1.1
North temperate	28	12.4	27	14.2
East Asia and North America disjunct	10	4.4	4	2.1
Old World temperate	1	0.4	2	1.1
Temperate Asia	0	0.0	0	0.0
Mediterranean, Western Asia to Central Asia	0	0.0	0	0.0
Central Asia	0	0.0	0	0.0
East Asia	8	3.6	3	1.6
Endemic to China	2	0.9	0	0.0
Total no. of families	225	100.0	190	100.0

* Percentages are calculated by the number of families in each geographical element divided by the total number of families in all geographical elements, then multiplied by 100%.

Taiwan (21.6%). In the flora of Yunnan, the genera of pantropical distribution constitute 14.4% of the total genera, followed by north temperate (10.9%) and East Asia (9.9%). In the flora of Taiwan, the genera of tropical Asian distribution contribute 13.4% of the total genera, followed by north temperate (12.3%). The genera endemic to China contribute 5.4% (115 genera) of the total flora of Yunnan but only 1.5% (18 genera) of the total flora of Taiwan.

FLORISTIC SIMILARITY BETWEEN THE FLORAS OF YUNNAN AND TAIWAN

Similarity coefficients between the floras of Yunnan and Taiwan at the family and generic levels are given in Table 4. They are 96.3% at the family level and 84.7% at the generic level. Among 190 families of seed plants in Taiwan, only seven families are not known from Yunnan: Flagellariaceae, Good-

Table 3. Biogeographical elements of seed plant taxa at the generic level in the floras of Yunnan (Southwest China) and Taiwan (Southeast China).

Biogeographical elements at generic level	Yunnan		Taiwan	
	No. of genera	%*	No. of genera	%*
Cosmopolitan	90	4.2	88	7.1
Pantropic	309	14.4	267	21.6
Tropical Asia and tropical America disjunct	45	2.1	34	2.8
Old World tropic	146	6.8	117	9.5
Tropical Asia to tropical Australia	146	6.8	115	9.3
Tropical Asia to tropical Africa	109	5.1	53	4.3
Tropical Asia	474	22.1	165	13.4
North temperate	234	10.9	152	12.3
East Asia and North America disjunct	89	4.2	62	5.0
Old World temperate	111	5.2	50	4.1
Temperate Asia	21	1.0	6	0.5
Mediterranean, Western Asia to Central Asia	23	1.1	7	0.6
Central Asia	17	0.8	0	0.0
East Asia	211	9.9	100	8.1
Endemic to China	115	5.4	18	1.5
Total no. of genera	2140	100.0	1234	100.0

* Percentage was calculated by the number of genera in each geographical element divided by the number of genera of all geographical elements, then multiplied by 100%.

Table 4. Similarity coefficients at the family and genus levels between the floras of Yunnan (225 families, 2140 genera) and Taiwan (190 families, 1234 genera).

Floristic similarities	Shared no./Similarity coefficients
At family level	183/96.3*
At generic level	1045/84.7*

* The similarity coefficient between A and B is calculated by the number of taxa shared by both A and B divided by the lowest number of taxa of A or B, then multiplied by 100%.

eniaceae, Phylodraceae, Ruppiaceae, Triuridaceae, Trochodendraceae, and Zosteraceae. Except for Trochodendraceae, which is distributed in Taiwan, the Ryukyu Islands, and Japan, the other six families are mostly seashore, wetland, or water plants and occur in southeast mainland China.

Among 225 families of seed plants in Yunnan, 43 families are not known from Taiwan (Table 5). They include 10 tropical Asian families, seven pantropical families, five North temperate families, six East Asian families, and two Chinese endemic families.

There are 1045 genera of native seed plants shared by Yunnan and Taiwan. However, 1095 genera in Yunnan are not known from Taiwan, while 190 genera in Taiwan are not known from Yunnan (Table 6). Of these shared genera, the pantropical elements contribute 23.2%, north temperate 13.4%, and tropical Asia 12.3%. Of those genera only in Yunnan, 343 genera are of tropical Asian distribution (31.3%), 138 genera are of East Asian distribution (12.6%), 106 are endemic to China (9.7%), and 94 genera are of north temperate distribution (8.6%). Of the genera only in Taiwan, those of tropical Asian distribution contribute 19.0%, those of tropical Asian to tropical Australian distribution contribute 14.8%, those of pantropical distribution contribute 13.2%, and those of East Asian distribution contribute 14.3%.

DISCUSSION

Yunnan and Taiwan are at similar latitudes and have a similar geography, although they are located at opposite ends of the Eastern Asiatic floristic region. They are conspicuously similar in floristic composition and geographical elements. They have higher similarities at the family and generic levels than usually expected. Although the flora of Yunnan is much more diverse in species than is the flora of Taiwan, the following similarities between them are revealed. (1) The top 50 families ranking in species richness in Yunnan and Taiwan contribute to 78.8% and 79.0% of their total floras, respectively. Thirty-nine of the top 50 families in both Yunnan and Taiwan are shared between the two provinces. (2) The

families of tropical distribution make up 52.4% and 50.5% of the total families in Yunnan and Taiwan, respectively, of which those of pantropical distribution contribute most among all geographical elements, making up 34.2% of the total families in Yunnan and 37.9% of the total families in Taiwan. The genera of tropical distribution contribute 57.3% of the flora of Yunnan and 60.9% of the flora of Taiwan. (3) The flora of Taiwan shares 96.3% of its families and 84.7% of its genera with the flora of Yunnan. The high floristic similarities between Yunnan and Taiwan indicate their close floristic affinities, despite the distance between the provinces.

The close floristic affinities cannot be explained only by the similar latitudes and geography of the provinces, but also by the geological history of East Asia and the Himalayas. It has been suggested that Taiwan was uplifted to an island after the Late Tertiary (Teng, 1990; Huang et al., 2001; Song & Huang, 2004), synchronous with the uplift of the Himalayas (Shi et al., 1998, 1999). During the formation of Taiwan, there were intermittent land connections to mainland China until the Late Holocene. The geological history of Taiwan might explain the close floristic affinity to Yunnan. Among the genera of East Asia distribution in Taiwan, Ying and Hsu (2002) mentioned that 15 genera were typical Sino-Himalayan distribution. Evidently, the floristic connection between Yunnan and Taiwan can be attributed to the success of the uplift of the Himalayas, which controlled their formations during the same geological time.

Table 7 shows the floristic similarities at the family and genus levels between the floras of Yunnan, Guangxi (Qin & Liu, 2010), Guangdong (Ye & Xing, 2005), Fujian, and Taiwan Provinces in southern China, which indicate that the floristic similarities between these provinces are high (more than 92.6% at the family level and 73.3% at the genus level), and their floras are in a continuous transition.

The high floristic similarity between these compared provinces makes it reasonable that main parts of Yunnan and Taiwan were included in the East Asian floristic region by Takhtajan (1978). There are eight families of East Asian distribution, Cephalotaxaceae, Cercidiphyllaceae, Circaeasteraceae, Dipentodontaceae, Eupteleaceae, Stachyuraceae, Tetracentraceae, and Toricelliaceae, and 211 genera of East Asian distribution in Yunnan. There are three families of East Asian distribution, i.e., Cephalotaxaceae, Stachyuraceae, and Trochodendraceae, and 100 genera of East Asian distribution in Taiwan. However, of the eight families of East Asian distribution in Yunnan, only two families are

Table 5. Seed plant families found in Yunnan but not in Taiwan (43 families). The number of species and genera are included as well as their biogeographical distribution types.

Family	Number of genera	Number of species	Distribution types
Borthwickiaceae	1	1	tropical Asia
Burseraceae	3	13	pantropic
Butomaceae	2	2	north temperate
Calycanthaceae	1	2	East Asia and North America disjunct
Carlemanniaceae	2	2	tropical Asia
Cercidiphyllaceae	1	1	Sino-Japan
Circaeasteraceae	1	1	Sino-Himalaya
Cletheraceae	1	5	tropical Asia and tropical America disjunct
Crypteroniaceae	1	1	tropical Asia
Dilleniaceae	2	4	pantropic
Dipentodontaceae	1	1	Sino-Himalaya
Dipterocarpaceae	5	7	pantropic
Ephedraceae	1	1	North temperate
Erythroxylaceae	1	2	pantropic
Escalloniaceae	1	1	tropical Asia
Eucommiaceae	1	1	endemic to China
Eupteleaceae	1	1	East Asia
Ginkgoaceae	1	1	endemic to China
Gnetaceae	1	4	pantropic
Hippocastanaceae	1	6	tropical Asia and tropical America disjunct
Ixonanthaceae	1	2	tropical Asia
Juncaginaceae	1	2	cosmopolitan
Linaceae	4	6	North temperate
Martyniaceae	1	1	tropical Asia and tropical America disjunct
Menyanthaceae	2	3	cosmopolitan
Myristicaceae	3	10	pantropic
Nyssaceae	2	5	East Asia and North America disjunct
Paeoniaceae	1	5	North temperate
Pandaceae	1	1	tropical Asia to tropical Africa
Pedaliaceae	1	1	Old World tropic
Pentaphragmataceae	1	1	tropical Asia
Pentaphylacaceae	1	1	tropical Asia
Podostemaceae	1	1	tropical Asia and tropical America disjunct
Polemoniaceae	1	1	North temperate
Rafflesiaceae	1	1	tropical Asia
Sargentodoxaceae	1	1	tropical Asia
Sladeniaceae	1	1	tropical Asia
Sonneratiaceae	1	1	Old World tropic
Stylidiaceae	1	1	pantropic
Tamaricaceae	2	4	Old World temperate

Table 5. Continued.

Family	Number of genera	Number of species	Distribution types
Tetracentraceae	1	1	Sino-Himalaya
Tetramelaceae	1	1	tropical Asia to tropical Australia
Toricelliaceae	1	1	Sino-Himalaya

shared with Taiwan. None of the two Chinese endemic families in Yunnan (Eucommiaceae and Ginkgoaceae) occurs in Taiwan. Although there are 73 genera of East Asian distribution common to Yunnan and Taiwan, there are another 138 East Asian genera found in Yunnan alone and 27 East Asian genera found in Taiwan alone. Similarly, there are 10 genera endemic to China that are common in Yunnan and Taiwan, while 106 Chinese endemic genera are found in Yunnan alone and eight Chinese endemic genera are found in Taiwan alone. These numbers indicate that Yunnan and Taiwan, although located at opposite ends of the Eastern Asiatic floristic region, have diverged to some extent. The flora of Yunnan has been diversified in its biogeographical elements, while the flora of Taiwan seems to have had a relatively unsophisticated evolutionary history.

The floristic similarities at the family and genus levels between these provinces in southern China (Table 7) indicate that the lowest similarities are between Fujian and adjacent Taiwan. Dipterocarpaceae fossils were found in the Middle Miocene at 24°12'N, 117°53'E in Fujian (Shi & Li, 2010) but have not been recorded in Taiwan. This may imply that the flora of Taiwan significantly evolved after the Miocene. Ying and Hsu (2002) mentioned that endemic species contribute 29.3% in Taiwan, but only four genera are endemic. If compared with Ceylon, an island of continental origin in tropical Asia, which has 27 endemic genera and 853 endemic species among its 1056 genera and 2855 angiosperm plants (Gunatilleke & Gunatilleke, 1990), the much lower endemism at the generic level in Taiwan may imply that it was not isolated biogeographically from mainland China by the Taiwan Strait until relatively recently.

In the flora of Yunnan, the genera of tropical Asian distribution contribute the highest proportion of the total genera at 22.1%, and those of pantropical distribution contribute 14.4%. In the flora of Taiwan, the genera of pantropical distribution contribute the highest proportion of the total genera at 21.6%, and those of tropical Asian distribution contribute 13.4%.

Table 6. Biogeographical elements at the generic level for genera shared by Yunnan and Taiwan and for genera found in only one of the two provinces.

Biogeographical elements at generic level	Shared by Yunnan and Taiwan		Found in Yunnan, SW China		Found in Taiwan, SE China	
	No. of genera	%*	No. of genera	%*	No. of genera	%*
Cosmopolitan	80	7.7	10	0.9	8	4.2
Pantropic	242	23.2	67	6.1	25	13.2
Tropical Asia and tropical America disjunct	28	2.7	17	1.6	6	3.2
Old World tropic	100	9.6	46	4.2	17	9.0
Tropical Asia to tropical Australia	87	8.3	59	5.4	28	14.8
Tropical Asia to tropical Africa	48	4.6	61	5.6	5	2.6
Tropical Asia	129	12.3	343	31.3	36	19.0
North temperate	140	13.4	94	8.6	12	6.3
East Asia and North America disjunct	54	5.2	36	3.3	8	4.2
Old World temperate	47	4.5	64	5.8	3	1.6
Temperate Asia	6	0.6	15	1.4	0	0.0
Mediterranean, Western Asia to Central Asia	1	0.1	22	2.0	6	3.2
Central Asia	0	0.0	17	1.6	0	0.0
East Asia	73	7.0	138	12.6	27	14.3
Endemic to China	10	1.0	106	9.7	8	4.2
Total no. of genera	1045	100.0	1095	100.0	190	100.0

*Percentage was calculated by the number of genera in each geographical element divided by the number of genera of all geographical elements, then multiplied by 100%.

The relatively high proportion of the tropical Asian element in Yunnan supports the tectonic hypothesis that the uplift in the Himalaya-Tibetan plateau region, resulting from crustal thickening and lateral extrusion of Indochina, occurred synchronously during the transition between the Oligocene and Miocene as a reaction to the Indo-Asian collision (Tapponnier et al., 1990; Che et al., 2010). It is apparent that the flora of Yunnan was strongly affected by the tropical Asian flora in its late evolution (Zhu, 2012).

Of the 474 genera of tropical Asian distribution in Yunnan, only 129 are shared with Taiwan (Table 6). Of the 12 tropical Asian families in Yunnan, 10 are not seen in Taiwan (Table 5). There are some pantropical families in Yunnan, such as Burseraceae, Dipterocarpaceae, Dilleniaceae, and Myristicaceae, which are well-diversified woody families in the tropical Asian rainforest, not found in Taiwan, with the exception of Myristicaceae, which is only naturally found in Lanyu Island, off of southwestern Taiwan. Obviously, these tropical Asian elements

Table 7. Similarity coefficients at the family and genus levels between the floras of Yunnan (225 families, 2140 genera), Guangxi (209 families, 1653 genera), Guangdong (197 families, 1413 genera), Fujian (193 families, 1155 genera), and Taiwan (190 families, 1234 genera).

Compared flora	Yunnan	Guangxi	Guangdong	Fujian	Taiwan
Similarity coefficients at family level*					
Yunnan	100				
Guangxi	93.3	100			
Guangdong	94.2	99.0	100		
Fujian	96.4	96.4	93.3	100	
Taiwan	95.8	95.8	93.2	92.6	100
Similarity coefficients at generic level*					
Yunnan	100				
Guangxi	87.4	100			
Guangdong	86.3	91.0	100		
Fujian	88.4	90.4	87.5	100	
Taiwan	84.6	78.2	75.0	73.3	100

* The similarity coefficient between A and B is calculated by the number of taxa shared by both A and B divided by the lowest number of taxa of A or B, then multiplied by 100%.

have been developed in Yunnan since the Late Tertiary, but they are not a major contribution to the flora of Taiwan. The pollen record from the Toushe Basin (23°49'N; 120°53'E; 650 m above sea level) in central Taiwan displayed that instead of today's closed subtropical evergreen broad-leaved forest dominated by *Machilus* Rumph.–*Castanopsis* (D. Don) Spach surrounding the basin, temperate deciduous forest predominated during most of the last glacial interval (Liew et al., 2006). This infers that Taiwan had a much colder climate in the past, which may be the reason that tropical plants of Southeast Asia have not been a major floristic element in Taiwan. In their floristic regionalization of China, Wu and Wu (1996) and Wu et al. (2010) moved Taiwan into the Paleotropical floristic kingdom. Based on the information above, it is better to keep Taiwan under the Eastern Asiatic Kingdom.

Looking across geographical elements at the shared genera, and the genera only in Yunnan or Taiwan (Table 6), the geographical elements can be divided into two groups. In one group, there are more shared than unshared genera, including cosmopolitan, pantropical, tropical Asia and tropical America disjunct, Old World tropic, north temperate, and East Asia and North America disjunct distributions. These geographical elements have a predominantly trans-continental distribution, although some of them could be easily dispersed ones. The second group has more unshared than shared genera, found in Yunnan, including those elements of tropical Asia, tropical Asia to tropical Africa, Old World temperate, temperate Asia, Mediterranean and western to central Asia, central Asia, East Asia, and Chinese endemic distributions. The occurrences of the genera of these distributions in Yunnan can be attributed to tectonic events, such as the collision of the Indian plate of Gondwana, the Tethys ocean closure, the Himalayan uplift, and extrusion of the Indochina block. From these patterns of geographical elements in Yunnan and Taiwan, one could infer that the floras of Yunnan and Taiwan are both derived from a common Tertiary flora of East Asia, composed mainly of elements with pantropic, Old World tropic, north temperate, and East Asia and North America disjunct distributions, and later diverged largely by the additions of tropical Asia, tropical Asia to tropical Africa, Old World temperate, East Asia, and Chinese endemic elements in Yunnan after tectonic events since the Late Tertiary. As a result, vegetation in northwestern Yunnan has evolved into a temperate-featured flora corresponding with the uplift of the Himalayas, while the vegetation in southern Yunnan has evolved a

more tropical Asian flora with the extrusion of the Indochina block. The flora of Taiwan underwent a relatively unsophisticated evolutionary history with uplifting to an island after the Late Tertiary.

Literature Cited

- APG III. 2009. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Bot. J. Linn. Soc.* 161: 105–121.
- Boufford, D. E., H. Ohashi, T. C. Huang, C. F. Hsieh, J. L. Tsai, K. C. Yang, C. I. Peng, C. S. Kuoh & A. Hsiao. 2003. A checklist of the vascular plants of Taiwan. Pp. 15–139 in Editorial Committee of the Flora of Taiwan (editors), *Flora of Taiwan*, Vol. 6, Second edition. Department of Botany, National Taiwan University, Taipei.
- Chase, M. W. & J. L. Reveal. 2009. A phylogenetic classification of the land plants to accompany APG III. *Bot. J. Linn. Soc.* 161: 122–127.
- Che, J., W. W. Zhou, J. S. Hu, F. Yan, T. J. Papenfuss, D. B. Wake & Y. P. Zhang. 2010. Spiny frogs (Paini) illuminate the history of the Himalayan region and Southeast Asia. *Proc. Natl. Acad. Sci. U.S.A.* 107(31): 13765–13770.
- Gunatilleke, I. A. U. N. & C. V. S. Gunatilleke. 1990. Distribution of floristic richness and its conservation in Sri Lanka. *Conservation Biol.* 4(1): 21–31.
- Huang, C. Y., K. Y. Xia, P. B. Yuan & P. G. Chen. 2001. Structural evolution from Paleogene extension to Latest Miocene–Recent arc-continent collision offshore Taiwan. *J. Asian Earth Sci.* 19: 619–639.
- Huang, T. C. & Editorial Committee of the Flora of Taiwan (editors). 1994. *Flora of Taiwan*, Vol. 1, Second edition. Department of Botany, National Taiwan University, Taipei.
- Huang, W. L. 1993. *Vegetation of Taiwan*. Environment Science Press, Beijing.
- Li, X. W. & D. Walker. 1986. The plant geography of Yunnan Province, southwest China. *J. Biogeogr.* 13: 367–397.
- Liew, P. M., S. Y. Huang & C. M. Kuo. 2006. Pollen stratigraphy, vegetation and environment of the last glacial and Holocene: A record from Toushe Basin, central Taiwan. *Quatern. Int.* 147: 16–33.
- Myers, N. 1998. Threatened biotas: “Hotspot” in tropical forests. *Environmentalist* 8(3): 1–20.
- Qin, H. N. & Y. Liu. 2010. A Checklist of Vascular Plants of Guangxi. Science Press, Beijing.
- Shi, G. L. & H. M. Li. 2010. A fossil fruit wing of *Dipterocarpus* from the middle Miocene of Fujian, China and its palaeoclimatic significance. *Rev. Palaeobot. Palynol.* 162: 599–606.
- Shi, Y. F., J. Y. Li & B. Y. Li. 1998. Uplift and environmental evolution of Qinghai-Xizang (Tibetan) plateau. Pp. 73–138 in H. L. Sun & D. Zheng (editors), *Formation, Evolution and Development of Qinghai-Xizang (Tibetan) Plateau*. Guangdong Science and Technology Press, Guangzhou.
- Shi, Y. F., J. Y. Li & B. Y. Li. 1999. Uplift of the Qinghai-Xizang (Tibetan) plateau and East Asia environmental change during late Cenozoic. *Acta Geogr. Sin.* 54(1): 10–21.

- Song, Y. C. & G. S. Xu. 2003. A scheme of vegetation classification of Taiwan, China. *Acta Bot. Sin.* 45(8): 883–895.
- Song, Z. C. & F. Huang. 2004. Cretaceous and Tertiary palynofloras in Taiwan area and its correlation with those in neighbouring coastal regions of mainland China. *J. Trop. Oceanogr.* 23(2): 1–9.
- Takhtajan, Y. 1978. Floristic Regions of the World. Soviet Sciences Press, Leningrad Branch. [In Russian.] Translated by T. J. Crovello, edited by A. Cronquist. 1986. University of California Press, Berkeley.
- Tapponnier, P., R. Lacassin, P. H. Leloup, U. Schärer, D. L. Zhong, H. W. Wu, X. H. Liu, S. H. Ji, L. S. Zhang & J. Y. Zhong. 1990. The Ailao Shan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China. *Nature* 343: 431–437.
- Teng, L. S. 1990. Geotectonic evolution of late Cenozoic arc-continent collision in Taiwan. *Tectonophysics* 183(1–4): 57–76.
- Wu, Z. Y. (editor-in-chief). 1977–2006. *Flora Yunnanica*, Vols. 1–16. Science Press, Beijing.
- Wu, Z. Y. 1987. *Vegetation of Yunnan*. Science Press, Beijing.
- Wu, Z. Y. 1991. The areal-types of Chinese genera of seed plants. *Acta Bot. Yunnan.* 4(suppl.): 1–139.
- Wu, Z. Y. & S. G. Wu. 1996. A proposal for a new floristic kingdom (realm): The Asiatic kingdom, its delineation and characteristics. Pp. 3–42 in A. L. Zhang & S. G. Wu (editors), *Floristic Characteristics and Diversity of East Asian Plants*. China Higher Education and Springer Press, Beijing.
- Wu, Z. Y., Z. K. Zhou, D. Z. Li, H. Peng & H. Sun. 2003. The areal-types of the world families of seed plants. *Acta Bot. Yunnan.* 25: 245–257.
- Wu, Z. Y., Z. K. Zhou, H. Sun, D. Z. Li & H. Peng. 2006. *The Areal-types of Seed Plants and Their Origin and Differentiation*. Yunnan Science and Technology Press, Kunming.
- Wu, Z. Y., H. Sun, Z. K. Zhou, D. Z. Li & H. Peng. 2010. *Floristics of Seed Plants from China*. Science Press, Beijing.
- Yan, L. C., J. P. Shi, H. Zhu, H. Peng, Y. H. Liu & H. Wang. 2009. The studies on floristics of seed plants in Ailaoshan Region, Yunnan, China. *J. Trop. Subtrop. Bot.* 17: 283–291.
- Ye, H. G. & F. W. Xing. 2005. *Checklist of Guangdong Plants*. World Book Press, Guangdong.
- Ying, T. S. & K. S. Hsu. 2002. An analysis of the flora of seed plants of Taiwan, China: Its nature, characteristics and relations with the flora of the mainland. *Acta Phytotax. Sin.* 41(1): 1–51.
- Yu, Y. F. 1995. Origin, evolution and distribution of the Taxodiaceae. *Acta Phytotax. Sin.* 33(4): 362–389.
- Zhu, H. 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, Southwest China with a special reference to its relation with rain forests of tropical Asia. *J. Biogeogr.* 24: 647–662.
- Zhu, H. 2008a. The tropical flora of southern Yunnan, China, and its biogeographical affinities. *Ann. Missouri Bot. Gard.* 95: 661–680.
- Zhu, H. 2008b. Distribution patterns of genera of Yunnan seed plants with references to their biogeographical significances. *Advances Earth Sci.* 23(8): 830–839.
- Zhu, H. 2012. Biogeographical divergence of the flora of Yunnan, southwestern China initiated by the uplift of Himalaya and extrusion of Indochina block. *PLoS ONE* 7(9): e45601.
- Zhu, H. 2015. Biogeography of Shangri-la flora in southwestern China. *Phytotaxa* 203(3): 231–244.
- Zhu, H. & L. C. Yan. 2009. Biogeographical affinities of the flora of southeastern Yunnan, China. *Bot. Stud.* 50: 467–475.
- Appendix 1. Families and genera of seed plants known for Yunnan (Y) and Taiwan (T). Note the sources that support the lists from the *Flora of Yunnan* (Wu, 1977–2006, and updated database at KUN) and the *Flora of Taiwan* (Boufford et al., 2003)
- Acanthaceae** (Y, gen. 55; T, gen. 14): *Acanthus* L. (Y, sp. 1); *Adenacanthus* Nees (Y, sp. 1), *Adhatoda* Mill. (Y, sp. 1), *Aechmanthera* Nees (Y, spp. 2), *Andrographis* Wall. (Y, spp. 2), *Asystasia* Blume (Y, spp. 3), *Asystasiella* Lindau (Y, sp. 1; T, sp. 1), *Avicennia* L. (T, sp. 1), *Baphicanthus* Bremek. (Y, sp. 1), *Barleria* L. (Y, spp. 3), *Calophanoides* Ridl. (Y, spp. 11), *Championella* Bremek. (Y, spp. 3), *Chroesthes* Benoist (Y, sp. 1), *Clinacanthus* Nees (Y, sp. 1), *Codonacanthus* Nees (Y, sp. 1; T, sp. 1), *Cystacanthus* T. Anderson (Y, spp. 4), *Dicliptera* Juss. (Y, spp. 5; T, sp. 1), *Difflugosa* Bremek. (Y, spp. 4), *Dipteracanthus* Nees (Y, sp. 1; T, sp. 1), *Echinacanthus* Nees (Y, sp. 1), *Eranthemum* L. (Y, spp. 4), *Gendarussa* Nees (Y, spp. 2), *Goldfussia* Nees (Y, spp. 7), *Gutzlaffia* Hance (Y, sp. 1), *Hemigraphis* Nees (T, spp. 3), *Hygrophila* R. Br. (Y, spp. 4; T, spp. 4), *Hymenochlaena* Bremek. (Y, sp. 1), *Hypoestes* Sol. ex R. Br. (Y, sp. 1; T, spp. 2), *Isoglossa* Oerst. (Y, sp. 1), *Kudoacanthus* Hosok. (T, sp. 1), *Lepidagathis* Willd. (Y, spp. 2; T, spp. 4), *Mananthes* Bremek. (Y, spp. 4), *Nelsonia* R. Br. (Y, sp. 1), *Ophiorrhizophyllum* Kurz (Y, sp. 1), *Paragutzlaffia* H. P. Tsui (Y, spp. 2), *Pararuellia* Bremek. & Nannenga-Bremek. (Y, spp. 3), *Perilepta* Bremek. (Y, spp. 3), *Peristrophe* Nees (Y, spp. 7; T, spp. 2), *Phaulopsis* Willd. (Y, sp. 1), *Phlogacanthus* Nees (Y, spp. 4), *Pseudaechmanthera* Bremek. (Y, sp. 1), *Pseuderanthemum* Radlk. (Y, spp. 7), *Pteracanthus* (Nees) Bremek. (Y, spp. 24), *Pteroptychia* Bremek. (Y, sp. 1), *Pyrrothrix* Bremek. (Y, spp. 3), *Rhaphidospora* Nees (Y, sp. 1), *Rhinacanthus* Nees (Y, spp. 3), *Rostellularia* Rechb. (Y, spp. 3), *Rungia* Nees (Y, spp. 6; T, spp. 2), *Semnostachya* Bremek. (Y, spp. 2), *Sericocalyx* Bremek. (Y, sp. 1), *Staurogyne* Wall. (Y, spp. 6; T, spp. 2), *Strobilanthes* Blume (Y, spp. 10; T, spp. 6), *Sympagis* (Nees) Bremek. (Y, sp. 1), *Tarphochlamys* Bremek. (Y, sp. 1), *Tetraglochidium* Bremek. (Y, spp. 2), *Tetragoga* Bremek. (Y, sp. 1), *Thunbergia* Retz. (Y, spp. 6).
- Acoraceae** (Y, gen. 1; T, gen. 1): *Acorus* L. (Y, spp. 4; T, sp. 1).
- Actinidiaceae** (Y, gen. 3; T, gen. 1): *Actinidia* Lindl. (Y, spp. 23; T, spp. 6), *Clematoclethra* (Franch.) Maxim. (Y, spp. 2), *Saurauia* Willd. (Y, spp. 12).
- Adoxaceae** (Y, gen. 2; T, gen. 1): *Adoxa* L. (Y, sp. 1), *Viburnum* L. (Y, spp. 43; T, spp. 14).
- Akaniaceae** (Y, gen. 1; T, gen. 1): *Bretschneidera* Hemsl. (Y, sp. 1; T, sp. 1).
- Alismataceae** (Y, gen. 3; T, gen. 3): *Alisma* L. (Y, sp. 1; T, sp. 1), *Caldesia* Parl. (Y, sp. 1; T, sp. 1), *Sagittaria* L. (Y, spp. 4; T, spp. 2).
- Amaranthaceae** (Y, gen. 9; T, gen. 8): *Achyranthes* L. (Y, spp. 2; T, spp. 2), *Aerva* Forssk. (Y, spp. 2; T, sp. 1), *Alternanthera* Forssk. (Y, spp. 4; T, spp. 4), *Amaranthus* L. (Y, spp. 7; T, spp. 4), *Celosia* L. (Y, spp. 2; T, spp. 2), *Cyathula* Blume (Y, spp. 3; T, sp. 1), *Deeringia* R. Br. (Y,

- sp. 1; T, spp. 2), *Philoxerus* R. Br. (T, sp. 1), *Psilotrichum* Blume (Y, sp. 1), *Stilbanthus* Hook. f. (Y, sp. 1)
- Amaryllidaceae** (Y, gen. 5; T, gen. 3): *Allium* L. (Y, spp. 25; T, spp. 2), *Crinum* L. (Y, spp. 2; T, sp. 1), *Lycoris* Herb. (Y, spp. 4; T, sp. 1), *Narcissus* L. (Y, sp. 1), *Nothoscordum* Kunth (Y, sp. 1).
- Anacardiaceae** (Y, gen. 15; T, gen. 4): *Buchanania* Spreng. (Y, spp. 2; T, sp. 1), *Choerospondias* Burt. & A. W. Hill (Y, sp. 1), *Cotinus* Mill. (Y, spp. 2), *Dobinea* Buch.-Ham. (Y, spp. 2), *Dracontomelon* Blume (Y, spp. 2), *Drimycarpus* Hook. f. (Y, spp. 2), *Lannea* A. Rich. (Y, sp. 1), *Mangifera* L. (Y, spp. 5), *Pegia* Colebr. (Y, spp. 2), *Pistacia* L. (Y, spp. 2; T, sp. 1), *Rhus* L. (Y, spp. 5; T, spp. 4), *Semecarpus* L. f. (Y, spp. 2; T, spp. 2), *Spondias* L. (Y, spp. 3), *Terminthia* Bernh. (Y, sp. 1), *Toxicodendron* Mill. (Y, spp. 13).
- Annonaceae** (Y, gen. 15; T, gen. 3): *Alphonsea* Hook. f. & Thomson (Y, spp. 5), *Artabotrys* R. Br. (Y, spp. 5), *Cyathostemma* Griff. (Y, sp. 1), *Dasymaschalon* (Hook. f. & Thomson) Dalle Torre & Harms (Y, spp. 2), *Desmos* Lour. (Y, spp. 4), *Fissistigma* Griff. (Y, spp. 16; T, spp. 2), *Goniothalamus* (Bl.) Hook. f. & Thomson (Y, spp. 5; T, sp. 1), *Mezzettiopsis* Ridl. (Y, sp. 1), *Miliusa* Lesch. (Y, spp. 4), *Mitrephora* (Bl.) Hook. f. & Thomson (Y, spp. 3), *Orophea* Blume (Y, spp. 2), *Phaeanthus* Hook. f. & Thomson (Y, spp. 1), *Polyalthia* Blume (Y, spp. 10; T, sp. 1), *Pseuduvaria* Miq. (Y, sp. 1), *Uvaria* L. (Y, spp. 5).
- Apocynaceae** (Y, gen. 48; T, gen. 19): *Aganosma* G. Don (Y, spp. 4), *Alstonia* R. Br. (Y, spp. 4), *Alyxia* Banks (Y, spp. 9; T, spp. 2), *Amalocalyx* Pierre (Y, sp. 1), *Anodendron* A. DC. (Y, sp. 1; T, spp. 2), *Asclepias* L. (Y, sp. 1; T, sp. 1), *Beaumontia* Wall. (Y, spp. 4), *Belostemma* Wall. (Y, spp. 2), *Biondia* Schl. (Y, spp. 2), *Bousigonia* Pierre (Y, spp. 2), *Brachystelma* R. Br. (Y, sp. 1), *Calotropis* R. Br. (Y, spp. 2), *Carissa* L. (Y, spp. 2), *Cerbera* L. (Y, sp. 1), *Ceropegia* L. (Y, spp. 8), *Chonemorpha* G. Don (Y, spp. 6), *Cynanchum* L. (Y, spp. 23; T, spp. 4), *Dischidia* R. Br. (Y, spp. 4; T, sp. 1), *Dolichopetalum* Tsiang (Y, sp. 1), *Dregea* E. Mey. (Y, spp. 3; T, sp. 1), *Epigynum* Wight (Y, sp. 1), *Ervatamia* (A. DC.) Stapf (Y, spp. 8), *Gongronema* (Endl.) Decne. (Y, sp. 1), *Gymnema* R. Br. (Y, spp. 7; T, sp. 1), *Heterostemma* Wight & Arn. (Y, spp. 6; T, sp. 1), *Holarrhena* R. Br. (Y, sp. 1; T, sp. 1), *Holostemma* R. Br. (Y, sp. 1), *Hoya* R. Br. (Y, spp. 15; T, sp. 1), *Ichnocarpus* R. Br. (Y, sp. 1), *Kopsia* Blume (Y, sp. 1), *Marsdenia* R. Br. (Y, spp. 15; T, spp. 2), *Melodinus* J. R. Forst. & G. Forst. (Y, spp. 6; T, sp. 1), *Metaplexis* R. Br. (Y, sp. 1), *Parameria* Benth. (Y, sp. 1), *Paravallaris* Pierre ex Hua (Y, spp. 2), *Parepigynum* Tsiang & P. T. Li (Y, sp. 1), *Parsonsia* R. Br. (T, sp. 1), *Pentasacme* Wall. (Y, sp. 1), *Pottsia* Hook. & Arn. (Y, spp. 3), *Raphistemma* Wall. (Y, sp. 1), *Rawolfia* L. (Y, spp. 6; T, sp. 1), *Sindechites* Oliv. (Y, sp. 1), *Stephanotis* Thouars (Y, spp. 2), *Strophanthus* DC. (Y, spp. 4), *Tabernaemontana* L. (T, spp. 2), *Telosma* Coville (Y, spp. 2; T, sp. 1), *Thevetia* L. (Y, sp. 1), *Trachelospermum* Lem. (Y, spp. 7; T, spp. 4), *Tylophora* R. Br. (Y, spp. 10; T, spp. 3), *Vallaris* Burm. f. (Y, sp. 1), *Wrightia* R. Br. (Y, spp. 5).
- Aponogetonaceae** (T, gen. 1): *Aponogeton* L. f. (Y, sp. 1; T, sp. 1).
- Aquifoliaceae** (Y, gen. 1; T, gen. 1): *Ilex* L. (Y, spp. 79; T, spp. 21).
- Araceae** (Y, gen. 21; T, gen. 14): *Aglaonema* Schott (Y, spp. 2), *Alocasia* Schott (Y, spp. 3; T, spp. 2), *Amorphophallus* Blume (Y, spp. 8; T, spp. 4), *Anadendrum* Schott (Y, spp. 2), *Arisaema* Mart. (Y, spp. 39; T, spp. 9), *Colocasia* Schott (Y, spp. 5; T, spp. 4), *Cryptocoryne* Fisch. (Y, sp. 1), *Epipremnopsis* Engl. (Y, spp. 2), *Epipremnum* Schott (Y, sp. 1; T, spp. 2), *Gonatanthus* Klotzsch (Y, spp. 2), *Hapaline* Schott (Y, sp. 1), *Homalomena* Schott (Y, spp. 2; T, spp. 2), *Lasia* Lour. (Y, sp. 1), *Pinellia* Ten. (Y, spp. 2; T, sp. 1), *Pistia* L. (Y, sp. 1; T, sp. 1), *Pothoidium* Schott (T, sp. 1), *Pothos* L. (Y, spp. 5; T, sp. 1), *Remusatia* Schott (Y, spp. 2; T, sp. 1), *Rhaphidophora* Hassk. (Y, spp. 9; T, spp. 2), *Sauromatum* Schott (Y, sp. 1), *Schismatoglottis* Zoll. & Moritzi (T, sp. 1), *Steudnera* K. Koch (Y, spp. 2), *Typhonium* Schott (Y, spp. 8; T, spp. 2).
- Araliaceae** (Y, gen. 18; T, gen. 9): *Acanthopanax* Miq. (Y, spp. 9), *Aralia* L. (Y, spp. 18; T, spp. 4), *Brassaiopsis* Decne. & Planch. (Y, spp. 20), *Dendropanax* Decne. & Planch. (Y, spp. 7; T, spp. 2), *Diplopanax* Hand.-Mazz. (Y, sp. 1), *Eleutherococcus* Maxim. (T, sp. 1), *Fatsia* Decne. & Planch. (Y, spp. 2; T, sp. 1), *Hedera* L. (Y, sp. 1), *Heteropanax* Seem. (Y, spp. 4), *Kalopanax* Miq. (Y, sp. 1), *Macropanax* Miq. (Y, spp. 5), *Merrillioanax* H. L. Li (Y, spp. 2), *Metapanax* J. Wen & Frodin (Y, spp. 2), *Osmoxylon* Miq. (T, sp. 1), *Panax* L. (Y, spp. 4), *Pentapanax* Seem. (Y, spp. 8; T, sp. 1), *Schefflera* J. R. Forst. & G. Forst. (Y, spp. 30; T, spp. 4), *Sinopanax* H. L. Li (T, sp. 1), *Tetrapanax* K. Koch (Y, sp. 1; T, sp. 1), *Trevesia* Vis. (Y, sp. 1), *Tupidanthus* Hook. f. & Thomson (Y, sp. 1).
- Aristolochiaceae** (Y, gen. 2; T, gen. 2): *Aristolochia* L. (Y, spp. 24; T, spp. 5), *Asarum* L. (Y, spp. 7; T, spp. 6).
- Asclepiadaceae** (Y, gen. 10; T, gen. 2): *Adelostemma* Hook. f. (Y, sp. 1), *Cryptolepis* R. Br. (Y, spp. 2; T, sp. 1), *Genianthus* Hook. f. (Y, sp. 1), *Goniostemma* Wight (Y, sp. 1), *Jasminanthus* Blume (Y, sp. 1; T, sp. 1), *Myriopteron* Griff. (Y, sp. 1), *Oxystelma* R. Br. (Y, sp. 1), *Periploca* L. (Y, spp. 3), *Secamone* R. Br. (Y, spp. 4), *Streptocaulon* Wight & Arn. (Y, spp. 2), *Toxicarpus* Wight & Arn. (Y, spp. 5).
- Asparagaceae** (Y, gen. 3; T, gen. 3): *Agave* L. (Y, spp. 3; T, sp. 1), *Asparagus* L. (Y, spp. 13; T, sp. 1), *Dracaena* Vand. ex L. (Y, spp. 6; T, spp. 2).
- Asteraceae** (Y, gen. 132; T, gen. 76): *Acanthospermum* Schrank (Y, sp. 1), *Achillea* L. (Y, sp. 1), *Acmella* Rich. (T, spp. 2), *Adenocaulon* Hook. (Y, sp. 1), *Adenostemma* J. R. Forst. & G. Forst. (Y, sp. 1; T, sp. 1), *Ageratina* Spach (Y, sp. 1; T, sp. 1), *Ageratum* L. (Y, spp. 2; T, spp. 2), *Ainsliaea* DC. (Y, spp. 27; T, spp. 3), *Ajania* Poljakov (Y, spp. 7), *Ambrosia* L. (T, sp. 1), *Anaphalis* DC. (Y, spp. 26; T, spp. 4), *Anisopappus* Hook. & Arn. (Y, sp. 1), *Arctium* L. (Y, sp. 1), *Artemisia* L. (Y, spp. 54; T, spp. 15), *Aster* L. (Y, spp. 36; T, spp. 16), *Atractylodes* DC. (Y, spp. 2), *Bidens* L. (Y, spp. 5; T, spp. 4), *Blainvillea* Cass. (Y, sp. 1), *Blumea* DC. (Y, spp. 26; T, spp. 11), *Blumeopsis* Gagnep. (Y, sp. 1), *Calendula* L. (Y, sp. 1), *Callistephus* Cass. (Y, sp. 1), *Camchaya* Gagnep. (Y, sp. 1), *Carduus* L. (Y, spp. 2), *Carpesium* L. (Y, spp. 11; T, spp. 5), *Carthamus* L. (Y, sp. 1), *Centaurea* L. (Y, sp. 1), *Centipeda* Lour. (Y, sp. 1; T, sp. 1), *Cephalorrhynchus* Boiss. (Y, sp. 1), *Chaetosaris* C. Shih (Y, spp. 14), *Chrysanthemum* L. (Y, spp. 2), *Cicerbita* Wallr. (Y, sp. 1), *Cichorium* L. (T, sp. 1), *Cirsium* Mill. (Y, spp. 16; T, spp. 8), *Cissampelopsis* (DC.) Miq. (Y, spp. 5), *Conyza* Less. (Y, spp. 8; T, spp. 6), *Coreopsis* L. (Y, spp. 2), *Cotula* L. (Y, sp. 1; T, sp. 1), *Crassocephalum* Moench (Y, sp. 1; T, sp. 1), *Cremanthodium* Benth. (Y, spp. 36), *Crepidiastrum* Nakai (T, spp. 2), *Crepis* L. (Y, spp. 7), *Crossostephium* Less. (T, sp. 1), *Cyathocline* Cass. (Y, sp. 1), *Dendranthema* (DC.) Des Moul. (Y, spp. 4; T, spp. 4), *Dichrocephala* L'Hér. ex DC. (Y, spp. 3; T, sp. 1), *Diplazoptilon* Y. Ling (Y, sp. 1), *Doellingeria* Nees (Y, sp. 1), *Dolomiaea* DC. (Y, spp. 6), *Doronicum* L. (Y, spp. 2), *Dubyaea* DC. (Y, spp. 5), *Echinops* L. (T, sp. 1), *Eclipta*

- L. (Y, sp. 1; T, spp. 2), *Elephantopus* L. (Y, sp. 1; T, spp. 2), *Emilia* Cass. (Y, spp. 2; T, sp. 1), *Enydra* Lour. (Y, sp. 1), *Epaltes* Cass. (Y, sp. 1; T, sp. 1), *Erechtites* Raf. (Y, sp. 1; T, spp. 2), *Erigeron* L. (Y, spp. 8; T, spp. 2), *Ethulia* L. f. (Y, sp. 1), *Eupatorium* L. (Y, spp. 6; T, spp. 7), *Faberia* Hemsl. (Y, spp. 3), *Farfugium* Lindl. (T, sp. 1), *Formania* W. W. Sm. & Small (Y, sp. 1), *Galinsoga* Ruiz & Pav. (Y, sp. 1; T, spp. 2), *Gerbera* L. (Y, spp. 5; T, sp. 1), *Glossocardia* Cass. (T, sp. 1), *Gnaphalium* L. (Y, spp. 7; T, spp. 8), *Gochnatia* Kunth (Y, sp. 1), *Grangea* Adans. (Y, sp. 1; T, sp. 1), *Gynura* Cass. (Y, spp. 8; T, spp. 3), *Hemistepia* Bunge (Y, sp. 1; T, sp. 1), *Heteropappus* Less. (Y, sp. 1), *Hieracium* L. (Y, sp. 1; T, sp. 1), *Hippolytia* Poljakov (Y, spp. 2), *Hypochoeris* L. (T, sp. 1), *Inula* L. (Y, spp. 9), *Ixeridium* (A. Gray) Tzvel. (Y, spp. 4; T, spp. 2), *Ixeris* Cass. (Y, sp. 1; T, spp. 6), *Kalimeris* Cass. (Y, sp. 1), *Lactula* L. (Y, spp. 2), *Lagenophora* Cass. (Y, sp. 1; T, sp. 1), *Laggera* Sch.-Bip. (Y, spp. 2; T, sp. 1), *Lapsana* L. (Y, sp. 1), *Lapsanastrum* Pak & K. Bremer (T, spp. 2), *Launaea* Cass. (Y, sp. 1), *Leibnitzia* Cass. (Y, spp. 4), *Leontopodium* R. Brown (Y, spp. 14; T, sp. 1), *Ligularia* Cass. (Y, spp. 57; T, spp. 3), *Microglossa* DC. (Y, sp. 1; T, sp. 1), *Mikania* Willd. (Y, sp. 1; T, sp. 1), *Mulgedium* Cass. (Y, spp. 3), *Myriactis* Less. (Y, spp. 4; T, sp. 1), *Nannoglottis* Maxim. (Y, spp. 3), *Nemesene* (Kitam.) B. Nord. (Y, spp. 3; T, sp. 1), *Neopallasia* (Pall.) Poljak. (Y, sp. 1), *Notoseris* C. Shih (Y, spp. 3; T, sp. 1), *Nouelia* Franch. (Y, sp. 1), *Paraixeris* Nakai (Y, spp. 2), *Paramicrorhynchus* Kirp. (Y, sp. 1), *Paraprenanthes* C. C. Chang (Y, spp. 6; T, sp. 1), *Parasenecio* W. W. Sm. & Small (Y, spp. 15; T, spp. 3), *Parthenium* L. (Y, spp. 2), *Pentanema* Cass. (Y, sp. 1), *Pertya* Sch.-Bip. (Y, spp. 3; T, sp. 1), *Petasites* Mill. (Y, spp. 2; T, sp. 1), *Picris* L. (Y, spp. 3), *Piloselloides* (Less.) C. Jeffr. (Y, sp. 1), *Pluchea* Cass. (Y, sp. 1; T, spp. 4), *Prenanthes* L. (Y, spp. 4), *Pseudelephantopus* Rohr (T, sp. 1), *Pterocypsella* C. Shih (Y, spp. 3; T, spp. 3), *Pyrethrum* Zinn. (Y, spp. 2), *Rhynchospermum* Reinw. (Y, sp. 1; T, sp. 1), *Saussurea* DC. (Y, spp. 90; T, spp. 5), *Senecio* L. (Y, spp. 28; T, spp. 7), *Serratula* L. (Y, sp. 1), *Sheareria* S. Moore (Y, sp. 1), *Sigesbeckia* L. (Y, spp. 3; T, sp. 1), *Sinacalia* H. Rob. & Brettell (Y, sp. 1), *Sinosenecio* B. Nord. (Y, spp. 7), *Solidago* L. (Y, sp. 1; T, sp. 1), *Soliva* Ruiz & Pav. (T, spp. 2), *Sonchus* L. (Y, spp. 6; T, spp. 3), *Soroiseris* Stebb. (Y, spp. 3), *Sphaeranthus* L. (Y, spp. 3; T, sp. 1), *Spilanthes* Jacq. (Y, spp. 2), *Stebbinsia* Lipsch. (Y, sp. 1), *Stenoseris* C. Shih (Y, spp. 4), *Syncalathium* Lipsch. (Y, sp. 1), *Synedrella* Gaertn. (Y, sp. 1; T, sp. 1), *Syneilesis* Maxim. (T, spp. 2), *Synotis* (C. B. Clarke) C. Jeffrey & Y. L. Che (Y, spp. 27), *Taraxacum* F. H. Wigg (Y, spp. 12; T, spp. 2), *Tephroseris* (Reichenb.) Reichenb. (Y, sp. 1; T, spp. 2), *Thespis* DC. (Y, sp. 1), *Tragopogon* L. (Y, sp. 1), *Tricholepis* DC. (Y, sp. 1), *Tridax* L. (Y, sp. 1; T, sp. 1), *Tussilago* L. (Y, sp. 1), *Vernonia* Schreb. (Y, spp. 22; T, spp. 5), *Wedelia* Jacq. (Y, spp. 3; Y, T, spp. 4), *Xanthium* L. (Y, sp. 1; T, sp. 1), *Xanthopappus* C. Winkl. (Y, sp. 1), *Youngia* Cass. (Y, spp. 14; T, sp. 1).
- Balanophoraceae** (Y, gen. 2; T, gen. 1): *Balanophora* J. R. Forst. & G. Forst. (Y, spp. 6; T, spp. 5), *Rhopalocnemis* Jungh. (Y, sp. 1).
- Balsaminaceae** (Y, gen. 1; T, gen. 1): *Impatiens* L. (Y, spp. 112; T, spp. 3).
- Begoniaceae** (Y, gen. 1; T, gen. 1): *Begonia* L. (Y, spp. 92; T, spp. 13).
- Berberidaceae** (Y, gen. 8; T, gen. 3): *Berberis* L. (Y, spp. 88; T, spp. 7), *Caulophyllum* Michx. (Y, sp. 1), *Diphylleia* Michx. (Y, sp. 1), *Dysosma* Woodson (Y, spp. 5; T, sp. 1), *Epimedium* L. (Y, spp. 2), *Mahonia* Nutt. (Y, spp. 17; T, spp. 2), *Nandina* Thunb. (Y, sp. 1), *Sinopodophyllum* T. S. Ying (Y, sp. 1).
- Betulaceae** (Y, gen. 6; T, gen. 3): *Alnus* Mill. (Y, spp. 3; T, sp. 1), *Betula* L. (Y, spp. 11), *Carpinus* L. (Y, spp. 14; T, spp. 3), *Corylus* L. (Y, spp. 6; T, sp. 1), *Ostrya* Scop. (Y, sp. 1), *Ostryopsis* Decne. (Y, sp. 1).
- Bignoniaceae** (Y, gen. 12; T, gen. 2): *Campsis* Lour. (Y, sp. 1), *Catalpa* Scop. (Y, spp. 3), *Dolichandrone* (Fenzl) Seem. (Y, spp. 2), *Incarvillea* Juss. (Y, spp. 6), *Mayodendron* Kurz (Y, sp. 1), *Millingtonia* L. f. (Y, sp. 1), *Nyctcalos* Teijsm. & Binn. (Y, spp. 2), *Oroxylum* Vent. (Y, sp. 1), *Pauleopia* Steenis (Y, sp. 1), *Paulownia* Sieb. & Zucc. (Y, spp. 4; T, spp. 3), *Radermachera* Zoll. & Moritz (Y, spp. 4; T, sp. 1), *Stereospermum* Cham. (Y, spp. 3).
- Bombacaceae** (Y, gen. 1; T, gen. 1): *Bombax* L. (Y, spp. 2; T, sp. 1).
- Boraginaceae** (Y, gen. 20; T, gen. 13): *Antiotrema* Hand-Mazz. (Y, sp. 1), *Bothriospermum* Bunge (Y, spp. 2; T, sp. 1), *Carmona* Cav. (T, sp. 1), *Chionocharis* I. M. Johnst. (Y, sp. 1), *Coldenia* L. (T, sp. 1), *Cordia* L. (Y, spp. 2; T, sp. 1), *Cynoglossum* L. (Y, spp. 4; T, spp. 3), *Ehretia* P. Browne (Y, spp. 7; T, spp. 5), *Eritrichum* Schrad. (Y, spp. 3), *Heliotropium* L. (Y, spp. 3; T, spp. 2), *Lasiocaryum* I. M. Johnst. (Y, spp. 2), *Lithospermum* L. (Y, spp. 2; T, sp. 1), *Microcaryum* I. M. Johnst. (Y, sp. 1), *Microula* Benth. (Y, spp. 8), *Myosotis* L. (Y, spp. 2; T, sp. 1), *Onosma* L. (Y, spp. 14), *Rotula* Lour. (Y, sp. 1), *Sinojohnstonia* Hu (Y, sp. 1), *Thyrocarpus* Hance (Y, sp. 1; T, sp. 1), *Tournefortia* L. (Y, sp. 1; T, spp. 2), *Trichodesma* R. Br. (Y, sp. 1; T, sp. 1), *Trigonotis* Steven (Y, spp. 14; T, spp. 3).
- Borthwickiaceae** (Y, gen. 1): *Borthwickia* W. W. Sm. (Y, sp. 1).
- Burmanniaceae** (Y, gen. 1; T, gen. 3): *Burmanna* L. (Y, spp. 7; T, spp. 3), *Gymnosiphon* Blume (T, sp. 1), *Thismia* Griff. (T, sp. 1).
- Burseraceae** (Y, gen. 3): *Canarium* L. (Y, spp. 7), *Garuga* Roxb. (Y, spp. 4), *Protium* Burm. f. (Y, spp. 2).
- Butomaceae** (Y, gen. 2): *Limnocharis* Bonpl. (Y, sp. 1), *Tenagocharis* Hochst. (Y, sp. 1).
- Buxaceae** (Y, gen. 3; T, gen. 3): *Buxus* L. (Y, spp. 8; T, sp. 1), *Pachysandra* Michx. (Y, spp. 2; T, sp. 1), *Sarcococca* Lindl. (Y, spp. 6; T, sp. 1).
- Cabombaceae** (Y, gen. 1; T, gen. 1): *Brasenia* Schreb. (Y, sp. 1; T, sp. 1).
- Calycanthaceae** (Y, gen. 1): *Chimonanthus* Lindl. (Y, spp. 2).
- Campanulaceae** (Y, gen. 13; T, gen. 9): *Adenophora* Fisch. (Y, spp. 7; T, spp. 2), *Asyneuma* Griseb. & Schenk (Y, sp. 1), *Campanula* L. (Y, spp. 12; T, sp. 1), *Campanumoea* Blume (Y, spp. 4), *Codonopsis* Wall. (Y, spp. 19; T, sp. 1), *Cyananthus* Wall. ex Benth. (Y, spp. 19), *Cyclocodon* Griff. (T, sp. 1), *Hippobroma* G. Don (T, sp. 1), *Homocodon* D. Y. Hong (Y, sp. 1), *Leptocodon* (Hook. f.) Lem. (Y, spp. 2), *Lobelia* L. (Y, spp. 15; T, spp. 4), *Peracarpa* Hook. f. & Thomson (Y, sp. 1; T, sp. 1), *Platycodon* A. DC. (Y, sp. 1), *Pratia* Gaudich. (Y, spp. 2), *Triodanis* Raf. Greene (T, sp. 1), *Wahlenbergia* Schrad. (Y, sp. 1; T, sp. 1).
- Cardiopteridaceae** (Y, gen. 1): *Cardiopteris* Wall. (Y, sp. 1).
- Capparidaceae** (Y, gen. 4; T, gen. 2): *Capparis* L. (Y, spp. 19; T, spp. 4), *Cleome* L. (Y, spp. 6; T, spp. 3), *Crateva* L. (Y, spp. 3), *Stixis* Lour. (Y, sp. 1).
- Caprifoliaceae** (Y, gen. 18; T, gen. 7): *Abelia* R. Br. (Y, spp. 6; T, sp. 1), *Acanthocalyx* (DC.) M. Cannon (Y, spp. 3), *Cephalostigma* A. DC. (Y, sp. 1), *Cryptothladia* (Bunge) M. Cannon (Y, sp. 1), *Dipelta* Maxim. (Y, sp. 1), *Dipsacus* L. (Y, spp. 5), *Leycesteria* Wall. (Y, spp. 4), *Lonicera* L. (Y, spp. 39; T, spp. 7), *Nardostachys* DC. (Y, sp. 1), *Patrinia* Juss. (Y, spp. 4; T, spp. 4), *Pterocephalus* Adans. (Y, spp. 2), *Sambucus* L. (Y, spp. 3; T, sp. 1), *Scabiosa* L. (Y, sp. 1;

- T, sp. 1), *Symphoricarpos* Duhamel (Y, sp. 1), *Triosteum* L. (Y, sp. 1), *Triplostegia* Wall. (Y, spp. 2; T, sp. 1), *Valeriana* L. (Y, spp. 8; T, spp. 3), *Weigela* Thunb. (Y, sp. 1).
- Carlemanniaceae** (Y, gen. 2): *Carlemannia* Benth. (Y, sp. 1), *Silvianthus* Hook. f. (Y, sp. 1).
- Caryophyllaceae** (Y, gen. 17; T, gen. 11): *Arenaria* L. (Y, spp. 43; T, spp. 3), *Brachystemma* D. Don (Y, sp. 1), *Cerastium* L. (Y, spp. 6; T, spp. 2), *Cucubalus* L. (Y, sp. 1; T, sp. 1), *Dianthus* L. (Y, spp. 5; T, spp. 3), *Drymaria* Willd. (Y, sp. 1; T, sp. 1), *Lychnis* L. (Y, spp. 3), *Moehringia* L. (T, sp. 1), *Myosoton* Moench (Y, sp. 1), *Polycarpaea* Lam. (Y, sp. 1; T, sp. 1), *Polycarpon* L. (Y, sp. 1), *Psammosilene* W. C. Wu & C. Y. Wu (Y, sp. 1), *Pseudostellaria* Pax (Y, spp. 3), *Sagina* L. (Y, spp. 2; T, spp. 2), *Silene* L. (Y, spp. 49; T, spp. 5), *Spergula* L. (T, sp. 1), *Spergularia* (Pers.) J. & C. Presl (Y, sp. 1), *Stellaria* L. (Y, spp. 19; T, spp. 5), *Vaccaria* Wolf (Y, sp. 1).
- Celastraceae** (Y, gen. 10; T, gen. 6): *Celastrus* L. (Y, spp. 18; T, spp. 4), *Euonymus* L. (Y, spp. 56; T, spp. 10), *Glyptopetalum* Thwaites (Y, spp. 5), *Loeseneriella* A. C. Sm. (Y, spp. 3), *Maytenus* Molina (Y, spp. 15; T, spp. 2), *Microtropis* Wall. (Y, spp. 18; T, spp. 2), *Perrottetia* Kunth (Y, sp. 1; T, sp. 1), *Pristimera* Miers (Y, spp. 3), *Salacia* L. (Y, spp. 6), *Tripterygium* Hook. f. (Y, sp. 1; T, sp. 1).
- Cephalotaxaceae** (Y, gen. 1; T, gen. 1): *Cephalotaxus* Sieb. & Zucc. (Y, spp. 6; T, sp. 1).
- Ceratophyllaceae** (Y, gen. 1; T, gen. 1): *Ceratophyllum* L. (Y, spp. 2; T, spp. 3).
- Cercidiphyllaceae** (Y, gen. 1): *Cercidiphyllum* Sieb. & Zucc. (Y, sp. 1).
- Chenopodiaceae** (Y, gen. 5; T, gen. 3): *Acroglochin* Schrad. (Y, spp. 2), *Atriplex* L. (T, spp. 2), *Axyris* L. (Y, sp. 1), *Chenopodium* L. (Y, spp. 6; T, spp. 5), *Kochia* Roth (Y, spp. 1), *Salsola* L. (Y, sp. 1), *Suaeda* Forsk. (T, sp. 1).
- Chloranthaceae** (Y, gen. 2; T, gen. 2): *Chloranthus* Sw. (Y, spp. 4; T, sp. 1), *Sarcandra* Gardn. (Y, spp. 2; T, sp. 1).
- Circaeasteraceae** (Y, gen. 1): *Circaeaster* Maxim. (Y, sp. 1).
- Clethraceae** (Y, gen. 1): *Clethra* L. (Y, spp. 5).
- Clusiaceae** (Y, gen. 4; T, gen. 2): *Calophyllum* L. (Y, spp. 2; T, spp. 2), *Garcinia* L. (Y, spp. 13; T, spp. 3), *Mesua* L. (Y, sp. 1), *Ochrocarpos* Noronha (Y, sp. 1).
- Combretaceae** (Y, gen. 4; T, gen. 2): *Anogeissus* Wall. (Y, sp. 1), *Combretum* Loeffl. (Y, spp. 10), *Lumnitzera* Willd. (T, sp. 1), *Quisqualis* L. (Y, spp. 2), *Terminalia* L. (Y, spp. 6; T, sp. 1).
- Commelinaceae** (Y, gen. 11; T, gen. 8): *Amisotolotype* Hassk. (Y, spp. 2; T, sp. 1), *Belosynapsis* Hassk. (Y, sp. 1; T, spp. 2), *Commelina* L. (Y, spp. 6; T, spp. 5), *Cyanotis* D. Don (Y, spp. 3; T, spp. 2), *Dictyospermum* Wight (Y, spp. 2), *Floscopa* Lour. (Y, spp. 2), *Murdannia* Royle (Y, spp. 14; T, spp. 4), *Polia* Thunb. (Y, spp. 5; T, spp. 3), *Porandra* D. Y. Hong (Y, spp. 2), *Rhopalephora* Hassk. (T, sp. 1), *Spatholirion* Ridl. (Y, spp. 2), *Streptolirion* Edgew. (Y, spp. 2).
- Connaraceae** (Y, gen. 3; T, gen. 2): *Connarus* L. (Y, sp. 1; T, sp. 1), *Rourea* Aubl. (Y, sp. 1; T, sp. 1), *Roureopsis* Planch. (Y, sp. 1).
- Convolvulaceae** (Y, gen. 16; T, gen. 14): *Argyreia* Lour. (Y, spp. 16; T, sp. 1), *Blinkworthia* Choisy (Y, sp. 1), *Calonyction* Choisy (Y, spp. 3), *Calystegia* R. Br. (Y, spp. 2; T, sp. 1), *Convolvulus* L. (Y, sp. 1), *Cuscuta* L. (Y, spp. 5; T, spp. 4), *Dichondra* J. R. Forst. & G. Forst. (Y, sp. 1; T, sp. 1), *Erycibe* Roxb. (Y, spp. 4; T, sp. 1), *Evolvulus* L. (Y, sp. 1; T, sp. 1), *Hewittia* Wight & Arn. (Y, sp. 1; T, sp. 1), *Ipomoea* L. (Y, spp. 12; T, spp. 21), *Jacquemontia* Choisy (Y, sp. 1; T, spp. 2), *Lepistemon* Blume (T, sp. 1), *Merremia* Dennst. (Y, spp. 12; T, spp. 7), *Neuropeltis* Wall. (Y, sp. 1), *Operculina* Silva Manso (Y, sp. 1; T, sp. 1), *Porana* Burm. f. (Y, spp. 12), *Stictocardia* Hallier f. (T, sp. 1), *Xenostegia* D. F. Austin & G. W. Staples (T, sp. 1).
- Coriariaceae** (Y, gen. 1; T, gen. 1): *Coriaria* L. (Y, spp. 2; T, sp. 1).
- Cornaceae** (Y, gen. 8; T, gen. 5): *Alangium* Lam. (Y, spp. 7; T, sp. 1), *Aucuba* Thunb. (Y, spp. 16; T, spp. 2), *Cornus* L. (= *Swida* Opiz) (Y, spp. 13; T, spp. 2), *Davidia* Baill. (Y, sp. 1), *Dendrobenthamia* Hutch. (Y, spp. 9; T, sp. 1), *Helwingia* Willd. (Y, spp. 4; T, sp. 1), *Macroparium* (Spach.) Nakai (Y, sp. 1), *Mastixia* Blume (Y, spp. 2).
- Crassulaceae** (Y, gen. 7; T, gen. 4): *Bryophyllum* Salisb. (Y, sp. 1; T, sp. 1), *Hylotelephium* H. Ohba (Y, spp. 2; T, sp. 1), *Kalanchoe* Adams. (Y, spp. 2; T, spp. 3), *Rhodiola* L. (Y, spp. 23), *Sedum* L. (Y, spp. 39; T, spp. 14), *Sinocrassula* A. Berger (Y, spp. 5), *Tillaea* L. (Y, spp. 2).
- Cruciferae** (Y, gen. 31; T, gen. 14): *Aphragmus* Andr. ex DC. (Y, sp. 1), *Arabidopsis* Heynh. (Y, spp. 4), *Arabis* L. (Y, spp. 2; T, spp. 3), *Barbarea* W. T. Aiton (T, spp. 2), *Brassica* L. (Y, spp. 11), *Braya* Sternb. & Hoppe (Y, spp. 2), *Capsella* Medik. (Y, sp. 1; T, sp. 1), *Cardamine* L. (Y, spp. 20; T, spp. 5), *Cheiranthus* L. (Y, spp. 2), *Cochlearia* L. (T, sp. 1), *Coronopus* Zinn (Y, sp. 1; T, spp. 2), *Descurainia* Webb & Berthel. (Y, sp. 1), *Dimorphostemon* Kitag. (Y, spp. 2), *Dipoma* Franch. (Y, sp. 1), *Draba* L. (Y, spp. 20; T, sp. 1), *Erysimum* L. (Y, spp. 6), *Eutrema* R. Br. (Y, spp. 4; T, sp. 1), *Hemilophia* Franch. (Y, sp. 1), *Isatis* L. (Y, spp. 2), *Lepidium* L. (Y, spp. 3; T, sp. 1), *Loxostemon* Hook. f. & Thomson (Y, spp. 6), *Matthiola* W. T. Aiton (Y, sp. 1), *Megacarpaea* DC. (Y, sp. 1), *Nasturtium* W. T. Aiton (Y, sp. 1; T, sp. 1), *Neomartinella* Pilg. (Y, sp. 1), *Neslia* Desv. (T, sp. 1), *Pegaeophyton* Hayek & Hand.-Mazz. (Y, sp. 1), *Raphanus* L. (Y, spp. 2; T, sp. 1), *Rorippa* Scop. (Y, spp. 6; T, spp. 6), *Sisymbrium* L. (Y, spp. 2; T, spp. 2), *Solms-laubachia* Muehl. (Y, spp. 5), *Staintoniella* H. Hara (Y, sp. 1), *Thlaspi* L. (Y, spp. 3), *Yinshania* Ma & Y. Z. Zhao (Y, sp. 1).
- Crypteraniaceae** (Y, gen. 1): *Crypteronia* Blume (Y, sp. 1).
- Cucurbitaceae** (Y, gen. 25; T, gen. 13): *Actinostemma* Griff. (Y, sp. 1; T, sp. 1), *Benincasa* Savi (Y, sp. 1), *Biswarea* Cogn. (Y, sp. 1), *Bolbostemma* Franquet (Y, sp. 1), *Coccinia* Wight & Arn. (Y, sp. 1; T, sp. 1), *Cucumis* L. (Y, spp. 3), *Diplocyclos* (Endl.) T. Post & Kuntze (T, sp. 1), *Gomphogyne* Griff. (Y, sp. 1), *Gynopetalum* Arn. (Y, spp. 2; T, sp. 1), *Gynostemma* Blume (Y, spp. 8; T, sp. 1), *Hemsleya* Cogn. (Y, spp. 20), *Herpetospermum* Wall. (Y, sp. 1), *Hodgsonia* Hook. f. & Thomson (Y, sp. 1), *Lagenaria* Ser. (Y, sp. 1), *Luffa* Mill. (Y, spp. 2), *Momordica* L. (Y, spp. 4; T, spp. 2), *Mukia* Arn. (Y, spp. 2; T, sp. 1), *Nealsomitra* Hutch. (Y, sp. 1; T, sp. 1), *Schizopepon* Maxim. (Y, spp. 2), *Sicyos* L. (Y, sp. 1), *Siraitia* Merr. (Y, spp. 2; T, sp. 1), *Solena* Lour. (Y, spp. 2; T, sp. 1), *Thladiantha* Bunge (Y, spp. 9; T, spp. 2), *Trichosanthes* L. (Y, spp. 26; T, spp. 6), *Zanonia* L. (Y, sp. 1), *Zehneria* Endl. (Y, spp. 5; T, spp. 3).
- Cupressaceae** (Y, gen. 6; T, gen. 3): *Calocedrus* Kurz (Y, sp. 1; T, sp. 1), *Chamaecyparis* Spach. (Y, spp. 3; T, sp. 1), *Cupressus* L. (Y, spp. 3), *Fokienia* A. Henry & H. H. Thomas (Y, sp. 1), *Juniperus* L. (Y, sp. 1; T, spp. 2), *Platycladus* Spach (Y, sp. 1).
- Cycadaceae** (Y, gen. 1; T, gen. 1): *Cycas* L. (Y, spp. 10; T, sp. 1).
- Cyperaceae** (Y, gen. 26; T, gen. 25): *Actinoscirpus* (Ohwi) R. W. Haines & Lye (T, sp. 1), *Blysmus* Panz. (Y, sp. 1), *Bolboschoenus* Palla (Y, sp. 1; T, sp. 1), *Bulbostylis* Kunth (Y, spp. 2; T, spp. 2), *Carex* L. (Y, spp. 134; T, spp. 57), *Cladium* P. Browne (Y, sp. 1; T, sp. 1), *Courtoisina* Sojak (Y, sp. 1), *Cyperus* L. (Y, spp. 20; T, spp. 22), *Diplacrum* R.

- Br. (T, sp. 1), *Eleocharis* R. Br. (Y, spp. 10; T, spp. 7), *Eriophorum* L. (Y, sp. 1), *Fimbristylis* Vahl (Y, spp. 23; T, spp. 23), *Fuirena* Rottb. (Y, spp. 3; T, spp. 2), *Gahnia* J. R. (Y, sp. 1; T, sp. 1), *Hypolytrum* Rich. (Y, sp. 1; T, sp. 1), *Isolepis* R. Br. (Y, sp. 1), *Juncellus* (Griseb.) C. B. Clarke (Y, sp. 1), *Kobresia* Willd. (Y, spp. 27), *Kyllinga* Rottb. (Y, spp. 4; T, spp. 2), *Lepironia* Rich. (T, sp. 1), *Lipocarpha* R. Br. (Y, spp. 3; T, spp. 2), *Mariscus* Vahl (Y, spp. 4; T, spp. 5), *Pycnus* P. Beauv. (Y, spp. 6; T, spp. 6), *Remirea* Aubl. (T, sp. 1), *Rhynchospora* Vahl (Y, spp. 3; T, spp. 5), *Schoenoplectus* (Reichb.) Palla (Y, spp. 9; T, spp. 5), *Schoenus* L. (Y, sp. 1; T, spp. 2), *Scirpus* L. (Y, spp. 2; T, sp. 1), *Scleria* P. J. Bergius (Y, spp. 12; T, spp. 8), *Thoracostachyum* Kurz (Y, sp. 1), *Torulinum* Desv. (T, sp. 1), *Trichophorum* Pers. (T, sp. 1).
- Daphniphyllaceae** (Y, gen. 2; T, gen. 1): *Daphniphyllum* Blume (Y, spp. 6; T, spp. 2), *Dichapetalum* Thouars (Y, sp. 1).
- Diapensiaceae** (Y, gen. 3; T, gen. 1): *Berneuxia* Decne. (Y, sp. 1), *Diapensia* L. (Y, spp. 3), *Shortia* Torr. & A. Gray (Y, sp. 1; T, sp. 1).
- Dilleniaceae** (Y, gen. 2): *Dillenia* L. (Y, spp. 3), *Tetracera* L. (Y, sp. 1).
- Dioscoreaceae** (Y, 1 gen.; T, 1 gen.): *Dioscorea* L. (Y, spp. 38; T, spp. 13).
- Dipentodontaceae** (Y, gen. 1): *Dipentodon* Dunn (Y, sp. 1).
- Dipterocarpaceae** (Y, gen. 5): *Dipterocarpus* C. F. Gaertn. (Y, spp. 3), *Hopea* Roxb. (Y, sp. 1), *Parashorea* Kurz (Y, sp. 1), *Shorea* Roxb. (Y, sp. 1), *Vatica* L. (Y, sp. 1).
- Droseraceae** (Y, gen. 1; T, gen. 1): *Drosera* L. (Y, spp. 2; T, spp. 4).
- Ebenaceae** (Y, gen. 1; T, gen. 1): *Diospyros* L. (Y, spp. 22; T, spp. 10).
- Elaeagnaceae** (Y, gen. 2; T, gen. 1): *Elaeagnus* L. (Y, spp. 27; T, spp. 9), *Hippophae* L. (Y, sp. 1).
- Elaeocarpaceae** (Y, gen. 2; T, gen. 2): *Elaeocarpus* L. (Y, spp. 32; T, spp. 4), *Sloanea* L. (Y, spp. 10; T, sp. 1).
- Elatinaceae** (Y, gen. 2; T, gen. 2): *Bergia* L. (Y, sp. 1; T, sp. 1), *Elatine* L. (Y, spp. 2; T, sp. 1).
- Ephedraceae** (Y, gen. 1): *Ephedra* L. (Y, sp. 1).
- Eriaceae** (Y, gen. 19; T, gen. 11): *Agapetes* D. Don ex G. Don (Y, spp. 20), *Arctous* Niedenzu (Y, sp. 1), *Cassiope* D. Don (Y, spp. 9), *Cheilothea* Hook. f. (Y, spp. 2; T, spp. 2), *Chimaphila* Pursh (Y, sp. 1; T, spp. 2), *Craibiodendron* W. W. Sm. (Y, spp. 4), *Diplarche* Hook. f. & Thomson (Y, spp. 2), *Enkianthus* Lour. (Y, spp. 6; T, sp. 1), *Eremotropa* Andres (Y, spp. 2), *Gaultheria* Kalm ex L. (Y, spp. 18; T, spp. 2), *Leucothoe* D. Don (Y, spp. 2), *Lyonia* Nutt. (Y, spp. 6; T, sp. 1), *Moneses* Salisb. (Y, sp. 1; T, sp. 1), *Monotropa* L. (Y, spp. 2; T, spp. 2), *Orthilia* Raf. (Y, sp. 1), *Pieris* D. Don (Y, sp. 1; T, spp. 2), *Pyrrola* L. (Y, spp. 7; T, spp. 3), *Rhododendron* L. (Y, spp. 230; T, spp. 14), *Vaccinium* L. (Y, spp. 45; T, spp. 6).
- Eriocaulaceae** (Y, gen. 1; T, gen. 1): *Eriocaulon* L. (Y, spp. 15; T, spp. 7).
- Erythroxylaceae** (Y, gen. 1): *Erythroxylum* P. Browne (Y, spp. 2).
- Escalloniaceae** (Y, gen. 1): *Polyosma* Blume (Y, sp. 1).
- Eucommiaceae** (Y, gen. 1): *Eucommia* Oliv. (Y, sp. 1).
- Euphorbiaceae** (Y, gen. 48; T, gen. 25): *Acalypha* L. (Y, spp. 7; T, spp. 10), *Actephila* Blume (Y, spp. 2), *Alchornea* Sw. (Y, spp. 6), *Aleurites* J. R. Forst. & G. Forst. (Y, sp. 1), *Andrachne* L. (Y, spp. 6), *Antidesma* L. (Y, spp. 12; T, sp. 1), *Aporosa* Blume (Y, spp. 4), *Baccaurea* Lour. (Y, spp. 2), *Baliospermum* Blume (Y, spp. 3), *Bischofia* Blume (Y, sp. 1; T, sp. 1), *Breynia* J. R. Forst. & G. Forst. (Y, spp. 5; T, sp. 1), *Bridelia* Willd. (Y, spp. 8; T, spp. 2), *Chaetocarpus* Thwaites (Y, sp. 1), *Chamaesyce* Gray (T, spp. 14), *Claoxylon* A. Juss. (Y, spp. 3; T, sp. 1), *Cleidiocarpon* Airy-Shaw (Y, sp. 1), *Cleidion* Blume (Y, spp. 3), *Cleistanthus* Hook. f. (Y, spp. 3), *Cnesmone* Blume (Y, sp. 1), *Croton* L. (Y, spp. 13; T, spp. 2), *Dalechampia* L. (Y, sp. 1), *Deutzianthus* Gagnep. (Y, sp. 1), *Drypetes* Vahl (Y, spp. 8; T, spp. 2), *Endospermum* Benth. (Y, sp. 1), *Epiprinus* Griff. (Y, sp. 1), *Euphorbia* L. (Y, spp. 30; T, spp. 8), *Excoecaria* L. (Y, spp. 2; T, spp. 3), *Flueggea* Willd. (Y, spp. 4; T, spp. 2), *Glochidion* J. R. Forst. & G. Forst. (Y, spp. 15; T, spp. 5), *Homonioia* Lour. (Y, sp. 1; T, sp. 1), *Jatropha* L. (Y, sp. 1), *Lasiococca* Hook. f. (Y, sp. 1), *Liodendron* H. Keng (T, sp. 1), *Macaranga* Thouars (Y, spp. 7; T, spp. 2), *Mallotus* Lour. (Y, spp. 16; T, spp. 5), *Margaritaria* L. f. (T, sp. 1), *Megistostigma* Hook. f. (Y, sp. 1), *Melanolepis* Rechb. (T, sp. 1), *Mercurialis* L. (Y, sp. 1; T, sp. 1), *Ostodes* Blume (Y, spp. 2), *Phyllanthodendron* Hemsl. (Y, spp. 4), *Phyllanthus* L. (Y, spp. 19; T, spp. 9), *Ricinus* L. (Y, sp. 1; T, sp. 1), *Sapium* Jacq. (Y, spp. 5; T, spp. 2), *Sauropus* Blume (Y, spp. 10), *Speranskia* Baill. (Y, spp. 2), *Strophoblachia* Boerl. (Y, sp. 1), *Sumbaviopsis* J. J. Sm. (Y, sp. 1), *Suregada* Roxb. (Y, sp. 1; T, sp. 1), *Synostemon* F. Muell. (T, sp. 1), *Trewia* L. (Y, sp. 1), *Trigonostemon* Blume (Y, spp. 4), *Vernicia* Lour. (Y, spp. 2).
- Eupteleaceae** (Y, gen. 1): *Euptelea* Sieb. & Zucc. (Y, sp. 1).
- Fabaceae** (Y, gen. 114; T, gen. 67): *Abarema* Pittier (Y, spp. 5), *Abrus* Adans. (Y, spp. 2; T, sp. 1), *Acacia* Mill. (Y, spp. 16; T, spp. 3), *Acrocarpus* Wight (Y, sp. 1), *Adenanthera* L. (Y, sp. 1), *Aeschynomene* L. (Y, sp. 1; T, spp. 2), *Afgekia* Craib (Y, sp. 1), *Albizia* Durazz. (Y, spp. 13; T, spp. 5), *Alysicarpus* Neck. (Y, spp. 5; T, spp. 4), *Amphicarpaea* Elliot (Y, spp. 3), *Antheroporum* Gagnep. (Y, spp. 2), *Apios* Fabr. (Y, spp. 4; T, sp. 1), *Archidendron* F. Muell. (T, sp. 1), *Astragalus* L. (Y, spp. 50; T, spp. 3), *Bauhinia* L. (Y, spp. 30; T, spp. 3), *Bowringia* Champ. (Y, sp. 1), *Butea* Roxb. (Y, spp. 2), *Caesalpinia* L. (Y, spp. 13; T, spp. 4), *Cajanus* Adans. (Y, spp. 7; T, spp. 2), *Callerya* Endl. (Y, spp. 9; T, spp. 2), *Calliandra* Benth. (Y, sp. 1), *Campylotropis* Bunge (Y, spp. 23; T, sp. 1), *Canavalia* Adans. (Y, spp. 3; T, spp. 4), *Caragana* Fabr. (Y, spp. 4), *Cassia* L. (Y, spp. 16), *Cercis* L. (Y, spp. 3), *Chamaecrista* Moench (T, spp. 3), *Chesneya* Lindl. ex Endl. (Y, spp. 3), *Christia* Moench (Y, spp. 2; T, spp. 2), *Cladrastis* Raf. (Y, spp. 3), *Clitoria* L. (Y, spp. 2; T, spp. 2), *Cochlianthus* Benth. (Y, spp. 2), *Codariocalyx* Hassk. (Y, spp. 2; T, sp. 1), *Colutea* L. (Y, sp. 1), *Craspedolobium* Harms (Y, sp. 1), *Crotalaria* L. (Y, spp. 25; T, spp. 19), *Cylindrokelupha* Kosterm. (Y, spp. 8), *Dalbergia* L. f. (Y, spp. 14; T, spp. 2), *Dendrolobium* (Wight & Arn.) Benth. (Y, sp. 1; T, spp. 3), *Derris* Lour. (Y, spp. 13; T, spp. 3), *Desmodium* Desv. (Y, spp. 30; T, spp. 15), *Dolichos* L. (Y, spp. 2), *Dumasia* DC. (Y, spp. 7; T, sp. 1), *Dunbaria* Wight & Arn. (Y, spp. 4; T, spp. 3), *Dysolobium* (Benth.) Prain (Y, sp. 1; T, sp. 1), *Entada* Adans. (Y, sp. 1; T, spp. 3), *Eriosema* (DC.) G. Don (Y, spp. 2; T, sp. 1), *Erythrina* L. (Y, spp. 7; T, sp. 1), *Erythrophleum* Afzel. (Y, sp. 1), *Euchresta* Benn. (Y, sp. 1; T, sp. 1), *Flemingia* Roxb. (Y, spp. 17; T, spp. 3), *Fordia* Hemsl. (Y, spp. 2), *Galactia* P. Browne (Y, spp. 2; T, spp. 2), *Gleditsia* L. (Y, spp. 2; T, sp. 1), *Glycine* Willd. (Y, spp. 2; T, spp. 3), *Glycyrrhiza* L. (Y, sp. 1), *Guelldenstaedtia* Fisch. (Y, spp. 3), *Gymnocladus* Lam. (Y, sp. 1), *Hedysarum* L. (Y, spp. 9), *Hylodesmum* H. Ohashi & R. R. Mill (Y, spp. 10; T, spp. 4), *Indigofera* L. (Y, spp. 48; T, spp. 15), *Kummerowia* Schindl. (Y, sp. 1; T, spp. 2), *Lablab* Adans. (Y, sp. 1; T, sp. 1), *Lathyrus* L. (Y, spp. 3), *Lespedeza* Michx. (Y, spp. 8; T, spp. 4), *Leucaena* Benth. (Y, sp. 1; T, sp. 1), *Lotus* L. (Y, sp. 1; T, sp. 1), *Lysidice*

- Hance (Y, sp. 1), *Maackia* Rupr. (T, sp. 1), *Macrotyloma* (Wight & Arn.) Verdc. (T, sp. 1), *Mecopus* Benn. (Y, sp. 1), *Medicago* L. (Y, spp. 2; T, spp. 3), *Melilotus* Mill. (Y, spp. 3; T, spp. 2), *Milletia* Wight & Arn. (Y, spp. 10; T, spp. 2), *Mimosa* L. (Y, spp. 2; T, spp. 3), *Mucuna* Adans. (Y, spp. 9; T, spp. 2), *Nogra* Merr. (Y, sp. 1), *Ohwia* H. Ohashi (T, sp. 1), *Ormocarpum* P. Beauv. (T, sp. 1), *Ormosia* Jacks. (Y, spp. 15; T, spp. 2), *Oxytropis* DC. (Y, spp. 3), *Parkia* R. Br. (Y, sp. 1), *Parochetus* Buch.-Ham. (Y, sp. 1), *Peltophorum* (Vogel) Benth. (Y, sp. 1), *Phaseolus* L. (Y, spp. 3), *Phylacium* Benn. (Y, sp. 1), *Phyllodium* Desv. (Y, spp. 4; T, sp. 1), *Piptanthus* (Hook.) D. Don (Y, spp. 2), *Pisum* L. (Y, sp. 1), *Pithecellobium* Mart. (Y, sp. 1), *Priotropis* Wight & Arn. (Y, sp. 1), *Psophocarpus* Neck. ex DC. (Y, sp. 1), *Pterocarpus* Jacq. (Y, spp. 2), *Pterolobium* R. Br. (Y, spp. 2), *Pueraria* DC. (Y, spp. 8; T, spp. 2), *Pycnospora* R. Br. (Y, sp. 1; T, sp. 1), *Rhynchosia* Lour. (Y, spp. 10; T, spp. 3), *Robinia* L. (Y, sp. 1), *Saraca* L. (Y, spp. 2), *Senna* Mill. (T, spp. 4), *Sesbania* Scop. (Y, spp. 3; T, spp. 2), *Shuteria* Wight & Arn. (Y, spp. 2), *Sindora* Miq. (Y, sp. 1), *Sinodolichos* Verdc. (Y, sp. 1), *Smithia* Aiton (Y, spp. 3; T, spp. 2), *Sophora* L. (Y, spp. 14; T, spp. 2), *Spatholobus* Hassk. (Y, spp. 8), *Tadehagi* H. Ohashi (Y, spp. 2), *Tamarindus* L. (Y, sp. 1), *Tephrosia* Pers. (Y, spp. 4; T, spp. 4), *Teramun* P. Browne (T, sp. 1), *Thermopsis* R. Br. (Y, spp. 4), *Tibetia* (Ali) H. P. Tsui (Y, spp. 4), *Trifolium* L. (Y, spp. 2; T, spp. 3), *Trigonella* L. (Y, sp. 1; T, sp. 1), *Uraria* Desv. (Y, spp. 7; T, spp. 4), *Uriopsis* Schindl. (Y, spp. 2), *Vicia* L. (Y, spp. 15; T, spp. 3), *Vigna* Savi (Y, spp. 7; T, spp. 8), *Wisteria* Nutt. (Y, spp. 3), *Zenia* Chun (Y, sp. 1), *Zornia* J. F. Gmel. (Y, sp. 1; T, spp. 2).
- Fagaceae** (Y, gen. 7; T, gen. 8): *Castanea* Mill. (Y, spp. 3; T, spp. 2), *Castanopsis* (D. Don) Spach (Y, spp. 34; T, spp. 7), *Cyclobalanopsis* Oersted (Y, spp. 30; T, spp. 14), *Fagus* L. (Y, spp. 2; T, sp. 1), *Limlia* Masam. & Tomiya (T, sp. 1), *Lithocarpus* Blume (Y, spp. 44; T, spp. 2), *Pasania* Oerst. (T, spp. 12), *Quercus* L. (Y, spp. 28; T, spp. 9), *Trigonobalanus* Forman (Y, sp. 1).
- Flacourtiaceae** (Y, gen. 9; T, gen. 4): *Bennettiodendron* Merr. (Y, spp. 2), *Carriera* Franch. (Y, spp. 2), *Flacourtia* Comm. (Y, spp. 4; T, sp. 1), *Gynocardia* R. Br. (Y, sp. 1), *Hydnocarpus* Gaertn. (Y, spp. 4), *Ilesia* Maxim. (Y, sp. 1; T, sp. 1), *Itoa* Hemsl. (Y, sp. 1), *Scolopia* Schreb. (Y, sp. 1; T, sp. 1), *Xylosma* G. Forst. (Y, spp. 3; T, sp. 1).
- Flagellariaceae** (T, gen. 1): *Flagellaria* L. (T, sp. 1).
- Fumariaceae** (Y, gen. 4; T, gen. 2): *Corydalis* DC. (Y, spp. 72; T, spp. 8), *Dactylicapnos* Wall. (Y, spp. 4), *Dicentra* Borkh. (Y, spp. 2), *Fumaria* L. (T, sp. 1), *Hypocoum* L. (Y, sp. 1).
- Gentianaceae** (Y, gen. 17; T, gen. 6): *Canscora* Lam. (Y, sp. 1), *Centaurium* Hill (T, sp. 1), *Comastoma* (Wettst.) Toyokuni (Y, spp. 6), *Cotylanthera* Blume (Y, sp. 1), *Craufurdia* Wall. (Y, spp. 8), *Exacum* L. (Y, spp. 2), *Gentiana* L. (Y, spp. 119; T, spp. 10), *Gentianella* Moench (Y, spp. 3), *Gentianopsis* Ma (Y, spp. 5), *Halenia* Borkh. (Y, sp. 1), *Latouchea* Franch. (Y, sp. 1), *Lomatogonium* A. Braun (Y, spp. 8; T, sp. 1), *Megacodon* (Hemsl.) Harry Sm. (Y, sp. 1), *Pterygocalyx* Maxim. (Y, sp. 1; T, sp. 1), *Sebaea* Sol. (Y, sp. 1), *Swertia* L. (Y, spp. 35; T, spp. 4), *Tripterospermum* Blume (Y, spp. 8; T, spp. 6), *Veratrilla* Baill. ex Franch. (Y, sp. 1).
- Geraniaceae** (Y, gen. 1; T, gen. 2): *Erodium* L'Hér. (T, spp. 2), *Geranium* L. (Y, spp. 29; T, spp. 5).
- Gesneriaceae** (Y, gen. 30; T, gen. 11): *Aeschynanthus* Jack (Y, spp. 31; T, sp. 1), *Ancylostemon* Craib (Y, spp. 6), *Anna* Pellegr. (Y, sp. 1), *Beccarinda* Kuntze (Y, spp. 5), *Boea* Comm. ex Lam. (Y, sp. 1), *Boeica* T. Anderson (Y, spp. 2), *Briggsia* Craib (Y, spp. 8), *Calcareoboea* C. Y. Wu (Y, sp. 1), *Chirita* Buch.-Ham. (Y, spp. 15; T, sp. 1), *Conandron* Sieb. & Zucc. (T, sp. 1), *Corallodiscus* Batalin (Y, spp. 11), *Cyrtandra* J. R. Forst. & G. Forst. (T, sp. 1), *Didissandra* C. B. Clarke (Y, spp. 2), *Didymocarpus* Wall. (Y, spp. 15), *Epithema* Blume (Y, sp. 1; T, sp. 1), *Hemiboea* C. B. Clarke (Y, spp. 8; T, sp. 1), *Hemiboeopsis* W. T. Wang (Y, sp. 1), *Lagarosolen* W. T. Wang (Y, sp. 1), *Leptoboea* Benth. (Y, sp. 1), *Loxostigma* C. B. Clarke (Y, spp. 7), *Lysionotus* D. Don (Y, spp. 17; T, sp. 1), *Oreocharis* Benth. (Y, spp. 14), *Ornithoboea* Parish (Y, spp. 4), *Paraboea* (C. B. Clarke) Ridl. (Y, spp. 5; T, sp. 1), *Petrocosmea* Oliv. (Y, spp. 20), *Rhabdothermopsis* Hemsl. (Y, sp. 1), *Rhynchoglossum* Blume (Y, sp. 1), *Rhynchotechum* Blume (Y, spp. 3; T, spp. 4), *Stauranthera* Benth. (Y, spp. 2), *Titanotrichum* Soler. (T, sp. 1), *Tremacron* Craib (Y, spp. 4), *Trisepalum* C. B. Clarke (Y, sp. 1), *Whytockia* W. W. Sm. (Y, spp. 5; T, sp. 1).
- Ginkgoaceae** (Y, gen. 1): *Ginkgo* L. (Y, sp. 1).
- Gnetaceae** (Y, gen. 1): *Gnetum* L. (Y, spp. 4).
- Goodeniaceae** (T, gen. 1): *Scaevola* L. (T, spp. 2).
- Grossulariaceae** (Y, gen. 1; T, gen. 1): *Ribes* L. (Y, spp. 16; T, sp. 1).
- Haloragaceae** (Y, gen. 2; T, gen. 2): *Haloragis* J. R. Forst. & G. Forst. (Y, spp. 2; T, sp. 1), *Myriophyllum* L. (Y, spp. 2; T, spp. 4).
- Hamamelidaceae** (Y, gen. 11; T, gen. 6): *Altingia* Noronha (Y, spp. 4), *Corylopsis* Sieb. & Zucc. (Y, spp. 9; T, spp. 2), *Distyliopsis* Endress (Y, spp. 3; T, sp. 1), *Distylium* Sieb. & Zucc. (Y, spp. 4; T, spp. 2), *Eustigma* Gardn. & Champ. (Y, spp. 2; T, sp. 1), *Liquidambar* L. (Y, sp. 1; T, sp. 1), *Loropetalum* R. Br. ex Rehb. (Y, spp. 2), *Mytilaria* Lecomte (Y, sp. 1), *Rhodoleia* Champ. (Y, spp. 3), *Sycopsis* Oliv. (Y, spp. 2; T, sp. 1), *Exbuchlandia* R. W. Brown (Y, spp. 2).
- Hernandiaceae** (Y, gen. 1; T, gen. 2): *Hernandia* L. (T, sp. 1), *Illigera* Blume (Y, spp. 11; T, sp. 1).
- Hippocastanaceae** (Y, gen. 1): *Aesculus* L. (Y, spp. 5).
- Hydrangeaceae** (Y, gen. 6; T, gen. 4): *Deutzia* Thunb. (Y, spp. 21; T, spp. 3), *Dichroa* Lour. (Y, spp. 4), *Hydrangea* L. (Y, spp. 18; T, spp. 7), *Philadelphus* L. (Y, spp. 10), *Pileostegia* Hook. f. & Thomson (Y, sp. 1; T, sp. 1), *Schizophragma* Sieb. & Zucc. (Y, spp. 4; T, sp. 1).
- Hydrocharitaceae** (Y, gen. 6; T, gen. 8): *Blyxa* Noronha (Y, spp. 4; T, spp. 3), *Halophila* Thouars (T, spp. 3), *Hydrilla* Rich. (Y, sp. 1; T, sp. 1), *Hydrocharis* L. (Y, sp. 1; T, sp. 1), *Najas* L. (Y, spp. 4; T, spp. 7), *Ottelia* Pers. (Y, spp. 2; T, sp. 1), *Thalassia* Banks (T, sp. 1), *Vallisneria* L. (Y, sp. 1; T, sp. 1).
- Hydrophyllaceae** (Y, gen. 1; T, gen. 1): *Hydrolea* L. (Y, sp. 1; T, sp. 1).
- Hypericaceae** (Y, gen. 3; T, gen. 2): *Cratoxylum* Blume (Y, spp. 2), *Hypericum* L. (Y, spp. 27; T, spp. 14), *Triadenum* Raf. (Y, sp. 1; T, sp. 1).
- Hypoxidaceae** (Y, gen. 2; T, gen. 3): *Curculigo* Gaertn. (Y, spp. 4; T, spp. 2), *Hypoxis* L. (Y, sp. 1; T, sp. 1), *Molinieria* Colla (T, sp. 1).
- Icacinaceae** (Y, gen. 10; T, gen. 3): *Apodytes* E. Mey. (Y, sp. 1), *Gomphandra* Wall. (Y, spp. 2; T, sp. 1), *Gonocaryum* Miq. (Y, sp. 1; T, sp. 1), *Iodes* Blume (Y, spp. 4), *Mappianthus* Hand.-Mazz. (Y, sp. 1), *Natsiatopsis* Kurz (Y, sp. 1), *Natsiatum* Buch.-Ham. (Y, sp. 1), *Nothapodytes* Blume (Y, spp. 3; T, sp. 1), *Pittosporopsis* Craib (Y, sp. 1), *Platea* Blume (Y, sp. 1).
- Iridaceae** (Y, gen. 4; T, gen. 3): *Belamcanda* Adans. (Y, sp. 1; T, sp. 1), *Crocus* L. (Y, sp. 1), *Iris* L. (Y, spp. 23; T, spp. 2), *Sisyrinchium* L. (Y, sp. 1; T, spp. 2).
- Iteaceae** (Y, gen. 1; T, gen. 1): *Itea* L. (Y, spp. 7; T, spp. 2).

- Ixonanthaceae** (Y, gen. 1): *Ixonanthes* Jack (Y, spp. 2).
- Juglandaceae** (Y, gen. 8; T, gen. 3): *Annamocarya* A. Chev. (Y, sp. 1), *Carya* Nutt. (Y, sp. 1), *Cyclocarya* Iljinsk. (Y, sp. 1), *Engelhardtia* Leschen. (Y, spp. 5; T, sp. 1), *Juglans* L. (Y, spp. 4; T, sp. 1), *Platycarya* Sieb. & Zucc. (Y, spp. 2; T, sp. 1), *Pterocarya* Kunth (Y, spp. 3), *Rhoiptelea* Diels & Hand.-Mazz. (Y, sp. 1).
- Juncaceae** (Y, gen. 2; T, gen. 2): *Juncus* L. (Y, spp. 51; T, spp. 5), *Luzula* DC. (Y, spp. 7; T, spp. 4).
- Juncaginaceae** (Y, gen. 1): *Triglochin* L. (Y, spp. 2).
- Lamiaceae** (Y, gen. 78; T, gen. 41): *Acrocephalus* Benth. (Y, sp. 1; T, sp. 1), *Agastache* J. Clayton. (Y, sp. 1; T, sp. 1), *Ajuga* L. (Y, spp. 12; T, spp. 5), *Amethystea* L. (Y, sp. 1), *Anisochilus* Wall. (Y, sp. 1), *Anisomeles* R. Br. (T, sp. 1), *Basilicum* Moench (T, sp. 1), *Bostrychanthera* Benth. (T, sp. 1), *Callicarpa* L. (Y, spp. 14; T, spp. 9), *Cardioteucris* C. Y. Wu (Y, sp. 1), *Caryopteris* Bunge (Y, spp. 9; T, sp. 1), *Ceratanthus* F. Muell. (Y, sp. 1), *Chelonopsis* Miq. (Y, spp. 8), *Clerodendranthus* Kudô (Y, sp. 1), *Clerodendrum* L. (Y, spp. 25; T, spp. 7), *Clinopodium* L. (Y, spp. 6; T, spp. 3), *Colebrookea* Sm. (Y, sp. 1), *Coleus* Lour. (Y, spp. 5; T, spp. 2), *Colquhounia* Wall. (Y, spp. 5), *Comanthosphace* S. Moore (T, sp. 1), *Congea* Roxb. (Y, spp. 2), *Craniotome* Rechb. (Y, sp. 1), *Dracocephalum* L. (Y, spp. 8), *Dysophylla* Blume (Y, spp. 5), *Elsholtzia* Willd. (Y, spp. 26; T, spp. 2), *Epimeredi* Adans. (Y, sp. 1), *Eriophyton* Benth. (Y, sp. 1), *Eurysolen* Prain (Y, sp. 1), *Galeopsis* L. (Y, sp. 1), *Garrettia* H. R. Fletcher (Y, sp. 1), *Geniosporum* Wall. (Y, sp. 1), *Glechoma* L. (Y, spp. 2), *Gmelina* L. (Y, spp. 3), *Gomphostemma* Wall. (Y, spp. 10; T, sp. 1), *Hanceola* Kudô (Y, spp. 2), *Heterolamium* C. Y. Wu (Y, sp. 1), *Holocheila* (Kudô) S. Chow ex C. Y. Wu & S. Ch (Y, sp. 1), *Hyptis* Jacq. (T, spp. 4), *Isodon* (Schrad.) Spach (T, spp. 3), *Keiskea* Miq. (Y, sp. 1), *Kinostemon* Kudô (Y, sp. 1), *Lagopsis* Bunge (Y, sp. 1), *Lamiophlomis* Kudô (Y, sp. 1), *Lamium* L. (Y, sp. 1; T, spp. 2), *Leonurus* L. (Y, sp. 1; T, sp. 1), *Leucas* R. Br. (Y, spp. 4; T, sp. 1), *Leucosceptrum* Sm. (Y, sp. 1), *Loxocalyx* Hemsl. (Y, sp. 1), *Lycopus* L. (Y, spp. 2; T, sp. 1), *Maesa* Forssk. (Y, spp. 19; T, spp. 3), *Meehania* Britt. (Y, sp. 1), *Melissa* L. (Y, spp. 2; T, sp. 1), *Mentha* L. (Y, spp. 4; T, sp. 1), *Mesona* Blume (Y, sp. 1; T, sp. 1), *Micromeria* Benth. (Y, spp. 3), *Microtoena* Prain (Y, spp. 10), *Mosla* (Benth.) Buch.-Ham. (Y, spp. 2; T, spp. 3), *Nepeta* L. (Y, spp. 8), *Notochaete* Benth. (Y, spp. 2), *Ocimum* L. (Y, spp. 3; T, spp. 3), *Origanum* L. (Y, sp. 1; T, sp. 1), *Orthosiphon* Benth. (Y, sp. 1; T, sp. 1), *Paralamium* Dunn (Y, sp. 1), *Paraphlomis* Prain (Y, spp. 4; T, spp. 3), *Perilla* L. (Y, sp. 1; T, sp. 1), *Phlomis* L. (Y, spp. 16), *Phyllophyton* Kudô (Y, sp. 1), *Pogostemon* Desf. (Y, spp. 12; T, spp. 3), *Prenna* L. (Y, spp. 27; T, spp. 5), *Prunella* L. (Y, spp. 2), *Rabdosia* (Blume) Hasskarl (Y, spp. 47), *Rostrinucula* Kudô (Y, sp. 1), *Rubiteucris* Kudô (Y, sp. 1; T, sp. 1), *Salvia* L. (Y, spp. 37; T, spp. 9), *Schizonepeta* Briq. (Y, sp. 1), *Schnabelia* Hand.-Mazz. (Y, sp. 1), *Scutellaria* L. (Y, spp. 33; T, spp. 6), *Siphocranion* Kudô (Y, spp. 2), *Skapanthus* C. Y. Wu & H. W. Li (Y, sp. 1), *Sphenodesme* Jack (Y, spp. 2; T, sp. 1), *Stachys* L. (Y, spp. 5; T, spp. 2), *Suzukia* Kudô (T, spp. 2), *Symphorema* Roxb. (Y, sp. 1), *Teucrium* L. (Y, spp. 10; T, spp. 3), *Vitex* L. (Y, spp. 10; T, spp. 4).
- Lardizabalaceae** (Y, gen. 5; T, gen. 2): *Akebia* Decne. (Y, sp. 1; T, sp. 1), *Decaisnea* Hook. f. & Thomson (Y, sp. 1), *Holboellia* Wall. (Y, spp. 5), *Sinofranchetia* Hemsl. (Y, sp. 1), *Stauntonia* DC. (Y, spp. 6; T, spp. 3).
- Lauraceae** (Y, gen. 16; T, gen. 12): *Actinodaphne* Nees (Y, spp. 7), *Alseodaphne* Nees (Y, spp. 7), *Beilschmiedia* Nees (Y, spp. 17; T, spp. 2), *Caryodaphnopsis* Airy Shaw (Y, spp. 4), *Cassytha* L. (Y, sp. 1; T, sp. 1), *Cinnamomum* Schaeffer (Y, spp. 26; T, spp. 14), *Cryptocarya* R. Br. (Y, spp. 8; T, spp. 3), *Dehaasia* Blume (T, sp. 1), *Endiandra* R. Br. (T, sp. 1), *Lindera* Thunb. (Y, spp. 21; T, spp. 7), *Litsea* Lam. (Y, spp. 43; T, spp. 10), *Machilus* Nees (Y, spp. 23; T, spp. 6), *Neocinnamomum* H. Liou (Y, spp. 4), *Neolitsea* Merr. (Y, spp. 16; T, spp. 10), *Nothaphoebe* Blume (Y, sp. 1), *Phoebe* Nees (Y, spp. 21; T, sp. 1), *Sassafras* T. Nees & C. H. Eberm. (Y, sp. 1; T, sp. 1), *Syndiclis* Hook. f. (Y, spp. 5).
- Lecythidaceae** (Y, gen. 1; T, gen. 1): *Barringtonia* J. R. Forst. & G. Forst. (Y, spp. 2; T, spp. 2).
- Lemnaceae** (Y, gen. 3; T, gen. 3): *Lemna* L. (Y, spp. 3; T, spp. 2), *Spirodela* Schleid. (Y, sp. 1; T, spp. 2), *Wolffia* Horkel (Y, sp. 1; T, sp. 1).
- Lentibulariaceae** (Y, gen. 2; T, gen. 1): *Pinguicula* L. (Y, sp. 1), *Utricularia* L. (Y, spp. 9; T, spp. 8).
- Liliaceae** (Y, gen. 36; T, gen. 20): *Alettris* L. (Y, spp. 8; T, spp. 2), *Aloe* L. (Y, sp. 1), *Aspidistra* Ker Gawl. (Y, 4 spp.; T, sp. 1), *Barnardia* Lindl. (T, sp. 1), *Campylandra* Baker (T, sp. 1), *Cardiocrinum* (Endl.) Lindl. (Y, sp. 1), *Chlorophytum* Ker-Gawl. (Y, spp. 4), *Clintonia* Raf. (Y, sp. 1), *Dianella* Lam. (Y, sp. 1; T, sp. 1), *Disporopsis* Hance (Y, spp. 4; T, sp. 1), *Disporum* Salisb. (Y, spp. 7; T, spp. 4), *Diuranthera* Hemsl. (Y, sp. 1), *Eremurus* M. Bieb. (Y, sp. 1), *Fritillaria* L. (Y, spp. 4), *Gloriosa* L. (Y, sp. 1), *Helonias* L. (T, sp. 1), *Hemerocallis* L. (Y, spp. 5; T, sp. 1), *Hosta* Tratt. (Y, spp. 2), *Iphigenia* Kunth (Y, sp. 1), *Lilium* L. (Y, spp. 23; T, spp. 2), *Liriope* Lour. (Y, spp. 3; T, spp. 2), *Lloydia* Rechb. (Y, spp. 6), *Maianthemum* F. H. Wigg. (Y, spp. 12), *Nomocharis* Franch. (Y, spp. 7), *Notholirion* Wall. (Y, spp. 3), *Ophiopogon* Ker Gawl. (Y, spp. 33; T, spp. 2), *Peliosanthes* Andrews (Y, spp. 7; T, sp. 1), *Petrosavia* Becc. (Y, sp. 1; T, sp. 1), *Polygonatum* Mill. (Y, spp. 10; T, spp. 2), *Reineckea* Kunth (Y, sp. 1), *Rohdea* Roth (Y, sp. 1), *Scilla* L. (Y, sp. 1; T, sp. 1), *Smilacina* Desf. (T, sp. 1), *Streptopus* Michx. (Y, spp. 3), *Theropogon* Maxim. (Y, sp. 1), *Thysanotus* R. Br. (T, sp. 1), *Tofieldia* Huds. (Y, spp. 2), *Tricyrtis* Wall. (Y, sp. 1; T, spp. 2), *Tupistra* Ker Gawl. (Y, spp. 11), *Veratrum* L. (Y, spp. 6; T, spp. 2), *Ypsilandra* Franch. (Y, spp. 3).
- Linaceae** (Y, gen. 4): *Anisadenia* Wall. (Y, spp. 2), *Linum* L. (Y, spp. 2), *Reinwardtia* Dumort. (Y, sp. 1), *Tirpitzia* Hallier f. (Y, sp. 1).
- Linderniaceae** (Y, gen. 2; T, gen. 2): *Lindernia* All. (Y, spp. 14; T, spp. 15), *Torenia* L. (Y, spp. 6; T, spp. 4).
- Loganiaceae** (Y, gen. 7; T, gen. 6): *Buddleja* L. (Y, spp. 23; T, spp. 2), *Fagraea* Thunb. (Y, sp. 1; T, sp. 1), *Gardneria* Wall. (Y, spp. 6; T, spp. 2), *Gelsemium* Juss. (Y, sp. 1), *Geniostoma* J. R. Forst. & G. Forst. (T, sp. 1), *Mitrasacme* Labill. (Y, sp. 1; T, spp. 2), *Mitreola* L. (Y, spp. 3), *Strychnos* L. (Y, spp. 4; T, sp. 1).
- Loranthaceae** (Y, gen. 10; T, gen. 4): *Arceuthobium* M. Bieb. (Y, spp. 2), *Dendrophthoe* Mart. (Y, sp. 1), *Elytranthe* (Blume) Blume (Y, spp. 2), *Helixanthera* Lour. (Y, spp. 5), *Korthalsella* Tiegh. (Y, sp. 1; T, sp. 1), *Loranthus* Jacq. (Y, sp. 1; T, spp. 2), *Macrosolen* (Bl.) Reichb. (Y, spp. 2), *Scurrula* L. (Y, spp. 7), *Taxillus* Tiegh. (Y, spp. 9; T, spp. 10), *Viscum* L. (Y, spp. 9; T, spp. 4).
- Lythraceae** (Y, gen. 7; T, gen. 5): *Ammannia* L. (Y, spp. 3; T, spp. 3), *Lagerstroemia* L. (Y, spp. 7; T, sp. 1), *Lausonia* L. (Y, sp. 1), *Lythrum* L. (Y, sp. 1), *Pemphis* J. R. Forst. & G. Forst. (T, sp. 1), *Rotala* L. (Y, spp. 5; T, spp. 6), *Trapa* L. (Y, spp. 3; T, sp. 1), *Woodfordia* Salisb. (Y, sp. 1).
- Magnoliaceae** (Y, gen. 12; T, gen. 2): *Alcimandra* Dandy (Y, sp. 1), *Liriodendron* L. (Y, spp. 2), *Magnolia* L. (Y, spp. 10; T, sp. 1), *Manglietia* Blume (Y, spp. 16), *Manglietiastrum* Y. W. Law (Y, sp. 1), *Michelia* L. (Y, spp. 23; T, sp. 1),

- Parakmeria* Hu & W. C. Cheng (Y, spp. 2), *Paramichelia* Hu (Y, sp. 1), *Talauma* Juss. (Y, sp. 1), *Tsoongiodendron* Chun (Y, sp. 1), *Woonyoungia* Law (Y, sp. 1), *Yulania* Spach (Y, spp. 6).
- Malpighiaceae** (Y, gen. 2; T, gen. 3): *Aspidopterys* Juss. (Y, spp. 6), *Hiptage* Gaertn. (Y, spp. 6; T, sp. 1), *Ryssopterys* Blume (T, sp. 1), *Tristellateia* Thouars (T, sp. 1).
- Malvaceae** (Y, gen. 11; T, gen. 8): *Abelmoschus* Medik. (Y, spp. 5; T, sp. 1), *Abutilon* Mill. (Y, spp. 8; T, spp. 3), *Althaea* L. (Y, sp. 1), *Cenocentrum* Gagnep. (Y, sp. 1), *Hibiscus* L. (Y, spp. 14; T, spp. 5), *Kydia* Roxb. (Y, spp. 3), *Malva* L. (Y, spp. 4; T, spp. 2), *Malvastrum* A. Gray (Y, sp. 1; T, spp. 2), *Sida* L. (Y, spp. 11; T, spp. 7), *Thespesia* Sol. (Y, sp. 1; T, sp. 1), *Urena* L. (Y, spp. 3; T, spp. 2).
- Marantaceae** (Y, gen. 3; T, gen. 1): *Donax* Lour. (Y, sp. 1; T, sp. 1), *Phrynium* Willd. (Y, spp. 3), *Stachyphrynium* K. Schum (Y, sp. 1).
- Martyniaceae** (Y, gen. 1): *Martynia* L. (Y, sp. 1).
- Melastomataceae** (Y, gen. 17; T, gen. 12): *Allomorpha* Blume (Y, spp. 4), *Astronia* Blume (T, sp. 1), *Barthea* Hook. f. (T, sp. 1), *Blastus* Lour. (Y, spp. 4; T, sp. 1), *Bredia* Blume (Y, spp. 5; T, spp. 2), *Cyphotheca* Diels. (Y, sp. 1), *Fordiophyton* Stapf (Y, spp. 4), *Medinilla* Gaudich. (Y, spp. 10; T, spp. 2), *Melastoma* L. (Y, spp. 4; T, spp. 3), *Memecylon* L. (Y, spp. 4; T, sp. 1), *Osbeckia* L. (Y, spp. 10; T, spp. 2), *Otanthera* Blume (T, sp. 1), *Oxyropa* DC. (Y, spp. 3), *Pachycentria* Blume (T, sp. 1), *Phyllagathis* Blume (Y, spp. 6), *Plagiopetalum* Rehder (Y, spp. 3), *Sarcopyramis* Wall. (Y, spp. 3; T, sp. 1), *Sonerila* Roxb. (Y, spp. 7; T, sp. 1), *Sporoxeia* W. W. Sm. (Y, spp. 3), *Staphiophyton* H. L. Li (Y, sp. 1), *Styrophyton* S. Y. Hu (Y, sp. 1).
- Meliaceae** (Y, gen. 12; T, gen. 5): *Aglaia* Lour. (Y, spp. 4; T, spp. 3), *Amoora* Roxb. (Y, spp. 7), *Aphanamixis* Blume (Y, spp. 3; T, sp. 1), *Chisocheton* Blume (Y, spp. 2; T, sp. 1), *Chukrasia* A. Juss. (Y, sp. 1), *Cipadessa* Blume (Y, spp. 2), *Dysoxylum* Blume (Y, spp. 10; T, spp. 4), *Melia* L. (Y, spp. 2; T, sp. 1), *Munronia* Wight (Y, spp. 3), *Toona* (Endl.) Roem. (Y, spp. 3), *Trichilia* P. Browne (Y, sp. 1), *Walsura* Roxb. (Y, spp. 2).
- Menispermaceae** (Y, gen. 16; T, gen. 6): *Albertisia* Becc. (Y, sp. 1), *Aspidocarya* Hook. f. & Thomson (Y, sp. 1), *Cissampelos* L. (Y, sp. 1), *Cocculus* DC. (Y, spp. 2; T, spp. 2), *Cyclea* Arn. (Y, spp. 7; T, spp. 3), *Diplocisia* Miers. (Y, spp. 2), *Eleutharrhena* Forman (Y, sp. 1), *Fibraurea* Lour. (Y, sp. 1), *Hypserpa* Miers (Y, sp. 1), *Parabaena* Miers (Y, sp. 1), *Pericampylus* Miers (Y, sp. 1; T, sp. 1), *Pycnarhena* Miers (Y, sp. 1), *Sinomenium* Diels (Y, sp. 1; T, sp. 1), *Stephania* Lour. (Y, spp. 17; T, spp. 4), *Tinomisium* Miers (Y, sp. 1), *Tinospora* Miers (Y, spp. 3; T, sp. 1).
- Menyanthaceae** (Y, gen. 2; T, gen. 1): *Menyanthes* L. (Y, sp. 1), *Nymphoides* Hill (Y, spp. 2; T, spp. 6).
- Mitrastemonaceae** (Y, gen. 1; T, gen. 1): *Mitrastemon* Makino (Y, sp. 1; T, spp. 2).
- Molluginaceae** (Y, gen. 2; T, gen. 2): *Glinus* L. (Y, spp. 2; T, spp. 2), *Mollugo* L. (Y, sp. 1; T, spp. 2).
- Moraceae** (Y, gen. 8; T, gen. 6): *Antiaris* Lesch. (Y, sp. 1), *Artocarpus* J. R. Forst. & G. Forst. (Y, spp. 12; T, spp. 2), *Broussonetia* L'Hér. (Y, spp. 4; T, spp. 3), *Cudrania* Trécul (Y, spp. 5), *Fatoua* Gaudich. (Y, sp. 1; T, spp. 2), *Ficus* L. (Y, spp. 66; T, spp. 22), *Maclura* Nutt. (T, sp. 1), *Morus* L. (Y, spp. 8; T, sp. 1), *Streblus* Lour. (Y, spp. 6).
- Musaceae** (Y, gen. 3; T, gen. 1): *Ensete* Bruce (Y, sp. 1), *Musa* L. (Y, spp. 8; T, sp. 1), *Musella* (Fr.) C. Y. Wu (Y, sp. 1).
- Myricaceae** (Y, gen. 1; T, gen. 1): *Myrica* L. (Y, spp. 3; T, spp. 2).
- Myristicaceae** (Y, gen. 3): *Horsfieldia* Willd. (Y, spp. 4), *Knema* Lour. (Y, spp. 5), *Myristica* Gronov. (Y, sp. 1).
- Myrsinaceae** (Y, gen. 4; T, gen. 3): *Ardisia* Sw. (Y, spp. 36; T, spp. 15), *Embelia* Burm. f. (Y, spp. 18; T, spp. 2), *Myrsine* L. (Y, spp. 3; T, spp. 3), *Rapanea* Aubl. (Y, spp. 6).
- Myrtaceae** (Y, gen. 4; T, gen. 4): *Acmena* DC. (T, sp. 1), *Cleistocalyx* Blume (Y, sp. 1), *Decaspermum* J. R. Forst. & G. Forst. (Y, sp. 1; T, sp. 1), *Rhodomyrtus* (DC.) Reichenbach (Y, sp. 1; T, sp. 1), *Syzygium* R. Br. (Y, spp. 34; T, spp. 8).
- Nelumbonaceae** (Y, gen. 1; T, gen. 1): *Nelumbo* Adans. (Y, sp. 1; T, sp. 1).
- Nyctaginaceae** (Y, gen. 3; T, gen. 2): *Boerhavia* L. (Y, sp. 1; T, sp. 1), *Commicarpus* Standl. (Y, sp. 1), *Pisonia* L. (Y, sp. 1; T, spp. 2).
- Nymphaeaceae** (Y, gen. 2; T, gen. 3): *Euryale* Salisb. (T, sp. 1), *Nuphar* Sm. (Y, spp. 2; T, sp. 1), *Nymphaea* L. (Y, spp. 4; T, spp. 2).
- Nyssaceae** (Y, gen. 2): *Camptotheca* Decne. (Y, sp. 1), *Nyssa* Gronov. (Y, spp. 4).
- Oleaceae** (Y, gen. 2; T, gen. 1): *Malania* Chun & S. K. Lee (Y, sp. 1), *Olex* L. (Y, sp. 1; T, sp. 1).
- Oleaceae** (Y, gen. 11; T, gen. 5): *Chionanthus* L. (Y, sp. 1; T, spp. 3), *Erythralum* Blume (Y, sp. 1), *Fontanesia* Labill. (Y, sp. 1), *Forsythia* Vahl (Y, spp. 3), *Fraxinus* L. (Y, spp. 12; T, spp. 2), *Jasminum* L. (Y, spp. 30; T, spp. 4), *Ligustrum* L. (Y, spp. 13; T, spp. 4), *Linociera* Sw. (Y, spp. 4), *Olea* L. (Y, spp. 9), *Osmanthus* Lour. (Y, spp. 10; T, spp. 6), *Syringa* L. (Y, spp. 6).
- Onagraceae** (Y, gen. 4; T, gen. 3): *Chamaenerion* Seguer (Y, spp. 2), *Circaea* L. (Y, spp. 8; T, spp. 3), *Epilobium* L. (Y, spp. 17; T, spp. 6), *Ludwigia* L. (Y, spp. 5; T, spp. 7).
- Opiliaceae** (Y, gen. 5; T, gen. 1): *Cansjera* Juss. (Y, sp. 1), *Champerea* Griff. (T, sp. 1), *Lepionurus* Blume (Y, sp. 1), *Melientha* Pierre (Y, sp. 1), *Opilia* Roxb. (Y, sp. 1), *Urobotrya* Stapf (Y, sp. 1).
- Orchidaceae** (Y, gen. 136; T, gen. 104): *Acampe* Lindl. (Y, spp. 3; T, sp. 1), *Acanthephippium* Blume (Y, spp. 2; T, spp. 2), *Acropsis* Reinw. (Y, sp. 1), *Aerides* Lour. (Y, spp. 4), *Agrostophyllum* Blume (Y, sp. 1; T, sp. 1), *Amitostigma* Schltr. (Y, spp. 10; T, spp. 2), *Androcorys* Schltr. (Y, spp. 3; T, sp. 1), *Ania* Lindl. (T, sp. 1), *Anoetochilus* Blume (Y, spp. 12; T, spp. 2), *Anthogonium* Wall. (Y, sp. 1), *Aphyllorchis* Blume (Y, spp. 2; T, sp. 1), *Apostasia* Blume (Y, spp. 2), *Appendicula* Blume (T, spp. 2), *Arachnis* Blume (Y, sp. 1; T, sp. 1), *Arundina* Blume (Y, sp. 1; T, sp. 1), *Ascocentrum* Schltr. (Y, spp. 2; T, sp. 1), *Bletilla* Rehb. f. (Y, spp. 3; T, spp. 2), *Brachycorythis* Lindl. (Y, spp. 2; T, sp. 1), *Bulbophyllum* Thouars (Y, spp. 65; T, spp. 24), *Bulleyia* Schltr. (Y, sp. 1), *Calanthe* Ker Gawl. (Y, spp. 27; T, spp. 19), *Calypso* Salisb. (Y, sp. 1), *Cephalanthera* Rich. (Y, spp. 4; T, sp. 1), *Cephalantheropsis* Guillaumin (Y, spp. 2; T, spp. 3), *Ceratostylis* Blume (Y, sp. 1), *Chamaegastrodia* Makino & F. Maek. (Y, spp. 2), *Cheirostylis* Blume (Y, spp. 3; T, spp. 8), *Chiloschista* Lindl. (Y, sp. 1; T, sp. 1), *Chrysoglossum* Blume (Y, spp. 2; T, sp. 1), *Cleisostoma* Blume (Y, spp. 12; T, spp. 2), *Coeloglossum* Hartm. (Y, sp. 1; T, sp. 1), *Coelogyne* Lindl. (Y, spp. 23), *Collabium* Blume (Y, spp. 3; T, spp. 2), *Corybas* Salisb. (Y, sp. 1; T, spp. 2), *Corymborkis* Thouars (Y, sp. 1), *Cremastra* Lindl. (Y, sp. 1; T, sp. 1), *Cryptochilus* Wall. (Y, spp. 2), *Cryptostylis* R. Br. (T, spp. 2), *Cymbidium* Sw. (Y, spp. 28; T, spp. 9), *Cypripedium* L. (Y, spp. 15; T, spp. 4), *Cyrtosia* Blume (T, sp. 1), *Dendrobium* Sw. (Y, spp. 59; T, spp. 12), *Dendrochilum* Blume (T, sp. 1), *Didickea* King & Prain (T, sp. 1), *Didymoplexiella* Garay (T, sp. 1), *Didymoplexis* Griff. (T, sp. 1), *Diglyphosa* Blume (Y, sp. 1), *Diphylax* Hook. f. (Y, spp. 3), *Diplomeris* D. Don (Y, sp. 1), *Diploprora* Hook. f. (Y, sp. 1; T, sp. 1), *Disperis* Sw. (T, sp. 1), *Epigeneium*

- Gagnep. (Y, spp. 6; T, spp. 2), *Epipactis* Zinn. (Y, spp. 3), *Epipogium* Gmelin (Y, spp. 2; T, spp. 2), *Eria* Lindl. (Y, spp. 30; T, spp. 7), *Eriodes* Rolfe (Y, sp. 1), *Erythrodies* Blume (Y, sp. 1; T, sp. 1), *Erythrorchis* Blume (T, sp. 1), *Esmeralda* Rehb. f. (Y, spp. 2), *Eulophia* R. Br. (Y, spp. 7; T, spp. 4), *Flickingeria* A. D. Hawkes (Y, spp. 6; T, spp. 2), *Galeola* Lour. (Y, spp. 2; T, spp. 2), *Gastrochilus* D. Don (Y, spp. 12; T, spp. 9), *Gastrodia* R. Br. (Y, spp. 4; T, spp. 9), *Geodorum* G. Jacks. (Y, spp. 4; T, sp. 1), *Goodyera* R. Br. (Y, spp. 16; T, spp. 20), *Gymnadenia* R. Br. (Y, spp. 3; T, spp. 4), *Habenaria* Willd. (Y, spp. 35; T, spp. 8), *Hancockia* Rolfe (Y, sp. 1), *Haraella* Kudô (T, sp. 1), *Hemipilia* Lindl. (Y, spp. 4; T, sp. 1), *Herminium* L. (Y, spp. 16; T, sp. 1), *Herpysma* Lindl. (Y, sp. 1), *Hetaeria* Blume (Y, sp. 1; T, sp. 1), *Holcoglossum* Schltr. (Y, spp. 7; T, sp. 1), *Hygrochilus* Pfitz. (Y, sp. 1), *Hylophila* Lindl. (T, sp. 1), *Kingidium* P. F. Hunt (Y, spp. 3), *Lecanorchis* Blume (Y, sp. 1; T, spp. 3), *Liparis* Rich. (Y, spp. 35; T, spp. 20), *Listera* R. Br. (Y, spp. 5; T, spp. 9), *Ludisia* A. Rich. (Y, sp. 1), *Luisia* Gaudich. (Y, spp. 7; T, spp. 3), *Malaxis* Sol. (Y, spp. 12; T, spp. 7), *Malleola* J. J. Sm. & Schltr. (Y, spp. 1), *Microtatorchis* Schltr. (T, sp. 1), *Microtis* R. Br. (T, sp. 1), *Mischobulbium* Schltr. (Y, sp. 1; T, sp. 1), *Monomeria* Lindl. (Y, sp. 1), *Myrmecis* Blume (Y, spp. 3; T, sp. 1), *Neogyna* Rehb. f. (Y, sp. 1), *Neottia* Guett. (Y, spp. 4; T, sp. 1), *Neottianthe* Schltr. (Y, spp. 7), *Nervilia* Comm. (Y, spp. 3; T, spp. 5), *Neuwiedia* Blume (Y, sp. 1), *Oberonia* Lindl. (Y, spp. 18; T, spp. 7), *Odontochilus* Blume (T, spp. 4), *Orchis* L. (Y, spp. 11), *Oreorchis* Lindl. (Y, spp. 7; T, spp. 4), *Ormithochilus* (Lindl.) Wall. (Y, spp. 2), *Otochilus* Lindl. (Y, spp. 4), *Pachystoma* Blume (Y, sp. 1; T, sp. 1), *Panisea* (Lindl.) Steud. (Y, spp. 4), *Paphiopedilum* Pfitz. (Y, spp. 14), *Papilionanthe* Schltr. (Y, spp. 2; T, sp. 1), *Parapteroceras* Averyanov (Y, sp. 1), *Pecteilis* Raf. (Y, spp. 2), *Pelatanthera* Ridl. (Y, spp. 3), *Pennilabium* J. J. Sm. (Y, sp. 1), *Peristylus* Blume (Y, spp. 15; T, spp. 4), *Phaius* Lour. (Y, spp. 7; T, spp. 4), *Phalaenopsis* Blume (Y, spp. 3; T, spp. 2), *Pholidota* Lindl. (Y, spp. 11; T, sp. 1), *Phreatia* Lindl. (Y, sp. 1; T, spp. 4), *Platanthera* Rich. (Y, spp. 22; T, spp. 6), *Pleione* D. Don (Y, spp. 15; T, sp. 1), *Podochilus* Blume (Y, sp. 1), *Pogonia* Juss. (Y, spp. 2; T, sp. 1), *Polystachya* Hook. (Y, sp. 1), *Pomatocalpa* Breda, Kuhl & Hasselt (T, sp. 1), *Porpax* Lindl. (Y, sp. 1), *Pteroceras* Hasselt (Y, spp. 2), *Renanthera* Lour. (Y, spp. 2), *Rhynchosstylis* Blume (Y, sp. 1), *Risleya* King & Pantl. (Y, sp. 1), *Robiquetia* Gaudich. (Y, sp. 1), *Sarcoglyphis* Garay (Y, spp. 1), *Satyrrium* Sw. (Y, spp. 3), *Schoenorchis* Blume (Y, spp. 2; T, sp. 1), *Sedirea* Garay & H. R. Sweet (Y, sp. 1), *Smithorchis* T. Tang & F. T. Wang (Y, sp. 1), *Smitinandia* Holtum (Y, sp. 1), *Spathoglottis* Blume (Y, sp. 1; T, sp. 1), *Spiranthes* Rich. (Y, sp. 1; T, sp. 1), *Staurochilus* Ridl. (Y, spp. 2; T, sp. 1), *Stereosandra* Blume (Y, sp. 1; T, sp. 1), *Sunipia* Lindl. (Y, spp. 7; T, sp. 1), *Taeniophyllum* Blume (Y, spp. 2; T, spp. 2), *Tainia* Blume (Y, spp. 5; T, spp. 3), *Thelasis* Blume (Y, spp. 2; T, sp. 1), *Thrixspermum* Lour. (Y, spp. 2; T, spp. 9), *Thunia* Rehb. f. (Y, sp. 1), *Tipularia* Nutt. (Y, sp. 1; T, sp. 1), *Trichoglottis* Blume (Y, sp. 1; T, sp. 1), *Tropidia* Lindl. (Y, spp. 2; T, spp. 3), *Tsaiorchis* Tang & F. T. Wang (Y, sp. 1), *Tuberolabium* Yamam. (T, sp. 1), *Tulotis* Raf. (Y, sp. 1; T, sp. 1), *Uncifera* Lindl. (Y, sp. 1), *Vanda* Jones ex R. Br. (Y, spp. 8; T, sp. 1), *Vandopsis* Pfitz. (Y, spp. 2), *Vanilla* Mill. (Y, sp. 1; T, sp. 1), *Vexillabium* F. Maek. (T, spp. 2), *Vrydagzynea* Blume (T, sp. 1), *Yoania* Maxim. (T, sp. 1), *Zeuxine* Lindl. (Y, spp. 5; T, spp. 10).
- Orobanchaceae** (Y, gen. 9; T, gen. 7): *Aeginetia* L. (Y, sp. 1; T, sp. 1), *Boschniakia* C. A. Mey. (Y, sp. 1; T, sp. 1), *Christisonia* Gardner (Y, sp. 1; T, sp. 1), *Euphrasia* L. (Y, sp. 1; T, spp. 3), *Gleadowia* Gamble & Prain (Y, sp. 1), *Melampyrum* L. (Y, sp. 1), *Orobanche* L. (Y, spp. 2; T, sp. 1), *Pedicularis* L. (Y, spp. 150; T, spp. 2), *Striga* Lour. (Y, spp. 3; T, spp. 2).
- Oxalidaceae** (Y, gen. 3; T, gen. 2): *Averrhoa* L. (Y, sp. 1), *Biophytum* DC. (Y, spp. 4; T, sp. 1), *Oxalis* L. (Y, spp. 5; T, spp. 2).
- Paeoniaceae** (Y, gen. 1): *Paeonia* L. (Y, spp. 5).
- Palmae** (Y, gen. 17; T, gen. 5): *Areca* L. (Y, spp. 2), *Arenga* Labill. (Y, spp. 4; T, sp. 1), *Calamus* L. (Y, spp. 23; T, spp. 2), *Caryota* L. (Y, spp. 5), *Chuniophoenix* Burret. (Y, spp. 2), *Cocos* L. (Y, sp. 1), *Daemonorops* Blume (Y, sp. 1), *Guihaia* J. Dransf., S. K. Lee & F. N. Wei (Y, sp. 1), *Licuala* Thunb. (Y, sp. 1), *Livistona* R. Br. (Y, spp. 3; T, sp. 1), *Phoenix* L. (Y, spp. 4; T, sp. 1), *Pinanga* Blume (Y, spp. 5; T, sp. 1), *Plectocomia* Mart. (Y, spp. 3), *Rhapis* L. f. (Y, spp. 3), *Salacca* Reinw. (Y, sp. 1), *Trachycarpus* H. Wendl. (Y, spp. 3), *Wallichia* Roxb. (Y, spp. 6).
- Pandaceae** (Y, gen. 1): *Microdesmis* Hook. f. (Y, sp. 1).
- Pandanaceae** (Y, gen. 1; T, gen. 2): *Freycinetia* Gaudich. (T, sp. 1), *Pandanus* Parkinson (Y, spp. 2; T, sp. 1).
- Papaveraceae** (Y, gen. 6; T, gen. 3): *Argemone* L. (Y, sp. 1; T, sp. 1), *Dicranostigma* Hook. f. & Thomson (Y, spp. 2), *Eomecon* Hance (Y, sp. 1), *Macleaya* R. Br. (Y, sp. 1; T, sp. 1), *Meconopsis* R. Vig. (Y, spp. 17), *Papaver* L. (Y, spp. 3; T, spp. 2).
- Passifloraceae** (Y, gen. 2; T, gen. 2), *Adenia* Forssk. (Y, spp. 2; T, sp. 1), *Passiflora* L. (Y, spp. 12; T, spp. 3).
- Pentaphragmataceae** (Y, gen. 1): *Pentaphragma* Wall. (Y, sp. 1).
- Pentaphyllaceae** (Y, gen. 1): *Pentaphyllax* Gardner & Champ. (Y, sp. 1).
- Phylidraceae** (T, gen. 1): *Philydrum* Banks (T, sp. 1).
- Phrymaceae** (Y, gen. 2; T, gen. 1): *Mazus* Lour. (Y, spp. 10; T, spp. 7), *Phryma* L. (Y, sp. 1).
- Pinaceae** (Y, gen. 8; T, gen. 6): *Abies* Mill. (Y, spp. 6; T, sp. 1), *Keteleeria* Carrière (Y, spp. 3; T, sp. 1), *Larix* Mill. (Y, sp. 1), *Picea* A. Dietr. (Y, spp. 2; T, sp. 1), *Pinus* L. (Y, spp. 15; T, spp. 3), *Pseudolarix* Gordon (Y, sp. 1), *Pseudotsuga* Carrière (Y, spp. 2; T, sp. 1), *Tsuga* Carrière (Y, spp. 3; T, sp. 1).
- Piperaceae** (Y, gen. 3; T, gen. 2): *Peperomia* Ruiz & Pav. (Y, spp. 6; T, spp. 6), *Piper* L. (Y, spp. 41; T, spp. 8), *Zippelia* Blume (Y, sp. 1).
- Pittosporaceae** (Y, gen. 1; T, gen. 1): *Pittosporum* Banks (Y, spp. 28; T, sp. 5).
- Plantaginaceae** (Y, gen. 10; T, gen. 7): *Bacopa* Aubl. (Y, sp. 1; T, sp. 1), *Callitriche* L. (Y, spp. 2; T, spp. 3), *Hippuris* L. (Y, sp. 1), *Lagotis* Geartn. (Y, spp. 5), *Limnophila* R. Br. (Y, spp. 8; T, spp. 7), *Linaria* Mill. (Y, spp. 3), *Plantago* L. (Y, spp. 7; T, spp. 5), *Scoparia* L. (Y, sp. 1; T, sp. 1), *Veronica* L. (Y, spp. 19; T, spp. 10), *Veronicastrum* Heister (Y, spp. 5; T, spp. 2).
- Plumbaginaceae** (Y, gen. 2; T, gen. 2): *Ceratostigma* Bunge (Y, spp. 2), *Limonium* Mill. (T, spp. 2), *Plumbago* L. (Y, spp. 3; T, sp. 1).
- Poaceae** (Y, gen. 175; T, gen. 123): *Achnatherum* P. Beauv. (Y, spp. 4), *Acidosasa* C. D. Chu & C. S. Chao (Y, sp. 1), *Acrachne* Wight & Arn. (Y, sp. 1), *Agropogon* P. Fourn. (Y, sp. 1), *Agropyron* Gaertn. (T, spp. 2), *Agrostis* L. (Y, spp. 31; T, spp. 2), *Alloteropsis* J. Presl (Y, sp. 1; T, sp. 1), *Alopecurus* L. (Y, spp. 2; T, sp. 1), *Ampelocalamus* S. L. Chen, T. H. Wen & G. Y. Sheng (Y, spp. 5), *Andropogon* L. (Y, spp. 3), *Anisachne* Keng (Y, sp. 1), *Aniselytron* Merr. (Y, sp. 1; T, spp. 2), *Anthoxanthum* L. (Y, spp. 3; T, sp. 1), *Apluda* L. (Y, sp. 1; T, sp. 1), *Apocypis* Nees (Y, spp. 4),

Aristida L. (Y, spp. 5; T, sp. 1), *Arthraxon* P. Beauv. (Y, spp. 13; T, spp. 3), *Arundinaria* Michx. (Y, spp. 5; T, spp. 6), *Arundinella* Raddi (Y, spp. 16; T, spp. 3), *Arundo* L. (Y, sp. 1; T, spp. 2), *Avena* L. (Y, spp. 5; T, spp. 2), *Axonopus* P. Beauv. (Y, sp. 1; T, spp. 2), *Bambusa* Schreb. (Y, spp. 21; T, spp. 18), *Beckmannia* Host (Y, sp. 1), *Bonia* Balansa (Y, sp. 1), *Bothriochloa* Kuntze (Y, spp. 9; T, spp. 3), *Brachiaria* Griseb. (Y, spp. 7; T, spp. 4), *Brachyelytrum* P. Beauv. (Y, sp. 1), *Brachypodium* P. Beauv. (Y, spp. 3; T, spp. 2), *Briza* L. (Y, sp. 1; T, sp. 1), *Bromus* L. (Y, spp. 15; T, spp. 4), *Calamagrostis* Adans. (Y, spp. 3; T, sp. 1), *Capillipedium* Stapf (Y, spp. 2; T, spp. 3), *Catabrosa* P. Beauv. (Y, sp. 1), *Cenchrus* L. (Y, spp. 2; T, sp. 1), *Centotheca* Desv. (Y, sp. 1; T, sp. 1), *Cephalostachyum* Munro (Y, spp. 6), *Chimonobambusa* Makino (Y, spp. 9; T, sp. 1), *Chimonocalamus* J. R. Kue (Y, spp. 9), *Chloris* Sw. (Y, spp. 3; T, spp. 4), *Chrysopogon* Trin. (Y, spp. 2; T, sp. 1), *Coelachne* R. Br. (Y, sp. 1), *Coelorachis* Brongn. (Y, spp. 2), *Coix* L. (Y, spp. 6; T, sp. 1), *Crypsis* Aiton. (Y, sp. 1), *Cymbopogon* Spreng. (Y, spp. 19; T, sp. 1), *Cynodon* Rich. (Y, sp. 1; T, spp. 2), *Cyrtococcum* Stapf (Y, spp. 4; T, spp. 2), *Dactylis* L. (Y, sp. 1; T, sp. 1), *Dactyloctenium* Willd. (Y, sp. 1; T, sp. 1), *Danthonia* DC. (Y, sp. 1), *Dendrocalamus* Nees (Y, spp. 22; T, spp. 5), *Deschampsia* P. Beauv. (Y, spp. 3; T, sp. 1), *Deyeuxia* Clarion (Y, spp. 16; T, spp. 2), *Dichanthium* Willemet (Y, spp. 4; T, spp. 2), *Digitaria* Haller (Y, spp. 20; T, spp. 13), *Dimeria* R. Br. (Y, spp. 2; T, spp. 2), *Dinebra* Jacq. (Y, sp. 1), *Diplachne* P. Beauv. (Y, sp. 1; T, sp. 1), *Drepanostachyum* Keng f. (Y, spp. 2), *Duthiea* Hack. (Y, sp. 1), *Eccolopus* Steud. (T, spp. 2), *Echinochloa* P. Beauv. (Y, spp. 9; T, spp. 3), *Eleusine* Gaertn. (Y, spp. 2; T, spp. 2), *Elymus* L. (Y, spp. 6), *Elytrigia* Desv. (Y, sp. 1), *Elytrophorus* P. Beauv. (Y, sp. 1), *Enneapogon* Desv. (Y, sp. 1), *Enteropogon* Nees (Y, sp. 1; T, spp. 2), *Eragrostiella* Bor (Y, sp. 1), *Eragrostis* Wolf (Y, spp. 23; T, spp. 17), *Eremochloa* Buese (Y, spp. 3; T, spp. 2), *Erianthus* Michx. (Y, spp. 4; T, spp. 2), *Eriochloa* Kunth (Y, sp. 1; T, spp. 2), *Eulalia* Kunth (Y, spp. 12; T, spp. 3), *Eulaliopsis* Honda (Y, sp. 1; T, sp. 1), *Eustachys* Desv. (T, sp. 1), *Fargesia* Franch. (Y, spp. 39), *Ferocalamus* J. R. Xue & Keng f. (Y, spp. 2), *Festuca* L. (Y, spp. 27; T, spp. 7), *Gaoligongshania* D. Z. Li, Hsueh & N. H. Xia (Y, sp. 1), *Garnotia* Brongn. (Y, spp. 3; T, sp. 1), *Germainia* Balansa & Poir. (Y, sp. 1), *Gigantochloa* Kurz (Y, spp. 6; T, sp. 1), *Glyceria* R. Br. (Y, spp. 4; T, sp. 1), *Hackelochloa* Kuntze (Y, spp. 2; T, sp. 1), *Harpachne* Hochst. (Y, sp. 1), *Helictotrichon* Besser (Y, spp. 6; T, sp. 1), *Hemarthria* R. Br. (Y, spp. 4; T, sp. 1), *Heteropogon* Pers. (Y, spp. 3; T, sp. 1), *Hierochloa* R. Br. (Y, sp. 1), *Hordeum* L. (Y, spp. 2; T, sp. 1), *Hygroryza* Nees (Y, sp. 1; T, sp. 1), *Hymenachne* P. Beauv. (Y, spp. 3; T, sp. 1), *Hyparrhenia* Andersson (Y, spp. 5), *Hystrix* Moench (Y, sp. 1), *Ichnanthus* P. Beauv. (Y, sp. 1; T, sp. 1), *Imperata* Cirillo (Y, sp. 1), *Indocalamus* Nakai (Y, sp. 1), *Indosasa* McClure (Y, spp. 5), *Isachne* R. Br. (Y, spp. 9; T, spp. 8), *Ischaemum* L. (Y, spp. 6; T, spp. 7), *Koeleria* Pers. (Y, sp. 1), *Leersia* Sw. (Y, sp. 1; T, sp. 1), *Leptaspis* R. Br. (T, sp. 1), *Leptocanna* L. C. Chia & H. L. Fung (Y, sp. 1), *Leptochloa* P. Beauv. (Y, spp. 2; T, spp. 2), *Lepturus* R. Br. (T, sp. 1), *Littledealea* Hemsl. (Y, spp. 2), *Lolium* L. (Y, spp. 2; T, spp. 2), *Lophatherum* Brongn. (Y, sp. 1; T, sp. 1), *Melica* L. (Y, spp. 4; T, sp. 1), *Melocalamus* Benth. (Y, spp. 3), *Microchloa* R. Br. (Y, sp. 1), *Microstegium* Nees (Y, spp. 8; T, spp. 8), *Milium* L. (Y, sp. 1; T, sp. 1), *Miscanthus* Andersson (Y, spp. 8; T, spp. 2), *Muhlenbergia* Schreb. (Y, spp. 5; T, sp. 1), *Narenga* Bor (T, sp. 1), *Neohusnotia* A. Camus (Y, sp. 1), *Neyraudia* Hook. f. (Y, sp. 1; T, sp. 1), *Ophiuros* C. F. Gaertn. (Y, sp.

1), *Oplismenus* P. Beauv. (Y, spp. 4; T, spp. 3), *Orthoraphium* Nees (Y, sp. 1), *Oryza* L. (Y, spp. 4; T, spp. 2), *Oryzopsis* Michx. (Y, spp. 6; T, sp. 1), *Ottlochloa* Dandy (Y, sp. 1; T, sp. 1), *Panicum* L. (Y, spp. 14; T, spp. 12), *Paspalidium* Stapf (Y, spp. 2; T, spp. 2), *Paspalum* L. (Y, spp. 10; T, spp. 13), *Pennisetum* Rich. (Y, spp. 9; T, spp. 4), *Perotis* Aiton (Y, spp. 2; T, spp. 2), *Phacelurus* Griseb. (Y, sp. 1), *Phaenosperma* Munro (Y, sp. 1; T, sp. 1), *Phalaris* L. (Y, spp. 4; T, spp. 2), *Phleum* L. (Y, spp. 2; T, sp. 1), *Phragmites* Adans. (Y, spp. 3; T, spp. 2), *Phyllostachys* Siebold & Zucc. (Y, spp. 12; T, spp. 8), *Poa* L. (Y, spp. 78; T, spp. 7), *Pogonatherum* P. Beauv. (Y, spp. 2; T, spp. 2), *Polypogon* Desf. (Y, spp. 2; T, spp. 2), *Polytoca* R. Br. (Y, sp. 1), *Pseudochinolaena* Stapf (Y, sp. 1), *Pseudopogonatherum* A. Camus (Y, spp. 2), *Pseudoraphis* Griff. (Y, sp. 1; T, sp. 1), *Pseudosasa* Makino (T, spp. 2), *Pseudosorghum* A. Camus (Y, spp. 2), *Pseudostachyum* Munro (Y, sp. 1), *Ptilagrostis* Griseb. (Y, spp. 3), *Qiongzhueta* (Wen & Ohmberger) Hsueh & Yi (Y, spp. 2), *Racemobambos* Holttum (Y, sp. 1), *Rhytachne* Desv. (Y, spp. 2), *Roegneria* K. Koch (Y, spp. 20), *Rottboellia* L. f. (Y, sp. 1; T, sp. 1), *Saccharum* L. (Y, spp. 7; T, spp. 4), *Sacciolepis* Nash (Y, spp. 3; T, sp. 1), *Schizachne* Hack. (Y, sp. 1), *Schizachyrium* Nees (Y, spp. 3; T, sp. 1), *Schizostachyum* Thomas Nees (Y, spp. 3; T, spp. 2), *Sehima* Forssk. (Y, sp. 1), *Semiarundinaria* Nakai (T, sp. 1), *Setaria* P. Beauv. (Y, spp. 13; T, spp. 9), *Shibataea* Makino (T, sp. 1), *Sinobambusa* Makino (Y, spp. 2; T, spp. 2), *Sorghum* Moench (Y, spp. 7; T, spp. 5), *Sphaerocaryum* Nees (Y, sp. 1; T, sp. 1), *Spinifex* L. (T, sp. 1), *Spodiopogon* Trin. (Y, spp. 4; T, sp. 1), *Sporobolus* R. Br. (Y, spp. 4; T, spp. 2), *Stenotaphrum* Trin. (Y, sp. 1), *Stipa* L. (Y, spp. 3), *Stipagrostis* Nees (Y, sp. 1), *Thaumastochloa* C. E. Hubb. (T, spp. 2), *Themeda* Forssk. (Y, spp. 14; T, spp. 2), *Thuarea* Pers. (T, sp. 1), *Thyrsia* Stapf (Y, sp. 1), *Thyrsostachys* Gamble (Y, spp. 2; T, sp. 1), *Thysanolaena* Nees (Y, sp. 1; T, sp. 1), *Tragus* Haller (Y, spp. 2), *Trikeria* Bor (Y, sp. 1), *Tripogon* Roem. & Schult. (Y, spp. 7; T, sp. 1), *Trisetum* Pers. (Y, spp. 5; T, sp. 1), *Triticum* L. (Y, sp. 1; T, sp. 1), *Urochloa* P. Beauv. (Y, spp. 5), *Vulpia* C. C. Gmel. (T, sp. 1), *Yushania* Keng f. (Y, spp. 27; T, sp. 1), *Zizania* L. (Y, sp. 1; T, sp. 1), *Zoysia* Willd. (Y, spp. 3; T, spp. 4).

Podocarpaceae (Y, gen. 1; T, gen. 2): *Nageia* Gaertn. (T, spp. 2), *Podocarpus* L'Hér. (Y, spp. 8; T, spp. 4).

Podostemaceae (Y, gen. 1), *Hydrobryum* Endl. (Y, sp. 1).

Polemoniaceae (Y, gen. 1): *Polemonium* L. (Y, sp. 1).

Polygalaceae (Y, gen. 4; T, gen. 3): *Epirixanthes* Blume (T, sp. 1), *Polygala* L. (Y, spp. 24; T, spp. 5), *Salomonia* Lour. (Y, spp. 3; T, sp. 1), *Securidaca* L. (Y, spp. 2), *Xanthophyllum* Roxb. (Y, spp. 3).

Polygonaceae (Y, gen. 9; T, gen. 3): *Antenoron* Raf. (Y, sp. 1), *Fagopyrum* Mill. Y. (Y, spp. 10; T, sp. 1), *Fallopia* Adans. (Y, spp. 6), *Koenigia* L. (Y, sp. 1), *Oxyria* Hill (Y, spp. 2), *Polygonum* L. (Y, spp. 64; T, spp. 35), *Reynoutria* Houtt. (Y, sp. 1), *Rheum* L. (Y, spp. 12), *Rumex* L. (Y, spp. 11; T, spp. 6).

Pontederiaceae (Y, gen. 2; T, gen. 2): *Eichhornia* Kunth (Y, sp. 1; T, sp. 1), *Monochoria* C. Presl (Y, spp. 2; T, sp. 1).

Portulacaceae (Y, gen. 2; T, gen. 2): *Portulaca* L. (Y, spp. 4; T, spp. 3), *Talinum* Adans. (Y, sp. 1; T, sp. 1).

Potamogetonaceae (Y, gen. 1; T, gen. 1): *Potamogeton* L. (Y, spp. 12; T, spp. 9).

Primulaceae (Y, gen. 4; T, gen. 5): *Anagallis* L. (T, sp. 1), *Androsace* L. (Y, spp. 23; T, sp. 1), *Lysimachia* L. (Y, spp. 65; T, spp. 10), *Omphalogramma* Franch. (Y, spp. 6),

- Primula* L. (Y, spp. 127; T, sp. 1), *Stimpsonia* C. Wright (T, sp. 1).
- Proteaceae** (Y, gen. 2; T, gen. 1): *Helicia* Lour. (Y spp. 12; T, spp. 3), *Heliciopsis* Sleum. (Y, sp. 1).
- Rafflesiaceae** (Y, gen. 1): *Sapria* Griff. (Y, sp. 1).
- Ranunculaceae** (Y, gen. 28; T, gen. 10): *Aconitum* L. (Y, spp. 66; T, sp. 1), *Actaea* L. (Y, sp. 1), *Adonis* L. (Y, sp. 1), *Anemoclema* (Franch.) W. T. Wang (Y, sp. 1), *Anemone* L. (Y, spp. 25; T, spp. 2), *Aquilegia* L. (Y, sp. 1), *Asteropyrum* J. R. Drumm. & Hutch. (Y, spp. 2), *Batrachium* (DC.) S. F. Gray (Y, spp. 3), *Beesia* Balf. f. & W. W. Sm. (Y, sp. 1), *Calathodes* Hook. f. & Thomson (Y, spp. 2; T, sp. 1), *Callianthemum* C. A. Mey. (Y, sp. 1), *Caltha* L. (Y, spp. 3), *Cimicifuga* Wernisch. (Y, spp. 4; T, sp. 1), *Clematis* L. (Y, spp. 56; T, spp. 15), *Coptis* Salisb. (Y, spp. 3; T, sp. 1), *Delphinium* L. (Y, spp. 49), *Dichocarpum* W. T. Wang & P. K. Hsiao (Y, spp. 5; T, sp. 1), *Halerpestes* Greene (Y, sp. 1), *Kingdonia* Balf. f. & W. W. Sm. (Y, sp. 1), *Metanemone* W. T. Wang (Y, sp. 1), *Naravelia* Adans. (Y, sp. 1), *Oxygraphis* Bunge (Y, spp. 3), *Paraquilegia* J. R. Drumm. & Hutch. (Y, sp. 1), *Pulsatilla* Mill. (Y, sp. 1), *Ranunculus* L. (Y, spp. 35; T, sp. 11), *Souliea* Franch. (Y, sp. 1), *Thalictrum* L. (Y, spp. 35; T, spp. 4), *Trollius* L. (Y, spp. 6; T, sp. 1).
- Rhamnaceae** (Y, gen. 14; T, gen. 6): *Alphitonia* Reissek (Y, sp. 1), *Berchemia* Neck. (Y, spp. 13; T, spp. 4), *Berchemiella* Nakai (Y, sp. 1), *Chaydaia* Pit. (Y, sp. 1), *Colubrina* Rich. (Y, sp. 1; T, sp. 1), *Gouania* Jacq. (Y, spp. 2), *Hovenia* Thunb. (Y, sp. 1), *Paliurus* Mill. (Y, spp. 3; T, sp. 1), *Rhamnella* Miq. (Y, spp. 4), *Rhamnus* L. (Y, spp. 30; T, spp. 7), *Sageretia* Brongn. (Y, spp. 20; T, spp. 2), *Scutia* Comm. (Y, sp. 1), *Ventilago* Gaertn. (Y, spp. 5; T, spp. 2), *Ziziphus* Mill. (Y, spp. 10).
- Rhizophoraceae** (Y, gen. 2; T, gen. 2): *Carallia* Roxb. (Y, spp. 2), *Kandelia* (DC.) Wight & Arn. (T, sp. 1), *Pellacalyx* Korth. (Y, sp. 1), *Rhizophora* L. (T, sp. 1).
- Rosaceae** (Y, gen. 41; T, gen. 23): *Agrimonia* L. (Y, sp. 1; T, sp. 1), *Amygdalus* L. (Y, spp. 4), *Aria* (Pers.) Host (T, sp. 1), *Armeniaca* Scop. (Y, spp. 2), *Aruncus* L. (Y, spp. 2), *Cerasus* Mill. (Y, spp. 20), *Chaenomeles* Lindl. (Y, spp. 4), *Coluria* R. Br. (Y, spp. 2), *Cotoneaster* Medik. (Y, spp. 40; T, spp. 5), *Crataegus* L. (Y, spp. 7), *Cydonia* Mill. (Y, sp. 1), *Dichotomanthes* Kurz (Y, sp. 1), *Docynia* Decne. (Y, spp. 2), *Duchesnea* Sm. (Y, spp. 2; T, spp. 2), *Eriobotrya* Lindl. (Y, spp. 12; T, spp. 2), *Filipendula* Mill. (Y, sp. 1; T, sp. 1), *Fragaria* L. (Y, spp. 7; T, sp. 1), *Geum* L. (Y, spp. 2), *Kerria* DC. (Y, sp. 1), *Laurocerasus* Duham. (Y, spp. 9), *Malus* Mill. (Y, spp. 12; T, spp. 2), *Neillia* D. Don (Y, spp. 8), *Osteomeles* Lindl. (Y, sp. 1; T, sp. 1), *Padus* Mill. (Y, spp. 7), *Photinia* Lindl. (Y, spp. 15; T, spp. 2), *Potentilla* L. (Y, spp. 40; T, spp. 6), *Pourthiaea* Decne. (T, sp. 1), *Prinsepia* Royle (Y, sp. 1; T, sp. 1), *Prunus* L. (Y, spp. 2; T, spp. 12), *Pygeum* Gaertn. (Y, spp. 5), *Pyracantha* M. Roem. (Y, spp. 4; T, sp. 1), *Pyrus* L. (Y, spp. 7; T, spp. 2), *Raphiolepis* Lindl. (Y, spp. 2; T, sp. 1), *Rosa* L. (Y, spp. 41; T, spp. 8), *Rubus* L. (Y, spp. 104; T, spp. 34), *Sanguisorba* L. (Y, spp. 2), *Sibbaldia* L. (Y, spp. 8; T, sp. 1), *Sibiraea* Maxim. (Y, sp. 1), *Sorbaria* (Ser.) A. Braun (Y, sp. 1), *Sorbus* L. (Y, spp. 48; T, sp. 1), *Spenceria* Trimen (Y, sp. 1), *Spiraea* L. (Y, spp. 26; T, spp. 4), *Stephanandra* Sieb. & Zucc. (T, sp. 1), *Stranvaesia* Lindl. (Y, spp. 4).
- Rubiaceae** (Y, gen. 68; T, gen. 39): *Acanthera* Arn. (Y, sp. 1), *Adina* Salisb. (Y, spp. 2), *Aidia* Lour. (Y, spp. 5), *Argostemma* Wall. (Y, spp. 3; T, sp. 1), *Borreria* G. Mey. (Y, spp. 3), *Brachytome* Hook. f. (Y, spp. 3), *Caelospermum* Blume (Y, sp. 1), *Canthium* Lam. (Y, spp. 3; T, sp. 1), *Catunaregam* Wolf (Y, sp. 1), *Cephaelis* Sw. (Y, sp. 1), *Cephalanthus* L. (Y, sp. 1; T, sp. 1), *Chassalia* Comm. (Y, sp. 1), *Clarkella* Hook. f. (Y, sp. 1), *Coptosapelta* Korth. (Y, sp. 1; T, sp. 1), *Damnacanthus* Gaertn. f. (Y, spp. 6; T, spp. 2), *Dentella* J. R. Forst. & G. Forst. (Y, sp. 1; T, sp. 1), *Diodia* L. (T, sp. 1), *Diplospora* DC. (Y, spp. 3), *Duperrea* Pierre ex Pit. (Y, sp. 1), *Emmenopterys* Oliv. (Y, sp. 1), *Fagerlindia* Tirveng. (Y, sp. 1), *Galium* L. (Y, spp. 17; T, spp. 10), *Gardenia* J. Ellis (Y, spp. 2; T, sp. 1), *Geophila* D. Don (Y, sp. 1; T, sp. 1), *Guettarda* L. (T, sp. 1), *Hayataella* Masam. (T, sp. 1), *Hedyotis* L. (Y, spp. 21; T, spp. 9), *Himalrandia* T. Yamaz. (Y, spp. 1), *Hymenodictyon* Wall. (Y, spp. 2), *Hyptianthera* Wight & Arn. (Y, sp. 1), *Ixora* L. (Y, spp. 16; T, sp. 1), *Kelloggia* Torr. (Y, sp. 1), *Knoxia* L. (Y, spp. 2; T, sp. 1), *Lasianthus* Jack (Y, spp. 21; T, sp. 14), *Leptodermis* Wall. (Y, spp. 16), *Leptomischus* Drake (Y, spp. 4), *Lerchea* L. (Y, spp. 2), *Litosanthes* Blume (Y, sp. 1; T, sp. 1), *Luculia* Sweet (Y, spp. 3), *Metadina* Bakh. f. (Y, sp. 1), *Mitchella* L. (T, sp. 1), *Mitragyna* Korth. (Y, sp. 1), *Morinda* L. (Y, spp. 15; T, spp. 3), *Mussaenda* L. (Y, spp. 21; T, spp. 2), *Mycetia* Reinw. (Y, spp. 11), *Myrioneuron* R. Br. (Y, spp. 4), *Nauclea* L. (Y, sp. 1), *Neanotis* W. H. Lewis (Y, spp. 4; T, sp. 1), *Neohymenopogon* Bennet (Y, spp. 2), *Neolamarchia* J. Bossier (Y, sp. 1), *Neonauclea* Merr. (Y, spp. 3; T, sp. 1), *Nertera* Banks (Y, spp. 2; T, spp. 2), *Ophiorrhiza* L. (Y, spp. 42; T, spp. 4), *Oxyceros* Lour. (Y, spp. 3), *Paederia* L. (Y, spp. 7; T, spp. 2), *Pavetta* L. (Y, spp. 5; T, sp. 1), *Porterandia* Ridl. (Y, sp. 1), *Prismatomis* Thwaites. (Y, sp. 1), *Psychotria* L. (Y, spp. 13; T, spp. 4), *Randia* L. (T, spp. 5), *Richardia* L. (T, spp. 2), *Rubia* L. (Y, spp. 19; T, spp. 3), *Saprosma* Blume (Y, spp. 3), *Schizomussaenda* H. L. Li (Y, sp. 1), *Serissa* Comm. (Y, spp. 2; T, sp. 1), *Sinoadina* Ridsdale (Y, sp. 1; T, sp. 1), *Spermacoce* L. (T, spp. 5), *Spiradialis* Blume (Y, spp. 6), *Tarenna* Gaertn. (Y, spp. 7; T, spp. 3), *Tarennoidea* Tirveng. & Sastre (Y, sp. 1), *Theligonum* L. (T, sp. 1), *Timonius* DC. (T, sp. 1), *Trailliaedoxa* W. W. Sm. & Forrest (Y, sp. 1), *Tricalysia* A. Rich. (T, sp. 1), *Uncaria* Schreb. (Y, spp. 9; T, spp. 2), *Urophyllum* Wall. (Y, spp. 3), *Wendlandia* Bartl. (Y, spp. 22; T, spp. 3), *Xanthophyllum* Reinw. (Y, sp. 1).
- Ruppiaceae** (T, gen. 1): *Ruppia* L. (T, sp. 1).
- Rutaceae** (Y, gen. 20; T, gen. 13): *Acronychia* J. R. Forst. & G. Forst. (Y, sp. 1; T, sp. 1), *Aegle* Corrêa (Y, sp. 1), *Alatalantia* Corrêa (Y, spp. 6), *Boenninghausenia* Rehb. (Y, spp. 2; T, sp. 1), *Citrus* L. (Y, spp. 13; T, spp. 4), *Clausena* Burm. f. (Y, spp. 11; T, spp. 2), *Euodia* J. R. (Y, spp. 11), *Evodia* Lam. (Y, sp. 1), *Fortunella* Swingle (Y, spp. 3), *Glycosmis* Corrêa (Y, spp. 8; T, sp. 1), *Luwunga* Buch.-Ham. (Y, spp. 2), *Melicope* J. R. Forst. & G. Forst. (T, spp. 3), *Micromelum* Blume (Y, spp. 3), *Murraya* J. König (Y, spp. 4; T, spp. 3), *Orixa* Thunb. (Y, sp. 1), *Paramignya* Wight (Y, spp. 2), *Phellodendron* Rupr. (Y, sp. 1; T, sp. 1), *Poncirus* Raf. (Y, spp. 2), *Severinia* Ten. (T, sp. 1), *Skimmia* Thunb. (Y, sp. 1; T, spp. 2), *Tetradium* Lour. (T, spp. 2), *Toddalia* Juss. (Y, sp. 1; T, sp. 1), *Zanthoxylum* L. (Y, spp. 28; T, spp. 9).
- Sabiaceae** (Y, gen. 2; T, gen. 2): *Meliosma* Blume (Y, spp. 22; T, spp. 4), *Sabia* Colebr. (Y, spp. 13; T, spp. 2).
- Salicaceae** (Y, gen. 4; T, gen. 3): *Casearia* Jacq. (Y, spp. 7; T, sp. 1), *Homalium* Jacq. (Y, sp. 1; T, sp. 1), *Populus* L. (Y, spp. 16), *Salix* L. (Y, spp. 87; T, spp. 5).
- Santalaceae** (Y, gen. 6; T, gen. 1): *Dendrotrophe* Miq. (Y, spp. 7), *Osyris* L. (Y, sp. 1), *Phacellaria* Benth. (Y, spp. 5), *Pyrularia* Michx. (Y, sp. 1), *Scleropyrum* Arn. (Y, sp. 1), *Thesium* L. (Y, spp. 9; T, sp. 1).
- Sapindaceae** (Y, gen. 20; T, gen. 9): *Acer* L. (Y, spp. 51; T, spp. 4), *Allophylus* L. (Y, spp. 3; T, sp. 1), *Amesiodendron* Hu (Y, sp. 1), *Arytera* Blume (Y, sp. 1), *Cardiospermum* L.

- (Y, sp. 1; T, sp. 1), *Delavaya* Franch. (Y, sp. 1), *Dimocarpus* Lour. (Y, spp. 3), *Dipteronia* Oliv. (Y, sp. 1), *Dodonaea* Mill. (Y, sp. 1; T, sp. 1), *Eurycorymbus* Hand-Mazz. (Y, sp. 1; T, sp. 1), *Harpullia* Roxb. (Y, sp. 1), *Koeleruteria* Laxm. (Y, spp. 2; T, sp. 1), *Lepisanthes* Blume (Y, spp. 3), *Litchi* Sonn. (Y, sp. 1; T, sp. 1), *Mischocarpus* Blume (Y, spp. 2), *Nephelium* L. (Y, sp. 1), *Pavieasia* Pierre (Y, sp. 1), *Pometia* J. R. Forst. & G. Forst. (Y, sp. 1; T, sp. 1), *Sapindus* L. (Y, spp. 4; T, sp. 1), *Xerospermum* Blume (Y, sp. 1).
- Sapotaceae** (Y, gen. 7; T, gen. 2): *Eberhardtia* Lecomte (Y, spp. 2), *Madhuca* J. F. Gmel. (Y, sp. 1), *Palaquium* Blanco (T, sp. 1), *Planchonella* Pierre (Y, spp. 2; T, spp. 2), *Pouteria* Aubl. (Y, sp. 1), *Sarcosperma* Hook. f. (Y, spp. 3), *Sinosideroxylon* (Engl.) Aubr. (Y, sp. 1), *Xantolis* Raf. (Y, spp. 3).
- Sargentodoxaceae** (Y, gen. 1): *Sargentodoxa* Rehder & E. H. Wilson (Y, sp. 1).
- Saururaceae** (Y, gen. 3; T, gen. 2): *Gymnotheca* Decne. (Y, sp. 1), *Houttuynia* Thunb. (Y, sp. 1; T, sp. 1), *Saururus* L. (Y, sp. 1; T, sp. 1).
- Saxifragaceae** (Y, gen. 9; T, gen. 7): *Astilbe* Buch.-Ham. (Y, spp. 3; T, spp. 2), *Bergenia* Moench (Y, spp. 2), *Cardiandra* Sieb. & Zucc. (T, sp. 1), *Chrysosplenium* L. (Y, spp. 11; T, spp. 2), *Mitella* L. (T, sp. 1), *Parnassia* L. (Y, spp. 20; T, sp. 1), *Penthorum* L. (Y, sp. 1), *Rodgersia* A. Gray (Y, spp. 3), *Saniculiphyllum* C. Y. Wu & Ku (Y, sp. 1), *Saxifraga* L. (Y, spp. 103; T, sp. 1), *Tiarella* L. (Y, sp. 1; T, sp. 1).
- Schisandraceae** (Y, gen. 3; T, gen. 3): *Illicium* L. (Y, spp. 12; T, spp. 3), *Kadsura* Juss. (Y, spp. 7; T, spp. 2), *Schisandra* Michx. (Y, spp. 11; T, sp. 1).
- Schoepfiaceae** (Y, gen. 1; T, gen. 1): *Schoepfia* Schreb. (Y, spp. 2; T, sp. 1).
- Scrophulariaceae** (Y, gen. 29; T, gen. 12): *Adenosma* R. Br. (Y, spp. 3), *Alectra* Thunb. (Y, sp. 1; T, sp. 1), *Brandisia* Hook. f. & Thomson (Y, spp. 6), *Buchnera* L. (Y, sp. 1), *Centranthera* R. Br. (Y, spp. 2; T, sp. 1), *Cyrtandromoea* Zoll. (Y, spp. 2), *Deinostema* T. Yamaz. (T, spp. 2), *Dopatrium* Buch.-Ham. (Y, sp. 1; T, sp. 1), *Ellisiophyllum* Maxim. (Y, sp. 1; T, sp. 1), *Gratiola* L. (Y, spp. 2), *Hemiphragma* Wall. (Y, sp. 1; T, sp. 1), *Lancea* Hook. f. & Thomson (Y, spp. 2), *Legazpia* Blanco (T, sp. 1), *Limosella* L. (Y, sp. 1), *Lindenbergia* Lehm. (Y, spp. 4), *Microcarpaea* R. Br. (Y, sp. 1; T, sp. 1), *Mimulicalyx* P. C. Tsoong (Y, spp. 2), *Mimulus* L. (Y, spp. 3), *Myoporum* Banks & Sol. (T, sp. 1), *Neopicrohiza* D. Y. Hong (Y, sp. 1), *Petitmenginia* Bonati (Y, sp. 1), *Phtheirospermum* Bunge (Y, spp. 3; T, sp. 1), *Picria* Lour. (Y, sp. 1), *Pseudolysimachion* (W. D. J. Koch) Opiz (Y, sp. 1), *Pterygiella* Oliv. (Y, spp. 4), *Rehmannia* Libosch. (Y, sp. 1), *Scrophularia* L. (Y, spp. 11; T, sp. 1), *Siphonostegia* Benth (Y, sp. 1; T, sp. 1), *Sopubia* Buch.-Ham. (Y, sp. 1), *Verbascum* L. (Y, spp. 2), *Wightia* Wall. (Y, spp. 2), *Xizangia* D. Y. Hong (Y, sp. 1).
- Simaroubaceae** (Y, gen. 3; T, gen. 3): *Ailanthus* Desf. (Y, spp. 5; T, sp. 2), *Brucea* J. F. Mill. (Y, spp. 2; T, sp. 1), *Picrasma* Blume (Y, spp. 2; T, sp. 1).
- Sladeniaceae** (Y, gen. 1): *Sladenia* Kurz (Y, sp. 1).
- Smilacaceae** (Y, gen. 2; T, gen. 2): *Heterosmilax* Kunth (Y, spp. 8; T, spp. 3), *Smilax* L. (Y, spp. 47; T, spp. 18).
- Solanaceae** (Y, gen. 11; T, gen. 5): *Antisodus* Link (Y, spp. 4), *Atropanthe* Pascher (Y, sp. 1), *Hyoscyamus* L. (Y, sp. 1), *Lycianthes* (Dunal) Hassl. (Y, spp. 6; T, sp. 2), *Lycium* L. (Y, spp. 2), *Mandragora* L. (Y, sp. 1), *Physaliastrum* Makino (Y, spp. 2; T, sp. 1), *Physalis* L. (Y, spp. 4; T, spp. 2), *Scopolia* Jacq. (Y, sp. 1), *Solanum* L. (Y, spp. 29; T, spp. 19), *Tubocapsicum* (Wettst.) Makino (Y, sp. 1; T, sp. 1).
- Sonneratiaceae** (Y, gen. 1): *Duabanga* Buch.-Ham. (Y, sp. 1).
- Sphenocleaceae** (Y, gen. 1; T, gen. 1): *Sphenoclea* Gaertn. (Y, sp. 1; T, sp. 1).
- Stachyuraceae** (Y, gen. 1; T, gen. 1): *Stachyurus* Sieb. & Zucc. (Y, spp. 8; T, sp. 1).
- Staphyleaceae** (Y, gen. 4; T, gen. 2): *Euscaphis* Sieb. & Zucc. (Y, sp. 1; T, sp. 1), *Staphylea* L. (Y, spp. 2), *Tapiscia* Oliv. (Y, sp. 1), *Turpinia* Vent. (Y, spp. 8; T, spp. 3).
- Stemonaceae** (Y, gen. 1; T, gen. 1): *Stemona* Lour. (Y, spp. 2; T, sp. 1).
- Sterculiaceae** (Y, gen. 16; T, gen. 9): *Ambroma* L. f. (Y, sp. 1), *Byttneria* Loebl. (Y, spp. 3), *Commersonia* J. R. Forst. & G. Forst. (Y, sp. 1), *Craigia* W. W. Sm. & W. E. Evans (Y, sp. 1), *Eriolaena* DC. (Y, spp. 5), *Firmiana* Marsili (Y, spp. 3; T, sp. 1), *Helicteres* L. (Y, spp. 8; T, sp. 1), *Heritiera* Aiton (Y, sp. 1; T, sp. 1), *Kleinhovia* L. (T, sp. 1), *Melhania* Forssk. (Y, sp. 1), *Melochia* L. (Y, sp. 1; T, sp. 1), *Paradombeya* Stapf (Y, sp. 1), *Pentapetes* L. (Y, sp. 1), *Pterospermum* Schreb. (Y, spp. 7; T, sp. 1), *Reevesia* Lindl. (Y, spp. 4; T, sp. 1), *Sterculia* L. (Y, spp. 18; T, sp. 1), *Waltheria* L. (Y, sp. 1; T, sp. 1).
- Stylidiaceae** (Y, gen. 1): *Stylidium* Sw. (Y, sp. 1).
- Styracaceae** (Y, gen. 8; T, gen. 2): *Alniphyllum* Matsum. (Y, spp. 2; T, sp. 1), *Bruinsmia* Boerl. & Koord. (Y, sp. 1), *Huodendron* Rehd. (Y, spp. 3), *Meliiodendron* Hand-Mazz. (Y, sp. 1), *Parastyrax* W. W. Sm. (Y, spp. 2), *Pterostyrax* Siebold & Zucc. (Y, spp. 2), *Rehderodendron* Hu (Y, spp. 7), *Styrax* L. (Y, spp. 18; T, spp. 3).
- Symplocaceae** (Y, gen. 1; T, gen. 1): *Symplocos* Jacq. (Y, spp. 41; T, spp. 26).
- Taccaceae** (Y, gen. 1; T, gen. 1): *Tacca* J. R. Forst. & G. Forst. (Y, spp. 2; T, sp. 1).
- Tamaricaceae** (Y, gen. 2): *Myricaria* Desv. (Y, spp. 3), *Tamarix* L. (Y, sp. 1).
- Taxaceae** (Y, gen. 3; T, gen. 2): *Amentotaxus* Pilg. (Y, sp. 1; T, sp. 1), *Taxus* L. (Y, spp. 2; T, sp. 1), *Torreya* Arn. (Y, spp. 2).
- Taxodiaceae** (Y, gen. 5; T, gen. 2): *Cryptomeria* D. Don (Y, sp. 1), *Cunninghamia* R. Br. (Y, sp. 1; T, sp. 1), *Glyptostrobus* Endl. (Y, sp. 1), *Metasequoia* Hu & W. C. Cheng (Y, sp. 1), *Taiwania* Hayata (Y, sp. 1; T, sp. 1).
- Tetracentraceae** (Y, gen. 1): *Tetracentron* Oliv. (Y, sp. 1).
- Tetramelaceae** (Y, gen. 1): *Tetrameles* R. Br. (Y, sp. 1).
- Theaceae** (Y, gen. 9; T, gen. 9): *Adinandra* Jack (Y, spp. 9; T, spp. 2), *Anneslea* Wall. (Y, sp. 1; T, sp. 1), *Camellia* L. (Y, spp. 39; T, spp. 12), *Cleyera* Thunb. (T, sp. 1), *Eurya* Thunb. (Y, spp. 43; T, sp. 12), *Gordonia* J. Ellis (Y, spp. 4; T, sp. 1), *Pyrenaria* Blume (Y, spp. 6; T, sp. 1), *Schima* Reinw. (Y, spp. 8; T, sp. 1), *Stewartia* L. (Y, spp. 4), *Ternstroemia* Mut. (Y, spp. 6; T, sp. 1).
- Thymelaeaceae** (Y, gen. 7; T, gen. 3): *Aquilaria* Lam. (Y, sp. 1), *Daphne* L. (Y, spp. 18; T, spp. 3), *Edgeworthia* Meisn. (Y, spp. 3), *Erioseola* Blume (Y, sp. 1), *Rhamnoneuron* Gilg (Y, sp. 1), *Stellera* L. (Y, sp. 1; T, sp. 1), *Wikstroemia* Endl. (Y, spp. 14; T, spp. 5).
- Tiliaceae** (Y, gen. 7; T, gen. 4): *Berrya* Roxb. (T, sp. 1), *Burretiodendron* Rehd. (Y, spp. 3), *Colona* Cav. (Y, spp. 2), *Corchorus* L. (Y, spp. 4; T, spp. 3), *Grewia* L. (Y, spp. 15; T, spp. 4), *Microcos* L. (Y, spp. 2), *Tilia* L. (Y, spp. 8), *Triumfetta* L. (Y, spp. 4; T, spp. 4).
- Toricelliaceae** (Y, gen. 1): *Toricellia* DC. (Y, sp. 1).
- Trilliaceae** (Y, gen. 2; T, gen. 2): *Paris* L. (Y, spp. 11; T, sp. 1), *Trillium* L. (Y, sp. 1; T, sp. 1).
- Triuridaceae** (T, gen. 1): *Sciaphila* Blume (T, spp. 2).
- Trochodendraceae** (T, gen. 1): *Trochodendron* Sieb. & Zucc. (T, sp. 1).

Typhaceae (Y, gen. 2; T, gen. 2): *Sparganium* L. (Y, spp. 5; T, sp. 1), *Typha* L. (Y, spp. 3; T, spp. 2).

Ulmaceae (Y, gen. 6; T, gen. 5): *Aphananthe* Planch. (Y, spp. 2; T, sp. 1), *Celtis* L. (Y, spp. 11; T, spp. 5), *Gironniera* Gaudich. (Y, sp. 1), *Trema* Lour. (Y, spp. 5; T, spp. 3), *Ulmus* L. (Y, spp. 8; T, spp. 2), *Zelkova* Spach (Y, spp. 2; T, sp. 1).

Umbelliferae (Y, gen. 50; T, gen. 17): *Acronema* Falc. (Y, spp. 10), *Anethum* L. (Y, sp. 1), *Angelica* L. (Y, spp. 8; T, spp. 4), *Anthriscus* (Pers.) Hoffm. (Y, spp. 2), *Arcuatopteris* Shan & Sheh (Y, spp. 3), *Bupleurum* L. (Y, spp. 12; T, sp. 1), *Carum* L. (Y, sp. 1), *Centella* L. (Y, sp. 1; T, sp. 1), *Chaerophyllum* L. (Y, sp. 1), *Chamaesium* H. Wolff (Y, spp. 6), *Cicuta* L. (Y, sp. 1), *Cnidium* Cuss. (Y, sp. 1; T, sp. 1), *Conioselinum* Hoffm. (T, sp. 1), *Coriandrum* L. (Y, sp. 1), *Cortia* DC. (Y, sp. 1), *Cryptotaenia* DC. (Y, sp. 1; T, sp. 1), *Cyclorhiza* M. L. Sheh & R. H. Shan (Y, spp. 2), *Daucus* L. (Y, sp. 1), *Dickinsia* Franch. (Y, sp. 1), *Eryngium* L. (Y, sp. 1; T, sp. 1), *Ferula* L. (Y, spp. 2), *Foeniculum* Mill. (Y, sp. 1), *Glehnia* F. Schmidt (T, sp. 1), *Haplosphaera* Hand.-Mazz. (Y, sp. 1), *Harrysmithia* H. Wolff (Y, sp. 1), *Heracleum* L. (Y, spp. 19), *Hydrocotyle* L. (Y, spp. 7; T, spp. 7), *Ligusticum* L. (Y, spp. 27), *Meeboldia* H. Wolff (Y, sp. 1), *Melanosciadium* H. Boissieu (Y, sp. 1), *Nothosmyrnium* Miq. (Y, sp. 1), *Notopterygium* H. Boissieu (Y, spp. 2), *Oenanthe* L. (Y, spp. 8; T, spp. 2), *Oreomyrrhis* Endl. (T, spp. 3), *Osmorhiza* Raf. (Y, sp. 1; T, sp. 1), *Ostericum* Hoffm. (Y, sp. 1), *Peucedanum* L. (Y, spp. 8; T, spp. 2), *Physospermopsis* H. Wolff (Y, spp. 6), *Pimpinella* L. (Y, spp. 28; T, spp. 2), *Pleurospermum* Hoffm. (Y, spp. 19), *Pternopetalum* Franch. (Y, spp. 17), *Sanicula* L. (Y, spp. 7; T, spp. 2), *Selinum* L. (Y, spp. 2), *Seseli* L. (Y, spp. 3), *Sinocarum* H. Wolff (Y, spp. 7), *Sinolimprichtia* H. Wolff (Y, sp. 1), *Sium* L. (T, sp. 1), *Tetrataenium* (DC.) Manden. (Y, spp. 2), *Tongoloo* H. Wolff (Y, spp. 7), *Torilis* Adans. (Y, spp. 2; T, spp. 2), *Trachydium* Lindl. (Y, spp. 7), *Trachyspermum* Link (Y, spp. 2), *Vicatia* DC. (Y, spp. 3).

Urticaceae (Y, gen. 19; T, gen. 21): *Boehmeria* Jacq. (Y, spp. 17; T, spp. 8), *Chamabainia* Wight (Y, sp. 1; T, sp. 1), *Cypholophus* Wedd. (T, sp. 1), *Debregeasia* Gaudich. (Y, spp. 5; T, sp. 1), *Dendrocnide* Miq. (T, spp. 2), *Droguetia* Gaudich. (Y, sp. 1), *Elatostema* J. R. Forst. & G. Forst. (Y,

spp. 71; T, spp. 14), *Girardinia* Gaudich. (Y, spp. 2; T, sp. 1), *Gonostegia* Turcz. (T, spp. 3), *Laportea* Gaudich. (Y, spp. 5; T, spp. 2), *Lecanthus* Wedd. (Y, spp. 3; T, sp. 1), *Leucosyke* Zoll. & Moritsi (T, sp. 1), *Maoutia* Wedd. (Y, sp. 1; T, sp. 1), *Memorialis* (Benn.) Buch.-Ham. (Y, sp. 1), *Nanocnide* Blume (Y, sp. 1; T, sp. 1), *Oreocnide* Miq. (Y, spp. 7; T, spp. 2), *Pellionia* Gaudich. (Y, spp. 14; T, spp. 2), *Pilea* Lindl. (Y, spp. 43; T, spp. 13), *Pipturus* Wedd. (T, sp. 1), *Poikilospermum* Zipp. (Y, spp. 2; T, sp. 1), *Pouzolzia* Gaudich. (Y, spp. 6; T, spp. 2), *Procris* Comm. (Y, sp. 1; T, sp. 1), *Sarcoclamys* Gaudich. (Y, sp. 1), *Urtica* L. (Y, spp. 8; T, spp. 2).

Verbenaceae (Y, gen. 5; T, gen. 2): *Duranta* L. (Y, sp. 1), *Lantana* L. (Y, sp. 1; T, sp. 1), *Phyla* Lour. (Y, sp. 1; T, sp. 1), *Stachytarpheta* Vahl (Y, sp. 1), *Tsoongia* Merr. (Y, sp. 1).

Violaceae (Y, gen. 1; T, gen. 2): *Hybanthus* Jacq. (T, sp. 1), *Viola* L. (Y, spp. 58; T, spp. 13).

Vitaceae (Y, gen. 9; T, gen. 7): *Ampelocissus* Planch. (Y, spp. 3), *Ampelopsis* Michx. (Y, spp. 10; T, sp. 1), *Cayratia* Juss. (Y, spp. 12; T, spp. 2), *Cissus* L. (Y, spp. 14; T, spp. 5), *Leea* D. Royen (Y, spp. 7; T, spp. 2), *Parthenocissus* Planch. (Y, spp. 4; T, sp. 1), *Tetrastigma* (Miq.) Planch. (Y, spp. 32; T, spp. 4), *Vitis* L. (Y, spp. 12; T, spp. 4), *Yua* C. L. Li (Y, spp. 2).

Xyridaceae (Y, gen. 1; T, gen. 1): *Xyris* L. (Y, sp. 1; T, sp. 1).

Zannichelliaceae (Y, gen. 1; T, gen. 2): *Halodule* Endl. (T, spp. 2), *Zannichellia* L. (Y, sp. 1; T, sp. 1).

Zingiberaceae (Y, gen. 18; T, gen. 5): *Alpinia* Roxb. (Y, spp. 25; T, spp. 12), *Amomum* Roxb. (Y, spp. 26), *Boesenbergia* Kuntze (Y, spp. 3), *Caulokaempferia* Larsen (Y, sp. 1), *Cautleya* Hook. f. (Y, spp. 2), *Costus* L. (Y, spp. 5; T, sp. 1), *Curcuma* L. (Y, spp. 11), *Etilingera* Giseke (Y, spp. 2), *Globba* L. (Y, spp. 3), *Hedychium* J. Koenig (Y, spp. 16; T, sp. 1), *Kaempferia* L. (Y, spp. 3), *Paramomum* S. Q. Tong (Y, sp. 1), *Pommereschea* Wittm. (Y, spp. 2), *Rhynchanthus* Hook. f. (Y, sp. 1), *Roscoea* Sm. (Y, spp. 10), *Siliquamomum* Baill. (Y, sp. 1), *Stahlianthus* Kuntze (Y, spp. 2), *Vanoverberghia* Merr. (T, sp. 1), *Zingiber* Mill. (Y, spp. 25; T, spp. 4).

Zosteraceae (T, gen. 1): *Zostera* L. (T, sp. 1).

Zygophyllaceae (Y, gen. 1; T, gen. 1): *Tribulus* L. (Y, spp. 2; T, spp. 2).



Geographical patterns of Yunnan seed plants may be influenced by the clockwise rotation of the Simao-Indochina geoblock

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OPEN ACCESS

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Specialty section:

This article was submitted to
Biogeoscience,
a section of the journal
Frontiers in Earth Science

Received: 03 July 2015

Accepted: 02 September 2015

Published: 15 September 2015

Citation:

Zhu H (2015) Geographical patterns of
Yunnan seed plants may be influenced
by the clockwise rotation of the
Simao-Indochina geoblock.
Front. Earth Sci. 3:53.
doi: 10.3389/feart.2015.00053

Floristic patterns of seed plants in Yunnan, southwestern China, were studied to assess the relationship between the floristic geography and geological history. A database of 38 regional floristic studies covering Yunnan was used and the patterns of seed plant distributions across these regional floras were quantified at the generic level. Genera with tropical Asian distributions are the most dominant geographical elements in the Yunnan flora. They show oblique patterns of abundance across Yunnan. They are most abundant in southern and western Yunnan, and their proportion in regional floras declines abruptly in eastern, central and northern Yunnan. The oblique abundance patterns of geographical elements in Yunnan differ from those of genera in southern and eastern China, which had a high correlation with latitudinal gradients controlled by climate. They cannot be explained by climate alone, but can be explained at least partly by the geological history. The oblique abundance patterns of Yunnan seed plants correspond well to the clockwise rotation and southeastward extrusion of the Simao-Indochina geoblock caused by the collision of India with Asia.

Keywords: distribution patterns, geographical elements, Simao-Indochina geoblock, Yunnan, southwestern China

Introduction

Yunnan province in southwest China (21°09' and 29°15' N, 97°32' and 106°12' E; **Figure 1**) is situated in a transitional zone between tropical south-east Asia and temperate Himalayas, and it has a mountainous topography with elevation ranges from 76.4 m at the lowest valley bottom in the southeast (Red River) to 6740 m at the highest mountain summit in the northwest (**Figure 2**). Yunnan is extremely diverse in habitats and biodiversity. Southern Yunnan with a tropical monsoon climate has a tropical flora of Malaysian affinity (Zhu, 1997, 2008a; Zhu and Yan, 2009a). Central Yunnan with a subtropical climate is largely characterized by a subtropical flora of East Asian affinity (Yan et al., 2009). Northwestern Yunnan, with a temperate climate and alpine-deep valley topography, has a temperate Himalayan flora (Zhu, 2009, 2015).

Studies of the floristic patterns of Yunnan seed plants reveal that the majority of genera found in southern, southwestern and southeastern Yunnan are tropical, while the majority of genera found in northern Yunnan are temperate (Zhu, 2008b, 2012). Among the tropical genera, tropical Asian genera are most common. The abundances of these tropical Asian genera show oblique patterns across Yunnan, not latitudinal gradients as they are in southern and eastern China (Zhu et al., 2007).

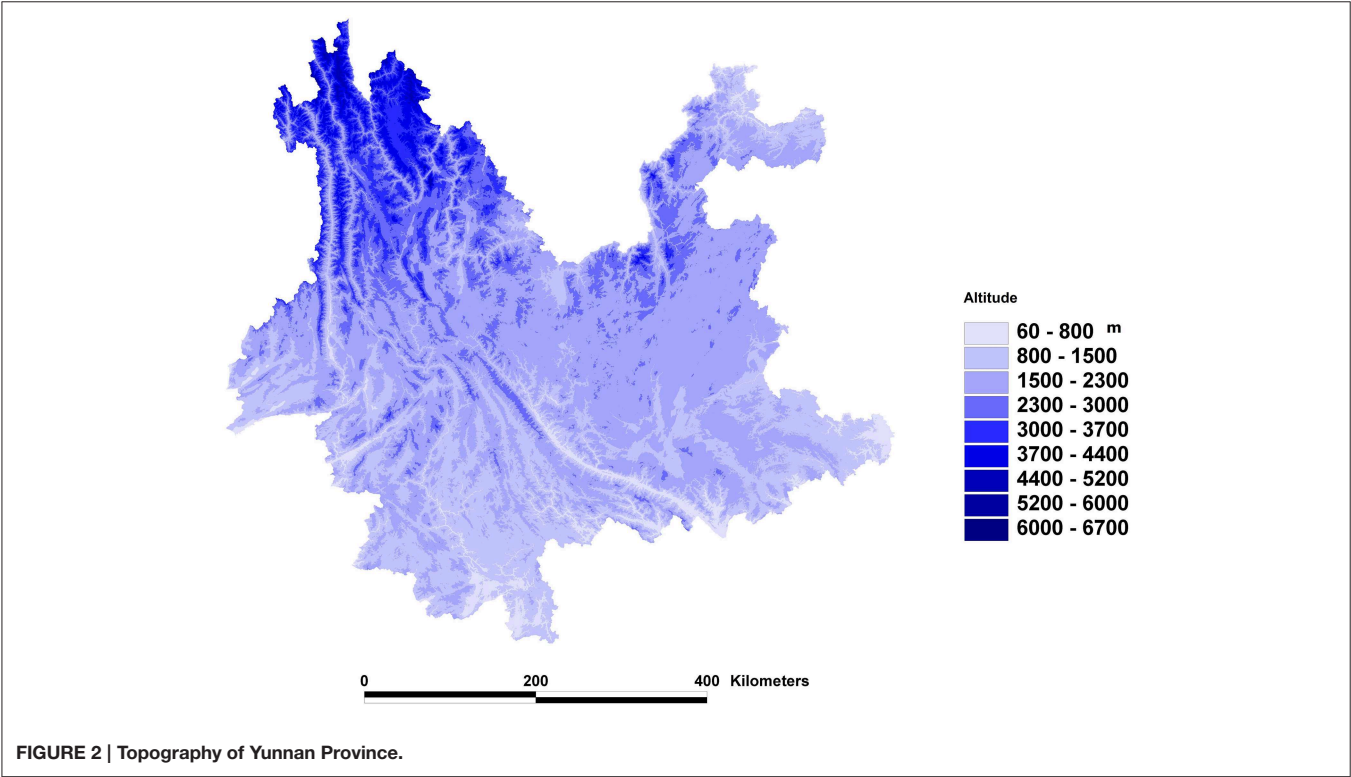
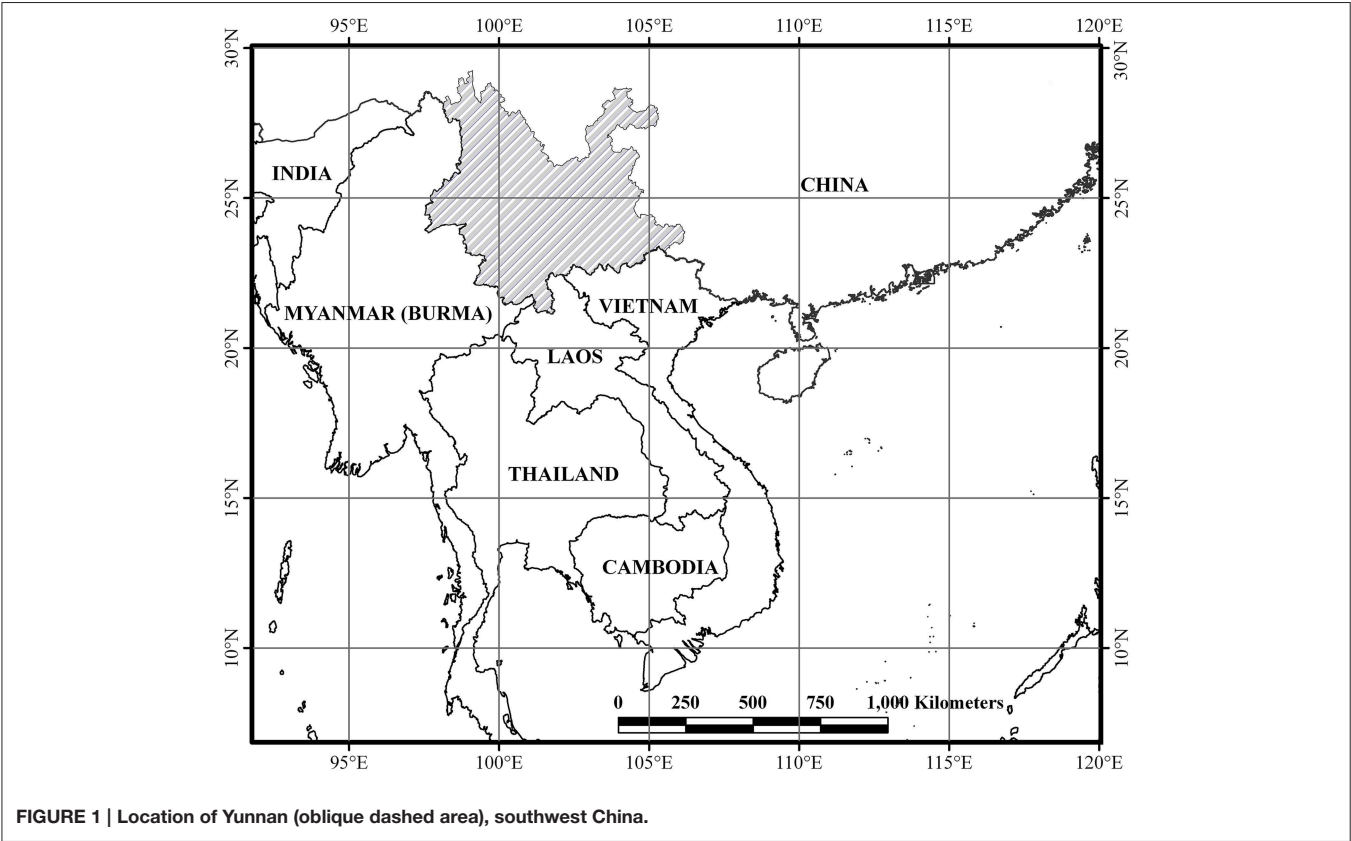


TABLE 1 | The geographical elements at generic level among the sites (regional flora) from references data.

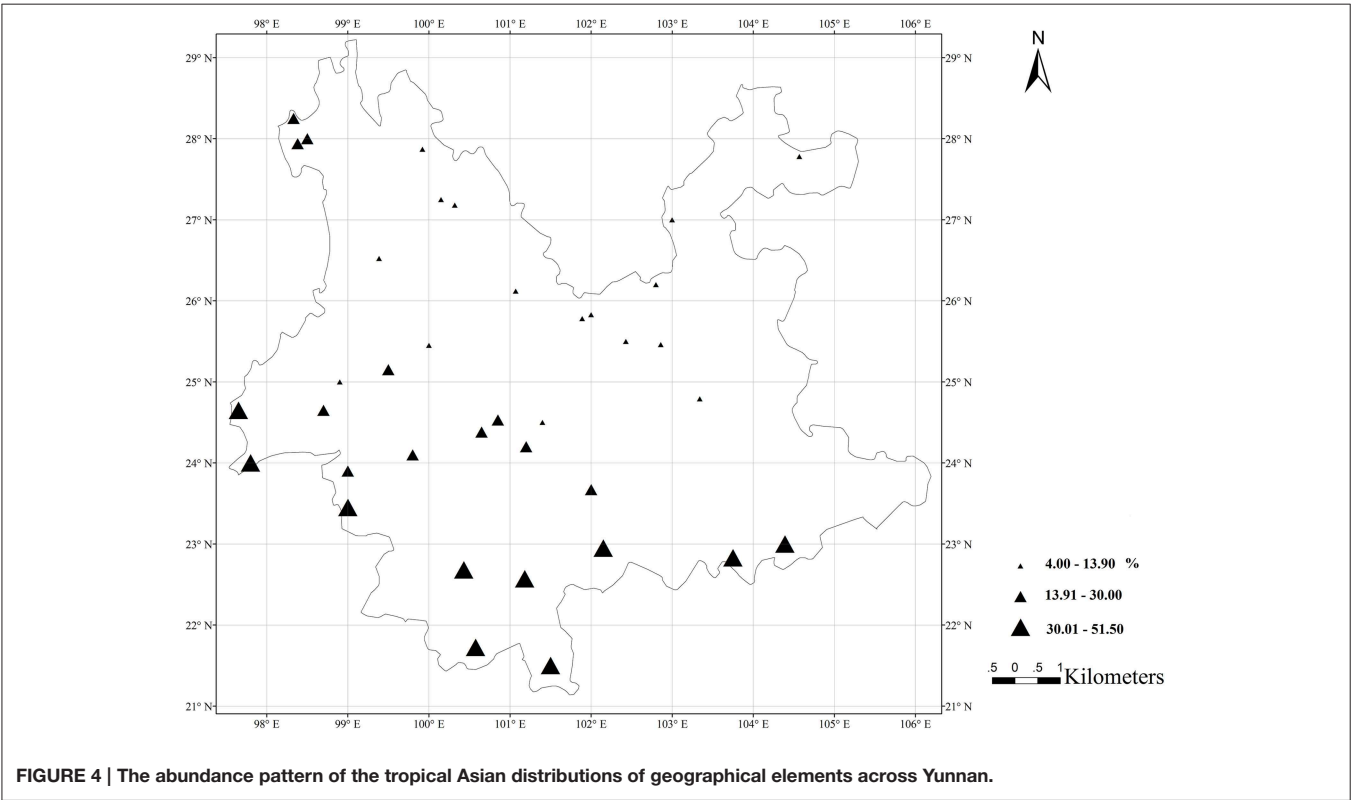
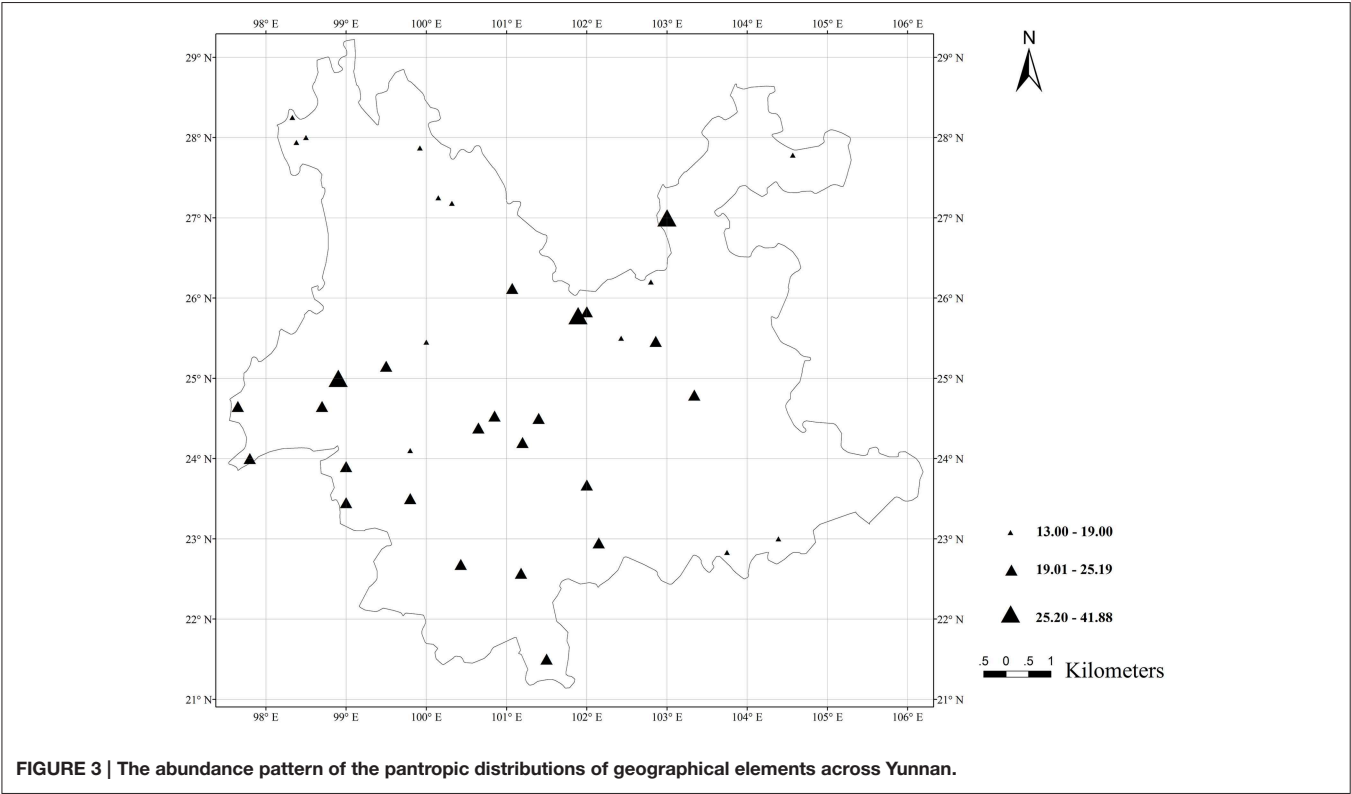
Research sites	Longitude	Latitude	PT*%	TA*%	TT*%	EA*%	References
Ailao Mts. NR	101.20	24.20	20.36	25.91	21.47	11.23	Zhu and Yan, 2009b
Bulong NR	101.00	22.00	22.33	37.52	9.91	3.69	Zhu et al., 2015
Caiyanghe NR	101.18	22.57	23.40	38.24	11.51	4.48	Zhu et al., 2006a
Cangshan NR	100.00	25.45	18.75	9.45	37.07	13.81	Duan, 1995
Dawei Mountain NR	103.75	22.83	18.75	37.00	13.85	8.46	Wang et al., 2006a
Dazhong Mt. NR	100.85	24.53	24.24	17.08	27.82	12.12	Ding et al., 2006
Dulongjiang NR	98.33	28.25	16.99	18.11	33.66	14.1	Li, 1994
Gaoligong Mt. NR	98.38	27.94	17.57	20.02	27.57	14.43	Li et al., 2000
Gulinqing NR	104.39	23.00	19.00	39.3	9.2	7.1	Kong, 2008
Haba Snow Mt. NR	100.15	27.25	13.98	4.1	43.9	14	Yunnan Forestry Survey Institute, 2009
Huanglianshan NR	102.15	22.95	21.66	37.28	12.31	7.57	Xu, 2003
Jiaozixueshan NR	102.80	26.20	13	6.9	43	12.1	Kunming Institute of Botany Chinese Academy of Sciences and Kunming Forestry Bureau, 2009
Jinguang Temple NR	99.50	25.15	19.19	22.12	25.25	12.77	Liu and Du, 1991
Langping Yunling NR	99.35	26.5	19.45	10.85	42.04	13.2	Yunnan Forestry Survey Institute, 2010
Luijiangba dry-hot valley	98.90	25.00	41.3	13.9	8.8	2.7	Cao, 1993
Nangunhe NR	99.00	23.45	24.40	38.1	10.39	4.62	Yang and Du, 2004
Nanpeng River NR	99.00	23.90	20.45	30	15.22	7.58	Zhang et al., 2010
Northern Gaoligong Mt. NR	98.50	28.00	14.8	17	33.2	17.5	Li et al., 2007
Nuozadu NR	100.43	22.68	25.19	35.39	11.34	4.53	Cao, 2004
Qiaojia dry-hot valley	103.00	27.00	34.00	11.2	24.2	5.3	Cao and Jing, 1989
Ruili Forest Park	97.80	24.00	24.90	35	10.1	2.1	Zhu et al., 2006b
Shilin NR	103.34	24.79	22.22	13.67	30.34	8.97	Cui et al., 2005
Shishan NR	102.86	25.46	21.58	9.34	37.76	12.24	Guo, 1988
Southern Gaoligong Mt. NR	98.76	24.83	25	31.26	18.8	7.8	Meng et al., 2013
Tongbiguan NR	97.65	24.65	20.42	33.8	14.97	9.24	Yin et al., 2007
Wuding region	102.00	25.83	20.38	11.43	32.35	10.27	Li et al., 2009
Wuliangshan NR	100.65	24.38	21.03	24.27	20.82	11.19	Peng, 1997
Xianggelila county	99.92	27.87	13.64	6.83	45.58	14.57	Li and Zeng, 2006
Xiaobaicaoling NR	101.07	26.12	19.62	10.58	39.04	12.5	Wang et al., 2005
Xiaoheishan NR	98.70	24.65	21.06	26.49	19.29	10.46	Wang et al., 2006b
Xishuangbanna NR	101.50	21.50	19.6	51.5	3.9	1.5	Zhu, 1993
Yongde Daxueshan NR	99.80	24.10	18.08	22.15	22.93	11.41	Liu and Peng, 2010
Yuanmou dry-hot valley NR	101.89	25.78	41.88	8.97	19.22	5.13	Li et al., 2008
Yulongxueshan NR	100.32	27.18	17.06	5.29	47.25	12.16	Ou, 1988
Yunajiang NR	102.00	23.67	23.69	24.92	16.88	7.54	Ma et al., 1995
Yunlong NR	102.43	25.50	17.42	11.74	43.57	10.61	Li et al., 2004
Zhaotong Region	104.57	27.78	15.47	12.19	33.27	14.53	Ding et al., 2008
Zixishan Natural Reserve	101.40	24.50	19.74	10.26	40	10	Li et al., 2010

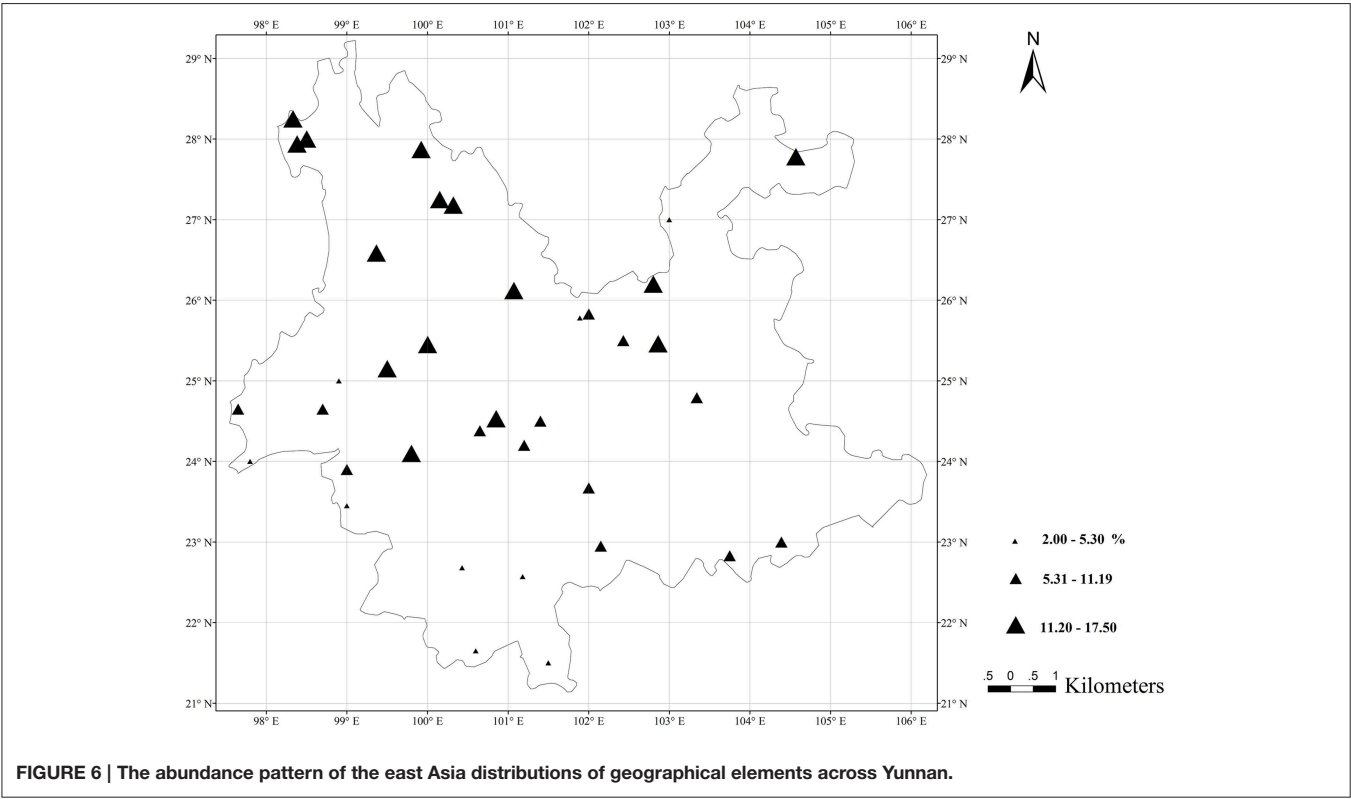
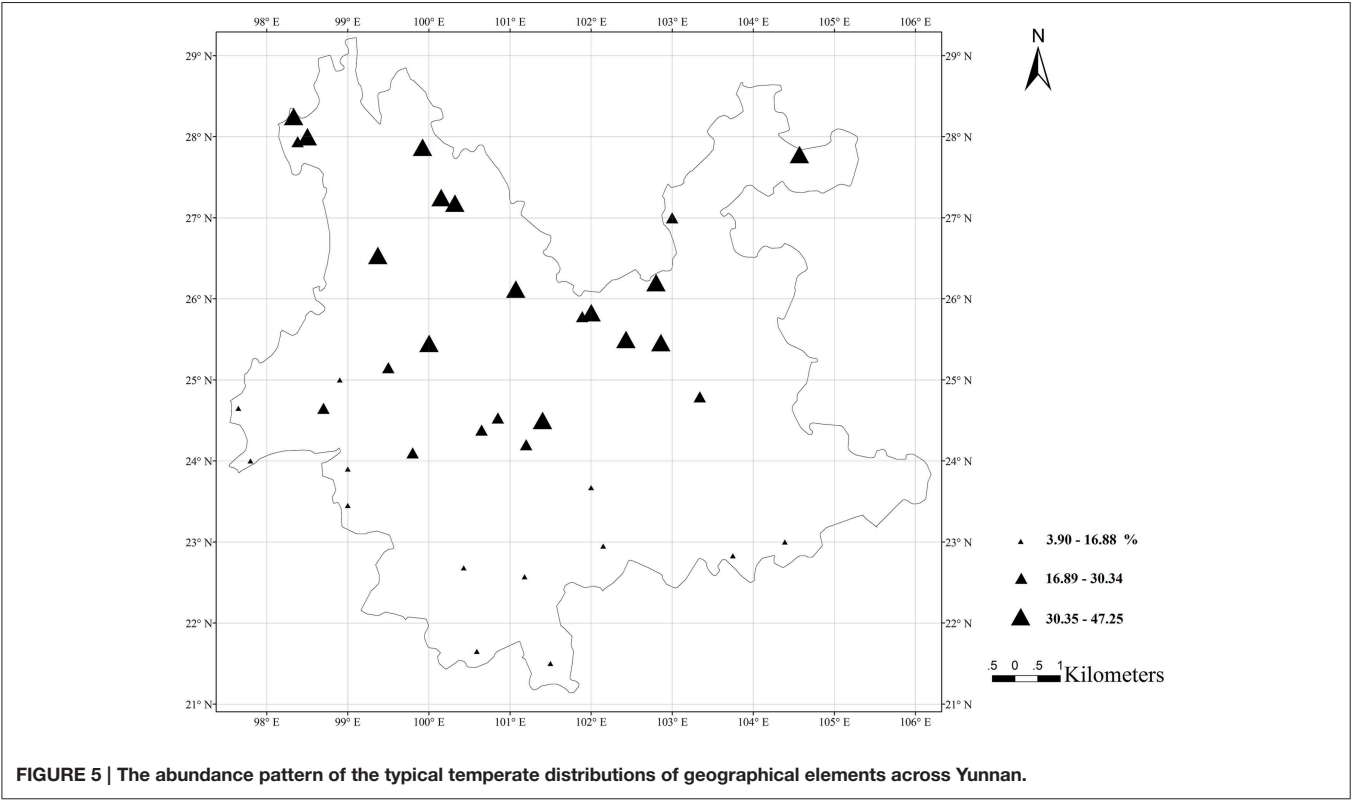
PT, Pantropic elements, defined with the distribution throughout the tropics of the world; TA, the tropical Asian elements, defined in *sensu lato*, including the typical tropical Asia distribution and tropical Asia to tropical Australia distribution; TT, the typical temperate elements, defined in *sensu lato*, including the typical north temperate distribution, east Asia and north America disjunct, and Old World temperate distributions; EA, East Asia elements, defined with the distribution from east Himalayas to Japan.

Biogeographical divergence of the flora of Yunnan was initiated by the uplift of the Himalayas and the extrusion of the Indochina block during the Tertiary (Zhu, 2012). The Indian continent collided with Asia at about 50 Ma (Rowley, 1996) causing uplift of the Himalayas, continuous deformation of southwestern China and a large clockwise rotation and southeastward extrusion of Indochina (Harrison et al., 1992; Funahara et al., 1993; Chen et al., 1995; Leloup et al., 1995). The Simao Terrane, which forms the present west and south parts of

Yunnan, has been suggested as one of the prominent fragments of the extruded Indochina block (Sato et al., 1999, 2001, 2007). As a whole, the Simao Terrane was displaced southward by 800 km, together with a clockwise rotation of 30°. The rotation processes were believed active until at least the Miocene (Schärer et al., 1990; Chen et al., 1995). These geological events may thus have affected the evolution of the Yunnan flora.

It is interesting to know whether the distribution patterns of seed plants in Yunnan have been affected by geological events. In





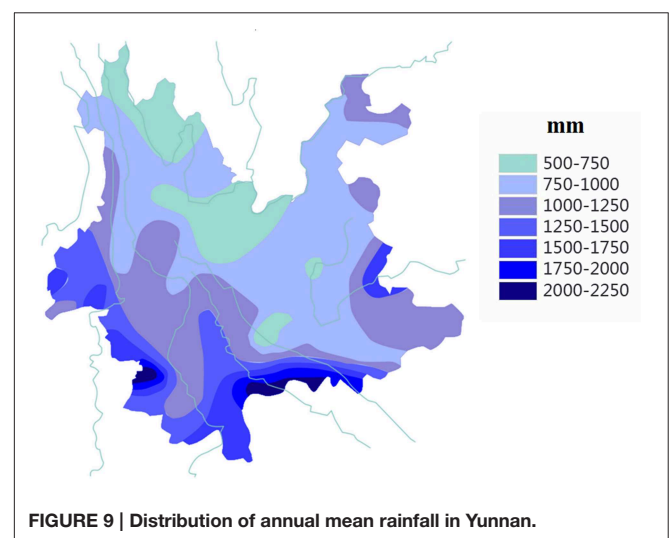
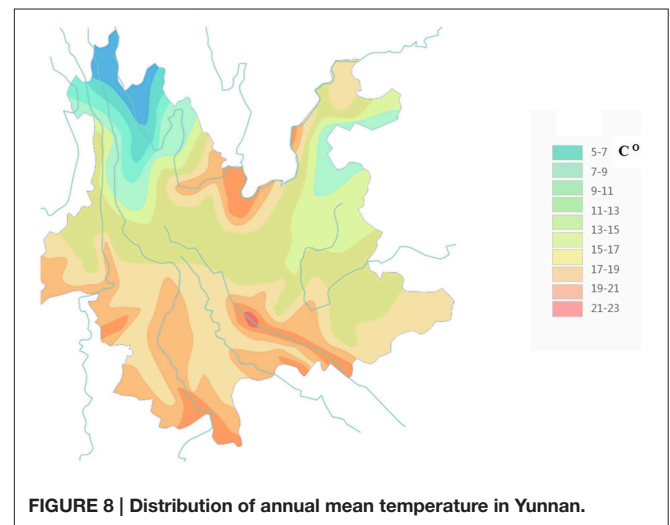
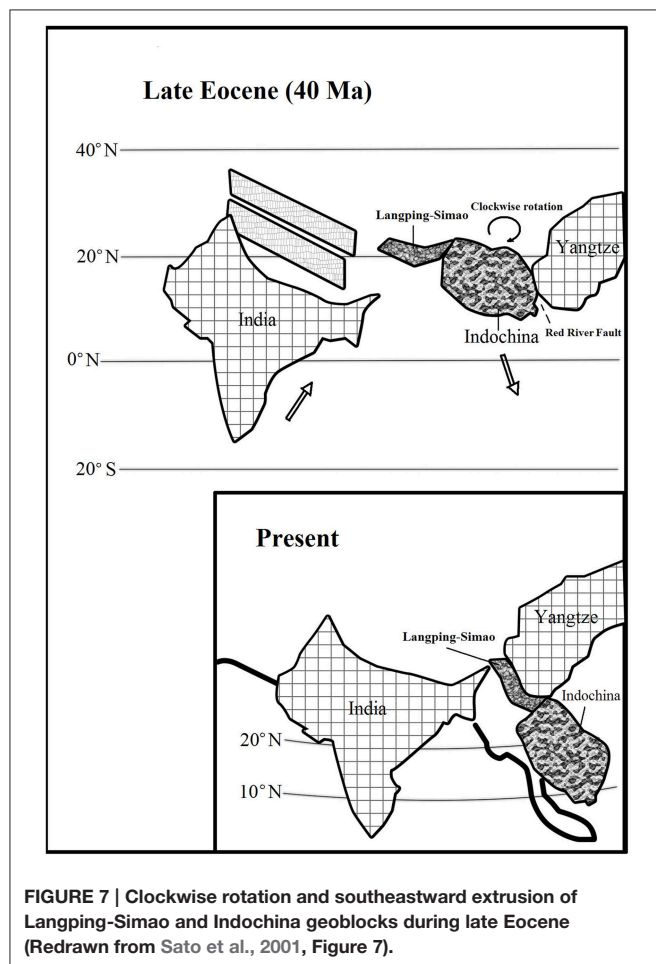
this article, I will address the correspondence by comparing the distribution patterns of Yunnan seed plants and the geological events.

Materials and Methods

A database of 38 regional floristic studies covering Yunnan was used to illustrate the distribution patterns of their floristic elements (Table 1). These studies were done mostly in well-protected nature reserves. The seed plant genera were assigned to 15 distribution patterns according to their worldwide geographical distributions, following Wu's classification (Wu, 1991) as follows: Cosmopolitan, Pantropic, Tropical Asia, and Tropical America disjunct, Old World Tropics, Tropical Asia to Tropical Australia, Tropical Asia to Tropical Africa, Tropical Asia, North Temperate, East Asia, and North America disjunct, Old World Temperate, Temperate Asia, Mediterranean region, West to Central Asia, Central Asia, East Asia, and Endemic to China. The Cosmopolitan distributions have little geographical significance and here are not used. Patterns of seed plant distributions across these regional floras were quantified at the generic level based on Wu's documentation. Here the tropical Asian elements are defined in *sensu lato*, including the typical tropical Asia distribution and tropical Asia to

tropical Australia distribution. The typical temperate elements are defined in *sensu lato*, including the typical north temperate distribution, east Asia and north America disjunct, and Old World temperate distributions. Such pantropic elements, the tropical Asian elements in *sensu lato*, and the typical temperate elements in *sensu lato*, as well as the East Asia elements are recognized to be the four dominant elements, which contribute the majority not only in the total flora of Yunnan, but also in the regional floras in Yunnan. These four dominant geographical elements were abstracted from the regional floras and are used in our study (Table 1).

ArcView software was used for making abundance maps of the four geographical elements from the regional floras. The abundances were grouped into three classes, which were classified by natural breaks, with breakpoints between classes identified using Jenk's optimization, a default classification method in ArcViewGIS 3.1 that reduces variance within classes and maximizes variance between them. Graduated symbols were used.



The Simao Terrane, which forms the present west and south parts of Yunnan, was displaced southward by 800 km, together with a clockwise rotation of 30°. The rotation processes were believed active until at least the Miocene. This unique geological history may influence these abundant patterns of dominant geographical elements across Yunnan. Here the abundant patterns of geographical elements across Yunnan were used to discuss the relationship between the floristic geography and geological history of Yunnan.

Results

Genera with pantropic distributions contribute 13–41.88% of the regional floras across Yunnan. The abundance pattern of the pantropic genera shows little correspondence with latitude, but has high proportion at dry-hot valleys (**Figure 3**). The highest proportion, which makes of 41.88% of the total regional flora, is at the Yuanmou dry-hot valley of Jingshan rive in northern Yunnan, and the second highest proportion is at the dry-hot valley of Lujiang rive in western Yunnan. Genera with tropical Asian (*sensu lato*) distributions contribute 4% (in northern Yunnan) to 51.5% (in southern Yunnan) of the regional floras across Yunnan. The abundance pattern shows that they occur mainly in southern and western Yunnan, and their proportions in regional floras declines abruptly in eastern, central and northern Yunnan (**Figure 4**). The typical temperate (*sensu lato*) genera contribute 3.9% (in southern Yunnan) to 47.25% (in northern Yunnan) of the regional floras across Yunnan (**Figure 5**). The east Asia genera contribute 2% in southern Yunnan to 17.5% in northern Yunnan (**Figure 6**).

Obviously, the tropical Asian genera show oblique abundance patterns across Yunnan. For example, in the Dulongjiang region in the far northwest of Yunnan (28.25 N, 98.33 E), the tropical Asian genera contribute 18.11% of the total regional flora, while in the adjacent Lijian region (27.18 N, 100.32 E), the tropical Asian genera only comprise 5.29%.

Discussion

Geographical elements were considered related to latitude and altitude. The abundances of geographical elements

across Yunnan show complicated patterns. The abundance pattern of the pantropic genera shows high proportion at dry-hot valleys despite latitude and altitude. The abundance pattern of the typical temperate genera shows some relations to latitude and altitude. The abundance pattern of the east Asia genera shows also some relations to latitude and altitude, but a higher proportion in southeast Yunnan.

In southern and eastern China, the abundances of tropical Asian genera have high correlations with latitudinal gradients (Zhu et al., 2007; Zhu, 2013). However, the abundances of these genera show oblique patterns across Yunnan, not latitudinal gradients. The tropical Asian genera unusually occur in a much higher percentages in western Yunnan than in eastern Yunnan. They decrease in proportion abruptly in northeast of Yunnan.

These abundance patterns of geographical elements across Yunnan show some correspondence with topography, but if we see the geological history of Yunnan (**Figure 7**), these abundance patterns correspond well to the clockwise rotation and southeastward extrusion of the Simao-Indochina geoblock. Compared with the distribution patterns of the annual mean temperature (**Figure 8**) and annual mean rainfall (**Figure 9**) in Yunnan, the abundances of geographical elements across Yunnan also do not show well correspondence with them as the usual.

Therefore, we consider that the relatively high proportion of tropical Asian genera in western and southwestern Yunnan matches the clockwise rotation of the Simao Terrane and the southeastward extrusion of the Simao-Indochina geoblock that facilitated migrations of SE Asian plants. These oblique patterns in Yunnan cannot be explained by climate alone, but can be explained at least partly by the geological history.

Acknowledgments

This research was supported by the National Natural Science Foundation of China, No. 41071040, 41471051, 31170195. The Database was put together by Yan Lichun. Prof. Richard Corlett helped improve the English of the article.

References

- Cao, M., and Jing, Z. Z. (1989). Classification of vegetation in Qiaojia dry-hot river valley of Jinsha river, Yunnan. *Acta Botan. Yunnan.* 17, 324–336.
- Cao, S. W. (2004). Flora analysis of seed plants in Nuozadu Nature Reserve. *J. West China For. Sci.* 33, 46–51.
- Cao, Y. H. (1993). A research on the flora of Nujiang dry-hot valley in Lujiangba, Yunnan. *Acta Botan. Yunnan.* 15, 339–345.
- Chen, H. H., Dobson, J., Heller, F., and Hao, J. (1995). Paleomagnetic evidence for clockwise rotation of the Simao region since the Cretaceous, A consequence of India-Asia collision. *Earth Planet. Sci. Lett.* 134, 203–217. doi: 10.1016/0012-821X(95)00118-V
- Cui, J. W., Liu, W. Y., Li, Y. H., She, Y. X., and Liu, L. H. (2005). The floristic elements of seed plants in stone forest limestone region, Yunnan Province. *Guihaia* 25, 517–525.
- Ding, L., Du, F., Wang, J., Shi, C. Y., and Su, W. P. (2008). The flora of seed plants in northern Zhaotong, Yunnan province. *Acta Botan. Yunnan.* 30, 139–145. doi: 10.3724/SP.J.1143.2008.00139
- Ding, Q., Li, X. W., and Fan, G. S. (2006). Study on flora of seed plants from dazhong mountain in the south central yunnan province. *J. Southw. For. College* 26, 6–9.
- Duan, C. Z. (ed.). (1995). *Scientific Investigation of Plant on Cangshan Mountain*. Kunming: Yunnan Science, Technology Press, 238.
- Funahara, S., Nishiwaki, N., Murata, F., Otofujii, Y., and Wang, Y. (1993). Clockwise rotation of the Red River fault inferred from paleomagnetic study of Cretaceous rocks in the Shan-Thai-Malay block of western Yunnan,

- China. *Earth Planet. Sci. Lett.* 117, 29–42. doi: 10.1016/0012-821X(93)90115-P
- Guo, Q. F. (1988). A preliminary study on the floristic plant geography of Shishan mountain Wuding, C. Yunnan. *Acta Botan. Yunnan.* 10, 183–200.
- Harrison, T. M., Chen, W. J., Leloup, P. H., Ryerson, F. J., and Tapponnier, P. (1992). An early Miocene transition in deformation regime within the Red River fault zone, Yunnan, and its significance for Indo-Asian tectonics. *J. Geophys. Res.* 97, 7159–7182. doi: 10.1029/92JB00109
- Kong, D. C. (2008). Plant diversity and integrated assessment for Gulinqing nature reserve in Maguang County. *For. Invent. Plann.* 33, 22–26.
- Kunming Institute of Botany Chinese Academy of Sciences and Kunming Forestry Bureau. (2009). *Scientific Investigation Report on Yunnan Jiaozixueshan Nature Reserve*, Kunming: Kunming Institute of Botany.
- Leloup, P. H., Lacassin, R., Tapponnier, P., Schärer, U., Dalai, Z., Liu, X. H., et al. (1995). The Ailao Shan-Red River shear zone Yunnan, China, Tertiary transform boundary of Indochina. *Tectonophysics* 251, 3–84. doi: 10.1016/0040-1951(95)00070-4
- Li, G. C., Meng, G. T., Peng, F. S., and Zhang, J. Z. (2010). Preliminary study on the flora of the tracheophytes in Zixishan Natural Reserve. *For. Surv.* 153, 65–69.
- Li, H. (1994). Delineation and feature of Dulongjiang region flora. *Acta Botan. Yunnan.* (Supp. XI), 1–100.
- Li, H., Guo, H. J., and Dao, Z. L. (2000). *Flora of Gaoligong Mountains*. Beijing: Science Press, 344.
- Li, H. T., Du, F., and Wang, J. (2008). Studies on floristics of seed plants in Yuanjiang Nature Reserve in Yunnan Province. *J. Trop. Subtrop. Bot.* 16, 446–451.
- Li, P. R., Meng, G. T., and Fang, X. J. (2009). Flora of seed plants in Wuding County, Yunnan. *J. North. For. Univ.* 37, 106–108.
- Li, P. R., and Zeng, J. M. (2006). Preliminary study on flora of seed plants in Xianggelila County, Yunnan Province. *J. Zhejiang For. College* 23, 367–372.
- Li, R. C., Yang, Y., Yang, Z. L., Zhao, L., Li, S. W., Li, X., et al. (2004). A floristic study on the seed plants from Yunlong reservoir area in Yunnan. *Guihaia* 24, 385–389.
- Li, R., Dao, Z. L., and Ji, Y. H. (2007). A floristic study on the seed plants of the Northern Gaoligong Mountains in Western Yunnan, China. *Acta Botan. Yunnan.* 29, 601–615.
- Liu, D. C., and Du, F. (1991). A preliminary study on flora of Jinguang Temple natural reserve in Western Yunnan. *J. Southw. For. College* 11, 115–124.
- Liu, E. D., and Peng, H. (2010). *Research on the Seed Plants and Forest Vegetation in Mount Yongdedaxueshan*. Kunming: Yunnan Science, Technology Press, 1–501.
- Ma, K. P., Gao, X. M., and Yu, S. L. (1995). On the characteristics of the flora of Dongling Mountain area and its relationship with a number of other flora mountainous floras in China. *Bull. Botan. Res.* 15, 501–515.
- Meng, G. Z., Chai, Y., Yuan, M. C., Ai, H. S., Li, G. X., Wang, Q., et al. (2013). Community characteristics of the mid-montane humid evergreen broad-leaved forest in Gaoligong Mountains, Yunnan. *Sci. Silv. Sin.* 49, 144–151.
- Ou, X. K. (1988). The study of the flora in Yuanmou dry hot river valley. *Acta Botan. Yunnan.* 10, 11–18.
- Peng, H. (1997). The endemism in the flora of seed plants in Mt. Wuliangshan. *Acta Botan. Yunnan.* 19, 1–14.
- Rowley, D. B. (1996). Age of initiation of collision between India and Asia, a review of stratigraphic data. *Earth Planet. Sci. Lett.* 145, 1–13. doi: 10.1016/S0012-821X(96)00201-4
- Sato, K., Liu, Y. Y., Wang, Y. B., Yokoyam, M., Yoshioka, S., Yang, Z. Y., et al. (2007). Paleomagnetic study of Cretaceous rocks from Pu'er, western Yunnan, China, Evidence of internal deformation of the Indochina block. *Earth Planet. Sci. Lett.* 258, 1–15. doi: 10.1016/j.epsl.2007.02.043
- Sato, K., Liu, Y. Y., Zhu, Z. C., Yang, Z. Y., and Otofujii, Y. (1999). Paleomagnetic study of middle Cretaceous rocks from Yunlong, western Yunnan, China, evidence of southward displacement of Indochina. *Earth Planet. Sci. Lett.* 165, 1–15. doi: 10.1016/S0012-821X(98)00257-X
- Sato, K., Liu, Y. Y., Zhu, Z. C., Yang, Z. Y., and Otofujii, Y. (2001). Tertiary paleomagnetic data from northwestern Yunnan, China, further evidence for large clockwise rotation of the Indochina block and its tectonic implications. *Earth Planet. Sci. Lett.* 185, 185–198. doi: 10.1016/S0012-821X(00)00377-0
- Schärer, U., Tapponnier, P., Lacassin, R., Leloup, P. H., Dalai, Z., and Ji, S. C. (1990). Intraplate tectonics in Asia, a precise age for large-scale Miocene movements along the Ailao Shan-Red River shear zone, China. *Earth Planet. Sci. Lett.* 97, 65–77. doi: 10.1016/0012-821X(90)90099-J
- Wang, J., Ma, Q. Y., and Du, F. (2006a). Flora diversity characteristics of seed plants of Dawei Mountain National Nature Reserve in Yunnan province, China. *Sci. Silv. Sin.* 42, 8–15.
- Wang, L. S., Kong, D. R., Ma, H. Y., and Peng, H. (2005). A preliminary study on floristics of spermatophyte from Mt.Xiaobaicaoling, Central Yunnan, China. *Acta Botan. Yunnan.* 27, 125–133.
- Wang, Y. B., Du, F., and Cao, S. W. (2006b). Study on floristic phytogeography of seed plants in Xiaoheishan reserve, Yunnan Province. *Guihaia* 26, 261–267.
- Wu, Z. Y. (1991). The areal-types of Chinese genera of seed plants. *Acta Botan. Yunnan* (Supp. IV), 1–139.
- Xu, J. C. (ed.). (2003). *Yunnan Huanglianshan Nature Reserve*. Kunming: Yunnan Sci., Tech. Press.
- Yan, L. C., Shi, J. P., Zhu, H., Peng, H., Liu, Y. H., and Wang, H. (2009). The studies on floristics of seed plants in Ailaoshan Region, Yunnan, China. *J. Trop. Subtrop. Bot.* 17, 283–291.
- Yang, Y. M., and Du, F. (2004). *Nangun River National Nature Reserve of China*. Kunming: Yunnan Sci., Techn. Press, 1–386.
- Yin, W. Y., Shu, Q. T., and Li, J. Y. (2007). A study on flora of spermatophyte of Tongbiguan nature reserve in Yunnan. *J. Northw. Agric. For. Univ.* 35, 204–210.
- Yunnan Forestry Survey Institute. (2009). *Scientific Investigation Report on Haba Snow Mt.* Kunming: Nature Reserve, 1–408.
- Yunnan Forestry Survey Institute. (2010). *Scientific Investigation Report on Langping Yunling*. Kunming: Nature Reserve, 1–222.
- Zhang, Q. R., Du, F., Du, X. L., He, X., Zhuang, C. Z., Yan, X. H., et al. (2010). Flora of Seed Plants in Nanpeng River Nature Reserve in Yunnan Province. *J. North. For. Univ.* 38, 71–74.
- Zhu, H. (1993). Floristic Plant geography on the dipterocarp forest of Xishuangbanna. *Acta Botan. Yunnan.* 15, 233–252.
- Zhu, H. (1997). Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *J. Biogeogr.* 24, 647–662. doi: 10.1111/j.1365-2699.1997.tb00075.x
- Zhu, H. (2008a). The tropical flora of southern Yunnan, China, and its biogeographical affinities. *Ann. Miss. Botan. Gard.* 95, 661–680. doi: 10.3417/2006081
- Zhu, H. (2008b). Distribution patterns of genera of Yunnan seed plants with references to their biogeographical significances. *Adv. Earth Sci.* 23, 830–839.
- Zhu, H. (2009). *Read the Nature—Geological Wonder and Vegetation Geography of the Three Parallel Rivers Region in Northwest Yunnan*. Beijing: Science Press, 1–155.
- Zhu, H. (2012). Biogeographical divergence of the flora of Yunnan, southwestern China initiated by the uplift of Himalaya and extrusion of indochina block. *PLoS ONE* 7:e45601. doi: 10.1371/journal.pone.0045601
- Zhu, H. (2013). Geographical elements of seed plants suggest the boundary of the tropical zone in China. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 386, 16–22. doi: 10.1016/j.palaeo.2013.04.007
- Zhu, H. (2015). Biogeography of Shangri-la flora in southwestern China. *Phytotaxa* 203, 231–244 doi: 10.11646/phytotaxa.203.3.2
- Zhu, H., Chai, Y., Zhou, S. S., Wang, H., and Yan, L. C. (2015). Vegetation, floristic composition and species diversity in a tropical mountain nature reserve in southern Yunnan, SW China with implications to conservation. *Trop. Conserv. Sci.* 8, 528–547.

- Zhu, H., Ma, Y. X., Yan, L. C., and Hu, H. B. (2007). The relationship between geography and climate in the generic-level patterns of Chinese seed plants. *J. Syst. Evol.* 45, 134–166.
- Zhu, H., and Yan, L. C. (2009a). Biogeographical affinities of the flora of southeastern Yunnan, China. *Botan. Stud.* 50, 467–475.
- Zhu, H., and Yan, L. C. (2009b). *List of Seed Plants in the Ailao Mts. of Yunnan Province, China*. Kunming: Yunnan Science, Technology Press, 1–731.
- Zhu, H., Zhao, C. J., Wang, H., Zhou, S. S., Shi, J. P., and Li, B. G. (2006a). A study on the flora of Caiyanghe Nature Reserve in Simao, Yunnan with references to the transition from tropical Asian flora to Eastern Asian flora. *Bull. Botan. Res.* 26, 38–52.
- Zhu, H., Zhao, J. M., Li, L., and Si, H. H. (2006b). A study on the flora of the seed plants of tropical rain forest of Rui-li, SW Yunnan. *Guihaia* 26, 400–405.
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Biogeography of Shangri-la flora in southwestern China

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Abstract

Shangri-la region of southwestern China is within the Hengduan Mountains biodiversity hotspot and is exceptional in floral diversity. Based on intensive field investigations and herbarium specimens, 6807 species of native seed plants from 1297 genera and 166 families were recognized. The flora is dominated by families and genera with cosmopolitan and north temperate distributions, including Apiaceae, Asteraceae, Ericaceae, Fabaceae, Gentianaceae, Lamiaceae, and the genera *Pedicularis*, *Rhododendron*, and *Salix*, which contribute up to 73.15 % of the total number of species, but only make up a small portion of the total number of families and genera. Families and genera with fewer species more commonly have tropical distributions, while East Asian and Chinese endemic families and genera are mostly monotypic and oligotypic, and contribute little to the floristic diversity of the region. It is revealed that the flora of Shangri-la might have evolved through rapid speciation mainly from families and genera of cosmopolitan and north temperate distributions with the uplift of the Himalayas and climatic oscillations after the late Tertiary. The macroevolution of the flora in the Shangri-la region interpreted by floristic patterns is well supported by phylogeographic studies on plant taxa in Hengduan-Qinghai-Tibet Plateau regions.

Keywords: Biogeography; floristic composition; geographical elements; Shangri-la; southwestern China

Introduction

Shangri-la region is situated in the northwestern corner of China's Yunnan Province (27°10'–28°27' N and 98°53'–99°42' E) (Figure 1). It lies within the Hengduan Mountains (Li 1987), which is one of the world's biodiversity hotspots (Boufford & Dijk 2000; Le *et al.* 2007). Shangri-la is one of the most biodiverse regions in China and is of global conservation priority (Myers *et al.* 2000).

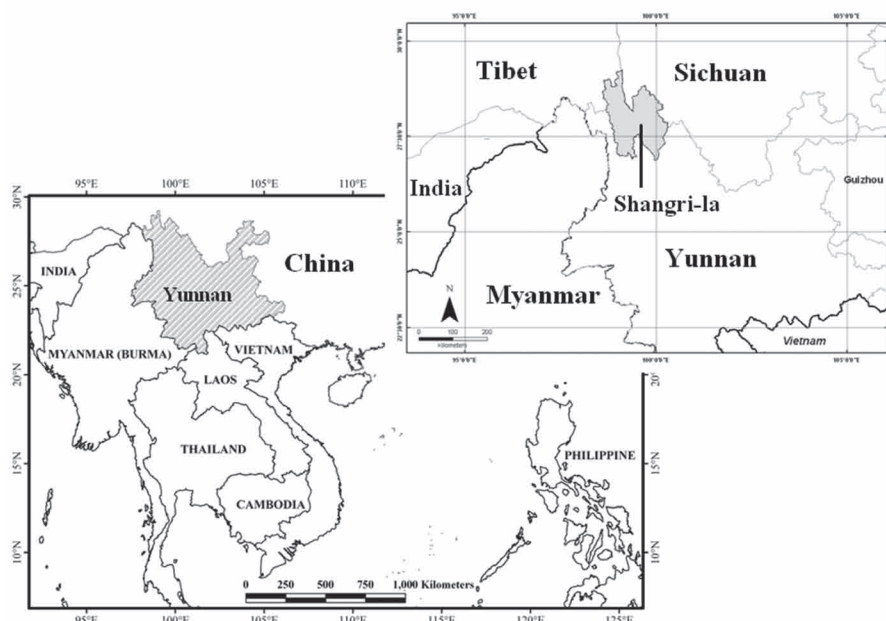


FIGURE 1. Map showing the study area, the Shangri-la region in SW China.

Shangri-la region has a very complex geology (Li 1987). The region was in a sutural zone between Gondwana and Laurasia (Jin 2002; Metcalfe 2006) and its topography shaped by the collision between the Indian and Eurasian plates and the uplift of the Himalayas (Office of Yunnan World Heritage management Committee 2002). The region underwent a more recent and rapid uplift with the Himalayas after the Pleistocene (Shi *et al.* 1999). Shangri-la region has an extremely diverse topography with altitudes from ca. 2000 m, at the bottoms of valleys, to 6740 m at the summit of the Meili Snow Mountain. Evidently, climatic variation in the region corresponds to altitude, with subtropical dry climates in valleys, and cold temperate climates in alpine areas.

Shangri-la region is extremely rich in biodiversity and is of great interest to botanists. The region holds more than 20% of the total sum of plant species in China, although it covers less than 0.2% of the country's territory. The region contains various habitats and vegetation types: subtropical evergreen broad-leaved forest, subtropical semi-humid evergreen broad-leaved forest, montane humid evergreen broad-leaved forest, sclerophyllous forest, warm temperate coniferous forest (such as *Pinus yunnanensis* forest), temperate deciduous broad-leaved forest, temperate coniferous forest (such as *Tsuga dumosa* forest and *Pinus densata* forest), cold temperate coniferous forest (such as *Picea* forest, *Abies* forest and *Larix* forest), microphyllous scrubs in warm and dry valleys, alpine meadows, and scrubs (Zhu 2009). Shangri-la is not only very rich in species diversity, but also in endemic species (Le *et al.* 2007). Understanding of the origin and evolution of the Shangri-la flora is extremely important for understanding the plant geography of Hengduan Mountains as a whole.

Shangri-la flora is composed largely of temperate elements and was suggested to have evolved with the uplift of the Himalayas (Zhu 2012). Studies on palaeobotany suggested that the region had a temperate and subtropical flora during the Tertiary (Mehrotra *et al.* 2005). Historic events such as the uplift of the Himalayas and climatic oscillations in the Quaternary period have affected the evolution of the flora of the Hengduan-Qinghai-Tibet Plateau. The divergence, radiation, evolution, and speciation of plants in these regions are considered to be correlated with the uplift of the Plateau (Chen *et al.* 2005; Liu *et al.* 2006; Yuan *et al.* 2008; Wang *et al.* 2009; Cun & Wang 2010; Zhang *et al.* 2011; Chen *et al.* 2012; Yang *et al.* 2012).

Phylogeographic studies revealed that divergence and speciation of plants in the Hengduan-Qinghai-Tibet Plateau are closely related to the uplift of Himalayas and many plants on these regions colonized from other areas or are recently derived endemic species (Liu *et al.* 2006; Ran *et al.* 2006; Yang *et al.* 2008). It is of interest to understand whether these phylogeographic patterns correspond to the macro-evolutionary patterns of regional flora. This paper aims to (i) analyze the floristic patterns and geographical elements of Shangri-la region; (ii) examine the origin and evolution of Shangri-la flora with the uplift of Himalayas; and, (iii) discuss the relationship between phylogeographic patterns and floristic evolution of the Hengduan Mountains.

Materials and Methods

Shangri-la region lies at the centre of the Hengduan Mountains and covers a total area of 23,870 km². During the years 2004–2009, the Xishuangbanna Tropical Botanical Garden of the Chinese Academy of Sciences conducted intensive plant inventories in the region. A complete list of native seed plant species was obtained based on inventory data, a recently completed Flora of Yunnan (Wu 1977–2006), a database of seed plants from KUN (herbarium of Kunming Institute of Botany, Chinese Academy of Sciences), and data from Wu and Ding (1999). The circumscriptions of families followed APG III (Chase & Reveal 2009; THE ANGIOSPERM PHYLOGENY GROUP 2009), and species followed the nomenclature of w³TROPICOS (<http://mobot.mobot.org/W3T/Search/vast.html>). Patterns of seed plant distribution were quantified at the generic and the family levels following Wu (1991) and Wu *et al.* (2003, 2006). The biogeographical affinity of the flora is studied in view of geographical elements at family and generic levels. In order to discuss the relationship of the Shangri-la flora to floras of Southern and Southeast China, three representative regional floras from southern-west, southern-centre and Southeast China respectively at almost the same latitude as the Shangri-la region are selected to make comparison. The macro-evolution of the flora of the Shangri-la is discussed referring phylogeographical patterns of plants in the plateau.

Results

Floristic composition

A total of 6807 native seed plant species, including 270 subspecies and varieties, from 1297 genera and 166 families were recognized from the Shangri-la region. Families with the highest species richness include Asteraceae (518 species), Poaceae (395), Rosaceae (358), Orchidaceae (323), Fabaceae (299), Ericaceae (284), Ranunculaceae (238) and Lamiaceae (220) (Table 1). These families are also the most species rich families worldwide.

TABLE 1. Dominant families and genera in species richness with their distribution.

Family ranking by their species richness	No. of species in the flora	Distribution type*	Genera ranking by their species richness	No. of species in the flora	Distribution type*
Asteraceae	518	1	<i>Rhododendron</i> L.	183	4
Poaceae	395	1	<i>Pedicularis</i> L.	119	4
Rosaceae	358	1	<i>Salix</i> L.	105	4
Orchidaceae	323	1	<i>Carex</i> L.	93	1
Fabaceae	299	1	<i>Primula</i> L.	93	4
Ericaceae	284	1	<i>Gentiana</i> L.	90	4
Ranunculaceae	238	1	<i>Saxifraga</i> L.	86	4
Lamiaceae	220	1	<i>Saussurea</i> DC.	71	5
Apiaceae	198	1	<i>Polygonum</i> L.	65	1
Orobanchaceae	181	1	<i>Rubus</i> L.	64	1
Cyperaceae	176	1	<i>Corydalis</i> DC.	59	4
Primulaceae	146	1	<i>Aconitum</i> L.	56	4
Gentianaceae	145	1	<i>Berberis</i> L.	56	4
Saxifragaceae	124	1	<i>Acer</i> L.	54	4
Salicaceae	121	4	<i>Astragalus</i> L.	52	1
Liliaceae	113	4	<i>Ligularia</i> Cass.	50	5
Rubiaceae	111	1	<i>Ilex</i> L.	46	2
Caryophyllaceae	110	1	<i>Juncus</i> L.	43	1
Polygonaceae	99	1	<i>Poa</i> L.	41	1
Urticaceae	99	2	<i>Cotoneaster</i> Medik.	39	4
Brassicaceae	94	1	<i>Delphinium</i> L.	39	4
Caprifoliaceae	85	4	<i>Silene</i> L.	39	4
Papaveraceae	83	4	<i>Potentilla</i> L.	38	4
Campanulaceae	78	1	<i>Arenaria</i> L.	37	4
Araliaceae	71	3	<i>Arisaema</i> Mart.	37	4
Berberidaceae	69	4	<i>Aster</i> L.	36	4
Lauraceae	65	2	<i>Euonymus</i> L.	36	1
Crassulaceae	64	1	<i>Sorbus</i> L.	36	4
Gesneriaceae	61	3	<i>Clematis</i> L.	35	1
Sapindaceae	56	2	<i>Indigofera</i> L.	35	2

*Distribution type: 1: cosmopolitan, 2: pantropic, 3: tropical Asia and tropical America disjunct, 4: north temperate, 5: old world temperate.

Our inventory included 18 families with more than 100 species each, and 16 families with 50–99 species, most of which are also large species-rich families throughout the world. There were 55 families with 10–49 species, and 78 families with 1–9 species. However, the 34 families with 50 species or more (comprising a total of 4979 species), contribute up to 73.15 % of the total number of species, but only form ca. 20% of the total number of families.

There are 36 genera with more than 30 species, and these are also the most abundant genera: *Rhododendron* L.

(183 species), *Pedicularis* L. (119), *Salix* L. (105), *Carex* L. (93), *Primula* L. (93), *Gentiana* L. (90), *Saxifraga* L. (86), *Saussurea* DC. (71). There are 102 genera with 11–30 species and 147 genera with 6–10 species. There are 1013 genera with 1–5 species, which include 1907 species, contributing up to 27.9 % of the number of species, but forming 78% of the total number of genera. However, the 138 genera with more than 10 species include 3820 species, which is 56.02 % of the number of species, but only 10.63% of the number of genera in the flora.

Geographical elements

Eleven distribution types at family level are recognized from the flora of Shangri-la region: 1. Cosmopolitan; 2. Pantropic; 3. Tropical Asian and Tropical American disjunct; 4. Old World Tropic; 5. Tropical Asian to Tropical Australian; 6. Tropical Asian; 7. North Temperate; 8. East Asian and North American disjunct; 9. Old World Temperate; 10. East Asian and; 11. Chinese endemics.

Of the 166 families, tropical elements (types 2–6) in total are 75 families, contributing to 45.18% of the flora (Table 2). Among tropical elements, 57 families (or 34.34%) are pantropic distributions, including Acanthaceae, Anacardiaceae, Euphorbiaceae, Melastomataceae and Rutaceae; 11 families (6.63%) are tropical Asian and tropical American disjunct distributions, such as Actinidiaceae, Aquifoliaceae, Staphyleaceae. Families with cosmopolitan distributions make up 30.12% of the total number of families, and include Asteraceae, Apiaceae, Ericaceae, Fabaceae, Lamiaceae and Poaceae. Temperate elements (types 7–11) in total are 41 families, contributing to 24.69% of the flora. Among them, 24 families (14.46%) are north temperate distribution, including Betulaceae, Cornaceae, Coriariaceae, Geraniaceae and Hydrangeaceae; 9 families are East Asia and North America disjunct distributions, such as Magnoliaceae, Nyssaceae, Saururaceae, Schisandraceae, contributing to 5.42%.

TABLE 2. Geographical elements of seed plants at the family level in the flora of Shangri-la region.

Geographical elements at family level	Number of family	%*
1 Cosmopolitan	50	30.12
2 Pantropic	57	34.34
3 Tropical Asia and Tropical America disjunct	11	6.63
4 Old World Tropic	2	1.20
5 Tropical Asia to Tropical Australia	3	1.81
6 Tropical Asia	2	1.20
Tropical elements (types 2–6) in total	75	45.18
7 North Temperate	24	14.46
8 East Asia and North America disjunct	9	5.42
9 Old World Temperate	1	0.60
10 East Asia	6	3.61
11 Endemic to China	1	0.60
Temperate elements (types 7–11) in total	41	24.69
Total number of families	166	100

*The number of families in each geographical element/ the number of families of all geographical elements times 100.

Fifteen distribution types at generic level are recognized from the flora (Table 3). Of the 1297 genera included in the inventory, temperate elements (types 8–15) contribute to 51.26%, and tropical elements (types 2–7) contribute to 42.87%. Among temperate genera, 16.19% have northern temperate distributions, and 14.26% have East Asian distributions. Other genera include those with old world temperate distributions (7.63 %), and East Asia and North American disjunct distributions (5.47 %). Among tropical genera, 14.80% have pantropic distributions, and 10.95% have tropical Asian distributions. There are 52 genera that are endemic or approximately endemic to China, including *Davidia* Baill. (which naturally occurs in Wei Xi county), *Dipelta* Maxim., *Ostryopsis* Decne., *Taiwania* Hayata.

Considering these geographical elements across families and genera, we might infer that families with high species richness (more than 50 species) predominantly have cosmopolitan and north temperate distributions, such as Apiaceae, Asteraceae, Ericaceae, Fabaceae and Lamiaceae, with a few having tropical distributions (Table 1). However, families

with 11–50 species all have pantropic distributions, such as Acanthaceae, Anacardiaceae, Asclepiadaceae, Theaceae. The families with 1–10 species are diverse in distribution, including 23 Pantropic families, 11 Northern temperate families, and 7 Tropical Asian and Tropical American disjunct distribution families, as well as 6 East Asian families, such as Cephalotaxaceae, Dipentodontaceae, Eupteleaceae, Stachyuraceae and Tetracentraceae (Wu *et al.* 2003).

TABLE 3 Geographical elements of seed plants at the generic level in the flora.

Geographical elements at generic level	Number of genera	%*
1 Cosmopolitan	76	5.86
2 Pantropic	192	14.80
3 Tropical Asia and Tropical America disjunct	31	2.39
4 Old World Tropic	81	6.25
5 Tropical Asia to Tropical Australia	64	4.93
6 Tropical Asia to Tropical Africa	46	3.55
7 Tropical Asia	142	10.95
Tropical elements (types 2–7) in total	556	42.87
8 North Temperate	210	16.19
9 East Asia and North America disjunct	71	5.47
10 Old World Temperate	99	7.63
11 Temperate Asia	18	1.39
12 Mediterranean, W Asia to C Asia	16	1.23
13 Center Asia	14	1.08
14 East Asia	185	14.26
15 Endemic to China	52	4.01
Temperate elements (types 8–15) in total	665	51.26
Total number of genera	1297	100.00

*The number of genera in each geographical element/ the number of genera of all geographical elements times 100.

Genera with high species richness (more than 30 species) predominantly have north temperate distributions (58.30 %), followed by cosmopolitan distributions (25.00 %) (Table 4). Among genera with 11–30 species, those with north temperate distributions still contribute the highest ratio (34.31%), followed by those with cosmopolitan (15.69%) and Pantropical distributions (14.71%). Genera with 1–5 species have very diverse distributions; those with East Asian distributions make up 15.5%, followed by pantropic (14.31%), tropical Asian (12.54%), and north temperate (12.04%) distributions. All 52 Chinese endemic genera included in the inventory are genera with 1–5 species (Table 4).

Comparison to regional floras at similar latitude in southern China

Three representative regional floras: Muchuan in southwestern China, Wulin Mts. in southern-centre China and Sanqingshan in southeastern China at almost the same latitude as the Shangri-la region are selected to make comparison (Figure 2). Muchuan is a county with a well-conserved national forest park. It has a record of 955 seed plant species of 127 families and 448 genera. Wulin Mts. is an important bio-diverse region and has a record of 3328 seed plant species of 174 families and 983 genera (Chen *et al.* 2002). Sanqingshan is a World Heritage site with well-conserved vegetation and biodiversity and has a record of 1772 seed plant species of 160 families and 785 genera (Peng *et al.* 2008).

The Shangri-la flora has similar compositions at the family (more than 89.94%) and the genera (more than 73%) levels, but differs at specific level to the three compared floras. The species similarities are low (32.51% and 29.23% respectively) between the flora of Shangri-la and those of Wulin Mts. and Sanqingshan (Table 5). The compositions

of geographical elements at the family and generic levels reveal that all these compared floras are similar (Table 6, 7). The tropical elements make up 43.31%–48.26% at family level, 38.73%–42.87% at generic level, while the temperate elements contribute to 24.39%–28.36% at family level, 50.18%–52.87% at generic level.

The Shangri-la flora has similar dominant families except Ericaceae and Orobanchaceae, as those compared floras in southern China, while Pantropic Lauraceae and Urticaceae, and north temperate Caprifoliaceae and Fagaceae are among the dominant families in the floras of southern China (Table 8). The species-rich genera in the Shangri-la flora are mostly temperate and cosmopolitan, while many tropical genera are in the species-rich genera in the floras of southern China (Table 9).

TABLE 4 Geographical elements across genera in the flora.

Distribution type	No. of genera (more than 30 species)	%	No. of genera (11–30 species)	%	No. of genera (6–10 species)	%	No. of genera (1–5 species)	%
Cosmopolitan	9	25.00	16	15.69	8	5.44	43	4.24
Pantropic	3	8.33	15	14.71	29	19.73	145	14.31
Tropical Asia and Tropical America disjunct	0	0	3	2.94	5	3.40	23	2.27
Old World Tropic	0	0	1	0.98	9	6.12	71	7.01
Tropical Asia to Tropical Australia	0	0	5	4.90	5	3.40	54	5.33
Tropical Asia to Tropical Africa	1	2.78	1	0.98	4	2.72	40	3.95
Tropical Asia	0	0	4	3.92	11	7.48	127	12.54
North Temperate	21	58.30	35	34.31	33	22.45	122	12.04
East Asia and North America disjunct	0	0	6	5.88	10	6.80	55	5.43
Old World Temperate	2	5.56	8	7.84	9	6.12	80	7.90
Temperate Asia	0	0	1	0.98	2	1.36	15	1.48
Mediterranean, W Asia to C Asia	0	0	1	0.98	0	0.00	15	1.48
Center Asia	0	0	0	0.00	1	0.68	13	1.28
East Asia	0	0	6	5.88	21	14.29	157	15.50
Endemic to China	0	0	0	0.00	0	0.00	52	5.23
Total number of genera	36	100	102	100.00	147	100.00	1012	100.00

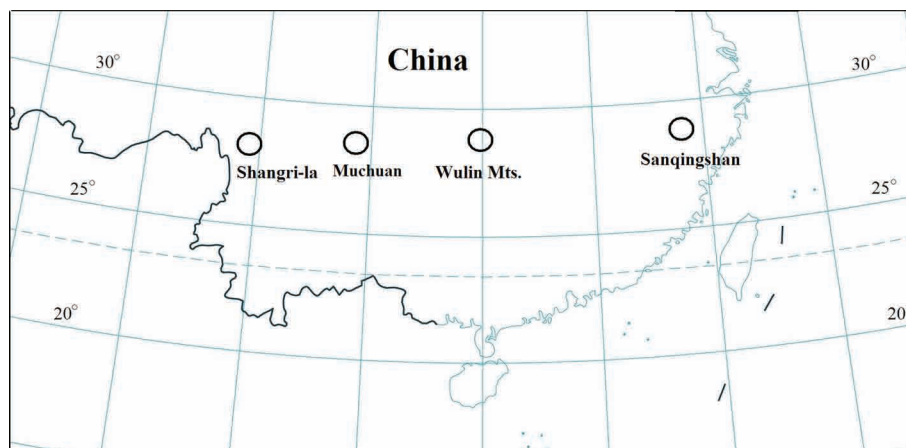


FIGURE 2. Map showing the locations of compared regional floras

TABLE 5. Comparison of floristic similarities at the family, generic and specific levels

Compared flora	Shangri-la 98°53'–99°42' E, 27°10'–28°27' N Similarity coefficient (%)	Muchuan 103°45'–103°59' E, 28°50'–29°5' N Similarity coefficient (%)	Wuling Mts. 107°02'–111°33' E, 27°28'–33°05' N Similarity coefficient (%)	Sanqingshan 118°00'–118°06' E, 28°54'–28°57' N Similarity coefficient (%)
Similarity coefficients at family level				
Shangri-la	100			
Muchuan	97.64			
Wuling Mts.	89.94	99.21	100	
Sanqingshan	90.63	94.49	97.5	100
Similarity coefficients at generic level				
Shangri-la	100			
Muchuan	88.33			
Wuling Mts.	77.01	91.75	100	
Sanqingshan	73.89	80.8	85.48	100
Similarity coefficients at specific level				
Shangri-la	100			
Muchuan	48.27			
Wuling Mts.	32.51	59.27	100	
Sanqingshan	29.23	36.86	59.88	100

*Similarity coefficient between A and B = the number of taxa shared by both A and B divided by the lowest number of taxa of A or B, multiplied by 100%

TABLE 6 Comparison of geographical elements of seed plants at the family level.

Compared regional floras	Shangri-la (166 families)	Muchuan (127 families)	Wuling Mts. (174 families)	Sanqingshan (160 families)
Geographical elements at family level	%*	%*	%*	%*
1 Cosmopolitan	30.12	28.35	25.86	27.5
2 Pantropic	34.34	31.5	34.47	35.01
3 Tropical Asia and Tropical America disjunct	6.63	7.09	7.47	6.88
4 Old World Tropic	1.20	2.36	2.3	1.88
5 Tropical Asia to Tropical Australia	1.81	1.57	2.3	2.5
6 Tropical Asia	1.20	0.79	1.72	1.89
Tropical elements (types 2–6) in total	45.18	43.31	48.26	48.16
7 North Temperate	14.46	18.91	15.5	15.01
8 East Asia and North America disjunct	5.42	3.94	5.17	5.63
9 Old World Temperate	0.60	0	0	0
10 East Asia	3.61	5.51	4.02	2.5
11 Endemic to China	0.60	0	1.15	1.25
Temperate elements (types 7–11) in total	24.69	28.36	25.84	24.39
Total	100	100	100	100

*The number of family in each geographical element/ the number of family of all geographical elements times 100.

TABLE 7 Comparison of geographical elements of seed plants at the generic level.

Compared regional floras	Shangri-la (1297 genera)	Muchuan (488 genera)	Wuling Mts. (983 genera)	Sanqingshan (785 genera)
Geographical elements at generic level	%*	%*	%*	%*
1 Cosmopolitan	5.86	8.40	7.02	8.54
2 Pantropic	14.80	14.75	15.46	18.59
3 Tropical Asia and Tropical America disjunct	2.39	2.87	2.54	2.42
4 Old World Tropic	6.25	4.51	5.39	5.35
5 Tropical Asia to Tropical Australia	4.93	3.89	5.49	4.08
6 Tropical Asia to Tropical Africa	3.55	3.69	2.94	2.93
7 Tropical Asia	10.95	9.02	10.27	7.89
Tropical elements (types 2–7) in total	42.87	38.73	42.09	41.26
8 North Temperate	16.19	20.90	16.68	17.44
9 East Asia and North America disjunct	5.47	7.99	7.93	8.66
10 Old World Temperate	7.63	5.94	6.21	6.62
11 Temperate Asia	1.39	1.02	1.22	1.27
12 Mediterranean, W Asia to C Asia	1.23	0.41	0.72	0.77
13 Center Asia	1.08	0.00	0	0.13
14 East Asia	14.26	13.11	13.12	12.36
15 Endemic to China	4.01	3.48	4.98	2.93
Temperate elements (types 8–15) in total	51.26	52.87	50.86	50.18
Total	100.00	100.00	100.00	100.00

*The number of genera in each geographical element/ the number of genera of all geographical elements times 100.

TABLE 8 Dominant (top 10) families in these compared regional floras

Shangri-la flora	No. of species	DT*	Muchuan flora	No. of species	DT*	Wuling Mts. flora	No. of species	DT*	Sanqingshan flora	No. of species	DT*
Asteraceae	518	1	Asteraceae	56	1	Rosaceae	199	1	Poaceae	147	1
Poaceae	395	1	Rosaceae	43	1	Asteraceae	189	1	Asteraceae	104	1
Rosaceae	358	1	Lamiaceae	35	1	Fabaceae	148	1	Rosaceae	102	1
Orchidaceae	323	1	Poaceae	32	1	Poaceae	124	1	Fabaceae	83	1
Fabaceae	299	1	Fabaceae	29	1	Lamiaceae	121	1	Cyperaceae	75	1
Ericaceae	284	1	Caprifoliaceae	25	3	Orchidaceae	94	1	Lamiaceae	54	1
Ranunculaceae	238	1	Lauraceae	22	2	Lauraceae	82	2	Fagaceae	41	3
Lamiaceae	220	1	Ranunculaceae	22	1	Ranunculaceae	76	1	Lauraceae	40	2
Apiaceae	198	1	Orchidaceae	21	1	Caprifoliaceae	72	3	Brassicaceae	37	1
Orobanchaceae	181	1	Apiaceae	20	1	Urticaceae	60	2	Rubiaceae	37	1

*DT=Distribution type: 1: cosmopolitan, 2: pantropic, 3: north temperate.

TABLE 9 Species-rich genera in these compared regional floras

Shangri-la flora	No. of species	DT*	Muchuan flora	No. of species	DT*	Wuling Mts. flora	No. of species	DT*	Sanqingshan flora	No. of species	DT*
<i>Rhododendron</i>	183	temp	Rubus	11	cosm	Rubus	57	cosm	Carex	32	cosm
<i>Pedicularis</i>	119	temp	Acer	9	temp	Ilex	47	trop	Rubus	28	cosm
<i>Salix</i>	105	temp	Lysimachia	9	cosm	Polygonum	41	cosm	Polygonum	26	cosm
<i>Carex</i>	93	cosm	Polygonum	9	cosm	Euonymus	32	cosm	Ilex	19	trop
<i>Primula</i>	93	temp	Rhododendron	8	temp	Acer	30	temp	Artemisia	18	cosm
<i>Gentiana</i>	90	temp	Symplocos	8	trop	Carex	29	cosm	Brassica	15	temp
<i>Saxifraga</i>	86	temp	Viburnum	7	temp	Viburnum	28	temp	Viola	15	cosm
<i>Saussurea</i>	71	temp	Ardisia	6	trop	Rhododendron	27	temp	Acer	12	temp
<i>Polygonum</i>	65	cosm	Hypericum	6	cosm	Smilax	27	trop	Euonymus	12	cosm
<i>Rubus</i>	64	cosm	Ilex	6	trop	Clematis	26	cosm	Eurya	12	trop
<i>Corydalis</i>	59	temp	Arisaema	5	temp	Symplocos	24	trop	Sedum	12	temp
<i>Aconitum</i>	56	temp	Cyclobalanopsis	5	trop:	Dioscorea	22	trop	Smilax	12	trop
<i>Berberis</i>	56	temp	Eurya	5	trop	Ficus	22	trop	Fimbristylis	11	trop
<i>Acer</i>	54	temp	Hydrangea	5	temp	Lysimachia	22	cosm	Lindera	11	temp
<i>Astragalus</i>	52	cosm	Lindera	5	temp	Zanthoxylum	22	trop	Lysimachia	11	cosm
<i>Ligularia</i>	50	temp	Lithocarpus	5	temp	Elatostema	21	temp	Castanopsis	10	trop
<i>Ilex</i>	46	trop	Litsea	5	trop	Rosa	19	temp	Clematis	10	cosm
<i>Juncus</i>	43	cosm	Lonicera	5	temp:	Artemisia	18	cosm	Ficus	10	trop
<i>Poa</i>	41	cosm	Magnolia	5	temp	Lindera	18	temp	Quercus	10	temp
<i>Cotoneaster</i>	39	temp	Primula	5	temp	Litsea	18	trop	Actinidia	9	temp

*DT=Distribution type: cosm= cosmopolitan, trop= tropical, temp= temperate; Generic name in bold are the dominant only in Shangri-la flora.

Discussion

Shangri-la region was included in the “Eastern Asiatic floristic region” delineated by Takhtajan (1978) in his floristic regionalization of the world. The large “Eastern Asiatic floristic region” is considered a major centre of higher plant evolution as it is especially rich in gymnosperms and primitive angiosperms (Wu & Wu 1996). However, East Asian and Chinese endemic families and genera make a minor contribution to the floristic richness of the Shangri-la flora, while large species-rich families and genera of cosmopolitan and north temperate distributions are well represented.

Comparisons of the Shangri-la flora and the other three representative regional floras at the same latitude in southern China reveal that they have high similarities at the family and genera levels, but low at specific level. The families Ericaceae and Orobanchaceae, which evolved mostly in mountain habitats, became dominant in the Shangri-la flora. Among the top 20 species-rich genera in the Shangri-la flora, 13 genera are the particular. All these compared floras should have originated from a common subtropical or temperate East Asian flora during the Tertiary. The uplift of the Himalayas since the late Tertiary caused a sudden uplift of the Shangri-la region and, resulted in the rapid speciation and diversification of plants.

Having undergone a rapid uplift with the Himalayas after the Pleistocene (Shi *et al.* 1999) Shangri-la region is evidently much younger in geological history than would be expected if the flora were of East Asian origin. Consequently, the flora is dominated by species-rich cosmopolitan and north temperate genera and families and is poor in primitive angiosperms. Therefore, the inclusion of the Shangri-la region in the “Eastern Asiatic floristic region” (Takhtajan 1978; Wu & Wu 1996) should be reconsidered.

Geographical elements of the Shangri-la flora at the specific level have not been documented. Of the 7000 species recorded from northwest Yunnan, 703 (13%) regional endemic species have been identified (Ma *et al.* 2007). Among large species-rich genera of cosmopolitan and north temperate distributions in the region, such as *Aconitum* L., *Gentiana*, *Pedicularis*, *Primula*, *Rhododendron*, *Saussurea* and *Saxifraga*, the regional endemic species contribute to more than 50%, as indicated by a study of selected taxa in the Hengduan Mountains (Zhang *et al.* 2009). This suggests that the dominant cosmopolitan and north temperate families and genera in Shangri-la region could have speciated rapidly. For example, *Solms-laubachia* Muschl. ex Diels, s.l. (Brassicaceae) is a genus of North Temperate distribution with 26 species in total, of which 11 species are endemic to the Hengduan Mountains region. A molecular phylogeny of *Solms-laubachia* s.l. suggested that the genus originated during the Pliocene in central Asia, and subsequently migrated eastward into the Hengduan Mountains, followed by rapid speciation in the region (Yue *et al.* 2009).

Phylogeographic studies have revealed that the uplift of the Himalayas resulted in divergence and speciation of a number of plant species. The *Ligularia* Cass.–*Cremanthodium* Benth.–*Parasenecio* W.W. Sm. and J. Small complex (Asteraceae) contains more than 200 species that are endemic to the Qinghai-Tibetan Plateau. The explosive radiation of the complex occurred mostly within the last 20 million years during the period of major uplift of the Qinghai-Tibetan Plateau (Liu *et al.* 2006). Significant increases in geological and ecological diversity that accompanied the uplift most likely promoted rapid and continuous allopatric speciation in small and isolated populations (Liu *et al.* 2006). For example, *Saussurea* (Asteraceae) is a species-rich genus that is mostly endemic to the Qinghai-Tibetan Plateau and species radiation was inferred to have occurred 14–7 Mya, during the period of major uplift of the Himalayas (Wang *et al.* 2009). Likewise, the genus *Incarvillea* Juss. (16 spp, Bignoniaceae) has a Himalayan to East Asia distribution (Chen *et al.* 2005), with genetic divergence associated with the uplift of the Himalayas (Chen *et al.* 2012). The genus *Dipentodon* Dunn (Dipentodontaceae) includes only two species in East Himalayan and Southwestern China, and species from the extremely uplifted (i.e., those at higher altitude) southeast Tibetan plateau contained more haplotype diversity than those of the much less uplifted region (i.e., lower altitude) (Yuan *et al.* 2008). Geographic isolation by the uplift of Himalayas and hybridization were suggested to be two important mechanisms responsible for population differentiation and speciation in *Meconopsis* Vig. (Papaveraceae), a species-rich genus in the Himalayas (Yang *et al.* 2012). The same suggestion was also given from *Tsuga* Carr. (Cun & Wang 2010). Geographical isolation caused by climatic oscillations also promoted plant diversification in the Hengduan-Qinghai-Tibet Plateau. For example, the Qinghai-Tibet Plateau developed during the largest glaciation of the early Quaternary, and mountainous isolation might have led to the deep intraspecific vicariance within the endemic species, *Cyananthus delavayi* Franch. (Campanulaceae) in the Hengduan Mountains (Li *et al.* 2012). The high species diversity of *Pedicularis* in the Hengduan-Qinghai-Tibet Plateau is thought to have originated through genetic isolation in the diverse habitats as a result of the rapid uplift of the Qinghai-Tibet Plateau (Axelrod *et al.* 1998). Additionally, as a consequence of further dispersal events of species responding to the Quaternary climatic change, recolonisation of some species to the Hengduan-Qinghai-Tibet Plateau from surrounding regions also resulted in the diversification of *Pedicularis* in these regions (Yang *et al.* 2008).

The Hengduan Mountains was also refugia for some north temperate genera during the last glacial cycle (Liu *et al.* 2006; Wang *et al.* 2008; Wang *et al.* 2009; Li *et al.* 2010; Sun *et al.* 2010; Zhang *et al.* 2010; Yang *et al.* 2012; Xue *et al.* 2012). For example, the genus *Angelica* L. (Apiaceae) consists of some 90–110 species distributed throughout north temperate regions, and 45 species in China, of which 32 are endemic to the Hengduan Mountains (She *et al.* 2005). A phylogeographic study revealed that Northeast Asia, Western Europe, and North America were ancestral areas of the genus, and the Hengduan Mountains was a refugia and a major diversification center for *Angelica* (Tu *et al.* 2009). Hengduan Mountains is also the centre of diversity for *Primula* (Hu 1994). It was found that Pleistocene climatic oscillations, combined with the complex local topography, were responsible for the phylogeographic pattern of *Primula ovalifolia* Franch., and that central and southwestern China were areas of important refugia for the survival, persistence, and further speciation of most East Asian flora, which has led to high species diversity in this region (Xie *et al.* 2012).

Evidently, the relatively quick uplift of the Himalayas and climatic oscillations after the late Tertiary have resulted in the rapid speciation and diversification of plants in the Hengduan Mountains. This is supported by both phylogeographic and floristic studies of the region that the dominant cosmopolitan and north temperate families and genera diversified rapidly in the region.

Conclusions

The flora of Shangri-la region is dominated by families and genera with cosmopolitan and north temperate distributions, while families and genera that are less species rich have diverse distributions, of which those with East Asian and Chinese endemic distributions are a minority. Among the species-rich families and genera of cosmopolitan and north temperate distributions, the regional endemic species contribute a conspicuously high percentage. The floristic patterns illustrate that the flora of Shangri-la could have evolved through rapid speciation mainly from families and genera of cosmopolitan and north temperate distributions, with the uplift of the Himalayas and climatic oscillations since the last glacial ages. The flora is obviously younger in evolutionary history than is usually supposed, and, therefore, not part of the age-old eastern Asian flora. The macroevolution of the flora in Shangri-la region is well corroborated by the phylogeographic implications of plant taxa in Hengduan-Qinghai-Tibet Plateau regions.

Acknowledgments

This research was supported by the National Natural Science Foundation of China, No. 41471051, 41071040, 31170195. The database was put together by Yan Lichun. Ms. Pelin Kayaalp helps improving English for the article.

References

- Axelrod, D.I., Al-Shehbaz, I. & Raven, P.H. (1998) History of the modern flora of China. In: Zhang, A.L. & Wu, S.G. (Eds.) *Floristic Characteristics and Diversity of East Asian Plants*. China Higher Education Press and Springer-Verlag Berlin Heidelberg, Beijing, pp. 43–55.
- Boufford, D.E. & Dijk, P.P.V. (2000) South-Central China. In: Mittermeier, R.A., Myers, N., Mittermeier, C.G. & Robles-Gil, P. (Eds.) *Hotspots: earth's biologically richest and most endangered terrestrial ecoregions*. Cemex, Mexico, pp. 338–351.
- Chase, M.W. & Reveal, J.L. (2009) A phylogenetic classification of the land plants to accompany APG III. *Botanical Journal of the Linnean Society* 161: 122–127.
<http://dx.doi.org/10.1111/j.1095-8339.2009.01002.x>
- Chen, G.X., Liao, W.B., Ao, C.Q., Liu, W.Q. & Zhang, H.D. (2002) Studies on character and feature of seed plants flora of Wulingshan region. *Bulletin of Botanical Research* 22: 98–120.
- Chen, S.T., Guan, K.Y., Zhou, Z.K., Olmstead, R. & Cronk, Q. (2005) Molecular phylogeny of *Incarvillea* (Bignoniaceae) based on IT SandtrnL-F sequences. *American Journal of Botany* 92: 625–633.
<http://dx.doi.org/10.3732/ajb.92.4.625>
- Chen, S.T., Xing, Y.W., Su, T., Zhou, Z.K., Dilcher, D.L. & Soltis, D.E. (2012) Phylogeographic analysis reveals significant spatial genetic structure of *Incarvillea sinensis* as a product of mountain building. *BMC Plant Biology* 12: 58.

<http://dx.doi.org/10.1186/1471-2229-12-58>

- Cun, Y.Z. & Wang, X.Q. (2010) Plant recolonization in the Himalaya from the southeastern Qinghai–Tibetan Plateau: Geographical isolation contributed to high population differentiation. *Molecular Phylogenetics and Evolution* 56: 972–982.
<http://dx.doi.org/10.1016/j.ympev.2010.05.007>
- Hu, C.M. (1994) On the geographical distribution of the Primulaceae. *Journal of Tropical and Subtropical Botany* 2: 1–14.
- Jin, X.C. (2002) Permo-Carboniferous sequences of Gondwana affinity in southwest China and their paleogeographical implications. *Journal of Asian Earth Sciences* 20: 633–646.
[http://dx.doi.org/10.1016/S1367-9120\(01\)00084-0](http://dx.doi.org/10.1016/S1367-9120(01)00084-0)
- Le, M.C., Moseley, R., Yun, C.W. & Zhou, Z.K. (2007) Plant diversity and priority conservation areas of Northwestern Yunnan, China. *Biodiversity and Conservation* 16: 757–774.
<http://dx.doi.org/10.1007/s10531-005-6199-6>
- Li, B.Y. (1987) On the boundaries of the Hengduan Mountains. *Mountain Research* 52: 74–82.
- Li, C., Shimono, A., Shen, H.H. & Tang, Y.H. (2010) Phylogeography of *Potentilla fruticosa*, an alpine shrub on the Qinghai-Tibetan Plateau. *Journal of Plant Ecology* 31: 9–15.
<http://dx.doi.org/10.1093/jpe/rtp022>
- Li, G.D., Yue, L.L., Sun, H. & Qian, Z.G. (2012) Phylogeography of *Cyananthus delavayi* (Campanulaceae) in Hengduan Mountains inferred from variation in nuclear and chloroplast DNA sequences. *Journal of Systematics and Evolution* 50: 305–315.
<http://dx.doi.org/10.1111/j.1759-6831.2012.00200.x>
- Liu, J.Q., Wang, Y.J., Wang, A.L., Hideaki, O. & Abbott, R.J. (2006) Radiation and diversification within the *Ligularia-Cremanthodium-Parasenecio* complex (Asteraceae) triggered by uplift of the Qinghai-Tibetan Plateau. *Molecular Phylogenetics and Evolution* 38: 31–49.
<http://dx.doi.org/10.1016/j.ympev.2005.09.010>
- Ma, C.L., Moseley, R., Chen, W.Y. & Zhou, Z.K. (2007) Plant diversity and priority conservation areas of Northwestern Yunnan, China. *Biodiversity and Conservation* 16: 757–774.
<http://dx.doi.org/10.1007/s10531-005-6199-6>
- Mehrotra, R.C., Liu, X.Q., Li, C.S., Wang, Y.F. & Chauhan, M.S. (2005) Comparison of the Tertiary flora of southwest China and northeast India and its significance in the antiquity of the modern Himalayan flora. *Review of Palaeobotany and Palynology* 135: 145–163.
<http://dx.doi.org/10.1016/j.revpalbo.2005.03.004>
- Metcalfe, I. (2006) Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean Peninsula in context. *Gondwana Research* 9: 24–46.
<http://dx.doi.org/10.1016/j.gr.2005.04.002>
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858.
<http://dx.doi.org/10.1038/35002501>
- Office of Yunnan World Heritage management Committee (2002) *Three parallel rivers national park*. Yunnan Fine Art Press, Kunming, pp. 11–12.
- Peng, S.L., Liao, W.B., Wang, Y.Y., Jia, F.L., Fan, Q., Shen, R.J., Li, Z., Wu, J.H. & Chen, H. (2008) Study on Biodiversity of Mount Sanqingshan in China. Science Press, Beijing, 272 pp.
- Ran, J.H., Wei, X.X. & Wang, X.Q. (2006) Molecular phylogeny and biogeography of *Picea* (Pinaceae): implications for phylogeographical studies using cytoplasmic haplotypes. *Molecular Phylogenetics and Evolution* 41: 405–419.
<http://dx.doi.org/10.1016/j.ympev.2006.05.039>
- She, M.L., Pu, F.T., Pan, Z.H., Watson, M.F., Cannon, J.F.M., Holmes-Smith, I., Kljuykov, E.V., Phillippe, L.R. & Pimenov, M.G. (2005) Apiaceae. In: *Flora of China. Vol. 14*. Missouri Botanical Garden Press, St. Louis, pp. 1–205.
- Shi, Y.F., Li, J.Y., Li, B.Y., Yao, T.D., Wang, S.M., Li, S.J., Tsui, Z.J., Wang, F.B., Pan, B.T., Fang, X.M. & Zhang, Q.S. (1999) Uplift of the Qinghai-Xizang Tibetan plateau and east Asia environmental change during late Cenozoic. *Acta Geographica Sinica* 54: 10–21.
- Socquet, A. & Pubellier, M. (2005) Cenozoic deformation in western Yunnan China–Myanmar border. *Journal of Asian Earth Sciences* 24: 495–515.
<http://dx.doi.org/10.1016/j.jseaes.2004.03.006>
- Sun, Y.S., Ikeda, H., Wang, Y.J. & Liu, J.Q. (2010) Phylogeography of *Potentilla fruticosa* (Rosaceae) in the Qinghai-Tibetan Plateau revisited: a reappraisal and new insights. *Plant Ecology & Diversity* 3: 249–257.
<http://dx.doi.org/10.1080/17550874.2010.516279>
- Takhtajan, Y. (1978) *Floristic Region of the World in Russian*. Soviet Sciences Press, Leningrad Branch, 544 pp.
- The Angiosperm Phylogeny Group (2009) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Botanical Journal of the Linnean Society* 161: 105–121.

<http://dx.doi.org/10.1111/j.1095-8339.2009.00996.x>

- Tu, F., Downie, S.R., Yu, Y., Zhang, X.M., Chen, W.W., He, X.J. & Liu, S. (2009) Molecular systematics of *Angelica* and allied genera (Apiaceae) from the Hengduan Mountains of China based on nrDNA ITS sequences: phylogenetic affinities and biogeographic implications. *Journal of Plant Research* 122: 403–414.
<http://dx.doi.org/10.1007/s10265-009-0238-4>
- Wang, F.Y., Gong, X., Hu, C.M. & Hao, G. (2008) Phylogeography of an alpine species *Primula secundiflora* inferred from the chloroplast DNA sequence variation. *Journal of Systematics and Evolution* 146: 13–22.
- Wang, Y.J., Susanna, A., Raab-Straube, E.V., Milne, R., & Liu, J.Q. (2009) Island-like radiation of *Saussurea* Asteraceae: Cardueae) triggered by uplifts of Qinghai-Tibetan Plateau. *Biological Journal of the Linnean Society* 97: 893–903.
<http://dx.doi.org/10.1111/j.1095-8312.2009.01225.x>
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 1. Science Press, Beijing, 870 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 2. Science Press, Beijing, 889 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 3. Science Press, Beijing, 795 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 4. Science Press, Beijing, 823 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 5. Science Press, Beijing, 809 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 6. Science Press, Beijing, 910 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 7. Science Press, Beijing, 824 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 8. Science Press, Beijing, 778 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 9. Science Press, Beijing, 807 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 10. Science Press, Beijing, 944 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 11. Science Press, Beijing, 754 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 12. Science Press, Beijing, 900 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 13. Science Press, Beijing, 918 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 14. Science Press, Beijing, 878 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 15. Science Press, Beijing, 874 pp. [in Chinese]
- Wu, Z.Y. (1977) *Flora Yunnanica*. Vol. 16. Science Press, Beijing, 892 pp. [in Chinese]
- Wu, Z.Y. (1991) The areal-types of Chinese genera of seed plants. *Acta Botanica Yunnanica* 14: 1–139.
- Wu, Z.Y. & Ding, T.Y. (1999) *China Seed Plant Database*. Yunnan Science and Technology Press, Kunming, Distributed as CD. [in Chinese]
- Wu, Z.Y. & Wu, S.G. (1996) A Proposal for a new floristic kingdom realm) ---- the Asiatic kingdom, its delineation and characteristics. In: Zhang, A.L. & Wu, S.G. (Eds.) *Floristic Characteristics and Diversity of East Asian Plants*. China Higher Education Press and Springer-Verlag Berlin Heidelberg, Beijing, pp. 3–42.
- Wu, Z.Y., Zhou, Z.K., Li, D.Z., Peng, H. & Sun, H. (2003) The areal-types of the world families of seed plants. *Acta Botanica Yunnanica* 25: 245–257.
- Wu, Z.Y., Zhou, Z.K., Sun, H., Li, D.Z. & Peng, H. (2006) *The areal-types of seed plants and their origin and differentiation*. Yunnan Science and Technology Press, Kunming, 566 pp.
- Xie, X.F., Yan, H.F., Wang, F.Y., Ge, X.J., Hu, Q.M. & Hao, G. (2012) Chloroplast DNA phylogeography of *Primula ovalifolia* in central and adjacent southwestern China: Past gradual expansion and geographical isolation. *Journal of Systematics and Evolution* 50: 284–294.
<http://dx.doi.org/10.1111/j.1759-6831.2012.00204.x>
- Yang, F.S., Li, Y.F., Ding, X. & Wang, X.Q. (2008) Extensive population expansion of *Pedicularis longiflora* (Orobanchaceae) on the Qinghai-Tibetan Plateau and its correlation with the Quaternary climate change. *Molecular Ecology* 17: 5135–5145.
<http://dx.doi.org/10.1111/j.1365-294X.2008.03976.x>
- Yang, F.S., Qin, A.L., Li, Y.F. & Wang, X.Q. (2012) Great genetic differentiation among populations of *Meconopsis integrifolia* and its implication for plant speciation in the Qinghai-Tibetan plateau. *PLoS ONE* 7 (5): e37196.
<http://dx.doi.org/10.1371/journal.pone.0037196>
- Yang, Z.Y., Yi, T.S., Pan, Y.Z. & Gong, X. (2012) Phylogeography of an alpine plant *Ligularia vellerea* (Asteraceae) in the Hengduan Mountains. *Journal of Systematics and Evolution* 50: 316–324.
<http://dx.doi.org/10.1111/j.1759-6831.2012.00199.x>
- Yuan, Q.J., Zhang, Z.Y., Peng, H. & Ge, S. (2008) Chloroplast phylogeography of *Dipentodon* (Dipentodontaceae) in southwest China and northern Vietnam. *Molecular Ecology* 17: 1054–1065.
<http://dx.doi.org/10.1111/j.1365-294X.2007.03628.x>
- Yue, J.P., Sun, H., Baum, D.A., Li, J.H., Al-Shehbaz, I. & Ree, R. (2009) Molecular phylogeny of *Solms-laubachia* (Brassicaceae) s.l., based on multiple nuclear and plastid DNA sequences, and its biogeographic implications. *Journal of Systematics and Evolution* 47:

- Zhang, J.W., Nie, Z.L., Wen, J. & Sun, H. (2011) Molecular phylogeny and biogeography of three closely related genera, *Soroseris*, *Stebbinsia*, and *Syncalathium* (Asteraceae, Cichorieae), endemic to the Tibetan Plateau, SW China. *Taxon* 60 (1): 15–26.
- Zhang, Y.H., Volis, S. & Sun, H. (2010) Chloroplast phylogeny and phylogeography of *Stellera chamaejasme* on the Qinghai-Tibet Plateau and in adjacent regions. *Molecular Phylogenetics and Evolution* 57: 1162–1172.
<http://dx.doi.org/10.1016/j.ympev.2010.08.033>
- Zhang, D.C., Zhang, Y.H., Boufford, D.E. & Sun, H. (2009) Elevational patterns of species richness and endemism for some important taxa in the Hengduan Mountains, southwestern China. *Biodiversity and Conservation* 18: 699–716.
<http://dx.doi.org/10.1007/s10531-008-9534-x>
- Zhu, H. (2009) *Read the Nature --- Geological Wonder and Vegetation Geography of the Three Parallel Rivers Region in Northwest Yunnan*. Science Press, Beijing, 155 pp.
- Zhu, H. (2012) Biogeographical divergence of the flora of Yunnan, southwestern China initiated by the uplift of Himalaya and extrusion of Indochina block. *PLoS ONE* 7 (9): e45601.
<http://dx.doi.org/10.1371/journal.pone.0045601>

The Floras of Southern and Tropical Southeastern Yunnan Have Been Shaped by Divergent Geological Histories

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Abstract

The southern and tropical southeastern regions of the Yunnan Province in southwestern China have similar monsoonal climates and lowland tropical rain forest vegetations. The floras of both regions are dominated by tropical floristic elements (78.3% in southern Yunnan and 68.83% in southeastern Yunnan), and both belong to the Indo-Malaysian flora at the northern margin of tropical Asia. However, some temperate East Asian characteristic families are well represented in the flora of tropical southeastern Yunnan, while families characteristic of tropical Asia are well represented in the flora of southern Yunnan. Additionally, there are 14 mainly east Asian families in tropical southeastern Yunnan that are not found in southern Yunnan. Although the two regions share 80% of their genera, 237 genera are restricted to southern Yunnan, and 349 genera to tropical southeastern Yunnan. Furthermore, 57 genera with an East Asian distribution, 53 genera with a North temperate distribution, 22 genera endemic to China, and 17 genera with an East Asia and North America disjunct distribution are found only in tropical southeastern Yunnan. The flora of tropical southeastern Yunnan is more closely related to Eastern Asian flora, while the flora of southern Yunnan is more closely related to Indo-Malaysian flora. The divergence of the flora is well supported by the geological history of the region; the flora of tropical southeastern Yunnan was mainly derived from the South China Geoblock, while the southern Yunnan flora derived from the Shan-Thai Geoblock.

Citation: Hua Z (2013) The Floras of Southern and Tropical Southeastern Yunnan Have Been Shaped by Divergent Geological Histories. PLoS ONE 8(5): e64213. doi:10.1371/journal.pone.0064213

Editor: Ting Wang, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan, China, China

Received: January 20, 2013; **Accepted:** April 10, 2013; **Published:** May 28, 2013

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Funding: This project was funded by The National Natural Science Foundation of China (41071040, 31170195). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The author has declared that no competing interests exist.

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Introduction

Yunnan, in southwestern China, is a region of exceptional interest to biologists not only because it is situated in a transitional zone between tropical south-east Asia and temperate east Asia [1,2], but also because it was at a sutural zone between Gondwana and Laurasia [3,4,5]. The origin and evolution of the Yunnan flora were largely influenced by the uplift of the Himalayas, the formation of the east Asian monsoon climate and the extrusion of the Indochina block into tropical SE Asia since the later Tertiary [6].

Little was known about the tropical flora and vegetation of southwestern China until the late 1950s because of poor access. After a China-Russia expedition in the late 1950s, which penetrated deep into southwestern China, including southern Yunnan, it was suggested that tropical rain forests existed in southwestern China, but these were considered different from those in Indo-Malaysia [7,8]. Further biogeographical and ecological studies on the vegetation and flora of tropical southwestern China revealed that it is comprised of Indo-Malaysian flora and has true evergreen rain forest with the same forest profile and physiognomic characteristics as equatorial lowland rain forests [9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27].

The tropical flora in southern Yunnan differs from that of southeastern Yunnan, although the two regions have a similar

climate and the same tropical rain forest at lowlands as those of southeastern Asia. The flora of the tropical region of southeastern Yunnan has a relatively high proportion of temperate east Asian characteristic families, such as Magnoliaceae, Cornaceae, Smilacaceae, Theaceae, Styracaceae, Symplocaceae, Aquifoliaceae, Caprifoliaceae and Celastraceae, while in southern Yunnan, tropical Asian characteristic families, such as Meliaceae, Annonaceae, Menispermaceae, Zingiberaceae, Apocynaceae, Asclepiadaceae, are well represented. The flora of tropical southeastern Yunnan is more closely related to eastern Asian flora, while the flora of southern Yunnan is more closely related to Indo-Malaysian flora. Based on comparisons of floristic composition and geological history between southern and tropical southeastern Yunnan, I will discuss the biogeographical divergence between these regions.

Materials and Methods

In this study, two neighboring tropical areas in southern and southeastern Yunnan were selected for comparison (Figure 1).

The tropical region of southeastern Yunnan lies between 22°26' and 23°26'N, 104°27' and 108°48'E, including six counties with an area of 14,389 km², and the altitude varies from 75 m at the red river to 3047 m at mountain peaks. This region has a typical tropical monsoon climate at lowlands with an annual mean temperature of 22.8°C, ≥10°C annual accumulative temperature

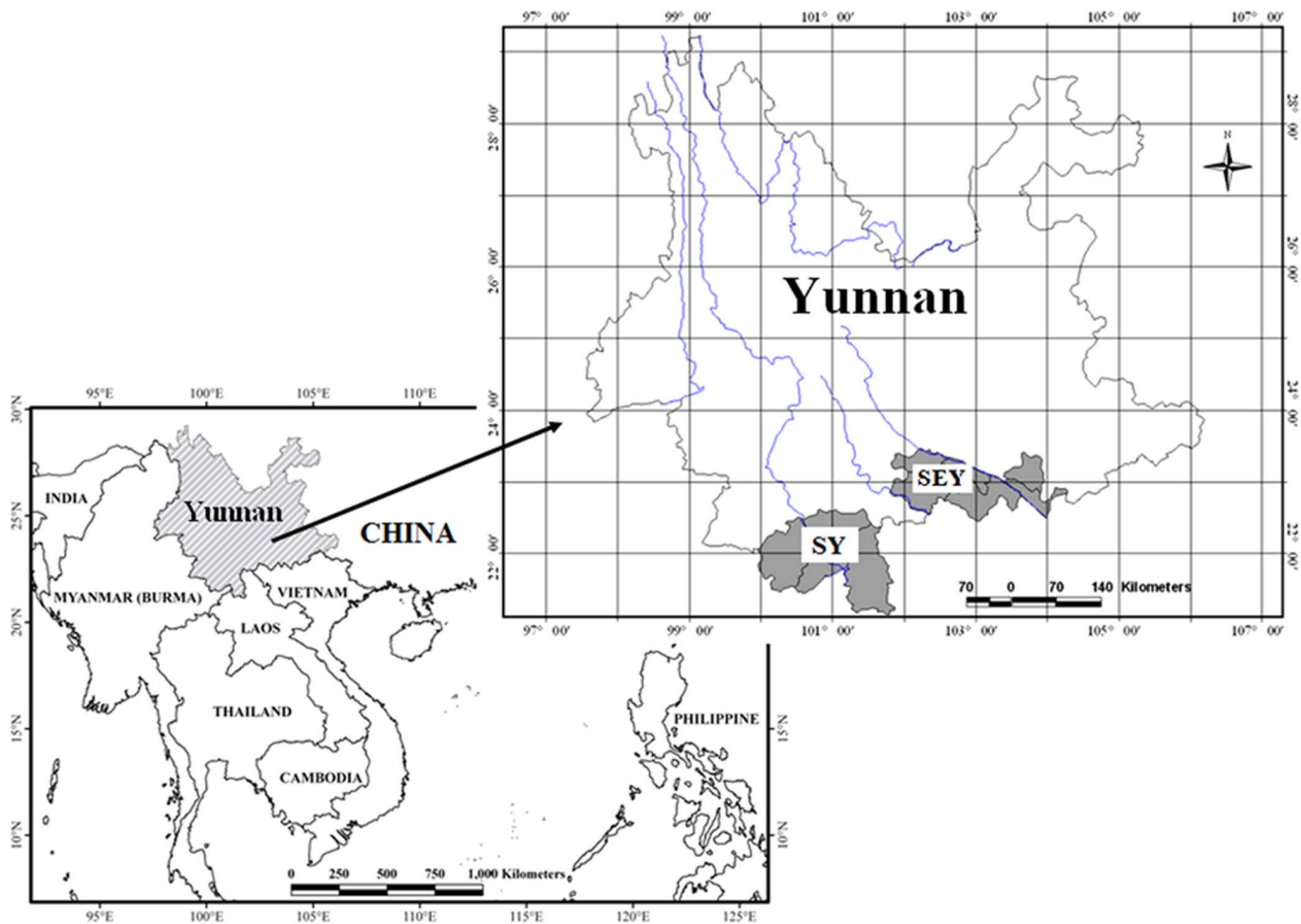


Figure 1. Location of study areas. SY: southern Yunnan; SEY: tropical southeastern Yunnan.
doi:10.1371/journal.pone.0064213.g001

of 8246°C, and annual precipitation of 1764 mm. A total of 4996 species and 1357 genera in 186 families of seed plants have been recognized from the region [28].

Tropical southern Yunnan is delimited here to the Xishuangbanna administrative region. It lies between 21°09' and 22°36' N, 99°58' and 101°50' E, including three counties. The region comprises an area of 19690 km² and lies between 480 m at the bottom of the lowest valley in the southern (Mekong River) to 2430 m at the highest peak in the north. The region has a typical tropical monsoon climate at lowlands with an annual mean temperature of 21°C, $\geq 10^\circ\text{C}$ annual accumulative temperature of 7639°C, and annual precipitation of 1532 mm. A total of 4150 native species including subspecies and varieties from 1240 genera and 183 families of seed plants have been recognized from southern Yunnan [29].

Circumscription of families and species followed the nomenclature of *w³TROPICOS* (<http://mobot.mobot.org/W3T/Search/vast.html>).

Based on these plant lists, floristic and geographical attributes of these two floras were analyzed. Distribution patterns of seed plants in each region were quantified at the generic level based on Wu's documentation [30,31] and at the family level following Wu et al. [32]. Comparisons of both floristic composition and geographical elements were made to assess the floristic divergence between the two regions.

Results

Floristic Composition

A total of 4996 species and 1357 genera in 186 families of seed plants from tropical southeastern Yunnan, and a total of 4150 native species (including subspecies and varieties) from 1240 genera and 183 families of seed plants from southern Yunnan were recognized. Both floras are comprised of almost the same primary species-rich families, such as Fabaceae, Orchidaceae, Rubiaceae, Poaceae, Asteraceae, Euphorbiaceae, Lauraceae and Urticaceae. However, among the secondary species-rich families, tropical families, such as Zingiberaceae, Asclepiadaceae, Apocynaceae, Annonaceae, are more dominant in the flora of southern Yunnan, while those with a mainly temperate distribution, such as Ericaceae, Theaceae, Liliaceae and Araliaceae, are more dominant in the flora of tropical southeastern Yunnan (Table 1).

Biogeographical Divergence of the Tropical Floras of Yunnan

The floristic similarities between the flora of southeastern and southern Yunnan is up to 99% at the family level, and 80% at the generic level, but 50.7% at the specific level [28].

Although the floras of tropical southeastern and southern Yunnan have a similar composition at the family level and share many very species-rich families, they differ in secondary species-rich families. The families Aquifoliaceae, Ericaceae, Hydrangea-

Table 1. The twenty families with most species richness among the floras of southern and southeastern Yunnan.

Flora of southern Yunnan			Flora of tropical southeastern Yunnan		
Family	No. sp.	% the flora	Family	No. sp.	% the flora
Orchidaceae	377	9.08	Fabaceae	285	5.7
Fabaceae	261	6.29	Orchidaceae	276	5.52
Rubiaceae	201	4.84	Rubiaceae	235	4.7
Poaceae	189	4.55	Poaceae	219	4.38
Euphorbiaceae	148	3.57	Asteraceae	180	3.6
Lamiaceae	139	3.35	Lamiaceae	151	3.02
Asteraceae	137	3.30	Lauraceae	141	2.82
Lauraceae	105	2.53	Urticaceae	134	2.68
Urticaceae	84	2.02	Euphorbiaceae	126	2.52
Zingiberaceae	84	2.02	Rosaceae	124	2.48
Moraceae	83	2.00	Fagaceae	109	2.18
Acanthaceae	77	1.86	Moraceae	104	2.08
Asclepiadaceae	66	1.59	Ericaceae	96	1.92
Cyperaceae	63	1.52	Cyperaceae	87	1.74
Cucurbitaceae	60	1.45	Acanthaceae	85	1.7
Fagaceae	60	1.45	Theaceae	81	1.62
Rosaceae	59	1.42	Gesneriaceae	79	1.58
Annonaceae	57	1.37	Celastraceae	65	1.3
Apocynaceae	56	1.35	Liliaceae	64	1.28
Vitaceae	56	1.35	Araliaceae	64	1.28

*Bold lettering indicates dominant families, which are in one of the two compared floras respectively.
doi:10.1371/journal.pone.0064213.t001

Table 2. Families with conspicuously more species richness in the southeastern Yunnan than the southern Yunnan.

Families	Distribution type	No. of species in southeastern Yunnan	No. of species in southern Yunnan
Rosaceae	Cosmopolitan	124	59
Ericaceae	Cosmopolitan	96	24
Theaceae	Pantropic	80	33
Magnoliaceae	East Asia and North America disjunct	53	13
Sapindaceae	Pantropic	50	22
Aquifoliaceae	Tropical Asia and Tropical America disjunct	35	13
Primulaceae	Cosmopolitan	28	12
Actinidiaceae	Tropical Asia and Tropical America disjunct	26	9
Symplocaceae	Pantropic	25	14
Cornaceae	North Temperate	22	13
Styracaceae	Tropical Asia and Tropical America disjunct	19	9
Hydrangeaceae	North Temperate	17	4
Lardizabalaceae	Tropical Asia and Tropical America disjunct	12	4
Saxifragaceae	Cosmopolitan	11	2
Betulaceae	North Temperate	11	5
Hamamelidaceae	North Temperate	11	2
Papaveraceae	North Temperate	10	2
Berberidaceae	North Temperate	8	2
Cycadaceae	Tropical Asia to Tropical Australia	6	2
Helwingiaceae	East Asia	5	1

doi:10.1371/journal.pone.0064213.t002

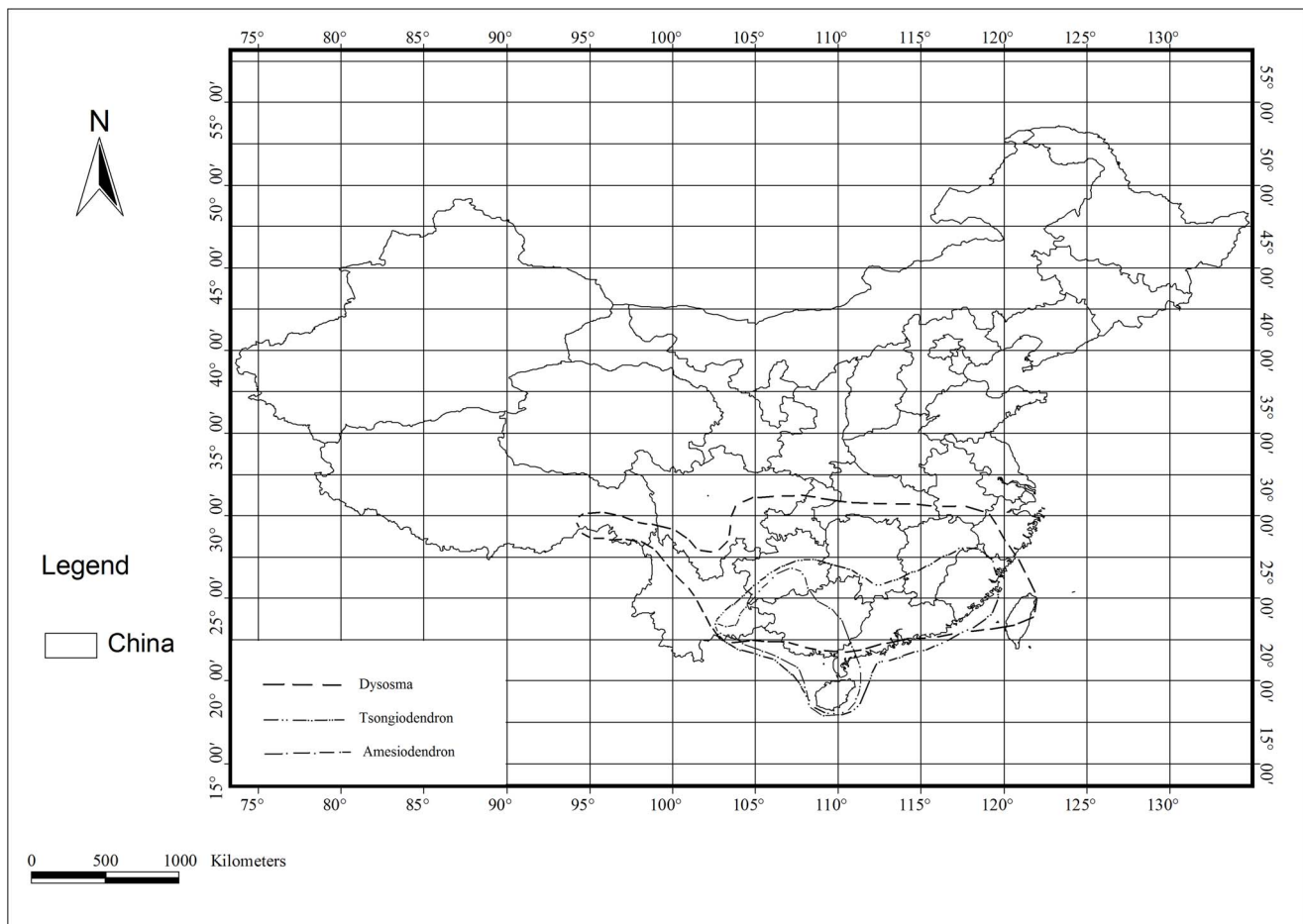


Figure 2. Chinese endemic genera in tropical southeastern Yunnan.
doi:10.1371/journal.pone.0064213.g002

Table 3. Generic-level diversity respectively in the southern Yunnan and tropical southeastern Yunnan across geographical elements.

Geographical element at generic level	Genera only in southern Yunnan %		Genera only in tropical southeastern Yunnan %	
1 Cosmopolitan	8	3.42	6	1.72
2 Pantropic	47	20.09	27	7.74
3 Tropical Asia and Tropical America disjunct	5	2.14	6	1.72
4 Old World Tropic	16	6.84	9	2.58
5 Tropical Asia to Tropical Australia	28	11.97	14	4.01
6 Tropical Asia to Tropical Africa	19	8.12	23	6.59
7 Tropical Asia	82	35.04	98	28.08
8 North Temperate	5	2.14	53	15.19
9 East Asia and North America disjunct	2	0.85	17	4.87
10 Old World Temperate	7	2.99	14	4.01
11 Temperate Asia	1	0.43	2	0.57
12 Mediterranean, W Asia to C Asia	1	0.43	1	0.29
13 C Asia	2	0.85	0	0.00
14 East Asia	7	2.99	57	16.33
15 Endemic to China	4	1.71	22	6.30
Total	234	100.00	349	100.00

doi:10.1371/journal.pone.0064213.t003

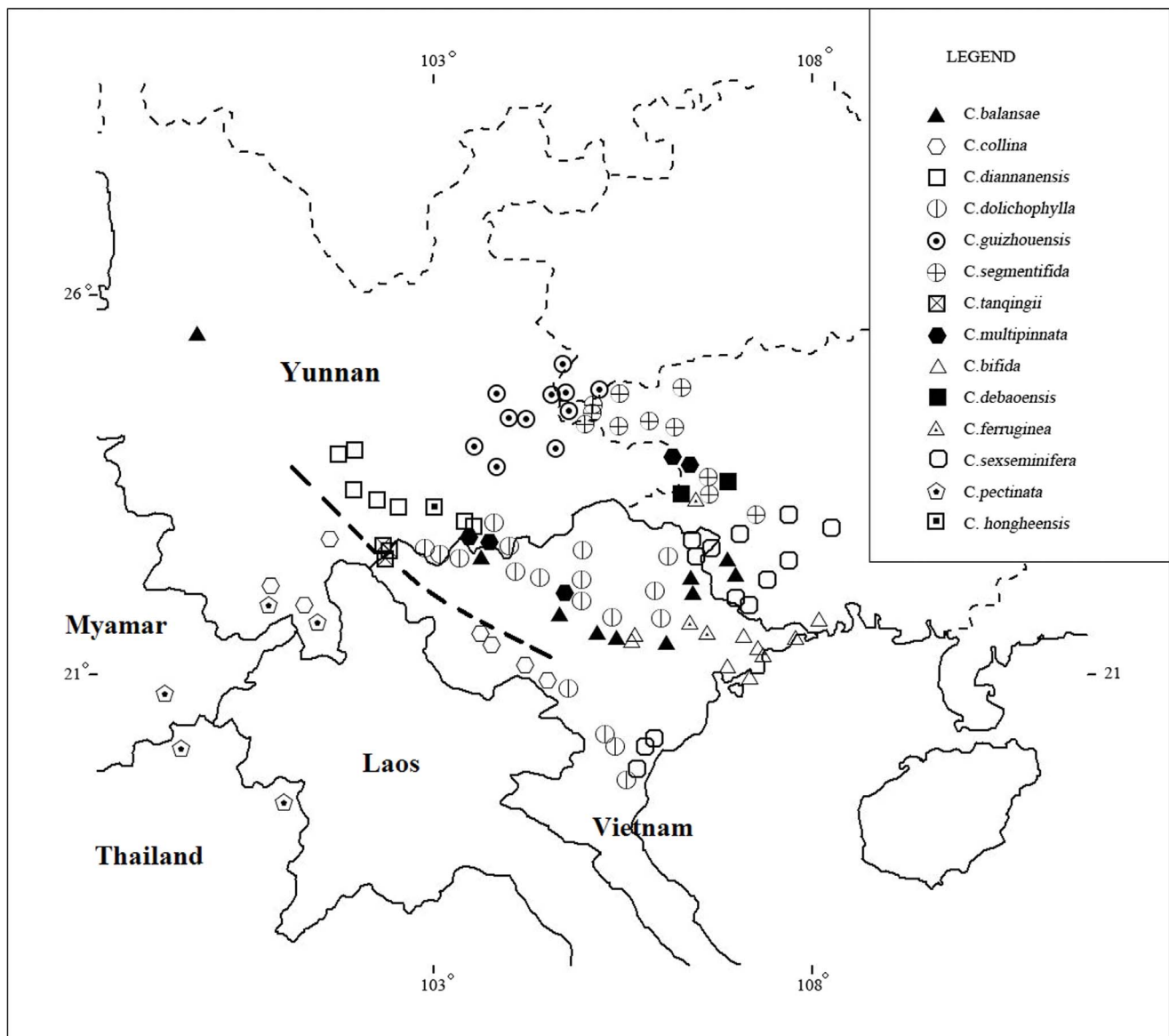


Figure 3. Distributions of *Cycas* species in Yunnan and neighboring areas. The dash-dot line shows a natural demarcation of *Cycas* species between southern and southeastern Yunnan.
doi:10.1371/journal.pone.0064213.g003

ceae, Magnoliaceae, Rosaceae, Sapindaceae, and Theaceae have greater species richness in tropical southeastern Yunnan (Table 2) and most are dominant in the temperate east Asian flora. Additionally, there are 14 families in tropical southeastern Yunnan that are not found in southern Yunnan: Dipsacaceae, Clethraceae, Coriariaceae, Eupteleaceae, Diapensiaceae, Dipentodontaceae, Nyctaginaceae, Taxaceae, Taxodiaceae, Tetracentraceae, Hippocrateaceae, Toricelliaceae, Valerianaceae and Pentaphylacaceae; while only one family, Calophyllaceae, is restricted to southern Yunnan.

Although the generic similarities between the flora of tropical southeastern and southern Yunnan is up to 80%, c. 340 tropical southeastern genera are not found in southern Yunnan, and 230 southern genera are not found in tropical southeastern Yunnan. For example, the genera *Amentotaxus*, *Amesiodendron*, *Carissa*, *Clethra*, *Delavaya*, *Deutzianthus*, *Dipterocarpus*, *Exbucklandia*, *Gonocarym*, *Hopea*, *Licuala*, *Lysidice*, *Madhuca*, *Pavieasia*, *Rhodoleia*, *Rhoiptelea*, are found

only in tropical southeastern Yunnan, while *Anogeissus*, *Arytera*, *Bruinsmia*, *Calophyllum*, *Gymnanthes*, *Kopsia*, *Neuropeltis*, *Polyosma* are found only in southern Yunnan.

Significantly, a number of genera are found in tropical southeastern Yunnan but not in southern Yunnan: 57 genera of east Asian distribution, including *Acanthopanax*, *Akebia*, *Dyosma*, *Dichocarpum*, *Euptelea*, *Keteleeria*, *Platycarya*, *Trachycarpus* and *Toricellia*, 53 genera of north temperate distribution, including *Aesculus*, *Berberis*, *Coriaria*, *Cotoneaster*, *Ribes*, *Spiraea*, *Taxus* and *Tilia*, 22 Chinese endemic genera, including *Delavaya*, *Dipteronia*, *Emmenopterys*, *Excentrodendron*, *Ferocalamus*, *Glyptostrobus*, *Manglietiastrum*, *Metapanax* and *Whytockia*, and 17 genera of east Asia and north America disjunct distribution (Table 3). Although these two neighboring regions have a similar tropical monsoon climate and similar tropical rainforests (Figure 2) there is a conspicuous divergence in these floras.

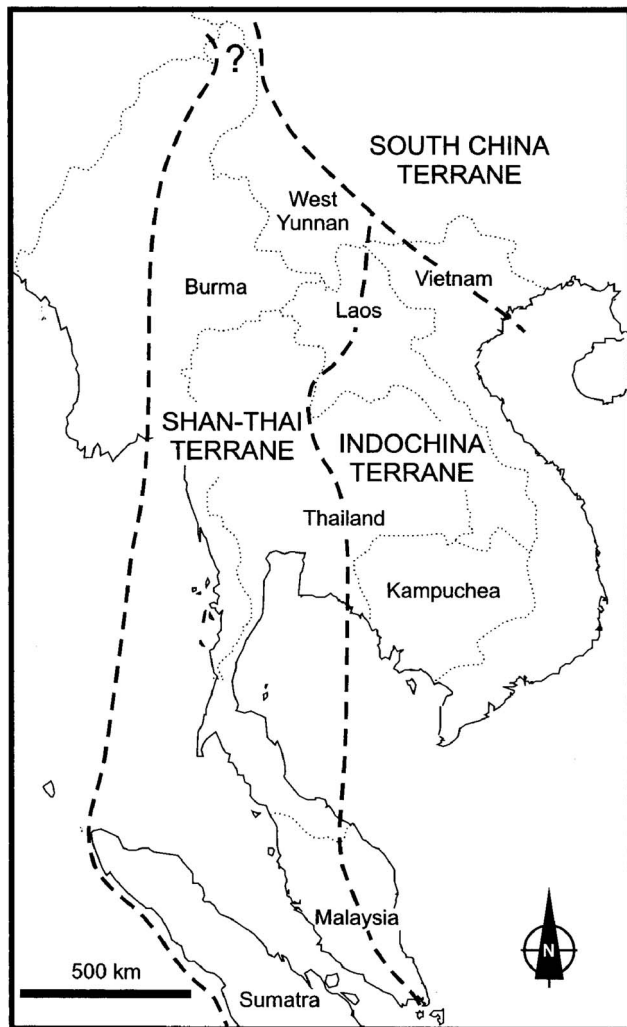


Figure 4. Map showing the boundaries of the various terrains in SE Asia. (from Fotey et al., 1998).
doi:10.1371/journal.pone.0064213.g004

Discussion and Conclusions

Geographical elements at the generic level reveal that the floras of southern and tropical southeastern Yunnan are dominated by tropical elements, of which, the tropical Asian elements make up the highest proportion. Both floras were therefore categorized as the tropical Asian flora in the floristic regionalization of the world [1,2], i.e. they belong to the Malaysia subkingdom of the Paleotropical kingdom. However, the families with temperate distributions, such as Rosaceae, Fagaceae, Ericaceae, Theaceae, Hamamelidaceae, Magnoliaceae, Berberidaceae, Araliaceae, Aquifoliaceae, have conspicuously more species in tropical southeastern Yunnan, and 14 mainly east Asian families, such as Eupteleaceae, Dipentodontaceae, Taxaceae, Tetracentraceae and Toricelliaceae, are found in tropical southeastern Yunnan, but not in southern Yunnan. A total of 340 genera in tropical southeastern Yunnan are not found in southern Yunnan. Of these, 57 are of east Asian distribution, 53 of north temperate distribution, and 22 are Chinese endemics; revealing that the flora of tropical southeastern Yunnan has some intrinsic affinity to the flora of east Asia.

At the specific level, a biogeographical divergence between southern and tropical southeastern Yunnan can be identified. For

example, six species of the primitive seed plant *Cycas* is found in tropical southeastern Yunnan, and only two species in southern Yunnan. The two species in southern Yunnan are from sect. Stangorioides, while the six species in tropical southeastern Yunnan are from sect. Indosinenses [33,34] (Figure 3).

Phylogeography could give implications on the divergence, evolution, and speciation of plants. References on the phylogeographic studies from the tropical areas of Yunnan have not been traced although many have been done in east Asia. Further phylogeographic studies are needed to discuss the biogeographical divergence between southern and tropical southeastern Yunnan.

The distributions of some animal taxa in Yunnan are also biogeographically divergent. Mammal species, such as the northern pig-tailed Macaque (*Macaca leonine*), Gaur (*Bos gaurus*), Banteng (*Bos javanicus*), large-toothed rat (*Dacnomys millardi*), and the Asian elephant are distributed only in southern Yunnan, while the pygmy slow loris (*Nycticebus pygmaeus*), Sun bear (*Helarctos malayanus*) and Owston's palm civet (*Chrotogale owstoni*) are distributed in tropical southeastern Yunnan [35].

Although it is logical that the flora of tropical southeastern Yunnan with much larger altitudinal range, has more temperate families and genera than the flora of southern Yunnan, the conspicuous disparity between the two floras could not be explained only by the difference of their altitudinal ranges.

Tropical southeastern Yunnan was derived from the Southern China Geoblock or Yangzi Block, while southern Yunnan derived from Shan-Thai Geoblock or Simao Block (Figure 4) [36,37,38,39,40]. There was a deep fault between the two regions during the early Tertiary. Southern Yunnan rose completely from a maritime downfold with the uplift of Himalayas until Tertiary, while southeastern Yunnan, as part of Yangzi Block, had been a land environment since the Mesozoic [41].

Although the tropical rain forests in southern and southeastern Yunnan are physiognomically very similar, some dominant tropical rain forest tree species in southeastern Yunnan, such as *Saraca dives*, *Lysidice rhodostegia*, *Amesiodendron chinense*, *Deutzianthus tonkinensis*, *Zenia insignis* and *Garcinia paucinervis*, are not found in southern Yunnan. These species occur to the east of the Lixianjiang River. The Lixianjiang River also divides the *Cycas* Sections Stangorioides (southern Yunnan) and Indosinenses (southwestern Yunnan) (Figure 3) and is a natural demarcation for many other plants and animals between southern and southeastern Yunnan. It is also the geographical demarcation between the Mekong drainage area and the red river drainage area. The Lixianjiang River is, therefore, considered a hypothetical biogeographical line between tropical southern and southeastern Yunnan (Figure 5), named the "Hua line" [42]. The possible biogeographical line was further supported by using a cluster analysis of species presence/absence in Yunnan [43]. The line well matches with the geological Song Ma zone between the southern China and the Shan-Thai-Indochina Geoblock.

Acknowledgments

The database was put together by Yan Lichun. Dr. Xiao Longqian helped with the distribution map of *Cycas* species. Dr. Jiang Xuelong offered information on mammal species distributions. I thank anonymous reviewers for their constructive comments on this article. Ms. Pelin Kayaalp helps improving English for the article.

Author Contributions

Conceived and designed the experiments: ZH. Performed the experiments: ZH. Analyzed the data: ZH. Contributed reagents/materials/analysis tools: ZH. Wrote the paper: ZH.

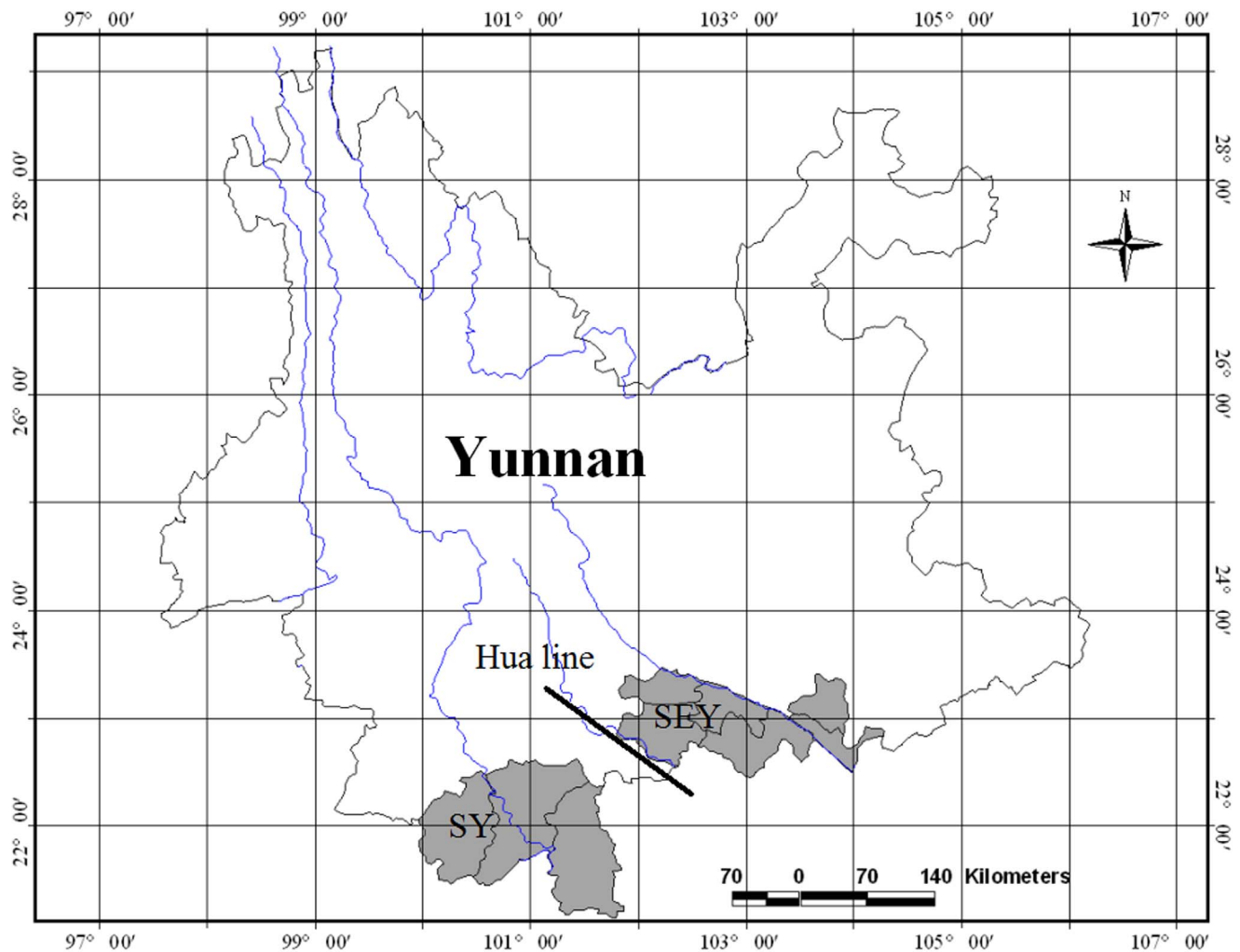


Figure 5. Hypothetical biogeographical line (Hua line) between southern and tropical southeastern Yunnan. Dark areas are southern Yunnan (SY), and tropical southeastern Yunnan (SEY).
doi:10.1371/journal.pone.0064213.g005

References

1. Takhtajan Y (1978) Floristic Region of the World (in Russian), Soviet Sciences Press, Leningrad Branch.
2. Wu CY, Wu SG (1996) A Proposal for a new floristic kingdom (realm) – the Asiatic kingdom, its delineation and characteristics. In: Zhang A, Wu S (editors). Floristic characteristics and diversity of East Asian plants. Beijing: China Higher Education & Springer Press. 3–42.
3. Audley-Charles MG (1987) Dispersal of Gondwanaland: Relevance to evolution of the Angiosperms. In: Whitmore, TC. Biogeographical Evolution of the Malay Archipelago. Clarendon Press. Oxford.
4. Jin XC (2002) Permo-Carboniferous sequences of Gondwana affinity in southwest China and their paleogeographical implications. *Journal of Asian Earth Sciences* 20: 633–646.
5. Metcalfe I (2006) Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean Peninsula in context. *Gondwana Research* 9: 24–46.
6. Zhu H (2012) Biogeographical divergence of the flora of Yunnan, southwestern China initiated by the uplift of Himalaya and extrusion of Indochina block. *PLoS ONE* 7(9), e45601.
7. Fedorov AnA (1957) The flora of southwestern China and its significance to the knowledge of the plant world of Eurasia. *Komarov Chten* 10: 20–50.
8. Fedorov AnA (1958) The tropical rain forest of China (in Russia with English summary). *Botanicheskii Zhurnal S.S.S.R.* 43: 1385–1480.
9. Whitmore TC (1982) Fleeting impressions of some Chinese rain forests. *Commonwealth Forestry Review* 61: 51–58.
10. Whitmore TC (1984) Tropical rain forests of far east. (Second edition). Clarendon Press, Oxford. 352 p.
11. Whitmore TC (1990) An introduction to tropical rain forests. Clarendon Press. Oxford. 226 p.
12. Zhu H (1992) Tropical rain forest vegetation in Xishuangbanna. *Chinese Geographical Science* 2 (1): 64–73.
13. Zhu H (1993a) A comparative study of phytosociology between *Shorea chinensis* forest of Xishuangbanna and other closer forest types. *Acta Botanica Yunnanica* 15: 34–46 (in Chinese with English abstract).
14. Zhu H (1993b) Floristic plant geography on the dipterocarp forest of Xishuangbanna. *Acta Botanica Yunnanica* 15: 233–253 (in Chinese with English abstract).
15. Zhu H (1994a) The floristic characteristics of the tropical rain forest in Xishuangbanna. *Chinese Geographical Science* 4: 174–185.
16. Zhu H (1994b) Floristic relationships between dipterocarp forest of Xishuangbanna and forests of tropical Asia and S China. *Acta Botanica Yunnanica* 16 (2): 97–106 (in Chinese with English abstract).
17. Zhu H (1997) Ecological and biogeographical studies on the tropical rain forest of southern Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *Journal of Biogeography* 24: 647–662.
18. Zhu H (2008a) Advances in biogeography of the tropical rainforest in southern Yunnan, southwestern China. *Tropical Conservation Science* 1: 34–42.
19. Zhu H (2008b) The tropical flora of southern Yunnan, China, and its biogeographical affinities. *Annals of the Missouri Botanical Garden* 95: 661–680.
20. Zhu H, Wang H, Li BG (1998a) The Structure, Species Composition and Diversity of the Limestone Vegetation in Xishuangbanna, SW China. *Gardens' Bulletin Singapore* 50: 5–33.

21. Zhu H, Li BG, Wang H (1998a) Species diversity of primary tropical rain forest of southern Yunnan of China with special reference to sampling area. *Chinese Biodiversity* 6 (4): 241–247 (in Chinese with English abstract).
22. Zhu H, Li YH, Wang H, Li BG (2001) Characteristics and affinity of the flora of Xishuangbanna, SW China. *Guihaia* 21: 127–136 (in Chinese with English abstract).
23. Zhu H, Wang H, Li BG, Sirirugsa P (2003) Biogeography and floristic affinity of the Limestone flora in southern Yunnan, China. *Annals of the Missouri Botanical Garden* 90: 444–446.
24. Zhu H, Roos MC (2004) The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* 10(2): 639–648.
25. Zhu H, Cai L (2005) Biogeography of the tropical rain forest of Yunnan and some implications to geographical history. *Advance in Earth Sciences* 20 suppl.: 1–57.
26. Zhu H, Cao M, Hu HB (2006a) Geological history, flora, and vegetation of Xishuangbanna, southern Yunnan, China. *Biotropica* 38(3): 310–317.
27. Zhu H, Wang H, Li BG (2006b) Floristic composition and biogeography of tropical montane rain forest in southern Yunnan of China. *Gardens' Bulletin Singapore* 58: 81–132.
28. Zhu H, Yan LC (2009) Biogeographical affinities of the flora of southeastern Yunnan, China. *Botanical Studies* 50(4): 467–475.
29. Zhu H, Yan LC (2012) Native seed plants in Xishuangbanna of Yunnan. Beijing: Science Press, 1–565.
30. Wu ZY (1991) The areal-types of Chinese genera of seed plants. *Acta Botanica Yunnanica Supp.* 4: 1–139.
31. Wu ZY, Zhou ZK, Sun H, Li DZ, Peng H (2006) The areal-types of seed plants and their origin and differentiation. Kunming: Yunnan Science and Technology Press.
32. Wu ZY, Zhou ZK, Li DZ, Peng H, Sun H (2003) The areal-types of the world families of seed plants. *Acta Botanica Yunnanica* 25: 245–257 (In Chinese with English abstract).
33. Hill KD, Hiep TN, Loc P (2000) The Genus *Cycas* (Cycadaceae) in Vietnam. *The Botanical Review* 70(2): 134–193.
34. Hill KD (2008) The genus *Cycas* (Cycadaceae) in China. *Telopea* 12(1): 71–118.
35. Pan QH, Wang YX, Yan K (2007) A field guide to the Mammals of China. Beijing: China Forestry Publishing House. 1–420.
36. Lee YT, Lawver LY (1995) Cenozoic plate reconstruction of Southeast Asia. *Tectonophysics* 251: 85–138.
37. Fortey RA, Cocks LRM (1998) Biogeography and palaeogeography of the Sibumasu terrane in the Ordovician: A review. In: Hall R, Holloway JD. *Biogeography and Geological Evolution of SE Asia*. Leiden: Backbuys Publishers, 43–56.
38. Feng QH, Chonglakmani C, Helmcke D, Ingavat-helmcke R, Liu BP (2005) Correlation of Triassic stratigraphy between the Simao and Lampang-Phrae Basins: implications for the tectonopaleogeography of Southeast Asia. *Journal of Asian Earth Sciences* 24: 777–785.
39. Lepvriere C, Vuong NV, Maluski H, Thi PT, Vu TV (2008) Indosinian tectonics in Vietnam. *Comptes Rendus Geoscience* 340: 94–111.
40. Hirsch F, Ishida K, Kozai T, Meeusook A (2006) The welding of Shan-Thai. *Geosciences Journal* 10(3): 195–204.
41. Yunnan Geology and Mineral Bureau (1995) Atlas of geology and palaeogeography of Yunnan. Kunming: Yunnan Science & Technology Press, 1–228.
42. Zhu H (2011) A new biogeographical line between south Yunnan and southeast Yunnan. *Advance in Earth Science* 26(9): 916–925. (in Chinese with English abstract).
43. Zhang MG, Zhou ZK, Chen WY, Slik JWF, Cannon CH et al. (2012) Using species distribution modeling to improve conservation and land use planning of Yunnan, China. *Biological Conservation* 153: 257–264.

Biogeographical Divergence of the Flora of Yunnan, Southwestern China Initiated by the Uplift of Himalaya and Extrusion of Indochina Block

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Abstract

The floral composition of Yunnan is conspicuously linked to the biogeographical history of this extremely species-rich province in southwestern China. The floristic compositions of three representative regions in Yunnan were compared to reveal their variation with geography. From southern Yunnan, 4150 native species (including subspecies and varieties) from 1240 genera and 183 families of seed plants were recognized. From central Yunnan 3389 native species from 1095 genera and 167 families of seed plants were recognized. From northwestern Yunnan 6807 native species from 1296 genera and 166 families of seed plants were recognized. Although these three floras across Yunnan are similar in familial composition, similarities between the floras of southern and northwestern Yunnan are low at the generic and specific levels. The flora of northwestern Yunnan is dominated by families and genera with cosmopolitan and north temperate distributions, while the flora of southern Yunnan is dominated by tropical families and genera. Northwestern Yunnan is composed largely of temperate genera, of which the highest proportion has a north temperate distribution. In contrast, southern Yunnan has mainly tropical genera, of which most have a tropical Asian distribution. The flora of central Yunnan is a combination of southern and northwestern Yunnan. These three floras might be derived from a common Tertiary tropical or subtropical East Asian flora, but the geological history of each region has influenced its flora, and they have remained divergent since the late Tertiary. The flora of northwestern Yunnan has evolved with the uplift of the Himalayas and by gradual proliferation of mainly cosmopolitan and north temperate floristic elements, while the flora of southern Yunnan has evolved with extrusion of the Indochina block and the influence of mainly tropical Asian elements.

Citation: Hua Z (2012) Biogeographical Divergence of the Flora of Yunnan, Southwestern China Initiated by the Uplift of Himalaya and Extrusion of Indochina Block. PLoS ONE 7(9): e45601. doi:10.1371/journal.pone.0045601

Editor: Martin Heil, Centro de Investigación y de Estudios Avanzados, Mexico

Received: July 2, 2012; **Accepted:** August 23, 2012; **Published:** September 24, 2012

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Funding: This project was funded by the National Natural Science Foundation of China (41071040, 31170195). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The author has declared that no competing interests exist.

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Introduction

The “Eastern Asiatic floristic region” was delineated by Takhtajan [1] in his floristic regionalization of the world. The region is considered to be one of the major centres of development of higher plants, as it is especially rich in gymnosperms and primitive angiosperms [2]. Yunnan province of south-western China is the core area of the west wing of the “Eastern Asiatic floristic region” with extremely rich biodiversity, and is among the hotspots for conservation priorities in the world [3]. The region is also important for understanding historical biogeography due to its location in a transitional zone between tropical south-east Asia and temperate east Asia, and its position in geological history at a sutural zone between Gondwana and Laurasia [4,5].

Yunnan is a mountainous region with an extremely diverse topography (from 76.4 m at the lowest valley in the southeast to 6740 m at the highest mountain summit in the northwest). Due to its diverse topography and climate, as well as its unique geological history, Yunnan is extremely rich in species and vegetation types, and the landscape varies vastly from tropical rain forests in southern Yunnan, to Taiga-like cold temperate coniferous forest in northwestern Yunnan.

The plant geography of Yunnan was primarily studied by Li and Walker [6]. There are many floristic works on local areas and nature reserves in Yunnan, with fewer large area and regional scale studies, but exceptions are the large Hengduan Mountains [7,8,9], southern Yunnan [10,11], southwestern Yunnan [12,13], and central Yunnan [14]. Southern Yunnan, with a tropical monsoon climate and lower mountain-basin topography, has a tropical flora of Malaysian affinity. Central Yunnan, with a subtropical climate and middle mountain-valley topography, has close affinities to the subtropical flora of East Asia. Northwestern Yunnan, with a temperate climate and alpine-deep valley topography, has a temperate Himalayan flora. These patterns in the flora and vegetation of Yunnan are of extreme interest to botanists. In the present study, we select three representative regions with different altitudes across this extremely biodiverse region of China, southern, central and northwestern Yunnan, to study their floristic compositions and variation with geography, and their evolution with geological history, as well as biogeographical affinities.

General Geography

Yunnan is in southwestern China between 21°09' and 29°15' N, 97°32' and 106°12' E (Figure 1) and occupies an area of 394,100 km². It has a mountainous topography with the mountain ridges generally running in a north-south direction, decreasing in elevation southward. Yunnan is extremely diverse in habitat and topography. The general climatic pattern consists of tropical wet climates in the southern lowlands (annual mean temperature 19–22°C), tropical dry climates in deep valleys below 1000 m alt. (20–24°C) due to the foehn effect, subtropical climates on the central plateau (14–18°C), and temperate to cold temperate climates in the northern high mountains (5–14°C). The climate changes conspicuously with altitude. Yunnan is therefore a region with tropical areas as the horizontal base [15].

Yunnan supports an extremely rich biodiversity and various vegetation types. A total of 13,245 species in 2,137 genera and 222 families of native seed plants are recognized from Yunnan [16], contributing to 50% of the total seed plant species in China. Twelve vegetation types including 169 formations were recognized in the vegetation classification of Yunnan [17], including tropical rain forest, subtropical evergreen broad-leaved forest, warm-temperate deciduous broad-leaved forest, temperate coniferous and broad-leaved mixed forest, cold temperate coniferous forest, alpine shrubs and meadows, as well as thorny shrubs and savanna in dry-hot valleys [18]. Southern Yunnan is generally covered by tropical rain forest at its lowlands [19]. Most of central Yunnan is

between 1300–2200 m, and is covered by subtropical evergreen broad-leaved forest and secondary *Pinus yunnanensis* forest. Northern Yunnan, with an elevation above 1900 m, is covered mainly by temperate sclerophyllous oak forest and cold-temperate coniferous forest [20]. The distribution of vegetation in Yunnan corresponds more with elevation than latitude [10].

Materials and Methods

This study focuses on three representative regional floras from southern, central and northwestern Yunnan. Southern Yunnan (Xishuangbanna administrative region) lies between 21°09' and 22°36' N, 99°58' and 101°50' E and has an area of 19690 km² with altitude varying from 480 m at the bottom of the lowest valley (Mekong River) to 2430 m at the highest mountain top. Central Yunnan, here including 7 counties, lies between 23°53' and 25°11' N, 100°32' and 101°58' E. It includes the core area of Wuliang and Ailao Mountains, and has an area of 25,424 km². Its altitude varies from 422 m at the lowest valley in the south (Red River) to 3156.9 m at the highest mountain top. Northwestern Yunnan, here including three counties, lies between 27°10' and 28°27' N, 98°53' and 99°42' E. It has an area of 23870 km² with altitude varying from 1900 m at the lowest valley to 6740 m at the highest mountain summit (Figure 1).

Complete lists of the total native seed plants of southern, central and northwestern Yunnan were based on the recently completed Flora of Yunnan [16], the data base of seed plants from KUN

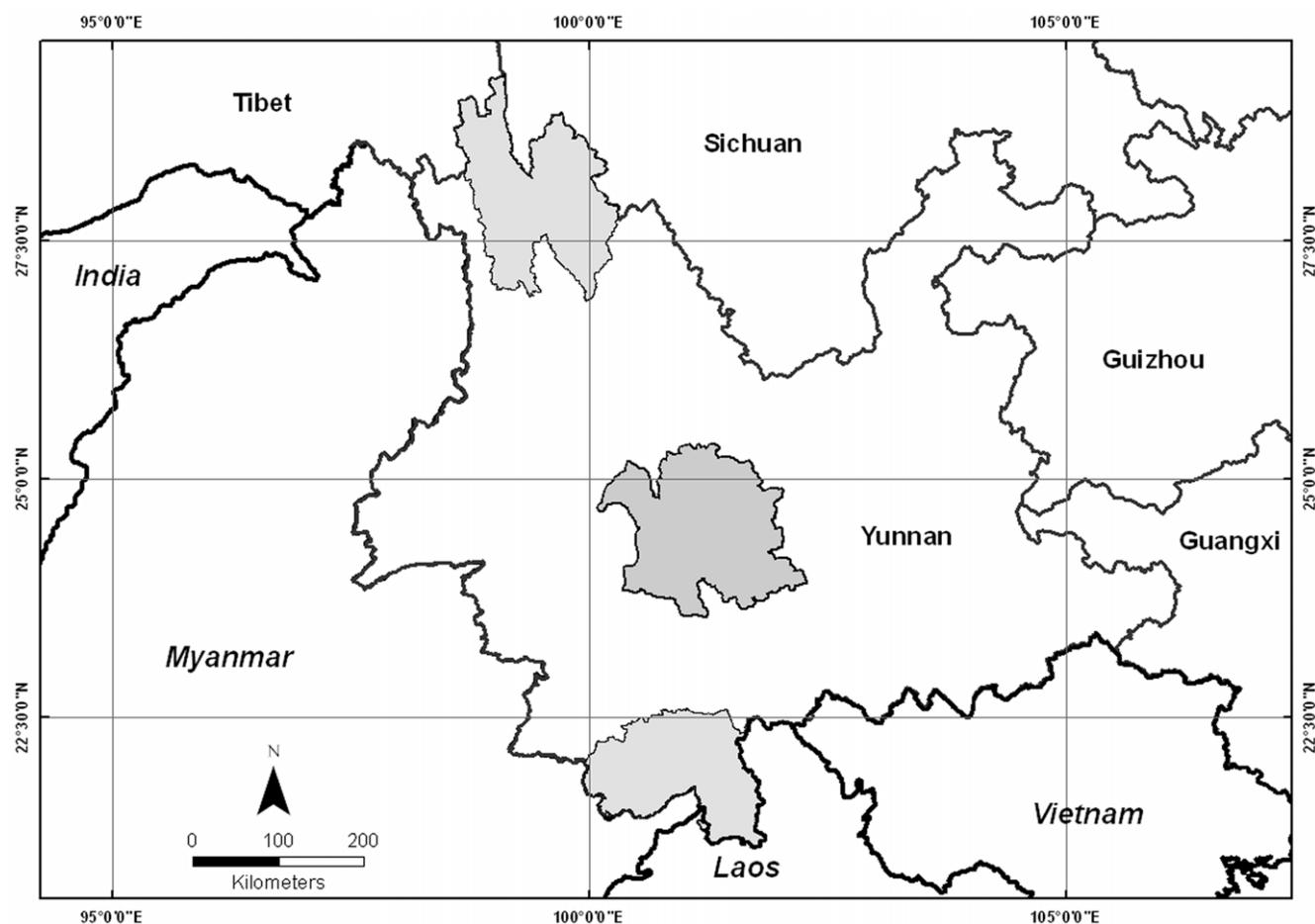


Figure 1. Map showing the study areas: Northwestern, Central and Southern Yunnan.

doi:10.1371/journal.pone.0045601.g001

(herbarium of Kunming Institute of Botany, Chinese Academy of Sciences), and floristic inventories [21,22,23]. Circumscription of families and species followed the nomenclature of *w*³TROPICOS (<http://mobot.mobot.org/W3T/Search/vast.html>).

Based on these plant lists, floristic and geographical attributes of the floras of the three areas were analyzed. Patterns of seed plant distributions of these floras were quantified at the generic level based on Wu's documentation [24] and at the family level following Wu et al. [25]. Comparisons of both floristic composition and geographical elements were made to assess floristic similarities and variation, as well as to determine biogeographical affinities between the three areas.

Results

Floristic Composition

A total of 4150 native species including subspecies and varieties from 1240 genera and 183 families of seed plants were recognized from southern Yunnan. Families with highest species richness include Orchidaceae (377 species and taxa under species), Fabaceae (261), Rubiaceae (201), Poaceae (189), Euphorbiaceae (148), Lamiaceae (139), Asteraceae (137), Lauraceae (105), Urticaceae (84), Zingiberaceae (84) and Moraceae (83).

A total of 3389 native species including subspecies and varieties from 1095 genera and 167 families of seed plants were recognized from central Yunnan. Families with the highest species richness include Asteraceae (202 species and taxa under species), Fabaceae (187), Poaceae (183), Lamiaceae (132), Orchidaceae (121), Rubiaceae (121), Rosaceae (119) and Ericaceae (87).

A total of 6807 native species including subspecies and varieties from 1296 genera and 166 families of seed plants were recognized from northwestern Yunnan. Families with the highest species richness include Asteraceae (518 species), Poaceae (395), Rosaceae (358), Orchidaceae (323), Fabaceae (299), Ericaceae (284), Ranunculaceae (238), Lamiaceae (220), Apiaceae (198), Orobanchaceae (181), Cyperaceae (176), Primulaceae (146), Gentianaceae (145), Saxifragaceae (124), Salicaceae (121), Liliaceae (113), Rubiaceae (111) and Caryophyllaceae (110).

The dominant families from these three floras are summarised in Table 1.

Genera with the highest species richness in southern Yunnan include *Ficus* (65 species), *Dendrobium* (47), *Bulbophyllum* (40), *Polygonum* (34) and *Litsea* (30). The dominant genera in central Yunnan include *Ficus* (49), *Rubus* (38), *Polygonum* (37), *Rhododendron* (33) and *Primula* (30); while the dominant genera in northwestern Yunnan are *Rhododendron* (183), *Pedicularis* (119), *Salix* (105), *Carex* (93), *Primula* (93), *Gentiana* (90), *Saxifraga* (86), *Saussurea* (71), *Polygonum* (65), *Rubus* (64), *Corydalis* (59), *Aconitum* (56), *Berberis* (56), *Acer* (54), *Astragalus* (52) and *Ligularia* (50) (Table 2).

Geographical Elements

Geographical elements at family level. Twelve distribution types of family are recognized from northwestern, central, and southern Yunnan (Table 3).

In the flora of southern Yunnan, there are 106 (57.92%) families with tropical distributions. Those with pantropic distributions make up 73.9% of the tropically distributed families, and 42.08% of the total number of families, such as Acanthaceae, Anacardiaceae, Annonaceae, Apocynaceae, Araceae, Arecaceae, Burseraceae, Clusiaceae, Myristicaceae, Sapotaceae and Icacinaceae. The remainder have old world tropic distributions (including Pittosporaceae, Pandanaceae and Musaceae), tropical Asian and tropical American disjunct distributions (including Araliaceae, Elaeocarpaceae, Gesneriaceae, Staphyleaceae and Styracaceae),

and tropical Asian distributions (such as Crypteroniaceae and Sabiaceae). Cosmopolitan families make up 25.68% of the total number of families in southern Yunnan, such as Asteraceae, Poaceae, Rosaceae, Fabaceae etc. Families with mainly temperate distributions contribute 16.39% to the total flora, including those with north temperate distributions (such as Caprifoliaceae, Betulaceae, Buxaceae and Salicaceae), east Asia and north America disjunct distributions (Magnoliaceae, Nyssaceae and Saururaceae), and east Asian distributions (Actinidiaceae, Cephalotaxaceae and Stachyuraceae).

In the flora of central Yunnan, there are 87 (52.10%) families with tropical distributions, including 67 (40.12%) families with pantropic distributions. Cosmopolitan families contribute to 28.14% of the total number of families. Families with mainly temperate distributions make up 19.76% of the total flora, including 21 families of north temperate distribution and seven families of east Asia and north America disjunct distributions.

In the flora of northwestern Yunnan, 45.18% of families have tropical distributions, of which 57 (34.34% of the total number of families) have pantropic distributions. The proportion of families with cosmopolitan distributions is 30.12%. There are 24 families (14.46%) with north temperate distributions, and 5.42% have east Asia and north America disjunct distributions.

Geographical elements at the generic level. Distributions of the seed plants at the generic level are summarized in Table 4.

In southern Yunnan, genera with tropical distributions (Table 4, types 2–7) comprise 77.02%, and those with tropical Asian distributions (e.g., *Alphonsea*, *Amoora*, *Pterospermum*, *Mitrephora*, *Mycetia*, *Aganosma*, *Chukrasia*, *Crypteronia*, and *Knema*) are most common, contributing to 27.74% of the flora. Genera with pantropic distributions, such as *Gnetum*, *Beilschmiedia*, *Cryptocarya*, *Capparis*, *Piper*, *Dioscorea*, *Uncaria* make up 20.48% of the flora. Genera with old world tropical distributions, such as *Thunbergia*, *Dracaena*, *Pandanus*, *Ventilago*, *Stephania*, *Fissistigma*, *Polyalthia*, and *Uvaria*, make up 9.92%, and 10.65% of genera have Asia to tropical Australia distributions, including *Ailanthus*, *Hoya*, *Argyrea*, *Dillenia*, *Lagerstroemia*, *Murraya* and *Toona*. Genera with temperate distributions (Table 4, types 8–14) contribute to 17.02%, including genera with north temperate distributions (e.g., *Artemisia*, *Carpinus*, *Betula*, *Salix*, and *Sorbus*), east Asia and north America disjunct distributions (e.g., *Schizandra*, *Photinia*, *Nyssa*, *Magnolia*, *Mahonia* and *Castanopsis*), old world temperate distributions (e.g., *Ajuga*, *Elsholtzia*, *Ligustrum* and *Paris*), and east Asian distributions (*Actinidia*, *Belamcandia*, *Aspidistra*, *Cephalotaxus* and *Pterocarya*). Only 15 genera are endemic to China, including *Biondia*, *Camptotheca*, *Craspedolobium*, *Cyphotheca*, *Dichotomanthe*, *Eleutherrhena*, *Noelia*, *Paramomum*, *Styrophyton*, *Tapiscia* and *Thyrocarpus*.

In the flora of central Yunnan, genera with tropical distributions (Type 2–7) make up 60.37% of the total genera, of which genera with pantropic distributions are most common (18.63%), followed by those with tropical Asia distributions (17.08%). Genera with temperate distributions (Type 8–14) in all make up 32.33% of the total genera, and those with north temperate distributions make up 12.60% of the total genera, followed by those with east Asia distributions, which make up 10.50% of the total genera.

In northwestern Yunnan, there are 612 (47.19%) genera with temperate distributions (Type 8–14). Among them, genera with northern temperate distributions (e.g., *Abies*, *Pinus*, *Carpinus*, *Betula*, *Salix* and *Populus*), contribute to 16.11% of the total genera. Genera with east Asian distributions (e.g., *Actinidia*, *Ainsliaea*, *Aucuba*, *Aspidistra*, *Cephalotaxus*, *Fargesia*, *Helwingia*, *Hovenia* and *Yushania*) contribute to 14.26% of the total genera. Genera with tropical distributions (Type 2–7) make up 42.87% of the genera, and most have pantropic (14.80%) (e.g., *Adenostemma*, *Ardisia*,

Table 1. Dominant families ranking by species richness of these three compared floras.

Flora of southern Yunnan			Flora of central Yunnan			Flora of northwestern Yunnan		
Family	No. sp.	Sp.%	Family	No. sp.	Sp.%	Family	No. sp.	Sp.%
Orchidaceae	377	9.08	Asteraceae	202	5.99	Asteraceae	518	7.61
Fabaceae	261	6.29	Fabaceae	187	5.52	Poaceae	395	5.80
Rubiaceae	201	4.84	Poaceae	183	5.40	Rosaceae	358	5.26
Poaceae	189	4.55	Lamiaceae	132	3.89	Orchidaceae	323	4.75
Euphorbiaceae	148	3.57	Orchidaceae	121	3.57	Fabaceae	299	4.39
Lamiaceae	139	3.35	Rubiaceae	121	3.57	Ericaceae	284	4.17
Asteraceae	137	3.30	Rosaceae	119	3.51	Ranunculaceae	238	3.50
Lauraceae	105	2.53	Ericaceae	87	2.57	Lamiaceae	220	3.23
Urticaceae	84	2.02	Euphorbiaceae	69	2.04	Apiaceae	198	2.91
Zingiberaceae	84	2.02	Urticaceae	65	1.92	Cyperaceae	176	2.59
Moraceae	83	2.00	Lauraceae	63	1.86	Orobanchaceae	181	2.66
Acanthaceae	77	1.86	Liliaceae	61	1.80	Primulaceae	146	2.14
Asclepiadaceae	66	1.59	Orobanchaceae	61	1.80	Gentianaceae	145	2.13
Cyperaceae	63	1.52	Moraceae	59	1.74	Saxifragaceae	124	1.82
Cucurbitaceae	60	1.45	Fagaceae	57	1.68	Salicaceae	121	1.78
Fagaceae	60	1.45	Ranunculaceae	52	1.53	Liliaceae	113	1.66
Rosaceae	59	1.42	Primulaceae	49	1.45	Rubiaceae	111	1.63
Annonaceae	57	1.37	Polygonaceae	47	1.39	Caryophyllaceae	110	1.62
Apocynaceae	56	1.35	Theaceae	45	1.33	Polygonaceae	99	1.45
Vitaceae	56	1.35	Araliaceae	44	1.30	Urticaceae	99	1.45
Orobanchaceae	55	1.33	Asclepiadaceae	44	1.30	Cruciferae	94	1.38
Araceae	47	1.13	Cyperaceae	42	1.24	Caprifoliaceae	85	1.25
Rutaceae	46	1.11	Gesneriaceae	41	1.21	Papaveraceae	83	1.22
Convolvulaceae	42	1.01	Rutaceae	40	1.18	Campanulaceae	78	1.15
Gesneriaceae	42	1.01	Acanthaceae	38	1.12	Araliaceae	71	1.04
Areaceae	41	0.99	Caprifoliaceae	36	1.06	Berberidaceae	69	1.01
Sterculiaceae	40	0.96	Apiaceae	36	1.06	Lauraceae	65	0.95
Malvaceae	38	0.92	Celastraceae	35	1.03	Crassulaceae	64	0.94
Polygonaceae	38	0.92	Gentianaceae	33	0.97	Gesneriaceae	61	0.90
Celastraceae	37	0.89	Vitaceae	33	0.97	Sapindaceae	56	0.82

The families showed by bold letter are the dominant families, which are only in one of the three floras respectively.
doi:10.1371/journal.pone.0045601.t001

Bauhinia, *Buxus*, *Diospyros*, *Smilax* and *Vitex*) or tropical Asian (10.95%) distributions (e.g., *Actinodaphne*, *Agapetes*, *Camellia*, *Cipadessa*, *Daphniphyllum*, *Engelhardtia* and *Exbucklandia*). There are 53 genera that are endemic or approximately endemic to China, including *Davidia*, *Dipelta*, *Kingdonia*, *Musella*, *Ostryopsis*, *Taiwania* etc.

Biogeographical Divergence of the Flora of Yunnan

The floristic similarity between these regional floras of Yunnan is more than 88% at the family level and more than 55.89% at the generic level, and lowest at the species level (26.72%–48.45%) (Table 5). Central Yunnan shares a nearly equal proportion of flora with both southern and northwestern Yunnan. The family Theaceae is particularly species rich in central Yunnan, but otherwise the dominant families of central Yunnan are also common to southern or northwestern Yunnan.

The dominant families in the floras of southern and northwestern Yunnan are different, with the exception of the most dominant families (see Table 1). The families Zingiberaceae, Cucurbitaceae, Apocynaceae, Annonaceae, Convolvulaceae, Are-

caceae and Sterculiaceae are dominant families in the flora of southern Yunnan, while Gentianaceae, Saxifragaceae, Salicaceae, Caryophyllaceae, Cruciferae, Papaveraceae, Campanulaceae, Berberidaceae and Crassulaceae are the dominant families in the flora of northwestern Yunnan.

A majority of the thirty most dominant genera in central Yunnan (Table 2) are also common to either southern or northwestern Yunnan. However, southern and northwestern Yunnan do not share any dominant genera.

Comparisons of geographical elements (distribution types) at family level from these regional floras revealed that, excluding cosmopolitan families, families with tropical distributions in all (Table 3, type 2–7) contribute to a majority of the total number of families in all three floras of Yunnan, and families with pantropic distributions make up the highest proportion among geographical elements.

Tropical genera in all (Type 2–7) make up 77.02% of the total number of genera in the flora of southern Yunnan, and genera with temperate distributions (Type 8–14) contribute only to

Table 2. Dominant genera ranking by species richness of these three compared floras.

Genera in southern Yunnan	No. of species	Genera in central Yunnan	No. of species	Genera in northwestern Yunnan	No. of species
<i>Ficus</i>	65	<i>Ficus</i>	49	<i>Rhododendron</i>	183
<i>Dendrobium</i>	47	<i>Rubus</i>	38	<i>Pedicularis</i>	119
<i>Bulbophyllum</i>	40	<i>Polygonum</i>	37	<i>Salix</i>	105
<i>Polygonum</i>	34	<i>Rhododendron</i>	33	<i>Carex</i>	93
<i>Litsea</i>	30	<i>Primula</i>	30	<i>Primula</i>	93
<i>Dioscorea</i>	28	<i>Clematis</i>	25	<i>Gentiana</i>	90
<i>Syzygium</i>	27	<i>Lithocarpus</i>	25	<i>Saxifraga</i>	86
<i>Calamus</i>	25	<i>Ilex</i>	23	<i>Saussurea</i>	71
<i>Piper</i>	25	<i>Euonymus</i>	20	<i>Polygonum</i>	65
<i>Begonia</i>	24	<i>Litsea</i>	20	<i>Rubus</i>	64
<i>Eria</i>	22	<i>Symplocos</i>	20	<i>Corydalis</i>	59
<i>Tetrastigma</i>	22	<i>Vaccinium</i>	20	<i>Aconitum</i>	56
<i>Desmodium</i>	21	<i>Smilax</i>	19	<i>Berberis</i>	56
<i>Elatostema</i>	21	<i>Camellia</i>	18	<i>Acer</i>	54
<i>Lithocarpus</i>	21	<i>Desmodium</i>	18	<i>Astragalus</i>	52
<i>Strobilanthes</i>	21	<i>Lysimachia</i>	18	<i>Ligularia</i>	50
<i>Castanopsis</i>	20	<i>Viola</i>	18	<i>Ilex</i>	46
<i>Lasianthus</i>	20	<i>Elsholtzia</i>	17	<i>Juncus</i>	43
<i>Smilax</i>	20	<i>Impatiens</i>	17	<i>Poa</i>	41
<i>Millettia</i>	19	<i>Pilea</i>	17	<i>Cotoneaster</i>	39
<i>Amomum</i>	18	<i>Carex</i>	16	<i>Delphinium</i>	39
<i>Clerodendrum</i>	18	<i>Elatostema</i>	16	<i>Silene</i>	39
<i>Elaeocarpus</i>	18	<i>Piper</i>	16	<i>Potentilla</i>	38
<i>Habenaria</i>	18	<i>Schefflera</i>	16	<i>Arenaria</i>	37
<i>Ophiorrhiza</i>	18	<i>Tetrastigma</i>	16	<i>Arisaema</i>	37
<i>Rubus</i>	18	<i>Crotalaria</i>	15	<i>Aster</i>	36
<i>Crotalaria</i>	17	<i>Dioscorea</i>	15	<i>Euonymus</i>	36
<i>Oberonia</i>	17	<i>Eurya</i>	15	<i>Sorbus</i>	36
<i>Vernonia</i>	17	<i>Gentiana</i>	15	<i>Clematis</i>	35
<i>Glochidion</i>	16	<i>Begonia</i>	14	<i>Indigofera</i>	35

doi:10.1371/journal.pone.0045601.t002

17.02% of the total genera, while in northwestern Yunnan tropical genera contribute to 42.87% and genera with temperate distributions contribute to 47.19% of the total genera. The flora of central Yunnan is comprised mainly of tropical genera (64.37%) and temperate genera contribute to 32.33%. Genera with tropical Asian and tropical Asia to tropical Australia distributions constitute a noticeably high proportion in the flora of southern Yunnan. Genera with north temperate, east Asia and north America disjunct, old world temperate, east Asia, and Chinese endemic distributions make up the highest proportion of flora in northwestern Yunnan.

Within these three regions, 352 genera are found only in southern Yunnan, while 375 genera are found only in northwestern Yunnan (Table 6). Among the genera only in southern Yunnan, 330 genera have tropical distributions, including 169 tropical Asian genera, 59 genera with pantropic distributions, and 44 genera with tropical Asia to tropical Australia distributions. Among the genera that are found only in northwestern Yunnan, 305 genera have a temperate distribution, including 78 genera from east Asia, 75 genera with north temperate distributions, 51

genera with old world temperate distributions and 39 Chinese endemic genera.

Of the genera that are shared by two of the three floras, 621 genera are found only in central and southern Yunnan, and 664 genera are present only in the floras of central and northwestern Yunnan. Among the genera found only in central and southern Yunnan, 551 genera have tropical distributions, including 253 genera from tropical Asia, 102 genera with pantropic distributions, and 78 genera with tropical Asia to tropical Australia distributions. Among the genera only to the floras of central and northwestern Yunnan, 495 genera have temperate distributions, including 146 north temperate genera, 137 genera of east Asia, and 75 genera with old world temperate distributions. It is evident that the flora of central Yunnan has floristic attributes of both southern and northwestern Yunnan, and is related to the flora of southern Yunnan mainly by tropical elements, especially tropical Asia and pantropic elements, while related to the flora of northwestern Yunnan mainly through temperate elements, especially north temperate and east Asian elements.

Table 3. Geographical elements of seed plants at the family level of these three compared floras.

Geographical elements at family level	Flora of southern Yunnan		Flora of central Yunnan		Flora of northwestern Yunnan	
	No. of family	%*	No. of family	%	No. of family	%
Cosmopolitan	47	25.68	47	28.14	50	30.12
Pantropic	77	42.08	67	40.12	57	34.34
Tropical Asia and Tropical America disjunct	11	6.01	10	5.99	11	6.63
Old World Tropic	3	1.64	2	1.20	2	1.20
Tropical Asia to Tropical Australia	5	2.73	3	1.80	3	1.81
Tropical Asia to Tropical Africa	1	0.55	1	0.60	0	0.00
Tropical Asia	9	4.92	4	2.40	2	1.20
North Temperate	19	10.38	21	12.57	24	14.46
East Asia and North America disjunct	7	3.83	7	4.19	9	5.42
Old World Temperate	0	0.00	0	0.00	1	0.60
East Asia	3	1.64	4	2.40	6	3.61
Endemic to China	1	0.55	1	0.60	1	0.60
Total	183	100.00	167	100.00	166	100.00

*The number of family in each geographical element/the number of family of all geographical elements.
doi:10.1371/journal.pone.0045601.t003

Discussion and Conclusions

The flora of Yunnan is noticeably divergent along altitude, latitude and topography. Southern Yunnan has a tropical flora of Malaysian affinity, while northwestern Yunnan has a temperate Himalayan flora. Whether these floral patterns are a consequence of mainly ecological divergence or historical-biogeography is of

important significance in revealing the formation and evolution of the flora of Yunnan.

Although the floras of southern and northwestern Yunnan have a similar composition at the family level (88% similarity), they differ at the generic (55.89% similarity) and especially at specific (26.72% similarity) levels.

The flora of northwestern Yunnan is dominated by families and genera with cosmopolitan and north temperate distributions, while

Table 4. Geographical elements of seed plants at the generic level of these three compared floras.

Geographical elements at generic level	Flora of southern Yunnan		Flora of central Yunnan		Flora of northwestern Yunnan	
	No. of genus	%*	No. of genus	%	No. of genus	%
Cosmopolitan	59	4.76	61	5.57	76	5.86
Pantropic	254	20.48	204	18.63	192	14.80
Tropical Asia and Tropical America disjunct	31	2.50	35	3.20	30	2.31
Old World Tropic	123	9.92	96	8.77	81	6.25
Tropical Asia to Tropical Australia	132	10.65	82	7.49	64	4.93
Tropical Asia to Tropical Africa	71	5.73	57	5.21	46	3.55
Tropical Asia	344	27.74	187	17.08	142	10.95
North Temperate	68	5.48	138	12.60	209	16.11
East Asia and North America disjunct	32	2.58	43	3.93	71	5.47
Old World Temperate	29	2.34	45	4.11	99	7.63
Temperate Asia	5	0.40	6	0.55	18	1.39
Mediterranean, W Asia to C Asia	3	0.24	5	0.46	16	1.23
Center Asia	2	0.16	2	0.18	14	1.08
East Asia	72	5.81	115	10.50	185	14.26
Endemic to China	15	1.21	19	1.74	53	4.09
Total no. of genera	1240	100.00	1095	100.00	1296	100.00

*The number of genera in each geographical element/the number of genera of all geographical elements.
doi:10.1371/journal.pone.0045601.t004

Table 5. Comparison of floristic similarities at the family, generic and specific levels between these floras of southern, centre and north-western Yunnan.

Compared flora	Southern Yunnan	Central Yunnan	Northwestern Yunnan
	Shared/Similarity coefficient (%) [*]	Shared/Similarity coefficient (%)	Shared/Similarity coefficient (%)
Similarity coefficients at family level			
Southern Yunnan	100/100		
Central Yunnan	157/94.01%	100/100	
Northwestern Yunnan	147/88.55	151/90.96	100/100
Similarity coefficients at generic level			
Southern Yunnan	100/100		
Central Yunnan	808/73.63	100/100	
Northwestern Yunnan	693/55.89	833/76.00	100/100
Similarity coefficients at specific level			
Southern Yunnan	100/100		
Central Yunnan	1527/45.06		
Northwestern Yunnan	1109/26.72	1642/48.45	

^{*}Similarity coefficient between A and B = the number of taxa shared by both A and B divided by the lowest number of taxa of A or B, multiplied by 100%.
doi:10.1371/journal.pone.0045601.t005

the flora of southern Yunnan, although sharing some large cosmopolitan families, is additionally dominated by tropical families and genera.

The flora of northwestern Yunnan is comprised more of tropical families (45.18) than temperate families (24.7%), but temperate genera are more dominant (47.19%). The flora of southern Yunnan is comprised mainly of tropical families (57.92%) and genera (77.02%). Furthermore, the flora of northwestern Yunnan is characterized by a relatively high proportion of genera with northern temperate, east Asian and old world temperate

distributions, while the flora of southern Yunnan is characterized by a relatively high proportion of genera with tropical Asian (making up the highest proportion), pantropic and tropical Asia to tropical Australia distributions. Among genera that are known from southern Yunnan but not central or northwestern Yunnan, the majority have tropical distributions. Among genera in northwestern Yunnan only, the majority have temperate distributions. These factors reveal that the flora of northwestern Yunnan is different from the flora of southern Yunnan in floristic attributes. The flora of northwestern Yunnan is temperate in nature, while

Table 6. Geographical elements of seed plants at the generic level in these floras respectively and shared by two of them.

Geographical elements at generic level	Genera only in southern Yunnan		Genera only in northwestern Yunnan		Genera only in central and southern Yunnan		Genera only in central and northwestern Yunnan	
	No. of genus	%	No. of genus	%	No. of genus	%	No. of genus	%
Cosmopolitan	4	1.14	12	3.20	7	1.13	22	3.31
Pantropic	59	16.76	17	4.53	102	16.43	41	6.17
Tropical Asia and Tropical America disjunct	6	1.70	4	1.07	18	2.90	15	2.26
Old World Tropic	29	8.24	5	1.33	58	9.34	15	2.26
Tropical Asia to Tropical Australia	44	12.50	4	1.07	78	12.56	10	1.51
Tropical Asia to Tropical Africa	23	6.53	4	1.07	42	6.76	17	2.56
Tropical Asia	169	48.01	24	6.40	253	40.74	49	7.38
North Temperate	0	0.00	75	20.00	5	0.81	146	21.99
East Asia and North America disjunct	3	0.85	31	8.27	10	1.61	48	7.23
Old World Temperate	2	0.57	51	13.60	5	0.81	75	11.30
Temperate Asia	0	0.00	10	2.67	1	0.16	13	1.96
Mediterranean, W Asia to C Asia	0	0.00	10	2.67	0	0.00	12	1.81
Center Asia	1	0.28	11	2.93	2	0.32	13	1.96
East Asia	8	2.27	78	20.80	27	4.35	137	20.63
Endemic to China	4	1.14	39	10.40	13	2.09	51	7.68
Total no. of genera	352	100.00	375	100.00	621	100.00	664	100.00

doi:10.1371/journal.pone.0045601.t006

the flora of southern Yunnan is tropical in nature and has strong tropical Asian affinities.

Furthermore, if we look at global species numbers from each family and consider the proportion of species that are found in each of these regional floras (excluding cosmopolitan families), the families characteristic of southern Yunnan are quite different from those of northwestern Yunnan. In the flora of southern Yunnan, tropical families, such as Tetramelaceae, Cardiopteridaceae, Sphenocleaceae, Sladeniaceae, Musaceae, Hernandiaceae, Gnetales and Opiliaceae are most characteristic; while in northwestern Yunnan, temperate families, especially those with east Asian distributions, such as Helwingiaceae, Tetracentraceae, Stachyuraceae, Cephalotaxaceae, Eupteleaceae, and those with north temperate distributions, such as Diapensiaceae, Caprifoliaceae, Hydrangeaceae, Betulaceae, Pinaceae, Juncaceae and Papaveraceae are characteristic.

The conspicuous divergence between the floras of southern and northwestern Yunnan might be attributed to differences in geological history as well as differences in ecological habitat. The northwestern Yunnan had a temperate and subtropical flora during the Tertiary [26], and underwent a quick uplift with the Himalayas after the Pleistocene [27]. Uplift of Himalaya mountains began about 50 Myr ago, and further significant increases in altitude of the Tibetan plateau are thought to have occurred about 10±8 Myr ago [28,29,30]. With the uplift of Himalaya, east Asian monsoons were appeared about 9-8 Myr ago, and intensified about 3.6–2.6 Myr ago [31]. Studies on fossil mammalian, pollen, assemblages and sedimentary mineralogy as well as carbon isotope data from fossil tooth enamels and paleosol carbonates revealed that the central Himalaya had a much

warmer environment in the late Neogene, and the “paleothermometer” were 21±6°C at c. 7 Myr ago, which is 19±6°C higher than the present-day, and it was suggested that these area have been raised by c.2–2.5 km since 7 Myr to its current elevation of 4100–4500 m above sea level [32]. The northwestern Yunnan, which is part of eastern Himalaya, should have the similar environmental changes and tectonic uplift as the central Himalaya since the late Neogene. On the other hand, collision between India and Asia also caused lateral extrusion of southeast Asia between 32 Ma and 10 Ma [28,33,34,35,36,37].

It could be inferred that these floras of Yunnan could derived from a common Tertiary tropical or subtropical Asian flora. Thereafter, the flora of northwestern Yunnan has evolved with the uplift of the Himalayas by gradual proliferation of mainly cosmopolitan and north temperate floristic elements, while the flora of southern Yunnan has evolved with extrusion of the Indochina block to southeast Asia by the influence of mainly tropical Asian elements.

Acknowledgments

The Database was put together by Yan Lichun, and the figure was drawn by Liu Wenjun from Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences. Ms. Pelin Kayaalp helps improving English for the article.

Author Contributions

Conceived and designed the experiments: ZH. Performed the experiments: ZH. Analyzed the data: ZH. Wrote the paper: ZH.

References

1. Takhtajan Y (1978) Floristic Region of the World (in Russian). Soviet Sciences Press, Leningrad Branch, 1986. English ed. Translated by T.S. Crovello, ed. By A. Cronquist. P.50.
2. Wu ZY, Wu SG (1996) A Proposal for a new floristic kingdom (realm)—the Asiatic kingdom, its delineation and characteristics. In: Zhang AL, Wu SG, eds. Floristic characteristics and diversity of east Asian plants. Beijing: China Higher Education and Springer Press. 3–42.
3. Myers N, Mittermeier RA, Mittermeier CG., da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858.
4. Jin XC (2002) Permo-Carboniferous sequences of Gondwana affinity in southwest China and their paleogeographical implications. *Journal of Asian Earth Sciences* 20: 633–646.
5. Metcalfe I (2006) Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean Peninsula in context. *Gondwana Research* 9: 24–46.
6. Li XW, Walker D (1986) The plant geography of Yunnan Province, southwest China. *Journal of Biogeography* 13: 367–397.
7. Wu ZY (1988) The Hengduan Mountain flora and her significance. *Journal of Japanese Botany* 63(9): 1–14.
8. Li XW, Li J (1993) A preliminary floristic study of the seed plants from the region of the Hengduan Mountains. *Acta Botanica Yunnanica* 15: 217–231 (in Chinese with English abstract).
9. Zhang DC, Zhang YH, Boufford DE, Sun H (2009) Elevational patterns of species richness and endemism for some important taxa in the Hengduan Mountains, southwestern China. *Biodiversity and Conservation* 18: 699–716.
10. Zhu H (2008a) The tropical flora of southern Yunnan, China, and its biogeographical affinities. *Annals of the Missouri Botanical Garden* 95: 661–680.
11. Zhu H, Yan LC (2009). Biogeographical affinities of the flora of southeastern Yunnan, China. *Botanical Studies* 50(4): 467–475.
12. Zhu H, Zhao JM, Cai M, Liu SL, Li L (2004) Studies on the flora of Dehong region, SW Yunnan (I) Floristic composition and geographical elements at generic level. *Guihaia* 24(3): 193–198.
13. Zhu H, Zhao JM, Li L, Si HH (2006) A study on the flora of the seed plants of tropical rain forest of Rui-li, SW Yunnan. *Guihaia* 26(4): 400–405.
14. Yan LC, Shi JP, Zhu H, Peng H, Liu YH, et al. (2009) The studies on floristics of seed plants in Ailaoshan Region, Yunnan, China. *Journal of Tropical and Subtropical Botany* 17(3): 283–29 (In Chinese with English abstract).
15. Zhu H (2008b) Distribution patterns of genera of Yunnan seed plants with references to their biogeographical significances. *Advances in Earth Science* 23(8): 830–839.
16. Wu ZY (1977–2006) *Flora Yunnanica* vols. 1–16. Beijing: Science Press (In Chinese).
17. Wu ZY (1987) Vegetation of Yunnan. Beijing: Science Press. 143–163. (in Chinese).
18. Jin ZZ (1992) The natural vegetation types of Yunnan, China. A series of geobotanical monographs. *Braun-Blanquetia* 8: 65–76.
19. Zhu H (1997) Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *Journal of Biogeography* 24: 647–662.
20. Zhu H (2009) Read the Nature — Geological Wonder and Vegetation Geography of the Three Parallel Rivers Region in Northwest Yunnan. Beijing: Science Press, 1–155.
21. Peng H (1998) The seed plants from Mt. Wuliang in the south-central Yunnan, China. Kunming: Yunnan Science and Technology Press. Pp. 1–170.
22. Zhu H, Yan LC (2009b) List of seed plants in the Ailao Mts. of Yunnan province, China. Kunming: Yunnan Sci. and Tech. Press, 1–731.
23. Zhu H, Yan LC (2012) Native seed plants in Xishuangbanna of Yunnan. Beijing: Science Press. Pp. 565.
24. Wu ZY (1991) The areal-types of Chinese genera of seed plants. *Acta Botanica Yunnanica Supp.* IV: 1–139 (in Chinese with English abstract).
25. Wu ZY, Zhou ZK, Li DZ, Peng H, Sun H (2003) The areal-types of the world families of seed plants. *Acta Botanica Yunnanica* 25: 245–257 (In Chinese with English abstract).
26. Mehrotra RC, Liu XQ, Li SC, Wang YF, Chauhan MS (2005) Comparison of the Tertiary flora of southwest China and northeast India and its significance in the antiquity of the modern Himalayan flora. *Review of Palaeobotany and Palynology* 135: 145–163.
27. Shi YF, Li JY, Li B, Yao TD, Wang SM, et al. (1999) Uplift of the Qinghai-Xizang (Tibetan) plateau and east Asia environmental change during late Cenozoic. *Acta Geographica Sinica* 54 (1): 10–21. (in Chinese with English abstract).
28. An Y (2010) Cenozoic tectonic evolution of Asia: A preliminary synthesis. *Tectonophysics* 488: 293–325.
29. Harrison TM, Copeland P, Kidd WSF, Yin A (1992) Raising Tibet. *Science* 255: 1663–1670.
30. Molnar P, England P, Martindale J (1993) Mantle dynamics, uplift of the Tibetan Plateau and the Indian monsoon development. *Rev. Geophys.* 34: 357–96.
31. An Z, Kutzbach J, Prell W, Porter S (2001) Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan plateau since Late Miocene times. *Nature* 411: 62–66.

32. Wang Y, Deng T, Flynn L, Wang XM, Yin A, et al. (2012) Late Neogene environmental changes in the central Himalaya related to tectonic uplift and orbital forcing. *Journal of Asia Earth Science* 44: 62–76.
33. Yang YQ, Liu M (2009) Crustal thickening and lateral extrusion during the Indo-Asian collision: A 3D viscous flow model. *Tectonophysics* 456: 128–135.
34. Tapponnier P, Lacassin R, Leloup PH, Schärer U, Zhong DL, et al. (1990) The Ailao Shan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China. *Nature* 343: 431–437.
35. Tapponnier P, Peltier G, Armijo R, Le Dain AY, Cobbold P (1982) Propagation extrusion tectonics in Asia: new insights from simple experiments with plasticine. *Geology* 10: 611–616.
36. Lee TY, Lawver LA (1995) Cenozoic plate reconstruction of Southeast Asia. *Tectonophysics* 251: 85–138.
37. Che J, Zhou WW, Hu JS, Yan F, Papenfuss TJ, et al. (2010) Spiny frogs (Paini) illuminate the history of the Himalayan region and Southeast Asia. *PNAS* 107(31): 13765–13770.

Biogeographical affinities of the flora of southeastern Yunnan, China¹

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(Received May 1, 2007; Accepted May 14, 2009)

ABSTRACT. Southeastern Yunnan has 4,996 species and varieties of 1,357 genera and 186 families of native seed plants recorded. Floristic attributes and biogeographical affinities of the flora were studied by analyzing its floristic composition and geographical elements. Tropical genera comprise a majority (68.83%) of the flora and those of tropical Asian distribution contribute to 27.34% of the total genera. The flora of southeastern Yunnan is similar in composition to the floras of southern Yunnan, southwestern Guangxi and Vietnam. They have similarities of more than 89% at the family level and more than 76% at the generic level. The flora of southeastern Yunnan, with the compared floras together, belongs to the same floristic unit and is suggested to be part of Indo-Malaysian flora at northern margin of tropical Asia. However, the taxa of strictly tropical distribution are still underrepresented in the flora of southeastern Yunnan compared to Indo-Malaysian flora, and the families of mainly subtropical to temperate distribution, such as Magnoliaceae, Theaceae, Cornaceae, Styracaceae, Symplocaceae, Aquifoliaceae and Caprifoliaceae, are well represented in the flora. Some characteristic families of temperate East Asia, such as Diapensiaceae, Dipentodontaceae, Eupteleaceae, Grossulariaceae and Toricelliaceae are also present in the flora of southeastern Yunnan. These suggest that the flora of southeastern Yunnan is related to Eastern Asian flora more than other compared floras. It is also revealed that the flora of southeastern Yunnan is biogeographically closer to the flora of southwestern Guangxi than that of southern Yunnan.

Keywords: Biogeographical affinities; Flora; Southeastern Yunnan.

INTRODUCTION

Southern China is located at the northern edge of tropical Asia, and is composed of the southeasternmost part of Xizang (Tibet) (lower valleys of southern Himalayas), southwestern, southern and southeastern parts of Yunnan, southern Guangxi, southern Guangdong, southern Taiwan and Hainan Island. Southeastern Yunnan borders Vietnam, is situated in the southern extension of the Eastern Himalayas, and located at the demarcation line with tropical “SE Asia” to the south, temperate “Sino-Himalaya” to the north biogeographically.

Southeastern Yunnan is of extreme interest to botanists not only for its richness of primitive angiosperm taxa, such as species of Magnoliaceae and being a centre of palaeoendemism in China (Li, 1994), but also for its biodiversity richness, a hotspot for biodiversity of the world (Myers, 1998). The montane flora of southeastern

Yunnan is more of the nature of the temperate Sino-Himalaya flora, but the lowland flora is of the nature of the tropical Asian flora with representatives of Dipterocarpaceae.

The flora of south China and its tropical Asian floristic affinity have been discussed since the China-Russia expedition which penetrated deep into the areas of southwestern China in the late 1950s (Fedorov, 1957, 1958; Wu, 1965; Zhu, 1993, 1994a, 1994b, 1997, 2008a, 2008b; Zhu et al., 2001, 2003, 2004a, 2004b, 2006). However, most of the research on flora and vegetation in tropical southwestern China has been conducted in southern Yunnan. The flora of southeastern Yunnan and its biogeographical affinities are less known except some local works in nature reserves (Li et al., 2002; Zhang et al., 2003; Shui et al., 2003; Wang et al., 2006; Zhu et al., 2007a).

To better understand the flora and its biogeographical affinities, the floristic composition and geographical elements of southeastern Yunnan were analyzed at family and generic levels. The floristic relationships of southeastern Yunnan to its neighboring southern Yunnan, southwestern Guangxi and Vietnam, are discussed by

¹This project was funded by The National Natural Science Foundation of China (30770158, 30570128).

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comparing the revised floristic inventories and checklists of these regions in this study.

Study site and topography

The area in southeastern Yunnan referred to in this study is located between the Tropic of Cancer and the Yunnan-Vietnam border, 22°26' ~ 23°26' N and 104°27' ~ 108°48' E (Figure 1). It borders Vietnam to the south, and has a mountainous topography with the mountain ridges running in a north-south direction, decreasing in elevation southeastward. The region, including the six counties of Pingbian, Hekou, Jingping, Luchun, Yuanyang and Honghe, is c. 14,389 km² in area and most of the area is limestone. Its altitude ranges from 74.6 m at the bottom of the lowest valley in the south (Hekou) to 3047.3 m at the top of Xilong Mountains in Jingping County.

Climate

The region has a monsoon climate. From the climatic station in Hekou County at 136.7 m alt. in the south of the region, the annual mean temperature is about 22.6°C and the annual cumulative temperature (the sum of daily temperature means $\geq 10^{\circ}\text{C}$) is 8322.8°C. Annual precipitation is 1777.7 mm, of which more than 80% of the rainfall is in the rainy season from May to October. The average relative humidity is about 86% (Yunnan Meteorological Bureau, 1983). However, the region has a strong climatic variation with altitude. For example, in Pingbian county at 1414.1 m alt., the annual mean temperature is 16.5°, and the annual cumulative temperature ($\geq 10^{\circ}\text{C}$) is 5933.2°C, as well as the annual precipitation is 1621.4 mm, while in Fenshuiling of Jingping county at 2300 m alt., the annual mean temperature is 10.6°, and the annual cumulative temperature ($\geq 10^{\circ}\text{C}$) is 2811.6°C, as well as the annual precipitation is 3287.4 mm (Xu, 2002).

Soil

There are four main soil types in the region. Laterite soils occur in the area below 600 m altitude. Kanhaplohumult soils occur in the areas between 600-1,200 m altitudes with a deep solum, but thin humus horizon. Paleudult soils derived from sandstone substrate occur in the areas between 1,200-1,900 m altitudes. Hapludalf soils occur in the areas above 1,900 m elevation. There is a large area of limestone in the region. The limestone hills have soil derived from a hard limestone substrate.

Vegetation

There are three main altitudinal zones of vegetation in the region. Below 800-900 m elevation is a seasonal rain forest in wet valleys and on lower slopes, and a monsoon forest in dry valleys. Between 900-2,000 m elevation is a lower montane rain forest in wet montane valleys, and an evergreen broad-leaved forest on slopes. An upper montane rain forest occurs on upper slopes

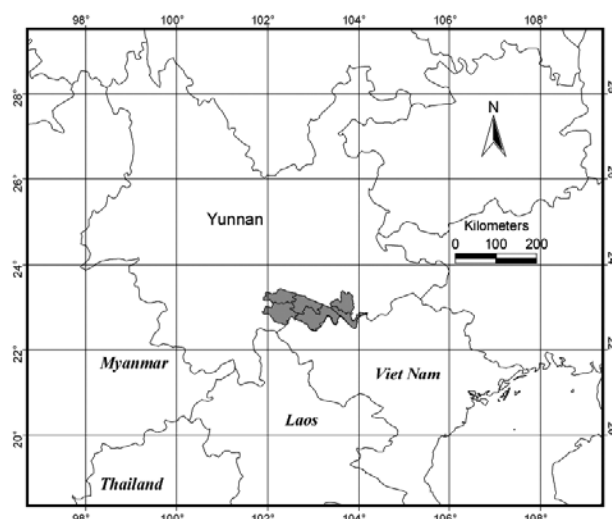


Figure 1. The study area in tropical southeastern Yunnan.

between 2,000-2,500 m elevations. Above 2,500 m elevation is a mossy dwarf forest and shrubs.

The seasonal rain forest, which is similar in forest profile, physiognomic characteristics and floristic composition to Southeast Asian rain forests, is a type of tropical Asian rain forest. It is characterized by tree species *Pometia tomentosa*, *Parashorea chinensis*, *Dipterocarpus retusus*, *Hopea mollissima*, *Lysidice rhodostegia*, *Saraca dives* and *Garcinia paucinervis*. The monsoon forest is a deciduous forest characterized by the deciduous tree species *Bombax malabaricum*, *Albizia chinensis*, *Erythrina stricta*, *Lannea coromandelica*, *Sterculia pexa*, *Mayodendron igneum* and *Stereospermum tetragonum*. The lower montane rain forest is characterized by tree species *Madhuca pasquierii*, *Altingia yunnanensis*, *Podocarpus imbricatus*, *Beilschmiedia fasciata*, *Michelia foveolata* and *Lithocarpus truncatus*. The evergreen broad-leaved forest has a wide distribution and is the main montane vegetation type in the region. It is dominated by species of Fagaceae, Euphorbiaceae, Lauraceae and Theaceae, such as *Castanopsis calcariformis*, *Castanopsis hystrix*, *Castanopsis fleuryi*, *Lindera communis*, *Machilus tenuipilis*, *Machilus longipedicellata* and *Schima wallichii*. The upper montane rain forest is characterized by the species *Castanopsis wattii*, *Lithocarpus xylocarpus*, *Machilus viridis*, *Schima sinensis*, *Hartia sinensis*, *Diplopanax stachyanthus*, *Rehderodendron macrocarpum*, *Rhodoleia henryi* and *Alcimandra cathcartii*. The mossy dwarf forest is characterized by *Lithocarpus pachyphyllodes*, *Vaccinium mandarinorum*, *Rhododendron irroratum*, *Myrsine stolonifera* and *Pieris formosa*.

MATERIALS AND METHODS

Shui (2003) published a checklist of seed plants from subtropical to tropical southeastern Yunnan. From Shui's work and references, we compiled a list of 4,996

species and varieties of native seed plants in 1,357 genera and 186 families from tropical southeastern Yunnan. Circumscription of families and species follows *w*³ TROPICOS of Missouri Botanical Garden (<http://mobot.mobot.org/W3T/Search/vast.html>). Based on the plant list, the floristic and geographical attributes of the flora of southeastern Yunnan were analyzed. Patterns of seed plant distribution were quantified at the generic level based on Wu (1991). Adjacent southern Yunnan, southwestern Guangxi and Northern Vietnam are floristically similar to southeastern Yunnan. To discuss the floristic similarity and variation as well as biogeographical affinities among these regions, comparisons of floristic composition and geographical elements between southeastern Yunnan and neighbouring regions were made by using updated checklists of their floras. The checklist of the flora of southern Yunnan refers to the Xishuangbanna administrative region (Zhu, 2008). Southwestern Guangxi refers also to its tropical area that was recognised by referring distribution of tropical genera of seed plants (Zhu et al., 2007b) and the floristic regionalization of Fang et al. (1995), which extends to northern Vietnam and lies between 21°30'~23°10' N and 106°~109° E. The checklist of southwestern Guangxi was abstracted from the database of the Institute of Botany, CAS. The checklist of the Vietnamese flora (Le, 1999) was used for making comparisons, although Vietnam is floristically heterogeneous in its northern and southern parts.

RESULTS

Floristic composition

Four thousand nine hundred ninety six species and varieties in 1,357 genera and 186 families of native seed plants were recognized to occur in southeastern Yunnan. The families with highest species richness include Fabaceae (70 genera/285 species), Orchidaceae (83/276), Rubiaceae (60/235), Poaceae (92/219), Asteraceae (59/180), Lauraceae (15/141), Urticaceae (17/134), Euphorbiaceae (41/126), Rosaceae (26/124), Fagaceae (5/109) and Moraceae (7/104), Ericaceae (10/96), Lamiaceae (39/91), Cyperaceae (13/87), Acanthaceae (40/85) and Theaceae (9/81) (Table 1). Both the families of mainly tropical elements, such as Orchidaceae, Rubiaceae, Lauraceae, Euphorbiaceae, Moraceae and Acanthaceae, and the families of mainly temperate elements, such as Fabaceae, Poaceae, Asteraceae, Lamiaceae, Rosaceae and Ericaceae have high species richness. The families Fagaceae and Theaceae, which are the dominant families in the forest of East Asia, also have high species richness in the flora.

Geographical elements at generic level

Patterns of seed plant distribution of the flora at the generic level are detailed in Table 2. The genera of tropical Asian distribution, such as *Alphonsea*, *Amoora*, *Pterospium*, *Mitrephora*, *Mycetia*, *Aganosma*, *Chukrasia*,

Table 1. The families of species richness in the flora of southeastern Yunnan.

Family	Genus	Species	% of the total species
Fabaceae	70	285	5.70
Orchidaceae	83	276	5.52
Rubiaceae	60	235	4.70
Poaceae	92	219	4.38
Asteraceae	59	180	3.60
Lauraceae	15	141	2.82
Urticaceae	17	134	2.68
Euphorbiaceae	41	126	2.52
Rosaceae	26	124	2.48
Fagaceae	5	109	2.18
Moraceae	7	104	2.08
Ericaceae	10	96	1.92
Lamiaceae	39	91	1.82
Cyperaceae	13	87	1.74
Acanthaceae	40	85	1.70
Theaceae	9	81	1.62
Gesneriaceae	21	79	1.58
Liliaceae	22	64	1.32
Celastraceae	10	65	1.30
Araliaceae	16	64	1.28
Vitaceae	9	60	1.20
Verbenaceae	10	60	1.20
Myrsinaceae	4	60	1.20
Scrophulariaceae	26	59	1.18
Rutaceae	15	58	1.16
Melastomataceae	16	58	1.16
Annonaceae	12	54	1.08
Asclepiadaceae	23	53	1.06
Polygonaceae	5	52	1.04
Magnoliaceae	14	52	1.04
Araceae	18	52	1.04
Begoniaceae	1	51	1.02
Zingiberaceae	11	50	1.00
Apocynaceae	23	47	0.94
Smilacaceae	2	43	0.86
Sterculiaceae	11	41	0.82
Cucurbitaceae	13	41	0.82
Ranunculaceae	7	38	0.76
Caprifoliaceae	8	37	0.74
Aquifoliaceae	1	35	0.70
Piperaceae	3	34	0.68
Convolvulaceae	12	34	0.68
Commelinaceae	12	32	0.64
Oleaceae	6	30	0.60

Crypteronia, and *Knema*, show the highest percentage among all distribution types, contributing 27.34% to the flora. Genera of Pantropical distribution, such as *Gnetum*, *Cryptocarya*, *Capparis*, *Piper*, *Croton*, *Dioscorea*, *Uncaria*, *Morinda*, *Ardisia*, *Bauhinia*, *Marsdenia* etc., contribute 17.96% to the flora. Next are the genera of Old World tropical distribution, such as *Thunbergia*,

Dracaena, *Pandanus*, *Ventilago*, *Stephania*, *Fissistigma*, *Polyalthia*, *Barringtonia*, *Carallia*, *Canarium*, *Chasalia* and *Uvaria*, contributing 8.55%. Genera with distributions from tropical Asia to tropical Australia include *Hoya*, *Argyreia*, *Dillenia*, *Lagerstroemia*, *Loesenneriella*, *Murray* and *Toona*. Genera of tropical Asian to tropical Africa distribution include *Bombax*, *Flacourtia*, *Bridenia*, *Premna*, *Strophanthus*, *Mitragyna*, *Garcinia*, *Anogeissus*, and *Cymbopogon*. Genera of tropical distribution in all (types 2~7) comprise 68.83% of the total number. The genera of Northern temperate distribution such as *Artemisia*, *Carpinus*, *Betula*, *Salix*, *Cornus*, *Corydalis*, *Pinus*, and *Sorbus* contribute to 8.18% of the total genera. The genera of East Asian distributions such as *Actinidia*, *Belamcandia*, *Aspidistra*, *Cephalotaxus*, *Choerospondia*, *Gardneria*, *Hovenia*, *Pegia*, *Skimmia*, *Stachyrsus*, *Pterocarya*, contribute to 8.84% of the total genera. Other genera include those which have a disjunct distribution in East Asia and North America, such as *Schizandra*, *Photinia*, *Nyssa*, *Osmanthus*, *Magnolia*, *Mahonia*, *Illicium*, *Castanopsis* etc., and Old World temperate distributions such as *Ajuga*, *Elsholtzia*, *Herminium*, *Inula*, *Ligustrum*, *Paris* etc. There are 41 genera which are endemic or approximately endemic to China, including *Bretschneidera*, *Camptotheca*, *Cephalantheropsis*, *Craspedolobium*, *Delavaya*, *Dipteronia*, *Eleutharrhena*, *Emmenopterys*, *Glyptostrobus*, *Gymnotheca*, *Hemiboeopsis*, *Neohusnotia*, *Tapiscia*, *Tetrapanax* etc.

Table 2. Geographical elements of seed plants at the generic level in the flora of southeastern Yunnan.

Geographical elements at generic level	Number of genera	%*
1 Cosmopolitan	62	4.57
2 Pantropic	240	17.69
3 Tropical Asia and Tropical America disjunct	30	2.21
4 Old World Tropic	116	8.55
5 Tropical Asia to Tropical Australia	82	6.04
6 Tropical Asia to Tropical Africa	95	7.00
7 Tropical Asia	371	27.34
8 North Temperate	111	8.18
9 East Asia and North America disjunct	47	3.46
10 Old World Temperate	32	2.36
11 Temperate Asia	6	0.44
12 Mediterranean, W Asia to C Asia	3	0.22
13 Center Asia	1	0.07
14 East Asia	120	8.84
15 Endemic to China	41	3.02
Total no. of genera	1357	100

*The no. of genera in each geographical element divided by the no. of genera of all geographical elements, then multiplied by 100%.

Comparison of the floras of southern Yunnan, southwestern Guangxi of SW China and Vietnam

The floristic similarities at the family and generic levels between southeastern Yunnan and southern Yunnan (Xishuangbanna), southwestern Guangxi and Vietnam are given in Table 3. The similarities in the flora of southeastern Yunnan and those compared floras exceed 89% at the family level and more than 76% at the generic level. The flora of southeastern Yunnan shows a higher floristic similarity to the flora of southwestern Guangxi than to the flora of southern Yunnan at the family and generic levels.

Table 3. Similarity coefficients at family and genus levels between the floras of southern Yunnan, southeastern Yunnan, southwestern Guangxi and Vietnam.

Similarity coefficients	Southern Yunnan/ Southeastern Yunnan	Southwestern Guangxi/ Southeastern Yunnan	Vietnam/Southeastern Yunnan
At family level	163/89.6*	177/95.2	176/94.6
At genus level	939/79.9**	857/84.68	1036/76.34

*Shared no. of families/ Similarity coefficients; **Shared no. of genera/ Similarity coefficients.

Similarity coefficient between A and B = The number of taxa shared by both A and B divided by the number of taxa of A or B which has less taxa, then multiplied by 100%.

Data for tropical southwestern Guangxi is from the database of Institute of Botany, CAS, from which we compiled a plant list with 190 families and 1012 genera of seed plants. Data for southern Yunnan is from Zhu (2008), in which a plant list with 182 families and 1176 genera of seed plants were enumerated. Data for Vietnam is from Le (1999), from which a plant list with 214 families and 1817 genera of seed plants were compiled.

Table 4. The twenty families with most species richness among the tropical floras of southern, southeastern Yunnan, southwestern Guangxi and Vietnam.

Flora of southern Yunnan		Flora of southeastern Yunnan		Flora of southwestern Guangxi		Flora of Vietnam	
Family	Species %*	Family	Species %	Family	Species %	Family	Species %
Orchidaceae	9.82	Fabaceae	5.70	Fabaceae	6.06	Fabaceae	6.98
Fabaceae	6.32	Orchidaceae	5.52	Euphorbiaceae	3.90	Orchidaceae	6.90
Rubiaceae	4.25	Rubiaceae	4.70	Rubiaceae	3.90	Poaceae	5.73
Poaceae	3.95	Poaceae	4.38	Asteraceae	3.46	Rubiaceae	4.72
Euphorbiaceae	3.50	Asteraceae	3.60	Orchidaceae	3.09	Euphorbiaceae	4.50
Asteraceae	3.17	Lauraceae	2.82	Poaceae	2.94	Cyperaceae	3.61
Moraceae	2.19	Urticaceae	2.68	Lauraceae	2.53	Asteraceae	3.26
Lauraceae	2.10	Euphorbiaceae	2.52	Rosaceae	2.42	Lauraceae	2.71
Urticaceae	2.16	Rosaceae	2.48	Urticaceae	2.16	Fagaceae	2.37
Zingiberaceae	2.10	Fagaceae	2.18	Fagaceae	2.12	Acanthaceae	2.17
Acanthaceae	2.04	Moraceae	2.08	Moraceae	1.75	Annonaceae	1.87
Lamiaceae	1.83	Ericaceae	1.92	Rutaceae	1.71	Apocynaceae	1.72
Asclepiadaceae	1.74	Lamiaceae	1.82	Zingiberaceae	1.71	Myrsinaceae	1.56
Apocynaceae	1.53	Cyperaceae	1.74	Asclepiadaceae	1.67	Moraceae	1.53
Annonaceae	1.47	Acanthaceae	1.70	Gesneriaceae	1.67	Verbenaceae	1.46
Verbenaceae	1.44	Theaceae	1.62	Apocynaceae	1.60	Lamiaceae	1.42
Cucurbitaceae	1.38	Gesneriaceae	1.58	Liliaceae	1.60	Araceae	1.42
Rosaceae	1.38	Liliaceae	1.32	Myrsinaceae	1.56	Rosaceae	1.38
Vitaceae	1.35	Celastraceae	1.30	Lamiaceae	1.45	Zingiberaceae	1.38
Fagaceae	1.32	Araliaceae	1.28	Vitaceae	1.38	Melastomataceae	1.31

*Species % indicates their percentage within the respective floras (the number of species for each family divided by the total number of species in the respective floras $\times 100$). The families showed in bold are the top twenty families, which are only in the flora of the tropical southeastern Yunnan.

The comparisons of the twenty families with the most species among these floras are enumerated in Table 4.

The top ranking families in all compared floras are basically the same. The families Zingiberaceae and Apocynaceae represent in the floras of southern Yunnan, southwestern Guangxi and Vietnam among the top twenty families, but not in the top twenty in the flora of southeastern Yunnan. Annonaceae and Verbenaceae are in the top twenty ranking families of the floras of southern Yunnan and Vietnam, while Liliaceae and Gesneriaceae are in the top twenty ranking families of the floras of southeastern Yunnan and southwestern Guangxi. However, Ericaceae, Theaceae, Celastraceae and Araliaceae are only in the top twenty ranking families of the flora of southeastern Yunnan. On the other hand, some families with less species richness, such as the mainly temperate families Coriariaceae, Diapensiaceae, Dipentodontaceae, Eupteleaceae, Grossulariaceae and Toricelliaceae present in southeastern Yunnan, but not in the floras of southern Yunnan and Vietnam.

If we rank the families of high species richness (more than 20 species) by their species percentage in the total of the family (The number of species for each family in the respective floras divided by the total number of species of the family worldwide), we obtained a different ranking pattern (Table 5). Magnoliaceae ranks first in the floras of southeastern Yunnan, southwestern Guangxi and Vietnam among the top ten families, followed by Theaceae. Smilacaceae and Caprifoliaceae are shared by the floras of southeastern Yunnan, southwestern Guangxi in the top ten families, while Symplocaceae is shared by southeastern Yunnan and Vietnam. However, Cornaceae and Styracaceae are among the top ten families only in southeastern Yunnan.

Comparisons of geographical elements at generic level from these regional floras revealed that the tropical elements (type 2~7) contribute more than 68% of the total genera in all these compared floras, and that the highest proportion of the tropical elements occurs in the flora of southern Yunnan (comprising 78.3% of all the genera)

Table 5. Comparison of the families ranked by their species percentage of the total in the family in the regional floras.

Southern Yunnan	Species % of the family*	Southeastern Yunnan	Species % of the family*	Southwestern Guangxi	Species % of the family*	Vietnam	Species % of the family*
Urticaceae	6.86	Magnoliaceae	31.52	Magnoliaceae	14.55	Magnoliaceae	31.52
Menispermaceae	6.67	Cornaceae	23.33	Fagaceae	8.14	Fagaceae	30.43
Moraceae	6.64	Fagaceae	15.57	Smilacaceae	6.25	Theaceae	16.07
Meliaceae	6.55	Smilacaceae	13.44	Caprifoliaceae	6.19	Meliaceae	13.63
Zingiberaceae	6.36	Theaceae	13.28	Theaceae	5.90	Symplocaceae	12.80
Fagaceae	6.29	Urticaceae	12.76	Urticaceae	5.52	Ebenaceae	12.78
Cucurbitaceae	5.94	Styracaceae	12.50	Menispermaceae	4.89	Verbenaceae	13.79
Vitaceae	5.29	Symplocaceae	10.40	Vitaceae	4.35	Moraceae	12.55
Commelinaceae	4.84	Moraceae	9.45	Moraceae	4.27	Myrsinaceae	11.43
Verbenaceae	4.17	Caprifoliaceae	8.81	Zingiberaceae	4.18	Zingiberaceae	11.27

* The number of species for each family in the respective floras divided by the total number of species of the family worldwide. The families showed in bold are the characteristic families of temperate East Asian flora.

Table 6. Comparison of geographical elements at generic level between the floras of southern, southeastern Yunnan, southwestern Guangxi and Vietnam (%)*.

Geographical elements of genera	Flora of southern Yunnan	Flora of southeastern Yunnan	Flora of southwestern Guangxi	Flora of Vietnam
1 Cosmopolitan	5	4.57	5.43	4.35
2 Pantropic	21.3	17.69	20.06	18.00
3 Tropical Asia and Tropical America disjunct	2.6	2.21	2.96	2.92
4 Old World Tropic (Tropical Africa via Tropical Asia to Tropical Australia)	9.5	8.55	9.19	9.08
5 Tropical Asia to Tropical Australia	6.5	6.04	9.98	7.82
6 Tropical Asia to Tropical Africa	8.2	7.00	4.45	8.26
7 Tropical Asia or Indo-Malesia	30.2	27.34	23.22	29.33
8 North Temperate	5.1	8.18	7.71	6.49
9 East Asia and North America disjunct	2.7	3.46	3.95	3.08
10 Old World Temperate	2	2.36	2.96	2.48
11 Temperate Asia	0.4	0.44	0.49	0.50
12 Mediterranean, W. Asia to C. Asia	0.2	0.22	0.30	0.83
13 Center Asia	0.1	0.07	0.00	0.06
14 East Asia	5.3	8.84	7.11	5.12
15 Endemic to China	0.9	3.02	2.17	0.00
16 Endemic to Vietnam				1.71

Data for Southern Yunnan used here is from Zhu (2008) (1176 genera included); Data for tropical southwestern Guangxi used here is from database of the Institute of Botany, CAS (1012 genera included); Data for Vietnam is from Li (1999) (1817 genera included).

(Table 6). All the compared floras have very similar geographical elements except the flora of southeastern Yunnan which has a slightly higher proportion of the geographical elements of East Asia, North Temperate and endemic to China.

Conclusions and discussion

Tropical genera comprise a majority (68.83%) of the flora of southeastern Yunnan. The dominant genera are those restricted to tropical Asia (27.34% of the total genera). This reveals that the flora of southeastern Yunnan is tropical in nature and has tropical Asian affinity although it occurs at the southern extension of the Eastern Himalayas.

The flora of southeastern Yunnan is similar to the floras of southern Yunnan, southwestern Guangxi and Vietnam in the families with the greatest species richness, and has high similarities to them at family and generic levels (more than 89% at the family level and more than 76% at the generic level). It is further confirmed that southeastern Yunnan, southern Yunnan, southwestern Guangxi and Vietnam are floristically continuous. The flora of southeastern Yunnan, along with these other floras, belongs to the same floristic unit and is part of tropical Asian or Indo-Malaysian flora in floristic regionalization. However, the families Ericaceae, Theaceae, Celastraceae and Araliaceae, which are well developed in East Asia, are in the top twenty ranking families of the flora of southeastern Yunnan only, while the more strictly tropical families, such as Zingiberaceae, Verbenaceae, Apocynaceae and Annonaceae are in the top twenty ranking families of the other compared floras. Some temperate East Asian families, such as Coriariaceae, Diapensiaceae, Dipentodontaceae, Eupteleaceae, Grossulariaceae and Toricelliaceae are exclusively present in southeastern Yunnan. These suggest that the flora of southeastern Yunnan is related to temperate Eastern Asian flora more than the other compared floras. The flora of southeastern Yunnan has also a lower percentage of tropical elements and more temperate elements than those of southern Yunnan, southwestern Guangxi and Vietnam. These features of the flora of southeastern Yunnan correspond well to the large cover of montane vegetation in the area.

Although tropical families and genera in a broad sense contribute most to its total flora, the taxa of strictly tropical distribution are still underrepresented in southeastern Yunnan, compared to the Malaysian flora. For example, Dipterocarpaceae has only four species of three genera respectively in southeastern Yunnan although they are the most abundant trees in some forest types. The flora of southeastern Yunnan is a marginal part of the tropical Asian flora.

In the families ranked by species percentage in the total of the family worldwide (Table 5), Magnoliaceae ranks the first in the flora of southeastern Yunnan, followed by Cornaceae, Smilacaceae, Theaceae, Styracaceae, Symplocaceae and Caprifoliaceae in the top ten ranking

families. These families are not only the characteristic families of the temperate East Asian flora, but also the ones well represented in the flora of southeastern Yunnan. The families with most species richness are not the same as the ones that well represented in the flora of southeastern Yunnan. These floristic patterns are quite different from those in Malesian floras, for example, in the flora of Malay Peninsula (Turner, 1995), the families Dipterocarpaceae, Zingiberaceae, Clusiaceae, Annonaceae, Rubiaceae, Apocynaceae, Arecaceae, Euphorbiaceae, Myrtaceae and Melastomataceae are the families with most species richness, but also the families that well represented in Malesia (Zhu and Roos, 2004). It is implied that the flora of southeastern Yunnan had a historical connection to Eastern Asian flora in origin, but deeply permeated by Malesian floristic elements. The flora of southeastern Yunnan has also a closer affinity to the floras of southwestern Guangxi and Vietnam than to the flora of southern Yunnan by sharing more of the well represented families in these regions. Studies on the geological history of SE Asia revealed that southeastern Yunnan and southwestern Guangxi were derived from South China Block or Yangzi Block, while southern Yunnan was part of Shan-Thai Block or Simao Block with Ailaoshan-Song Ma or Ailaoshan Belt being a suture zone (Feng et al., 2005; Metcalfe, 2006; Lepvriere et al., 2008). Our results could be well explained by the geological history of these regions. It is also revealed that direct land connection between mainland SE Asia and western Malesia existed until the early Pliocene (5 million years ago) (Hall, 1998), and there was no geographical barrier between Yunnan, mainland SE Asia and west Malesia during most of the Tertiary (Morley, 1998). The geological history may explain the high percentage of tropical floristic elements, including tropical Asian elements, in the flora of southeastern Yunnan.

Acknowledgments. This project was funded by The National Natural Science Foundation of China (30770158, 30570128). Figure 1 was made by Dr. Hu Huabin. We thank anonymous reviewers for their constructive comments on this article. We also thank Dr. Douglas A. Schaefer for his help in English improvements in this article.

LITERATURE CITED

- Fang, R.Z., P.Y. Bai, G.B. Huang and Y.G. Wei. 1995. A floristic study on the seed plants from tropics and subtropics of Dian-Qian-Gui (in Chinese). *Acta Botanica Yunnanica* (Suppl.) **VII**: 111-150.
- Fedorov, A.A. 1957. The flora of southwestern China and its significance to the knowledge of the plant world of Eurasia (in Russian). *Komarov Chten* **10**: 20-50.
- Fedorov, A.A. 1958. The tropical rain forest of China (in Russian with English summary). *Botanicheskii Zhurnal S.S.S.R.* **43**: 1385-1480.

- Feng, Q.L., C. Chonglakmani, D. Helmcke, R. Ingavat-Helmcke, and B.P. Liu. 2005. Correlation of Triassic stratigraphy between the Simao and Lampang-Phrae Basins: implications for the tectonopaleogeography of Southeast Asia. *J. Asian Earth Sci.* **24**: 777-785.
- Hall, R. 1998. The plate tectonics of Cenozoic SE Asia and the distribution of land and sea. *In* R. Hall and J.D. Holloway (eds.), *Biogeography and Geological Evolution of SE Asia*. Leiden: Backuys Publishers, pp. 99-131.
- Le, T.C. (ed.). 1999. Some basic characters of Vietnam flora. Hanoi: Science & Techniques Publishing House.
- Lepvriere, C., N.V. Vuong, H. Maluski, P.T. Thi, and T.V. Vu. 2008. Indosinian tectonics in Vietnam. *C.R. Geoscience* **340**: 94-111.
- Li, X.W. 1994. Two big biodiversity centres of Chinese endemic genera of seed plants and their characteristics in Yunnan province. *Acta Bot. Yunn.* **16**(3): 221-227. (in Chinese with English abstract).
- Li, Y.L., H. Zhu, and H. Wang. 2002. A study on the flora of seed plants of tropical rainforest of southeastern Yunnan. *Guihaia* **22**(4): 320-326.
- Metcalfe, I. 2006. Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean Peninsula in context. *Gondwana Res.* **9**: 24-46.
- Myers, N. 1998. Threatened biotas: "Hotspot" in tropical forests. *Environmentalist* **8**(3): 1-20.
- Shui, Y.M. (ed.). 2003. Seed plants of Honghe region in SE Yunnan, China. Kunming: Yunnan Science and Technology Press, pp. 665 (in Chinese).
- Shui, Y.M., G.J. Zhang, W.H. Chen, Z.M. Mo, and Z.K. Zhou. 2003. Montane mossy forest in the Chinese part in the Xilongshan mountain, bounding China and Vietnam, Yunnan province, China. *Acta Bot. Yunn.* **25**(4): 397-414 (in Chinese with English abstract).
- Takhtajan, A. 1978. Floristic regions of the World. Leningrad: Soviet Science Press.
- Turner, I.M. 1995. A catalogue of the vascular plants of Malaya. *Garden's Bull. Singapore* **47**: 1-757.
- Wang, J., Q.Y. Ma, and F. Du. 2006. Flora diversity characteristics of seed plants of Dawei Mountain National Nature Reserve in Yunnan province, China. *Sci. Silvae Sin.* **42**(1): 7-15 (in Chinese with English abstract).
- Wu, Z.Y. 1965. The tropical floristic affinity of the flora of China. *Chinese Sci. Bull.* **1**: 25-33 (in Chinese).
- Wu, Z.Y. (Wu, C.Y.). 1991. The areal-types of Chinese genera of seed plants. *Acta Bot. Yunn. (Supp.)* **IV**: 1-139 (in Chinese with English abstract).
- Wu, C.Y. and S.G. Wu. 1996. A Proposal for a new floristic kingdom (realm) --- the Asiatic kingdom, its delineation and characteristics. *In* A. Zhang and S. Wu (eds.), *Floristic characteristics and diversity of East Asian plants*. Beijing: China Higher Education & Springer Press, pp. 3-42.
- Yunnan Meteorological Bureau. 1983. Climatic data of Yunnan Agriculture. Kunming: Yunnan People's Press.
- Xu, J.C. (ed.). 2002. Reports on comprehensive surveys to Fenshuiling Nature Reserve of Jingping, Yunnan. Kunming: Yunnan Science & Technology Press.
- Zhang, G.J., Y.M. Shui, W.Y. Chen, and Z.K. Zhou. 2003. The introduction to plant diversity in Xilong Mountain Natural Reserves on the border between China and Vietnam. *Guihaia* **23**(6): 511-516 (in Chinese with English abstract).
- Zhu, H. 1993. Floristic plant geography on the dipterocarp forest of Xishuangbanna. *Acta Bot. Yunn.* **15**(3): 233-253 (in Chinese with English abstract).
- Zhu, H. 1994a. Floristic relationships between dipterocarp forest of Xishuangbanna and forests of tropical Asia and S China. *Acta Bot. Yunn.* **16**(2): 97-106 (in Chinese with English abstract).
- Zhu, H. 1994b. The floristic characteristics of the tropical rainforest in Xishuangbanna. *Chinese Geograp. Sci.* **4**(1): 174-185.
- Zhu, H. 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *J. Biogeogr.* **24**: 647-662.
- Zhu, H. 2008a. The tropical flora of southern Yunnan, China, and its biogeographical affinities. *Annals of the Missouri Bot. Gard.* **95**: 661-680.
- Zhu, H. 2008b. Advances in biogeography of the tropical rainforest in southern Yunnan, southwestern China. *Trop. Conser. Sci.* **1**: 34-42.
- Zhu, H., Y.H. Li, H. Wang, and B.G. Li. 2001. Characteristics and affinity of the flora of Xishuangbanna, SW China. *Guihaia* **21**(2): 127-136 (in Chinese with English abstract).
- Zhu, H., H. Wang, B.G. Li, and P. Sirirugsa. 2003. Biogeography and floristic affinity of the Limestone flora in southern Yunnan, China. *Ann. Missouri Bot. Gard.* **90**: 444-465.
- Zhu, H., J.M. Zhao, M. Cai, S.L. Liu, and L. Li. 2004a. Studies on the flora of Dehong region, SW Yunnan (I) --- Floristic composition and geographical elements at generic level. *Guihaia* **24**(3): 193-198 (in Chinese with English abstract).
- Zhu, H. and M.C. Roos. 2004b. The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* **10**(2): 639-648.
- Zhu, H., M. Cao, and H.B. Hu. 2006. Geological history, flora, and vegetation of Xishuangbanna, southern Yunnan, China. *Biotropica* **38**(3): 310-317.
- Zhu, H., H. Wang, and W.X. Xiao. 2007a. A study on *Parashorea chinensis* community of tropical rain forest in Gulinqing of Maguan County, SE Yunnan, China. *Guihaia* **27**(1): 62-70 (in Chinese with English abstract).
- Zhu, H., Y.X. Ma, L.C. Yan, and H.B. Hu. 2007b. The relationship between geography and climate in the generic-level patterns of Chinese seed plants. *J. Syst. Evol.* **45**(2): 134-166.

雲南東南部熱帶植物區系的生物地理親緣

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雲南東南部熱帶地區記錄有種子植物 186 科，1,357 屬，4,996 種及變種。通過分析其植物區系組成和地理成分，本文研究了該植物區系的特徵及其生物地理親緣。該植物區系熱帶成分占總屬數的 68.83%，其中，又以熱帶亞洲分佈屬比例最高，占總屬數的 27.34%。在與周邊雲南南部（西雙版納）、廣西西南部及越南植物區系的比較上，雲南東南部的熱帶植物區系與它們在科、屬水準上具有高的類似性，它們之間科的類似性在 89%，屬的類似性在 76% 以上。它們隸屬於同一植物區系分區單元，在植物區系分區中為熱帶亞洲或印度 — 馬來西亞植物區系的北緣部分。由於位於東南亞熱帶北緣山地及其地質歷史原因，雲南東南部的熱帶植物區系中嚴格熱帶分佈的成分不多，仍以邊緣熱帶成分為主，並有相對豐富的亞熱帶 - 溫帶科如木蘭科、山茶科、山茱萸科、山礬科、忍冬科、冬青科等以及一些東亞和喜馬拉雅特徵科，如岩梅科、十齒花科、領春木科、茶藨子科和鞘柄木科，顯示了它與東亞溫帶植物區系也有較多聯繫。與雲南南部、廣西西南部及越南熱帶植物區系比較，雲南東南部植物區系中熱帶地理成分的比例相對較低，並且與廣西西南部的聯繫強于雲南南部。

關鍵詞：生物地理親緣；植物區系；雲南東南部。

THE TROPICAL FLORA OF SOUTHERN YUNNAN, CHINA, AND ITS BIOGEOGRAPHIC AFFINITIES¹

Zhu Hua²

ABSTRACT

The flora of Xishuangbanna in southern Yunnan, southwestern China, consists of 3340 native seed plant species belonging to 1176 genera and 182 families. Tropical floristic elements at the generic level form a major contribution (78.3%) to the total flora of southern Yunnan, of which the dominant geographic elements are those of tropical Asian distribution. The tropical Asian flora of Xishuangbanna is similar in composition to other tropical floras from Yunnan, especially in the families with the most species richness. These regional floras have similarities of more than 89% at the family level and more than 76% at the generic level, but share only 43%–50% similarity at the specific level. Comparison with mainland Southeast Asia (Thailand) and Malesia (Malay Peninsula) floras reveals that most of the dominant families from southern Yunnan are also dominant in mainland Southeast Asian and Malesian floras. The floristic similarities between the flora of southern Yunnan and those of tropical Asia are more than 80% at the family level and more than 64% at the generic level. This suggests that the tropical flora of southern Yunnan has a close affinity with tropical Asian flora and supports the idea that the flora of southern Yunnan, together with mainland Southeast Asian flora, belongs to the Indo-Malaysian floristic subkingdom of the Paleotropical kingdom as suggested by Takhtajan, or the Malaysian subkingdom of the Paleotropical kingdom as suggested by Wu and Wu. However, situated at the northern margin of tropical Asia, the flora of southern Yunnan comprises less strictly tropical elements compared to Malaysian flora and, consequently, represents only a marginal type of Indo-Malaysian flora. The tropical flora of southern Yunnan is supposed to be derived from tropical Asian flora with the formation of the eastern monsoon climate after the Tertiary.

Key words: Biogeographic affinity, southern Yunnan, floristic composition.

The tropical area of southern China is located at the northern edge of tropical Asia and is composed of the extreme southeastern part of Xizang (Tibet) among the lower valleys of the southern Himalayas, southern Yunnan, southwestern Guangxi, southern Taiwan, and Hainan separately. The largest tropical area still covered by forests is in southern Yunnan, the most southwestern region of China, which is also a key area in biogeography and a hotspot for biodiversity (Myers, 1998). This is a mountainous region at the northern margin of mainland Southeast Asia, with a monsoon climate and a slightly lower annual mean temperature (ca. 21°C) and lower annual precipitation (average, 1500 mm) in lowlands and valleys compared to the main tropical rainforest areas of the world, e.g., Malaysia (Richards, 1996). The tropical forest in southern Yunnan is therefore intermediate between classic tropical rainforests and monsoon forests as defined by Schimper (1903), or a type of subtropical rainforest, which differs in various aspects from the true tropical rainforests described by Richards (1952).

After the Chinese-Russian expedition to remote areas of southwestern China, including southern Yunnan, in the late 1950s, papers on the tropical rainforest vegetation (Fedorov, 1958; Wang, 1961) and tropical flora (Fedorov, 1957; Wu, 1965) of this part of China were published. It was basically accepted that biogeographically real tropical rainforests exist in southwestern China, but these were considered to be a different type from those in Indo-Malaysia because of the lack of representatives from Dipterocarpaceae, which dominate the rainforests of tropical Southeast Asia.

Botanical interest was rekindled in the 1970s by the discovery of a dipterocarp forest in southern Yunnan, thus the Indo-Malaysian affinity of the tropical flora of Yunnan was reconsidered. Further results from biogeographic and ecological studies of the vegetation and flora of tropical southern Yunnan revealed that it does in fact comprise a part of the Indo-Malaysian flora (Zhu, 1992, 1993a, b, 1994, 1997, 2004; Zhu et al., 1998a, b, 2001, 2003; Zhu &

¹ This project was funded by the National Natural Science Foundation of China (30570128, 30770158). Figure 1 was prepared by Li Hong-mei. The author thanks David E. Boufford of Harvard University Herbaria for his constructive comments and Chris Carpenter from University of California for improving the English grammar within the manuscript. I also give many thanks to the reviewers for their important and constructive comments.

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doi: 10.3417/2006081

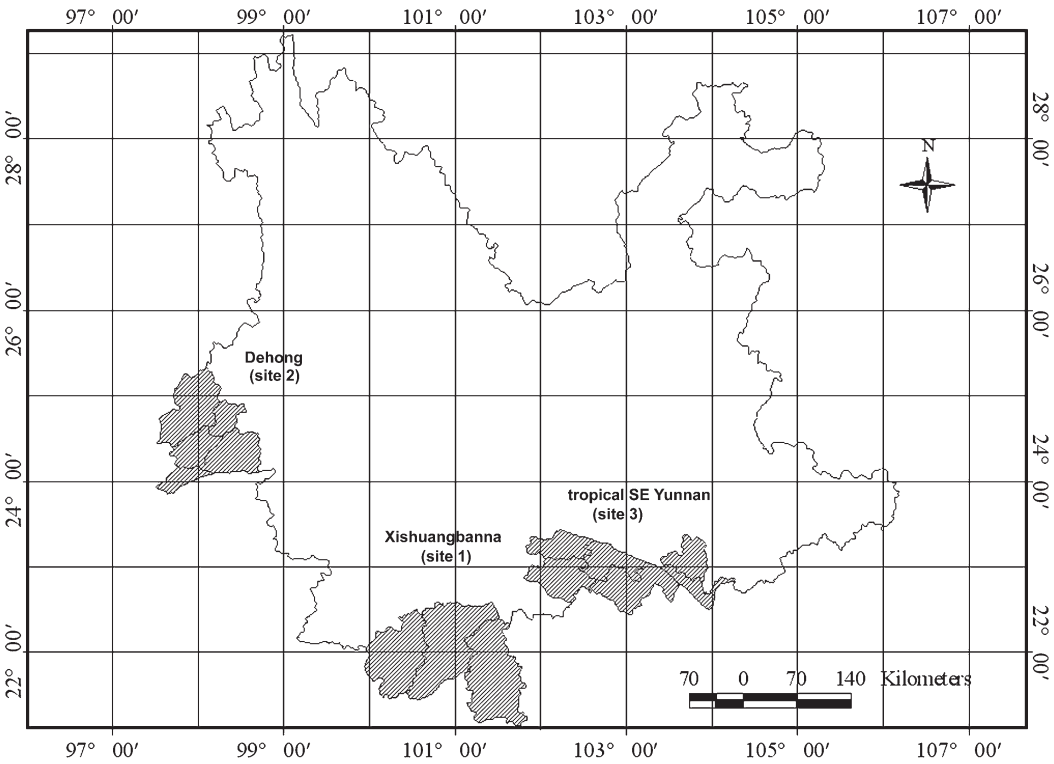


Figure 1. Map showing the locations of the tropical areas in southern Yunnan. Site 1: Xishuangbanna administrative region in south Yunnan; site 2: Dehong administrative region in southwestern Yunnan; site 3: tropical southeastern Yunnan.

Roos, 2004). Also, T. C. Whitmore, from his visit to southern Yunnan, observed that the birds in the tropical rainforest there sang the same songs as the birds in the tropical rainforest of Malaysia (Whitmore, 1982), and he confirmed that there is true evergreen rainforest present in the southern fringe of China (Whitmore, 1984).

To better understand the affinities of southern Yunnan’s flora, the floristic composition was concisely enumerated, and its geographic elements were analyzed at family and generic levels. Also, the floristic similarities between southern, southeastern, and southwestern Yunnan (Fig. 1, sites 1–3), as well as between mainland Southeast Asia (Thailand) and Malesia (Malay Peninsula), were compared using revised floristic inventories and checklists.

GEOGRAPHY

TOPOGRAPHY

Xishuangbanna in southern Yunnan lies between 21°09’N and 22°36’N, 99°58’E and 101°50’E (Fig. 1). The region occupies an area of 19,690 km². It borders Burma and Laos and has a mountainous topography with mountain ridges running in a north-

south direction, decreasing in elevation southward. Its elevation ranges from 480 m at the lowest valley bottom in the south (Mekong River) to 2429.5 m at the highest mountain summit in the north. The Mekong River runs through the region from the northwest to the southeast (Xu et al., 1987).

CLIMATE

The region has a typical monsoon climate. The annual mean temperature varies from 21.7°C at an elevation of 550 m to 15.1°C at 1979 m, and the 20°C isotherm is equal to the 850 m elevation isoline. The hottest month is June, with a mean temperature of 17.9°C at 1979 m and 25.3°C at 550 m, while the coldest month is January, with a mean temperature ranging from 8.8°C–15.6°C. Annual precipitation increases from 1193 mm at Mengyang in the central part of the region at 740 m to 2491 mm at the summit of Nangongshan in the southern part at 1979 m. More than 80% of the precipitation falls during the rainy season from May to October. In areas of lower hills and valleys covered by tropical rainforests, the annual mean temperature is about 21°C and the annual cumulative temperature (the sum of daily temperature means > 10°C) is 7600°C–7800°C. Annual precip-

itation is more than 1500 mm, relative humidity is about 80%, and frost has never been recorded (Xu et al., 1987).

Dense fog is frequent throughout the dry season on the lower hills and in the valleys, averaging 146 foggy days per year and 1 mm precipitation per foggy day in Mengla Xian in southern Xishuangbanna. The fog is thought to compensate for the insufficient precipitation so that a tropical moist climate can form locally despite relatively low annual precipitation (Zhu, 1997).

SOIL

There are three main soil types in the region. Lateritic soils developed from siliceous rocks such as granite, and gneiss occurs at 600–1000 m with a deep solum, but thin humus horizon. Lateritic red soils derived from sandstone substrate occur in areas above 1000 m. Limestone hill soils are derived from a hard limestone substrate of Permian origin with a pH of 6.75. The tropical rainforest in southern Yunnan occurs mainly on lateritic soils with pH values of 4.5–5.5.

GEOLOGICAL HISTORY

Southern Yunnan is at the junction of the Indian and Burmese plates of Gondwana and the Eurasian plate of Laurasia (Audley-Charles, 1987; Hall, 1998). Before the Mesozoic, the area was part of the Tethys margin, and later some fragments from Gondwana were combined. Since the Tertiary, the region had gone through several stages of rising and descending with the intermittent uplift of the Himalayas, and gradually formed the modern topography in the mid-Tertiary (Shi et al., 1998, 1999).

During the late Cretaceous, the region had a hot, dry climate, based on fossil records from Mengla in which a relatively high proportion of *Ulmipollenites* and *Ephedripites* were found (Sun, 1979). From the Paleocene to the Eocene, the region went through a rising stage with the uplift of the Himalayas and was influenced by a dry climate with a high deposition of salt minerals. From the Miocene to Pliocene, the region descended and formed a series of basins with a wet and warm climate. Since the Quaternary, the region has again experienced rapid uplift, associated with alternative climatic changes of wet and dry periods (Liu et al., 1986).

Paleobotanical data from the Tertiary in southern Yunnan (Xishuangbanna) are extremely insufficient. Available information from neighboring regions suggests that southern Yunnan could be a subtropical evergreen broad-leaved forest characterized by Faga-

ceae species during this period (Song et al., 1976, 1983; Song, 1984; Wang, 1996; Penny, 2001; Mehrotra et al., 2005).

The present tropical rainforest in southern Yunnan is at the elevational and latitudinal limits of tropical rainforests in the Northern Hemisphere. It is believed that the tropical moist climate in southern Yunnan did not form until the Himalayas uplifted to a certain elevation after the late Tertiary (Zhu, 1997). Thus, the tropical rainforests in the region were developed after the later Tertiary. The fundamental topography and climate of the region have been strongly affected by the uplift of the Himalayas and the formation of the eastern monsoon climate (Shi et al., 1998, 1999).

METHODS

Based on identifications of ca. 60,000 specimens from southern Yunnan in HITBC, acquired during more than 40 years of intermittent field collections, the former *List of Plants in Xishuangbanna* (Li, 1996) was revised and updated, and 3340 native species of 1176 genera and 182 families of seed plants have been recognized (see Appendix 1). Circumscription of families and species nomenclature follows *w*³TROPICOS of the Missouri Botanical Garden (<<http://www.tropicos.org>>). Floristic and geographic attributes of the flora of southern Yunnan were analyzed. Patterns of seed plant distribution of the flora were quantified at the family and generic levels based on C. Y. Wu's documentations (Wu, 1991; Wu et al., 2003). The inventory data of the floras of southwestern Yunnan from the Dehong administrative region (Zhu et al., 2004) and southeastern Yunnan (Shui, 2003) (see Fig. 1, sites 2 and 3, respectively) were compared to demonstrate the floristic variation in tropical Yunnan. The revised checklist of the vascular plants of Malay Peninsula (Turner, 1995) and the checklist of Thai plants (Smitinand, 2001) were also used to compare the floristic affinity between the tropical flora of southern Yunnan (Fig. 1, site 1) and that of mainland Southeast Asia and Malaysia.

FLORISTIC COMPOSITION

A total of 3340 native species of 1176 genera and 182 families of seed plants were recognized from Xishuangbanna in southern Yunnan. The families with highest species richness include Orchidaceae (94 genera/328 species), Fabaceae (65/211), Rubiaceae (45/142), Poaceae (63/132), Euphorbiaceae (36/117), Asteraceae (59/106), Moraceae (7/73), Lauraceae (14/70), Urticaceae (14/72), Zingiberaceae (17/72), Acanthaceae (32/68), Lamiaceae (28/61), Asclepiadaceae (26/58), and Apocynaceae (23/51) (Table 1).

Table 1. The flora of southern Yunnan (Xishuangbanna) by family. Only native species in southern Yunnan (Xishuangbanna) are included. Family size is from the Missouri Botanical Garden's w³TROPICOS (<<http://www.tropicos.org>>).

	No. of genera	No. of species		No. of genera	No. of species
Families with >100 spp.					
Orchidaceae	94	328	Poaceae	63	132
Fabaceae	65	211	Euphorbiaceae	36	117
Rubiaceae	45	142	Asteraceae	59	106
Families with 51–100 spp.					
Moraceae	7	73	Acanthaceae	32	68
Lauraceae	14	70	Lamiaceae	28	61
Urticaceae	14	72	Asclepiadaceae	26	58
Zingiberaceae	17	72	Apocynaceae	23	51
Families with 21–50 spp.					
Annonaceae	15	49	Scrophulariaceae	15	33
Verbenaceae	11	48	Sterculiaceae	12	33
Cucurbitaceae	17	46	Commelinaceae	10	31
Rosaceae	18	46	Menispermaceae	14	30
Vitaceae	7	45	Gesneriaceae	13	29
Fagaceae	5	44	Myrsinaceae	4	28
Araceae	17	43	Melastomataceae	9	27
Arecaceae	8	40	Araliaceae	10	26
Cyperaceae	14	40	Rhamnaceae	9	26
Rutaceae	14	40	Solanaceae	5	25
Meliaceae	12	37	Myrtaceae	2	23
Convolvulaceae	13	36	Oleaceae	7	23
Liliaceae	19	35	Dioscoreaceae	1	22
Malvaceae	10	34	Theaceae	9	22
Piperaceae	3	33			
Families with 6–20 spp.					
Polygalaceae	4	20	Bignoniaceae	7	10
Polygonaceae	4	19	Lythraceae	4	10
Apiaceae	8	18	Ulmaceae	5	10
Boraginaceae	9	18	Myristicaceae	3	9
Elaeocarpaceae	2	18	Primulaceae	1	9
Loranthaceae	6	18	Symplocaceae	1	9
Anacardiaceae	12	18	Violaceae	1	9
Campanulaceae	9	17	Actinidiaceae	2	8
Tiliaceae	5	17	Burseraceae	3	8
Celastraceae	4	16	Proteaceae	2	8
Flacourtiaceae	6	16	Sabiaceae	2	8
Loganiaceae	6	15	Sapotaceae	3	8
Smilacaceae	1	15	Balsaminaceae	1	7
Caprifoliaceae	5	14	Caryophyllaceae	6	7
Capparaceae	4	14	Hernandiaceae	1	7
Ranunculaceae	4	14	Juglandaceae	3	7
Amaranthaceae	7	13	Lentibulariaceae	1	7
Clusiaceae	5	13	Styracaceae	4	7
Ericaceae	4	13	Viscaceae	2	7
Magnoliaceae	8	13	Aristolochiaceae	1	6
Sapindaceae	11	13	Ebenaceae	1	6
Aquifoliaceae	1	12	Malpighiaceae	2	6
Icacinaceae	8	12	Musaceae	2	6
Begoniaceae	1	11	Onagraceae	2	6
Combretaceae	4	11	Passifloraceae	2	6
Cornaceae	4	11	Pittosporaceae	1	6
Hippocrateaceae	3	11	Santalaceae	5	6

Table 1. Continued.

	No. of genera	No. of species		No. of genera	No. of species
Families with 1–5 spp.					
Brassicaceae	3	5	Podostemaceae	2	2
Elaeagnaceae	1	5	Portulacaceae	2	2
Gentianaceae	5	5	Potamogetonaceae	1	2
Hydrocharitaceae	4	5	Rhizophoraceae	2	2
Oxalidaceae	3	5	Saururaceae	2	2
Simaroubaceae	3	5	Stemonaceae	1	2
Staphyleaceae	2	5	Thymelaeaceae	2	2
Balanophoraceae	1	4	Xyridaceae	1	2
Betulaceae	3	4	Berberidaceae	1	1
Connaraceae	4	4	Cephalotaxaceae	1	1
Dilleniaceae	2	4	Ceratophyllaceae	1	1
Iridaceae	2	4	Crypteroniaceae	1	1
Lemnaceae	3	4	Cupressaceae	1	1
Nyssaceae	2	4	Datisceaeae	1	1
Podocarpaceae	3	4	Dichapetalaceae	1	1
Saxifragaceae	3	4	Droseraceae	1	1
Aizoaceae	2	3	Erythroxylaceae	1	1
Alismataceae	2	3	Geraniaceae	1	1
Amaryllidaceae	2	3	Grossulariaceae	1	1
Burmanniaceae	1	3	Hydrangeaceae	1	1
Chloranthaceae	2	3	Hydrophyllaceae	1	1
Cycadaceae	1	3	Juncaceae	1	1
Gnetaceae	1	3	Lecythidaceae	1	1
Marantaceae	3	3	Menyanthaceae	1	1
Olacaceae	3	3	Myricaceae	1	1
Plantaginaceae	1	3	Najadaceae	1	1
Pontederiaceae	1	3	Nyctaginaceae	1	1
Aceraceae	1	2	Orobanchaceae	1	1
Bombacaceae	1	2	Pandanaceae	1	1
Butomaceae	2	2	Papaveraceae	1	1
Buxaceae	2	2	Pinaceae	1	1
Chenopodiaceae	2	2	Rafflesiaceae	1	1
Crassulaceae	2	2	Salicaceae	1	1
Daphniphyllaceae	2	2	Sonneratiaceae	1	1
Dipterocarpaceae	2	2	Sparganiaceae	1	1
Elatinaceae	2	2	Sphenocleaceae	1	1
Eriocaulaceae	1	2	Stachyuraceae	1	1
Fumariaceae	1	2	Stylidiaceae	1	1
Hamamelidaceae	2	2	Taccaceae	1	1
Lardizabalaceae	1	2	Trapaceae	1	1
Linaceae	2	2	Valerianaceae	1	1
Nymphaeaceae	2	2	Zygophyllaceae	1	1
Opiliaceae	2	2			

Total: 182 families, 1176 genera, and 3340 species including infraspecific taxa

The family Orchidaceae has higher species richness in Xishuangbanna than in Laos and Cambodia (Chen & Tsi, 1996).

Some families have only a small number of species, but are very abundant in the tropical forests of southern Yunnan, such as Sapindaceae (11 genera/13 species), Anacardiaceae (12/18), Burseraceae (3/8), Elaeocarpaceae (2/18), Ebenaceae (1/6), Combreta-

ceae (4/11), Ulmaceae (5/10), and Myrtaceae (2/23). The families Dipterocarpaceae (2/2), Datisceae (1/1), Myristicaceae (3/9), Clusiaceae (5/13), Icacinaceae (8/12), Linaceae (2/2), and Sapotaceae (3/8) have even fewer species, but are also very abundant in some forest types.

At the generic level, *Ficus* L. has the most taxa (58 species including infraspecific taxa). Other genera

Table 2. Geographic elements of seed plants at the family level from the flora of southern Yunnan (Xishuangbanna).

Geographic elements	No. of families (%)
1. Cosmopolitan	52 (28.57)
2. Pantropic	77 (42.31)
3. Tropical Asia and tropical America disjunctions	10 (5.49)
4. Old World Tropic	4 (2.20)
5. Tropical Asia to tropical Australia	5 (2.75)
6. Tropical Asia	3 (1.65)
7. North temperate	24 (13.19)
8. East Asia and North America disjunctions	3 (1.65)
9. Old World temperate	1 (0.55)
10. East Asia	3 (1.65)
Total	182 (100.00)

with high species richness include *Dendrobium* Sw. (43 species), *Bulbophyllum* Thouars (40), *Piper* L. (27), *Calamus* L. (24), *Dioscorea* L. (22), *Syzygium* P. Browne ex Gaertn. (22), *Eria* Lindl. (22), *Litsea* Lam. (21), *Pilea* Lindl. (17), *Lithocarpus* Blume (16), *Millettia* Wight & Arn. (16), *Castanopsis* (D. Don) Spach (16), *Tetrastigma* (Miq.) Planch. (16), *Elaeocarpus* L. (16), *Elatostema* J. R. Forst. & G. Forst. (14), *Amomum* Roxb. (14), *Clerodendrum* L. (14), *Ardisia* Sw. (10), *Lasianthus* Jack (12), *Dysoxylum* Blume (10), and *Fissistigma* Griff. (9). *Pometia* J. R. Forst. & G. Forst., *Terminalia* L., *Antiaris* Lesch., *Gironniera* Gaudich., *Pouteria* Aubl., *Pterospermum* Schreb., and *Tetrameles* R. Br. have fewer species, but are highly abundant in the dominant tree layer of the tropical rainforests. *Lasiococca* Hook. f., *Garcinia* L., *Mitrephora* Hook. f. & Thomson, *Alphonsea* Hook. f. & Thomson, *Cleidion* Blume, *Sumbaviopsis* J. J. Sm., *Trigonostemon* Blume, and *Pittosporopsis* Craib are abundant in the lower tree layer (Zhu et al., 1998a; Zhu, 2006). In the tropical montane rainforest of southern Yunnan, *Castanopsis*, *Lithocarpus*, *Machilus* Nees, *Litsea*, *Phoebe* Nees, *Anneslea* Wall., and *Schima* Reinw. ex Blume are the most abundant genera (Zhu et al., 2006).

GEOGRAPHIC ELEMENTS

GEOGRAPHIC ELEMENTS AT THE FAMILY LEVEL

In the flora of southern Yunnan, families of tropical distribution contribute 54.4% of the total flora (Table 2). These families include those of pantropic distribution (contributing to 42.31% of the total flora), such as Acanthaceae, Anacardiaceae, Annonaceae, Apocynaceae, Araceae, Arecaceae, Burseraceae, Clusiaceae, Combretaceae, Myristicaceae, Sapotaceae,

Table 3. Geographic elements of seed plants at the generic level from the flora of southern Yunnan (Xishuangbanna).

Geographic elements at the generic level	No. of genera (%)
1. Cosmopolitan	59 (5.02)
2. Pantropic	251 (21.34)
3. Tropical Asia and tropical America disjunctions	30 (2.55)
4. Old World Tropics	112 (9.52)
5. Tropical Asia to tropical Australia	76 (6.46)
6. Tropical Asia to tropical Africa	96 (8.16)
7. Tropical Asia	355 (30.19)
8. North temperate	60 (5.10)
9. East Asia and North America disjunctions	32 (2.72)
10. Old World temperate	24 (2.04)
11. Temperate Asia	5 (0.43)
12. Mediterranean region, western to central Asia	2 (0.17)
13. Central Asia	1 (0.09)
14. East Asia	62 (5.27)
15. Endemic to China	11 (0.94)
Total	1176 (100)

and Icacinaceae; Old World Tropic distribution, such as Pittosporaceae, Pandanaceae, and Musaceae; tropical Asian and tropical American disjunct distribution, including Araliaceae, Elaeocarpaceae, Gesneriaceae, Lardizabalaceae, Staphyleaceae, and Styracaceae; and the tropical Asian distribution, such as Crypteroniaceae, Rafflesiaceae, and Sabiaceae. Families of mainly temperate distribution contribute 17.04% of the total flora, including the ones of north temperate distribution such as Caprifoliaceae, Pinaceae, Aceraceae, Betulaceae, Buxaceae, Cornaceae, Fagaceae, Hamamelidaceae, Juglandaceae, and Salicaceae; East Asia and North America disjunct distribution, such as Magnoliaceae, Nyssaceae, and Saururaceae; and East Asia distribution, such as Actinidiaceae, Cephalotaxaceae, and Stachyuraceae.

GEOGRAPHIC ELEMENTS AT THE GENERIC LEVEL

Patterns of seed plant distribution of the flora at the generic level are enumerated in Table 3. The genera of tropical Asian distribution, such as *Alphonsea*, *Amoora* Roxb., *Pterospermum*, *Mitrephora*, *Mycetia* Reinw., *Aganosma* (Blume) G. Don, *Chukrasia* A. Juss., *Crypteronia* Blume, and *Knema* Lour., show the highest percentage among all distribution types, contributing to 30.19% of the flora. Genera of pantropic distribution, such as *Gnetum* L., *Beilschmiedia* Nees, *Cryptocarya* R. Br., *Capparis* L., *Piper*, *Croton* L., *Dioscorea*, *Uncaria* Schreb., *Lasianthus*, *Morinda* L., *Ardisia*, *Bauhinia* L., and *Marsdenia* R. Br., contribute to 21.34% of the flora.

Table 4. Similarity coefficients at family, generic, and species levels for three tropical regions of Yunnan.^{1, 2}

Compared regional flora	Southern Yunnan ³ Shared/similarity coefficient, %	Southwestern Yunnan ⁴ Shared/similarity coefficient, %	Tropical southeastern Yunnan ⁵ Shared/similarity coefficient, %
Similarity coefficients at family level			
Southern Yunnan	100/100		
Southwestern Yunnan	180/98.4	100/100	
Tropical southeastern Yunnan	163/89.1	179/96.2	100/100
Similarity coefficients at generic level			
Southern Yunnan	100/100		
Southwestern Yunnan	946/80.4	100/100	
Tropical southeastern Yunnan	939/79.9	1037/76.6	100/100
Similarity coefficients at specific level			
Southern Yunnan	100/100		
Southwestern Yunnan	1834/47.9	100/100	
Tropical southeastern Yunnan	1773/50.7	2165/43.2	100/100

¹ Data are from Zhu et al. (2004) for southwestern Yunnan and Shui (2003) for tropical southeastern Yunnan. There were 4933 species of native seed plants in 1432 and 199 families recognized from southwestern Yunnan (Dehong), and 4996 species of native seed plants in 1355 and 186 families recognized from tropical southeastern Yunnan based on Shui's list.

² The similarity coefficient between two regions equals the number of taxa shared by both regions divided by the lowest number of taxa of region 1 or 2, multiplied by 100%.

³ Southern Yunnan is defined as Xishuangbanna administrative region (site 1 in Fig. 1).

⁴ Southwestern Yunnan is defined as Dehong administrative region (site 2 in Fig. 1).

⁵ Tropical southeastern Yunnan is defined as the tropical area of southeastern part of Yunnan (site 3 in Fig. 1).

Next are the genera of Old World tropical distribution, such as *Thunbergia* Retz., *Dracaena* Vand. ex L., *Pandanus* Parkinson, *Ventilago* Gaertn., *Stephania* Lour., *Fissistigma*, *Polyalthia* Blume, *Barringtonia* J. R. Forst. & G. Forst., *Carallia* Roxb., *Canarium* L., *Chasalia* DC., and *Uvaria* L. Genera with distributions from tropical Asia to tropical Australia include *Ailanthus* Desf., *Hoya* R. Br., *Argyrea* Lour., *Dillenia* L., *Lagerstroemia* L., *Loeseneriella* A. C. Sm., *Murraya* J. König ex L., and *Toona* (Endl.) M. Roem. Genera with tropical Asian to tropical African distribution include *Bombax* L., *Flacourtia* Comm. ex L'Hér., *Quisqualis* L., *Bridelia* Willd., *Premna* L., *Urophyllum* Jack ex Wall., *Strophanthus* DC., *Mitragyna* Korth., *Garcinia*, *Anogeissus* (DC.) Wall. ex Guill., Perr. & A. Rich., and *Cymbopogon* Spreng. Genera of tropical distribution in all (Table 3, types 2–7) comprise 78.2% of the total number, while genera of temperate distribution in all (Table 3, types 8–14) contribute 15.82% of the total genera, including genera with north temperate distribution, such as *Artemisia* L., *Carpinus* L., *Betula* L., *Salix* L., *Swida* Opiz, *Corydalis* DC., *Pinus* L., and *Sorbus* L., those with a disjunct distribution in East Asia and North America, such as *Schisandra* Michx., *Photinia* Lindl., *Nyssa* L., *Osmanthus* Lour., *Magnolia* L., *Mahonia* Nutt., *Illicium* L., and *Castanopsis*, those of Old World temperate distribution such as *Ajuga* L., *Elsholtzia* Moench, *Herminium* L., *Inula* L., *Ligustrum* L., and *Paris* L., and East Asian distributions such as *Actinidia* Lindl., *Belamcanda* Adans., *Aspidistra* Ker Gawl., *Cephalo-*

taxus Siebold & Zucc. ex Endl., *Choerospondias* B. L. Burt & A. W. Hill, *Gardneria* Wall., *Hovenia* Thunb., *Pegia* Colebr., *Skimmia* Thunb., *Stachyurus* Siebold & Zucc., and *Pterocarya* Kunth. Only 11 genera are endemic to China, including *Biondia* Schltr., *Campthoeca* Decne., *Craspedolobium* Harms, *Cyphotheca* Diels, *Dichotomanthes* Kurz, *Eleutharrhena* Forman, *Nouelia* Franch., *Paramomum* S. Q. Tong, *Styrophyton* S. Y. Hu, *Tapiscia* Oliv., and *Thyrocarpus* Hance.

COMPARISON WITH TROPICAL FLORAS OF SOUTHWESTERN AND SOUTHEASTERN YUNNAN

The tropical area in southwestern Yunnan is located mainly in the Dehong administrative region (Fig. 1, site 2), which borders Burma and lies between 23°50'–25°20'N and 97°31'–98°43'E. The region is 11,229 km² in area and has a monsoon climate with an annual mean temperature of 19.2°C and an annual precipitation of 1540 mm. There have been 4933 species of 1432 genera and 199 families of native seed plants recognized from the region (Zhu et al., 2004).

The tropical area in southeastern Yunnan referred to in this study (Fig. 1, site 3) is located between the Tropic of Cancer and the Yunnan–Vietnam border, 22°26'–23°26' N and 104°27'–108°48'E. The region, including six counties, such as Pingbian, Hekou, Jingping, Luchun, Yuanyang, and Honghe, is 14,389 km² in area. It also has a monsoon climate with an annual mean temperature of 22.8°C and an annual precipitation of 1764 mm. From Shui (2003),

Table 5. Top 20 families with the highest species richness among the tropical floras of southern, southwestern, and southeastern Yunnan.^{1, 2}

Flora of southern Yunnan ³		Flora of southwestern Yunnan ⁴		Flora of tropical southeastern Yunnan ⁵	
Family	No. of species (%) ⁶	Family	No. of species (%) ⁶	Family	No. of species (%) ⁶
Orchidaceae	328 (9.82)	Fabaceae	297 (6.02)	Fabaceae	285 (5.70)
Fabaceae	211 (6.32)	Poaceae	269 (5.45)	Orchidaceae	276 (5.52)
Rubiaceae	142 (4.25)	Asteraceae	267 (5.41)	Rubiaceae	232 (4.64)
Poaceae	132 (3.95)	Orchidaceae	259 (5.25)	Poaceae	219 (4.38)
Euphorbiaceae	117 (3.50)	Rubiaceae	166 (3.36)	Asteraceae	196 (3.92)
Asteraceae	106 (3.17)	Rosaceae	153 (3.10)	Lauraceae	141 (2.82)
Moraceae	73 (2.19)	Euphorbiaceae	110 (2.23)	Urticaceae	134 (2.68)
Lauraceae	70 (2.10)	Lauraceae	101 (2.05)	Euphorbiaceae	126 (2.52)
Urticaceae	72 (2.16)	Cyperaceae	97 (1.96)	Rosaceae	124 (2.48)
Zingiberaceae	72 (2.16)	Urticaceae	90 (1.82)	Fagaceae	109 (2.18)
Acanthaceae	68 (2.04)	Moraceae	89 (1.80)	Moraceae	104 (2.08)
Lamiaceae	61 (1.83)	Ericaceae	85 (1.72)	Ericaceae	96 (1.92)
Asclepiadaceae	58 (1.74)	Acanthaceae	77 (1.56)	Lamiaceae	91 (1.82)
Apocynaceae	51 (1.53)	Theaceae	71 (1.44)	Cyperaceae	89 (1.78)
Annonaceae	49 (1.47)	Liliaceae	71 (1.44)	Theaceae	81 (1.62)
Verbenaceae	48 (1.44)	Scrophulariaceae	69 (1.40)	Gesneriaceae	79 (1.58)
Cucurbitaceae	46 (1.38)	Fagaceae	68 (1.38)	Acanthaceae	77 (1.54)
Rosaceae	46 (1.38)	Araliaceae	66 (1.34)	Celastraceae	65 (1.30)
Vitaceae	45 (1.35)	Apiaceae	66 (1.34)	Araliaceae	64 (1.28)
Fagaceae	44 (1.32)	Asclepiadaceae	64 (1.30)	Verbenaceae	62 (1.24)
Sum of the top 20 families	1839 (55.10)		2535 (51.38)		2650 (53.04)
All other families	1501 (44.90)		2398 (48.62)		2346 (46.6)
Total flora	3340 (100)		4933 (100)		4996 (100)

¹ Data are from Zhu et al. (2004) for southwestern Yunnan and Shui (2003) for the tropical southeastern Yunnan.
² Families in boldface are the top 20 families, which can be found only in the flora of Xishuangbanna, in both the floras of Dehong and tropical southeastern Yunnan, or in one of them, respectively.
³ Southern Yunnan is defined as Xishuangbanna administrative region (site 1 in Fig. 1).
⁴ Southwestern Yunnan is defined as Dehong administrative region (site 2 in Fig. 1).
⁵ Tropical Southeastern Yunnan is defined as the tropical area of southeastern part of Yunnan (site 3 in Fig. 1).
⁶ Number of species for each family in the respective floras, and their percentage within the respective floras.

we compiled a list of 4996 species of 1355 genera and 186 families of native seed plants from the region in southeastern Yunnan.

Floristic similarities at the family, generic, and species levels between the floras of southern Yunnan (Xishuangbanna), southwestern Yunnan (Dehong), and southeastern Yunnan (Fig. 1, sites 1, 2, and 3, respectively) are detailed in Table 4. The floristic similarity between these regional floras of tropical Yunnan is more than 89% at the family level and more than 76% at the generic level, but it is lower at the species level (43%–50%).

The comparison of the 20 families with the most species among these tropical floras of southern, southwestern, and southeastern Yunnan is enumerated in Table 5.

The top-ranking families in all three regional floras are basically similar. These three regional floras belong to the same floristic unit and represent the tropical flora of Yunnan. The families Zingiberaceae,

Apocynaceae, Annonaceae, and Cucurbitaceae are in the top 20 ranking families of the flora of southern Yunnan (Fig. 1, site 1), while Ericaceae, Theaceae, and Araliaceae are in the top 20 ranking families of these floras of southwestern and southeastern Yunnan (Fig. 1, sites 2 and 3, respectively).

Comparison of geographic elements at the generic level from these regional floras revealed that the tropical elements (Table 6, types 2–7) contribute more than 64% of the total genera in these regional floras of Yunnan, and the highest proportion of the tropical elements occurs in the flora of southern Yunnan (making up 78.3% of all the genera).

COMPARISON WITH TROPICAL FLORAS OF MAINLAND SOUTHEAST ASIA AND MALESIA

A Catalogue of the Vascular Plants of Malaya (Turner, 1995) and *Thai Plant Names* (Smitinand, 2001) provide recently updated and relatively com-

Table 6. Comparison of geographic elements at the generic level from the tropical floras of southern, southwestern, and southeastern Yunnan.

Geographical elements of genera	Southern Yunnan ¹	Southwestern Yunnan ²	Tropical southeastern Yunnan ³
	No. of genera (%) ⁴	No. of genera (%) ⁴	No. of genera (%) ⁴
1. Cosmopolitan	59 (5.0)	76 (5.3)	62 (4.6)
2. Pantropic	251 (21.3)	267 (18.6)	239 (17.6)
3. Tropical Asia and tropical America disjunctions	30 (2.6)	30 (2.1)	29 (2.1)
4. Old World Tropics	112 (9.5)	120 (8.4)	116 (8.6)
5. Tropical Asia to tropical Australia	76 (6.5)	74 (5.2)	82 (6.1)
6. Tropical Asia to tropical Africa	96 (8.2)	94 (6.6)	95 (7.0)
7. Tropical Asia	355 (30.2)	340 (23.7)	371 (27.4)
8. North temperate	60 (5.1)	157 (11.0)	111 (8.2)
9. East Asia and North America disjunctions	32 (2.7)	54 (3.8)	47 (3.5)
10. Old World temperate	24 (2.0)	50 (3.5)	32 (2.4)
11. Temperate Asia	5 (0.4)	11 (0.8)	6 (0.4)
12. Mediterranean region, western to central Asia	2 (0.2)	5 (0.3)	3 (0.2)
13. Central Asia	1 (0.1)	4 (0.3)	1 (0.1)
14. East Asia	62 (5.3)	125 (8.7)	120 (8.9)
15. Endemic to China	11 (0.9)	25 (1.7)	41 (3.0)
Total	1176 (100)	1432 (100)	1355 (100)

¹ Southern Yunnan is defined as Xishuangbanna administrative region (site 1 in Fig. 1).
² Southwestern Yunnan is defined as Dehong administrative region (site 2 in Fig. 1).
³ Tropical southeastern Yunnan is defined as the tropical area of the southeastern part of Yunnan (site 3 in Fig. 1).
⁴ Number of genera for each geographical element in the respective floras, and their percentage within the respective floras.

plete data on the regional flora of mainland Southeast Asia and Malaysia, respectively. Comparisons of the floristic composition and similarities at the family and generic levels between southern Yunnan (Xishuangbanna), Thailand, and the Malay Peninsula are compared in Tables 7 and 8.

Most of the top 20 families with the most species richness in the flora of southern Yunnan (Xishuangbanna) are shared by the floras of Thailand and the Malay Peninsula as the top 20 families (Table 7). The families Orchidaceae, Rubiaceae, Euphorbiaceae, Lauraceae, Moraceae, Apocynaceae, Annonaceae, Zingiberaceae, and Acanthaceae are large tropical families shared by both southern Yunnan (Xishuangbanna) and Thailand–Malaysia. However, those families with strongly tropical characteristics such as Dipterocarpaceae, Melastomataceae, Myrtaceae, Arecaceae, and Clusiaceae are also dominant in the Thai–Malaysian flora, while Urticaceae, Lamiaceae, Cucurbitaceae, Rosaceae, and Vitaceae, which are of tropical to temperate distributions, are dominant in southern Yunnan (Xishuangbanna). The families with strongly tropical characteristics have a small number of species in the flora of southern Yunnan, but are highly abundant there (Zhu, 1997). The floristic similarity between the flora of southern Yunnan and the floras of Thailand and Malaysia exceeds 82.5% at the family level and 65.6% at the generic level (Table 8).

DISCUSSION

Tropical genera comprise a majority (78.2%) of the southern Yunnan (Xishuangbanna) flora. The dominant genera are those of tropical Asian distribution (Table 3). This reveals that the flora of southern Yunnan is tropical in nature and has strong tropical Asian affinity.

The tropical floras from southwestern, southern, and southeastern Yunnan (Fig. 1, sites 1–3) are similar in families with the most species richness and have high similarities at family and generic levels (more than 89% at the family level and more than 76% at the generic level; see Table 4). The tropical elements comprise more than 64% of the total genera, of which the tropical Asian element contributes more than 23.7% of the total genera in these regional floras of tropical Yunnan. These patterns suggest that these three regions of Yunnan belong to the same floristic unit and are part of tropical Asian or Indo-Malaysian flora.

In comparing the flora of southern Yunnan (Xishuangbanna) to the tropical floras of Guangxi in southern China and Hainan in southeastern China (Zhu & Roos, 2004), the top-ranking families are similar, except that the family Cucurbitaceae is in the top 20 ranking families of the flora of southern Yunnan only, and Theaceae, Myrsinaceae, Liliaceae, and Myrtaceae (in Hainan) are in the top 20 families of those of southern and southeastern China. When

Table 7. Top 20 families with the most species richness among the tropical floras of southern Yunnan, Thailand, and the Malay Peninsula.^{1, 2}

Flora of southern Yunnan (Xishuangbanna)		Flora of Thailand		Flora of the Malay Peninsula	
Family	No. of species (%) ³	Family	No. of species (%) ³	Family	No. of species (%) ³
Orchidaceae	328 (9.82)	Orchidaceae	530 (8.67)	Orchidaceae	853 (11.16)
Fabaceae	211 (6.32)	Fabaceae	398 (6.51)	Rubiaceae	562 (7.35)
Rubiaceae	142 (4.25)	Euphorbiaceae	365 (5.97)	Euphorbiaceae	369 (4.81)
Poaceae	132 (3.95)	Rubiaceae	357 (5.84)	Fabaceae	298 (3.90)
Euphorbiaceae	117 (3.50)	Poaceae	227 (3.71)	Poaceae	238 (3.11)
Asteraceae	106 (3.17)	Cyperaceae	222 (3.63)	Myrtaceae	215 (2.81)
Moraceae	73 (2.19)	Araceae	167 (2.73)	Lauraceae	214 (2.80)
Lauraceae	70 (2.10)	Araceae	151 (2.47)	Annonaceae	202 (2.64)
Urticaceae	72 (2.16)	Apocynaceae	120 (1.96)	Araceae	198 (2.59)
Zingiberaceae	72 (2.16)	Annonaceae	117 (1.91)	Gesneriaceae	189 (2.47)
Acanthaceae	68 (2.04)	Zingiberaceae	112 (1.83)	Melastomataceae	172 (2.25)
Lamiaceae	61 (1.83)	Scrophulariaceae	103 (1.69)	Cyperaceae	162 (2.12)
Asclepiadaceae	58 (1.74)	Moraceae	103 (1.69)	Acanthaceae	158 (2.07)
Apocynaceae	51 (1.53)	Asteraceae	100 (1.64)	Dipterocarpaceae	156 (2.04)
Annonaceae	49 (1.47)	Fagaceae	100 (1.64)	Zingiberaceae	153 (2.00)
Verbenaceae	48 (1.44)	Myrtaceae	96 (1.57)	Araceae	141 (1.84)
Cucurbitaceae	46 (1.38)	Verbenaceae	83 (1.36)	Moraceae	138 (1.81)
Rosaceae	46 (1.38)	Lauraceae	82 (1.34)	Clusiaceae	120 (1.57)
Vitaceae	45 (1.35)	Acanthaceae	80 (1.31)	Apocynaceae	119 (1.56)
Fagaceae	44 (1.32)	Convolvulaceae	78 (1.28)	Asclepiadaceae	116 (1.52)
Sum of the top 20 families	1839 (55.10)		3591 (58.75)		4773 (62.42)
All other families	1501 (44.90)		2520 (41.25)		2864 (37.58)
Total flora	3340 (100)		6111 (100)		7637 (100)

¹ Data are from Smitinand (2001) for Thailand and from Turner (1995) for the Malay Peninsula. There were 6111 species of native seed plants in 1573 genera and 198 families recognized from Smitinand's list, and 7637 species of native seed plants in 1554 genera and 191 families recognized from Turner's list. Circumscription of families and nomenclature follow the Missouri Botanical Garden's w³TROPICOS (<<http://www.tropicos.org>>).

² Families in boldface are the top 20 families, which can be found only in the flora of Xishuangbanna, in both the floras of Thailand and the Malay Peninsula, or in one of them, respectively.

³ Number of species for each family in the respective floras, and their percentage within the respective floras.

Table 8. Comparison of floristic similarities at the family and generic levels between southern Yunnan, Thailand, and the Malay Peninsula.^{1, 2}

Compared flora	Southern Yunnan	Thailand	Malay Peninsula
	Shared/similarity coefficient, %	Shared/similarity coefficient, %	Shared/similarity coefficient, %
Similarity coefficients at family level			
Southern Yunnan (Xishuangbanna)	100/100		
Thailand	174/95.08	100/100	
Malay Peninsula	151/82.51	173/90.58	100/100
Similarity coefficients at generic level			
Southern Yunnan (Xishuangbanna)	100/100		
Thailand	867/73.72	100/100	
Malay Peninsula	772/65.65	1099/70.72	100/100

¹ Data are from Smitinand (2001) for Thailand and from Turner (1995) for the Malay Peninsula.

² The similarity coefficient between two regions equals the number of taxa shared by both regions divided by the lowest number of taxa of region 1 or 2, multiplied by 100%.

Table 9. Comparison of the distribution types of genera from the flora of southern Yunnan (Xishuangbanna), the flora of tropical Guangxi, and the flora of Hainan.¹

Distribution types (geographic elements)	Southern Yunnan (Xishuangbanna)	Tropical Guangxi ²	Hainan
	Genera %	Genera %	Genera %
1. Cosmopolitan	5.02	5.56	5.09
2. Pantropic	21.34	19.71	23.42
3. Tropical Asia and tropical America disjunctions	2.55	2.24	2.75
4. Old World Tropics	9.52	9.35	11.39
5. Tropical Asia to tropical Australia	6.46	7.42	10.26
6. Tropical Asia to tropical Africa	8.16	7.19	7.03
7. Tropical Asia	30.19	25.81	25.93
8. North temperate	5.1	6.8	4.44
9. East Asia and North America disjunctions	2.72	3.48	2.99
10. Old World temperate	2.04	2.55	1.94
11. Temperate Asia	0.43	0.46	0.32
12. Mediterranean region, western to central Asia	0.17	0.15	0.16
13. Central Asia	0.09	0.00	0.00
14. East Asia	5.27	6.65	2.75
15. Endemic to China	0.94	2.63	1.53
Total	100	100	100.00

¹ Data are from Fang et al. (1995) for tropical Guangxi (1294 genera) and from Wu et al. (1996) for Hainan (1238 genera).
² Tropical Guangxi is in the southwestern part of Guangxi province in southern China.

comparing geographic elements at the generic level, the tropical elements contribute to more than 71% of the total genera in all these tropical floras of China (Table 9).

Most of the dominant families from the flora of southern Yunnan (Xishuangbanna) are also dominant in mainland Southeast Asian and Malaysian floras. The similarities between the flora of southern Yunnan and these floras of tropical Asia are more than 82.5% at the family level and more than 65.6% at the generic level (Table 8). This pattern indicates that the tropical flora of southern Yunnan is similar to the Indo-Malaysian flora and belongs to the Indo-Malaysian or Malesian floristic region as suggested by Takhtajan (1988) and Wu and Wu (1996). In our study, these floras of southern Yunnan, Thailand, and the Malay Peninsula comprise a floristic continuum. We agree with van Balgooy that the number of taxa in common is the first step in surveying floristic affinity (van Balgooy et al., 1996). The higher percentage of taxa shared by these floras suggests their close floristic affinity.

The flora of southern Yunnan occurs on the margin of tropical Asia. However, although tropical families and genera contribute most to its total flora, the taxa of strictly tropical distribution are still under-represented compared to the Malaysian flora. For example, Dipterocarpaceae has only two species from two genera, respectively, in the flora of southern Yunnan, although these taxa are the most abundant trees in some forest types (Zhu, 1992).

The flora of southern Yunnan is similar to both the Tertiary flora and the present flora of northeast India. The Tertiary flora of northeast India, such as *Syzygium*, *Terminalia*, *Artocarpus* J. R. Forst. & G. Forst., *Ficus*, *Mangifera* L., *Bombax*, *Garcinia*, *Calophyllum* L., *Nephelium* L., *Rhizophora* L., *Memecylon* L., *Barringtonia*, *Canarium*, *Pometia*, *Sterculia* L., and *Garuga* Roxb. (Mehrotra et al., 2005), which are frequent genera in the flora of southern Yunnan, were formed by tropical elements. A floristic comparison between the dipterocarp forest in southern Yunnan (Xishuangbanna) and the dipterocarp forest in the upper Assam (Rajkhowa, 1961) revealed that the floristic similarities are 97.3% at the family level and 79.7% at the generic level (Zhu, 1994). The vegetation history of southern Yunnan (Xishuangbanna) during the Tertiary could not be accurately portrayed because of the lack of paleobotanical data. However, the available information from the neighboring regions suggested that southern Yunnan could be a subtropical evergreen broad-leaved forest during the Tertiary. A 40,000-year palynological record from northeast Thailand indicated that the region supported a Fagaceae-coniferous forest, similar to contemporary vegetation from subtropical southwest China, and climatic conditions were cooler and probably drier in the Pleistocene than in present-day northern Thailand (Penny, 2001). Southern Yunnan is geographically near northern Thailand, so it is possible that southern Yunnan had similar vegetation and climatic condi-

tions during the Pleistocene. The migration of tropical Asian elements into southern Yunnan could have mainly taken place after the Tertiary. The tropical flora of southern Yunnan is believed to be derived from tropical Asian flora with the uplift of the Himalayas and the formation of the eastern monsoon climate after the Tertiary.

Studies on the geological history of Southeast Asia reveal that the direct land connection between mainland Southeast Asia and western Malesia existed until the early Pliocene 5 million years ago (Hall, 1998), and there was no geographical barrier between southern Yunnan, mainland Southeast Asia, and western Malesia during most of the Tertiary (Morley, 1998). Thus, geology contributes to and underlies the close affinity between the flora of southern Yunnan and the flora of Malaysia.

Literature Cited

- Audley-Charles, M. G. 1987. Dispersal of Gondwanaland: Relevance to evolution of the Angiosperms. Pp. 5–25 in T. C. Whitmore (editor), *Biogeographical Evolution of the Malay Archipelago*. Oxford Monographs on Biogeography, Vol. 4. Oxford University Press, Oxford.
- Chen, S. & Z. Tsi. 1996. A review of the Orchid flora of Xishuangbanna, southern Yunnan. Pp. 107–113 in A. Zhang & S. Wu (editors), *Floristic Characteristics and Diversity of East Asian Plants*. China Higher Education & Springer Asia, Beijing.
- Fang, R. Z., P. Y. Bai & G. B. Huang. 1995. A floristic study on the seed plants from tropics and subtropics of Dian-Qian-Gui. *Acta Bot. Yunnan.*, Suppl. VII: 111–150 [In Chinese.].
- Fedorov, A. A. 1957. The flora of southwestern China and its significance to the knowledge of the plant world of Eurasia. *Komarovskie Chtenija* (Moscow & Leningrad) 10: 20–50 [In Russian.].
- . 1958. The tropical rain forest of China. *Bot. Zhurn. S.S.S.R.* 43: 1385–1480 [In Russian with English summary.].
- Hall, R. 1998. The plate tectonics of Cenozoic SE Asia and the distribution of land and sea. Pp. 99–131 in R. Hall & J. D. Holloway (editors), *Biogeography and Geological Evolution of SE Asia*. Backhuys Publishers, Leiden.
- Li, Y. H. (editor). 1996. List of Plants in Xishuangbanna. Yunnan National Press, Kunming. [In Chinese.].
- Liu, J. L., L. Y. Tan, Y. Qiao, M. J. Head & D. Walker. 1986. Late Quaternary vegetation history at Menghai, Yunnan province, southwest China. *J. Biogeogr.* 13: 399–418.
- Mehrotra, R. C., X. Q. Liu, C. S. Li, Y. F. Wang & M. S. Chauhan. 2005. Comparison of the Tertiary flora of southwest China and northeast India and its significance in the antiquity of the modern Himalayan flora. *Rev. Palaeobot. Palynol.* 135: 146–163.
- Morley, J. R. 1998. Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate. Pp. 221–234 in R. Hall & J. D. Holloway (editors), *Biogeography and Geological Evolution of SE Asia*. Backhuys Publishers, Leiden.
- Myers, N. 1998. Threatened biotas: “Hotspot” in tropical forests. *Environmentalist* 8(3): 1–20.
- Penny, D. 2001. A 40,000 year palynological record from north-east Thailand; implications for biogeography and palaeo-environmental reconstruction. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 171: 97–128.
- Rajkhowa, S. 1961. The upper Assam Dipterocarpus-Mesua forests and their regeneration. *Indian Forester* 1961(6): 406–425.
- Richards, P. W. 1952. *The Tropical Rain Forest*. Cambridge University Press, London.
- . 1996. *The Tropical Rain Forest: An Ecological Study*, 2nd ed. Cambridge University Press, London.
- Schimper, A. F. W. 1903. *Plant-Geography upon a Physiological Basis*. Oxford University Press, Oxford.
- Shi, Y. F., J. Y. Li, B. Y. Li, B. T. Pan, X. M. Fang, T. D. Yao, S. M. Wang, Z. J. Tsui & S. J. Li. 1998. Uplift and environmental evolution of Qinghai-Xizang (Tibetan) plateau. Pp. 73–138 in H. L. Sun & D. Zheng (editors), *Formation, Evolution and Development of Qinghai-Xizang (Tibetan) Plateau*. Guangdong Science and Technology Press, Guangzhou [In Chinese.].
- , ———, T. D. Yao, S. M. Wang, S. J. Li, Z. J. Tsui, F. B. Wang, B. T. Pan, X. M. Fang & Q. S. Zhang. 1999. Uplift of the Qinghai-Xizang (Tibetan) plateau and east Asia environmental change during late Cenozoic. *Acta Geogr. Sin.* 54(1): 10–21 [In Chinese with English abstract.].
- Shui, Y. M. (editor). 2003. *Seed Plants of Honghe Region in SE Yunnan, China*. Yunnan Science and Technology Press, Kunming [In Chinese.].
- Smitinand, T. 2001. *Thai Plant Names*. The Forest Herbarium of Royal Forest Department, Bangkok.
- Song, Z. Z. 1984. Miocene phytogeographical area of east Asia. Pp. 63–69 in *Nanjing Institute of Geology and Paleontology* (editor), *Stratum and Paleontology*, Vol. 13 [In Chinese.].
- , M. Y. Li & W. B. Li. 1976. Fossil pollens from Yunnan during Mesozoic and early Tertiary. Pp. 1–64 in *Mesozoic Fossils of Yunnan*. Science Press, Beijing [In Chinese.].
- , H. M. Li, Y. H. Zheng & G. Liu. 1983. Miocene floristic region of China. Pp. 178–184 in Y. H. Lu (editor), *Palaeobiogeographic Provinces of China*. Science Press, Beijing [In Chinese.].
- Sun, X. J. 1979. Palynofloristical investigation on the Late Cretaceous and Paleocene of China. *Acta Phytotax. Sin.* 17(3): 8–21 [In Chinese with English abstract.].
- Takhtajan, A. 1988. Pp. 203–299 in *Floristic Regions of the World*. Science Press, Beijing. [Translated by G. C. Huang.].
- Turner, I. M. 1995. A catalogue of the vascular plants of Malaya. *Gard. Bull. Singapore* 47: 1–757.
- van Balgooy, M. M. J., P. H. Hovenkamp & P. C. van Welzen. 1996. Phytogeography of the Pacific—Floristic and historical distribution patterns in plants. Pp. 191–213 in A. Keast & S. E. Miller (editors), *The Origin and Evolution of Pacific Island Biotas*. New Guinea to Eastern Polynesia: Patterns and Processes. SPB Academic Publishing, Amsterdam.
- Wang, C. W. 1961. Pp. 155–164 in *The Forests of China with a Survey of Grassland and Desert Vegetation*. Maria Moors Cabot Foundation Publication 5, Harvard University, Cambridge, Massachusetts.
- Wang, W. M. 1996. A palynological survey of Neocene strata in Xiaolongtan Basin, Yunnan province of south China. *Acta Bot. Sin.* 38(9): 743–748 [In Chinese with English abstract.].

Whitmore, T. C. 1982. Fleeting impressions of some Chinese rain forests. *Commonwealth Forestry Rev.* 61: 51–58.

———. 1984. *Tropical Rain Forests of the Far East*, 2nd ed. Clarendon Press, Oxford.

Wu, T. L., F. W. Xing, H. G. Ye, Z. X. Li & B. H. Chen. 1996. Study on the spermatophytic flora of South China Sea Islands. *J. Trop. Subtrop. Bot.* 4(1): 1–22 [In Chinese with English abstract.].

Wu, Z. Y. (C. Y.). 1965. The tropical floristic affinity of the flora of China. *Chin. Sci. Bull.* 1965(1): 25–33 [In Chinese.].

———. 1991. The areal-types of Chinese genera of seed plants. *Acta Bot. Yunnan., Suppl. IV*: 1–139 [In Chinese with English abstract.].

——— & S. Wu. 1996. A proposal for a new floristic kingdom (realm)—The Asiatic kingdom, its delineation, and characteristics. Pp. 3–42 in A. Zhang & S. Wu (editors), *Floristic Characteristics and Diversity of East Asian Plants*. China Higher Education & Springer Asia, Beijing.

Wu, Z. Y., Z. K. Zhou, D. Z. Li, H. Peng & H. Sun. 2003. The areal-types of the world families of seed plants. *Acta Bot. Yunnan.* 25(3): 245–257.

Xu, Y. C., H. Q. Jiang & F. Quan. 1987. Reports on the Nature Reserve of Xishuangbanna. Yunnan Science & Technology Press, Kunming. [In Chinese.].

Zhu, H. 1992. Research of community ecology on *Shorea chinensis* forest in Xishuangbanna. *Acta Bot. Yunnan.* 14(3): 237–258 [In Chinese with English abstract.].

———. 1993a. A comparative study of phytosociology between *Shorea chinensis* forest of Xishuangbanna and other closer forest types. *Acta Bot. Yunnan.* 15(1): 34–46 [In Chinese with English abstract.].

———. 1993b. Floristic plant geography on the dipterocarp forest of Xishuangbanna. *Acta Bot. Yunnan.* 15(3): 233–253 [In Chinese with English abstract.].

———. 1994. Floristic relationships between dipterocarp forest of Xishuangbanna and forests of tropical Asia and S China. *Acta Bot. Yunnan.* 16(2): 97–106 [In Chinese with English abstract.].

———. 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *J. Biogeogr.* 24: 647–662.

———. 2004. A tropical seasonal rain forest at its altitudinal and latitudinal limits in southern Yunnan, SW China. *Gard. Bull. Singapore* 56: 55–72.

———. 2006. Forest vegetation of Xishuangbanna, south China. *Forestry Studies in China* 8(2): 1–58.

———, H. Wang & B. G. Li. 1998a. Research on the tropical seasonal rainforest of Xishuangbanna, south Yunnan. *Guihaia* 18(4): 371–384 [In Chinese with English abstract.].

———, ——— & ———. 1998b. The structure, species composition, and diversity of the limestone vegetation in Xishuangbanna, SW China. *Gard. Bull. Singapore* 50: 5–33.

———, Y. H. Li, H. Wang & B. G. Li. 2001. Characteristics and affinity of the flora of Xishuangbanna, SW China. *Guihaia* 21(2): 127–136 [In Chinese with English abstract.].

———, H. Wang, B. G. Li & P. Siriruga. 2003. Biogeography and floristic affinity of the limestone flora in southern Yunnan, China. *Ann. Missouri Bot. Gard.* 90: 444–465.

——— & M. C. Roos. 2004. The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* 10(2): 639–648.

———, J. M. Zhao, M. Cai, S. L. Liu & L. Li. 2004. Studies on the flora of Dehong region, SW Yunnan (I)—Floristic composition and geographical elements at generic level. *Guihaia* 24(3): 193–198.

———, H. Wang & B. G. Li. 2006. Floristic composition and biogeography of tropical montane rain forest in southern Yunnan of China. *Gard. Bull. Singapore* 58: 81–132.

APPENDIX 1. Genera list of the flora of southern Yunnan (Xishuangbanna). Numbers in parentheses after the family and genus names indicate the inclusive number of genera and species, respectively.

Families	Genera
Acanthaceae (32)	<i>Acanthus</i> L. (1), <i>Adhatoda</i> Mill. (1), <i>Andrographis</i> Wall. ex Nees (2), <i>Asystasia</i> Blume (2), <i>Asystasiella</i> Lindau (1), <i>Baphicacanthus</i> Bremek. (1), <i>Barleria</i> L. (1), <i>Calophanoides</i> Ridl. (1), <i>Chroesthes</i> Benoist (2), <i>Codonacanthus</i> Nees (2), <i>Dicliptera</i> Juss. (2), <i>Eranthemum</i> L. (1), <i>Goldfussia</i> Nees (1), <i>Hemigraphis</i> Nees (1), <i>Hygrophila</i> R. Br. (1), <i>Hypoestes</i> Sol. ex R. Br. (1), <i>Isoglossa</i> Oerst. (1), <i>Lepidagathis</i> Willd. (1), <i>Mananthes</i> Bremek. (1), <i>Nelsonia</i> R. Br. (1), <i>Ophiorrhizophyllum</i> Kurz (1), <i>Peristrophe</i> Nees (1), <i>Phaulopsis</i> Willd. (1), <i>Phlogacanthus</i> Nees (2), <i>Pseuderanthemum</i> Radlk. (3), <i>Pteracanthus</i> (Nees) Bremek. (1), <i>Rhaphidosperma</i> G. Don (1), <i>Rostellularia</i> Rchb. (2), <i>Rungia</i> Nees (4), <i>Sericocalyx</i> Bremek. (1), <i>Strobilanthes</i> Blume (21), <i>Thunbergia</i> Retz. (5)
Aceraceae (1)	<i>Acer</i> L. (4).
Actinidiaceae (2)	<i>Actinidia</i> Lindl. (2), <i>Saurauia</i> Willd. (6)
Aizoaceae (2)	<i>Glinus</i> L. (2), <i>Mollugo</i> L. (1)
Alismataceae (2)	<i>Caldesia</i> Parl. (1), <i>Sagittaria</i> L. (2)
Amaranthaceae (7)	<i>Achyranthes</i> L. (4), <i>Aerva</i> Forssk. (1), <i>Alternanthera</i> Forssk. (2), <i>Amaranthus</i> L. (3), <i>Celosia</i> L. (1), <i>Cyathula</i> Blume (1), <i>Deeringia</i> R. Br. (1)
Amaryllidaceae (2)	<i>Curculigo</i> Gaertn. (2), <i>Hypoxis</i> L. (1)
Anacardiaceae (12)	<i>Buchanania</i> Spreng. (1), <i>Choerospondias</i> B. L. Burt & A. W. Hill (1), <i>Dracontomelon</i> Blume (1), <i>Drimycarpus</i> Hook. f. (1), <i>Lannea</i> A. Rich. (1), <i>Mangifera</i> L. (2), <i>Pegia</i> Colebr. (1), <i>Pistacia</i> L. (1), <i>Rhus</i> L. (2), <i>Semecarpus</i> L. f. (2), <i>Spondias</i> L. (2), <i>Toxicodendron</i> Mill. (3)

APPENDIX 1. Continued.

Families	Genera
Annonaceae (15)	<i>Alphonsea</i> Hook. f. & Thomson (5), <i>Artabotrys</i> R. Br. ex Ker Gawl. (2), <i>Cyathostemma</i> Griff. (1), <i>Dasymaschalon</i> Dalla Torre & Harms (1), <i>Desmos</i> Lour. (3), <i>Fissistigma</i> Griff. (9), <i>Goniothalamus</i> (Blume) Hook. f. & Thomson (2), <i>Mezzettiopsis</i> Ridl. (1), <i>Miliusa</i> Lesch. (6), <i>Mitrephora</i> Hook. f. & Thomson (3), <i>Orophea</i> Blume (1), <i>Phaeanthus</i> Hook. f. & Thomson (1), <i>Polyalthia</i> Blume (8), <i>Pseuduaria</i> Miq. (1), <i>Uvaria</i> L. (5)
Apiaceae (8)	<i>Centella</i> L. (1), <i>Eryngium</i> L. (1), <i>Heracleum</i> L. (1), <i>Hydrocotyle</i> L. (6), <i>Oenanthe</i> L. (3), <i>Pimpinella</i> L. (4), <i>Sanicula</i> L. (1), <i>Trachyspermum</i> Link (1)
Apocynaceae (23)	<i>Aganosma</i> (Blume) G. Don (4), <i>Alstonia</i> R. Br. (2), <i>Alyxia</i> Banks ex R. Br. (4), <i>Amalocalyx</i> Pierre (1), <i>Anodendron</i> A. DC. (2), <i>Beaumontia</i> Wall. (2), <i>Bousigonia</i> Pierre (2), <i>Chonemorpha</i> G. Don (4), <i>Cleghornia</i> Wight (1), <i>Epigynum</i> Wight (1), <i>Holarrhena</i> R. Br. (1), <i>Ichnocarpus</i> R. Br. (2), <i>Kibatalia</i> G. Don (2), <i>Kopsia</i> Blume (1), <i>Melodinus</i> J. R. Forst. & G. Forst. (2), <i>Parameria</i> Benth. (1), <i>Pottisia</i> Hook. & Arn. (1), <i>Rauwolfia</i> L. (1), <i>Strophanthus</i> DC. (2), <i>Tabernaemontana</i> L. (3), <i>Trachelospermum</i> Lem. (3), <i>Urceola</i> Vand. (4), <i>Wrightia</i> R. Br. (5)
Aquifoliaceae (1)	<i>Ilex</i> L. (12)
Araceae (17)	<i>Acorus</i> L. (2), <i>Aglaonema</i> Schott (1), <i>Alocasia</i> (Schott) G. Don (2), <i>Amorphophallus</i> Blume ex Decne. (7), <i>Arisaema</i> Mart. (4), <i>Colocasia</i> Schott (4), <i>Cryptocoryne</i> Fischer ex Wydler (1), <i>Epipremnum</i> Schott (1), <i>Gonatanthus</i> Klotzsch (1), <i>Homalomena</i> Schott (2), <i>Lasia</i> Lour. (1), <i>Pistia</i> L. (1), <i>Pothos</i> L. (3), <i>Remusatia</i> Schott (2), <i>Rhaphidophora</i> Hassk. (8), <i>Staudnera</i> K. Koch (1), <i>Typhonium</i> Schott (2)
Araliaceae (10)	<i>Aralia</i> L. (5), <i>Brassaiopsis</i> Deene. & Planch. (3), <i>Eleutherococcus</i> Maxim. (1), <i>Euraliopsis</i> Hutch. (2), <i>Heteropanax</i> Seem. (2), <i>Macropanax</i> Miq. (3), <i>Panax</i> L. (2), <i>Schefflera</i> J. R. Forst. & G. Forst. (6), <i>Trevesia</i> Vis. (1), <i>Tupidanthus</i> Hook. f. & Thomson (1)
Arecaceae (8)	<i>Arenga</i> Labill. (1), <i>Calamus</i> L. (24), <i>Caryota</i> L. (3), <i>Livistona</i> R. Br. (1), <i>Phoenix</i> L. (2), <i>Pinanga</i> Blume (4), <i>Plectocomia</i> Mart. ex Blume (3), <i>Wallichia</i> Roxb. (2)
Aristolochiaceae (1)	<i>Aristolochia</i> L. (6)
Asclepiadaceae (26)	<i>Asclepias</i> L. (1), <i>Biondia</i> Schltr. (1), <i>Brachystelma</i> R. Br. (1), <i>Calotropis</i> R. Br. (1), <i>Ceropegia</i> L. (2), <i>Cryptolepis</i> R. Br. (2), <i>Cynanchum</i> L. (3), <i>Dischidia</i> R. Br. (2), <i>Dregea</i> E. Mey. (1), <i>Genianthus</i> Hook. f. (1), <i>Gongronema</i> (Endl.) Decne. (1), <i>Goniostemma</i> Wight (1), <i>Gymnema</i> R. Br. (4), <i>Heterostemma</i> Wight & Arn. (7), <i>Hoya</i> R. Br. (8), <i>Marsdenia</i> R. Br. (7), <i>Metaplexis</i> R. Br. (1), <i>Micholitzia</i> N. E. Br. (1), <i>Myriopteron</i> Griff. (1), <i>Oxystelma</i> R. Br. (1), <i>Pentasachme</i> Wall. ex Wight (1), <i>Raphistemma</i> Wall. (1), <i>Stelmocrypton</i> Baill. (1), <i>Streptocaulon</i> Wight & Arn. (1), <i>Toxocarpus</i> Wight & Arn. (4), <i>Tylophora</i> R. Br. (3)
Asteraceae (59)	<i>Acanthospermum</i> Schrank (2), <i>Achillea</i> L. (1), <i>Adenostemma</i> J. R. Forst. & G. Forst. (2), <i>Ageratum</i> L. (1), <i>Arctium</i> L. (1), <i>Artemisia</i> L. (4), <i>Bidens</i> L. (4), <i>Blainvillea</i> Cass. (1), <i>Blumea</i> DC. (9), <i>Blumeopsis</i> Gagnep. (1), <i>Camchaya</i> Gagnep. (1), <i>Carpesium</i> L. (1), <i>Centipeda</i> Lour. (1), <i>Chromolaena</i> DC. (1), <i>Cirsium</i> Mill. (1), <i>Conyza</i> Less. (4), <i>Cotula</i> L. (1), <i>Crassocephalum</i> Moench (1), <i>Crepis</i> L. (1), <i>Cyathocline</i> Cass. (1), <i>Dichrocephala</i> L'Hér. ex DC. (3), <i>Eclipta</i> L. (1), <i>Elephantopus</i> L. (1), <i>Emilia</i> Cass. (1), <i>Enydra</i> Lour. (1), <i>Ethulia</i> L. f. (1), <i>Eupatorium</i> L. (1), <i>Galinsoga</i> Ruiz & Pav. (1), <i>Gerbera</i> L. (1), <i>Gnaphalium</i> L. (3), <i>Gochnatia</i> Kunth (1), <i>Grangea</i> Adans. (1), <i>Gynura</i> Cass. (2), <i>Hemisteptia</i> Bunge ex Fisch. & C. A. Mey. (1), <i>Inula</i> L. (1), <i>Ixeridium</i> (A. Gray) Tzvelev (1), <i>Lactuca</i> L. (1), <i>Laggera</i> Sch. Bip. ex Benth. & Hook. f. (2), <i>Microglossa</i> DC. (1), <i>Nouelia</i> Franch. (1), <i>Pentanema</i> Cass. (2), <i>Picris</i> L. (1), <i>Pluchea</i> Cass. (1), <i>Pterocypsela</i> C. Shih (1), <i>Senecio</i> L. (1), <i>Siegesbeckia</i> Steud. (3), <i>Sonchus</i> L. (1), <i>Sphaeranthus</i> L. (3), <i>Sphaeromorphaea</i> DC. (1), <i>Spilanthes</i> Jacq. (2), <i>Synedrella</i> Gaertn. (1), <i>Synotis</i> (C. B. Clarke) C. Jeffrey & Y. L. Chen (1), <i>Thespis</i> DC. (1), <i>Tricholepis</i> DC. (1), <i>Tridax</i> L. (1), <i>Vernonia</i> Schreb. (14), <i>Wedelia</i> Jacq. (2), <i>Xanthium</i> L. (1), <i>Youngia</i> Cass. (3)
Balanophoraceae (1)	<i>Balanophora</i> J. R. Forst. & G. Forst. (4)
Balsaminaceae (1)	<i>Impatiens</i> L. (7)
Begoniaceae (1)	<i>Begonia</i> L. (11)
Berberidaceae (1)	<i>Mahonia</i> Nutt. (1)
Betulaceae (3)	<i>Alnus</i> Mill. (1), <i>Betula</i> L. (1), <i>Carpinus</i> L. (2)
Bignoniaceae (7)	<i>Fernandoa</i> Welw. ex Seem. (1), <i>Markhamia</i> Seem. ex Baill. (2), <i>Mayodendron</i> Kurz. (1), <i>Nyctocalos</i> Teijsm. & Binn. (1), <i>Oroxylum</i> Vent. (1), <i>Radermachera</i> Zoll. & Moritz (2), <i>Stereospermum</i> Cham. (2)
Bombacaceae (1)	<i>Bombax</i> L. (2)
Boraginaceae (9)	<i>Bothriospermum</i> Bunge (1), <i>Cordia</i> L. (2), <i>Cynoglossum</i> L. (2), <i>Ehretia</i> P. Browne (5), <i>Heliotropium</i> L. (3), <i>Thyrocarpus</i> Hance (1), <i>Tournefortia</i> L. (2), <i>Trichodesma</i> R. Br. (1), <i>Trigonotis</i> Steven (1)

APPENDIX 1. Continued.

Families	Genera
Brassicaceae (3)	<i>Cardamine</i> L. (2), <i>Raphanus</i> L. (1), <i>Rorippa</i> Scop. (2)
Burmanniaceae (1)	<i>Burmannia</i> L. (3)
Burseraceae (3)	<i>Canarium</i> L. (4), <i>Garuga</i> Roxb. (3), <i>Protium</i> Burm. f. (1)
Butomaceae (2)	<i>Butomopsis</i> Kunth (1), <i>Limnocharis</i> Bonpl. (1)
Buxaceae (2)	<i>Buxus</i> L. (1), <i>Sarcococca</i> Lindl. (1)
Campanulaceae (9)	<i>Asyneuma</i> Griseb. & Schenk (1), <i>Campanula</i> L. (1), <i>Campanumoea</i> Blume (4), <i>Cephalostigma</i> A. DC. (1), <i>Codonopsis</i> Wall. (1), <i>Lobelia</i> L. (6), <i>Pentaphragma</i> Wall. ex G. Don (1), <i>Pratia</i> Gaudich. (1), <i>Wahlenbergia</i> Schrad. ex Roth (1)
Capparaceae (4)	<i>Borthwickia</i> W. W. Sm. (1), <i>Capparis</i> L. (10), <i>Crateva</i> L. (2), <i>Stixis</i> Lour. (1)
Caprifoliaceae (5)	<i>Carlemannia</i> Benth. (1), <i>Lonicera</i> L. (4), <i>Sambucus</i> L. (1), <i>Silvianthus</i> Hook. f. (1), <i>Viburnum</i> L. (7)
Caryophyllaceae (6)	<i>Brachystemma</i> D. Don (1), <i>Drymaria</i> Willd. ex Schult. (1), <i>Myosoton</i> Moench (1), <i>Polycarpon</i> Loeff. ex L. (1), <i>Silene</i> L. (1), <i>Stellaria</i> L. (2)
Celastraceae (4)	<i>Celastrus</i> L. (6), <i>Glyptopetalum</i> Thwaites (2), <i>Maytenus</i> Molina (6), <i>Microtropis</i> Wall. ex Meisn. (2)
Cephalotaxaceae (1)	<i>Cephalotaxus</i> Siebold & Zucc. ex Endl. (1)
Ceratophyllaceae (1)	<i>Ceratophyllum</i> L. (1)
Chenopodiaceae (2)	<i>Chenopodium</i> L. (1), <i>Dysphania</i> R. Br. (1)
Chloranthaceae (2)	<i>Chloranthus</i> Sw. (2), <i>Sarcandra</i> Gardner (1)
Clusiaceae (5)	<i>Calophyllum</i> L. (1), <i>Cratoxylum</i> Blume (2), <i>Garcinia</i> L. (6), <i>Hypericum</i> L. (3), <i>Triadenum</i> Raf. (1)
Combretaceae (4)	<i>Anogeissus</i> (DC.) Wall. ex Guill. & Perr. & A. Rich. (1), <i>Combretum</i> Loeff. (6), <i>Quisqualis</i> L. (2), <i>Terminalia</i> L. (2)
Commelinaceae (10)	<i>Amischotolype</i> Hassk. (2), <i>Commelina</i> L. (5), <i>Cyanotis</i> D. Don (3), <i>Dictyospermum</i> Wight (1), <i>Floscopa</i> Lour. (2), <i>Murdannia</i> Royle (9), <i>Polia</i> Thunb. (5), <i>Porandra</i> D. Y. Hong (2), <i>Rhopalephora</i> Hassk. (1), <i>Streptolirion</i> Edgew. (1)
Connaraceae (4)	<i>Connarus</i> L. (1), <i>Rourea</i> Aubl. (1), <i>Roureopsis</i> Planch. (1), <i>Santaloides</i> G. Schellenb. (1)
Convolvulaceae (13)	<i>Argyria</i> Lour. (12), <i>Cuscuta</i> L. (2), <i>Dichondra</i> J. R. Forst. & G. Forst. (1), <i>Dinetus</i> Buch.-Ham. ex Sweet (1), <i>Erycibe</i> Roxb. (2), <i>Ipomoea</i> L. (7), <i>Merremia</i> Dennst. ex Endl. (5), <i>Neuropeltis</i> Wall. (1), <i>Operculina</i> Silva Manso (1), <i>Porana</i> Burm. f. (1), <i>Poranopsis</i> Roberty (1), <i>Tridynamia</i> Gagnep. (1), <i>Xenostegia</i> D. F. Austin & Staples (1)
Cornaceae (4)	<i>Alangium</i> Lam. (6), <i>Helwingia</i> Willd. (1), <i>Mastixia</i> Blume (3), <i>Swida</i> Opiz (1)
Crassulaceae (2)	<i>Bryophyllum</i> Salisb. (1), <i>Kalanchoe</i> Adans. (1)
Crypteroniaceae (1)	<i>Crypteronia</i> Blume (1)
Cucurbitaceae (17)	<i>Coccinia</i> Wight & Arn. (1), <i>Cucumis</i> L. (2), <i>Gomphogyne</i> Griff. (1), <i>Gymnopetalum</i> Arn. (2), <i>Gynostemma</i> Blume (6), <i>Hemsleya</i> Cogn. ex F. B. Forbes & Hemsl. (2), <i>Hodgsonia</i> Hook. f. & Thomson (2), <i>Luffa</i> Mill. (1), <i>Momordica</i> L. (2), <i>Mukia</i> Arn. (2), <i>Neosalsomitra</i> Hutch. (1), <i>Siraitia</i> Merr. (1), <i>Solena</i> Lour. (1), <i>Thladiantha</i> Bunge (3), <i>Trichosanthes</i> L. (14), <i>Zanonia</i> L. (1), <i>Zehneria</i> Endl. (4)
Cupressaceae (1)	<i>Calocedrus</i> Kurz (1)
Cycadaceae (1)	<i>Cycas</i> L. (3)
Cyperaceae (14)	<i>Bulbostylis</i> Kunth (1), <i>Carex</i> L. (2), <i>Courtoisia</i> Marchand (1), <i>Cyperus</i> L. (14), <i>Eleocharis</i> R. Br. (4), <i>Fimbristylis</i> Vahl (4), <i>Fuirena</i> Rottb. (1), <i>Kyllinga</i> Rottb. (2), <i>Lipocarpha</i> R. Br. (1), <i>Mariscus</i> Vahl (3), <i>Pycneus</i> P. Beauv. (2), <i>Schoenoplectus</i> (Rchb.) Palla (2), <i>Scirpus</i> L. (1), <i>Scleria</i> P. J. Bergius (2)
Daphniphyllaceae (1)	<i>Daphniphyllum</i> Blume (2)
Datisceae (1)	<i>Tetrameles</i> R. Br. (1)
Dichapetalaceae (1)	<i>Dichapetalum</i> Thouars (1)
Dilleniaceae (2)	<i>Dillenia</i> L. (3), <i>Tetracera</i> L. (1)
Dioscoreaceae (1)	<i>Dioscorea</i> L. (22)
Dipterocarpaceae (2)	<i>Parashorea</i> Kurz (1), <i>Vatica</i> L. (1)
Droseraceae (1)	<i>Drosera</i> L. (1)
Ebenaceae (1)	<i>Diospyros</i> L. (6)
Elaeagnaceae (1)	<i>Elaeagnus</i> L. (5)
Elaeocarpaceae (2)	<i>Elaeocarpus</i> L. (16), <i>Sloanea</i> L. (2)
Elatinaceae (2)	<i>Bergia</i> L. (1), <i>Elatine</i> L. (1)
Ericaceae (4)	<i>Agapetes</i> D. Don ex G. Don (4), <i>Craibiodendron</i> W. W. Sm. (1), <i>Rhododendron</i> L. (4), <i>Vaccinium</i> L. (5)
Eriocaulaceae (1)	<i>Eriocaulon</i> L. (2)
Erythroxylaceae (1)	<i>Erythroxylum</i> P. Browne (1)

APPENDIX 1. Continued.

Families	Genera
Euphorbiaceae (36)	<i>Actephila</i> Blume (2), <i>Alchornea</i> Sw. (2), <i>Antidesma</i> L. (10), <i>Aporosa</i> Blume (3), <i>Baccaurea</i> Lour. (1), <i>Baliospermum</i> Blume (2), <i>Bischofia</i> Blume (1), <i>Blachia</i> Baill. (1), <i>Breynia</i> J. R. Forst. & G. Forst. (5), <i>Bridelia</i> Willd. (4), <i>Chaetocarpus</i> Thwaites (1), <i>Claoxylon</i> A. Juss. (4), <i>Cleidion</i> Blume (3), <i>Cleistanthus</i> Hook. f. ex Planch. (1), <i>Croton</i> L. (7), <i>Dalechampia</i> L. (1), <i>Drypetes</i> Vahl (4), <i>Epiprinus</i> Griff. (1), <i>Euphorbia</i> L. (3), <i>Flueggea</i> Willd. (2), <i>Glochidion</i> J. R. Forst. & G. Forst. (12), <i>Gymnanthes</i> Sw. (1), <i>Homonoia</i> Lour. (1), <i>Lasiococca</i> Hook. f. (1), <i>Macaranga</i> Thouars (4), <i>Mallotus</i> Lour. (14), <i>Megistostigma</i> Hook. f. (1), <i>Ostodes</i> Blume (3), <i>Phyllanthodendron</i> Hemsl. (1), <i>Phyllanthus</i> L. (8), <i>Sapium</i> Jacq. (5), <i>Sauropus</i> Blume (2), <i>Sumbaviopsis</i> J. J. Sm. (1), <i>Suregada</i> Roxb. ex Rottler (1), <i>Trewia</i> L. (1), <i>Trigonostemon</i> Blume (3)
Fabaceae (65)	<i>Abrus</i> Adans. (1), <i>Acacia</i> Mill. (6), <i>Acrocarpus</i> Wight & Arn. (1), <i>Adenanthera</i> L. (1), <i>Aeschynomene</i> L. (1), <i>Albizia</i> Durazz. (6), <i>Alysicarpus</i> Desv. (2), <i>Antheroporum</i> Gagnep. (1), <i>Bauhinia</i> L. (9), <i>Caesalpinia</i> L. (7), <i>Cajanus</i> Adans. (4), <i>Campylotropis</i> Bunge (5), <i>Cassia</i> L. (2), <i>Catenaria</i> Benth. in Miquel (1), <i>Chamaecrista</i> Moench (1), <i>Clitoria</i> L. (1), <i>Codariocalyx</i> Hassk. (2), <i>Craspedolobium</i> Harms (1), <i>Crotalaria</i> L. (15), <i>Cylindrokelupha</i> Kosterm. (3), <i>Dalbergia</i> L. f. (6), <i>Dendrolobium</i> (Wight & Arn.) Benth. (2), <i>Derris</i> Lour. (4), <i>Desmodium</i> Desv. (9), <i>Dunbaria</i> Wight & Arn. (1), <i>Entada</i> Adans. (2), <i>Eriosema</i> (DC.) Desv. (1), <i>Erythrina</i> L. (2), <i>Euchresta</i> Benn. (2), <i>Flemingia</i> Roxb. ex W. T. Aiton (11), <i>Fordia</i> Hemsl. (2), <i>Gleditsia</i> L. (1), <i>Gueldenstaedtia</i> Fisch. (1), <i>Indigofera</i> L. (6), <i>Lespedeza</i> Michx. (1), <i>Mecopus</i> Benn. (1), <i>Melilotus</i> Mill. (1), <i>Milletia</i> Wight & Arn. (16), <i>Mimosa</i> L. (1), <i>Mucuna</i> Adans. (6), <i>Nicolsonia</i> DC. (11), <i>Ormosia</i> Jacks. (5), <i>Pachyrhizus</i> Rich. ex DC. (1), <i>Phaseolus</i> L. (1), <i>Phylacium</i> Benn. (1), <i>Phyllodium</i> Desv. (3), <i>Pithecolobium</i> Benth. (1), <i>Podocarpium</i> (Benth.) Yen C. Yang & P. H. Huang (3), <i>Priotropis</i> Wight & Arn. (1), <i>Psoralea</i> L. (1), <i>Pueraria</i> DC. (5), <i>Pycnospora</i> R. Br. ex Wight & Arn. (1), <i>Rhynchosia</i> Lour. (1), <i>Senna</i> Mill. (3), <i>Sesbania</i> Scop. (2), <i>Shuteria</i> Wight & Arn. (3), <i>Smithia</i> Aiton (2), <i>Sophora</i> L. (5), <i>Spatholobus</i> Hassk. (4), <i>Tadehagi</i> H. Ohashi (2), <i>Tephrosia</i> Pers. (2), <i>Uraria</i> Desv. (4), <i>Urariopsis</i> Schindl. (1), <i>Whitfordiodendron</i> Elmer (1), <i>Zornia</i> J. F. Gmel. (1)
Fagaceae (5)	<i>Castanopsis</i> (D. Don) Spach (16), <i>Cyclobalanopsis</i> Oerst. (6), <i>Lithocarpus</i> Blume (16), <i>Quercus</i> L. (5), <i>Trigonobalanus</i> Forman (1)
Flacourtiaceae (6)	<i>Bennettiodendron</i> Merr. (1), <i>Casearia</i> Jacq. (5), <i>Flacourtia</i> Comm. ex L'Hér. (4), <i>Homalium</i> Jacq. (2), <i>Hydnocarpus</i> Gaertn. (1), <i>Xylosma</i> G. Forst. (3)
Fumariaceae (1)	<i>Corydalis</i> DC. (2)
Gentianaceae (5)	<i>Canscora</i> Lam. (1), <i>Exacum</i> L. (1), <i>Gentiana</i> L. (1), <i>Swertia</i> L. (1), <i>Tripterospermum</i> Blume (1)
Geraniaceae (1)	<i>Geranium</i> L. (1)
Gesneriaceae (13)	<i>Aeschynanthus</i> Jack (10), <i>Chirita</i> Buch.-Ham. ex D. Don (4), <i>Didissandra</i> C. B. Clarke (1), <i>Didymocarpus</i> Wall. (1), <i>Epithema</i> Blume (1), <i>Leptoboea</i> C. B. Clarke (1), <i>Oreocharis</i> Benth. (1), <i>Ornithoboea</i> Parish ex C. B. Clarke (2), <i>Paraboea</i> (C. B. Clarke) Ridl. (3), <i>Petrocosmea</i> Oliv. (1), <i>Rhynchoglossum</i> Blume (1), <i>Rhynchotechum</i> Blume (2), <i>Trisepalum</i> C. B. Clarke (1)
Gnetaceae (1)	<i>Gnetum</i> L. (3)
Grossulariaceae (1)	<i>Polyosma</i> Blume (1)
Hamamelidaceae (2)	<i>Altingia</i> Noronha (1), <i>Distyliopsis</i> P. K. Endress (1)
Hernandiaceae (1)	<i>Illigera</i> Blume (7)
Hippocrateaceae (3)	<i>Loeseneriella</i> A. C. Sm. (3), <i>Pristimera</i> Miers (3), <i>Salacia</i> L. (5)
Hydrangeaceae (1)	<i>Dichroa</i> Lour. (1)
Hydrocharitaceae (4)	<i>Blyxa</i> Noronha ex Thouars (2), <i>Hydrilla</i> Rich. (1), <i>Hydrocharis</i> L. (1), <i>Ottelia</i> Pers. (1)
Hydrophyllaceae (1)	<i>Hydrolea</i> L. (1)
Icacinaceae (8)	<i>Apodytes</i> E. Mey. ex Arn. (1), <i>Gomphandra</i> Wall. ex Lindl. (1), <i>Iodes</i> Blume (2), <i>Mappianthus</i> Hand.-Mazz. (1), <i>Natsiatopsis</i> Kurz (1), <i>Nothapodytes</i> Blume (3), <i>Peripterygium</i> Hassk. (2), <i>Pittosporopsis</i> Craib (1)
Iridaceae (2)	<i>Belamcanda</i> Adans. (1), <i>Iris</i> L. (3)
Juglandaceae (3)	<i>Engelhardia</i> Lesch. ex Blume (4), <i>Juglans</i> L. (2), <i>Pterocarya</i> Kunth (1)
Juncaceae (1)	<i>Juncus</i> L. (1)
Lamiaceae (28)	<i>Acrocephalus</i> Benth. (1), <i>Ajuga</i> L. (1), <i>Anisochilus</i> Wall. ex Benth. (1), <i>Anisomeles</i> R. Br. (1), <i>Ceratanthus</i> F. Muell. ex G. Taylor (1), <i>Clinopodium</i> L. (1), <i>Colebrookea</i> Sm. (1), <i>Coleus</i> Lour. (1), <i>Colquhounia</i> Wall. (1), <i>Craniotome</i> Rehb. (1), <i>Dysophylla</i> Blume (1), <i>Elsholtzia</i> Willd. (10), <i>Eurysolen</i> Prain (1), <i>Geniosporum</i> Wall. ex Benth. (1), <i>Glechoma</i> L. (1), <i>Gomphostemma</i> Benth. (9), <i>Leonurus</i> L. (1), <i>Leucas</i> R. Br. (3), <i>Leucosceptrum</i> Sm. (1), <i>Microtoena</i> Prain (2), <i>Mosla</i> (Benth.) Buch.-Ham. ex Maxim. (1), <i>Origanum</i> L. (1), <i>Paraphlomis</i> (Prain) Prain (1), <i>Pogostemon</i> Desf. (7), <i>Rabdosia</i> Hassk. (6), <i>Salvia</i> L. (2), <i>Scutellaria</i> L. (2), <i>Teucrium</i> L. (1)

APPENDIX 1. Continued.

Families	Genera
Lardizabalaceae (1)	<i>Stauntonia</i> DC. (2)
Lauraceae (14)	<i>Actinodaphne</i> Nees (2), <i>Alseodaphne</i> Nees (2), <i>Beilschmiedia</i> Nees (7), <i>Camphora</i> Fabr. (1), <i>Cassytha</i> L. (1), <i>Cinnamomum</i> Schaeff. (9), <i>Cryptocarya</i> R. Br. (5), <i>Lindera</i> Thunb. (6), <i>Litsea</i> Lam. (21), <i>Machilus</i> Nees (1), <i>Neocinnamomum</i> H. Liu (1), <i>Neolitsea</i> (Benth.) Merr. (1), <i>Persea</i> Mill. (5), <i>Phoebe</i> Nees (8)
Lecythidaceae (1)	<i>Barringtonia</i> J. R. Forst. & G. Forst. (1)
Lemnaceae (3)	<i>Lemna</i> L. (2), <i>Spirodela</i> Schleid. (1), <i>Wolffia</i> Horkel ex Schleid. (1)
Lentibulariaceae (1)	<i>Utricularia</i> L. (7)
Liliaceae (19)	<i>Allium</i> L. (1), <i>Asparagus</i> L. (2), <i>Aspidistra</i> Ker Gawl. (1), <i>Campylandra</i> Baker (2), <i>Chlorophytum</i> Ker Gawl. (2), <i>Dianella</i> Lam. ex Juss. (1), <i>Disporopsis</i> Hance (1), <i>Disporum</i> Salisb. ex D. Don (2), <i>Dracaena</i> Vand. ex L. (4), <i>Gloriosa</i> L. (1), <i>Hemerocallis</i> L. (1), <i>Heterosmilax</i> Kunth (1), <i>Liriope</i> Lour. (1), <i>Ophiopogon</i> Ker Gawl. (7), <i>Paris</i> L. (1), <i>Peliosanthes</i> Andrews (1), <i>Polygonatum</i> Mill. (3), <i>Reineckea</i> Kunth (1), <i>Tupistra</i> Ker Gawl. (2)
Linaceae (2)	<i>Ixonanthes</i> Jack (1), <i>Reinwardtia</i> Dumort. (1)
Loganiaceae (6)	<i>Buddleja</i> L. (6), <i>Fagraea</i> Thunb. (1), <i>Gardneria</i> Wall. (2), <i>Gelsemium</i> Juss. (1), <i>Mitreola</i> L. (1), <i>Strychnos</i> L. (4)
Loranthaceae (6)	<i>Dendrophthoe</i> Mart. (1), <i>Elytranthe</i> (Blume) Blume (1), <i>Helixanthera</i> Lour. (4), <i>Macrosolen</i> (Blume) Blume (4), <i>Scurrula</i> L. (7), <i>Taxillus</i> Tiegh. (1)
Lythraceae (4)	<i>Ammannia</i> L. (3), <i>Lagerstroemia</i> L. (4), <i>Rotala</i> L. (2), <i>Woodfordia</i> Salisb. (1)
Magnoliaceae (9)	<i>Alcimandra</i> Dandy (1), <i>Illicium</i> L. (2), <i>Kadsura</i> Juss. (1), <i>Magnolia</i> L. (1), <i>Manglietia</i> Blume (2), <i>Michelia</i> L. (2), <i>Parakmeria</i> Hu & W. C. Cheng (1), <i>Paramichelia</i> Hu (1), <i>Schisandra</i> Michx. (3)
Malpighiaceae (2)	<i>Aspidopterys</i> A. Juss. ex Endl. (3), <i>Hiptage</i> Gaertn. (3)
Malvaceae (10)	<i>Abelmoschus</i> Medik. (5), <i>Abutilon</i> Mill. (2), <i>Cenocentrum</i> Gagnep. (1), <i>Hibiscus</i> L. (4), <i>Kydia</i> Roxb. (3), <i>Malva</i> L. (1), <i>Malvastrum</i> A. Gray (1), <i>Sida</i> L. (11), <i>Thespesia</i> Sol. ex Corrêa (1), <i>Urena</i> L. (5)
Marantaceae (3)	<i>Donax</i> Lour. (1), <i>Phrynium</i> Willd. (2), <i>Stachyphrynium</i> K. Schum. (1)
Melastomataceae (9)	<i>Allomorphia</i> Blume (2), <i>Cyphotheca</i> Diels (1), <i>Medinilla</i> Gaudich. ex DC. (4), <i>Melastoma</i> L. (3), <i>Memecylon</i> L. (3), <i>Osbeckia</i> L. (6), <i>Oxyspora</i> DC. (2), <i>Sonerila</i> Roxb. (5), <i>Styrophyton</i> S. Y. Hu (1)
Meliaceae (12)	Juss. (2), <i>Cipadessa</i> Blume (1), <i>Dysoxylum</i> Blume (10), <i>Melia</i> L. (2), <i>Munronia</i> Wight (1), <i>Toona</i> (Endl.) M. Roem. (5), <i>Trichilia</i> P. Browne (2), <i>Walsura</i> Roxb. (2)
Menispermaceae (14)	<i>Aspidocarya</i> Hook. f. & Thomson (1), <i>Cissampelos</i> L. (1), <i>Cocculus</i> DC. (2), <i>Cyclea</i> Arn. ex Wight (6), <i>Diplocisia</i> Miers (1), <i>Eleutharrhena</i> Forman (1), <i>Hypserpa</i> Miers (1), <i>Pachygone</i> Miers (1), <i>Parabaena</i> Miers (1), <i>Pericampylus</i> Miers (1), <i>Pycnarrhena</i> Miers ex Hook. f. & Thomson (1), <i>Stephania</i> Lour. (9), <i>Tinomisium</i> Miers ex Hook. f. & Thomson (1), <i>Tinospora</i> Miers (3)
Menyanthaceae (1)	<i>Nymphoides</i> Ség. (1)
Moraceae (7)	<i>Antiaris</i> Lesch. (1), <i>Artocarpus</i> J. R. Forst. & G. Forst. (5), <i>Broussonetia</i> L'Hér. ex Vent. (2), <i>Ficus</i> L. (58), <i>Maclura</i> Nutt. (3), <i>Morus</i> L. (2), <i>Streblus</i> Lour. (2)
Musaceae (2)	<i>Ensete</i> Horan. (1), <i>Musa</i> L. (5)
Myricaceae (1)	<i>Myrica</i> L. (1)
Myristicaceae (3)	<i>Horsfieldia</i> Willd. (4), <i>Knema</i> Lour. (4), <i>Myristica</i> Gronov. (1)
Myrsinaceae (4)	<i>Ardisia</i> Sw. (10), <i>Embelia</i> Burm. f. (8), <i>Maesa</i> Forssk. (8), <i>Myrsine</i> L. (2)
Myrtaceae (2)	<i>Decaspermum</i> J. R. Forst. & G. Forst. (1), <i>Syzygium</i> P. Browne ex Gaertn. (22)
Najadaceae (1)	<i>Najas</i> L. (1)
Nyctaginaceae (1)	<i>Pisonia</i> L. (1)
Nymphaeaceae (2)	<i>Brasenia</i> Schreb. (1), <i>Nuphar</i> Sm. (1)
Nyssaceae (2)	<i>Camptotheca</i> Decne. (1), <i>Nyssa</i> L. (3)
Oleaceae (3)	<i>Erythralium</i> Blume (1), <i>Olex</i> L. (1), <i>Schoepfia</i> Schreb. (1)
Oleaceae (7)	<i>Chionanthus</i> L. (1), <i>Fraxinus</i> L. (2), <i>Jasminum</i> L. (10), <i>Ligustrum</i> L. (4), <i>Linociera</i> Sw. ex Schreb. (1), <i>Olea</i> L. (3), <i>Osmanthus</i> Lour. (2)
Onagraceae (2)	<i>Epilobium</i> L. (1), <i>Ludwigia</i> L. (5)
Opiliaceae (2)	<i>Opilia</i> Roxb. (2), <i>Urobotrya</i> Stapf (1)
Orchidaceae (94)	<i>Acampe</i> Lindl. (2), <i>Acanthephippium</i> Blume ex Endl. (2), <i>Acriopsis</i> Blume (1), <i>Aerides</i> Lour. (2), <i>Agrostophyllum</i> Blume (1), <i>Ania</i> Lindl. (3), <i>Anoectochilus</i> Blume (3), <i>Anthogonium</i> Wall. ex Lindl. (1), <i>Aphyllorchis</i> Blume (2), <i>Apostasia</i> Blume (1), <i>Arachnis</i> Blume (1), <i>Arundina</i> Blume (1), <i>Ascocentrum</i> Schltr. ex J. J. Sm. (1), <i>Brachycorythis</i> Lindl. (1), <i>Bulbophyllum</i> Thouars (40), <i>Calanthe</i> R. Br. (5), <i>Callostylis</i> Blume (1), <i>Cephalantheropsis</i> Guillaumin (1), <i>Ceratostylis</i> Blume (1),

APPENDIX 1. Continued.

Families	Genera
	<i>Cheirostylis</i> Blume (2), <i>Chiloschista</i> Lindl. (1), <i>Chrysoglossum</i> Blume (1), <i>Cleisostoma</i> Blume (10), <i>Coelogyne</i> Lindl. (9), <i>Corymborchis</i> Thouars (1), <i>Cymbidium</i> Sw. (10), <i>Dendrobium</i> Sw. (43), <i>Diploprora</i> Hook. f. (1), <i>Epipactis</i> Zinn (1), <i>Epipogium</i> J. F. Gmel. ex Borkh. (2), <i>Eria</i> Lindl. (22), <i>Eriodes</i> Rolfe (1), <i>Erythroides</i> Blume (1), <i>Esmeralda</i> Rehb. f. (1), <i>Eulophia</i> R. Br. ex Lindl. (1), <i>Flickingeria</i> A. D. Hawkes (6), <i>Galeola</i> Lour. (2), <i>Gastrochilus</i> D. Don (5), <i>Gastrodia</i> R. Br. (1), <i>Geodorum</i> Jacks. (2), <i>Goodyera</i> R. Br. (3), <i>Habenaria</i> Willd. (12), <i>Hemipilia</i> Lindl. (1), <i>Herminium</i> L. (1), <i>Hetaeria</i> Blume (1), <i>Holcoglossum</i> Schltr. (2), <i>Hygrochilus</i> Pfitzer (1), <i>Kingidium</i> P. F. Hunt (1), <i>Lecanorchis</i> Blume (1), <i>Liparis</i> Rich. (11), <i>Luisia</i> Gaudich. (4), <i>Malaxis</i> Sol. ex Sw. (9), <i>Nervilia</i> Commons ex Gaudich. (2), <i>Oberonia</i> Lindl. (13), <i>Ornithochilus</i> (Lindl.) Wall. ex Benth. (1), <i>Otochilus</i> Lindl. (2), <i>Panisea</i> Lindl. (1), <i>Paphiopedilum</i> Pfitzer (2), <i>Papilionanthe</i> Schltr. (2), <i>Parapteroceras</i> Aver. (1), <i>Pecteilis</i> Raf. (2), <i>Pelatantheria</i> Ridl. (3), <i>Pennilabium</i> J. J. Sm. (1), <i>Peristylus</i> Blume (4), <i>Phaius</i> Lour. (6), <i>Phalaenopsis</i> Blume (1), <i>Pholidota</i> Lindl. ex Hook. (4), <i>Phreatia</i> Lindl. (1), <i>Platanthera</i> Rich. (1), <i>Pleione</i> D. Don (1), <i>Podochilus</i> Blume (1), <i>Polystachya</i> Hook. (1), <i>Porpax</i> Lindl. (1), <i>Pteroceras</i> Hasselt ex Hassk. (1), <i>Rhynchostylis</i> Blume (1), <i>Robiquetia</i> Gaudich. (1), <i>Sarcoglyphis</i> Garay (1), <i>Schoenorchis</i> Blume (2), <i>Spathoglottis</i> Blume (1), <i>Spiranthes</i> Rich. (1), <i>Staurochilus</i> Ridl. ex Pfitzer (2), <i>Sunipia</i> Lindl. (5), <i>Taeniophyllum</i> Blume (2), <i>Tainia</i> Blume (2), <i>Thelasis</i> Blume (1), <i>Thrixspermum</i> Lour. (2), <i>Thunia</i> Rehb. f. (1), <i>Trichoglottis</i> Blume (1), <i>Tropidia</i> Lindl. (2), <i>Uncifera</i> Lindl. (1), <i>Vanda</i> R. Br. (4), <i>Vandopsis</i> Pfitzer (2), <i>Vanilla</i> Plum. ex Mill. (1), <i>Zeuxine</i> Lindl. (3)
Orobanchaceae (1)	<i>Aeginetia</i> L. (1)
Oxalidaceae (3)	<i>Averrhoa</i> L. (1), <i>Biophytum</i> DC. (3), <i>Oxalis</i> L. (1)
Pandanaceae (1)	<i>Pandanus</i> Parkinson (1)
Papaveraceae (1)	<i>Argemone</i> L. (1)
Passifloraceae (2)	<i>Adenia</i> Forssk. (2), <i>Passiflora</i> L. (4)
Pinaceae (1)	<i>Pinus</i> L. (1)
Piperaceae (3)	<i>Peperomia</i> Ruiz & Pav. (5), <i>Piper</i> L. (27), <i>Zippelia</i> Blume (1)
Pittosporaceae (1)	<i>Pittosporum</i> Banks ex Gaertn. (6)
Plantaginaceae (1)	<i>Plantago</i> L. (3)
Poaceae (63)	<i>Acroceras</i> Stapf (1), <i>Apluda</i> L. (1), <i>Arthraxon</i> P. Beauv. (1), <i>Arundinella</i> Raddi (2), <i>Arundo</i> L. (1), <i>Bambusa</i> Schreb. (3), <i>Bothriochloa</i> Kuntze (1), <i>Brachiaria</i> (Trin.) Griseb. (1), <i>Centotheca</i> Desv. (1), <i>Cephalostachyum</i> Munro (2), <i>Chimonobambusa</i> Makino (2), <i>Chloris</i> Sw. (1), <i>Chrysopogon</i> Trin. (1), <i>Coix</i> L. (1), <i>Cymbopogon</i> Spreng. (2), <i>Cynodon</i> Rich. (2), <i>Cyrtococcum</i> Stapf (1), <i>Dendrocalamus</i> Nees (20), <i>Digitaria</i> Haller (4), <i>Echinochloa</i> P. Beauv. (2), <i>Eleusine</i> Gaertn. (2), <i>Eragrostis</i> Wolf (6), <i>Erianthus</i> Michx. (1), <i>Eriochloa</i> Kunth (1), <i>Fargesia</i> Franch. (1), <i>Gigantochloa</i> Kurz ex Munro (6), <i>Hackelochloa</i> Kuntze (1), <i>Hymenachne</i> P. Beauv. (1), <i>Hyparrhenia</i> Andersson ex E. Fourn. (1), <i>Imperata</i> Cirillo (1), <i>Indosasa</i> McClure (3), <i>Isachne</i> R. Br. (1), <i>Ischaemum</i> L. (1), <i>Leptochloa</i> P. Beauv. (1), <i>Lophatherum</i> Brongn. (1), <i>Melocalamus</i> Benth. (3), <i>Microstegium</i> Nees (1), <i>Miscanthus</i> Andersson (1), <i>Neyraudia</i> Hook. f. (1), <i>Oplismenus</i> P. Beauv. (2), <i>Oryza</i> L. (2), <i>Panicum</i> L. (3), <i>Paspalidium</i> Stapf (1), <i>Paspalum</i> L. (5), <i>Phyllostachys</i> Siebold & Zucc. (3), <i>Pleioblastus</i> Nakai (1), <i>Poa</i> L. (1), <i>Pogonatherum</i> P. Beauv. (1), <i>Pseudechinolaena</i> Stapf (1), <i>Pseudostachyum</i> Munro (1), <i>Rottboellia</i> L. f. (1), <i>Saccharum</i> L. (2), <i>Sacciolepis</i> Nash (3), <i>Schizostachyum</i> Nees (3), <i>Setaria</i> P. Beauv. (4), <i>Sorghum</i> Moench (2), <i>Sporobolus</i> R. Br. (1), <i>Stenotaphrum</i> Trin. (1), <i>Themeda</i> Forssk. (5), <i>Thyrsostachys</i> Gamble (2), <i>Thysanolaena</i> Nees (1), <i>Urochloa</i> P. Beauv. (1), <i>Yushania</i> Keng f. (1)
Podocarpaceae (3)	<i>Dacrycarpus</i> (Endl.) de Laub. (1), <i>Nageia</i> Gaertn. (2), <i>Podocarpus</i> L'Hér. ex Pers. (1)
Podostemaceae (2)	<i>Cladopus</i> H. Möller (1), <i>Hydrobryum</i> Endl. (1)
Polygalaceae (4)	<i>Polygala</i> L. (13), <i>Salomonina</i> Lour. (4), <i>Securidaca</i> L. (1), <i>Xanthophyllum</i> Roxb. (2)
Polygonaceae (4)	<i>Fagopyrum</i> Mill. (1), <i>Polygonum</i> L. (16), <i>Reynoutria</i> Houtt. (1), <i>Rumex</i> L. (1)
Pontederiaceae (1)	<i>Monochoria</i> C. Presl (3)
Portulacaceae (2)	<i>Portulaca</i> L. (1), <i>Talinum</i> Adans. (1)
Potamogetonaceae (1)	<i>Potamogeton</i> L. (2)
Primulaceae (1)	<i>Lysimachia</i> L. (9)
Proteaceae (2)	<i>Helicia</i> Lour. (6), <i>Heliciopsis</i> Sleumer (2)
Rafflesiaceae (1)	<i>Sapria</i> Griff. (1)
Ranunculaceae (4)	<i>Anemone</i> L. (2), <i>Clematis</i> L. (9), <i>Naravelia</i> Adans. (1), <i>Ranunculus</i> L. (2)
Rhamnaceae (9)	<i>Berchemia</i> Neck ex DC. (3), <i>Chaydaia</i> Pit. (1), <i>Gouania</i> Jacq. (4), <i>Hovenia</i> Thunb. (1), <i>Rhamnus</i> L. (2), <i>Sageretia</i> Brongn. (2), <i>Scutia</i> (Comm. ex A. DC.) Brongn. (1), <i>Ventilago</i> Gaertn. (5), <i>Ziziphus</i> Mill. (6)

APPENDIX 1. Continued.

Families	Genera
Rhizophoraceae (2)	<i>Carallia</i> Roxb. (1), <i>Pellacalyx</i> Korth. (1)
Rosaceae (18)	<i>Agrimonia</i> L. (2), <i>Cerasus</i> Mill. (1), <i>Chaenomeles</i> Lindl. (1), <i>Dichotomanthes</i> Kurz (1), <i>Docynia</i> Decne. (1), <i>Duchesnea</i> Sm. (2), <i>Eriobotrya</i> Lindl. (2), <i>Laurocerasus</i> Duhamel (4), <i>Neillia</i> D. Don (1), <i>Photinia</i> Lindl. (5), <i>Potentilla</i> L. (3), <i>Pygeum</i> Gaertn. (3), <i>Pyracantha</i> M. Roem. (1), <i>Pyrus</i> L. (2), <i>Rosa</i> L. (1), <i>Rubus</i> L. (10), <i>Sorbus</i> L. (5), <i>Stranvaesia</i> Lindl. (1)
Rubiaceae (45)	<i>Aidia</i> Lour. (2), <i>Borreria</i> G. Mey. (1), <i>Brachytome</i> Hook. f. (2), <i>Canthium</i> Lam. (3), <i>Cephalanthus</i> L. (1), <i>Chassalia</i> DC. (1), <i>Dentella</i> J. R. Forst. & G. Forst. (1), <i>Diplospora</i> DC. (2), <i>Duperrea</i> Pierre ex Pit. (1), <i>Gardenia</i> J. Ellis (1), <i>Geophila</i> D. Don (1), <i>Hedyotis</i> L. (14), <i>Hymenodictyon</i> Wall. (3), <i>Hypitanthus</i> Wight & Arn. (1), <i>Ixora</i> L. (6), <i>Knoxia</i> L. (1), <i>Lasianthus</i> Jack (12), <i>Litosanthes</i> Blume (1), <i>Metadina</i> Bakh. f. (1), <i>Mitragyna</i> Korth. (1), <i>Morinda</i> L. (3), <i>Mussaenda</i> L. (7), <i>Mycetia</i> Reinw. (9), <i>Myrioneuron</i> R. Br. ex Kurz (1), <i>Neanotis</i> W. H. Lewis (4), <i>Neolamarckia</i> Bosser (1), <i>Neonauclea</i> Merr. (3), <i>Ophiorrhiza</i> L. (13), <i>Oxyceros</i> Lour. (3), <i>Paederia</i> L. (2), <i>Paetia</i> L. (4), <i>Prismatomeris</i> Thwaites (1), <i>Psychotria</i> L. (6), <i>Randia</i> L. (1), <i>Rubia</i> L. (2), <i>Saprosma</i> Blume (1), <i>Schizomussaenda</i> H. L. Li (1), <i>Sinoadina</i> Ridsdale (1), <i>Spiradiclis</i> Blume (2), <i>Tarenna</i> Gaertn. (1), <i>Tarennoidea</i> Tirveng. & Sastre (2), <i>Uncaria</i> Schreb. (5), <i>Urophyllum</i> Jack ex Wall. (1), <i>Wendlandia</i> Bartl. ex DC. (11), <i>Xeromphis</i> Raf. (1)
Rutaceae (14)	<i>Acronychia</i> J. R. Forst. & G. Forst. (1), <i>Atalantia</i> Corrêa (1), <i>Boenninghausenia</i> Rehb. ex Meisn. (1), <i>Citrus</i> L. (1), <i>Clausena</i> Burm. f. (5), <i>Euodia</i> J. R. Forst. & G. Forst. (8), <i>Fortunella</i> Swingle (1), <i>Glycosmis</i> Corrêa (6), <i>Micromelum</i> Blume (3), <i>Murraya</i> J. König ex L. (2), <i>Paramignya</i> Wight (1), <i>Skimmia</i> Thunb. (1), <i>Toddalia</i> Juss. (1), <i>Zanthoxylum</i> L. (8)
Sabiaceae (2)	<i>Meliosma</i> Blume (5), <i>Sabia</i> Colebr. (3)
Salicaceae (1)	<i>Salix</i> L. (1)
Santalaceae (5)	<i>Dendrotrophe</i> Miq. (1), <i>Osyris</i> L. (1), <i>Phacellaria</i> Benth. (2), <i>Pyrularia</i> Michx. (1), <i>Scleropyrum</i> Arn. (1)
Sapindaceae (11)	<i>Allophylus</i> L. (3), <i>Arytera</i> Blume (1), <i>Cardiospermum</i> L. (1), <i>Dodonaea</i> Mill. (1), <i>Harpullia</i> Roxb. (1), <i>Litchi</i> Sonn. (1), <i>Mischocarpus</i> Blume (1), <i>Nephelium</i> L. (1), <i>Pometia</i> J. R. Forst. & G. Forst. (1), <i>Sapindus</i> L. (1), <i>Xerospermum</i> Blume (1)
Sapotaceae (3)	<i>Pouteria</i> Aubl. (1), <i>Sarcosperma</i> Hook. f. (4), <i>Xantolis</i> Raf. (3)
Saururaceae (2)	<i>Houttuynia</i> Thunb. (1), <i>Saururus</i> L. (1)
Saxifragaceae (3)	<i>Bergenia</i> Moench (1), <i>Itea</i> L. (2), <i>Tiarella</i> L. (1)
Scrophulariaceae (15)	<i>Adenosma</i> R. Br. (3), <i>Alectra</i> Thunb. (1), <i>Bacopa</i> Aubl. (1), <i>Brandisia</i> Hook. f. & Thomson (2), <i>Centranthera</i> R. Br. (2), <i>Dopatrium</i> Buch.-Ham. ex Benth. (1), <i>Limnophila</i> R. Br. (4), <i>Lindenbergia</i> Lehm. (2), <i>Lindernia</i> All. (10), <i>Mazus</i> Lour. (1), <i>Microcarpaea</i> R. Br. (1), <i>Picria</i> Lour. (1), <i>Torenia</i> L. (2), <i>Veronica</i> L. (1), <i>Wightia</i> Wall. (1)
Simaroubaceae (3)	<i>Ailanthus</i> Desf. (2), <i>Brucea</i> J. F. Mill. (2), <i>Picrasma</i> Blume (1)
Smilacaceae (1)	<i>Smilax</i> L. (15)
Solanaceae (4)	<i>Lycianthes</i> (Dunal) Hassl. (6), <i>Nicandra</i> Adans. (1), <i>Physalis</i> L. (2), <i>Solanum</i> L. (15)
Sonneratiaceae (1)	<i>Duabanga</i> Buch.-Ham. (1)
Sparganiaceae (1)	<i>Sparganium</i> L. (1)
Sphenocleaceae (1)	<i>Sphenoclea</i> Gaertn. (1)
Stachyuraceae (1)	<i>Stachyurus</i> Siebold & Zucc. (1)
Staphyleaceae (2)	<i>Tapiscia</i> Oliv. (1), <i>Turpinia</i> Vent. (4)
Stemonaceae (1)	<i>Stemona</i> Lour. (2)
Sterculiaceae (12)	<i>Ambroma</i> L. f. (1), <i>Byttneria</i> Loebl. (3), <i>Eriolaena</i> DC. (4), <i>Erythropsis</i> Lindl. ex Schott & Endl. (2), <i>Helicteres</i> L. (6), <i>Heritiera</i> Aiton (1), <i>Melochia</i> L. (1), <i>Pterospermum</i> Schreb. (5), <i>Pterygota</i> Schott & Endl. (1), <i>Reevesia</i> Lindl. (3), <i>Sterculia</i> L. (5), <i>Waltheria</i> L. (1)
Stylidiaceae (1)	<i>Stylidium</i> Sw. ex Willd. (1)
Styracaceae (4)	<i>Alniphyllum</i> Matsum. (1), <i>Bruinsmia</i> Boerl. & Koord. (1), <i>Huodendron</i> Rehder (1), <i>Styrax</i> L. (4)
Symplocaceae (1)	<i>Symplocos</i> Jacq. (9)
Taccaceae (1)	<i>Tacca</i> J. R. Forst. & G. Forst. (1)
Theaceae (9)	<i>Adinandra</i> Jack (1), <i>Anneslea</i> Wall. (1), <i>Camellia</i> L. (6), <i>Eurya</i> Thunb. (5), <i>Gordonia</i> J. Ellis (1), <i>Pyrenaria</i> Blume (3), <i>Schima</i> Reinw. ex Blume (2), <i>Sladenia</i> Kurz (1), <i>Ternstroemia</i> Mutis ex L. f. (2)
Thymelaeaceae (2)	<i>Aquilaria</i> Lam. (1), <i>Erioseola</i> Blume (1)
Tiliaceae (5)	<i>Colona</i> Cav. (2), <i>Corchorus</i> L. (3), <i>Grewia</i> L. (6), <i>Microcos</i> L. (2), <i>Triumfetta</i> L. (4)
Trapaceae (1)	<i>Trapa</i> L. (1)
Ulmaceae (5)	<i>Aphananthe</i> Planch. (2), <i>Celtis</i> L. (3), <i>Gironniera</i> Gaudich. (1), <i>Trema</i> Lour. (3), <i>Ulmus</i> L. (1)

APPENDIX 1. Continued.	
Families	Genera
Urticaceae (14)	<i>Boehmeria</i> Jacq. (13), <i>Debregeasia</i> Gaudich. (4), <i>Dendrocnide</i> Miq. (3), <i>Elatostema</i> J. R. Forst. & G. Forst. (14), <i>Girardinia</i> Gaudich. (1), <i>Gonostegia</i> Turcz. (1), <i>Maoutia</i> Wedd. (1), <i>Oreocnide</i> Miq. (3), <i>Pellionia</i> Gaudich. (6), <i>Pilea</i> Lindl. (17), <i>Poikilospermum</i> Zipp. ex Miq. (2), <i>Pouzolzia</i> Gaudich. (4), <i>Procris</i> Comm. ex Juss. (1), <i>Urtica</i> L. (2)
Valerianaceae (1)	<i>Triplostegia</i> Wall. ex DC. (1)
Verbenaceae (11)	<i>Callicarpa</i> L. (11), <i>Caryopteris</i> Bunge (1), <i>Clerodendrum</i> L. (14), <i>Congee</i> Roxb. (2), <i>Garrettia</i> H. R. Fletcher (1), <i>Gmelina</i> L. (1), <i>Phyla</i> Lour. (1), <i>Premna</i> L. (8), <i>Sphenodesme</i> Jack (1), <i>Symphorema</i> Roxb. (1), <i>Vitex</i> L. (7)
Violaceae (1)	<i>Viola</i> L. (9)
Viscaceae (2)	<i>Korthalsella</i> Tiegh. (1), <i>Viscum</i> L. (6)
Vitaceae (7)	<i>Ampelopsis</i> Michx. (4), <i>Cayratia</i> Juss. (4), <i>Cissus</i> L. (9), <i>Leea</i> D. Royen ex L. (7), <i>Tetrastigma</i> (Miq.) Planch. (16), <i>Vitis</i> L. (4), <i>Yua</i> C. L. Li (1)
Xyridaceae (1)	<i>Xyris</i> L. (2)
Zingiberaceae (17)	<i>Alpinia</i> Roxb. (11), <i>Amomum</i> Roxb. (14), <i>Boesenbergia</i> Kuntze (1), <i>Cautleya</i> Hook. f. (1), <i>Costus</i> L. (3), <i>Curcuma</i> L. (9), <i>Curcumorpha</i> A. S. Rao & D. M. Verma (1), <i>Etilingera</i> Giseke (1), <i>Globba</i> L. (4), <i>Hedychium</i> J. König (7), <i>Kaempferia</i> L. (3), <i>Paramomum</i> S. Q. Tong (1), <i>Pommerneschea</i> Wittm. (2), <i>Rhynchanthus</i> Hook. f. (1), <i>Siliquamomum</i> Baill. (1), <i>Stahlianthus</i> Kuntze (1), <i>Zingiber</i> Mill. (11)
Zygophyllaceae (1)	<i>Tribulus</i> L. (1)

Short Communication

Advances in biogeography of the tropical rain forest in southern Yunnan, southwestern China

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Abstract

The tropical rainforest of southern Yunnan, which is similar to the equatorial rainforest of Asia in floristic composition and physiognomy, is a type of tropical Asian rainforest. Its tropical floristic elements contribute more than 90% at the generic level and more than 80% at the specific level to the total flora. Those of typical tropical Asian distribution contribute about 75% of the species. Occurring at the northern edge of the tropical zone (up to 24°40' N), the tropical rainforest of Yunnan differs from the equatorial rainforest in having deciduous trees in the canopy layer and fewer megaphanerophytes and epiphytes, but more abundant lianas as well as more plants with microphyllous leaves. It is suggested that the tropical rainforest did not emerge until the late Tertiary in the region, and that the rainforest is more dependent on topography and local habitats than on the regional climate.

Key words: Tropical rain forest, plant diversity, biogeography, southern Yunnan, China

摘要

中国云南的热带雨林具有与亚洲赤道热带雨林类似的生态外貌特征和植物区系组成, 是热带亚洲雨林的一个类型. 云南的热带雨林中有多于90%的属和多于80%的种为热带植物区系成分, 其中约75%的种为热带亚洲成分. 由于发生在季风热带北缘山地(up to 24°40' N), 云南热带雨林在其林冠层中有落叶树种存在, 大高位芽植物和附生植物较逊色而藤本植物和在叶级谱上的小叶植物更丰富, 这些特征又有别于赤道低地的热带雨林. 云南热带雨林是在晚第三纪以后才发展起来, 它们的分布主要受制于局部生境, 并非地区性气候条件.

关键词: 云南 热带雨林 生物地理

Received: 16 January, 2008, Accepted: 18 February, 2008, Published: 3 March, 2008

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Cite this paper as: Zhu Hua. 2008. Advances in biogeography of the tropical rain forest in southern Yunnan, southwestern China. *Tropical Conservation Science* 1(1):34-42. Available online: tropicalconservationscience.org.

Introduction

The tropical area of southern China located at the northern edge of tropical Asia, including southeastern Xizang (Tibet), southern Yunnan, southwestern Guangxi, southern Taiwan and Hainan Island between 86° and 123° E, 18°21' and 24°40' N with a disjunct site at c. 29° N in southeastern Xizang [1]. The largest tropical area still covered by forests is in southern Yunnan.

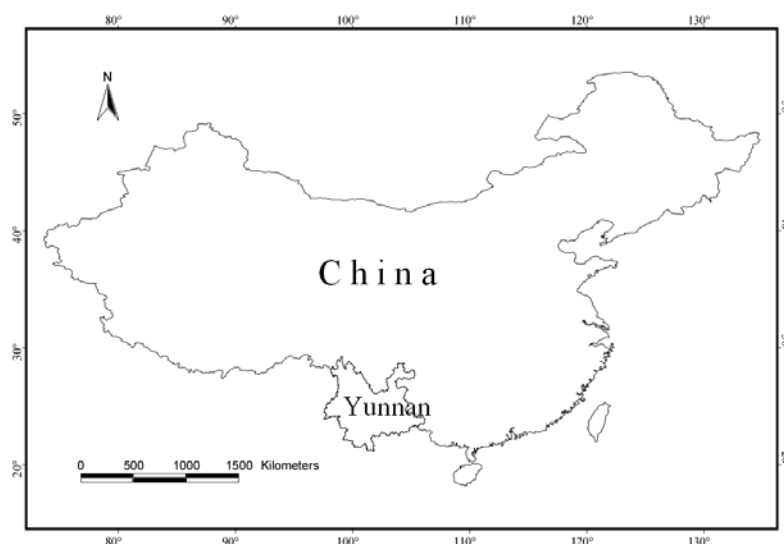


Fig. 1. Province of Yunnan, China

The tropical areas in southern Yunnan are those of valleys and lower montane generally below 900 m asl. between 21°01' and 24°40' N [2]. The main tropical rainforests of the world are in tropical lowlands with a mean annual temperature generally more than 24°C and mean annual rainfall of more than 2,000 mm [3]. By comparison, the tropical area of southern Yunnan is at a higher latitude (500-900 m asl.) with relatively lower annual mean temperature (c. 22°C) and lower annual mean precipitation (1,500 mm). The tropical forests in southern Yunnan were first mentioned by Wang in 1939 [4]. Between 1955 and 1960, these forests were surveyed by Sino-Russian expeditions and Yunnan University. It was then suggested that tropical rainforests existed in southern Yunnan, but these were considered to be a type different from the ones in Indo-Malaya [5] because of the lack of representatives of Dipterocarpaceae, which dominates the rainforests of tropical Asia. However, a dipterocarp forest was found in southernmost Yunnan in the 1970s, which indicated that the Indo-Malayan tropical rainforest existed in the region. It was later confirmed by Whitmore [6, 7], after a short visit to southern Yunnan, that there are true evergreen rainforests present in the southern fringes of China. Further biogeographical and ecological studies on the vegetation and flora of southern Yunnan revealed that the tropical rainforest in southern Yunnan, with physiognomic and floristic similarities to the Indo-Malayan rainforests, is a type of tropical Asian rainforest at the climatic limit of the northern edge of the tropical zone. It is identified as "tropical seasonal rainforest" [8-16].

Physiognomy and species diversity of the tropical rain forest in southern Yunnan

The tropical seasonal rainforest in southern Yunnan, occurring on lower montane and valleys between 500-900 m asl., has a profile of three tree layers, of which the top layer is composed of emergent trees, and the second layer is the main canopy with the most density of individuals. This is the typical profile of equatorial lowland rainforests [17, 18]. In life forms, phanerophytes contribute 87.5-89.7% of the total species in the tropical seasonal rainforest. Of these, liana phanerophytes contribute 18.3-20.3%, megaphanerophytes 7.2-9.7%, mesophanerophytes 27-28%, microphanerophytes 12-15%, nanophanerophytes 8.3-9.7%, and herbaceous phanerophytes 4.2-4.6%. In leaf-scale spectra, mesophyllous leaves make up 71%, microphyllous leaves 20-23%, and macrophyllous leaves 5.5-7.5% of the total woody plants. In leaf types, compound leaves make up 21.4-24.5% of the total tree species [19].

In species diversity, 150-200 vascular plant species were recorded from a single sampling plot based on 10 sampling plots of 0.25 ha, of which 44-63 species were trees (if saplings and seedlings are included, it was 80-90 species), 30-40 species were lianas, 15-20 species were herbaceous plants, and 5-20 were epiphytes [20]. Shannon-Wiener's diversity indexes (base : 2.718283) are 3.1594-3.599. A survey of 1 ha sampling plot yielded 150 tree species with DBH > 5 cm, and 119 species with DBH > 10 cm, respectively [15].

The long-tailed rank/abundance diagrams of the tropical seasonal rainforest indicate that the species with small population sizes make up an unusually large proportion of the total species composition [8, 16]. The frequency patterns also revealed that 40%-60% of tree species have only one individual, and 30%-40% of tree species two to five individuals. Fewer than 15% have 6-10 individuals and fewer than 10% have more than 10 individuals, from a 0.25 ha sampling plot [20].



Fig. 2. The tropical seasonal rain forest in southern Yunnan, China

Floristic composition and geographical elements

The families with most species richness in the tropical seasonal rainforest were ranked as Rubiaceae, Lauraceae, Annonaceae, Moraceae, Orchidaceae, Meliaceae, Vitaceae, Apocynaceae, Urticaceae, Rutaceae, Fagaceae, Acanthaceae, and Papilionaceae. Some families have only a small number of species, but they are the dominant families in phytosociological importance (dominant in individuals), such as Sapindaceae, Anacardiaceae, Burseraceae, Ebenaceae, Combretaceae, Ulmaceae, and Myrtaceae. The families Dipterocarpaceae, Barringtoniaceae, Tetrameleaceae, Myristicaceae, Guttiferae, Icacinaceae, Ixonanthaceae, and Sapotaceae have even fewer species, but have high phytosociological importance.

At the generic level, *Ficus* has the highest species richness. Other genera with high species richness include *Piper*, *Syzygium*, *Litsea*, *Lasianthus*, *Lithocarpus*, *Millettia*, *Pilea*, *Castanopsis*, and *Tetrastigma*. *Pometia*, *Terminalia*, *Antiaris*, *Girroniera*, *Pouteria*, and *Tetrameles* have fewer species but high phytosociological importance in the dominant tree layer, as do *Lasiococca*, *Garcinia*, *Mitrephora*, *Alphonsea*, *Cleidion*, *Sumbaviopsis*, and *Pittosporopsis* in the lower tree layer of the tropical seasonal rainforest.

Based on the study of the distribution patterns of Chinese genera [21] and the studies on species distribution of the flora in southern Yunnan [10], 12 distribution types at generic level and 8 distribution types at specific level were recognized in the flora of the tropical seasonal rainforest. The genera of tropical distribution contribute 94% of the total genera; of these, the genera of tropical Asian distribution have the highest percentage among all distribution types, contributing 33-42%, while the genera of pantropical distribution contribute 20-25% of the total genera. The species of strictly tropical distribution contribute 76-80% of the total flora, and of these the species of tropical Asian distribution also show the highest percentage among all distribution types of species. These data indicate that the tropical seasonal rainforest has strong tropical Asiatic affinity floristically and is a type of tropical Asian rainforest.

Comparison to tropical rain forests in equatorial Asia

The tropical seasonal rainforest in southern Yunnan, which is similar to equatorial Asian lowland rainforests in profile, life-form spectra and leaf-scale spectra, was classified as a type of lowland rainforest, although it occurs at mountain habitats with higher altitude [2]. It differs from the latter only in having some deciduous trees in the canopy layer, more abundant woody lianas, fewer megaphanerophytes, and a relatively higher percentage of microphylls. It is a type of semi-evergreen rainforest at altitudinal and latitudinal limits.

In species richness, the tropical seasonal rainforest of Yunnan has a relatively lower number of species per unit area than typical lowland rainforests in equatorial Asia. For example, in a 1 ha sampling area, 119 tree species with DBH > 10 cm were recorded from the tropical seasonal rainforest in southern Yunnan [15], while 214-223 tree species with DBH > 10 cm were recorded in Sarawak, Malaysia [22], 129-149 tree species in Kalimantan, Indonesia [23], and 145-184 tree species in Papua New Guinea [24].

In floristic composition, most of the dominant families from the tropical seasonal rainforest of southern Yunnan are dominant in the tropical rainforests in Malaysia. However, the tropical seasonal rainforest occurs on the margin of tropical Asia. Although tropical families and genera make up the majority of its total flora, the taxa of strictly tropical distribution are still under-represented in species richness compared to the Malaysian flora. For example, Dipterocarpaceae, Melastomaceae, Guttiferae, Myrtaceae,

Myristicaceae, and Sapotaceae, which are dominant families in the tropical rainforests in Malaysia, have fewer species or less species richness in southern Yunnan.

Geological history and factors resulting in formation of southern Yunnan rain forest

During the Tertiary, southern Yunnan was covered by a subtropical evergreen broad-leaved forest characterized by Fagaceae species, and the climate was cooler and drier than the present day [25-27]. Current distribution patterns of the vegetation in southern Yunnan, shows deciduous forests dominated by tree species such as *Anogeissus acuminata* and *Bombax ceiba* on the banks and lower mountain slopes of the Mekong valley. The forest dominated by the palm species *Livistona saribus*, which usually occurs in drier habitats, is patchily distributed on lower mountains. The usual savanna species, such as *Woodfordia fruticosa*, *Phyllanthus emblica*, *Cipadessa cinerascens*, *Lannea coromandelica*, *Bauhinia variegata*, *Grewia eriocarpa*, *Dalbergia obtusifolia*, *Helicteres angustifolia*, *Helicteris isora*, *Lagerstroemia tomentosa*, *Albizia*, *Eriolaena*, and *Acacia*, and the species that prefer dry habitats, such as *Pistacia weinmanifolia*, *Cycas*, and *Dracaena*, are frequently found in the tropical forests in southern Yunnan. These data indicate that the region did experience drier climate in the historical past [28].

The fundamental topography and climate of southern Yunnan have been strongly affected by the uplift of the Himalayas and the formation of the monsoon climate of East Asia [29]. It has been suggested that the moist tropical climate in southern Yunnan did not form until the Himalaya lifted to a certain elevation after the late Tertiary, allowing the development of the tropical rainforest in the region [2]. The Hengduan Mountains, which are situated north of southern Yunnan, form a barrier keeping out the cold air in winter, resulting, in southern Yunnan, in dense fog during the whole dry season to supplement the insufficient precipitation and in keeping the ground warm by reducing radiation cooling or long-wave effective radiation, conditions that seemed to have allowed for the presence of the tropical rain forest.

A direct land connection between mainland SE Asia and Western Malesia existed until the early Pliocene (5 million years ago) and there was no geographical barrier to natural distribution of plants between mainland Southeast Asia and Western Malesia during most of the Tertiary [30]. The geological history of Southeast Asia could explain the Malaysian floristic affinity of the tropical seasonal rainforest in southern Yunnan.



Fig. 3. Left: People of village of Yao. Right: Village and people of Dai. Southern Yunnan, China

Discussion and implications for conservation

The tropical seasonal rainforest in southern Yunnan has almost the same forest profile and physiognomic characteristics as equatorial lowland rainforests. It is undoubtedly a type of truly tropical rainforest. As the tropical seasonal rainforest occurs at the northern edge of the tropical zone and at the extreme limit of rainfall and temperature usually required by tropical rainforest, it differs from lowland rainforests in equatorial areas in having deciduous trees in the canopy layer, fewer megaphanerophytes and epiphytes, but more abundant lianas as well as more plants with microphylls. Abundant lianas could be a characteristic of rainforest in a monsoon climate. Fewer megaphanerophytes and a relatively higher percentage of microphylls may be a result of the fact that this occurs at climatic limits at the northern edge of the tropical zone and is influenced by seasonal dryness and the relatively low temperature.

The flora of the tropical seasonal rainforest consists mainly of tropical floristic elements, which contribute more than 90 % at the generic level and more than 80% at the specific level to its total flora. The most dominant floristic elements at both the generic and specific levels are the ones of tropical Asian distribution. Most of the dominant families from the tropical seasonal rainforest are also dominant in the Indo-Malayan rain forests. This reveals that the flora of the rainforest of Yunnan is of tropical nature with a strong tropical Asian affinity.

The tropical seasonal rainforest of southern Yunnan, in terms of physiognomy, is similar to the evergreen seasonal forest of the tropical America of Beard [31], or the moist evergreen type of African tropical rainforest of Hall and Swaine [32], or the Mesophyll vine forest of the Australian rainforest of Webb [33], as well as the semi-evergreen rainforest of Walter [34]. However, it is most equivalent to Whitmore's [7] semi-evergreen rainforests of Southeast Asia. The tropical seasonal rainforest in southern Yunnan nonetheless belongs to the tropical rainforest formation of Southeast Asia and is a type of semi-evergreen rainforest.

Tropical rainforests occur at c. 27°31' N in northeastern India [35] and Burma [36]. The tropical rainforest in southern Yunnan, although it is not the northernmost type of tropical rainforest, occurs really at the climatic limits of tropical rainforest due to its high altitude. The occurrence of the tropical rainforest in southern Yunnan was more influenced by local habitats and microclimates than by regional climate.



Fig. 4. Left: Village of Dai with rubber plantation behind. Right: Rubber plantation. Southern Yunnan, China

The tropical seasonal rainforest in southern Yunnan conspicuously decreased from a cover of 10.9% of the total area of the region in 1976 down to 3.6% in 2003, mainly due to rubber planting [37]. The high price of rubber has continued to promote the expansion of rubber plantations in the region (Fig. 3, 4). Rubber plantations, by replacing this unique type of tropical rainforest, are resulting in a loss of biodiversity. In the last 2,000 years, southern Yunnan reportedly has experienced six periods of climate change marked by alternating warm-wet and cool-dry conditions and 11 drought events and cold events, as well as 12 periods of fire damage [38]. Rubber is a strictly tropical species and the climatic conditions in southern Yunnan may not be suitable for its growth in the long-term, given the geological history of the area. Limiting further expansion of rubber plantations is the only way to conserve the tropical seasonal rainforest in southern Yunnan.

Acknowledgements

This project was funded by The National Natural Science Foundation of China (30570128, 30770158). I thank three anonymous reviewers very much for their important and constructive comments. I am very grateful to Tropical Conservation Science for assistance in improving the English and for other technical improvements in preparing this article.

References

- [1] Cao, M., Zhou, X. M., Warren, M., and Zhu, H. 2006. Tropical forests of Xishuangbanna, China. *Biotropica* 38(3): 306-309.
- [2] Zhu, H. 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *Journal of Biogeography* 24: 647-662.
- [3] Richards, P. W. 1996. The tropical rain forest, an ecological study. Second edition. London: Cambridge University Press.
- [4] Wang, C. W. 1939. A preliminary study of the vegetation of Yunnan. *Bulletin of the Fan Memorial Institute of Biology* 9 (2): 65-125.
- [5] Fedorov, An. A. 1958. The tropical rain forest of China (in Russian with English summary). *Botanicheskii Zhurnal S.S.S.R.* 43: 1385-1480.
- [6] Whitmore, T. C. 1982. Fleeting impressions of some Chinese rain forests. *Commonwealth Forestry Review* 61: 51-58.
- [7] Whitmore, T. C. 1984. Tropical rain forest of the far east. Second Edition, Oxford: Clarendon Press.
- [8] Zhu, H. 2004. A tropical seasonal rain forest at its altitudinal and latitudinal limits in southern Yunnan, SW China. *Gardens' Bulletin Singapore* 56: 55-72.
- [9] Zhu, H. 2006. Forest vegetation of Xishuangbanna, south China. *Forestry Studies in China* 8(2): 1-58.
- [10] Zhu, H., Wang, H., Li, B. G., and Sirirugsa, P. 2003. Biogeography and floristic affinity of the Limestone flora in southern Yunnan, China. *Annals of the Missouri Botanical Garden* 90: 444-465.
- [11] Zhu, H. and Roos, M. C. 2004. The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* 10(2): 639-648.

-
- [12] Zhu, H., Shi J. P., and Zhao, C. J. 2005. Species composition, physiognomy and plant diversity of the tropical montane evergreen broad-leaved forest in southern Yunnan. *Biodiversity and Conservation* 14: 2855-2870.
- [13] Zhu, H., Cao, M., and Hu, H. B. 2006b. Geological history, flora, and vegetation of Xishuangbanna, southern Yunnan, China. *Biotropica* 38(3): 310-317.
- [14] Zhu, H., Wang, H. and Li, B.G. 2006a. Floristic composition and biogeography of tropical montane rain forest in southern Yunnan of China. *Gardens' Bulletin Singapore* 58: 81-132.
- [15] Cao, M., Zhang, J. H., Feng, Z. L., Deng, J. W., and Deng, X. B. 1996. Tree species composition of a seasonal rain forest in Xishuangbanna, Southwest China. *Tropical Ecology* 37(2) : 183-192.
- [16] Cao, M., Zhang, J. H. 1997. Tree species diversity of tropical forest vegetation in Xishuangbanna, SW China. *Biodiversity and Conservation* 6 : 995-1006.
- [17] Robbins, R. G. 1968. The biogeography of tropical rain forest in SE Asia. In: Misra, R. and Gopal, B. (eds.) Proceedings of the Symposium in Recent Advances in Tropical Ecology. Varanasi: International Society for Tropical Ecology, Banaras Hindu University: 531-535.
- [18] Richards, P. W. 1983. The three-dimensional structure of tropical rain forest. In: Sutto, S. L. Ed. Tropical rain forest: ecology and management. Oxford: Blackwell Sci. Pub.: 3-10.
- [19] Zhu, H., Wang, H., and Li, B. G. 1998. Research on the tropical seasonal rainforest of Xishuangbanna, south Yunnan. *Guihaia* 18 (4): 37-384. (in Chinese with English abstract)
- [20] Zhu, H., Li, B. G., Wang, H., and Xu, Z. F. 1998. Species diversity of primary tropical rain forest of south Yunnan of China with special reference to sampling area. *Chinese Biodiversity* 6 (4): 241-247. (in Chinese with English abstract)
- [21] Wu, Z. Y. 1991. The areal-types of Chinese genera of seed plants. *Acta Botanica Yunnanica* Supp. 4: 1-139. (in Chinese with English abstract)
- [22] Proctor, J., Anderson, J. M., Chai, P., and Vallack, H. W. 1983. Ecological studies in four contrasting rain forests in Gunung Mulu National Park, Sarawak. I. Forest environment, structure and floristics. *Journal of Ecology* 71: 237-360.
- [23] Kartawinata, K., Abdulhadi, R., and Partomihardjo, T. 1981. Composition and structure of a lowland dipterocarp forest at Wanariset, East Kalimantan. *Malayan Forester* 44: 397-406.
- [24] Pajmians, K. 1970. An analysis of four tropical rain forest sites in New Guinea. *Journal of Ecology* 58 (1): 77-101.
- [25] Liu, J. L., Tan, L. Y., Qiao, Y., Head, M. J., and Walker, D. 1986. Late Quaternary vegetation history at Menghai, Yunnan province, southwest China. *Journal of Biogeography* 13: 399-418.
- [26] Penny, D. 2001. A 40,000 year palynological record from north-east Thailand; implications for biogeography and palaeo-environmental reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology* 171: 97-128.
- [27] Mehrotra, R. C., Liu, X. Q., Li, C. S., Wang, Y. F., and Chauhan, M.S. 2005. Comparison of the Tertiary flora of southwest China and northeast India and its significance in the antiquity of the modern Himalayan flora. *Review of Palaeobotany and Palynology* 135: 146-163.
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- [28] Zhu, H. and Cai, L. 2005. Biogeography of the tropical rain forest of Yunnan and some implications to geographical history. *Advance in Earth Sciences* 20 suppl.: 1-57. (in Chinese with English abstract).
- [29] Shi, Y. F., Li, J. Y., Li, B. Y., Yao, T. D., Wang, S. M., Li, S. J., Tsui, Z. J., Wang, F. B., Pan, B. T., Fang, X. M., and Zhang, Q. S. 1999. Uplift of the Qinghai-Xizang (Tibetan) plateau and east Asia environmental change during late Cenozoic. *Acta Geographica Sinica* 54 (1): 10-21. (in Chinese with English abstract)
- [30] Morley, J. R. 1998 Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate. In: Hall, R. and Holloway, J. D. ed. *Biogeography and Geological Evolution of SE Asia*. Leiden: Backbuys Publishers: 221-234.
- [31] Beard, J. S. 1955. The classification of tropical American vegetation types. *Ecology* 36: 359-412.
- [32] Hall, J. B., Swaine, M. D. 1976. Classification and ecology of closed-canopy forest in Ghana. *Journal of Ecology* 64: 913-953.
- [33] Webb, L. J. 1959. A physiognomic classification of Australian rain forests. *Journal of Ecology* 47: 551-570.
- [34] Walter, H. 1971. Ecology of tropical and subtropical vegetation. Edinburgh: Oliver & Boyd.: 207-236.
- [35] Proctor, J., Haridasan, K., and Smith, G. W. 1998. How far north does lowland evergreen tropical rain forest go? *Global Ecology and Biogeography Letters* 7: 141-146.
- [36] Kingdon-Ward, F. 1945. A sketch of the botany and geography of north Burma. *Journal of Bombay Natural History Society* 45: 16-30.
- [37] Li, H. M., Aide, T. M., Ma, Y. X., Liu, W. J., and Cao, M. 2007. Demand for rubber is causing the loss of high diversity rain forest in SW China. *Biodiversity and Conservation* 16: 1731-1745.
- [38] Gu, Y. H., Deborah, M. P., Xie, S. C., and Yu, J. X. 2007. Vegetation and fire history of a Chinese site in southern tropical Xishuangbanna derived from phytolith and charcoal records from Holocene sediments. *Journal of Biogeography* Online early Articles.

Species Composition and Biogeography of Tropical Montane Rain Forest in Southern Yunnan of China

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Abstract

The species composition, physiognomy and biogeography of tropical montane rain forest in southern Yunnan, SW China, have been studied based on data from 10 sampling plots and a complete floristic inventory. Two separate communities are recognized: a *Mastixia euonymoides*-*Phoebe megacalyx* forest and a *Parakmeria yunnanensis*-*Gymnanthes remota* forest based mainly on species composition and forest structures. The tropical montane rain forest is characterized by evergreen meso-phanerophytes and micro-phanerophytes with simple, leathery and entire mesophyllous leaves, more or less frequent woody lianas and epiphytes, abundant herbaceous phanerophytes. However, it has few buttresses or cauliflory in physiognomy. The montane rain forest has similar species diversity to the lowland seasonal rain forest in the region. This indicates that species richness is not necessarily reduced with increasing altitude. We suggest this rain forest is a type of lower montane rain forest based mainly on its physiognomy, structure and floristics, but one that occurs at a higher altitude than those in equatorial SE Asia. The montane rain forest is dominated, in terms of species richness, by Lauraceae, Euphorbiaceae, Fagaceae, Theaceae, Rubiaceae and Papilionaceae, but by Lauraceae, Magnoliaceae, Euphorbiaceae, Fagaceae, Mastixiaceae and Nyssaceae in terms of phytosociological importance. In floristic composition, a total of 623 native species in 327 genera and 115 families of seed plants were recorded from the montane rain forest, of which recognizably 'tropical' elements contributed about 78.9% at the generic level and more than 80% at the specific level. Plants of tropical Asian distribution contribute 63.7% of the total sum of species. We conclude that the montane rain forest has strong tropical Asian affinities floristically even though it occurs at the northern margin of mainland SE Asia and at a higher altitude.

Introduction

Southern Yunnan in southwestern China is exceptionally interesting to botanists because of its diversified biota and unique geological-biogeographical history. The region is the most species rich and has the largest tropical-subtropical forest cover in southern China. The region is at a transitional zone between tropical Southeast Asia and subtropical East Asia geographically, and is also supposed to be a conjunction area between the Shan-Tai fragment of Gondwanaland and the southeastern margin of the Asian continent geologically (Fortey et al., 1998, Metcalfe, 1998). Accordingly southern Yunnan is a key area in biogeography as well as being a global 'hot spot' for biodiversity (Myers, 1998).

The vegetation of southern Yunnan was mentioned, albeit briefly, for the first time by C.W. Wang in 1939 (Wang, 1939), but little was known until late 1950s because of poor access. Studies on the tropical forests in southern Yunnan have been done although little has been published in English (Zhu, 1992, 1993; Wu, 1987; Jin, 1997; Cao, 1996; Cao & Zhang, 1997; Zhu, 1997; Zhu et al., 1998a, 1998b, 2003, 2004; Zhu & Roos, 2004). Previous work on the forest in southern Yunnan has been restricted, largely, to the tropical rain forests at lowland sites below 900 m above sea level. The tropical montane rain forests are still poorly known (but see the descriptive works of Wu, 1987; Wang et al., 2001; Zhu et al., 2004).

Pristine montane rain forests were discovered recently at Mengsong in southern Yunnan, in the border between Myanmar and Yunnan (Wang et al., 2001). The montane rain forests occur in valleys and on some mountain slopes between 1500-1800 m and are a type of 'lower montane rain forest' according to Ashton's (2003) categorization of altitudinal forest zonation in Southeastern Asia.

Montane forests and their altitudinal zonation in tropical southeastern Asia have been studied by a great many authors since Brown (1919). The more important of these include Steenis (1935, 1984), Whitmore & Burnham (1969), Whitmore (1984), Ohsawa et al. (1985), Ohsawa (1991, 1993, 1995), Kitayama (1992), Nakashizuka (1992), Pendry & Proctor (1996), Aiba & Kitayama (1999), Buot & Okitsu (1999) and Ashton (2003). It has been accepted, commonly, that there is an ecotone between the tropical lowland forest and lower montane forest with changes in physiognomic, structural and floristic attributes, occurring usually between 900-1200 m altitude. The montane rain forest in southern Yunnan occurs at much higher altitudes on the northern margin of tropical Southeast Asia. Its physiognomy, floristics and biogeography are accordingly of special interest.

Site Description

Southern Yunnan is located in the southernmost part of Mainland China (**Figure 1**). It borders Myanmar and Laos, and has a mountainous topography with the mountain ridges running in a north-south direction and becoming lower in elevation southward. Altitude ranges from 480 m at the bottom of the lowest valley in the south (Mekong River) to 2429.5 m at the top of the highest mountain in the north. The Mekong River traverses the region from northwest to southeast (Xu & Jiang, 1987).

Mengsong is an administrative district in the west of southern Yunnan occupied by Hani people, an indigenous ethnic group. It is located in the border between Myanmar and Yunnan. Topographically it is a high basin surrounded by mountains, and varies in altitude from 1557 m within the basin to 2100 m at the top of the surrounding mountains. The region has a monsoon climate. From our climatic observation at 1600 m elevation, the mean annual temperature is 16.7 °C; the extreme minimum air temperature is 1.7 °C, the maximum air temperature 28.5 °C, and the annual temperature accumulation (the sum of daily temperature means of > 10 °C) 6083 °C. The mean annual precipitation is between 1800 and 2379 mm. More than 80% of the precipitation falls during the rainy season between May and the end of October, and the annual mean relative humidity is 83.4%.

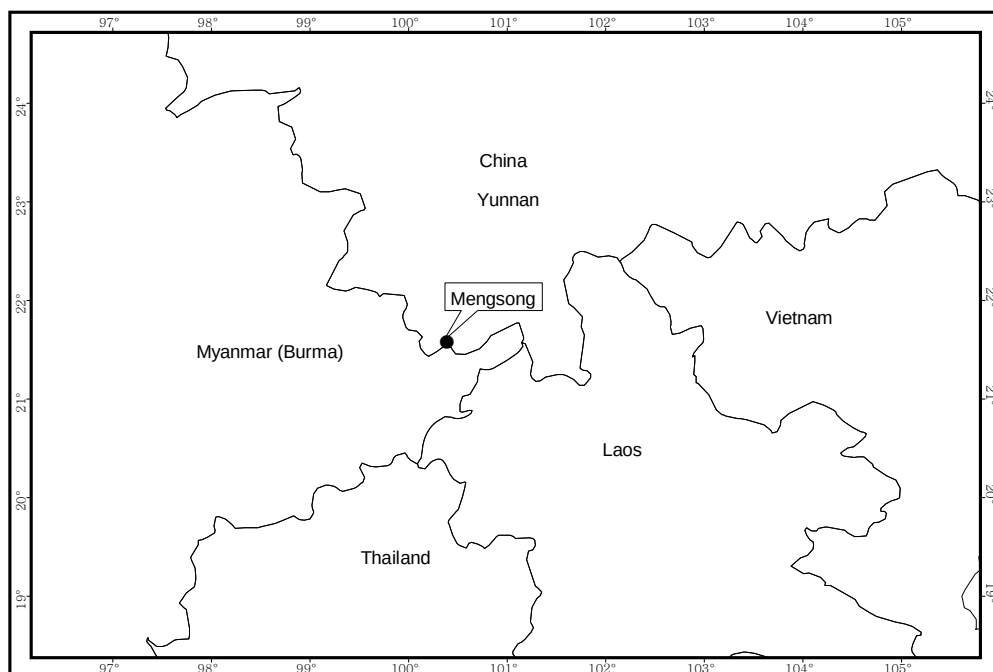


Figure 1 Map showing the location of Mengsong region in Xishuangbanna, southern Yunnan.

Methodology

The study was conducted in two stages: First, there was a general, landscape-scale, floristic inventory of the tropical montane rain forest in Mengsong, in which all plant species in the forest were recorded and specimens collected whenever possible. When habitat-related floristic variation had been identified, a systematic plot-based study was carried out. Five sampling plots each 25×20 m in size were established in each assemblage in order to characterize floristic variation. All trees in these plots were identified and their d.b.h. (minimum 5 cm), height and crown cover measured. In each plot, five 5×5 m sub-plots were established to facilitate floristic survey of the understorey. In these sub-plots, saplings, shrubs and herbaceous plants were counted. Lianas in these plots were identified and their abundance estimated. The importance value index (IVI) suggested by Curtis and McIntosh (1951) was calculated. Physiognomy (life forms and leaf sizes) was analyzed using Raunkiaer's criteria (1934) as revised by Mueller-Dombois and Ellenberg (1974). Webb (1959) split off the lower end of Raunkiaer's big mesophyll class ($2025 - 18225 \text{ mm}^2$) as notophylls ($2025 - 4500 \text{ mm}^2$), which is to be preferred for detailed categorization of leaf size spectrum. Nevertheless, Chinese botanists and their local audiences are familiar with Raunkiaer's big mesophyll class. Accordingly we retain the big mesophyll class of Raunkiaer in this analysis.

Based on intensive floristic inventory of the forest, a more or less complete species list has been compiled, from which the floristics and geographical elements have been analyzed. Physiognomic comparisons between the montane rain forest and lowland rain forests in southern Yunnan and the equatorial tropics, and other montane rain forests in southeastern Asia have been made to demonstrate further the characteristics of the Yunnan montane rain forests. Specimens were identified and voucher material is lodged in the herbarium of Xishuangbanna Tropical Botanical Garden (HITBC). Species authorities follow "Flora of China"

Results

The vegetation

Based mainly on their habitats, species composition and forest profiles, we have divided the vegetation of the montane rain forest into two distinct assemblages which we name based on their dominant and subdominant species, viz.:

1 *Mastixia euonymoides*- *Phoebe megacalyx* forest2 *Parakmeria yunnanensis*- *Gymnanthes remota* forest*Mastixia euonymoides*- *Phoebe megacalyx* forest ('ME-PM')

The ME-PM forest occurs mainly in wetter montane valleys. The forest has usually two tree layers. The upper layer is up to 35 m high with a crown cover of 70-80%, and is dominated by *M. euonymoides*, *Manglietia hookeri*, *Michelia cavaleriei* and *Nyssa wenshanensis* var. *longipedunculata*. In some sites *M. euonymoides* grew sufficiently tall as to be considered as emergents. The lower tree layer was further divided into two sub-layers in some sites. The upper sub-layer was 10-20 m high with a crown cover of 60-70%, and was dominated by *Phoebe megacalyx*, *Syzygium brachythyrsum* and *Dysoxylum binectariferum*. The lower sub-layer is 5-10 m high with a cover of 40-50%. The most frequent species are *Ardisia thyrsoiflora*, *Cylindrokelupha kerrii*, *Ostodes kuangii* and *Brassaiopsis lepidota* (see **Appended Table 1**).

The shrub layer is up to 1-5 m high and is dominated by juvenile trees. The most frequent shrub species are *Psychotria symplocifolia*, *Brassaiopsis fatsioides*, *Mycetia gracilis*, *Brachytome hirtellata* var. *glabrescens* and *Oxyspora vagans*.

The herbaceous layer is well developed with a cover of 50-70%. Frequent species are *Ophiorrhizophyllum macrobotryum*, *Allantodia dilatata*, *Ctenitopsis* sp., *Microsorium dilatatum*, *Porandra scandens*, *Rhynchotechum obovatum* and *Strobilanthes* sp.

There are a few lianas but some big woody individuals belonging to species such as *Epigynum auritum*, *Bousigonia angustifolia*, *Calamus nambariensis*, and *Gnetum montanum* are present.

Epiphytes are abundant. They include *Pothos chinensis*, *Neottopteris nidus*, *Rhaphidophora hongkongensis*, *Aeschynanthus bracteatus*, *Pholidota imbricata* and *Asplenium normale*.

Parakmeria yunnanensis- *Gymnanthes remota* forest (PY-GR)

The PY-GR forest occurs on shady slopes and the tops of hills. The forest is 25-30 m high with a very even canopy. It also has two tree layers. The upper layer with a crown cover of 80%, is dominated by *P. yunnanensis*, *Nyssa wenshanensis*, *Cinnamomum javanicum* and *Calophyllum*

polyanthum. The lower layer is at 5-20 m with a cover of 70-80%, and is dominated by *G. remota*, *Syzygium brachythyrsum*, *Xanthophyllum yunnanensis* and *Wendlandia pingpiensis* (see

Appended Table 2).

Appended Table 1. Importance values Index (IVI) of tree species in *Mastixia euonymoides*- *Phoebe megacalyx* forest.

Altitude: 1650-1780 m	Height of canopy: 35 (m)			
Plot number and size: 5 (25×20) = 2500 m ²	Coverage: > 90%			
Slope degree: 10-35	No. of sp. (>5 cm dbh): 62			
	No. of stems: 263			
Species name	RA	RF	RD	IVI*
<i>Mastixia euonymoides</i>	0.76	1.64	23.46	25.86
<i>Phoebe megacalyx</i>	9.13	4.1	6.00	19.22
<i>Syzygium brachythyrsum</i>	9.51	4.1	3.01	16.62
<i>Dysoxylum binectariferum</i>	9.51	4.1	2.35	15.95
<i>Manglietia hookeri</i>	0.38	0.82	14.14	15.34
<i>Michelia cavaleriei</i>	1.9	2.46	8.73	13.09
<i>Nyssa wenshanensis</i> var. <i>longipedunculata</i>	1.52	2.46	7.12	11.10
<i>Linociera insignis</i>	4.94	3.28	1.66	9.88
<i>Ardisia thyrsoflora</i>	4.56	4.1	0.87	9.53
<i>Cinnamomum javanicum</i>	2.66	3.28	3.21	9.15
<i>Helicia pyrrhobotrya</i>	4.18	3.28	0.58	8.05
<i>Calophyllum polyanthum</i>	2.66	3.28	1.72	7.66
<i>Ostodes kuangii</i>	3.8	2.46	1.38	7.64
<i>Xanthophyllum yunnanensis</i>	3.42	3.28	0.88	7.58
<i>Brassaiopsis lepidota</i>	2.28	2.46	1.90	6.64
<i>Cylindrokelupha kerrii</i>	3.8	2.46	0.29	6.55
<i>Cryptocarya rolletii</i>	3.04	3.28	0.17	6.49
<i>Alcimandra cathcartii</i>	1.52	2.46	2.29	6.27
<i>Litsea vang</i> var. <i>lobata</i>	1.52	3.28	0.13	4.93
<i>Litsea lancifolia</i> var. <i>pedicellata</i>	2.28	2.46	0.12	4.86
<i>Randia</i> sp.	2.66	1.64	0.52	4.82
<i>Michelia hedyosperma</i>	1.14	1.64	1.93	4.71

<i>Drypetes salicifolia</i>	0.76	1.64	2.30	4.70
<i>Hovenia acerba</i> var. <i>kiukiangensis</i>	0.76	0.82	2.82	4.40
<i>Lithocarpus hancei</i>	0.76	0.82	2.56	4.14
<i>Litsea verticillata</i>	1.52	1.64	0.03	3.19
<i>Mastixia pentandra</i> var. <i>chinensis</i>	1.14	1.64	0.28	3.06
<i>Reevesia thyrsoidea</i>	1.14	1.64	0.26	3.04
<i>Randia wallichii</i>	1.14	1.64	0.25	3.03
<i>Dimocarpus yunnanensis</i>	0.76	1.64	0.45	2.85
<i>Macaranga henryi</i>	1.52	0.82	0.17	2.51
<i>Machilus shweliensis</i>	0.38	0.82	1.27	2.47
<i>Alseodaphne andersonii</i>	0.38	0.82	0.91	2.11
<i>Litsea lancifolia</i>	0.76	0.82	0.39	1.97
<i>Walsura yunnanensis</i>	0.38	0.82	0.73	1.93
<i>Cinnamomum tamala</i>	0.76	0.82	0.27	1.85
<i>Elaeocarpus glabripetalus</i> var. <i>alata</i>	0.38	0.82	0.61	1.81
<i>Rhododendron moulmainensis</i>	0.76	0.82	0.22	1.80
<i>Alsophila costularis</i>	0.76	0.82	0.18	1.76
<i>Beilschmiedia roxburghiana</i>	0.38	0.82	0.45	1.65
<i>Alphonsea tsangyuanensis</i>	0.38	0.82	0.43	1.63
<i>Cyclobalanopsis chrysocalyx</i>	0.38	0.82	0.38	1.58
<i>Meliosma simplicifolia</i>	0.38	0.82	0.33	1.53
<i>Tapiscia yunnanensis</i>	0.38	0.82	0.28	1.48
<i>Alseodaphne pectolaris</i>	0.38	0.82	0.27	1.47
<i>Eriobotrya bengalensis</i> var. <i>angustifolia</i>	0.38	0.82	0.27	1.47
<i>Gymnanthes remota</i>	0.38	0.82	0.26	1.46
<i>Michelia floribunda</i>	0.38	0.82	0.19	1.39
<i>Diospyros kaki</i> var. <i>sylvestris</i>	0.38	0.82	0.18	1.38
<i>Laurocerasus jenkinsii</i>	0.38	0.82	0.15	1.35
<i>Nyssa wenshanensis</i>	0.38	0.82	0.14	1.34
<i>Beilschmiedia linocieroidea</i>	0.38	0.82	0.12	1.31
<i>Ficus auriculata</i>	0.38	0.82	0.09	1.29
<i>Walsura robusta</i>	0.38	0.82	0.08	1.28
<i>Artocarpus nitidus</i>	0.38	0.82	0.08	1.28
<i>Lithocarpus pseudoreinwardtii</i>	0.38	0.82	0.04	1.24

<i>Lindera latifolia</i>	0.38	0.82	0.03	1.23
<i>Oxyspora vagans</i>	0.38	0.82	0.03	1.23
<i>Litsea garretii</i>	0.38	0.82	0.02	1.22
<i>Castanopsis argyrophylla</i>	0.38	0.82	0.01	1.21
<i>Microtropis tetragona</i>	0.38	0.82	0.00	1.20
<i>Gymnosphaera gigantea</i>	0.38	0.82	0.00	1.20
Total (62 species) 263 stems	100	100	100.00	300.00

* RA: Relative abundance; RD: Relative dominance; RF: Relative frequency; IVI: Importance value index (Curtis & McIntosh, 1951)

Appended Table 2. Importance values Index (IVI) of tree species in *Parakmeria yunnanensis*-*Gymnanthes remota* forest.

Altitude: 1650-1700 m	Height of canopy: (m)			
Plot number and size: 5 (25×20) = 2500 m ²	Coverage: > 90%			
Slope degree: 5-30	No. of sp. (>5 cm dbh): 70			
	No. of stems: 293			
Species name	RA	RF	RD	IVI*
<i>Gymnanthes remota</i>	15.36	4.20	3.97	23.53
<i>Parakmeria yunnanensis</i>	1.02	2.52	11.08	14.62
<i>Xanthophyllum yunnanensis</i>	7.17	3.36	2.22	12.75
<i>Syzygium brachythyrsum</i>	7.17	3.36	1.65	12.18
<i>Wendlandia pingpiensis</i>	6.83	3.36	1.19	11.38
<i>Nyssa wenshanensis</i>	1.02	1.68	8.13	10.84
<i>Cinnamomum javanicum</i>	3.07	3.36	3.83	10.26
<i>Calophyllum polyanthum</i>	3.41	3.36	3.38	10.15
<i>Nyssa wenshanensis</i> var. <i>longipedunculata</i>	2.05	1.68	5.93	9.66
<i>Mastixia pentandra</i> subsp. <i>chinensis</i>	4.10	1.68	3.72	9.49
<i>Cyclobalanopsis chapensis</i>	3.42	2.52	3.29	9.23
<i>Manglietia insignis</i>	0.68	0.84	6.17	7.70
<i>Acer decandrum</i>	2.05	3.36	2.26	7.67
<i>Ostodes kuangii</i>	4.44	0.84	0.53	5.80
<i>Cyclobalanopsis chrysocalyx</i>	0.34	0.84	3.97	5.16

<i>Machilus shweliensis</i>	1.37	2.52	1.11	5.00
<i>Engelhardtia spicata</i>	0.34	0.84	3.78	4.96
<i>Alcimandra cathcartii</i>	0.68	1.68	2.58	4.94
<i>Michelia floribunda</i>	1.37	1.68	1.79	4.83
<i>Podocarpus neriifolius</i>	0.68	0.84	3.22	4.75
<i>Craibiodendron stellatum</i>	1.02	0.84	2.55	4.42
<i>Lithocarpus gagnepainianus</i>	1.71	0.84	1.85	4.40
<i>Dimocarpus yunnanensis</i>	2.05	1.68	0.55	4.28
<i>Gomphandra tetrandra</i>	2.73	0.84	0.69	4.26
<i>Cinnamomum bejolghota</i>	1.37	2.52	0.28	4.17
<i>Lithocarpus pseudoreinwardtii</i>	2.05	1.68	0.24	3.96
<i>Linociera ramiflora</i>	0.68	1.68	1.16	3.52
<i>Castanopsis hystrix</i>	0.34	0.84	2.24	3.43
<i>Litsea lancifolia</i>	0.34	0.84	2.21	3.39
<i>Lindera metcalfiana</i> var. <i>dictyophylla</i>	1.37	1.68	0.23	3.27
<i>Castanopsis argyrophylla</i>	0.68	0.84	1.47	2.99
<i>Lithocarpus fohaiensis</i>	0.34	1.68	0.90	2.92
<i>Reevesia thyrsoidea</i>	0.68	1.68	0.52	2.88
<i>Ardisia thyrsoflora</i>	1.02	1.68	0.15	2.86
<i>Randia griffithii</i>	0.68	1.68	0.47	2.84
<i>Schima wallichii</i>	0.68	0.84	1.27	2.80
<i>Symplocos wikstroemiifolia</i>	1.02	1.68	0.07	2.77
<i>Dysoxylum binectariferum</i>	1.02	1.68	0.06	2.76
<i>Pygeum henryi</i>	0.68	1.68	0.33	2.69
<i>Litsea euosma</i>	0.34	0.84	1.26	2.44
<i>Cylindrokellupha kerrii</i>	0.68	1.68	0.06	2.43
<i>Eurya aurea</i>	0.68	1.68	0.06	2.42
<i>Linociera insignis</i>	0.68	1.68	0.04	2.40
<i>Eriobotrya obovata</i>	0.68	0.84	0.84	2.37
<i>Rhododendron moultmainensis</i>	1.02	0.84	0.44	2.30
<i>Acer huianum</i>	0.34	0.84	1.03	2.21
<i>Alangium chinensis</i>	0.34	0.84	0.92	2.10
<i>Elaeocarpus howii</i>	0.34	0.84	0.77	1.95
<i>Machilus rufipes</i>	0.34	0.84	0.61	1.79

<i>Ternstroemia gymnanthera</i>	0.34	0.84	0.54	1.72
<i>Itea macrophylla</i>	0.68	0.84	0.16	1.68
<i>Beilschmiedia robusta</i>	0.34	0.84	0.39	1.57
<i>Lithocarpus truncatus</i>	0.34	0.84	0.38	1.56
<i>Pittosporum kerrii</i>	0.34	0.84	0.26	1.45
<i>Laurocerasus jenkinsii</i>	0.34	0.84	0.23	1.41
<i>Helicia tsaii</i>	0.34	0.84	0.17	1.35
<i>Tricalysia fruticosa</i>	0.34	0.84	0.17	1.35
<i>Styrax grandiflora</i>	0.34	0.84	0.16	1.34
<i>Bruinsmia polysperma</i>	0.34	0.84	0.15	1.33
<i>Garcinia cowa</i>	0.34	0.84	0.08	1.27
<i>Eurya prunifolia</i>	0.34	0.84	0.06	1.24
<i>Casearia velutina</i>	0.34	0.84	0.04	1.22
<i>Carallia lanceaefolia</i>	0.34	0.84	0.03	1.21
<i>Sarcosperma griffithii</i>	0.34	0.84	0.02	1.20
<i>Oxyspora vagans</i>	0.34	0.84	0.02	1.20
<i>Platea latifolia</i>	0.34	0.84	0.02	1.20
<i>Cyclobalanopsis myrsinaefolia</i>	0.34	0.84	0.01	1.20
<i>Amoora yunnanensis</i>	0.34	0.84	0.01	1.19
<i>Paramichelia baillonii</i>	0.34	0.84	0.01	1.19
<i>Anneslea fragrans</i>	0.34	0.84	0.01	1.19
Total (70 species) 293 stems	100.00	100.00	100.00	300.00

* See Appended Table 1.

The shrub layer is 1-5 m high with a cover of 30%-40%, and is dominated by juvenile trees. Frequent shrub species are *Euodia leptae*, *Fargesia plurisetosa*, *Lasianthus lucidus*, *Psychotria symplocifolia*, *Oxyspora vagans* and *Lasianthus inodorus*.

The herbaceous layer is usually less developed than in the preceding forest type. Frequent species are *Davallia mairesii*, *Pteris insignis*, *Ophiopogon graminifolia*, *Colysis pothifolia* and *Strobilanthes* sp.

Lianas are fewer but there are some big woody lianas such as *Connarus paniculatus*, *Celastrus monospermum*, *Epigeum auritum*, *Bousigonia angustifolia*, *Gnetum montanum* and *Alyxia balansae*.

Epiphytes are fewer than in the ME-PM forests.

We have analyzed forest physiognomy based on 261 vascular species from the 10 plots of these two montane rain forest types. Both forests are dominated by phanerophytes, which make up 79.3% of all species (**Table 1**). In terms of the spectrum of leaf sizes, the plants with mesophyllous leaves contribute up to 68.2% of the total species, and 76.4% of tree species (**Table 2**). Woody plants with simple leaves contribute up to 90.6% and those with entire leaf margins, up to 76.5% (**Table 3**).

The flora

623 native seed plant species (including varieties) in 327 genera and 115 families of seed plants were recorded from the montane rain forest (see appendix). The families with highest species richness included Lauraceae (51 species), Euphorbiaceae (36), Rubiaceae (23), Fagaceae (20), Liliaceae (20), Rosaceae (19), Araceae (18), Theaceae (17) and Papilionaceae (16).

Table 1. Life form spectrum of the tropical montane rain forest in southern Yunnan.

	Life form*	Number of species	%
Trees	Megaphanerophyte	12	4.6
	Mesophanerophyte	61	23.4
	Microphanerophyte	54	20.7
	(All trees)	(127)	(48.7)
Shrubs	Nanophanerophyte	22	8.4
Herbaceous plants	Herbaceous phanerophyte	24	9.2
	Geophyte	5	1.9
	Chamaephyte	25	9.6
	(All herbs)	(54)	(20.7)
Liana	Liana phanerophyte	34	13.0
Epiphyte	Epiphyte	24	9.2
Total species		261	100

* Raunkiaer's criteria (1934) revised by Mueller-Dombois and Ellenberg (1974): Megaphanerophyte (perennials over 30 m high); Mesophanerophyte (perennials 8 to 30 m high); Microphanerophyte (perennials 2 to 8 m high); Nanophanerophyte (perennials 0.25 to 2 m high); Herbaceous phanerophyte (herbaceous perennials over 0.25 m high);

Chamaephytes (perennials less than 0.25 m high above ground); Geophyte (perennials, dying back above ground).

Table 2. Leaf sizes of the tropical montane rain forest in southern Yunnan.

		Macrophyll 18226-164025 mm ²	Mesophyll 2026-18225 mm ²	Microphyll 226-2025 mm ²	Total
Trees	Number of species	1	97	29	127
	%	0.8	76.4	22.8	
Shrubs	Number of species	—	9	13	22
	%	—	40.8	59.1	
Herbs	Number of species	9	32	13	54
	%	16.7	59.2	24.1	
Lianas	Number of species	1	28	5	34
	%	3.0	82.4	14.7	
Epiphytes	Number of species	4	12	8	24
	%	16.7	50.0	33.3	
Total species	Number of species	15	198	48	261
	%	5.7	68.2	26.1	

Table 3. Leaf types, leaf textures and leaf margins of the tropical montane rain forest in southern Yunnan.

		Leaf type		Leaf texture		Leaf margin		
		S	C	P	L	E	N	
Trees	Number of species	113	14	51	76	97	30	127
	%	89.0	11.0	40.2	59.8	76.4	23.6	
Shrubs	Number of species	21	1	17	5	17	5	22
	%	95.4	4.6	77.3	22.7	77.3	22.7	
All woody plants	Number of species	134	15	68	81	114	35	149
	%	90.6	9.4	45.6	54.4	76.5	23.5	

S: Simple; C: Compound; P: Papery; L: Leathery; E: Entire; N: non-entire.

The various types of geographic distributions of seed plants from China at the generic level have been documented by Z.Y. Wu (1991). Using Wu's documentation, we have quantified the distribution types of the flora of the montane forest at the generic level and these are summarized in **Table 4**.

Distributions described as 'tropical Asian', such as *Mastixia*, *Pterospermum* and *Knema*, represent up to 27.5% of total genera of the flora. 'Pantropic' distributions, such as those of *Gnetum*, *Piper*, *Lasianthus* and *Bauhinia*, contribute up to 26 %. 'Old World Tropical' distributions, such as those of *Thunbergia*, *Pandanus* and *Carallia* are the next most abundant. These tropical distributions (Types 2-7) compose 78.9% of the total genera. This indicates that the flora of the montane rain forest in southern Yunnan is of tropical nature and has strong tropical Asiatic affinity.

At the specific level, nine geographical elements (distribution types) were recognized from 623 seed plant species of the montane forest (see Table 4). 'Tropical Asian' elements and their subtypes contribute up to 63.7% of the total sum of species, including those of 'Indo-Malesian' distribution, such as *Garcinia cowa*, *Knema furfuracea* and *Gironniera subaequalis*; those of 'Southern Asian' to 'Mainland Southeast Asian' distribution, such as *Alcimandra cathcartii* and *Silvianthus bracteatus*; and those of 'Mainland SE Asia' to 'SW and SE China' distributions, such as *Vaccinium exaristatum*, *Metadina trichotoma* and *Semecarpus reticulata*. The elements of 'Chinese Endemics' and subtypes, which were defined on available references, contribute up to 26%, including those of 'SW to SE China' distribution, such as *Lithocarpus fordianus* and *Craspedolobium schochii*; and the 'Yunnan Endemics', such as *Lithocarpus fohaiensis* and *Cryptocarya rolletii*.

Comparison with the lowland rain forest in southern Yunnan and the equatorial tropics and montane rain forests in SE Asia

Compared with the tropical montane rain forest in Java at similar altitude (Meijer, 1959), the montane rain forest in southern Yunnan has fewer epiphytes (**Figure 2**), but a higher proportion of woody phanerophytes.

Compared with the tropical seasonal rain forests at lower altitude in southern Yunnan (Zhu et al., 1998a) and equatorial lowland rain forests (Beard, 1946; Paijmans, 1970; Givnish, 1978; Proctor et al., 1998), the montane rain forest has fewer mega-and meso-phanerophytes and lianas, fewer plants with compound leaves, fewer plants with macrophyllous leaves, but more

abundant herbaceous plants and more plants with non-entire leaf margins (**Figures 3 and 4**).

The families with highest species richness in the montane rain forest are, to some extent, similar to those in the seasonal rain forests at lower altitudes in the region, but there is greater species richness in Fagaceae, Theaceae, Liliaceae, Rosaceae and Magnoliaceae (**Figure 5**). In terms of phytosociological importance, most of the dominant families in the montane forest are also dominant families in the lowland seasonal rain forests, but Magnoliaceae, Fagaceae, Mastixiaceae, Nyssaceae and Polygalaceae are of greater importance (**Figure 6**).

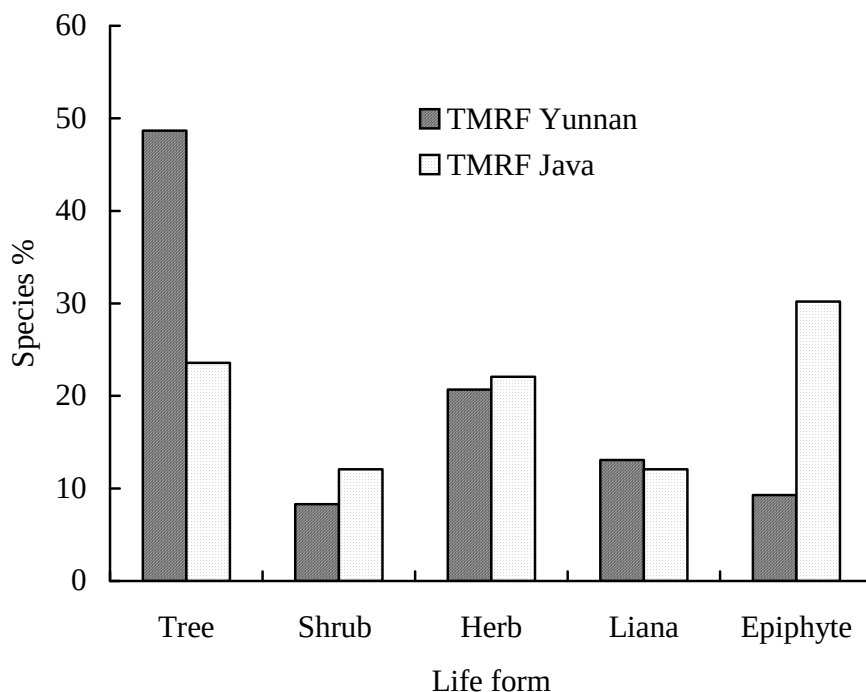


Figure 2. Comparison of life form spectra between the tropical montane rain forest of Mengsong in southern Yunnan and the tropical montane rain forest in Java, Indonesia.

TMRF Java: Montane rain forest at altitudes 1450-1500 m in Java (Meijer, 1959); TMRF Yunnan: Tropical montane rain forest at altitudes 1500-1800 m in Mengsong, southern Yunnan.

Table 4. Geographical elements at generic and specific levels of the flora of the montane rain forest in Mengsong, southern Yunnan

Distribution types at generic level	No. of genera	%	Distribution type at specific level	No. of species	%
1. Cosmopolitan	10	3.1	1. Cosmopolitan	12	1.9
2. Pantropics	85	26.0	2. Pantropics	7	1.1
3. Tropical Asia & Tropical America disjuncted	13	4.0	3. Tropical Asia & Tropical America disjuncted	2	0.3
4. Old World Tropics	30	9.2	4. Old World Tropics	4	0.6
5. Tropical Asia to Tropical Australia	16	4.9	5. Tropical Asia to Tropical Australia	10	1.6
6. Tropical Asia to Tropical Africa	24	7.3	6. Tropical Asia to Tropical Africa	11	1.8
7. Tropical Asia (Indo-Malaysia)	90	27.5	7. Tropical Asia and its subtypes	(397)	(63.7)
8. North Temperate	25	7.6	7-1. Indo-Malesia	120	19.3
9. E. Asia and N. America disjuncted	12	3.7	7-2. S Asia to Mainland SE Asia	130	20.9
10. Old World Temperate	2	0.6	7-3. Mainland SE Asia to SW and SE China	147	23.6
11. Mediterranean and W. Asia to C. Asia	2	0.6	8. Eastern Asia	18	2.9
14. E. Asia	14	4.3	9. Endemic to China and its subtypes	(162)	(26)
15. Endemic to China	4	1.2	9-1. SW to SE China	91	14.6
Total genera	327	100.0	9-2. Endemic to Yunnan	71	11.4
			Total species	623	100.0

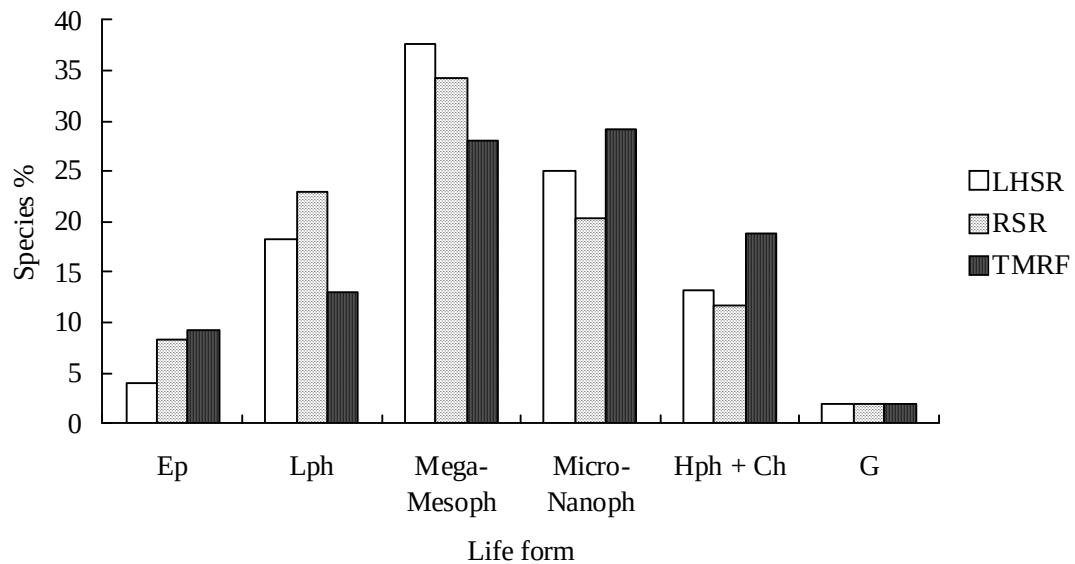


Figure 3. Comparison of life form spectra from the tropical montane rain forest in Mengsong and seasonal rain forests in southern Yunnan.

LHSR: Lower hill seasonal rain forest;

RSR: Ravine seasonal rain forest;

TMRF: Tropical montane rain forest in Mengsong.

Ep=Epiphyte; Ch=Chamaephyte; G=Geophyte; Lph=Liana-phanerophyte

Hph=Herbaceous phanerophyte; Mega-Mesoph=Megaphanerophyte + Mesophanerophyte

Micro-Nanoph=Microphanerophyte + Nanophanerophyte

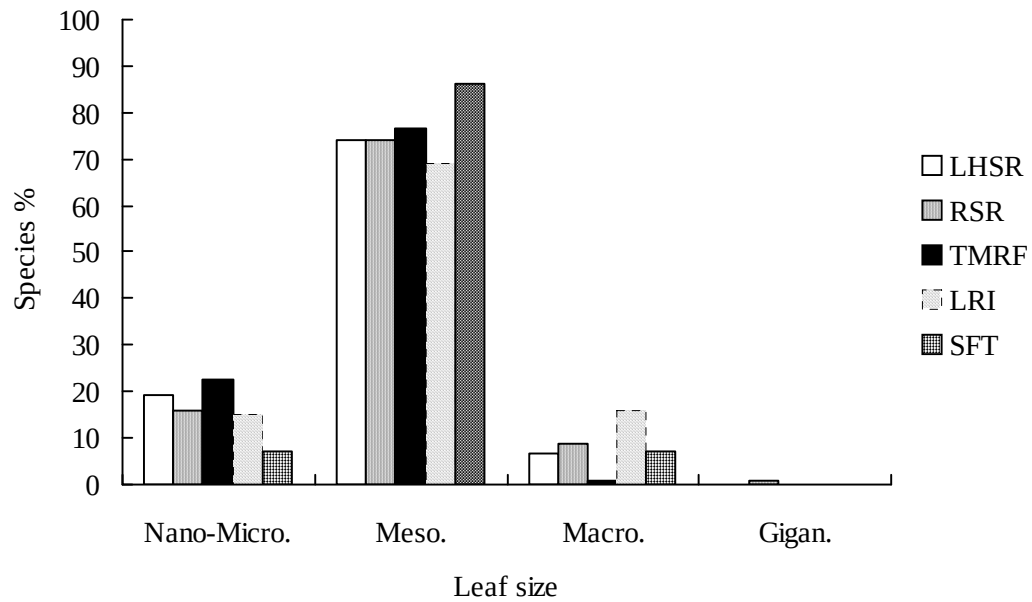


Figure 4. Comparison of leaf size spectra from the tropical montane rain forest in Mengsong and the seasonal rain forests in southern Yunnan as well as the ones from the equatorial lowland.

LHSR: Lower hill seasonal rain forest in southern Yunnan

RSR: Ravine seasonal rain forest in southern Yunnan

TMRF: Tropical montane rain forest in southern Yunnan

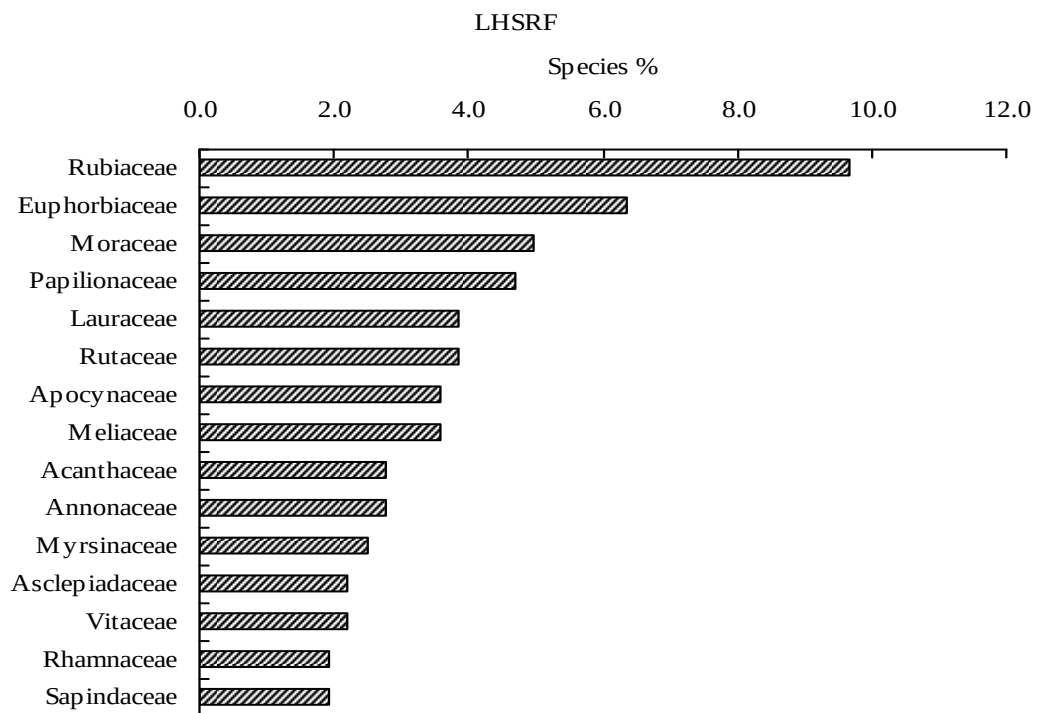
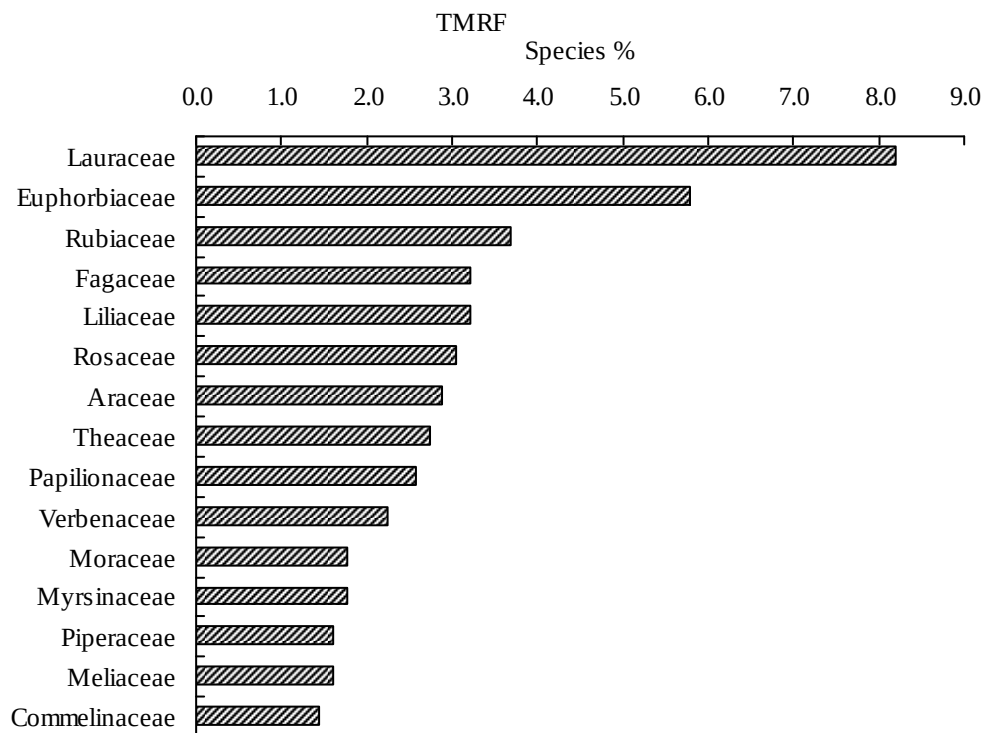
LRI: Lowland tropical evergreen rain forest in India²

SFT: Evergreen tropical seasonal forest in Trinidad¹

Nano-Micro.: Nanophyll + Microphyll; Meso.: Mesophyll; Macro.: Macrophyll; Gigan.: Gigantophyll

Gigantophyll

¹ from Beard (1946); ²from Proctor et al. (1998)



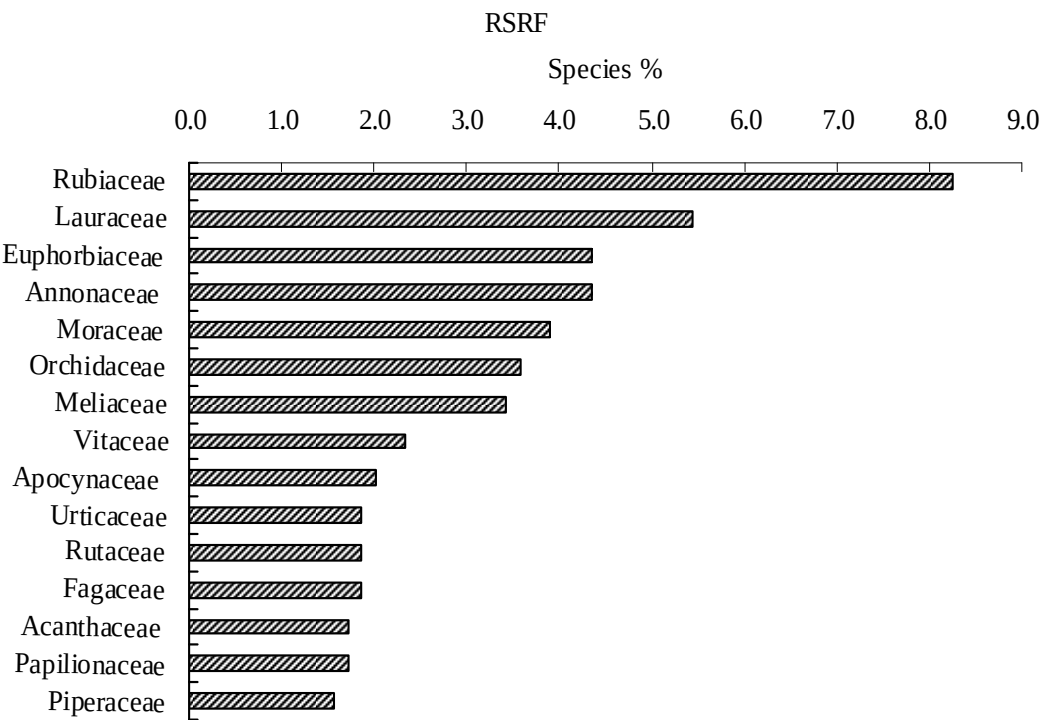
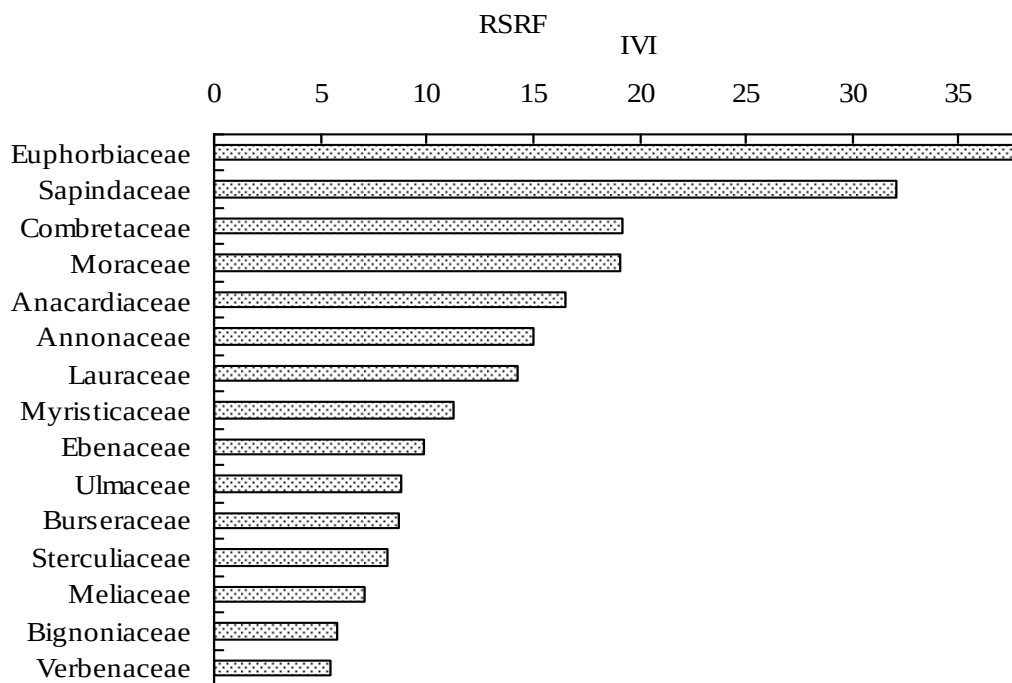
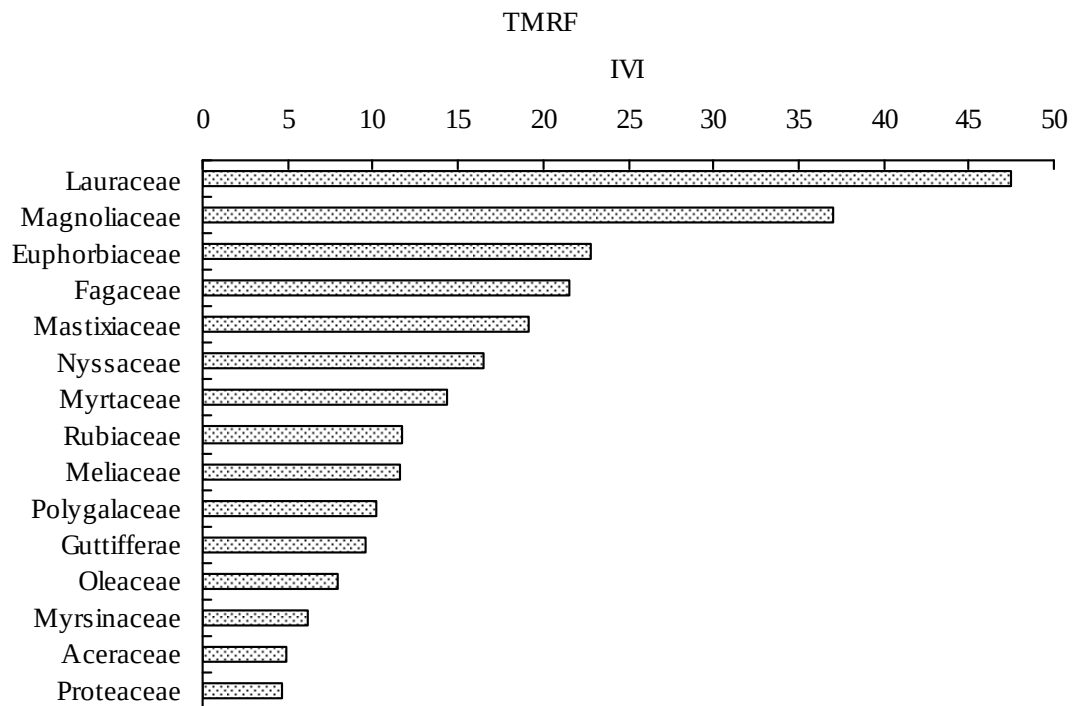


Figure 5. Comparison of abundant families with most species richness between the montane rain forest and seasonal rain forests at lower altitudes in the region.
TMRF: Tropical montane rain forest in southern Yunnan;
LHSR: Lower hill seasonal rain forest in southern Yunnan;
RSR: Ravine seasonal rain forest in southern Yunnan.



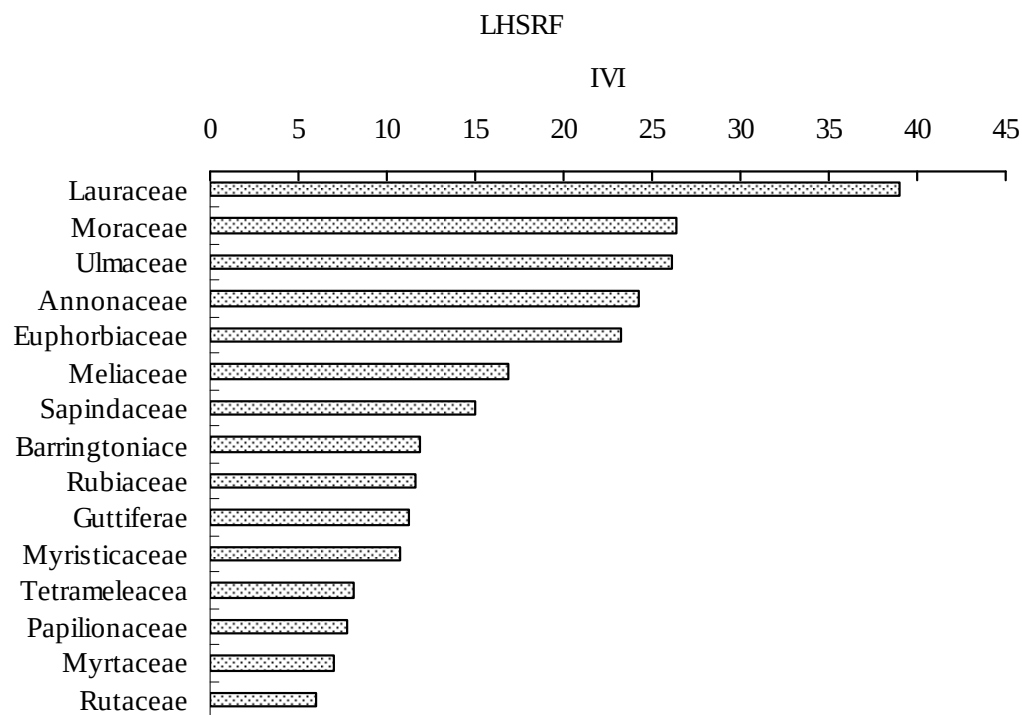


Figure 6. Comparison of these families with the highest phytosociological importance between the montane rain forest and seasonal rain forests at lower altitudes in the region. TMRF: Tropical montane rain forest in southern Yunnan; LHSR: Lower hill seasonal rain forest in southern Yunnan; RSR: Ravine seasonal rain forest in southern Yunnan.

Discussions

Altitudinal zonation of tropical forest

Montane vegetation zones in tropical America have been classified by Beard (1944, 1955) into rain forest, lower montane rain forest, montane rain forest, montane thicket and elfin woodland with increasing altitude. Similarly, Richards (1952) used the terms tropical rain forest, submontane rain forest and montane rain forest for the vegetation zonation in tropical mountains. In contrast, Grubb et al. (1963), Whitmore (1984, 1990) and Ashton (2003) prefer the terms of lowland rain forest, lower montane rain forest and upper montane rain forest. The tropical montane rain forest in southern Yunnan occurs at an altitude comparable with lower montane rain forest zone as defined by Grubb et al. (1963), Whitmore (1984, 1990) and Ashton (2003).

Equatorial lower montane rain forests are 15-33 m tall and have two tree strata, few emergent trees, few trees with buttresses and cauliflory, few big woody lianas, and fewer plants with pinnate leaves. Plants with mesophyll (Grubb et al., 1963; Whitmore, 1984, 1990) or notophyll leaves (Ashton, 2003) are dominant among the woody plants, and there are abundant vascular epiphytes. Floristic zonation of forests in tropical mountains has been discussed by Ashton (2003), who stresses the laurel-oak attributes of the floras of lower montane rain forests in SE Asia.

The montane rain forest in southern Yunnan is similar to equatorial lower montane rain forests in SE Asia in physiognomy, but differs in having fewer epiphytes and more tree species with pinnate leaves (which contribute up to 11% of the sum of tree species).

The montane rain forest is dominated, in terms of species richness, by the families Lauraceae, Euphorbiaceae, Fagaceae, Rubiaceae, Papilionaceae and Theaceae. In terms of phytosociological importance the dominant families are Lauraceae, Magnoliaceae, Euphorbiaceae, Fagaceae, Mastixiaceae and Nyssaceae. The laurel-oak floristic attribute of the montane forest is overshadowed by some dominant families such as Euphorbiaceae, Rubiaceae and Magnoliaceae more commonly associated with lowland forests.

These differences may be due to the monsoonal climate (seasonal dryness) in southern Yunnan and the so-called "Massenerhebung", or 'mass elevation effect' (Whitmore, 1990). This may reflect the fact that these montane forests in Yunnan have characteristics more usually

associated with lowland sites. The montane rain forests in Yunnan may represent a transition between lowland and lower montane forest in physiognomy and floristics, but appears closer to lower montane rain forest.

The physiognomic changes observed with increasing altitudes in southern Yunnan are similar to those in tropical America (Grubb et al., 1963). Microphyllous leaves increased with increasing altitudes.

Tropical montane rain forests in Yunnan were generally classified into a subtype of tropical rain forest by Wu (1987) based on their floristic composition and physiognomy. They are most similar to the lower montane rain forest in equatorial Asia, which was included under the category of tropical rain forest by Whitmore (1990). We agree with Wu and Whitmore's classification that the montane rain forest in southern Yunnan is a type of lower montane rain forest within the broader category of tropical rain forest.

Biogeographical affinity

The montane rain forest in southern Yunnan has strong tropical Asian affinities floristically even though it occurs at the northern margin of mainland Southeast Asia and at a high altitude. The tropical elements contribute about 78.9% at the generic level and more than 80 % at the specific level of its total flora. Elements with 'tropical Asian' affinities contribute 63.7% of the total sum of species.

Some species of particular biogeographical importance were encountered in these tropical montane rain forests. *Mastixia euonymoides* is a dominant and the biggest tree in the montane rain forest. This species occurs only in the limited border area between Myanmar, Yunnan and Thailand, but it was widely distributed in European and America Tertiary flora, which has even been called the Mastixioidean European Flora (Mai, 1993; Eyde et al., 1990; Tiffney et al., 1996). Its vicarious species, *Mastixia octandra*, occurs in mountains of central Sumatra in Indonesia (Matthew, 1976) at similar altitude (1700-1800 m alt.).

Gymnanthes remota (Euphorbiaceae), a relic and dominant species in the lower tree layer of the montane rain forest, occurs disjunctively in Mengsong in southern Yunnan and in Sumatra (Zhu et al., 2000). The frequent shrub species *Lasianthus inodorus* (Rubiaceae), which is distributed in mainland SE Asia and Sumatra as well as Java, has also occurs vicariously on Mt Kinabalu in Borneo (Zhu, 2001). It is interesting that many taxa in the montane rain forest in southern Yunnan have their vicarious species in Malesian montane forests, suggesting a special

biogeographical significance for the region. Further floristic and biogeographical studies on the pristine montane rain forest in southern Yunnan are needed.

Acknowledgments

This project was funded by The National Natural Science Foundation of China (30570128). Figure 1 was made by Dr. Hu Huabin. I thank Professor R. Kitching from Griffith University of Australia for his English grammatical improvements in my manuscript. I also thank reviewers very much for their important and constructive comments.

References

- Aiba, S. & K. Kitayama. 1999. Structure, composition and species diversity in an altitude-substrate matrix of rain forest tree communities on Mount Kinabalu, Borneo. *Plant Ecology* **140**(2): 139-157.
- Ashton, P.S. 2003. Floristic zonation of tree communities on wet tropical mountains revisited. *Perspectives in Plant Ecology, Evolution and Systematics*. **6**: 87-104.
- Audley-Charles, M.G. 1987. Dispersal of Gondwanaland: relevance to evolution of the
- Angiosperms. In: Whitmore, T.C. (ed.) *Biogeographical Evolution of the Malay Archipelago*. Clarendon Press, Oxford.
- Beard, J.S. 1944. Climax vegetation in tropical America. *Ecology* **25**: 127-158.
- Beard, J.S. 1955. The classification of tropical American vegetation types. *Ecology* **36**: 359-412.
- Brown, W.H. 1919. *Vegetation of the Philippine Mountains*. Bureau of Science, Manila, Publication 13.
- Buot, I.E.Jr. & S. Okitsu. 1999. Leaf size zonation pattern of woody species along an altitudinal gradient on Mt. Pulog, Philippines. *Plant Ecology* **145**(2): 197-208.
- Curtis, J.T. & R.P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* **32**: 467-496.

- Eyde, R.H. & Q.Y. Xiang. 1990. Fossil Mastixioid (Cornaceae) alive in eastern Asia. *American Journal of Botany* **77**(5): 689-692.
- Givnish, T.J. 1978. On the adaptive significance of compound leaves, with particular reference to tropical trees. In: Tomlison, P.B. & M.H. Zimmerman. (eds.) *Tropical trees as living systems*. pp.351-380. Cambridge Univ. Press, London.
- Grubb, P.J., Lloyd, J.R., Pennington, T.D. & T.C. Whitmore. 1963. A comparison of montane and lowland rain forest in Ecuador. I. The forest structure, physiognomy and floristics. *Journal of Ecology* **51**: 567-601.
- Hall, R. & J.D. Holloway. 1998. *Biogeography and Geological Evolution of SE Asia*. Backbuys Publishers, Leiden.
- Kitayama, K. 1992. An altitudinal transect study of the vegetation on Mount Kinabalu, Borneo. *Vegetatio* **102**: 149-171.
- Mai, D.H. 1993. On the extinct Mastixiaceae (Cornales) in Europe. *Geophytology* **23**(1): 53-63.
- Matthew, K. M. 1976. A revision of the genus *Mastixia* (Cornaceae). *Blumea* **23**: 51-93.
- Meijer, W. 1959. Plant sociological analysis of montane rain forest near Tjibodas, West Java. *Acta Botanica Neerlandica* **8**: 277-291.
- Metcalf, I. 1998. Paleozoic and Mesozoic geological evolution of the SE Asia region: multidisciplinary constraints and implications for biogeography, pp. 25-41. In: Hall R. & J.D. Holloway (eds.) *Biogeography and Geological Evolution of SE Asia*. Backbuys Publishers, Leiden.
- Morley, J.R. 1998. Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate, pp. 221-234. In: Hall, R. & J.D. Holloway. (eds.) *Biogeography and Geological Evolution of SE Asia*. Backbuys Publishers, Leiden.
- Mueller-Dombois, D. & H. Ellenberg. 1974. *Aims and methods of vegetation ecology*. John Wiley & Sons.
- Myers, N. 1998. Threatened biotas: "Hotspot" in tropical forests. *Environmentalist* **8**: 1-20
- Nakashizuka, T., Zulkifli, Y. & N. Rahim. 1992. Altitudinal zonation of forest communities in Selangor, Peninsular Malaysia. *Journal of Tropical forest Science* **4**: 233-244.

- Ohsawa, M., Nainggolan, P.H.J., Tanaka, N. & C. Anwar. 1985. Altitudinal zonation of forest vegetation on Mount Kerinci, Sumatra: with comparisons to zonation in the temperate region of east Asia. *Journal of Tropical Ecology* **1**: 192-216.
- Ohsawa, M. 1991. Structural comparison of tropical montane forests along latitudinal and altitudinal gradients in south and east Asia. *Vegetatio* **97**: 1-10.
- Ohsawa, M. 1993. Latitudinal pattern of mountain vegetation zonation in southern and eastern Asia. *Journal of Vegetation Science* **4**: 13-18.
- Ohsawa, M. 1995. Latitudinal comparison of altitudinal changes in forest structure, leaf types, and species richness in humid monsoon Asia. *Vegetatio* **121**: 3-10.
- Paijmans, K. 1970. An analysis of four tropical rain forest sites in New Guinea. *Journal of Ecology* **58** (1): 77-101.
- Pendry C. & J. Proctor. 1996. Altitudinal zonation of rain forest on Bukit Belalong, Brunei: soils, forest structure and floristics. *Journal of Tropical Ecology* **13**: 221-241.
- Proctor, J., Haridasan, K. & G.W. Smith. 1998. How far north does lowland evergreen tropical rain forest go? *Global Ecology and Biogeography Letters* **7**: 141-146.
- Qu, Z.X. 1960. Nature reserves in Yunnan. *Journal of Yunnan University (Natural Science)* **1**: 1-4 (in Chinese).
- Raunkiaer, C. 1934. The life forms of plants and statistical plant geography. Oxford University Press, Oxford.
- Richards, P.W. 1952. The tropical rain forest. Cambridge University Press, London.
- Richards, P.W. 1996. The tropical rain forest, an ecological study. Second edition. Cambridge University Press, London.
- Steenis, C.G.G.J. van. 1935. On the origin of the Malaysian mountain flora. 2. Altitudinal zones, general considerations, and renewed statement of the problem. *Bulletin du Jardin Botanique de Buitenzorg series 3*, **13**: 289-417.
- Steenis, C.G.G.J. van. 1984. Floristic altitudinal zones in Malesia. *Botanical Journal of the Linnean Society* **89**: 289-292.

- Tiffney, B.H. & K.K. Haggard. 1996. Fruits of Mastixioideae (Cornaceae) from the Paleogene of western North America. *Review of Palaeobotany and Palynology* **92**: 29-54.
- Wang, H., Zhu, H. & B.G. Li. 2001. A study on the tropical montane rainforest in Mengsong, Xishuangbanna, S. Yunnan. *Guihaia* **21**: 303-314 (in Chinese with English abstract).
- Whitmore, T.C. & C.P. Burnham. 1969. The altitudinal sequence of forests and soils on granite near Kuala Lumpur. *Malayan Natural Journal* **22**: 99-118.
- Whitmore, T.C. 1984. Tropical rain forest of the far east. Second edition. Clarendon Press, Oxford.
- Whitmore, T.C. 1990. An introduction to tropical rain forests. Clarendon Press, Oxford.
- Wu, C.Y. 1987. Vegetation of Yunnan. pp. 143-163. Science Press, Beijing (in Chinese).
- Wu, C.Y. 1991. The areal-types of Chinese genera of seed plants. *Acta Botanica Yunnanica Supp.* **IV** (in Chinese with English abstract).
- Zhu, H. 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *Journal of Biogeography* **24**: 647~662
- Zhu, H., Wang, H. & B.G. Li. 1998a. Research on the tropical seasonal rainforest of Xishuangbanna, South Yunnan. *Guihaia* **18**: 371-384 (in Chinese with English abstract).
- Zhu, H., Wang, H. & B.G. Li. 1998b. The structure, species composition and diversity of the limestone vegetation in Xishuangbanna, SW China. *Gardens' Bulletin Singapore* **50**: 5-33.
- Zhu, H., Wang, H. & B.G. Li. 2000. *Gymnanthes* Sw. (Euphorbiaceae), new to China and its biogeographical implication. *Acta Phytotaxonomica Sinica* **38**: 462-463
- Zhu, H. 2001. New Plants of *Lasianthus* Jack (Rubiaceae) from Kinabalu, Borneo and its biogeographical implication. *Blumea* **46**: 447-455.
- Zhu, H., Wang, H., Li, B.G. & P. Sirirugsa. 2003. Biogeography and floristic affinity of the Limestone flora in southern Yunnan, China. *Annals of the Missouri Botanical Garden* **90**: 444-46.

Zhu, H., Wang, H. & B.G. Li. 2004. Plant diversity and physiognomy of a tropical montane rain forest in Mengsong, southern Yunnan, China. *Acta Phytoecologica Sinica* **28**: 351-360.

Zhu, H. & M. C. Roos. 2004. The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* **10**: 639-648.

Appendix 3. Species checklist of the montane rain forest in Mengsong, southern Yunnan.

ACANTHACEAE	<i>Lepidagathis incurva</i> Buch.-Ham. ex D. Don
ACANTHACEAE	<i>Mananthes patentiflora</i> ((Hemsl.) Bremek.
ACANTHACEAE	<i>Phaulopsis imbricata</i> (Forssk.) Sweet
ACANTHACEAE	<i>Phlogacanthus curviflorus</i> (Wall.) Nees
ACANTHACEAE	<i>Pseuderanthemum malaccense</i> (C.B. Clarke) Lindau
ACANTHACEAE	<i>Pteracanthus alatus</i> (Wall.) Bremek.
ACANTHACEAE	<i>Rhaphidosperma vagabunda</i> (R.Ben) C.Y.Wu ex Y.C.Tang
ACANTHACEAE	<i>Rungia pectinata</i> (L.) Nees
ACERACEAE	<i>Acer decandrum</i> Merr.
ACERACEAE	<i>Acer huianum</i> W.P. Fang & C.K. Hsieh
ACERACEAE	<i>Acer jingdongense</i> T.Z. Hsu
ALANGIACEAE	<i>Alangium barbatum</i> (R. Br.) Baill.
ALANGIACEAE	<i>Alangium chinense</i> (Lour.) Harms
ALANGIACEAE	<i>Alangium kurzii</i> Craib
ALISMATACEAE	<i>Sagittaria trifolia</i> L.
AMARANTHACEAE	<i>Achyranthes bidentata</i> Blume
AMARANTHACEAE	<i>Aerva sanguinolenta</i> (L.) Blume
AMARYLLIDACEAE	<i>Allium hookeri</i> Thwaites
ANACARDIACEAE	<i>Choerospondias axillaris</i> (Roxb.) B.L. Burtt & A.W. Hill
ANACARDIACEAE	<i>Pegia nitida</i> Colobr.
ANACARDIACEAE	<i>Rhus chinensis</i> Mill.
ANACARDIACEAE	<i>Semecarpus reticulata</i> Lecomte
ANACARDIACEAE	<i>Spondias lakonensis</i> var. <i>hirsuta</i> C.Y. Wu & T.L. Ming

ANACARDIACEAE	<i>Toxicodendron acuminatum</i> (DC.) C. Y. Wu. T. L. Ming
ANACARDIACEAE	<i>Toxicodendron succedaneum</i> (L.) Kuntze
ANNONACEAE	<i>Alphonsea boniana</i> Finet & Gagnep.
ANNONACEAE	<i>Alphonsea monogyna</i> Merr. & Chun
ANNONACEAE	<i>Alphonsea squamosa</i> Finet & Gagnep.
ANNONACEAE	<i>Alphonsea tsangyuanensis</i> P.T. Li
ANNONACEAE	<i>Fissistigma acuminatissimum</i> Merr.
ANNONACEAE	<i>Fissistigma maclurei</i> Merr.
ANNONACEAE	<i>Fissistigma polyanthum</i> (Hook. f. & Thomson) Merr.
ANNONACEAE	<i>Mitrephora maingayi</i> Hook. f. & Thomson
APOCYNACEAE	<i>Alstonia rostrata</i> C.E.C. Fisch.
APOCYNACEAE	<i>Bousigonia angustifolia</i> Pierre
APOCYNACEAE	<i>Epigynum auritum</i> (C.K. Schneid.) Tsiang & P.T. Li
APOCYNACEAE	<i>Tabernaemontana corymbosa</i> Roxb. ex Wall.
APOSTASIACEAE	<i>Apostasia odorata</i> Blume
AQUIFOLIACEAE	<i>Ilex polyneura</i> (Hand.-Mazz.) S.Y. Hu
AQUIFOLIACEAE	<i>Ilex tetramera</i> var. <i>glabra</i> (C.Y. Wu) T.R. Dudley
ARACEAE	<i>Alocasia macrorrhizos</i> (L.) Schott
ARACEAE	<i>Amorphophallus bannanensis</i> H. Li
ARACEAE	<i>Amorphophallus rivieri</i> Durieu ex Carrière
ARACEAE	<i>Amorphophallus ximengensis</i> H. Li
ARACEAE	<i>Arisaema austroyunnanense</i> H. Li
ARACEAE	<i>Arisaema inkiangense</i> H. Li
ARACEAE	<i>Colocasia esculenta</i> (L.) Schott
ARACEAE	<i>Colocasia gigantea</i> (Blume) Hook. f.
ARACEAE	<i>Gonatanthus pumilus</i> (D. Don) Engl. & K. Krause
ARACEAE	<i>Pothos chinensis</i> (Raf.) Merr.

ARACEAE	<i>Pothos scandens</i> L.
ARACEAE	<i>Remusatia hookeriana</i> Schott
ARACEAE	<i>Remusatia vivipara</i> (Lodd.) Schott
ARACEAE	<i>Rhaphidophora crassicaulis</i> Engl. & K. Krause
ARACEAE	<i>Rhaphidophora decursiva</i> (Roxb.) Schott
ARACEAE	<i>Rhaphidophora hookeri</i> Schott
ARACEAE	<i>Rhaphidophora lancifolia</i> Schott
ARACEAE	<i>Rhaphidophora megaphylla</i> H. Li
ARALIACEAE	<i>Aralia armata</i> (Wall.) Seem.
ARALIACEAE	<i>Brassaiopsis producta</i> (Dunn) C.B. Shang
ARALIACEAE	<i>Macropanax dispermus</i> (Blume) Kuntze
ARALIACEAE	<i>Macropanax undulatus</i> var. <i>simplex</i> H.L. Li
ARALIACEAE	<i>Schefflera chapana</i> Harms
ARALIACEAE	<i>Schefflera octophylla</i> (Lour.) Harms
ARALIACEAE	<i>Tupidanthus calyptratus</i> Hook. & Thomson
ARISTOLOCHIACEAE	<i>Aristolochia cathcartii</i> Hook. f.
ARISTOLOCHIACEAE	<i>Aristolochia fangchi</i> Y.C. Wu ex L.D. Chow & S.M. Hwang
ARISTOLOCHIACEAE	<i>Aristolochia tagala</i> Cham.
ASCLEPIADACEAE	<i>Hoya villosa</i> Costantin
BALANOPHORACEAE	<i>Balanophora harlandii</i> Hook. f.
BALSAMINACEAE	<i>Impatiens balansae</i> Hook. f.
BALSAMINACEAE	<i>Impatiens mengtzeana</i> Hook. f.
BEGONIACEAE	<i>Begonia augustinei</i> Hemsl.
BEGONIACEAE	<i>Begonia crassirostris</i> Irmsch.
BEGONIACEAE	<i>Begonia versicolor</i> Irmsch.
BETULACEAE	<i>Alnus nepalensis</i> D. Don
BETULACEAE	<i>Betula alnoides</i> Buch.-Ham. ex D. Don

BETULACEAE	<i>Betula luminifera</i> H.J.P. Winkl.
BIGNONIACEAE	<i>Mayodendron igneum</i> (Kurz) Kurz
BURSERACEAE	<i>Canarium pimela</i> Leenh.
BURSERACEAE	<i>Canarium strictum</i> Roxb.
BURSERACEAE	<i>Canarium tonkinense</i> (Leenh.) Engl.
CAESALPINIACEAE	<i>Bauhinia variegata</i> L.
CAESALPINIACEAE	<i>Caesalpinia cucullata</i> Roxb.
CAESALPINIACEAE	<i>Cassia agnes</i> (De Wit) Brenen
CAESALPINIACEAE	<i>Gleditsia fera</i> (Lour.) Merr.
CAPPARIDACEAE	<i>Capparis fohaiensis</i> B.S. Sun
CAPRIFOLIACEAE	<i>Viburnum cylindricum</i> Buch.-Ham. ex D. Don
CAPRIFOLIACEAE	<i>Viburnum punctatum</i> Buch.-Ham. ex D. Don
CARLEMANNIACEAE	<i>Silvianthus bracteatus</i> Hook. f.
CELASTRACEAE	<i>Celastrus angulata</i> Maxim.
CELASTRACEAE	<i>Celastrus paniculata</i> subsp. <i>multiflorus</i> (Roxb.) Hou
CELASTRACEAE	<i>Celastrus paniculatus</i> Willd.
CELASTRACEAE	<i>Glyptopetalum sclerocarpum</i> (Kurz) Lawson
CELASTRACEAE	<i>Microtropis discolor</i> (Wallich) Arn.
CELASTRACEAE	<i>Microtropis tetragona</i> Merr. & F.L. Freeman
CHLORANTHACEAE	<i>Sarcandra glabra</i> subsp. <i>brachystachys</i> (Blume) Verdc.
COMMELINACEAE	<i>Amischotolype hispida</i> (Less. & A. Rich.) D.Y. Hong
COMMELINACEAE	<i>Amischotolype hookeri</i> (Hassk.) H. Hara
COMMELINACEAE	<i>Commelina paludosa</i> Blume
COMMELINACEAE	<i>Cyanotis cristata</i> (L.) D. Don
COMMELINACEAE	<i>Cyanotis vaga</i> (Lour.) Roem. & Schult.
COMMELINACEAE	<i>Dictyospermum conspicuum</i> (Blume) Hassk.
COMMELINACEAE	<i>Floscopa scandens</i> Lour.

COMMELINACEAE	<i>Porandra scandens</i> D.Y. Hong
COMMELINACEAE	<i>Rhopalephora scaberrima</i> (Blume) Faden
COMPOSITAE	<i>Artemisia argyi</i> H. Lév. & Vaniot
COMPOSITAE	<i>Dichrocephala benthamii</i> C.B. Clarke
COMPOSITAE	<i>Emilia prenanthoidea</i> DC.
COMPOSITAE	<i>Senecio scandens</i> Buch.-Ham. ex D. Don
COMPOSITAE	<i>Vernonia cinerea</i> (L.) Less.
CONNARACEAE	<i>Connarus paniculatus</i> Roxb.
CORNACEAE	<i>Mastixia euonymoides</i> Prain
CORNACEAE	<i>Mastixia pentandra</i> subsp. <i>chinensis</i> (Merr.) K.M. Matthew
CORYLACEAE	<i>Carpinus londoniana</i> H.J.P. Winkl.
CUCURBITACEAE	<i>Gynostemma laxum</i> (Wall.) Cogn.
CUCURBITACEAE	<i>Gynostemma pentaphyllum</i> (Thunb.) Makino
CUCURBITACEAE	<i>Gynostemma pubescens</i> (Gagnep.) C.Y. Wu
CYPERACEAE	<i>Carex baccans</i> Nees
	<i>Mariscus sumatrensis</i> var. <i>subcompositus</i> (C.B. Clarke) S.
CYPERACEAE	Karhikeyan
DIOSCOREACEAE	<i>Dioscorea bulbifera</i> L.
DIOSCOREACEAE	<i>Dioscorea chingii</i> Prain & Burkill
DIOSCOREACEAE	<i>Dioscorea esquirolii</i> Prain & Burkill
DIOSCOREACEAE	<i>Dioscorea glabra</i> Roxb.
EBENACEAE	<i>Diospyros kaki</i> var. <i>silvestris</i> Makino
EBENACEAE	<i>Diospyros kerrii</i> Craib
EBENACEAE	<i>Diospyros nigrocortex</i> C.Y. Wu
EBENACEAE	<i>Diospyros yunnanensis</i> Rehder & E.H. Wilson
ELAEAGNACEAE	<i>Elaeagnus conferta</i> var. <i>menghaiensis</i> W.K. Hu & H.F. Chow
ELAEAGNACEAE	<i>Elaeagnus gonyanthes</i> Benth.

ELAEAGNACEAE	<i>Elaeagnus macrantha</i> Rehder
ELAEOCARPACEAE	<i>Elaeocarpus apiculatus</i> Masters in Hook. f.
ELAEOCARPACEAE	<i>Elaeocarpus austroyunnanensis</i> Hu
ELAEOCARPACEAE	<i>Elaeocarpus decipiens</i> Hemsl.
ELAEOCARPACEAE	<i>Elaeocarpus glabripetalus</i> Merr.
ELAEOCARPACEAE	<i>Elaeocarpus glabripetalus</i> var. <i>alatus</i> (Kunth) Hung T. Chang
ELAEOCARPACEAE	<i>Elaeocarpus howii</i> Merr. & Chun
ELAEOCARPACEAE	<i>Elaeocarpus petiolatus</i> (Jack) Wall. ex Kurz
ELAEOCARPACEAE	<i>Sloanea mollis</i> Gagnep.
ELAEOCARPACEAE	<i>Sloanea tomentosa</i> (Benth.) Rehder & E.H. Wilson
ERICACEAE	<i>Craibiodendron stellatum</i> (Pierre) W.W. Sm.
ERICACEAE	<i>Rhododendron moulmainense</i> Hook.
ESCALLONIACEAE	<i>Itea macrophylla</i> Wall.
EUPHORBIACEAE	<i>Antidesma fordii</i> Hemsl.
EUPHORBIACEAE	<i>Antidesma montanum</i> Blume
EUPHORBIACEAE	<i>Aporusa dioica</i> (Roxb.) Müll. Arg.
EUPHORBIACEAE	<i>Aporusa villosa</i> (Lindl.) Baill.
EUPHORBIACEAE	<i>Aporusa yunnanensis</i> (Pax & K. Hoffm.) F.P. Metcalf
EUPHORBIACEAE	<i>Baccaurea ramiflora</i> Lour.
EUPHORBIACEAE	<i>Baliospermum effusum</i> Pax & Hoffm. in Engl.
EUPHORBIACEAE	<i>Baliospermum montanum</i> (Willd.) Müll. Arg.
EUPHORBIACEAE	<i>Bischofia javanica</i> Blume
EUPHORBIACEAE	<i>Breynia fruticosa</i> (L.) Hook. f.
EUPHORBIACEAE	<i>Bridelia tomentosa</i> Blume
EUPHORBIACEAE	<i>Croton caudatus</i> Geiseler
EUPHORBIACEAE	<i>Croton damayeshu</i> Y.T. Chang
EUPHORBIACEAE	<i>Drypetes cumingii</i> (Baill.) Pax & K. Hoffm.

EUPHORBIACEAE	<i>Drypetes salicifolia</i> Gagnep.
EUPHORBIACEAE	<i>Glochidion assamicum</i> (Müll. Arg.) Hook. f.
EUPHORBIACEAE	<i>Glochidion hirsutum</i> (Roxb.) Voigt
EUPHORBIACEAE	<i>Glochidion khasicum</i> (Müll. Arg.) Hook. f.
EUPHORBIACEAE	<i>Glochidion lanceolarium</i> (Roxb.) Voigt
EUPHORBIACEAE	<i>Glochidion puberum</i> (L.) Hutch.
EUPHORBIACEAE	<i>Gymnanthes remota</i> (Steenis) Esser
EUPHORBIACEAE	<i>Macaranga denticulata</i> (Blume) Müll. Arg.
EUPHORBIACEAE	<i>Macaranga henryi</i> (Pax & K. Hoffm.) Rehder
EUPHORBIACEAE	<i>Macaranga indica</i> Wight
EUPHORBIACEAE	<i>Macaranga kurzii</i> (Kuntze) Pax & Hoffm. in Engl.
EUPHORBIACEAE	<i>Mallotus barbatus</i> (Wall.) Müll. Arg.
EUPHORBIACEAE	<i>Mallotus macrostachyus</i> (Miq.) Müll. Arg.
EUPHORBIACEAE	<i>Mallotus paniculatus</i> (Lam.) Müll. Arg.
EUPHORBIACEAE	<i>Mallotus philippinensis</i> (Lam.) Müll. Arg.
EUPHORBIACEAE	<i>Mallotus tetracoccus</i> (Roxb.) Kurz
EUPHORBIACEAE	<i>Ostodes katharinae</i> Pax
EUPHORBIACEAE	<i>Ostodes kuangii</i> Y.T. Chang
EUPHORBIACEAE	<i>Ostodes paniculata</i> Blume
EUPHORBIACEAE	<i>Phyllanthus emblica</i> L.
EUPHORBIACEAE	<i>Sapium baccatum</i> Roxb.
EUPHORBIACEAE	<i>Sapium discolor</i> (Champ. ex Benth.) Müll. Arg.
FAGACEAE	<i>Castanopsis argyrophylla</i> King ex Hook. f.
FAGACEAE	<i>Castanopsis calathiformis</i> (Skan) Rehder & E.H. Wilson
FAGACEAE	<i>Castanopsis carlesii</i> var. <i>spinulosa</i> W.C. Cheng & C.S. Chao
FAGACEAE	<i>Castanopsis ceratacantha</i> Rehder & E.H. Wilson
FAGACEAE	<i>Castanopsis echidnocarpa</i> Hook. f. & Thomson ex Miq.

FAGACEAE	<i>Castanopsis hystrix</i> Miq.
FAGACEAE	<i>Castanopsis indica</i> (Roxb. ex Lindl.) A. DC.
FAGACEAE	<i>Castanopsis mekongensis</i> A. Camus
FAGACEAE	<i>Castanopsis tcheponensis</i> Hickel & A. Camus
FAGACEAE	<i>Cyclobalanopsis kerrii</i> (Craib) Hu
FAGACEAE	<i>Cyclobalanopsis myrsinifolia</i> (Blume) Oerst.
FAGACEAE	<i>Lithocarpus fohaiensis</i> (Hu) A. Camus
FAGACEAE	<i>Lithocarpus fordianus</i> (Hemsl.) Chun
FAGACEAE	<i>Lithocarpus grandifolius</i> (D. Don) S.N. Biswas
FAGACEAE	<i>Lithocarpus hancei</i> (Benth.) Rehder
FAGACEAE	<i>Lithocarpus hypoglaucus</i> (Hu) C.C. Huang
FAGACEAE	<i>Lithocarpus microspermus</i> A. Camus
FAGACEAE	<i>Lithocarpus pseudoreinwardtii</i> A. Camus
FAGACEAE	<i>Lithocarpus rhabdostachyus</i> subsp. <i>dakhaensis</i> A. Camus
FAGACEAE	<i>Lithocarpus truncatus</i> (King ex Hook. f.) Rehder & E.H. Wilson
FLACOURTIACEAE	<i>Xylosma congesta</i> (Lour.) Merr.
FLACOURTIACEAE	<i>Xylosma longifolia</i> Clos
FUMARIACEAE	<i>Corydalis balansae</i> Prain
GENTIANACEAE	<i>Tripterospermum membranaceum</i> (C. Marquand) Harry Sm.
GESNERIACEAE	<i>Rhynchoetechum ellipticum</i> (Wall. ex D. Dietr.) A. DC.
GNETACEAE	<i>Gnetum montanum</i> f. <i>megalocarpum</i> Markgr.
GNETACEAE	<i>Gnetum montanum</i> Markgr.
GNETACEAE	<i>Gnetum pendulum</i> C.Y. Cheng
GUTTIFERAE	<i>Calophyllum polyanthum</i> Wall. ex Choisy
GUTTIFERAE	<i>Garcinia cowa</i> Roxb.

HAMAMELIDACEAE	<i>Altingia excelsa</i> Noronha
HAMAMELIDACEAE	<i>Distyliopsis yunnanensis</i> (Hung T. Chang) C.Y. Wu
HYDRANGIACEAE	<i>Dichroa febrifuga</i> Lour.
HYPERICACEAE	<i>Cratoxylum cochinchinense</i> (Lour.) Blume
HYPPOCRATEACEAE	<i>Pristimera arborea</i> (Roxb.) A.C. Sm.
ICACINACEAE	<i>Apodytes dimidiata</i> E. Mey. ex Arn.
ICACINACEAE	<i>Gomphandra tetrandra</i> (Wall.) Sleumer
ICACINACEAE	<i>Iodes ovalis</i> Blume
ICACINACEAE	<i>Mappianthus iodoides</i> Hand.-Mazz.
ICACINACEAE	<i>Natsiatopsis thunbergiaefolia</i> Kurz
ICACINACEAE	<i>Nothapodytes collina</i> C.Y. Wu
ICACINACEAE	<i>Platea latifolia</i> Blume
JUGLANDACEAE	<i>Engelhardia roxburghiana</i> Wall.
JUGLANDACEAE	<i>Engelhardia serrata</i> Blume
JUGLANDACEAE	<i>Engelhardia spicata</i> Lesch. ex Blume
JUGLANDACEAE	<i>Juglans sigillata</i> Dode
LABIATAE	<i>Gomphostemma arbusculum</i> C.Y. Wu
LABIATAE	<i>Gomphostemma crinitum</i> Wall. ex Benth.
LABIATAE	<i>Gomphostemma stellatohirsutum</i> C.Y. Wu
LABIATAE	<i>Leucosceptrum canum</i> Sm.
LABIATAE	<i>Paraphlomis javanica</i> (Blume) Prain
LABIATAE	<i>Pogostemon glaber</i> Benth.
LARDIZABALACEAE	<i>Stauntonia brunoniana</i> Wall. ex Hemsl.
LAURACEAE	<i>Actinodaphne henryi</i> Gamble
LAURACEAE	<i>Actinodaphne obovata</i> (Nees) Blume
LAURACEAE	<i>Alseodaphne andersonii</i> (King ex Hook. f.) Kosterm.
LAURACEAE	<i>Alseodaphne petiolaris</i> (Meisn.) Hook. f.

LAURACEAE	<i>Beilschmiedia linocieroides</i> H.W. Li
LAURACEAE	<i>Beilschmiedia percoriacea</i> C.K. Allen
LAURACEAE	<i>Beilschmiedia purpurascens</i> H.W. Li
LAURACEAE	<i>Beilschmiedia robusta</i> C.K. Allen
LAURACEAE	<i>Beilschmiedia roxburghiana</i> Nees
LAURACEAE	<i>Beilschmiedia yunnanensis</i> Hu
LAURACEAE	<i>Cassytha filiformis</i> L.
LAURACEAE	<i>Cinnamomum austroyunnanense</i> H.W. Li
LAURACEAE	<i>Cinnamomum bejolghota</i> (Buch.-Ham.) Sweet
LAURACEAE	<i>Cinnamomum glanduliferum</i> (Wall.) Nees
LAURACEAE	<i>Cinnamomum iners</i> Reinw. ex Blume
LAURACEAE	<i>Cinnamomum mollifolium</i> H.W. Li
LAURACEAE	<i>Cinnamomum tamala</i> (Buch.-Ham.) T. Nees & Eberm.
LAURACEAE	<i>Cinnamomum tenuipilis</i> Kosterm.
LAURACEAE	<i>Cryptocarya brachythyrsa</i> H.W. Li
LAURACEAE	<i>Cryptocarya calcicola</i> H.W. Li
LAURACEAE	<i>Cryptocarya densiflora</i> Blume
LAURACEAE	<i>Cryptocarya rolletii</i> H. Wang & H. Zhu
LAURACEAE	<i>Iteadaphne caudata</i> (Nees) H.W. Li
LAURACEAE	<i>Lindera latifolia</i> Hook. f.
LAURACEAE	<i>Lindera menghaiensis</i> H.W. Li
LAURACEAE	<i>Lindera metcalfiana</i> var. <i>dictyophylla</i> (C.K. Allen) H.B. Cui
LAURACEAE	<i>Litsea atrata</i> S.K. Lee
LAURACEAE	<i>Litsea balansae</i> Lecomte
LAURACEAE	<i>Litsea baviensis</i> Lecomte
LAURACEAE	<i>Litsea chinpingensis</i> Y. C. Yang & P.H. Huang
LAURACEAE	<i>Litsea cubeba</i> (Lour.) Pers.

LAURACEAE	<i>Litsea elongata</i> (Nees) Benth. & Hook. f.
LAURACEAE	<i>Litsea euosma</i> W.W. Sm.
LAURACEAE	<i>Litsea garrettii</i> Gamble
LAURACEAE	<i>Litsea glutinosa</i> (Lour.) C.B. Rob.
	<i>Litsea lancifolia</i> (Roxb. ex Nees in Wall.) Benth. & Hook. f. ex
LAURACEAE	Villar
LAURACEAE	<i>Litsea lancifolia</i> var. <i>ellipsoidea</i> Y.C. Yang & P.H. Huang
LAURACEAE	<i>Litsea lancifolia</i> var. <i>pedicellata</i> Hook. f.
LAURACEAE	<i>Litsea liyuyingi</i> H. Liu
LAURACEAE	<i>Litsea longistaminata</i> (H. Liu) Kosterm.
LAURACEAE	<i>Litsea magnoliifolia</i> Y.C. Yang & P.H. Huang
LAURACEAE	<i>Litsea vang</i> Lecomte var. <i>lobata</i> Lecomte
LAURACEAE	<i>Litsea verticillata</i> Hance
LAURACEAE	<i>Machilus salicina</i> Hance
LAURACEAE	<i>Persea robusta</i> (W.W. Sm.) Kosterm.
LAURACEAE	<i>Persea rufipes</i> (H.W. Li) Kosterm.
LAURACEAE	<i>Persea shweliensis</i> (W.W. Sm.) Kosterm.
LAURACEAE	<i>Phoebe lanceolata</i> (Nees) Nees
LAURACEAE	<i>Phoebe macrocarpa</i> C.Y. Wu
LAURACEAE	<i>Phoebe puwenensis</i> Cheng
LAURACEAE	<i>Phoebe rufescens</i> H.W. Li
LILIACEAE	<i>Asparagus subscandens</i> F.T. Wang & S.C. Chen
LILIACEAE	<i>Aspidistra typica</i> Baill.
	<i>Campylandra chinensis</i> (Baker) M.N. Tamura, S.Y. Liang &
LILIACEAE	Turland
LILIACEAE	<i>Chlorophytum malayense</i> Ridl.
LILIACEAE	<i>Dianella ensifolia</i> (L.) DC.

LILIACEAE	<i>Disporopsis longifolia</i> Craib
LILIACEAE	<i>Disporum calcaratum</i> D. Don
LILIACEAE	<i>Disporum cantoniense</i> (Lour.) Merr.
LILIACEAE	<i>Liriope graminifolia</i> (L.) Baker
LILIACEAE	<i>Ophiopogon tsaii</i> F.T. Wang & Ts. Tang
LILIACEAE	<i>Peliosanthes sinica</i> F.T. Wang & Ts. Tang
LILIACEAE	<i>Reineckea carnea</i> (Andrews) Kunth
LILIACEAE	<i>Smilax hemsleyana</i> Craib
LILIACEAE	<i>Smilax hypoglauca</i> Benth.
LILIACEAE	<i>Smilax megacarpa</i> A. DC.
LILIACEAE	<i>Smilax myrtilus</i> A. DC.
LILIACEAE	<i>Smilax ocreata</i> A. DC.
LILIACEAE	<i>Smilax perfoliata</i> Lour.
LILIACEAE	<i>Smilax quadrata</i> A. DC.
LILIACEAE	<i>Tupistra grandistigma</i> F.T. Wang & S.Y. Liang
LOGANIACEAE	<i>Buddleja officinalis</i> Maxim.
LYTHRACEAE	<i>Rotala rotundifolia</i> (Buch.-Ham. ex Roxb.) Koehne
MAGNOLIACEAE	<i>Alcimandra cathcartii</i> (Hook. f. & Thomson) Dandy
MAGNOLIACEAE	<i>Manglietia forrestii</i> W.W. Sm.ex Dandy
MAGNOLIACEAE	<i>Manglietia garrettii</i> Craib
MAGNOLIACEAE	<i>Manglietia insignis</i> (Wall.) Blume
MAGNOLIACEAE	<i>Michelia cavaleriei</i> Finet & Gagnep.
MAGNOLIACEAE	<i>Michelia floribunda</i> Finet & Gagnep.
MAGNOLIACEAE	<i>Michelia hedyosperma</i> Y.W. Law
MAGNOLIACEAE	<i>Parakmeria yunnanensis</i> Hu
MAGNOLIACEAE	<i>Paramichelia baillonii</i> (Pierre) Hu
MALVACEAE	<i>Hibiscus indicus</i> (Burm. f.) Hochr.

MALVACEAE	<i>Kydia calycina</i> Roxb.
MALVACEAE	<i>Kydia glabrescens</i> var. <i>intermedia</i> S.Y. Hu
MALVACEAE	<i>Sida szechuensis</i> Matsuda
MALVACEAE	<i>Urena lobata</i> L.
MARANTACEAE	<i>Phrynium placentarium</i> (Lour.) Merr.
MARANTACEAE	<i>Stachyphrynium sinense</i> H. Li
MELASTOMACEAE	<i>Medinilla septentrionalis</i> (W.W. Sm.) H.L. Li
MELASTOMACEAE	<i>Melastoma affine</i> D. Don
MELASTOMACEAE	<i>Melastoma normale</i> D. Don
MELASTOMACEAE	<i>Oxyspora vagans</i> (Roxb.) Wall.
MELIACEAE	<i>Aglaia abbreviata</i> C.Y. Wu
MELIACEAE	<i>Aglaia perviridis</i> Hiern
MELIACEAE	<i>Amoora yunnanensis</i> (H.L. Li) C.Y. Wu
MELIACEAE	<i>Dysoxylum binectariferum</i> (Roxb.) Hook. f. ex Bedd.
MELIACEAE	<i>Dysoxylum lukii</i> Merr.
MELIACEAE	<i>Melia toosendan</i> Siebold & Zucc.
MELIACEAE	<i>Toona ciliata</i> M. Roem.
MELIACEAE	<i>Toona sinensis</i> (Juss.) Roem.
MELIACEAE	<i>Trichilia connaroides</i> (Wight & Arn.) Benth.
MELIACEAE	<i>Walsura yunnanensis</i> C.Y. Wu
MENISPERMACEAE	<i>Cocculus laurifolius</i> DC.
MENISPERMACEAE	<i>Stephania forsteri</i> (DC.) A. Gray
MIMOSACEAE	<i>Albizia bracteata</i> Dunn
MIMOSACEAE	<i>Albizia chinensis</i> (Osbeck) Merr.
MIMOSACEAE	<i>Albizia crassiramea</i> Lace
MIMOSACEAE	<i>Albizia lucidior</i> (Steud.) I.C. Nielsen
MIMOSACEAE	<i>Albizia odoratissima</i> (Linn. f.) Benth.

MIMOSACEAE	<i>Cylindrokelupha kerrii</i> (Gagnep.) T.L. Wu
MIMOSACEAE	<i>Pithecolobium clypearia</i> Benth.
MORACEAE	<i>Artocarpus lakoocha</i> Wall. ex Roxb.
MORACEAE	<i>Artocarpus nitidus</i> subsp. <i>griffithii</i> (King) F.M. Jarrett
MORACEAE	<i>Artocarpus tonkinensis</i> A. Chev.
MORACEAE	<i>Broussonetia papyrifera</i> (L.) L'Hér. ex Vent.
MORACEAE	<i>Ficus auriculata</i> Lour.
MORACEAE	<i>Ficus cyrtophylla</i> Wall. ex Miq.
MORACEAE	<i>Ficus esquiroliana</i> H. Lév.
MORACEAE	<i>Ficus fistulosa</i> Reinw. ex Blume
MORACEAE	<i>Ficus hookeriana</i> Corner
MORACEAE	<i>Ficus semicordata</i> Buch.-Ham. ex Sm.
MORACEAE	<i>Morus macroura</i> Miq.
MUSACEAE	<i>Musa acuminata</i> Colla
MYRICACEAE	<i>Myrica esculenta</i> Buch.-Ham. ex D. Don
MYRISTICACEAE	<i>Horsfieldia glabra</i> (Reinw. ex Blume) Warb.
MYRISTICACEAE	<i>Horsfieldia tetratapa</i> C.Y. Wu
MYRISTICACEAE	<i>Knema cinerea</i> var. <i>glauca</i> (Blume) Y.H. Li
MYRISTICACEAE	<i>Knema erratica</i> (Hook. f. & Thomson) J. Sincl.
MYRISTICACEAE	<i>Knema furfuracea</i> (Hook. f. & Thomson) Warb.
MYRISTICACEAE	<i>Knema globularia</i> (Lam.) Warb.
MYRSINACEAE	<i>Ardisia corymbifera</i> Mez
MYRSINACEAE	<i>Ardisia depressa</i> C.B. Clarke
MYRSINACEAE	<i>Ardisia thyrsiflora</i> D. Don
MYRSINACEAE	<i>Ardisia villosa</i> Roxb.
MYRSINACEAE	<i>Ardisia virens</i> Kurz
MYRSINACEAE	<i>Embelia laeta</i> (L.) Mez

MYRSINACEAE	<i>Maesa indica</i> (Roxb.) A. DC.
MYRSINACEAE	<i>Maesa macilentoides</i> C. Chen
MYRSINACEAE	<i>Maesa perlaria</i> (Lour.) Merr.
MYRSINACEAE	<i>Maesa permollis</i> Kurz
MYRSINACEAE	<i>Myrsine seguinii</i> H. Lév.
MYRTACEAE	<i>Decaspermum fruticosum</i> J.R. Forst. & G. Forst.
MYRTACEAE	<i>Syzygium brachythyrsum</i> Merr. & L.M. Perry
MYRTACEAE	<i>Syzygium cathayense</i> Merr. & L.M. Perry
MYRTACEAE	<i>Syzygium polypetaloideum</i> Merr. & L.M. Perry
MYRTACEAE	<i>Syzygium rockii</i> Merr. & L.M. Perry
MYRTACEAE	<i>Syzygium tetragonum</i> (Wight) Wall. ex Walp.
MYRTACEAE	<i>Syzygium thumra</i> (Roxb.) Merr. & L.M. Perry
MYRTACEAE	<i>Syzygium yunnanense</i> Merr. & L.M. Perry
NYSSACEAE	<i>Nyssa wenshanensis</i> Fang & Soong
NYSSACEAE	<i>Nyssa wenshanensis</i> var. <i>longipedunculata</i> W.P. Fang & Soong
NYSSACEAE	<i>Nyssa yunnanensis</i> W. C. Yin
OLACACEAE	<i>Schoepfia fragrans</i> Wall.
OLEACEAE	<i>Chionanthus ramiflorus</i> Roxb.
OLEACEAE	<i>Fraxinus floribunda</i> Wall.
OLEACEAE	<i>Jasminum attenuatum</i> Roxb. ex G. Don
OLEACEAE	<i>Jasminum lanceolarium</i> Roxb.
OLEACEAE	<i>Ligustrum sinense</i> Lour.
OLEACEAE	<i>Linociera insignis</i> C.B. Clarke
OLEACEAE	<i>Olea rosea</i> Craib
OXALIDACEAE	<i>Oxalis corniculata</i> L.
PAPILIONACEAE	<i>Craspedolobium schochii</i> Harms
PAPILIONACEAE	<i>Dalbergia assamica</i> Benth.

PAPILIONACEAE	<i>Dalbergia pinnata</i> (Lour.) Prain
PAPILIONACEAE	<i>Dalbergia stipulacea</i> Roxb.
PAPILIONACEAE	<i>Erythrina subumbrans</i> (Hassk.) Merr.
PAPILIONACEAE	<i>Fordia cauliflora</i> Hemsl.
PAPILIONACEAE	<i>Fordia microphylla</i> Dunn ex Z. Wei
PAPILIONACEAE	<i>Millettia leptobotrya</i> Dunn
PAPILIONACEAE	<i>Millettia pachycarpa</i> Benth.
PAPILIONACEAE	<i>Millettia tetraptera</i> Kurz
PAPILIONACEAE	<i>Millettia unijuga</i> Gagnep.
PAPILIONACEAE	<i>Mucuna pruriens</i> (L.) DC.
PAPILIONACEAE	<i>Ormosia fordiana</i> Oliv.
PAPILIONACEAE	<i>Ormosia olivacea</i> L. Chen
PAPILIONACEAE	<i>Pycnospora lutescens</i> (Poir.) Schindl.
PAPILIONACEAE	<i>Spatholobus pulcher</i> Dunn
PASSIFLORACEAE	<i>Passiflora siamica</i> Craib
PASSIFLORACEAE	<i>Passiflora wilsonii</i> Hemsl.
PINACEAE	<i>Pinus kesiya</i> Royle ex Gordon
PIPERACEAE	<i>Peperomia blanda</i> (Jacq.) Kunth
PIPERACEAE	<i>Peperomia heyneana</i> Miq.
PIPERACEAE	<i>Peperomia pellucida</i> (L.) Kunth
PIPERACEAE	<i>Peperomia tetraphylla</i> (G. Forst.) Hook. & Arn.
PIPERACEAE	<i>Piper chaudocanum</i> C. DC.
PIPERACEAE	<i>Piper flaviflorum</i> C. DC.
PIPERACEAE	<i>Piper longum</i> L.
PIPERACEAE	<i>Piper macropodium</i> C. DC.
PIPERACEAE	<i>Piper thomsonii</i> (C. DC.) Hook. f.
PIPERACEAE	<i>Piper yunnanense</i> Y.Q. Tseng

PITTOSPORACEAE	<i>Pittosporum kerrii</i> Craib
PLANTAGINACEAE	<i>Plantago erosa</i> Wall. ex Roxb.
PLANTAGINACEAE	<i>Plantago major</i> L.
POACEAE	<i>Fargesia plurisetosa</i> T.H. Wen
POACEAE	<i>Imperata cylindrica</i> (L.) P. Beauv.
POACEAE	<i>Microstegium ciliatum</i> (Trin.) A. Camus
POACEAE	<i>Setaria palmifolia</i> (J. König) Stapf
POACEAE	<i>Thysanolaena maxima</i> (Roxb.) Kuntze
PODOCARPACEAE	<i>Podocarpus neriifolius</i> D. Don
POLYGALACEAE	<i>Polygala arillata</i> Buch.-Ham. ex D. Don
POLYGALACEAE	<i>Polygala glomerata</i> Lour.
POLYGALACEAE	<i>Securidaca inappendiculata</i> Hassk.
POLYGONACEAE	<i>Polygonum chinense</i> L.
POLYGONACEAE	<i>Polygonum chinense</i> var. <i>hispidum</i> Hook. f.
POLYGONACEAE	<i>Polygonum chinense</i> var. <i>ovalifolium</i> Meisn.
POLYGONACEAE	<i>Polygonum hydropiper</i> L.
POLYGONACEAE	<i>Polygonum lapathifolium</i> L.
POLYGONACEAE	<i>Polygonum orientale</i> L.
POLYGONACEAE	<i>Polygonum perfoliatum</i> L.
PORTULACACEAE	<i>Portulaca oleracea</i> L.
PROTEACEAE	<i>Helicia cochinchinensis</i> Lour.
PROTEACEAE	<i>Helicia nilagirica</i> Bedd.
PROTEACEAE	<i>Helicia pyrrhobotrya</i> Kurz
PROTEACEAE	<i>Helicia reticulata</i> W.T. Wang
PROTEACEAE	<i>Helicia shweliensis</i> W.W. Sm.
PROTEACEAE	<i>Helicia silvicola</i> W.W. Sm.
PROTEACEAE	<i>Helicia tsaii</i> W.T. Wang

PROTEACEAE	<i>Heliciopsis terminalis</i> (Kurz) Sleumer
RANUCULACEAE	<i>Clematis fulvicoma</i> Rehder & E.H. Wilson
RANUCULACEAE	<i>Clematis peterae</i> Hand.-Mazz.
RANUCULACEAE	<i>Clematis subumbellata</i> Kurz
RHAMNACEAE	<i>Gouania leptostachya</i> DC.
	<i>Hovenia acerba</i> var. <i>kiukiangensis</i> (Hu & Cheng) C. Y. Wu ex Y.
RHAMNACEAE	L. Chen
RHAMNACEAE	<i>Rhamnus leptophylla</i> C.K. Schneid.
RHAMNACEAE	<i>Ventilago calyculata</i> Tul.
RHIZOPHORACEAE	<i>Carallia brachiata</i> (Lour.) Merr.
RHIZOPHORACEAE	<i>Carallia diplopetala</i> Hand.-Mazz.
ROSACEAE	<i>Cerasus cerasoides</i> (Buch.-Ham. ex D. Don) S.Y. Sokolov
ROSACEAE	<i>Docynia delavayi</i> (Franch.) C.K. Schneid.
ROSACEAE	<i>Duchesnea chrysantha</i> (Zoll. & Moritzi) Miq.
ROSACEAE	<i>Eriobotrya bengalensis</i> var. <i>angustifolia</i> Cardot
ROSACEAE	<i>Eriobotrya obovata</i> W.W. Sm.
ROSACEAE	<i>Laurocerasus jenkinsii</i> (Hook. f.) Browicz
ROSACEAE	<i>Laurocerasus menghaiensis</i> T.T. Yu & L.T. Lu
ROSACEAE	<i>Laurocerasus zippeliana</i> (Miq.) Yu et Lu
ROSACEAE	<i>Photinia glabra</i> (Thunb.) Maxim.
ROSACEAE	<i>Potentilla kleiniana</i> Wight & Arn.
ROSACEAE	<i>Pygeum arboretum</i> (Bl.) C. Kalkman
ROSACEAE	<i>Pygeum topengii</i> Merr.
ROSACEAE	<i>Pyrus pashia</i> Buch.-Ham. ex D. Don
ROSACEAE	<i>Rubus pirifolius</i> Sm.
ROSACEAE	<i>Rubus poliophyllus</i> Kuntze
ROSACEAE	<i>Rubus rufus</i> var. <i>palmatifidus</i> Cardot

ROSACEAE	<i>Sorbus corymbifera</i> (Miq.) Khep & Yakovlev
ROSACEAE	<i>Sorbus globosa</i> T.T. Yu & Tsai
ROSACEAE	<i>Stranvaesia oblanceolata</i> (Rehder & E.H. Wilson) Stapf
RUBIACEAE	<i>Aidia cochinchinensis</i> Lour.
RUBIACEAE	<i>Brachytome hirtellata</i> var. <i>glabrescens</i> W.C. Chen
RUBIACEAE	<i>Canthium parvifolium</i> Roxb.
RUBIACEAE	<i>Discospermum fruticosum</i> (Hemsl.) Kuntze
RUBIACEAE	<i>Geophila herbacea</i> (Jacq.) K. Schum.
RUBIACEAE	<i>Hedyotis capitellata</i> var. <i>mollissima</i> (Pit.) W.C. Ko
RUBIACEAE	<i>Hedyotis diffusa</i> Willd.
RUBIACEAE	<i>Hedyotis scandens</i> Roxb.
RUBIACEAE	<i>Lasianthus inodorus</i> Bl.
RUBIACEAE	<i>Lasianthus lucidus</i> Bl.
RUBIACEAE	<i>Lasianthus sikkimensis</i> Hook.f.
RUBIACEAE	<i>Metadina trichotoma</i> (Zoll. & Moritzi) Bakh. f.
RUBIACEAE	<i>Mussaenda hossei</i> Craib
RUBIACEAE	<i>Mycetia gracilis</i> Craib
RUBIACEAE	<i>Ophiorrhiza mungos</i> L.
RUBIACEAE	<i>Oxyceros sinensis</i> Lour.
RUBIACEAE	<i>Psychotria symplocifolia</i> Kurz
RUBIACEAE	<i>Tarennoidea wallichii</i> (Hook. f.) Tirveng. & Sastre
RUBIACEAE	<i>Uncaria laevigata</i> Wall. ex G. Don
RUBIACEAE	<i>Uncaria sessilifructus</i> Roxb.
RUBIACEAE	<i>Wendlandia pingpienensis</i> F.C. How
RUBIACEAE	<i>Wendlandia scabra</i> Kurz
RUBIACEAE	<i>Wendlandia tinctoria</i> (Roxb.) DC.
RUTACEAE	<i>Acronychia pedunculata</i> (L.) Miq.

RUTACEAE	<i>Evodia austrosinensis</i> Hand.-Mazz.
RUTACEAE	<i>Evodia glabrifolia</i> (Champ. ex Benth.) C.C. Huang
RUTACEAE	<i>Evodia leptota</i> (Spreng.) Merr.
RUTACEAE	<i>Evodia leptota</i> var. <i>cambodiana</i> (Pierre) C.C. Huang
RUTACEAE	<i>Evodia simplicifolia</i> Ridl.
RUTACEAE	<i>Evodia trichotoma</i> (Lour.) Pierre
RUTACEAE	<i>Paramignya rectispina</i> Craib
RUTACEAE	<i>Toddalia asiatica</i> (L.) Lam.
SABIACEAE	<i>Meliosma simplicifolia</i> (Roxb.) Walp.
SABIACEAE	<i>Meliosma velutina</i> Rehder & E.H. Wilson
SALICACEAE	<i>Salix tetrasperma</i> Roxb.
SAMYDACEAE	<i>Casearia balansae</i> Gagnep.
SAMYDACEAE	<i>Casearia velutina</i> Blume
SAPINDACEAE	<i>Dimocarpus yunnanensis</i> (W.T. Wang) C.Y. Wu & T.L. Ming
SAPINDACEAE	<i>Nephelium chryseum</i> Blume
SAPINDACEAE	<i>Sapindus rarak</i> DC.
SAPOTACEAE	<i>Pouteria grandifolia</i> (Wall.) Baehni
SAPOTACEAE	<i>Sarcosperma arboreum</i> Buch.-Ham. ex C.B. Clarke
SAPOTACEAE	<i>Sarcosperma griffithii</i> Hook. f. ex C.B. Clarke
	<i>Sarcosperma kachinense</i> var. <i>simondii</i> (Gagnep.) H.J. Lam & P.
SAPOTACEAE	Royen
SAPOTACEAE	<i>Xantolis boniana</i> var. <i>rostrata</i> (Merr.) P. Royen
SAPOTACEAE	<i>Xantolis stenosepala</i> (Hu) P. Royen
SAPOTACEAE	<i>Xantolis stenosepala</i> var. <i>brevistylis</i> C.Y. Wu
SAURAUACEAE	<i>Saurauia cerea</i> Griff. ex Dyer
SAURAUACEAE	<i>Saurauia macrotricha</i> Kurz ex Dyer
SAURAUACEAE	<i>Saurauia miniata</i> C.F. Liang & Y.S. Wang

SAURAUACEAE	<i>Saurauia napaulensis</i> DC.
SAURAUACEAE	<i>Saurauia punduana</i> Wall.
SAURAUACEAE	<i>Saurauia yunnanensis</i> C.F. Liang & Y.S. Wang
SCHIZANDRACEAE	<i>Kadsura ananosma</i> Kerr
SCHIZANDRACEAE	<i>Kadsura angustifolia</i> A.C. Smith
SCHIZANDRACEAE	<i>Schisandra henryi</i> var. <i>yunnanensis</i> A.C. Sm.
SCHIZANDRACEAE	<i>Schisandra neglecta</i> A.C. Sm.
SCHIZANDRACEAE	<i>Schisandra plena</i> A.C. Sm.
SCROPHULARIACEAE	<i>Lindenbergia indica</i> (L.) Vatke
SLADENIACEAE	<i>Sladenia celastriifolia</i> Kurz
SOLANACEAE	<i>Lycianthes biflora</i> (Lour.) Bitter
SOLANACEAE	<i>Lycianthes biflora</i> var. <i>subtusochracea</i> Bitter
SOLANACEAE	<i>Solanum aculeatissimum</i> Jacq.
SOLANACEAE	<i>Solanum anguivi</i> Lam.
SOLANACEAE	<i>Solanum erianthum</i> D. Don
SOLANACEAE	<i>Solanum merrillianum</i> Liou
SOLANACEAE	<i>Solanum spirale</i> Roxb.
SOLANACEAE	<i>Solanum torvum</i> Sw.
STAPHYLACEAE	<i>Tapiscia yunnanensis</i> W.C. Cheng & C.D. Chu
STAPHYLACEAE	<i>Turpinia cochinchinensis</i> (Lour.) Merr.
STAPHYLACEAE	<i>Turpinia pomifera</i> (Roxb.) DC.
STEMONACEAE	<i>Stemona tuberosa</i> Lour.
STERCULIACEAE	<i>Pterospermum acerifolium</i> Willd.
STERCULIACEAE	<i>Reevesia pubescens</i> Mast.
STERCULIACEAE	<i>Reevesia thsoidea</i> Lindl.
STERCULIACEAE	<i>Sterculia lanceifolia</i> Roxb.
STERCULIACEAE	<i>Sterculia lanceolata</i> Cav.

STYRACACEAE	<i>Bruinsmia polysperma</i> (Clarke) Steenis
STYRACACEAE	<i>Styrax grandiflorus</i> Griff.
STYRACACEAE	<i>Styrax rugosus</i> Kurz
STYRACACEAE	<i>Styrax tonkinensis</i> (Pierre) Craib ex Hartwich
SYMPLOCACEAE	<i>Symplocos sulcata</i> Kurz
SYMPLOCACEAE	<i>Symplocos wikstroemiifolia</i> Hayata
TACCACEAE	<i>Tacca chantrieri</i> André
THEACEAE	<i>Adinandra megaphylla</i> Hu
THEACEAE	<i>Camellia sinensis</i> var. <i>assamica</i> (J.W. Mast.) Kitam.
THEACEAE	<i>Camellia pachyandra</i> Hu
THEACEAE	<i>Camellia sinensis</i> (L.) Kuntze
THEACEAE	<i>Eurya aurea</i> H.T. Chang
THEACEAE	<i>Eurya austroyunnanensis</i> T.L. Ming & H. Chu
THEACEAE	<i>Eurya groffii</i> Merr.
THEACEAE	<i>Eurya jintungensis</i> Hu & L.K. Ling
THEACEAE	<i>Eurya persicaefolia</i> Gagnep.
THEACEAE	<i>Eurya pseudocerasifera</i> Kobuski
THEACEAE	<i>Gordonia chrysandra</i> Cowan
THEACEAE	<i>Pyrenaria yunnanensis</i> Hu
THEACEAE	<i>Schima argentea</i> E. Pritz.
THEACEAE	<i>Schima khasiana</i> Dyer
THEACEAE	<i>Schima wallichii</i> Choisy
THEACEAE	<i>Ternstroemia gymnanthera</i> (Wight & Arn.) Bedd.
THEACEAE	<i>Tutcheria pingpienensis</i> Hung T. Chang
THYMELEACEAE	<i>Eriosolena composita</i> (L. f.) Tiegh.
TILIACEAE	<i>Colona floribunda</i> (Wall. ex Voigt) Craib
TILIACEAE	<i>Microcos chungii</i> (Merr.) Chun

TILIACEAE	<i>Microcos paniculata</i> L.
ULMACEAE	<i>Celtis sinensis</i> Pers.
ULMACEAE	<i>Celtis timorensis</i> Span.
ULMACEAE	<i>Gironniera subaequalis</i> Planch.
ULMACEAE	<i>Trema orientalis</i> (L.) Blume
URTIACEAE	<i>Boehmeria macrophylla</i> Hornem.
URTIACEAE	<i>Debregeasia libera</i> Chien et C.J. Chen
URTIACEAE	<i>Debregeasia longifolia</i> (Burm. f.) Wedd.
URTIACEAE	<i>Debregeasia squamata</i> King ex Hook. f.
URTIACEAE	<i>Dendrocide sinuata</i> (Blume) Chew
URTIACEAE	<i>Oreocnide rubescens</i> (Blume) Miq.
VACCINIACEAE	<i>Agapetes lobbii</i> C.B. Clarke
VACCINIACEAE	<i>Agapetes mannii</i> Hemsl.
VACCINIACEAE	<i>Vaccinium exaristatum</i> Kurz
VERBENACEAE	<i>Callicarpa arborea</i> Roxb.
VERBENACEAE	<i>Callicarpa bodinieri</i> H. Lév.
VERBENACEAE	<i>Callicarpa cathayana</i> H.T. Chang
VERBENACEAE	<i>Callicarpa giraldii</i> Hesse ex Rehder
VERBENACEAE	<i>Callicarpa longifolia</i> Lam.
VERBENACEAE	<i>Clerodendrum bungei</i> Steud.
VERBENACEAE	<i>Clerodendrum colebrookianum</i> Walp.
VERBENACEAE	<i>Clerodendrum japonicum</i> (Thunb.) Sweet
VERBENACEAE	<i>Clerodendrum serratum</i> (L.) Moon
VERBENACEAE	<i>Clerodendrum serratum</i> var. <i>amplexifolium</i> Moldenke
	<i>Clerodendrum serratum</i> var. <i>herbaceum</i> (Roxb. ex Schauer) C.Y.
VERBENACEAE	Wu
VERBENACEAE	<i>Clerodendrum villosum</i> Blume

VERBENACEAE	<i>Premna scandens</i> Roxb.
VERBENACEAE	<i>Vitex quinata</i> var. <i>puberula</i> (H.J. Lam) Moldenke
VIOLACEAE	<i>Viola diffusoides</i> Ching J. Wang
VIOLACEAE	<i>Viola hossei</i> W. Becker
VITACEAE	<i>Ampelopsis cantoniensis</i> (Hook. & Arn.) Planch.
VITACEAE	<i>Cayratia timoriensis</i> var. <i>mekongensis</i> (C.Y. Wu) C.L. Li
VITACEAE	<i>Tetrastigma obovatum</i> (Lawson) Gagnep.
XANTHOPHYLLACEAE	<i>Xanthophyllum yunnanense</i> C.Y. Wu
ZINGIBERACEAE	<i>Amomum koenigii</i> J.F. Gmel.
ZINGIBERACEAE	<i>Boesenbergia rotunda</i> (L.) Mansf.
ZINGIBERACEAE	<i>Globba barthei</i> Gagnep.
ZINGIBERACEAE	<i>Globba racemosa</i> Sm.
ZINGIBERACEAE	<i>Globba schomburgkii</i> Hook. f.
ZINGIBERACEAE	<i>Rhynchanthus beesianus</i> W.W. Sm.

Geological History, Flora, and Vegetation of Xishuangbanna, Southern Yunnan, China¹

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ABSTRACT

Xishuangbanna of southern Yunnan is biogeographically located at a transitional zone from tropical Southeast (SE) Asia to subtropical East Asia, and is at the junction of the Indian and Burmese plates of Gondwana and the Eurasian plate of Laurasia. The flora of the region consists of a recorded 3336 native seed plant species, belonging to 1140 genera in 197 families, among which 83.5 percent are tropical genera and 32.8 percent are endemic to tropical Asia, suggesting a strong affinity to tropical Asian flora. The vegetation of Xishuangbanna is organized into four forest types: tropical rain forest, tropical seasonal moist forest, tropical montane evergreen broad-leaved forest, and tropical monsoon forest. The tropical rain forest in Xishuangbanna has the same floristic composition of families and genera as some lowland equatorial rain forests in SE Asia, and is dominated (with a few exceptions) by the same families both in species richness and stem dominance. The exceptions include some deciduous trees in the canopy layer, fewer megaphanerophytes and epiphytes, and a higher abundance of lianas and microphyllous plants. We consider the tropical rain forest of Xishuangbanna as a type of tropical Asian rain forest, based on their conspicuous similarities in ecological and floristic characteristics.

Key words: floristic composition; southern Yunnan; tropical rain forest; vegetation types; Xishuangbanna.

THE TROPICAL AREA OF SOUTHERN CHINA is climatically and biogeographically located at the northern edge of tropical Asia. The largest tropical area still covered by native forests is in southern Yunnan. C.W. Wang briefly mentioned the tropical flora and vegetation of southern China, especially those of southwestern China, for the first time in 1939 (Wang 1939). Tropical rain forests of southwestern China were little known to the scientific community until the late 1950s because of poor access to the region. For a long time there has been discussion as to whether there is true tropical rain forest in southern Yunnan owing to its location at the northern edge of tropical Southeast (SE) Asia and monsoon climate. It was commonly assumed that if there were tropical rain forests in the region, they would probably be intermediate between tropical rain forests and monsoon forests, as defined by Schimper (1903), or be types of subtropical rain forests which differ in various aspects from tropical rain forests described by Richards (1952). Some papers on the tropical rain forest vegetation (Fedorov 1958, Qu 1960, Wang 1961) and tropical flora (Fedorov 1957, Wu 1965) of this region were published after a China–Russia expedition that penetrated deep into the areas of southwestern China (including southern Yunnan) in the late 1950s. It was then accepted that true tropical rain forests exist in the southern Yunnan region of southwestern China. These forests were considered distinct from the Indo-Malaysian forests, however, because they lacked representatives of Dipterocarpaceae, which dominate the typical rain forests of tropical SE Asia.

Botanical interest in the area was rekindled in the 1970s by the discovery of a dipterocarp forest in southern Yunnan. From that finding, the Indo-Malaysian affinity of the tropical flora of China was taken into consideration. Further biogeographical and ecological studies on the vegetation and flora of tropical southern Yunnan revealed that it indeed comprises a part of Indo-Malaysian

flora (Zhu 1992; 1993a, b; 1994; 1997; 2002; Zhu *et al.* 1998a, b; 2001; 2002; 2003; 2004). Furthermore, on a short visit to southern Yunnan, T. C. Whitmore felt that the birds in the tropical rain forest sing the same songs as those heard in the tropical rain forests of Malaysia (Whitmore 1982). He also confirmed that there is true evergreen rain forest present in the southern fringe of China (Whitmore 1984, 1990).

Xishuangbanna is an administrative region in southern Yunnan. It has a typical monsoon climate. Despite its relatively high latitude and elevation, Xishuangbanna has a tropical moist climate in the southern area due to the Hengduan Mountains which form a barrier, keeping out northern cold air during winter. Additionally, the montane topography produces dense radiation fog during the dry season, which can supplement the reduction in precipitation. Biogeographically, the region is located at a transitional zone with tropical SE Asia to the south, subtropical East Asia to the north, the Sino-Japanese floristic region to the east, and the Sino-Himalayan floristic region to the west. Southern Yunnan is therefore a key area in biogeography and a hotspot for biodiversity (Myers 1998).

GEOLOGICAL HISTORY

Southern Yunnan is at the junction of the Indian and Burmese plates of Gondwana and the Eurasian plate of Laurasia (Audley-Charles 1987, Hall 1998). Before the Mesozoic era, the area was a part of the Tethys margin, and later some fragments from Gondwanaland were combined. Since the Tertiary period, the region had gone through several stages of rising and descending with the intermittent uplift of the Himalayas, and gradually formed the modern topography in the mid-Tertiary period (Shi *et al.* 1998, 1999).

During the late Cretaceous period, the region was under a dry and hot climatic condition, based on fossil records from Mengla, where a relatively high proportion of *Ulmipollenites* and *Ephedripites*

¹Received 11 October 2004; revision accepted 1 November 2005.

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were found (Sun 1979). From the Paleocene to the Eocene periods, the region went through a rising stage with the uplift of the Himalayas, and was influenced by a dry climate with a high deposition of salt minerals. From the Miocene to the Neocene periods, the region descended to some extent, and formed a series of basins with a wet and warm climate. Since the Quaternary period, the region has gone through rapid rising again, associated with alternative climatic changes of wet and dry periods (Liu *et al.* 1986).

Paleobotanical work is insufficient in the region, especially for the Tertiary period. From pollen deposition in Mengla during the late Cretaceous to the early Tertiary periods (except *Ulmipollenites*, and *Ephedripites*), Sun (1979) found the presence of gymnosperms such as *Tsugaepollenites*, *Araucariacites*, *Taxodiaceapollenites*, *Abietinaepollenites*, and *Pinuspollenites*, and angiosperms such as *Engelhardtoidites*, *Faguspollenites*, *Ilexpollenites*, *Symplocospollenites*, *Rhamnacidites*, *Cupuliferuipollenites*, *Caprifoliidites*, *Quercoidites*, *Fraxinoipollenites*, and *Liquidambarpollenites*. This evidence indicates that the representative vegetation in the period was a subtropical montane evergreen broad-leaved forest, which was similar to the present vegetation in subtropical Yunnan.

Song *et al.* (1976, 1983) defined the region and neighboring northern SE Asia as a paleo-phytogeographical region of *Quercus-Betula* vegetation of the Miocene–Neocene plateau, suggesting that the vegetation in Xishuangbanna could have been a subtropical montane evergreen broad-leaved forest during that period. From other available references (Wulff 1944, Editorial Group for Cenozoic Plants from China 1978, Song 1984, Zhou and Ren 1984, Wang 1996), the vegetation of regions neighboring southern Yunnan was considered to be subtropical evergreen broad-leaved forests during the Tertiary period. A 40,000-yr palynological record from northeast Thailand indicated that the region supported a Fagaceae-coniferous forest, similar to contemporary vegetation from subtropical southwest China, and climatic conditions were cooler and probably drier in the Pleistocene than present northern Thailand (Penny 2001). Xishuangbanna is geographically near northern Thailand. Therefore, it is possible that Xishuangbanna had vegetation and climatic conditions similar to northern Thailand during the Pleistocene period.

The present tropical rain forest in Xishuangbanna is at the altitudinal and latitudinal limits of tropical rain forests in the northern hemisphere. It was believed that the tropical moist climate in southern Yunnan did not form until the Himalayas lifted up to a certain elevation after the late Tertiary period. Thus, the tropical rain forests in the region were developed after the later Tertiary period. The fundamental topography and climate of the region have been strongly affected by the uplift of the Himalayas and the formation of the eastern monsoon climate (Shi *et al.* 1998, 1999).

THE FLORA

FLORISTIC COMPOSITION.—Based on more than 40 yr of intermittent field collections, 3336 native species of 1218 genera and

207 families of seed plants have been recognized from this region in southern Yunnan (Li 1996). The families with highest species richness include Orchidaceae (96 genera/334 species), Fabaceae (68/232), Rubiaceae (43/147), Poaceae (65/141), Euphorbiaceae (38/119), Asteraceae (59/107), Lamiaceae (36/105), Moraceae (6/77), Urticaceae (12/72), Lauraceae (12/68), Zingiberaceae (15/67), Asclepiadaceae (25/62), Apocynaceae (27/61), Annonaceae (15/52), Acanthaceae (32/50), and Cucurbitaceae (17/50). The family Orchidaceae has higher species richness in Xishuangbanna than in Laos and Cambodia (Chen & Tsi 1996).

Some families have only a small number of species in Xishuangbanna, but are the dominant families in phytosociological importance (dominant in stems) in the tropical forests of the region. Such families include: Sapindaceae, Anacardiaceae, Burseraceae, Elaeocarpaceae, Ebenaceae, Combretaceae, Ulmaceae, and Myrtaceae. The families Dipterocarpaceae, Barringtoniaceae, Tetrameleaceae, Myristicaceae, Clusiaceae, Icacinaceae, Ixonanthaceae, and Sapotaceae also have even few species, but high phytosociological importance.

At the generic level, *Ficus* has the highest species richness with 51 species. Other genera with high species richness include *Dendrobium* (43 species), *Bulbophyllum* (40), *Piper* (24), *Dioscorea* (23), *Syzygium* (23), *Eria* (22), *Litsea* (21), *Lasianthus* (17), *Lithocarpus* (17), *Millettia* (17), *Pilea* (17), *Castanopsis* (16), *Tetrastigma* (16), *Calamus* (16), *Elaeocarpus* (14), *Elatostema* (14), *Anomum* (14), *Clerodendrum* (14), *Ardisia* (12), *Dysoxylum* (10), and *Fissistigma* (10). *Pometia*, *Terminalia*, *Antiaris*, *Girroniera*, *Pouteria*, *Pterosperma*, and *Tetrameles* have fewer species but high phytosociological importance in the dominant tree layer, and *Lasiococca*, *Garcinia*, *Mitrephora*, *Alphonsea*, *Cleidion*, *Sumbaviopsis*, *Trigonostemon*, and *Pittosporopsis* in the lower tree layer of the tropical rain forest in the region. In the tropical montane rain forest of the region, *Castanopsis*, *Lithocarpus*, *Machilus*, *Litsea*, *Phoebe*, *Anneslea*, and *Schima* are the most dominant genera.

GEOGRAPHICAL ELEMENTS.—In the flora of Xishuangbanna, families of strictly tropical distribution contribute 18.2 percent of the total sum of the flora. These families include those of pantropical distribution, such as Dipterocarpaceae, Myristicaceae, Taccaceae, and Icacinaceae; Old World tropical distribution, such as Sonneratiaceae and Barringtoniaceae; tropical Asian, African, and American distribution, including Aristolochiaceae, Bombacaceae, and Ixonanthaceae; and the tropical Asian Carlemanniaceae, Mastixiaceae, Sladeniaceae, Crypteroniaceae, and Pentaphragmaceae. Families with tropical as well as nontropical species contribute 41 percent of the total flora. Such families include Rubiaceae, Acanthaceae, Euphorbiaceae, Moraceae, Apocynaceae, and Meliaceae. The families of mainly subtropical distribution contribute 17.7 percent of the total flora, including Fagaceae, Magnoliaceae, Theaceae, Symplocaceae, Hamamelidaceae, and Aquifoliaceae. Families of mainly temperate distribution contribute 22.2 percent of the total flora, such as Primulaceae, Ranunculaceae, Scrophulariaceae, and Lamiaceae.

At the generic level, patterns of seed plant distribution in China were summarized by the Chinese botanist Wu (1991). From Wu's documentation, the distribution patterns of genera from the flora of Xishuangbanna are quantified and given in Table 1.

The genera of tropical Asian distribution, such as *Alphonsea*, *Pterospermum*, *Mitrephora*, *Chukrasia*, *Crypteronia*, and *Knema*, show the highest percentage among all distribution types, contributing to 32.8 percent of the flora. Genera of pantropical distribution, such as *Gnetum*, *Cryptocarya*, *Piper*, *Lasianthus*, *Bauhinia*, and *Marsdenia*, contribute to 22.8 percent of the flora. Following are the genera with Old World tropical distribution, such as *Thunbergia*, *Dracaena*, *Pandanus*, *Carallia*, and *Canarium*. The flora of tropical distribution (see above) compose 83.5 percent of the total number of genera, while genera of temperate distribution such as *Betula*, *Salix*, *Cornus*, and *Sorbus* contribute 10.6 percent of the total genera. Other genera include those with distributions disjunct from East Asia to North America such as *Schizandra*, *Photinia*, *Nyssa*, and *Mahonia*, Old World temperate distributions such as *Ajuga*, *Elsholzia*, *Ligustrum*, *Paris*, etc., and East Asian distributions such as *Actinidia*, *Belamcandia*, and *Cephalotaxus*. The Chinese endemics are only in eight genera, which are *Craspedolobium*, *Cyphotheca*, *Dichotomanthes*, *Biondia*, *Styrophyton*, *Tapiscia*, *Thyrocarpus*, and *Tutcheria*. These data show that the flora of Xishuangbanna is tropical in nature and has strong tropical Asiatic affinity.

The tropical flora of Yunnan (from Southwest to Southeast Yunnan) is composed of 4815 species representing 1447 genera of seed plants (Li 1995). The flora of Xishuangbanna includes more

than 3336 species and 1140 genera. Xishuangbanna is therefore the area with the highest species richness in Yunnan.

VEGETATION TYPES

Terminology and classification of tropical vegetation have not been standardized, and different researchers have used various methods of classification. For example, physiognomic and ecological characters, which were initiated by Drude (1913) and Warming (1909), were used as the main basis for vegetation classification by most American researchers, while floristic aspects (Braun-Blanquet 1932) were used by continental European researchers. Our vegetation classification is based on a combination of physiognomic and ecological characters, floristic composition, and habitats. Physiognomic and ecological characters were used mainly for classification at the vegetation type level, whereas floristic composition and habitats were combined mainly at the formation level. Thus, the vegetation of Xishuangbanna is classified into four main vegetation types: tropical rain forest, tropical seasonal moist forest, tropical montane evergreen broad-leaved forest, and tropical monsoon forest.

TROPICAL RAIN FOREST.—The tropical rain forest (vegetation type) in Xishuangbanna has been classified into two subtypes: tropical seasonal rain forest and tropical montane rain forest (Qu 1960; Wu 1980, 1987; Jin 1983; Zhang & Cao 1995; Cao *et al.* 1996, 1997; Zhu 1992, 1993a, 1997; Jin & Ou 1997; Zhu *et al.* 1998a). The tropical seasonal rain forest is found in the lowlands, usually below 900 m in elevation, while tropical montane rain forest occurs locally at higher elevation.

Like equatorial lowland rain forest, the tropical seasonal rain forest has 3–4 indistinct tree layers, of which the top layer is mainly emergent trees greater than 30 m tall (tallest up to 60 m), with about 30 percent crown coverage. The second layer is the main canopy layer, and is up to 30 m tall with an almost continuous canopy (70–80% coverage), and greatest stem density. The third layer is 5–18 m tall with crown cover of about 40 percent, consisting of small trees and juveniles of species from the upper layers. In some sites, the third tree layer can be further divided into two sublayers: the upper (10–18 m tall), and lower sub-layers (5–9 m tall). Buttresses and cauliflory are common, and both big woody lianas and vascular epiphytes are abundant. The forest is mainly evergreen despite the fact that there are some deciduous trees in the emergent layer.

Based mainly on habitats and floristic composition, the tropical seasonal rain forest of Xishuangbanna is further classified into two formation groups including lower hill seasonal rain forest and ravine seasonal rain forest (Wu 1980, 1987; Zhu 1992, 1997; Jin 1997; Jin & Ou 1997; Zhu *et al.* 1998a). Ravine seasonal rain forest occurs in wet ravine habitats, has relatively high species diversity, more epiphytes, and fewer deciduous trees than lower hill seasonal rain forest. Ravine seasonal rain forest is similar to classic Equatorial lowland tropical rain forest, whereas lower hill seasonal rain forest tends to be a transitional type to tropical montane rain forest.

TABLE 1. Distribution types of seed plants at the generic level from the flora of Xishuangbanna (1135 genera).

Distribution types	Number of genera	Percent
1. Cosmopolitan	48	–
2. Pantropic	248	22.8
3. Tropical Asia and Tropical America disjunct	26	2.4
4. Old World Tropic	112	10.3
5. Tropical Asia to Tropical Australia	75	6.9
6. Tropical Asia to Tropical Africa	91	8.4
7. Tropical Asia	356	32.8
Type 2–7 (total tropical elements)	908	83.5
8. North temperate	57	5.2
9. East Asia and North America disjunct	34	3.1
10. Old World temperate	16	1.5
11. Temperate Asia	4	0.4
12. Mediterranean, W Asia to C Asia	4	0.4
13. Center Asia	1	0.1
14. East Asia	55	5.1
15. Endemic to China	8	0.7
Type 8–15	227	16.5

The tropical montane rain forest in Xishuangbanna occurs in the wet montane habitats between 900 and 1600 m. Structurally, the forest is 20–30 m tall with 2–3 tree layers. A top tree layer with 70–80 percent crown cover forms a canopy without emergent trees. The dominant tree species are *Alstonia scholaris*, *Paramichelia baillonii*, *Michelia floribunda*, *Mastixia euonymoides*, *Alcimandra cathcartii*, *Dysoxylum spicatum*, *Schima wallichii*, *Phoebe nanum*, *Calophyllum polyanthum*, *Phoebe megacalyx*, *Ostodes paniculata*, and *Gymnanthes remota* (Wang *et al.* 2001).

In floristic composition, the tropical montane rain forest is dominated by Magnoliaceae, Mastixiaceae, Lauraceae, Fagaceae, Theaceae, Meliaceae, Euphorbiaceae, and Elaeocarpaceae. In physiognomy, the montane rain forest is dominated by evergreen mesophanerophytes and microphanerophytes with simple, leathery, and entire mesophyllous leaves. The forest has frequent woody lianas and epiphytes, abundant herbaceous phanerophytes, few buttresses, and little cauliflory (Zhu *et al.* 2004).

TROPICAL SEASONAL MOIST FOREST.—Tropical seasonal moist forest occurs on the middle and upper limestone slopes with shallow soils ranging from 650 to 1300 m in elevation. This vegetation type is adjacent to the seasonal rain forest. The forest is evergreen, with two distinct tree layers. The top tree layer has a crown cover of 40–60 percent and is 15–25 m tall. The second tree layer has a crown cover of 70–80 percent and is 3–15 m tall. Woody lianas are very abundant, and vascular epiphytes with small thick leaves are frequent. *Lasiococca comberi* var. *pseudoverticillata*, and *Osmanthus polyneurus* are the dominant species in the top layer, and *Dracaena cochinchinensis* and *Cleistanthus sumatranus* are usually dominant in the second layer. The understory consists of saplings and creeping lianas. The most common lianas are *Loeseneriella yunnanensis* and *Hiptage benhalensis*. Herbaceous species of the family Urticaceae, such as *Procris crenata*, *Elatostemma* spp., and *Pilea* spp., are abundant. Epiphytes are also frequently found on rock substrates (Zhu *et al.* 1998b).

TROPICAL MONTANE EVERGREEN BROAD-LEAVED FOREST.—The primary montane vegetation type in Xishuangbanna is tropical montane evergreen broad-leaved forest. It is distributed on mountain slopes and summits above 1000 m elevation and valleys above 1300 m. The forest is mainly dominated by the families Fagaceae, Euphorbiaceae, Theaceae, and Lauraceae. Physiognomically, the forest is characterized by abundant (ca 70%) trees with mesophyllous and leathery leaves.

The tropical montane evergreen broad-leaved forest has two conspicuous tree layers, of which the top layer is 15–25 m tall with dense crown coverage and the lower layer is 3–15 m tall with coverage of ca 50 percent. The top layer is dominated by species in the Fagaceae and Lauraceae, such as *Castanopsis fleuryi*, *Lithocarpus leucostachyus*, *Lithocarpus grandifolius*, *Lithocarpus truncatus*, *Castanopsis mekongensis*, *Machilus tenuipila*, and *Machilus rufipes*. The frequent species in the lower layer are *Syzygium tetragonum*, *Tricalysia fruticosa*, *Cinnamomum bejolghota*, *Nephelium lappaceum* var. *pallens*, *Macropanax dispermus*, *Harpulia cupanioides*, *Aporosa yunnanensis*, and *Phoebe lanceolata*. The frequent shrub species are

Ardisia spp., *Psychotria symplocifolia*, *Lasianthus hookeri* var. *dunnuanus*, and *Evodia leptota*. Herbaceous plants are abundant. Common species are *Strobilanthes* spp., *Alpinia* spp., *Phrynium capitatum*, and ferns. The common liana species are *Tetrastigma* spp., *Celastrus paniculata*, *Parameria laevigata*, and *Millettia* spp. Common epiphytes are *Rhaphidophora hongkongensis*, *Pothos chinensis*, *Schefflera venulosa*, *Ficus* spp., *Dendrobium* spp., *Bulbophyllum* spp., and *Eria* spp.

MONSOON FOREST.—Monsoon forest is a tropical deciduous forest under the influence of strong monsoon climate as defined by Schimper (1903). In southern Yunnan and SE Asia, monsoon forest often has a mosaic distribution within seasonal rain forest. Monsoon forest seems to be a transitional forest type between seasonal rain forest and savanna. In Xishuangbanna, monsoon forest occurs on the banks of the Mekong River and at wide basins where there is evidently an annual dryness due to the strong monsoon climate. The monsoon forest is usually 20–25 m tall with 1–2 deciduous tree layers. Woody lianas and epiphytes are scarce. Frequent tree species are *Bombax ceiba*, *Ficus altissima*, *Chukrasia tabularis* var. *velutina*, *Erythrina stricta*, *Pterocarya tonkinensis*, *Albizia chinensis*, *Bischoffia javanica*, *Bauhinia variaegata*, *Anogeissus acumunata*, *Stereospermum tetragonum*, and *Mitragyna brunonis*. The monsoon forest is often a single dominant tree community or consociation (Wang & Zhu 1990, Li *et al.* 1993, Zhu 2005).

FLORISTIC AFFINITY TO TROPICAL ASIAN FLORA

The floristic similarity between Xishuangbanna and the Malay Peninsula was compared in order to demonstrate floristic affinity. The catalog of vascular plants of Malaya (Turner 1995) is the revised and relatively complete reference for the regional flora of West Malesia and was used in this study.

The top 20 families with high species richness from the flora of Xishuangbanna and the flora of the Malay Peninsula are relatively equivalent (Table 2). Except for the Urticaceae, Lamiaceae, Cucurbitaceae, Rosaceae, and Fagaceae, other families with species richness in the flora of Xishuangbanna are shared by Malesian floras as the top 20 families. Conversely, Arecaceae, Clusiaceae, Dipterocarpaceae, Gesneriaceae, Melastomaceae, and Myristicaceae are among the top 20 families in Malay Peninsula, but are not among the top 20 families in the flora of Xishuangbanna. The floristic similarity between the flora of Xishuangbanna and Malay Peninsula is more than 80 percent at the family level and more than 60 percent at the generic level (Zhu & Roos 2004). These results strongly support floristic affinity of southern Yunnan to Malesia.

The flora of Xishuangbanna occurs on the margin of tropical Asia. On the other hand, although tropical families and genera *sensu lato* contribute most to its total flora, the families and genera of strictly tropical distribution are still underrepresented as compared to the Malesian flora. For example, Dipterocarpaceae has only two species in the flora of Xishuangbanna, although it is the dominant tree (in individuals) in some forest types of the region. Many

TABLE 2. *Top 20 families with most species richness among the floras of Xishuangbanna and the Malay Peninsula. Names in bold indicate families unique to each location.*

Flora of Xishuangbanna, southern Yunnan (Li 1996)			Flora of Malay Peninsula (Turner 1995)		
Name of family	No. of genera	No. of species	Name of family	No. of genera	No. of species
Orchidaceae	96	334	Orchidaceae	147	853
Fabaceae	68	232	Rubiaceae	79	562
Rubiaceae	43	147	Euphorbiaceae	70	368
Poaceae	67	143	Fabaceae	81	298
Euphorbiaceae	38	119	Poaceae	92	238
Asteraceae	59	107	Myrtaceae	11	215
Lamiaceae	36	105	Lauraceae	16	214
Moraceae	6	77	Annonaceae	36	202
Urticaceae	12	72	Areaceae	32	198
Lauraceae	12	68	Gesneriaceae	20	189
Zingiberaceae	15	67	Melastomataceae	22	172
Asclepiadaceae	25	62	Cyperaceae	29	162
Apocynaceae	27	61	Acanthaceae	29	158
Annonaceae	15	52	Dipterocarpaceae	9	156
Cucurbitaceae	17	50	Zingiberaceae	18	150
Acanthaceae	32	49	Araceae	23	141
Rosaceae	17	49	Moraceae	10	138
Fagaceae	6	45	Clusiaceae	7	120
Araceae	16	43	Apocynaceae	31	119
Cyperaceae	13	43	Asclepiadaceae	30	116

Malesian elements reach their northern limits in southern Yunnan. This implies that the flora of Xishuangbanna is on the northern limit of the Indo-Malaysian flora.

DISCUSSION

Holdridge (1947) established a scheme for the classification of plant formations based on the climatic factors of mean annual temperature, average total annual precipitation, and potential evapotranspiration to precipitation ratio combined. With a mean annual temperature of 21°C, annual precipitation of 1500 mm, and potential evapotranspiration to precipitation ratio of *ca* 0.9, the tropical forest in Xishuangbanna would be classified into the category of subtropical moist forest according to the Holdridge system. The forests of Xishuangbanna would also be classified into the climatic class between the tropical wet seasonal and the tropical wet-dry, or into the vegetation type between evergreen seasonal moist forest, and semievergreen seasonal moist forest according to Richard's climatic classification for tropical rain forest regions (Richards 1996).

Although the forests of Xishuangbanna could be classified as lower montane subtropical moist forests according to the Holdridge

system, they share similar forest profiles, physiognomic characteristics, species richness per unit area, and numbers of individuals in each tree species and diameter size-classes as equatorial lowland rain forests (Zhu 1997). The distribution of tropical moist forests occurring in Xishuangbanna tends to be at higher elevation than would be expected under the Holdridge system, owing to the unique geography. Floristically and physiognomically, forests in Xishuangbanna are atypical of subtropical lower montane moist forests, and are more similar to lowland tropical rain forests elsewhere.

The tropical seasonal rain forest of Xishuangbanna, in terms of physiognomy and structure, is similar to the evergreen seasonal forest of tropical America following Beard (1944, 1955), which was reclassified by Richards (1952) as a subformation of tropical rain forest; or the moist evergreen type of African tropical rain forest following Hall and Swaine (1976, 1981). Xishuangbanna's tropical seasonal forest can also be compared to the Mesophyll Vine Forest of the Australian rain forest following Webb (1959), as well as semievergreen rain forest of Walter (1971). However, it is most equivalent to the semievergreen rain forests of SE Asia defined by Whitmore (1975, 1984). Because the rain forest in Xishuangbanna occurs at latitudinal and altitudinal limits, and shows pronounced seasonal changes in physiognomy, Chinese botanists prefer to describe this forest as "tropical seasonal rain forest" (Wu 1980, 1987; Jin 1983, 1997; Zhu 1992 1997; Zhang & Cao 1995; Cao *et al.* 1996; Zhu *et al.* 1998a). Nonetheless, the forest belongs to the tropical rain forest formation of SE Asia, and is a type of semievergreen rain forest on the northern edge of the tropical zone. The same forest type also occurs in northern Thailand (Smitinand 1966) and North Vietnam (Thin 1997), although different names have been used.

The tropical montane rain forest in Xishuangbanna is similar to the lower montane rain forest of tropical Asia (Whitmore 1984, 1990). Compared with the seasonal rain forest of the region, the montane rain forest has fewer megaphanerophytes and large woody lianas, and more micro- and nanophanerophytes, herbaceous phanerophytes, and plants with simple, leathery, and nonentire and microphyllous leaves. Although different from lowland rain forest in floristic and physiognomic characteristics, tropical montane rain forest is recognized as a type of tropical rain forest by most researchers (Beard 1944, 1955; Richards 1952, 1996; Grubb *et al.* 1964; Whitmore 1984, 1990).

Tropical seasonal moist forest has been called "monsoon forest" by some Chinese authors (Wu 1980, 1987). The term "seasonal moist forest" is preferred here, because the forest is not equivalent to Schimper's monsoon forest (Schimper 1903), despite the fact that it is affected by seasonal dryness and contains a variable percentage of deciduous trees (Zhu *et al.* 1998a, 2003). The seasonal dryness in the region is compensated to some extent by dense fog accompanied by low temperatures in the dry months from November to April (Whitmore 1984). Some deciduous trees shed leaves toward the end of the dry season, while others such as *Cratogeomys cochinchinensis* shed their old leaves as new ones develop. This suggests that deciduousness in the region is more frequently associated with locally dry habitats than the seasonal dryness of climate. Therefore, using the term monsoon forest for the evergreen or semievergreen forest on limestone soil is confusing, because Schimper's monsoon

forest is more or less completely leafless during the dry season (Zhu 2005).

The term “monsoon evergreen broad-leaved forest” was used for the tropical montane evergreen broad-leaved forest in Xishuangbanna by some Chinese authors (Jin 1979, Wu 1980, 1987). Again, “monsoon forest” is widely used for deciduous forest with a strong monsoonal climate in SE Asia (Schimper 1903). This evergreen forest in Xishuangbanna is evidently not a monsoon forest of the same type as in SE Asia. It is also different from the tropical montane rain forest of SE Asia due to a lack of epiphytes. The term “tropical montane evergreen broad-leaved forest” was suggested for this forest type in Xishuangbanna, considering its physiognomy, and habitats, and to avoid confusion with the “monsoon forest” and “tropical montane rain forest” of SE Asia and Xishuangbanna (Zhu *et al.* 2005).

The tropical forests of Xishuangbanna, though surprisingly far from the Equator, are not the northern-most types of tropical rain forest, because tropical rain forest has been recorded in northern Myanmar at about 27°30'N latitude (Kingdon-Ward 1945) and in northeastern India at 27°31'N latitude (Proctor *et al.* 1998). Both of these northern sites still have tropical wet climates due to their low elevations. However, the tropical rain forest in Xishuangbanna occurs at the altitudinal and latitudinal limits. This could be partially explained by the so-called *Massenerhebung* or mass elevation effect (see Whitmore 1990, Richards 1996).

The tropical rain forest in Xishuangbanna occurs quite locally in limited habitats, controlled mainly by topography, and forms a mosaic with tropical montane evergreen broad-leaved forests and monsoon forests in the region. The occurrence of tropical rain forest in the region is mainly controlled by topography and local habitats, not by the regional climate (Zhu 2004).

Flora in Xishuangbanna has a strong affinity to the Malesian flora, owing to the floristic similarity between the two regions at family and generic levels. A clear generic demarcation knot exists between Malesia and mainland SE Asia, as found by Van Steenis (1950) and further confirmed by Johns (1995). Certainly there is this kind of demarcation knot between southern Yunnan and Malesia, but the high percentage of shared taxa in both regions suggests that they should be considered as the same floristic region. We agree with Van Balgooy *et al.*'s (1996) conclusion that the number of taxa in common is the first step to survey floristic affinity.

Research on the geological history of SE Asia has revealed that the direct land connection between mainland SE Asia and west Malesia existed until the early Pliocene period (5 million yr ago; Hall 1998), and no geographical barrier to the natural distribution of plants between mainland SE Asia and west Malesia existed during most of the Tertiary period (Morley 1998). This geological history is a probable explanation for the close affinity between the flora of southern Yunnan and Malesia.

ACKNOWLEDGMENTS

This project was funded by The National Natural Science Foundation of China (40271048) and the Yunnan Natural Science Founda-

tion (2002C0067M). The field works were helped by Mr. Wang Hong, Li Bao-gui, Shi Ji-pu, and other colleagues. We thank reviewers very much for their constructive comments.

LITERATURE CITED

- AUDLEY-CHARLES, M. G. 1987. Dispersal of Gondwanaland: Relevance to evolution of the angiosperms. In T. C. Whitmore (Ed.): Biogeographical evolution of the Malay Archipelago, pp. 5–25. Oxford Monographs on Biogeography 4, Oxford Scientific Publications.
- BEARD, J. S. 1944. Climax vegetation in tropical America. *Ecology* 25: 127–158.
- . 1955. The classification of tropical American vegetation types. *Ecology* 36: 359–412.
- BRAUN-BLANQUET, J. 1932. Plant sociology: The study of plant communities. McGraw-Hill Comp., London.
- CAO, M., AND J. H. ZHANG. 1997. Tree species diversity of tropical forest vegetation in Xishuangbanna, SW China. *Biodiv. Conserv.* 6: 995–1006.
- , Z. L. FENG, J. W. DENG, AND X. B. DENG. 1996. Tree species composition of a seasonal rain forest in Xishuangbanna, Southwest China. *Trop. Ecol.* 37(2): 183–192.
- CHEN, S., AND Z. TSI. 1996. A review of the Orchid flora of Xishuangbanna, southern Yunnan. *Proceedings of the IFCD (1996)*, pp. 107–113. CHEP and Springer Press.
- DRUDE, O. 1913. Die ökologie der Pflanzen. Die Wissenschaft, F. Vieweg, Braunschweig 50.
- Editorial Group for Cenozoic Plants from China. 1978. Plant fossils of China—Tertiary. In Institute of Botany of the Chinese Academy of Sciences (Ed.): Plant fossils of China, pp. 177–182. Science Press, Beijing.
- FEDOROV, A. A. 1957. The flora of southwestern China and its significance to the knowledge of the plant world of Eurasia (in Russian). *Komarov Chten* 10: 20–50.
- . 1958. The tropical rain forest of China (in Russian with English summary). *Botanicheskii Zhurnal S.S.S.R.* 43: 1385–1480.
- GRUBB, P. J., LLOYD, J. R., T. D. PENNINGTON, AND T. C. WHITMORE. 1964. A comparison of montane and lowland rain forest in Ecuador. *J. Ecol.* 51: 567–601.
- HALL, R. 1981. Distribution and ecology of vascular plant in a tropical rain forest—forest vegetation in Ghana. In M. J. A. Werger (Ed.): *Geobotany* 1. Dr W. Junk Publishers, London.
- . 1998. The plate tectonics of Cenozoic SE Asia and the distribution of land and sea. In R. Hall and J. D. Holloway (Eds.). *Biogeography and geological evolution of SE Asia*, pp. 99–131. Backuys Publishers, Leiden.
- , AND M. D. SWAINE. 1976. Classification and ecology of closed-canopy forest in Ghana. *J. Ecol.* 64: 913–953.
- HOLDRIDGE, L. R. 1947. Determination of world plant formation from simple climatic data. *Science* 105: 367–368.
- JIN, Z. Z. 1979. The types and characteristics of evergreen broad-leaved forests in Yunnan. *Acta Bot. Yun.* 1(1): 90–105 (in Chinese with English abstract).
- . 1983. The characteristics of tropical rain forest and monsoonal forest in Yunnan. *J. Yun. Univ.* 1983(1 and 2): 197–205 (in Chinese with English abstract).
- . 1997. The diversity features of the ecological structures of plant species composition in the tropical rain forest of Xishuangbanna, Yunnan. *Acta Bot. Yun. Suppl.* IX: 32–58 (in Chinese with English abstract).
- , AND X. K. OU. 1997. The diversity features of plant community types in the tropical rain forest vegetation of Xishuangbanna, Yunnan. *Acta Bot. Yun. Suppl.* IX: 1–30 (in Chinese with English abstract).
- JOHNS, R. J. 1995. Malesia—an introduction. *Curtis Bot. Mag.* 12(2): 52–62.
- KINGDON-WARD, F. 1945. A sketch of the botany and geography of north Burma. *J. Bomb. Nat. Hist. Soc.* 45: 16–30.
- LI, X. W. 1995. A floristic study on the seed plants from tropical Yunnan. *Acta Bot. Yun.* 17(2): 115–1282 (in Chinese with English abstract).

- LI, Y. H. (Ed.): 1996. List of plants in Xishuangbanna. Yunnan National Press, Kunming. (in Chinese).
- LI, B. G., H. ZHU, AND H. WANG. 1993. The *Bombax ceiba* forest in Menghai, Xishuangbanna. *Acta Bot. Yun.* 15(2): 191–195 (in Chinese with English abstract).
- LIU, J. L., L. Y. TAN, Y. QIAO, M. J. HEAD, AND D. WALKER. 1986. Late quaternary vegetation history at Menghai, Yunnan province, southwest China. *J. Biogeogr.* 13: 399–418.
- MORLEY, J. R. 1998. Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate. *In* R. Hall and J. D. Holloway (Eds.). *Biogeography and geological evolution of SE Asia*, pp. 221–234. Backbuys Publishers, Leiden.
- MYERS, N. 1998. Threatened biotas: "Hotspot" in tropical forests. *Environmentalist* 8(3): 1–20.
- PENNY, D. 2001. A 40,000 year palynological record from north-east Thailand; implications for biogeography and palaeo-environmental reconstruction. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 171: 97–128.
- PROCTOR, J., K. HARIDASAN, AND G. W. SMITH. 1998. How far north does lowland evergreen tropical rain forest go? *Glob. Ecol. Biogeogr. Lett.* 7: 141–146.
- QU, Z. X. 1960. Nature reserves in Yunnan. *J. Yun. Univ. (Nat. Sci.)* 1: 1–4 (in Chinese).
- RICHARDS, P. W. 1952. The tropical rain forest, p. 450. Cambridge University Press, London.
- . 1996. The tropical rain forest: An ecological study, 2nd edition, p. 575. Cambridge Univ. Press, London.
- SCHIMPER, A. F. W. 1903. Plant-geography upon a physiological basis, p. 839. Oxford University Press, Oxford.
- SHI, Y. F., J. Y. LI, B. Y. LI, B. T. PAN, X. M. FANG, T. D. YAO, S. M. WANG, Z. J. TSUI, AND S. J. LI. 1998. Uplift and environmental evolution of Qinghai-Xizang (Tibetan) plateau. *In* H. L. Sun and D. Zheng (Eds.). *Formation, evolution and development of Qinghai-Xizang (Tibetan) Plateau*, pp. 73–138. Guangdong Science and Technology Press, Guangzhou (in Chinese).
- , T. D. YAO, S. M. WANG, S. J. LI, Z. J. TSUI, F. B. WANG, B. T. PAN, X. M. FANG, AND Q. S. ZHANG. 1999. Uplift of the Qinghai-Xizang (Tibetan) plateau and east Asia environmental change during late Cenozoic. *Acta Geograph. Sin.* 54(1): 10–21 (in Chinese with English abstract).
- SMITINAND, T. 1966. The vegetation of Dao Chiangdao, a limestone massive in Chiangmai, north Thailand. *Nat. Hist. Bull. Siam Soc.* 21(1–2): 93–128.
- SONG, Z. 1984. Miocene phytogeographical area of east Asia. *In* Nanjing Institute of Geology and Paleontology (Ed.), *Stratum and Paleontology*, Vol. 13, pp. 63–69 (in Chinese).
- , M. Y. LI, AND W. B. LI. 1976. Fossil pollens from Yunnan during Mesozoic and early Tertiary. *In* *Mesozoic fossils of Yunnan*, pp. 1–64. Beijing Science Press, Beijing (in Chinese).
- , H. LI, Y. ZHENG, AND G. LIU. 1983. Miocene floristic region of China. *In* Y. H. Lu (Ed.), *Palaeobiogeographic provinces of China*, pp. 178–184. Beijing Science Press, Beijing (in Chinese).
- SUN, X. J. 1979. Palynofloristical investigation on the Late Cretaceous and Paleocene of China. *Acta Phytotaxon. Sin.* 17(3): 8–21 (in Chinese with English abstract).
- THIN, N. N. 1997. The vegetation of Cucphuong National Park, Vietnam. *Sida* 17: 719–759.
- TURNER, I. M. 1995. A catalogue of the vascular plants of Malaya. *Gard. Bull. Sing.* 47: 1–757.
- VAN BALGOOY, M. M. J., P. H. HOVENKAMP, AND P. C. VAN WELZEN. 1996. Phytogeography of the Pacific—Floristic and historical distribution patterns in plants. *In* A. Keast and S. E. Miller (Eds.). *The origin and evolution of Pacific Island biotas, New Guinea to Eastern Polynesia: Patterns and processes*, pp. 191–213. SPB Academic Publishing, Amsterdam.
- VAN STEENIS, C. G. J. 1950. The delimitation of Malaysia and its main plant geographical divisions. *In* *Flora Malesiana series 1*, pp. LXX–LXXV. Noordhoff N V, Djakarta.
- WALTER, H. 1971. Ecology of tropical and subtropical vegetation, p. 539. Oliver and Boyd, Edinburgh.
- WANG, C. W. 1939. A preliminary study of the vegetation of Yunnan. *Bull. Fan Mem. Inst. Biol.* 9(2): 65–125.
- . 1961. The forests of China with a survey of Grassland and desert vegetation, pp. 155–164. Maria Moors Cabot Foundation Publication Harvard Univ., Cambridge, MA (5).
- WANG, H., AND H. ZHU. 1990. A study on *Anogeissus acuminata* community. *Acta Bot. Yun.* 12(1): 67–74 (in Chinese with English abstract).
- WANG, H., H. ZHU, AND B. G. LI. 2001. A study on the tropical montane rainforest in Mengsong, Xishuangbanna, S. Yunnan. *Guihaia* 21(4): 303–314 (in Chinese with English abstract).
- WANG, W. M. 1996. A palynological survey of Neocene strata in Xiaolongtan Basin, Yunnan province of south China. *Acta Bot. Sin.* 38(9): 743–748 (in Chinese with English abstract).
- WARMING, E. 1909. Oecology of plants. An introduction to the study of plant communities, p. 422. Oxford University Press, London.
- WEBB, L. J. 1959. A physiognomic classification of Australian rain forests. *J. Ecol.* 47: 551–570.
- WHITMORE, T. C. 1975. Tropical rain forests of the Far East, p. 282. Clarendon Press, Oxford.
- . 1982. Fleeting impressions of some Chinese rain forests. *Commonwealth For. Rev.* 61: 51–58.
- . 1984. Tropical rain forests of Far East, 2nd edition, p. 352. Clarendon Press, Oxford.
- . 1990. An introduction to tropical rain forests. p. 226. Clarendon Press, Oxford.
- WU, C. Y. (Ed.): 1980. Vegetation of China, p. 1375. Science Press, Beijing. (in Chinese).
- . 1987. Vegetation of Yunnan, pp. 143–163. Science Press, Beijing (in Chinese).
- . 1991. The areal-types of Chinese genera of seed plants. *Acta Bot. Yun. Suppl. Vol. IV*: 1–139 (in Chinese with English abstract).
- . 1965. The tropical floristic affinity of the flora of China. *Chin. Sci. Bull.* 1965(1): 25–33 (in Chinese).
- WULFF, E. V. 1944. Historical geography of plants: History of floras of the earth (in Russian), p. 632. Moscow and Leningrad, Beijing Science Press. Chinese version, 1964.
- ZHANG, J., AND M. CAO. 1995. Tropical forest vegetation of Xishuangbanna SW China and its secondary changes, with special reference to some problems in local nature conservation. *Biol. Conserv.* 73: 225–238.
- ZHOU, T. R., AND S. H. REN. 1984. Physical geography of China—Paleogeography, p. 262. Science Press, Beijing (in Chinese).
- ZHU, H. 1992. Research of community ecology on *Shorea chinensis* forest in Xishuangbanna. *Acta Bot. Yun.* 14(3): 237–258 (in Chinese with English abstract).
- . 1993a. A comparative study of phytosociology between *Shorea chinensis* forest of Xishuangbanna and other closer forest types. *Acta Bot. Yun.* 15(1): 34–46 (in Chinese with English abstract).
- . 1993b. Floristic plant geography on the dipterocarp forest of Xishuangbanna. *Acta Bot. Yun.* 15(3): 233–253 (in Chinese with English abstract).
- . 1994. Floristic relationships between dipterocarp forest of Xishuangbanna and forests of tropical Asia and S China. *Acta Bot. Yun.* 16(2): 97–106 (in Chinese with English abstract).
- . 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. *J. Biogeogr.* 24: 647–662.
- . 2002. Ecology and biogeography of the tropical dipterocarp rain forest in Xishuangbanna, p. 245. Yunnan Science and Technology Press, Kunming (in Chinese with English abstract).
- . 2004. A tropical seasonal rain forest at its altitudinal and latitudinal limits in southern Yunnan, SW China. *Gard. Bull. Sing.* 56: 55–72.
- . 2005. Reclassification of monsoon tropical forests in southern Yunnan,

- SW China. *Acta Phytocol. Sin.* 29(1): 170–174 (in Chinese with English abstract).
- , Y. H. LI, H. WANG, AND B. G. LI. 2001. Characteristics and affinity of the flora of Xishuangbanna, SW China. *Guihaia* 21(2): 127–136 (in Chinese with English abstract).
- , AND M. C. ROOS. 2004. The tropical flora of S China and its affinity to Indo-Malesian flora. *Telopea* 10 (2): 639–648.
- , J. P. SHI, AND C. J. ZHAO. 2005. Species composition, physiognomy and plant diversity of the tropical montane evergreen broad-leaved forest in southern Yunnan. *Biodiv. Conserv.* 14: 2855–2870.
- , H. WANG, AND B. G. LI. 1998a. Research on the tropical seasonal rainforest of Xishuangbanna, South Yunnan. *Guihaia* 18(4): 371–384 (in Chinese with English abstract).
- , ———, AND ———, 1998b. The structure, species composition and diversity of the limestone vegetation in Xishuangbanna, SW China. *Gard. Bull. Sing.* 50: 5–33.
- , ———, AND ———, 2004. Plant diversity and physiognomy of the tropical montane rain forest in Mengsong, southern Yunnan of China. *Acta Phytocol. Sin.* 28(3): 351–360 (in Chinese with English abstract).
- , ———, ———, AND P. SIRIRUGSA. 2003. Biogeography and floristic affinity of the limestone flora in southern Yunnan, China. *Ann. Missouri Bot. Gard.* 90: 444–465.
- , AND H. X. ZHOU. 2002. A comparative study on the tropical rain forests in Xishuangbanna and Hainan. *Acta Bot. Yun.* 24(1): 1–13 (in Chinese with English abstract).

CHINESE GEOGRAPHICAL SCIENCE
Volume 14, Number 3, pp. 221-226, 2004
Science Press, Beijing, China

BIOGEOGRAPHICAL IMPLICATIONS OF SOME PLANT SPECIES FROM A TROPICAL MONTANE RAIN FOREST IN SOUTHERN YUNNAN

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ABSTRACT: A pristine montane rain forest was recently discovered from Mengsong of Xishuangbanna in the southern Yunnan. It interests botanists that many primitive plant taxa across various life forms were co-existed in the montane rain forest. In order to know the biogeography of the montane rain forest, distribution patterns of some species of biogeographical importance from the montane forest were enumerated and their biogeographical implications were discussed with geological explanation. It was concluded that the montane rain forest in the southern Yunnan has strong affinity to montane rain forests in Sumatra or Southeast Asia in broad sense. It was tentatively suggested that Sumatra could be once connected to Myanmar and drifted away due to northward movement of continental Asia by bumping of India plate.

KEY WORDS: biogeography; montane rain forest; southern Yunnan

CLC number: Q948.5

Document code: A

Article ID: 1002-0063 (2004) 03-0221-06

1 INTRODUCTION

Southern Yunnan of the southwestern China is exceptionally interested to botanists because of its diversified biota and particularly geological-biogeographical history. The region is at a transitional zone from tropical Southeast Asia to temperate East Asia geographically, and is supposed to be a conjunction area between Shan-Tai fragment of Gondwanaland and the southeastern margin of Asian continent geologically (AUDLEY-CHARLES, 1987; FORTEY and COCKS, 1998; METCALFE, 1998). Southern Yunnan is not only a key area in biogeography but also a hot spot of biodiversity (MYERS, 1998).

A pristine montane rain forest was recently discovered from Mengsong of Xishuangbanna in the southern Yunnan, at the border between Myanmar and Yunnan of China (WANG *et al.*, 2001; ZHU *et al.*, 2004). The montane rain forest, which occurs at valleys and on montane slopes between 1500–1800m a. s. l., is dominated by families Magnoliaceae, Mastixiaceae, Lauraceae and Euphorbiaceae. Magnoliaceae and Lauraceae were supposed to be ones of primitive angiosperm families (STEVENS, 2001 onwards). *Mastixia euonymoides*, a dominant and the biggest tree species in the montane rain forest, is a primitive taxon in the family Mastixiaceae (TAKHTAJAN, 1997), Cornaceae (MATTHEW, 1976) or Nyssaceae (STEVENS, 2003). This species occurs only in the limited border area among Myanmar, Yunnan of China and Thailand, but its fossil taxa were widely distributed in European and America Tertiary floras, which were even called Mastixioidean European Flora (MAI, 1993; EYDE and XIANG, 1990; TIFFNEY and HAGGARD, 1996). *Gymnanthes remota* of Euphorbiaceae, a relic and dominant species in the lower tree layer of the montane rain forest, occurs disjunctively in Mengsong of the southern Yunnan and Sumatra of Indonesia (ZHU *et al.*, 2000). Frequent shrub species *Lasianthus inodorus* of Rubiaceae, which distributed in mainland Southeast Asia and Sumatra as

Received date: 2004-02-06

Foundation item: * Under the auspices of the National Natural Science Foundation of China (No. 40271048) and Yunnan Natural Science Foundation (No. 2002C0067M).

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well as Java, has its vicarious species in Kinabalu Mountain in Borneo (ZHU, 2001). Dominant herbaceous plant *Sarcandra hainanensis* of Chloranthaceae, was also supposed to be a primitive angiosperm (ZHOU, 1999). It is interesting that many primitive taxa across various life forms were co-existed in the montane rain forest in the southern Yunnan. These indicate that the montane rain forest in the southern Yunnan is of importance to science not only for its biodiversity, but also for biogeography. Distribution patterns of taxa could give us some implications to biogeography of the montane rain forest in the southern Yunnan.

2 DISTRIBUTION OF TAXA

2.1 *Mastixia euonymoides* Prain.

It is a dominant species of the upper tree layer in the montane rain forest in Mengsong of the southern Yunnan. *M. euonymoides* is in the primitive subgenus *Manglesia* of Mastixiaceae. The subgenus *Manglesia* is composed by two species, i.e. *M. euonymoides* which occurs in the northeastern India, northern Burma, northern Thailand and southern Yunnan of China (ZHU, 1993), and *M. octandra* Matthew, which occurs in mountains of center Sumatra in Indonesia (MATTHEW, 1976) at similar altitudes (1700–1800m a. s. l.) (Fig. 1). The similar distribution pattern was found in some other taxa of seed plants, such as *Pinus merkusii* (SANTISUK, 1997) (Fig.1).

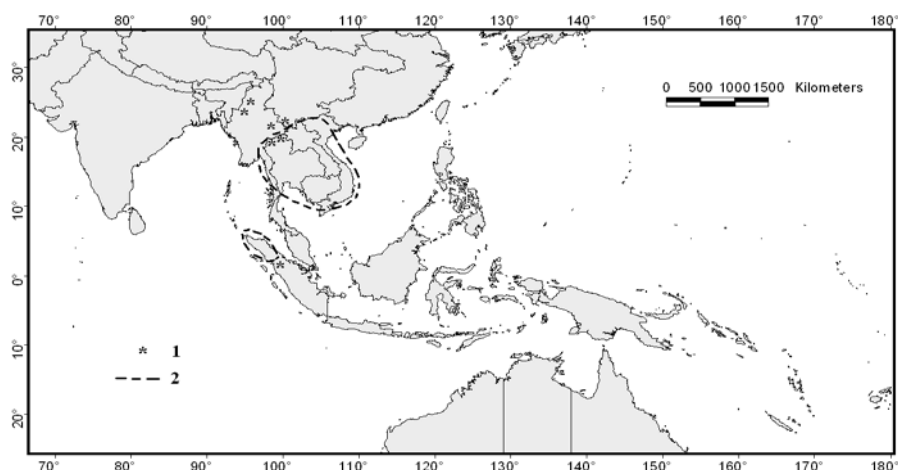


Fig. 1 Distribution of subgenus *Manglesia* (1) and species *Pinus merkusii* (2)

2.2 *Gymnanthes remota* (Steenis) Esser

Gymnanthes remota occurs in montane rain forests between 1600–2000m a. s. l. in the northern Sumatra. It was recently found in the montane rain forest in Mengsong at the border area between the northern Myanmar and the southern Yunnan at a similar habitat as at Sumatra (ZHU *et al.*, 2000). It is a dominant species in lower tree layer of the montane rain forest in Mengsong (Fig. 2).

Gymnanthes is a genus of pantropical distribution. It is composed of 25 species, of which 21 species occur in the New World from the USA (Florida) to the Antilles and Paraguay, 2 in Africa (Congo Basin from Cameroon to Zaire), and 2 in Asia (ESSER, 1999). *G. borneensis*, which occurs in Peninsular Malaysia, center Sumatra, Lingga Archipelago, Borneo (Sabah, Sarawak, Brunei, center Kalimantan), while *G. remota* occurs in the northern Sumatra and Yunnan. *Gymnanthes*, sensu Pax et Hoffmann (1912), is originally restricted to the Neotropics, while sensu lato, as proposed by ESSER (1999) is pantropical distribution and has a center of diversity in the New World. It is conspicuous that the genus could be Gondwana origin. The existence of *G. remota* in the southern Yunnan implies that *Gymnanthes* could migrate to Asia by the drift of India plate from

Gondwana. *Terminalia myriocarpa* Heurck et Muell.-Arg., another tree species in southern Yunnan, has a similar distribution as *Gymnanthes remota* (Fig. 2) (STEENIS, 1954), which also consolidates the idea that there is a closer floristic connection between northern Mainland SE Asia and Sumatra.

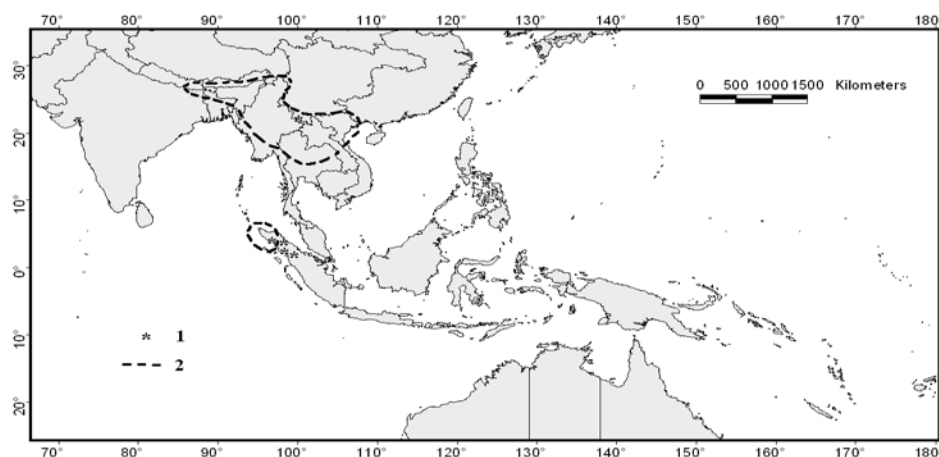


Fig. 2 Distribution of species *Gymnanthes remota* (1) and *Terminalia myriocarpa* (2)

2.3 *Bruinsmia* Boerl. & Koord.

Bruinsmia is a tropical Asian genus with two species. *Bruinsmia styracoides* Boerl. & Koord. is distributed in Sumatra, west Java, Borneo, Celebes and New Guinea in tropical montane forests between 700–1600m a.s.l. A vicarious species *Bruinsmia polysperma* (Clarke) Steenis occurs at montane forests over 1300m a.s.l. in the northeastern India, northern Myanmar, northern Thailand and southeastern Xishuangbanna of southern Yunnan (STEENIS and BAKHUIZEN, 1967). *Bruinsmia* was not seen in the southern Thailand, southern Myanmar and Malay peninsula (Fig. 3).

2.4 *Lasianthus inodorus* Bl.

This is a frequent shrub species in the montane rain forest in the southern Yunnan. It is composed by three vicarious subspecies (ZHU, 2001, 2002).

The typical subspecies *L. inodorus* has a wide, disjunctive distribution. It occurs in montane evergreen forests and montane rain forests over 1000m a. s. l. in the southern Yunnan, India (northeast part), Bangladesh (eastern part), Thailand, Cambodia, Vietnam and Indonesia (Sumatra, Java) (Fig. 4). However the specimens from mainland Southeast Asia and the ones from Sumatra and Java are almost identical so that clear variation within this subspecies could not be recognized.

Vicarious subspecies *L. inodorus* Bl. subsp. *montigenus* H. Zhu and *L. inodorus* Bl. subsp. *pubescens* H. Zhu occur on Mount Kinabalu in Borneo, but at different habitats. Subspecies *montigenus* occurs in mossy forests over 1700m a. s. l., while subspecies *pubescens* occurs in montane evergreen forest between 400–2000m a. s. l.

3 DISCUSSIONS

It was suggested that the tropical flora of the southern Yunnan had a close affinity to tropical Asian flora (ZHU, 1994, 1996, 1997; ZHU and ROOS, 2002, 2004; ZHU *et al.*, 1997, 2001, 2003). Distribution patterns of those species mentioned above indicate that the montane rain forest in southern Yunnan has strong affinity to the same

forest type in Sumatra or Southeast Asia in broad sense. The similar distribution patterns were also found in some other taxa of seed plants, such as *Pinus merkusii* (Fig.1), *Terminalia myriocarpa* Heurck et Muell.-Arg. (Fig. 2), *Ulmus lanceaefolia* Roxb. ex Wall. (STEENIS, 1977) (Fig. 3), and *Altingia excelsa* Noron., *Dysoxylum excelsa* Bl., *Saprosma ternatum* (Wall.) Hook.f. (ZHU, 2000) etc.

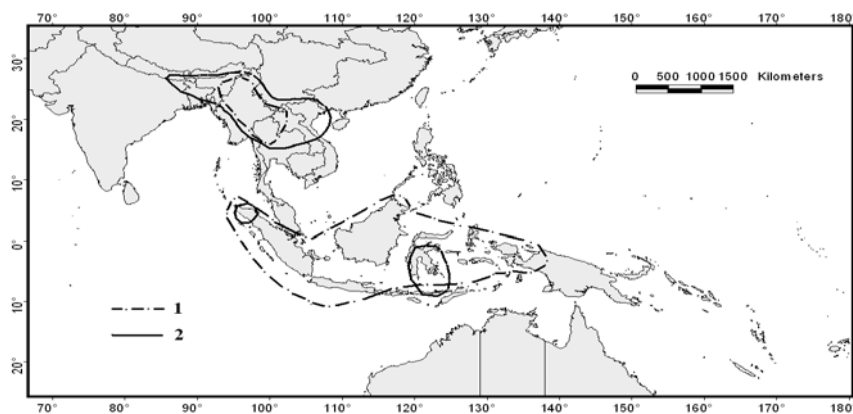


Fig. 3 Distribution of genus *Bruinsmia* (1) and species *Ulmus lanceaefolia* (2)

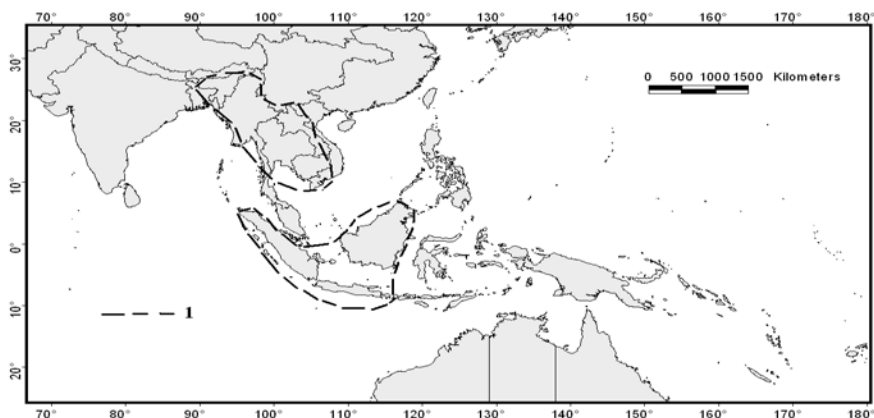


Fig. 4 Distribution of species *Lasianthus inodorus*

There were some possible explanations to the close floristic affinity between the southern Yunnan (or Southeast Himalayas) and Malesia. The floristic connections between islands of the Malay Archipelago and mainland Southeast Asia were mostly explained on the basis of stepping stones of various mountains or bridges in the region before wide acceptance of plate tectonic theory, such as van STEENIS (1962, 1964), and now better explained by plate tectonic theory based on more geological and biogeographical evidence. Direct land connection between mainland Southeast Asia and Western Malesia could be existent until early Pliocene (5Ma ago) (HALL, 1998) and there was no geographical barrier to natural distribution of plants between mainland SE Asia and Western Malesia during most of the Tertiary (MORLEY, 1998).

Those distribution patterns of plant taxa suggest the historical connection between the southern Yunnan and mainland Southeast Asia, and the Malay Archipelago and support tectonic explanation.

Based on those patterns of disjunctive distribution between mainland Southeast Asia and Sumatra, a tentative suggestion was come out as that Sumatra could be once connected to Myanmar and drifted away due to northward movement of continental Asia by bumping of India plate. It is coincided with some geological point of view (PENNY, 1997). If it is true, the close floristic affinity between the southeastern Himalayas and the southern Yunnan, and Sumatra and Java could be better explanation (Fig. 5).

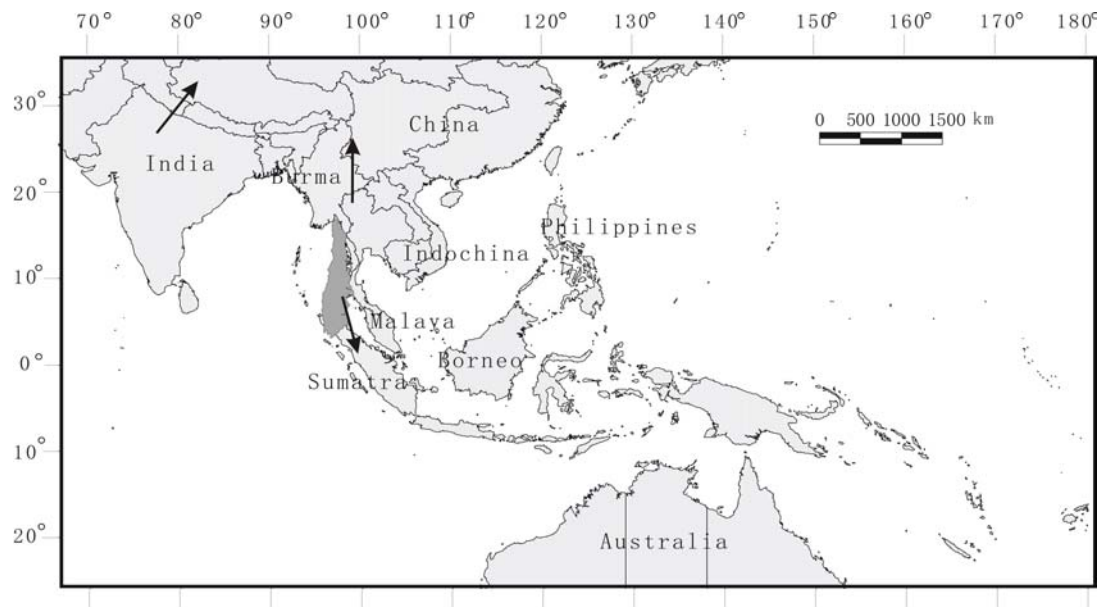


Fig. 5 Conjectural movements of Southeast Asian tectonics since the Tertiary

ACKNOWLEDGEMENTS

I thank Dr. HU Hua-bin and Mr. SUN Yong very much for their helps in drawing figures.

REFERENCES

- AUDLEY-CHARLES M G, 1987. Dispersal of Gondwanaland: relevance to evolution of the angiosperms [A]. In: WHITMORE T C (ed.). *Biogeographical Evolution of the Malay Archipelago* [C]. Oxford: Clarendon Press, 5-25.
- ESSER H J, 1999. A partial revision of the *Hippomaneae* (Euphorbiaceae) in Malesia [J]. *Blumea*, 44(1): 149-215
- EYDE R H, XIANG Q Y, 1990. Fossil Mastixioid (Cornaceae) alive in eastern Asia [J]. *America Journal of Botany*, 77(5): 689-692.
- FORTEY R A, COCKS L R M, 1998. Biogeography and palaeogeography of the Sibumasu terrane in the Ordovician: a review [A]. In: HALL R and HOLLOWAY J D (eds.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backuys Publishers, 43-56.
- HALL R, 1998. The plate tectonics of Cenozoic SE Asia and the distribution of land and sea [A]. In: HALL R and HOLLOWAY J D (eds.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backuys Publishers, 99-131.
- MAI D H, 1993. On the extinct Mastixiaceae (Cornales) in Europe [J]. *Geophytology*, 23(1): 53-63.
- MATTHEW K M, 1976. A revision of the genus *Mastixia* (Cornaceae) [J]. *Blumea*, 23(1): 51-93.
- METCALFE I, 1998. Palaeozoic and Mesozoic geological evolution of the SE Asia region: multidisciplinary constraints and implications for biogeography [A]. In: HALL R, HOLLOWAY J D (eds.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backuys Publishers, 25-41.
- MORLEY J R, 1998. Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and

- climate [A]. In: HALL R, HOLLOWAY J D (eds.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backuys Publishers, 221-234.
- MYERS N. 1998. Threatened biotas: "Hotspot" in tropical forests [J]. *Environmentalist*, 8(3): 1-20.
- PENNY van Oosterzee, 1997. *Where Worlds Collide---- the Wallace Line* [M]. London: Cornell University Press, 233.
- SANTISUK T, 1997. Geographical and Ecological Distributions of the two Tropical Pines, *Pinus kesiya* and *Pinus merkusii*, in Southeast Asia [J]. *Thai Forest Bulletin*, 25: 102-123.
- STEENIS C G G J van (ed.), 1954. *Flora Malesiana*, Series I, 4(5) [M]. Leiden: National Herbarium of the Netherlands.
- STEENIS C G G J van, 1962. The mountain flora of the Malaysian tropics [J]. *Endeavour*, 1962: 183-193.
- STEENIS C G G J van, 1964. Plant geography of the mountain flora of Mt. Kinabalu [J]. *Proceedings of Royal Society B*, 161: 7-38.
- STEENIS C G G J van, BAKHUIZEN van den Brink, 1967. Miscellaneous botanical notes XVI [J]. *Botanische Jahrbücher*, lxxxvi: 390-393.
- STEENIS C G G J van (ed.), 1977. *Flora Malesiana*, Series I, 8(2) [M]. Leiden: National Herbarium of the Netherlands.
- STEVENS P F, 2003. Angiosperm Phylogeny Website. Version 4. <http://www.mobot.org/MOBOT/research/APweb/>, May 2003.
- TAKHTAJAN A, 1997. *Diversity and Classification of Flowering Plants* [M]. New York: Columbia University Press, 382p.
- TIFFNEY B H, HAGGARD K K, 1996. Fruits of Mastixioideae (Cornaceae) from the Paleogene of western North America [J]. *Review Palaeobot Palynol*, 92: 29-54.
- WANG Hong, ZHU Hua, LI Bao-gui, 2001. A study on the tropical montane rainforest in Mengsong, Xishuangbanna, S. Yunnan [J]. *Guihaia*, 21 (4): 303-314. (in Chinese).
- ZHOU Zhe-kun, 1999. Origin, evolution and distribution of Chloranthaceae [A]. In: LU A M (ed.), *The Geography of Spermatophytic Families and Genera* [M]. Beijing: Science Press, 116-125. (in Chinese).
- ZHU Hua, 1993. A revision of the genus *Mastixia* Bl. (Cornaceae) from China [J]. *Acta Botanica Yunnanica*, 15 (2): 131-133. (in Chinese).
- ZHU Hua, 1994. Floristic relationships between dipterocarp forests of Xishuangbanna and forests of tropical Asia and S China [J]. *Acta Botanica Yunnanica*, 16 (2): 97-106. (in Chinese).
- ZHU Hua, 1996. On the floristic occurrence of the dipterocarp forest of Xishuangbanna [A]. In: *Collected Research Papers on the Tropical Botany IV* [C]. Kunming: Yunnan University Press, 36-52. (in Chinese).
- ZHU Hua, 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia [J]. *Journal of Biogeography*, 24: 647-662.
- ZHU Hua, 2000. *Ecology and Biogeography of the Dipterocarp Rain Forest of Xishuangbanna, S Yunnan* [M]. Kunming: Yunnan Science Press. (in Chinese).
- ZHU Hua, 2001. New plants of *Lasianthus* Jack (Rubiaceae) from Kinabalu, Borneo and its biogeographical implication [J]. *Blumea*, 46 (3): 447-455.
- ZHU Hua, 2002. A revision of the genus *Lasianthus* (Rubiaceae) from China [J]. *Systematics and Geography of Plant*, 72: 63-110.
- ZHU Hua, LI Yan-hui, WANG Hong, LI Bao-gui, 2001. Characteristics and affinity of the flora of Xishuangbanna, SW China [J]. *Guihaia*, 21(2): 127-136. (in Chinese).
- ZHU Hua, ROOS M C, 2002. The Characteristics and affinity of the tropical flora of southern China [J]. *Forest Study in China*, 4: 18-24.
- ZHU, Hua, ROOS M C, 2004. The tropical flora of S China and its affinity to Indo-Malesian flora [J]. *Telopea*, 10(2): 639-648.
- ZHU Hua, WANG Hong, LI Bao-gui, 1997. Floristic relationships between the limestone flora and neighboring floras of tropical Asia and south China [J]. *Acta Botanica Yunnanica*, 19 (4): 357-365. (in Chinese).
- ZHU Hua, WANG Hong, LI Bao-gui, 2000. *Gymnanthes* Sw. (Euphorbiaceae), new to China and its biogeographical implication [J]. *Acta Phytotaxonomica Sinica*, 38 (5): 462-463.
- ZHU Hua, WANG Hong, LI Bao-gui, 2004. Plant diversity and physiognomy of a tropical montane rain forest in Mengsong, southern Yunnan, China [J]. *Acta Phytoecologica Sinica*, 28(3): 351-360. (in Chinese).
- ZHU Hua, WANG Hong, LI Bao-gui, SIRIRUGS A P, 2003. Biogeography and floristic affinity of the limestone flora in southern Yunnan, China [J]. *Annals of Missouri Botanical Garden*, 90 (3): 444-465.

BIOGEOGRAPHY AND FLORISTIC AFFINITIES OF THE LIMESTONE FLORA IN SOUTHERN YUNNAN, CHINA¹

H. Zhu,² H. Wang,² B. Li,² and
P. Sirirugsa³

ABSTRACT

The forests on limestone in southern Yunnan, in tropical southwest China, were inventoried, and their floristic composition and biogeographical affinities are discussed. These limestone forests were characterized by phanerophytes making up ca. 78% of the total species and those with mesophyllous leaves comprising 75%. Ecological species groups based on their habitat preferences were discerned from field observations: the species exclusive to the limestone habitats make up 10% and the preferents make up ca. 12% of the total limestone flora. From these limestone forests, 1394 vascular plant species belonging to 640 genera and 153 families were recorded. Based on their distributions, 12 biogeographic elements at the generic level and nine at the specific level were recognized. About 90% of the seed plant genera (over 90% of the species) were tropical; furthermore, 35% of the seed plant genera (65% of the species) have tropical Asian affinities. In a comparison with other regional floras from southern China and tropical Asia, the limestone flora of southern Yunnan revealed closer affinity to tropical floras than to temperate elements of eastern Asian floras. This limestone flora is thus tropical and part of the tropical Asian flora at its northern margin.

Key words: biogeography, China, limestone forest, southern Yunnan.

Limestone in tropical China occurs mainly in Yunnan and Guangxi Provinces of southern and central China. Because of the great diversity of edaphic conditions and topography, vegetation types on limestone are extremely diverse and rich in endemic taxa. Limestone vegetation in southern China has been destroyed as much as other vegetation types even though these limestone areas are more difficult to access and to farm. Limestone vegetation is also more vulnerable because it recovers much more slowly on usually thin soils. Our research was conducted mainly in the area of Xishuangbanna, in the southern part of Yunnan, where about 19% (3600 km²) of the total area is limestone (Liu et al., 1990). Most of this limestone area is still forested and is receiving increasing attention for its biodiversity and its urgent need of conservation. Primary floristic works in southern Yunnan have been written (Zhu et al., 1996, 1997, 1998a, 1998b; Wang et al., 1997). This paper represents a synthesis of its floristics, physiognomy, and biogeographical affinities.

GENERAL GEOGRAPHY

Xishuangbanna, the southern part of Yunnan, which borders Burma and Laos, is a mountainous area at the northern margin of tropical Southeast Asia (Fig. 1). Basically, the study area has a mountainous topography with the mountains running north-south and decreasing in elevation southward. Altitude varies from 480 m in the lowest valley in the south to 2400 m at the top of the highest mountain in the north. The limestone strata occur mainly in southeastern Xishuangbanna and range in altitude from 600 to 1600 m.

The region of Xishuangbanna has a typical tropical monsoon climate with an annual mean temperature of 22°C, annual temperature accumulation (the sum of daily temperature means where they are > 10°C) of 8000°C, and annual precipitation varying from 1200 to 1556 mm, of which more than 80% falls during the rainy season between May and the end of October (Xu et al., 1987).

The rock substrate is hard limestone of Permian origin with a rugged topography. The soil is mainly

¹ This project was funded by The National Natural Science Foundation of China (40271048), the Chinese Academy of Sciences (The Fund for Top One Hundred Young Scientists and KSCX2-1-06B), and the Yunnan Natural Science Foundation. The senior author thanks Xu Zaifu for his great help with his research and Wu Zheng-yi and Zhang Hong-da, his academic advisors. He particularly thanks E. Tanner and P. Grubb for their help in analyzing data and preparing this paper during his visiting scholar's year at the University of Cambridge. Finally, he thanks T. C. Whitmore, who has greatly supported and helped him in his research, and two anonymous reviewers for their constructive comments on this article.

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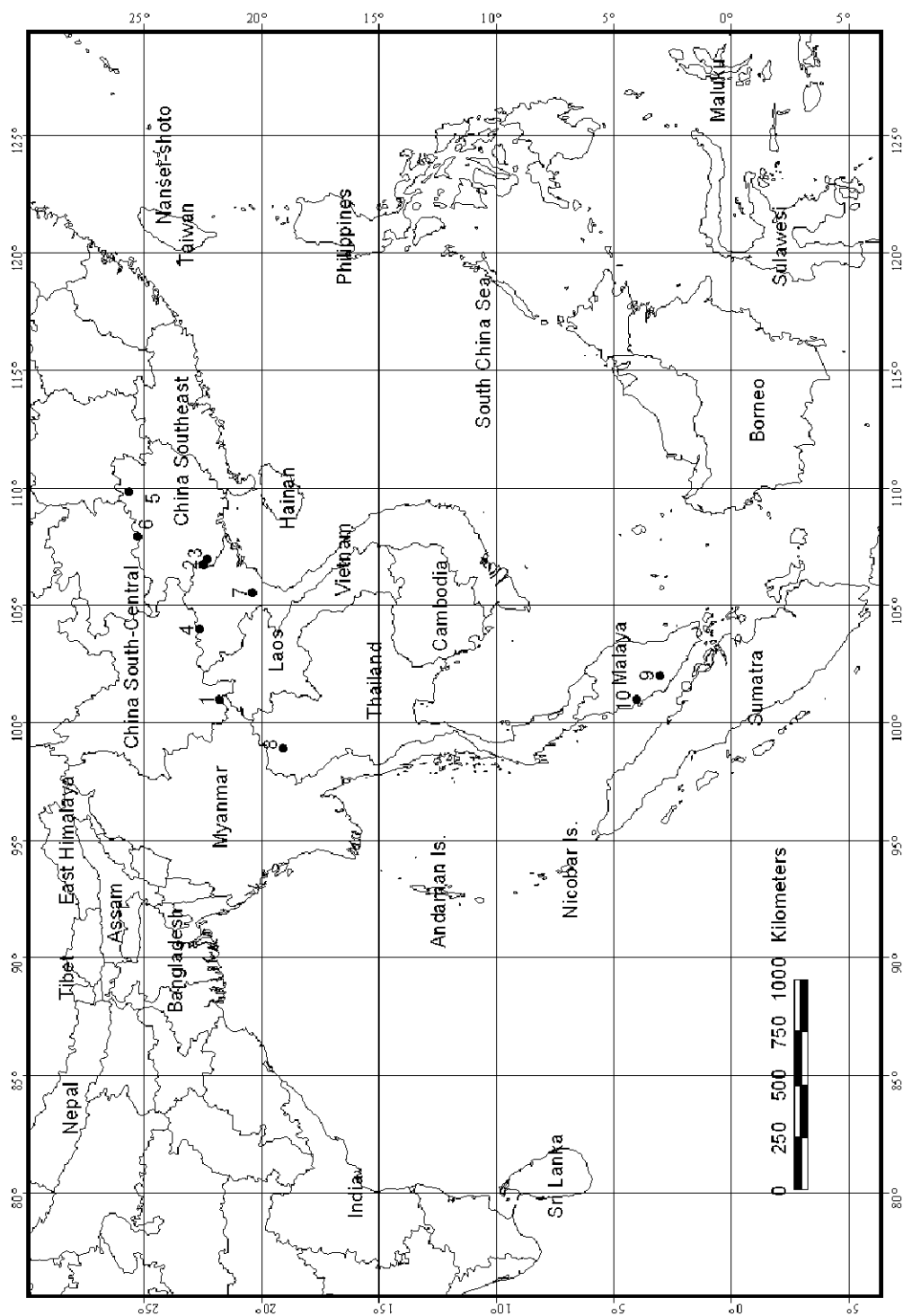


Figure 1. Locations of the research area in Xishuangbanna, southern Yunnan, China, and compared regional floras (see Table 6). —1. Our research area. —2. Longgan, SW China. —3. Daqinshan Mountains, SW China. —4. Gulingqing, SW China. —5. Huapin, China. —6. Dongyang Mountains, China. —7. Cuephuong, N Vietnam. —8. Chiengdao, N Thailand. —9. The Malay Peninsula limestone. —10. Taping, Malay Peninsula.

brown, coarse in texture, and composed of loamy limestone with a pH of ca. 6.75 and ca. 3.56% organic matter (Liu et al., 1990).

METHODS

A complete floristic inventory was made based on the identification of more than 5000 plant specimens collected from the limestone habitat in southern Yunnan during 1985–1995 and deposited mainly at HITBC and SYS. The flora of the vegetation on the limestone consisted of 153 families of vascular plants, including 640 genera and 1394 species. An initial floristic analysis was made based on the inventory (Zhu et al., 1996). Three main vegetation types occur on the limestone—tropical seasonal rain forest, tropical seasonal moist forest, and tropical montane dwarf forest—which were selected for establishing plots. For the tropical seasonal rain forest, seven separate plots ranging in size from 2000 to 2500 m² were established. For the tropical seasonal moist forest seven separate plots ranging in size from 500 to 2000 m² were laid out. For the tropical montane dwarf forest, only two plots of 10 by 10 m were made due to its restriction to limestone summits. These different plot sizes were used because of the differential coverage of forest type and site restrictions. The structure and species composition of the vegetation on the limestone were analyzed based on plot data already published (Zhu et al., 1998a). In the present paper, plant inventory lists of the two main forest types (excluding montane dwarf forest) were compiled from sample plots separately for the physiognomic (life form and leaf size) analysis. The criteria for life form and leaf size classes suggested by Raunkiaer (1934) and the importance value index (IVI) suggested by Curtis and McIntosh (1951) were used in the physiognomic or ecological analysis. Ecological species groups were discriminated from field observation and correspond to groups used in Shimizu (1964) and Chin (1977). Species-level biogeographical affinities were assessed for the total flora of the limestone vegetation. The floristic similarities between the limestone flora of southern Yunnan and the floras on limestone and non-limestone habitats from southwest China, northern Vietnam, northern Thailand, and the Malay Peninsula were also discussed.

CLASSIFICATION OF LIMESTONE VEGETATION

Based on plant physiognomy, forest profile, floristic composition, and habitat, the primary limestone vegetation can be classified into three vegetation types, i.e., tropical seasonal rain forest,

tropical seasonal moist forest, and tropical montane dwarf forest (Zhu et al., 1998a). Within these, six formations, including nine communities, were recognized:

- (1) Ravine seasonal rain forest (including the *Pometia tomentosa*–*Alphonsea monogyna* community and *Pometia tomentosa*–*Celtis philippensis* var. *wightii* community);
- (2) Lower hill seasonal rain forest (including only the *Celtis philippensis* var. *wightii*–*Lasiococca comberi* var. *pseudoverticillata* community);
- (3) Evergreen moist forest (including the *Osmanthus polyneurus*–*Dracaena cochinchinensis* community and *Lasiococca comberi* var. *pseudoverticillata*–*Cleistanthus sumatranus* community);
- (4) Semi-evergreen moist forest (including the *Bombax insignis*–*Colona floribunda* community and *Bombax insignis*–*Garcinia bracteata* community);
- (5) Evergreen dwarf forest (including only the *Photinia angusta*–*Pistacia weinmannifolia* community);
- (6) Semi-evergreen dwarf forest (including only the *Ficus neriifolia*–*Dracaena cochinchinensis* community).

Detailed descriptions and ecological analyses of the communities have been reported earlier (Zhu et al., 1998a). Here the classification of the limestone vegetation is concisely enumerated so that the biogeographical components of the limestone vegetation can be better understood.

TROPICAL SEASONAL RAIN FOREST

Tropical seasonal rain forest on limestone, just as the regional tropical seasonal rain forest off limestone, shares characteristics with the equatorial lowland rain forest. These forests are mainly evergreen, but there are some deciduous trees in the emergent layer. This is equivalent to the tropical semi-evergreen rain forest of Southeast Asia (Whitmore, 1984), or the tropical semi-evergreen forest of India–Burma (Champion, 1936), as well as the evergreen seasonal forest of tropical America (Beard, 1944, 1955). In southern Yunnan, these limestone forests occur in wet valleys and on lower slopes of hills or mountains below 1000 m altitude. This same forest type also occurs in northern Thailand (Smitinand, 1966) and North Vietnam (Thin, 1997), although different names were used. The tropical seasonal rain forest represents Southeast Asian tropical rain forest at its latitudinal and altitudinal limits. The ecological structure of the tropical seasonal rain forest on limestone is almost exactly the same as the seasonal rain forest off limestone in the Xishuangbanna region (Zhu, 1992,

Table 1. Life forms of the limestone forest in southern Yunnan.

Life form*	Para	Liana					Phanerophytes					Thero- phytes	
		Epiph	Woody	Herb	Megaph	Mesoph	Microph	Nanoph	Hph	All	Cham	Geoph	phytes
Limestone seasonal rain forest (14300 m ² of 7 plots, total 249 species)	1	7	48	3	9	84	34	17	12	156	31	3	—
	Number of species	2.8%	19.3%	1.2%	3.6%	33.7%	13.7%	6.8%	4.8%	62.7%	12.4%	1.2%	—
Limestone seasonal moist forest (9650 m ² of 7 plots, total 211 species)	—	18	27	5	2	62	36	21	3	124	28	7	2
	Percentage of total species	8.5%	12.8%	2.3%	0.9%	29%	17%	9.9%	1.4%	58.8%	13%	3.3%	0.9%

* Life form (Raunkiaer, 1934); Megaph = Megaphanerophyte (perennials over 30 m high); Mesoph = Mesophanerophyte (perennials 8 to 30 m high); Microph = Microphanerophyte (perennials 2 to 8 m high); Nanoph = Nanophanerophyte (perennials 0.25 to 2 m high); Hph = Herbaceous phanerophyte (herbaceous perennials over 0.25 m high); Cham = Chamaephytes (perennials less than 0.25 m high above ground); Geoph = Geophyte (perennials, dying back above ground); Para = Parasitic; Epiph = Epiphytes; Thero-phytes (annuals).

1997). Most species in the seasonal rain forest on limestone are also found in the adjacent non-limestone seasonal rain forest, but the latter is more diverse with additional species, which are not found on the limestone.

TROPICAL SEASONAL MOIST FOREST

Tropical seasonal moist forest occurs on the middle and upper limestone slopes ranging from 650 to 1300 m altitude. This vegetation type abuts the seasonal rain forest and was called monsoon forest by some Chinese authors (Liu, 1987; Wu, 1980). The term seasonal moist forest is preferred here because the forest is not equivalent to Schimper's monsoon forest (Schimper, 1903), in spite of the fact that it is affected by seasonal dryness and contains a variable percentage of deciduous trees. The seasonal dryness in the region is compensated to some extent by dense fog accompanied by low temperatures in the same months (November to April) (Whitmore, 1984). Some deciduous trees, such as *Gmelina arborea* Roxb., *Anthocephalus chinensis* (Lam.) Rich. ex Walp., and *Homalium laoticum* Gagn. var. *glabretum* C. Y. Wu, shed leaves toward the end of the dry season, while others, such as *Cratoxylon cochinchinensis* (Lour.) Bl., *Ficus religiosa* L., and *Elaeocarpus varunua* Buch.-Ham. ex Mast., shed their old leaves as new ones develop. This suggests that deciduousness in the region is more frequently associated with locally dry habitats than the seasonal dryness of climate. Therefore, using the term monsoon forest for the evergreen or semi-evergreen forest on limestone is confusing because Schimper's monsoon forest is more or less completely leafless during the dry season.

MONTANE DWARF FOREST

Montane dwarf forest occurs only on the tops of hills and summits of mountains at altitudes above 900 m. There is only one dwarf tree layer with a canopy height of 7–15 m. Epiphytic orchids, such as *Eria hainanensis* Rolfe and *Bulbophyllum nigrescens* Rolfe, and non-vascular epiphytes (bryophytes and lichens) are abundant. In some sites small woody climbers, such as *Derris caudatilimba* How (Papilionaceae) and *Pristimera arborea* (Roxb.) A. C. Smith (Hippocrateaceae), are also frequent.

PLANT PHYSIOGNOMY OR ATTRIBUTES

From plot data, life form spectra (Raunkiaer, 1934) of the two main forest types (seasonal rain forest and seasonal moist forest) are compiled in

Table 2. Physiognomic characteristics of the limestone forest in southern Yunnan.

Forest type		Leaf form		Leaf texture		Leaf size			
		S	C	P	L	Na	Mi	Me	Ma
Limestone seasonal rain forest ¹	Percentage of species	72.3	27.7	47.9	52.1	0	13.8	76.6	9.6
	Percentage of Importance Value Index (IVI) ³	76.3	23.7	52.8	47.2	0	3.8	91	5.3
Limestone seasonal moist forest ²	Percentage of species	68	32	51.5	48.5	1	21.5	74.2	3.1
	Percentage of Importance Value Index (IVI)	74.8	25.2	41.7	58.3	0.4	23.3	66.5	9.7

¹ From 14800 m² of 7 plots, total of 94 tree species > 5 cm DBH.² From 9650 m² of 7 plots, total of 97 tree species > 5 cm DBH.³ IVI = Relative dominant density + Relative frequency + Relative dominant breast area (Curtis & McIntosh, 1951). S: Simple leaves; C: Compound leaves; P: Papery leaves; L: Leathery leaves; Ma: Macrophyll (large to 164,025 mm²); Me: Mesophyll (to 18,222 mm²); Mi: Microphyll (to 2025 mm²); Na: Nanophyll (to 225 mm²) (Raunkiaer, 1934).

Table 1. Leaf size spectra, leaf form, and leaf texture are shown in Table 2. Both forest types were dominated by phanerophytes. Including lianas, these perennial phanerophytes make up 73.9–83.2% of the total species, while annual chamaephytes account for only 12.4–13%. However, the seasonal moist forest shows lower percentages of woody lianas as well as megaphanerophytes and mesophanerophytes, but higher percentages of epiphytes as well as microphanerophytes and nanophanerophytes than the seasonal rain forest.

Both forest types have species with mesophyllous leaves making up ca. 75% of the total tree species, but the forests show clear differences if the species are weighted by importance value index (IVI). This increases the percentage of mesophyllous perennials and decreases the percentage of micro- and macrophyllous trees in seasonal rain forest, while the opposite trend is seen in seasonal moist forest. Seasonal moist forest occupies much more rugged habitats with thinner and drier soils, and has more microphyllous species. In weighting by IVI, the increase in percentage of macrophyllous trees in seasonal moist forest is mainly due to the dominant evergreen species *Dracaena cochinchinensis* (Lour.) S. C. Chen (Agavaceae), with its long leathery lanceolate leaves, and the dominant deciduous tree species *Colona floribunda* (Wall. ex Voigt) Craib (Tiliaceae) also with large leaves to 30 cm long. In

weighting the species by IVI, the percentage of leathery leaves decreases in seasonal rain forest but increases in seasonal moist forest due to the presence of some species with these leathery leaves such as *Cleistanthus sumatranus* (Miq.) Muell.-Arg. (Euphorbiaceae) and *Dracaena cochinchinensis*.

ECOLOGICAL SPECIES GROUP

Based on the study of the limestone floras of Japan and Taiwan, Shimizu (1964) divided limestone plants into five ecological groups:

- (1) plants exclusive to limestone habitat;
- (2) plants selective for and found mainly in limestone;
- (3) plants preferring and dominant on limestone;
- (4) taxa indifferent, with no special association with limestone;
- (5) plants found only occasionally on limestone or strangers to limestone.

To Shimizu, these first three groups were characteristic species for the limestone habitats and in particular his exclusive and selective taxa were calcicoles. Chin (1977) accepted this classification and similarly categorized plants on limestone in the Malay Peninsula into four groups, combining selective and preferent plants. Similar ecological species groups have been later recognized by Chinese botanists (Liang et al., 1985; Liu et al., 1994).

Table 3. The ecological species groups of the limestone flora of southern Yunnan.

Ecological species groups (see Shimizu, 1964; Chin, 1977)	Number of species	%
Plants found only on limestone: endemic to southern Yunnan	24	1.7
not endemic to southern Yunnan	117	8.4
Plants dominant on limestone	170	12.2
Plants no restriction on limestone	858	61.6
Plants found occasionally on limestone	225	16.1
Total	1394	100

Table 4. Predominant families found in limestone forests of southern Yunnan.

	No. of genera	No. of species	%*		No. of genera	No. of species	%
Orchidaceae	35	86	26.9	Verbenaceae	6	20	43.5
Rubiaceae	34	58	64.1	Labiatae	13	20	30.1
Euphorbiaceae	27	58	60.4	Gesneriaceae	13	19	63.3
Papilionaceae	22	55	43.4	Sterculiaceae	7	18	46.8
Moraceae	7	48	73.8	Dioscoriaceae	1	18	64.3
Vitaceae	7	38	79.5	Menispermaceae	10	17	60.7
Acanthaceae	26	36	65.4	Liliaceae	10	16	64.0
Rutaceae	11	35	71.4	Araceae	10	15	44.1
Asclepiadaceae	16	35	53.0	Compositae	8	15	14.6
Urticaceae	12	35	53.0	Myrsinaceae	4	14	38.2
Lauraceae	10	35	45.0	Commelinaceae	7	14	60.9
Apocynaceae	19	33	58.9	Zingiberaceae	6	14	42.4
Meliaceae	12	30	83.0	Myrtaceae	1	13	45.8
Annonaceae	12	30	50.9	Tiliaceae	3	12	57.1
Cucurbitaceae	9	24	52.3	Mimosaceae	6	12	66.6
Rhamnaceae	19	21	70.4	Anacardiaceae	7	11	64.7
Piperaceae	3	20	54.8	Convolvulaceae	4	11	37.4
				Ulmaceae	5	11	100

$$* \% = \frac{\text{the no. of species on limestone}}{\text{the total no. of species in southern Yunnan}} \times 100$$

Following Shimizu and Chin's classifications, we divided the limestone flora of southern Yunnan into these four ecological species groups (Table 3). In our study, 141 vascular plant species are restricted to limestone habitats and thus are exclusively found here. These include the following common species *Celtis philippensis* var. *wightii*, *Amoora calcicola*, *Murraya tetramera*, *Pistacia weinmannifolia*, as well as species in *Agapetes*, *Sageretia*, *Tupistra*, and *Pristimera*. Of these, 24 species are endemic to southern Yunnan. Taxa exclusive to limestone make up about 10% of the total limestone flora, which agrees with the results from Longgan limestone (exclusive taxa, 13%) (Liang et al., 1985) and Longhua limestone (exclusive taxa, 10%) (Liu et al., 1994) from Guangxi Province in China. Both the exclusive and preferent taxa make up 22.3% of the total sum. They could be termed as characteristic species for limestone habitats (see Appendix 1). This is similar to the results from Longgan in Guangxi (with these characteristic species making up 20% of the total sum) (Liang et al., 1985) and from the Malay Peninsula (27.5%) (Chin, 1977).

THE FLORA AND ITS BIOGEOGRAPHY

In the limestone forests of southern Yunnan, China, 153 families of vascular plants including 640 genera and 1394 species and varieties, were recorded, of which seed plants compose 129 families, 558 genera, and 1269 species (see Appendix 1).

More than 80% of the species also occur in the non-limestone habitats of the Xishuangbanna region.

The limestone flora makes up about one quarter of the total species of the regional flora. (The flora of the Xishuangbanna region was primarily documented with 3336 native species of 1218 genera and 207 families of seed plants; see Li, 1996.) Some families show relative preference for limestone habitats (with more than 60% of the total number of species in the region on limestone), for example, Acanthaceae, Euphorbiaceae, Gesneriaceae, Meliaceae, Menispermaceae, Moraceae, Rhamnaceae, Rubiaceae, Rutaceae, Vitaceae, and Ulmaceae (Table 4). Other families, such as Hippocrateaceae, Icacinaceae, and Vacciniaceae, show an even stronger preference for limestone (found almost exclusively in limestone habitats in southern Yunnan), although they are not among the predominant families in species richness.

The distribution types of Chinese seed plants at the generic level were documented by Wu (1991). Based on Wu's document, 544 of the 558 genera of seed plants from the limestone forest of southern Yunnan can be divided into 12 distribution types or geographic elements (14 genera, which are cosmopolitan in distribution, are not included in the geographic statistics). One thousand two hundred forty-four of the 1269 species of seed plants from the limestone forest can be recognized in nine dis-

Table 5. Geographic affinities of the limestone forests of southern Yunnan.

Geographic element at the generic level (see Wu, 1991)	Percentage of genera	Geographic elements at the specific level	Percentage of species
1. Pantropic	21.1%	1. Pantropic	0.6%
2. Tropical Asia–Tropical America disjunct	2.9%	2. Tropical Asia–Tropical America disjunct	0.2%
3. Old World Tropics	13.8%	3. Old World Tropics	0.4%
4. Tropical Asia to Tropical Australia	9.0%	4. Tropical Asia to Tropical Australia	3.2%
5. Tropical Asia to Tropical Africa	7.9%	5. Tropical Asia to Tropical Africa	1.3%
6. Tropical Asia	35.3%	6. Tropical Asia	(64.5%)
7. Northern Temperate	2.8%	6a. India-Malaysia	17.0%
8. Temperate Eastern Asia and Northern America disjunct	2.8%	6b. Mainland Southeastern Asia to Malaysia	7.3%
9. Old World Temperate	0.9%	6c. Southern Asia to Mainland Southeastern Asia	19.9%
10. Temperate Mediterranean, Western Asia to Central Asia	0.2%	6d. Mainland Southeastern Asia to Southern China	20.3%
11. Eastern Asia	2.9%	7. Eastern Asia	0.5%
12. Endemic to China	0.4%	8. Southern China	10.6%
		9. Endemic to Yunnan	18.6%
Total of 544 genera	100%	Total of 1244 species	100%

tribution types based on their geographic distribution (25 species of seed plants are not included due to insufficient distribution references) (Table 5). At the generic level, the geographic elements of tropical distribution (1–6, Table 5) compose 90% of the total genera; the geographic elements of temperate distribution (7–10, Table 5) make up only 6.7%. At the specific level, the species that are of typical tropical distribution (1–6, Table 5) account for 70.2% of the total species. Among these, the geographic types that are considered to be from tropical Asia make up 64.5% of the total species from limestone forests in Xishuangbanna. If the species from the tropical areas adjacent to Xishuangbanna from southern China and Yunnan are included, these tropical species compose more than 90%. This indicates that the limestone flora at Xishuangbanna is principally tropical in nature and represents the tropical Asian flora at its northern tropical margin.

In a floristic comparison with nine similar floras, both limestone and non-limestone, from southwest China, northern Vietnam (Thin, 1997), northern Thailand (Smitinand, 1966), and the Malay Peninsula (Chin, 1977, 1979; Burkill & Henderson, 1925) (Table 6), the limestone flora of southern Yunnan displays explicit taxonomic affinities to the tropical floras and shows a closer affinity to the floras from the Malay Peninsula than to other floras from subtropical China (the floras of Huapin and Dongyang, see Li et al., 1986; Xu, 1984), even though these Malaysian floras lie farther away geographically from southern Yunnan. Our limestone flora in southern Yunnan shares the most genera with the limestone flora of northern Vietnam (Cuc-phuong, see Thin, 1997) among those floras compared in this study. The similarity at the generic level between our limestone flora and the limestone flora of northern Thailand (Doi Chiengdao) (Smitinand, 1966) is less than would be expected from its geographic proximity. This lack of correspondence could be because the plant list for Doi Chiengdao used here for comparison is an incomplete one consisting of only 512 species, less than half reported for most other sites in Table 6. The limestone flora of Xishuangbanna did not show a higher floristic similarity to other regional limestone floras than to non-limestone floras in our comparison. It appears that limestone floras develop from local or regional floras, supported also by the fact that only about 10% of the total species of limestone floras (the exclusive group) are restricted to limestone habitats in our study.

The floristic relationships between our limestone flora in southern Yunnan and neighboring floras of

Table 6. Comparison of floristic similarities between the limestone habitats of Xishuangbanna, southern Yunnan, and the limestone and non-limestone habitats from southwestern China and southeastern Asia.

Location	Habitat	Size of flora (Seed plants)	Shared taxa by both floras	Similarity coefficients
2. Longgan, SW China 22°14–33'N, 106°46'E	limestone	149 families 669 genera 1363 species	118 371	91.2 66.5
3. Daqinshan Mountains, SW China 22°14'N, 107°E	non-limestone	182 fam. 871 gen. 1813 spp.	126 389	97.4 69.8
4. Gulinqing, SW China 22°36'N, 104°E	limestone	143 fam. 496 gen. 1095 spp.	116 261	89.9 52.6
5. Huapin, SW China 25°31–39'N, 109°50'E	non-limestone	151 fam. 475 gen. 1051 spp.	83 150	72.8 33.2
6. Dongyang Mountains, SW China 25°14'N, 107°56'E	limestone	116 fam. 367 gen. 736 spp.	86 153	73.7 41.6
7. Cucphuong, N Vietnam 20°14–24'N, 105°24–44'E	limestone	167 fam. 860 gen. 1661 spp.	120 428	93 76.7
8. Chiendae, N Thailand 19°2'N, 98°54'E	limestone	101 fam. 342 gen. 512 spp.	93 181	92.1 52.9
9. Malay peninsula limestone 1–6°N, 100–104°E	limestone	117 fam. 535 gen. 1112 spp.	93 244	81.6 51.6
10. Taiping, Malay peninsula 4°N, 101°E	non-limestone	115 fam. 682 gen. 1939 spp.	94 243	82.5 51.6

Notes: The direct comparison of species composition between the different floras is not very significant before the local floras are updated and the taxa revised; therefore, the comparison of floristic similarities between the different floras at the specific level is not made.

References: location 2 (Chen, 1985); 3 (Daqinshan Forest station of Guanxi Forestry Bureau, 1980); 4 (Li, 1987); 5 (Li et al., 1986); 6 (Xu, 1984); 7 (Thin, 1997); 8 (Smitinand, 1966); 9 (Chin, 1977, 1979); 10 (Burkill & Henderson, 1925).

tropical Asia and southern China were discussed by Zhu (1997). This limestone flora shares all families and 88% of its genera with the flora of Indochina (Lecomte, 1907–1951; Aubréville et al., 1960–1996), 96% of its families and 68% of its genera with the flora of the Malay Peninsula (Ridley, 1967; Keng, 1978), 73% of its woody plant genera with Burma (Kurz, 1877), and more than 97% of its families and more than 80% of its genera with other tropical floras of south China (including Hainan Island; see Wu, 1994). The limestone flora of Xishuangbanna demonstrates strong affinity to other tropical Asian floras.

Literature Cited

- Aubréville, A., N. L. Tardieu-Blot & J. E. Vidal (editors). 1960–1996. *Flora du Cambodge, du Laos et du Vietnam*. No. 1–28. Museum National d'Histoire Naturelle, Paris.
- Beard, J. S. 1944. Climax vegetation in tropical America. *Ecology* 25: 127–158.
- . 1955. The classification of tropical American vegetation types. *Ecology* 36: 359–412.
- Burkill, I. H. & M. R. Henderson. 1925. The flowering plants of Taiping, in the Malay Peninsula. *Gard. Bull. Straits Settlements* 3: 300–459.
- Champion, H. G. 1936. A preliminary survey of the forest types of India and Burma. *Indian Forest Rec.*, n.s. 1: 1–286.
- Chen, F. P. 1985. *Limestone Flora in Longgang, Guangxi, China*. Unpublished M.S. Thesis, Zhongshan University. [In Chinese.]
- Chin, S. C. 1977, 1979. The limestone hill flora of Malaya, I, II. *Gard. Bull. Singapore* 30: 165–219; 32: 64–203.
- Curtis, J. T. & R. P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* 32: 467–496.
- Daqinshan Forest station of Guangxi Forestry Bureau. 1980. Plant list of Daqinshan, Guangxi. [Unpublished manuscript, in Chinese.]
- Keng, H. 1978. *Orders and Families of Malayan Seed Plants*. Singapore Univ. Press, Singapore.

- Kurz, W. S. 1877. Forest Flora of British Burma 1 & 2. Office of the Superintendent of Government Printing, Calcutta. [Reprint 1974, International Book Distributors.]
- Lecomte, H. (editor). 1907–1951. Flora generale de L'Indochine. Tome 1–7. Masson et Cie Editeurs, Paris.
- Li, B. 1987. Flora of Gulinqing Nature Reserve in southeastern Yunnan. Unpublished M.S. Thesis, Zhongshan University. [In Chinese.]
- Li, S. K., S. F. Yuan, L. F. Liu & Z. Z. Chen. 1986. The flora of Huapin. *In*: Reports on the Huapin Forest Area in Guangxi. Shandong Science Press, Jinan. [In Chinese.]
- Li, Y. H. (editor). 1996. List of Plants in Xishuangbanna. Yunnan National Press, Kunming. [In Chinese.]
- Liang, C. F., J. Y. Liang & L. F. Liu. 1985. A report on the exploration of the flora of Longgang. *Guihaia* 5(3): 191–209. [In Chinese with English abstract.]
- Liu, L. H. 1987. Rain forest. *In*: C. Y. Wu (editor), Vegetation of Yunnan. Science Press, Beijing. [In Chinese.]
- Liu, L., Y. T. Hu, Y. C. Yang, W. W. Liu & R. X. Guo (editors). 1990. Reports on Land and Economy of Xishuangbanna. Yunnan People's Press, Kunming. [In Chinese.]
- , H. Ye, G. Zhang & H. Chen. 1994. Floristic analysis of the Longhua natural reserve. *Acta Bot. Austrosinica* 9: 1–16. [In Chinese with English abstract.]
- Raunkiaer, C. 1934. The Life Forms of Plants and Statistical Plant Geography. Oxford Univ. Press, Oxford.
- Ridley, H. N. 1967. The Flora of Malay Peninsula, I–V. L. Reeve, London. [Reprint.]
- Schimper, A. F. W. 1903. Plant-Geography upon a Physiological Basis. Oxford Univ. Press, Oxford.
- Shimizu, T. 1964. Studies on the limestone flora of Japan and Taiwan. Part II. J. Fac. Textile Sci. Technol. Shinsu Univ., A 12: 1–88.
- Smitinand, T. 1966. The vegetation of Dao Chiengdao, a limestone massive in Chiengmai, north Thailand. *Nat. Hist. Bull. Siam Soc.* 21(1–2): 93–128.
- Thin, N. N. 1997. The vegetation of Cucphuong national park, Vietnam. *Sida* 17: 719–759.
- Wang, H., H. Zhu & B. G. Li. 1997. Vegetation on limestone in Xishuangbanna, southwest China. *Guihaia* 17: 101–117. [In Chinese with English abstract.]
- Whitmore, T. C. 1984. Tropical Rain Forests of the Far East, 2nd ed. Clarendon Press, Oxford.
- Wu, C. Y. (editor). 1980. Vegetation of China, pp. 363–397. Science Press, Beijing. [In Chinese.]
- . 1991. The areal-types of Chinese genera of seed plants. *Acta Bot. Yunnan Suppl.* IV: 1–139.
- Wu, T. L. (editor). 1994. A Checklist of Flowering Plants of Islands and Reefs of Hainan and Guangdong Province. Science Press, Beijing. [In Chinese.]
- Xu, Y. C., H. Q. Jiang & F. Quan (editors). 1987. Reports on the Nature Reserve of Xishuangbanna. Yunnan Sci. & Techn. Press, Kunming. [In Chinese.]
- Xu, Z. R. 1984. Limestone Flora of Dongyang Mountain in Libo, Guizhou, China. Unpublished M.S. Thesis, Zhongshan University. [In Chinese.]
- Zhu, H. 1992. Tropical rain forest vegetation in Xishuangbanna. *Chin. Geogr. Sci.* 2: 64–73.
- . 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relationship with rain forests of tropical Asia. *J. Biogeogr.* 24: 647–662.
- , H. Wang, B. G. Li & Z. F. Xu. 1996. A phyto-geographical research on forest flora of limestone hills in Xishuangbanna. *Guihaia* 16: 317–330. [In Chinese with English abstract.]
- , ———, ——— & ———. 1997. Floristic relationships between the limestone flora of Xishuangbanna and neighboring floras of tropical Asia and south China. *Acta Bot. Yunn.* 19: 357–365. [In Chinese with English abstract.]
- , H. Wang & B. G. Li. 1998a. The Structure, Species Composition and Diversity of the Limestone Vegetation in Xishuangbanna, SW China. *Gard. Bull. Singapore* 50: 5–33.
- , H. Wang, B. G. Li & Z. F. Xu. 1998b. Research on the tropical seasonal rainforest of Xishuangbanna, south Yunnan. *Guihaia* 18: 371–384. [In Chinese with English abstract.]

Appendix 1. Ecological species groups of the limestone vegetation in southern Yunnan. *Flora Reipublicae Popularis Sinicae* is the authoritative source for specific and infraspecific names except for ones recently revised and in IPNI (www.ipni.org) and TROPICOS (<http://mobot.mobot.org/W3T/Search/vast.html>). The family names of angiosperms are according to the Angiosperm Phylogeny Website (<http://www.mobot.org/MOBOT/research/APweb/>).

Seed Plant Taxa exclusive to limestone habitats and endemic to southern Yunnan		
ACANTHACEAE		
<i>Baphicacanthus multibracteolata</i> H. T. Chang & H. Chu		Chu Hua 1192 (holotype, SYS)
AGAVACEAE		
<i>Dracaena menglaensis</i> G. Z. Ye		Ye Guang-zheng 9035 (holotype, YCE; isotype, KUN)
ALANGIACEAE		
<i>Alangium kurzii</i> var. <i>pachyphyllum</i> W. P. Fang & H. Y. Su		Zhang Shun-cheng 24027 (HITBC); Li Yan-hui 1255 (holotype, KUN)
DIOSCOREACEAE		
<i>Dioscorea menglaensis</i> H. Li		Pei Sheng-ji 10347 (holotype, KUN)
EBENACEAE		
<i>Diospyros atrotricha</i> H. W. Li		Li Yan-hui 4215 (holotype, KUN; isotype, HITBC)
EUPHORBIACEAE		
<i>Croton yanhuii</i> Y. T. Chang		Ch1050 (SYS); Li Yan-hui 03587 (holotype, KUN; isotype, HITBC)
<i>Trigonostemon lii</i> Y. T. Chang		Li Yan-hui 4576 (holotype, KUN)
FAGACEAE		
<i>Quercus yiwuensis</i> Huang		Pei Sheng-ji 59-10040 (holotype, KUN)
GESNERIACEAE		
<i>Ornithoboea calcicola</i> C. Y. Wu ex H. W. Li		Pei Sheng-ji 59-10072 (isotype, HITBC)
LAURACEAE		
<i>Lindera nactusia</i> var. <i>monglunensis</i> H. P. Tsui		Li Yan-hui 4231 (HITBC), 386 (holotype, KUN)
<i>Neolisea menglaensis</i> Y. C. Yang & P. H. Huang		Li Yan-hui 20078 (holotype, KUN; isotype, HITBC)
MAIVACEAE		
<i>Pterospermum menglunensis</i> H. H. Hsue		Ch378 (SYS); Li Yan-hui 4634 (holotype, KUN; isotype, HITBC)
<i>Pterospermum yunnanensis</i> H. H. Hsue		Li Yan-hui 33830 (HITBC), 3717 (holotype, KUN); Tao Guo-da 13655 (HITBC)
MELIACEAE		
<i>Amoora calcicola</i> C. Y. Wu & H. Li		Li Yan-hui 3712 (HITBC), 3814 (HITBC), 2804 (HITBC); Pei Sheng-ji 59-10292 (holotype, KUN)
PIPERACEAE		
<i>Piper mischocarpum</i> Y. C. Tseng		Cai C.T. 59-10784 (holotype, KUN); Li Yan-hui 3771 (HITBC); Tao Guo-da 4177 (HITBC), 7152 (HITBC)
<i>Sageretia thea</i> var. <i>cordiformis</i> Y. L. Chen & P. K. Chou		W. T. Wang 10496 (holotype, KUN)

Appendix 1. Continued.

THEACEAE		Tao Guo-da 15933 (holotype, KUN; isotype, HITBC)
<i>Pyrenaria menglaensis</i> G. D. Tao		
Seed Plant Taxa exclusive to limestone habitats but not endemic to southern Yunnan		
ACANTHACEAE		
<i>Andrographis laxiflora</i> var. <i>glomeruliflora</i> (Bremek.) H. Chu		Ch1193 (SYS), Ch1219 (SYS)
<i>Daedalacanthus tetragonus</i> T. Anders.		Ch255 (SYS), Ch1175 (SYS), Ch1217 (SYS); Tao Guo-da 3797 (HITBC)
<i>Pieracanthus alatus</i> (Wall. ex Nees) Bremek.		Li Yan-hui 20047 (HITBC)
<i>Strobilanthes pstotachys</i> C. B. Clarke ex W. W. Smith		Li Yan-hui 4605 (HITBC)
<i>Thunbergia coccinea</i> Wall.		Ch454 (SYS), Ch1186 (SYS); Li Yan-hui 5190 (HITBC), 2911 (HITBC)
AGAVACEAE		
<i>Dracena cambodiana</i> Pierre ex Gagnep.		Wang Hong 3159 (HITBC), 3160 (HITBC)
<i>Dracena terniflora</i> Roxb.		Yang Zheng-hong 12178 (HITBC); Expedition 32120 (HITBC), 34923 (HITBC)
ANACARDIACEAE		
<i>Pistacia weinmannifolia</i> Poiss. ex Franch.		Expedition 32613 (HITBC); Pei Sheng-ji 10045 (HITBC); Tao Guo-da 1212 (HITBC)
<i>Spondias lakonensis</i> var. <i>hirsutus</i> C. Y. Wu & T. L. Ming		Wang Hong 1792 (HITBC)
<i>Toxicodendron fulvum</i> (Craib) C. Y. Wu & T. L. Ming		Pei Sheng-ji 10034 (HITBC); Tao Guo-da 13650 (HITBC)
ANNONACEAE		
<i>Alphonsea boniana</i> Finet & Gagnep.		Ch56 (SYS)
<i>Alphonsea mollis</i> Dunn		Li Yan-hui 1043 (HITBC), 4610 (HITBC)
<i>Alphonsea squamosa</i> Finet & Gagnep.		Ch815 (SYS)
<i>Milusa velutina</i> Hook. f. & Thoms.		Ch386 (SYS), Ch814 (SYS), Ch985 (SYS); Zhu Hua & Wang Hong 2416 (HITBC)
<i>Mitrephora calcarea</i> Diels ex Ast		Ch545 (SYS)
<i>Polyalthia petelotii</i> Merr.		Ch909 (SYS)
APOCYNACEAE		
<i>Aganosma acuminata</i> (Roxb.) G. Don		Ch584 (SYS)
<i>Anodendron affine</i> var. <i>pingpienense</i> Tsiang & P. T. Li		Ch802 (SYS), Ch715 (SYS)
<i>Cosmostigma hainanense</i> Tsiang		Ch870 (SYS)
ARACEAE		
<i>Anorphophallus yunnanensis</i> Engl.		Li Yan-hui 4225 (HITBC)
<i>Gonatanthus pumilus</i> Engl. & K. Krause		Tao Guo-da et al. 16166 (HITBC)
<i>Remusatia vivipara</i> Schott		Expedition 10201 (HITBC)
BOMBACACEAE		
<i>Bombax insignis</i> Wall.		Tao Guo-da 9007 (HITBC), 9008 (HITBC)
BORAGINACEAE		
<i>Ehretia dunniana</i> Lévl.		Ch29 (SYS), Ch373 (SYS); Li Yan-hui 3300 (HITBC), 3726 (HITBC)

Appendix 1. Continued.

BUXACEAE		
<i>Sarcococca vagans</i> Stapf		Tao Guo-da 15739 (HITBC), 13691 (HITBC)
CAPPARIDACEAE		
<i>Capparis bodinieri</i> Lévl.		Ch321 (SYS)
CELASTRACEAE		
<i>Loeseneriella merrilliana</i> A. C. Smith		Li Yan-hui 455 (HITBC); Tao Guo-da 13672 (HITBC)
<i>Loeseneriella yunnanensis</i> (Hu) A. C. Smith		Ch1015 (SYS), Ch1063 (SYS); Li Yan-hui 2736 (HITBC); Wang Hong 1573 (HITBC)
<i>Pristimera cambodiana</i> (Pierre) A. C. Smith		Ch24 (SYS); Wang Hong 1575 (HITBC)
<i>Pristimera setulosa</i> A. C. Smith		Li Yan-hui 3141 (HITBC)
COMBRETACEAE		
<i>Anogeissus acuminata</i> Wall.		Tong Shao-quan 24960 (HITBC)
COMPOSITAE		
<i>Pterocypela indica</i> (L.) C. Shih		YB004125 (HITBC)
<i>Vernonia curtisii</i> Craib & Hutchison		Li Yan-hui 3780 (HITBC); Tao Guo-da 13664 (HITBC)
CONVOLVULACEAE		
<i>Porana paniculata</i> Roxb.		Ch1170 (SYS); Wang Hong 2655 (HITBC)
<i>Porana racemosa</i> Roxb.		Ch469 (SYS); Zhu Pei-zhi 10527 (HITBC)
<i>Tridynamia sinensis</i> (Hemsl.) G. W. Staples		Ch1232 (SYS)
<i>Tridynamia sinensis</i> var. <i>delavayi</i> (Gagnep. & Courchet) G. W. Staples		Ch513 (SYS)
CRUCIFERAE		
<i>Cardamine calicicola</i> W. Smith		Li Yan-hui 4217 (HITBC)
DIOSCOREACEAE		
<i>Dioscorea arachidna</i> Prain & Burkill		Ch845 (SYS)
<i>Dioscorea aspersa</i> Prain & Burkill		Ch921 (SYS)
<i>Dioscorea chingii</i> Prain & Burkill		Ch473 (SYS); Li Yan-hui 2036 (HITBC)
<i>Dioscorea pulvereae</i> Prain & Burkill		Ch791 (SYS); Wang Hong 3147 (HITBC)
<i>Dioscorea tentaculigera</i> Prain & Burkill		Pei Sheng-ji 9985 (HITBC)
ERICACEAE		
<i>Agapetes burmanica</i> W. E. Evans		Li Yan-hui 3718 (HITBC), 2739 (HITBC)
<i>Agapetes lobbii</i> C. B. Clarke		Li Yan-hui 3719 (HITBC)
<i>Agapetes mannii</i> Hemsl.		Li Yan-hui 3629 (HITBC)
EUPHORBIACEAE		
<i>Cleistanthus sumatranus</i> (Miq.) Muell.-Arg.		Li Yan-hui 3095 (HITBC), 2529 (HITBC)
<i>Croton argyriatus</i> Blume		Ch179 (SYS)
<i>Phyllanthus clarkei</i> Hook. f.		Ch563 (SYS), Ch812 (SYS)
<i>Trigonostemon bonianus</i> Gagnep.		Ch367 (SYS), Ch39 (SYS), Ch353 (SYS)

Appendix 1. Continued.

FABACEAE*Albizia odoratissima* (L.) Benth.*Bauhinia carinophylla* Merr.*Caesalpinia tsoongii* Merr.*Callerya eurybotrya* (Drake) A. M. Schot*Derris caudatilimba* How*Milletia tetrapera* Kurz*Sophora prazeri* Prain*Sophora tonkinensis* Gagnep.*Li Yan-hui 1411* (HITBC)*Ch1097* (SYS)*Ch118* (SYS)*Li Yan-hui 4200* (HITBC)*Ch398* (SYS), *Ch504* (SYS)*Li Yan-hui 4100* (HITBC)*Ch394* (SYS), *Ch559* (SYS); *Li Yan-hui 2802* (HITBC), 4277 (HITBC)*Ch619* (SYS)**FUMARIACEAE***Corydalis taliensis* var. *siamensis* (Craib) X. Zhang*Li Yan-hui 20062* (HITBC), 3727 (HITBC)**GESNERIACEAE***Raphiocarpus begoniifolius* (H. Lévl.) B. L. Burt*Didymocarpus margaritae* W. W. Sm.*Lysionotus serratus* D. Don*Ornithoboea henryi* Craib*Ch947* (SYS); *Pei Sheng-ji 9892* (HITBC); *Tao Guo-da 15902* (HITBC)*Pei Sheng-ji 1054* (HITBC)*Ch624* (SYS), *Ch806* (SYS); *Pei Sheng-ji 59-9937* (HITBC); *Tao Guo-da 15750* (HITBC)*Expedition 32625* (HITBC); *Pei Sheng-ji 59-10069* (HITBC)**GUTTIFERAE***Garcinia bracteata* C. Y. Wu ex Y. H. Li*Li Yan-hui 4103* (HITBC), 3813 (HITBC)**ICACINACEAE***Gomphandra tetrandra* (Wall.) Sleum.*Tao Guo-da 11182* (HITBC)**LABIATAE***Coleus xanthanthus* C. Y. Wu & Y. C. Huang*Gomphostemma parviflorum* Wall.*Rabdosia eriocalyx* var. *laxiflora* C. Y. Wu & H. W. Li*Pei Sheng-ji 10138* (HITBC)*Cui Jing-yun 14659* (HITBC); *Tao Guo-da 15798* (HITBC)*Li Bao-gui 9911209* (HITBC); *Li Yan-hui 3759* (HITBC); *Wang Zhong-yu s.n.* (HITBC)**LAMIACEAE***Symphorema involucratum* Roxb.*Li Yan-hui 2988* (HITBC), 4852 (HITBC)**LAURACEAE***Cryptocarya acutifolia* H. W. Li*Li Yan-hui 1029* (HITBC), 3052 (HITBC)**LINACEAE***Reinwardtia indica* Dum.*Expedition 34310* (HITBC)**MALVACEAE***Pterospermum chingtungense* C. Y. Wu & Hsue*Pterospermum proteus* Burkill*Expedition 34533* (HITBC)*Li Yan-hui 3586* (HITBC); *Wang Hong 831* (HITBC), 842 (HITBC)

Appendix 1. Continued.

MELIACEAE		
<i>Aglaia testicularis</i> C. Y. Wu	Ch339 (SYS)	
<i>Anoora tetrapetala</i> (Pierre) C. Y. Wu	Ch529 (SYS); Wang Hong 1710 (HITBC), 1715 (HITBC)	
<i>Munronia henryi</i> Harms	Ch351 (SYS), Ch192 (SYS); Li Yan-hui 3327 (HITBC)	
MENISPERMACEAE		
<i>Cyclea sutchuenensis</i> Gagnep.	Ch901 (SYS)	
<i>Stephania chingtungensis</i> H. S. Lo	Tao Guo-da 43898 (HITBC)	
<i>Stephania epigaea</i> H. S. Lo	Tao Guo-da 15672 (HITBC)	
MYRSINACEAE		
<i>Myrsine semiserrata</i> Wall.	Li Yan-hui 20032 (HITBC); Tao-Guo-da 15729 (HITBC); Wang Hong 1960 (HITBC)	
OLACACEAE		
<i>Natsiatopsis thunbergiaefolia</i> Kurz	Tao Guo-da 42370 (HITBC)	
OLEACEAE		
<i>Ligustrum sinense</i> var. <i>coryanum</i> (W. W. Smith) Hand.-Mazz.	Li Yan-hui 429 (HITBC); Tao Guo-da 16440 (HITBC); Wang Hong 2101 (HITBC), 2091 (HITBC)	
ORCHIDACEAE		
<i>Bulbophyllum ambrosia</i> (Hance) Schltr.	Ch679 (SYS)	
<i>Bulbophyllum kuangtungense</i> Schltr.	Ch222 (SYS)	
<i>Bulbophyllum nigrescens</i> Rolfe	Zhu Pei-zhi 8683 (HITBC)	
<i>Dendrobium salaccense</i> Lindl.	Ch158 (SYS)	
<i>Eulophia bracteosa</i> Lindl.	Li Yan-hui 4150 (HITBC)	
<i>Pholidota chinensis</i> Lindl.	Tao Guo-da 44107 (HITBC)	
PALMAE		
<i>Caryota urens</i> L.	Chen San-yang 18959 (HITBC)	
PIPERACEAE		
<i>Peperomia leptostachya</i> var. <i>cambodiana</i> (C. DC.) Merr.	Ch950 (SYS)	
PRIMULACEAE		
<i>Lysimachia garrettii</i> Fletcher	Li Yan-hui 3302 (HITBC)	
RHAMNACEAE		
<i>Gouania javanica</i> Miq.	Ch798 (SYS), Ch850 (SYS); Li Yan-hui 3714 (HITBC)	
<i>Hovenia acerda</i> var. <i>kiukiangensis</i> (Hu & Cheng) C. Y. Wu ex Y. L. Chen	Tao Guo-da 39915 (HITBC)	
<i>Sageretia laxiflora</i> Hand.-Mazz.	Ch399 (SYS); Zhu Pei-zhi 10478 (HITBC), 10479 (HITBC)	
<i>Ventilago calyculata</i> var. <i>trichoclada</i> Y. L. Chen & P. K. Chou	Ch550 (SYS); Li Yan-hui 5230 (HITBC)	

Appendix 1. Continued.

RUBIACEAE

- Damiancanthus indicus* Gaertn. f.
Hymenopogon parvispicus var. *longiflorus* How ex W. C. Chen
Pavetta polyantha R. Br.
Pavetta scabrifolia Brennek.

Ch361 (SYS), Ch816 (SYS)
 Tao Guo-da 13651 (HITBC)
 Ch368 (SYS), Ch270 (SYS); Li Yan-hui 1773 (HITBC), 4111 (HITBC)
 Li Yan-hui 4240 (HITBC), 3871 (HITBC)

RUTACEAE

- Murraya euchrestifolia* Hayata
Murraya tetramera Huang

Li Yan-hui 3716 (HITBC), 3309 (HITBC); Tao Guo-da 15722 (HITBC); Expedition 32673 (HITBC)
 Li Yan-hui 3815 (HITBC), 4269 (HITBC)

SCROPHULARIACEAE

- Lindenbergia philippinensis* (Cham. & Schltdl.) Benth.

Ch96 (SYS); Li Yan-hui 363 (HITBC), 3952 (HITBC)

SIMARUBACEAE

- Brucea mollis* Wall.

Li Yan-hui 4203 (HITBC)

STAPHYLEACEAE

- Turpinia robusta* Craib

Li Yan-hui 393 (HITBC); Zhang Jian-hou 13707 (HITBC)

ULMACEAE

- Celtis wightii* var. *philippensis* (Planch.) E. Soepadmo

Ch32 (SYS), Ch371 (SYS), Ch1089 (SYS); Li Yan-hui 391 (HITBC), 4211 (HITBC)

URTICACEAE

- Elatostema herbaceifolium* Hayata
Elatostema salviniioides W. T. Wang
Laportea urentissima Gagnep.
Pellionia scabra Benth.
Pilea cadieri Gagnep. & Guillaumin
Procris crenata C. B. Rob.

Ch877 (SYS)
 Ch879 (SYS); Li Yan-hui 4105 (HITBC); Zhu Pei-zhi 8649 (HITBC)
 Li Yan-hui 396 (HITBC)
 Ch917 (SYS)
 Ch572 (SYS), Ch719 (SYS)
 Ch514 (SYS), Ch632 (SYS); Li Yan-hui 3751 (HITBC)

VERBENACEAE

- Garrettia siamensis* Fletcher

Ch358 (SYS), Ch710 (SYS), Ch941 (SYS)

VITACEAE

- Tetrastigma cambodianum* Pierre ex Gagnep.
Tetrastigma dubium (Lawson) Planch.
Tetrastigma rupestre Planch.

Ch91 (SYS), Ch925 (SYS); Zhang Jian-hou 13602 (HITBC)
 Li Yan-hui 3700 (HITBC), 2737 (HITBC)
 Ch139 (SYS)

ZINGIBERACEAE

- Pommereschea lackneri* Wittm.

Pei Sheng-ji 10073 (HITBC); Tao Guo-da 44091 (HITBC)

Seed Plant Taxa preferent to limestone habitats

Appendix 1. Continued.

ACANTHACEAE

- Andrographis laxiflora* (Blume) Lindau
Eranthemum pulchellum Andr.
Goldfussia glomerata Nees
Pseuderanthemum palatiferum Radlk.
Pseuderanthemum polyanthum (C. B. Clarke) Merr.
Rhapidospora vagabunda (R. Ben) C. Y. Wu
Semnostachya longispicata (Hayata) C. F. Hsieh & T. C. Huang

- Ch376 (SYS), Ch808 (SYS), Ch974 (SYS); *Li Yan-hui* 3721 (HITBC)
Li Yan-hui 2898 (HITBC)
Ch1191 (SYS); *Tao Guo-da* 3775 (HITBC)
Ch137 (SYS); Ch172 (SYS), Ch180 (SYS), Ch310 (SYS)
Ch91 (SYS); *Li Yan-hui* 1011 (HITBC)
Ch36 (SYS), Ch247 (SYS); *Li Yan-hui* 2829 (HITBC)
Ch1182 (SYS)

ANNONACEAE

- Milusa chunii* W. T. Wang
Mitrephora maingayi Hook. f. & Thoms.
Mitrephora thorelii Pierre

- Ch499 (SYS), Ch1211 (SYS); *Unknown coll.* 74317 (HITBC), 74318 (HITBC)
Li Yan-hui 3139 (HITBC)
Ch673 (SYS), Ch420 (SYS); *Li Yan-hui* 67493 (HITBC)

APOCYNACEAE

- Antiostelma lankangensis* (Tsiang & P. T. Li) P. T. Li
Bidaria yunnanense (Tsiang) P. T. Li
Dischidia esquirolii (Lév.) Tsiang
Dischidia minor (Vahl) Merr.
Gynemna sylvestre (Retz.) Schult.
Gynemna latifolium Wall. ex Wight
Hoya carmosa (L. f.) R. Br.
Hoya lvi Lév.
Hoya nervosa Tsiang & P. T. Li
Hoya villosa Costantin.
Jasminanthus saxatilis (Tsiang & P. T. Li) W. D. Stevens & P. T. Li
Marsdenia tenacissima (Roxb.) Moon
Toxocarpus villosus (Blume) Decne.

- Ch658 (SYS)
Ch242 (SYS), Ch764 (SYS)
Ch23 (SYS)
Ch729 (SYS)
Expedition 34523 (HITBC)
Ch586 (SYS), Ch633 (SYS), Ch716 (SYS); *Yang Zheng-hong* 10976 (HITBC)
Ch651 (SYS)
Tao Guo-da 35474 (HITBC)
Zhang Jian-hou 18562 (HITBC)
Ch960 (SYS); *Li Yan-hui* 2574 (HITBC)
Tao Guo-da 44195 (HITBC)
Ch438 (SYS); *Expedition* 32621 (HITBC)
Ch544 (SYS), Ch587 (SYS), Ch646 (SYS)

ARACEAE

- Aglaonema pierreanum* Engl.
Colocasia gigantea Hook. f.
Rhaphidophora decursiva (Roxb.) Schott
Rhaphidophora hongkongensis Schott

- Ch233 (SYS); Ch240 (SYS); *Pei Sheng-ji* 10274 (HITBC)
Ch1169 (SYS); *Tao Guo-da* 9123 (HITBC)
Ch1160 (SYS); *Li Jie* 722 (HITBC)
Ch706 (SYS), Ch1179 (SYS)

BEGONIACEAE

- Begonia augustinei* Hensl.
Begonia dryadis Irmsch.
Begonia prostrata Irmsch.

- Ch265 (SYS); *Tao Guo-da* 15926 (HITBC)
Zhu Pei-zhi 10364 (HITBC)
Ch976 (SYS)

BOMBACACEAE

- Bombax ceiba* L.

- Li Yan-hui* 2946 (HITBC)

Appendix 1. Continued.

BORAGINACEAE	
<i>Ehretia tsangii</i> I. M. Johnst.	<i>Li Yan-hui</i> 3360 (HITBC), 3726 (HITBC)
CAPPARIDACEAE	
<i>Capparis membranifolia</i> Kurz	<i>Ch</i> 612 (SYS); <i>Zhao Shi-wang</i> 22582 (HITBC)
<i>Capparis urophylla</i> F. Chun	<i>Ch</i> 853 (SYS), <i>Ch</i> 136 (SYS), <i>Ch</i> 153 (SYS), <i>Ch</i> 195 (SYS); <i>Li Yan-hui</i> 2112 (HITBC)
CAPRIFOLIACEAE	
<i>Viburnum tsangii</i> Rehder	<i>Li Yan-hui</i> 4235 (HITBC); <i>Zhu Pei-zhi</i> 10470 (HITBC)
CARDIOPTERIDACEAE	
<i>Periperygium quinquelobum</i> Hassk.	<i>Expedition</i> 34761 (HITBC)
COMMELINACEAE	
<i>Porandra scandens</i> D. Y. Hong	<i>Ch</i> 902 (SYS); <i>Pei Sheng-ji</i> 9947 (HITBC); <i>Unknown coll.</i> 262 (HITBC)
COMPOSITAE	
<i>Youngia japonica</i> (L.) DC.	<i>Ch</i> 1201 (SYS), <i>Ch</i> 326 (SYS); <i>Tao Guo-da</i> 1742 (HITBC)
EBENACEAE	
<i>Diospyros yunnanensis</i> Rehder & Wils.	<i>Ch</i> 516 (SYS), <i>Ch</i> 1214 (SYS); <i>Cui Jing-yun</i> 14656 (HITBC); <i>Pei Sheng-ji</i> 10300 (HITBC)
EUPHORBIACEAE	
<i>Adenochlaena silhetensis</i> Benth.	<i>Ch</i> 807 (SYS); <i>Zou Shuang-yun</i> 356 (HITBC)
<i>Antidesma montanum</i> var. <i>microphyllum</i> (Hemsl.) P. Hoffmann	<i>Li Yan-hui</i> 3575 (HITBC)
<i>Cleidion bracteosum</i> Gagnep.	<i>Li Yan-hui</i> 4250 (HITBC)
<i>Cleidion brevipetiolatum</i> Pax & K. Hoffm.	<i>Ch</i> 922 (SYS); <i>Li Yan-hui</i> 399 (HITBC)
<i>Lasiococca comberi</i> var. <i>pseudoverticellata</i> (Merr.) H. S. Ku	<i>Ch</i> 309 (SYS), <i>Ch</i> 226 (SYS), <i>Ch</i> 38 (SYS); <i>Li Yan-hui</i> 1694 (HITBC)
<i>Sumbatiopsis albicans</i> (Blume) J. J. Smith	<i>Ch</i> 131 (SYS); <i>Li Yan-hui</i> 2423 (HITBC)
FABACEAE	
<i>Bauhinia genulexa</i> Craib	<i>Ch</i> 25 (SYS), <i>Ch</i> 97 (SYS); <i>Li Yan-hui</i> 1500 (HITBC)
<i>Milletia yunnanensis</i> Pampan.	<i>Tao Guo-da</i> 13668 (HITBC)
<i>Whitfordiodendron filipes</i> (Dunn) Dunn	<i>Zhao Shi-wang</i> 22492 (HITBC)
FLACOURTIACEAE	
<i>Flacourtia rukam</i> Zoll. & Mor.	<i>Ch</i> 784 (SYS)
GESNERIACEAE	
<i>Chirita dimidiata</i> R. Br.	<i>Ch</i> 948 (SYS)
<i>Paraboea rufescens</i> (Franch.) B. L. Burt	<i>Ch</i> 379 (SYS); <i>Wang Hong</i> 2724 (HITBC)
<i>Paraboea dictyonera</i> (Hance) B. L. Burt	<i>Ch</i> 842 (SYS); <i>Wang Hong</i> 2707 (HITBC)
<i>Paraboea sinensis</i> f. <i>macrophylla</i> (Stapf) C. Y. Wu	<i>Ch</i> 272 (SYS); <i>Expedition</i> 34359 (HITBC); <i>Tao Guo-da</i> 16748 (HITBC), 3792 (HITBC)

Appendix 1. Continued.

GRAMINEAE		<i>Ch1058</i> (SYS); <i>Sun Ji-liang 18151</i> (HITBC)
<i>Dendrocalamus strictus</i> (Roxb.) Nees		
ICACINACEAE		<i>Tao Guo-da 16690</i> (HITBC)
<i>Apodytes dimidiata</i> E. Meyer ex Am.		
LABIATAE		<i>Ch151</i> (SYS); <i>Li Yan-hui 252</i> (HITBC), <i>Sun Ji-liang 18005</i> (HITBC)
<i>Colebrookea oppositifolia</i> Sm.		<i>Tao Guo-da 3798</i> (HITBC)
<i>Eisholtzia stachyodes</i> (Link) C. Y. Wu		
LAMIACEAE		<i>Wang Hong 2921</i> (HITBC), <i>2922</i> (HITBC), <i>2940</i> (HITBC)
<i>Clerodendron henryi</i> Pei		<i>Expedition 32276</i> (HITBC); <i>Unknown coll. 2434</i> (HITBC), <i>456</i> (HITBC); <i>Wang Hong 2727</i> (HITBC)
<i>Garrettia stamensis</i> Fletcher		<i>Ch177</i> (SYS), <i>Ch278</i> (SYS); <i>Expedition 32617</i> (HITBC)
<i>Premna hamiltonii</i> J. L. Ellis		<i>Ch864</i> (SYS)
<i>Sphenodesme mollis</i> Craib		
LAURACEAE		<i>Li Yan-hui 3053</i> (HITBC)
<i>Litsea dillenifolia</i> P. Y. Bai & P. H. Huang		<i>Ch269</i> (SYS), <i>Ch119</i> (SYS)
<i>Litsea elongata</i> (Wall. ex Nees) Benth. & Hook. f.		<i>Ch161</i> (SYS), <i>Ch61</i> (SYS), <i>Ch324</i> (SYS); <i>Li Yan-hui 754</i> (HITBC)
<i>Phoebe lanceolata</i> (Wall. ex Nees) Nees		
LILIACEAE		<i>Ch711</i> (SYS)
<i>Polygonatum punctatum</i> Royle ex Kunth		<i>Expedition 34321</i> (HITBC); <i>Yang Zhen-hong 6971</i> (HITBC); <i>Wang Hong 3102</i> (HITBC)
<i>Tupistra watii</i> Hook. f.		
MALPIGHIACEAE		<i>Ch45</i> (SYS); <i>Li Yan-hui 1051</i> (HITBC)
<i>Hiptage benghalensis</i> var. <i>tonkinensis</i> (Dop) S. K. Chen		
MAIVACEAE		<i>Zou Shuang-yun 324</i> (HITBC)
<i>Sterculia villosa</i> Roxb.		
MELIACEAE		<i>Li Yan-hui 385</i> (HITBC)
<i>Chukrasia tabularia</i> var. <i>velutina</i> King		<i>Ch508</i> (SYS); <i>Cui Jing-yun 22658</i> (HITBC)
<i>Dysoxylum lenticellatum</i> C. Y. Wu & H. Li		<i>Unknown coll. 250</i> (SYS)
<i>Dysoxylum spicatum</i> H. L. Li		<i>Ch680</i> (SYS), <i>Ch566</i> (SYS), <i>Ch581</i> (SYS)
<i>Toona ciliata</i> var. <i>pubescens</i> (Franch.) Handl.-Mazz.		
MORACEAE		<i>Li Yan-hui 3135</i> (KUN)
<i>Cudrania jinghongensis</i> S. S. Chang		<i>Ch41</i> (SYS); <i>Li Yan-hui 3802</i> (HITBC)
<i>Ficus orthoneura</i> Lévl. & Vaniot		<i>Zhu Hua & Wang Hong 88-11</i> (HITBC)
<i>Ficus prostata</i> Wall. ex Miq.		<i>Li Yan-hui 3223</i> (HITBC)
<i>Ficus pubigera</i> var. <i>maliformis</i> (King) Corner		
MYRSINACEAE		<i>Ch130</i> (SYS), <i>Ch170</i> (SYS), <i>Ch47</i> (SYS); <i>Li Yan-hui 3867</i> (HITBC)
<i>Ardisia garrettii</i> Fletcher		

Appendix 1. Continued.

MYRTACEAE		
<i>Syzygium claviflorum</i> (Roxb.) Wall ex A. M. & J. M. Cowan		Ch501 (SYS), Ch492 (SYS)
ORCHIDACEAE		
<i>Gastrochilus obliquus</i> (Lindl.) Kuntze		Li Yan-hui 2734 (HITBC)
<i>Nervilia plicata</i> (Andr.) Schltr.		Ch713 (SYS); Li Yan-hui 3138 (HITBC)
<i>Tropidia angulosa</i> (Lindl.) Blume		Li Yan-hui 392 (HITBC); Wang Pei-qun 11115 (HITBC)
OROBANCHACEAE		
<i>Aeginetia indica</i> L.		Zhao Shi-xiang 165 (HITBC)
OXALIDACEAE		
<i>Averrhoa carambola</i> L.		Li Yan-hui 3129 (HITBC)
<i>Biophytum esquirolii</i> Lévl.		Li Yan-hui 4004 (HITBC)
PALMAE		
<i>Caryota ochlandra</i> Hance		Chen Yu 62079 (HITBC)
PIPERACEAE		
<i>Peperomia heyneana</i> Miq.		Ch804 (SYS); Li Yan-hui 2738 (HITBC)
<i>Piper arboricola</i> C. DC.		Ch585 (SYS), Ch924 (SYS), Ch1216 (SYS); Unknown coll. 865 (HITBC)
<i>Piper curtipedunculatum</i> C. DC.		Cui jing-yun 22811 (HITBC)
RHAMNACEAE		
<i>Ventilago leiocarpa</i> var. <i>pubescens</i> Y. L. Chen & P. K. Chou		Ch1088 (SYS), Ch645 (SYS)
<i>Zizyphus attopensis</i> Pierre		Li Yan-hui 1289 (HITBC), Ch251 (SYS)
RUBIACEAE		
<i>Ixora cephalophora</i> Merr.		Ch1218 (SYS), Ch1229 (SYS)
<i>Pavetta arenosa</i> Lour.		Li Yan-hui 246 (HITBC), 2814 (HITBC)
<i>Pavetta hongkongensis</i> Bremek.		Ch355 (SYS); Zhu Hua & Wang Hong 3004 (HITBC)
<i>Psychotria pilifera</i> Hutch.		Ch712 (SYS), Ch165 (SYS); Li Yan-hui 1498 (HITBC)
<i>Psychotria siamica</i> (Craib) Hutch.		Ch836 (SYS); Li Yan-hui 2473 (HITBC), 258 (HITBC)
<i>Spiradiclis caespitosa</i> f. <i>subimmersa</i> Lo		Li Yan-hui 12675 (HITBC)
RUTACEAE		
<i>Glycosmis citrifolia</i> (Willd.) Lindl.		Ch222 (SYS), Ch146 (SYS); Zou Shuang-yun 333 (HITBC)
<i>Murraya koenigii</i> (L.) Spreng.		Ch176 (SYS), Ch330 (SYS), Ch352 (SYS), Ch313 (SYS); Li Yan-hui 1859 (HITBC)
<i>Murraya microphylla</i> (Merr. & Chun) Swingle		Expedition 34267 (HITBC); Tao Guo-da 44056 (HITBC)
<i>Murraya paniculata</i> (L.) Jack.		Li Yan-hui 3315 (HITBC)
<i>Zanthoxylum armatum</i> var. <i>ferrugineum</i> (Rehder & E. H. Wilson) C. C. Huang		Ch887 (SYS); Unknown coll. 1010 (HITBC)
<i>Zanthoxylum laetum</i> Drake		Ch475 (SYS), Ch578 (SYS)
<i>Zanthoxylum utile</i> C. C. Huang		Ch636 (SYS), Ch777 (SYS)

Appendix 1. Continued.

STAPHYLEACEAE		
<i>Tapiscia yunnanensis</i> W. C. Cheng & S. D. Chu		Zhu Hua 93011 (HITBC)
TETRAMELACEAE		
<i>Tetrameles nudiflora</i> R. Br.		Li Yan-hui 8541 (HITBC)
TILIACEAE		
<i>Colona floribunda</i> (Wall.) Craib		Ch700 (SYS); Ch932 (SYS); Pei Sheng-ji 10084 (HITBC)
<i>Colona thorelii</i> (Gagnep.) Burret		Li Yan-hui 1696 (HITBC)
URTICACEAE		
<i>Boehmeria zollingeriana</i> Wedd.		Ch1064 (SYS); Cui Jing-yun 19416 (HITBC)
<i>Debregeasia edulis</i> (Siebold & Zucc.) Wedd.		Ch311 (SYS); Tao Guo-da 41641 (HITBC)
<i>Elatostema rupestre</i> (Buch.-Ham.) Wedd.		Ch168 (SYS); Ch388 (SYS); Ch359 (SYS); Wang Hong 1494 (HITBC)
<i>Pilea monilifera</i> Hand.-Mazz.		Ch984 (SYS); Wang Hong 1484 (HITBC)
<i>Pilea plataniflora</i> C. H. Wright		Ch381 (SYS); Ch657 (SYS); Li Yan-hui 4210 (HITBC); Tao Guo-da 16090 (HITBC)
<i>Pouzolzia sanguinea</i> (Blume) Merr.		Cui Jing-yun 22793 (HITBC)
VITACEAE		
<i>Leea aequata</i> L.		Ch468 (SYS); Ch714 (SYS); Pei Sheng-ji 9359 (HITBC)
<i>Yua austro-orientalis</i> (Metcalfe) C. L. Li		Ch844 (SYS)
<i>Tetrastigma cauliflorum</i> Merr.		Ch268 (SYS); Li Yan-hui 11915 (HITBC)
<i>Tetrastigma delavayi</i> Gagnep.		Ch507 (SYS); Ch811 (SYS)
<i>Tetrastigma erubescens</i> var. <i>monospermum</i> Gagnep.		Ch463 (SYS); Ch1054 (SYS); Tao Guo-da 9189 (HITBC)
<i>Tetrastigma pubinerve</i> Merr. & Chun		Ch653 (SYS); Ch616 (SYS)
<i>Vitis balansaeana</i> Planch.		Ch668 (SYS); Tao Guo-da 16447 (HITBC)
<i>Vitis betulifolia</i> Diels & Gilg		Ch654 (SYS); Ch408 (SYS)
ZINGIBERACEAE		
<i>Hedychium sino-aureum</i> Stapf		Ch1240 (SYS); Wang Hong 3066 (HITBC); Tao Guo-da 16049 (HITBC)
<i>Hedychium villosum</i> var. <i>teniflorum</i> Wall. ex Baker		Li Yan-hui 4866 (HITBC)
<i>Pommereschea spectabilis</i> (King & Prain) K. Schum.		Tao Guo-da 13661 (HITBC); Zhu Pei-zhi 8642 (HITBC)
Pteridophyta preferent to limestone habitats		
ADIANTACEAE		
<i>Adiantum capillus-veneris</i> L.		Expedition 34430 (HITBC)
<i>Adiantum caudatum</i> L.		Li Yan-hui 2554 (HITBC)
<i>Adiantum caudatum</i> var. <i>edgeworthii</i> (Hook.) Bedd.		Li Bao-gui 734 (HITBC)
<i>Adiantum malesianum</i> J. Ghatak		Zhu Pei-zhi 8668 (HITBC)
ANTROPHYACEAE		
<i>Antrophyum callifolium</i> Blume		Li Bao-gui 803 (HITBC)

Appendix 1. Continued.

ASPLENIACEAE

- Asplenium austrochinese* Ching
Asplenium excisum C. Presl
Asplenium interjectum H. Christ
Asplenium prolongatum Hook.
Asplenium saxicola Rosenst.
Asplenium varians Wall. ex Hook. & Grev.
Hymenaspkenium chelosorum (Kunze ex Mett.) Tagawa
Neottopteris antrophyoides (H. Christ) Ching

ATHYRIACEAE

- Allantodia alata* (Christ) Ching
Allantodia pinnatifido-pinnata (Hook.) Ching
Kuniatatsukia cuspidata (Bedd.) Pic. Sem.

BOLBITIDACEAE

- Egenolfia tonkinensis* C. Chr. ex Ching

DRYNARIACEAE

- Drynaria bonii* H. Christ
Drynaria fortunei (Kunze ex Mett.) J. Sm.
Drynaria rigidula (Sw.) Bedd.

DRYOPTERIDACEAE

- Dryopteris cochaeta* (D. Don) C. Chr.
Polystichum deltodon (Baker) Diels

HEMONITIDACEAE

- Pityrogramma calomelanos* (L.) Link

NEPHROLEPIDACEAE

- Nephrolepis auriculata* (L.) Trimen

POLYPODIACEAE

- Lepisorus bicolor* (Takeda) Ching
Lepidogrammitis rostrata (Bedd.) Ching
Lemmaphyllum microphyllum C. Presl
Lemmaphyllum carnosum (Wall.) C. Presl
Phymatodes cuspidata (D. Don) J. Sm.
Pyrosia assimilis (Baker) Ching
Pyrosia mollis (Kunze) Ching
Pyrosia nuda (Giesenh.) Ching
Pyrosia nummularifolia (Sw.) Ching
Pyrosia subfurfuracea (Hook.) Ching
Pyrosia tonkinensis (Giesenh.) Ching

- Li Yan-hui* 3810 (HITBC)
Li Bao-gui 737 (HITBC); *Unknown coll.* 9498 (HITBC)
Li Bao-gui 880 (HITBC)

- Li Yan-hui* 3739 (HITBC)
Li Yan-hui 2749 (HITBC)

- Tao Guo-da* 43453 (HITBC)
Li Qing-jun 42749 (HITBC)
Zhu Pei-zhi 10487 (HITBC)

- Li Bao-gui* 674 (HITBC)
Tao Guo-da 43571 (HITBC)
Tao Guo-da 17161 (HITBC)

- Li Bao-gui* 756 (HITBC)

- Li Yan-hui* 2735 (HITBC)
Tao Guo-da 38772 (HITBC)
Expedition 34292 (HITBC)

- Li Bao-gui* 98085 (HITBC)
Tao Guo-da 15730 (HITBC)

- Li Bao-gui* 45749 (HITBC)

- Tao Guo-da* 16010 (HITBC)

- Tao Guo-da* 39738 (HITBC)
Li Bao-gui 774 (HITBC)

- Li Bao-gui* 600 (HITBC)

- Li Bao-gui* 604 (HITBC)
Li Yan-hui 3808 (HITBC)

- Expedition* 34719 (HITBC)

- Tao Guo-da* 38843 (HITBC)

- Tao Guo-da* 38875 (HITBC)

- Li Qing-jun* 42624 (HITBC)

- Li Bao-gui* 9904152 (HITBC)
Pei Sheng-ji 9933 (HITBC)

Appendix 1. Continued.

PTERIDACEAE	
<i>Pteris actiniopteroides</i> H. Christ	<i>Li Bao-gui</i> 921 (HITBC)
SELAGINELLACEAE	
<i>Selaginella involvens</i> (Sw.) Spring	<i>Li Bao-gui</i> 960463 (HITBC)
<i>Selaginella pubinata</i> (Hook. & Grev.) Maxim.	<i>Li Bao-gui</i> 45178 (HITBC)
SINOPTERIDACEAE	
<i>Aleuritopteris pseudofarinosa</i> Ching & S. K. Wu	<i>Mengliandui</i> 10242 (HITBC)
<i>Cheilosoria tenuifolia</i> (Burn. f.) Trev.	<i>Mengliandui</i> 10140 (HITBC)
TECTARIACEAE	
<i>Tenitopsis denexa</i> (Kunze) Ching & C. H. Wang	<i>Li Qing-jun</i> 42687 (HITBC)
<i>Tectaria decurrens</i> (C. Presl) Copel.	<i>Pei Sheng-ji</i> 9277 (HITBC)
<i>Tectaria simaoensis</i> (Bedd.) Ching & C. H. Wang	<i>Sun Ji-liang</i> 18185 (HITBC)
THELYPTERIDACEAE	
<i>Cyclosorus papilio</i> (Hope) Ching	<i>Li Bao-gui</i> 98086 (HITBC)
<i>Cyclosorus parasitica</i> (L.) Tardieu	<i>Li Yan-hui</i> 1326 (HITBC)

A DISCUSSION ON BIOGEOGRAPHICAL LINES OF THE TROPICAL-SUBTROPICAL YUNNAN

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ABSTRACT Based on comparative studies on four regional floras from northwest, west, south and southeast of Yunnan respectively, the formerly suggested two biogeographical lines, i.e. the “Tanaka Line” and the “Ecogeographical Diagonal Line”, both going from northwest to southeast of Yunnan, and their significance are discussed. At family and generic levels, similarity coefficients among the four compared floras are more than 93% and 60% respectively, which indicate the close floristic affinities among them. The highest similarity coefficient, i.e. 98.7% at family level and 78.6% at generic level respectively, is found between the regional flora of northwest Yunnan and the flora of southeast Yunnan although these two regions are the most distant away each other among the compared regional floras. The flora of northwest Yunnan is also the most similar to the flora of southeast Yunnan in floristic composition. These support the idea of “Ecogeographical Diagonal Line”. At specific level, the relatively high similarity coefficient is between the regional flora of west Yunnan and the one of south Yunnan. The floristic affinities among these regional floras and some distribution patterns could be explained by the geological history and tectonic theory of Yunnan.

KEY WORDS: biogeographical lines, floristic affinity, Yunnan

CLC number: Q151

Document code: A

Article ID: 1002-0063 (2002) 01-0090-07

1 INTRODUCTION

Tropical-subtropical Yunnan of southwestern China, which is supposed to be a sutural area between part of Gondwana land and the southeastern margin of Asian continent, has a sophisticated geological history. The fundamental topography and climate of the region have been strongly affected by the uplift of the Himalayas and the formation of the eastern monsoon climate (SHI *et al.*, 1998). The region is biogeographically located at a transitional area between the tropical SE Asia from south and the subtropical East Asia from north, and between the Sino-Japanese floristic region from east and the Sino-Himalayan floristic region from west. The diversified biota and sophisticated biogeographical patterns have been formed through the particular geological-biogeographical history of the region.

With the gradual accumulation of knowledge on the flora and the biogeography of the region, more and more interesting biogeographical distributions and patterns have been recognized. One of the most significant biogeographical patterns is the floristic line, named as “Tanaka Line”. The “Tanaka line” was originally suggested by the Japanese botanist T. TANAKA based on the observation of the distribution of citrus species group (TANAKA, 1954). The line was imagined as a straight line that starts from a crossing point of 28° N and 98° E in the northwestern Yunnan, running down southeastward to a location of approximately 18° 45' N or 19° N and 108° E in the South China Sea. In the west of the line, the citrus species group chains were predominated by “*Archicitrus*” and in the east predominated by “*Metacitrus*”. TANAKA further implied that the line had some significance in demarcating the floristic elements of Indo-Malaysia and the ones of East Asia. LI Xi-wen & LI Jie (1992) discussed the significance of “Tanaka Line” in demarcating Sino-Japanese and Sino-Himalayan genera in the Eastern Asiatic floristic kingdom. Later LI Xi-wen & LI Jie (1997) modified “Tanaka Line” by adding a line, which was called the “Kaiyong Line” as a northern extension of it. The “Kaiyong Line”, which is in western Sichuan of SW China and

Received data: 2002-01-08

Foundation item: Under the auspices of the grants of the Chinese Academy of Sciences for Top One Hundred Young Scientists and the project KSCX2-1-06B.

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formally named by LI Xi-wen & LI Jie (1997), was first suggested being a line also separating Sino-Himalayan and Sino-Japanese floristic regions by the Chinese scholar LANG Kaiyong (1994) based on the distribution patterns of some orchid taxa. The modified line was named as the “Tanaka-Kaiyong Line” and suggested as a dividing line in the floristic kingdom of East Asia for separating Sino-Himalayan and Sino-Japanese subkingdoms. Similarly, a line, which has almost the same running direction and locality as the “Tanaka Line” in Yunnan, was suggested and named as “Ecogeographical Diagonal Line” by the Chinese botanist LI Heng (1994a) in a somewhere different biogeographical explanation based on her study on the regional flora of west Yunnan. At the two end of the “Ecogeographical Diagonal Line”, i.e. the northwest and the southeast Yunnan, some vicarious taxa and disjunct distribution of species were recognized. The “Ecogeographical Diagonal Line” was further reinforced by adding some tectonic theories and geological explanation. The “Ecogeographical Diagonal Line”, which runs from the northwest Yunnan to southeast Yunnan, was supposed to be running latitudinally in a period of the geological history, and then turn clockwise and move some degrees to the present position by the northward thrusting of Burma-Malay fragment of Gondwana. The “Ecogeographical Diagonal Line”, which indicates the patterns of the vicarious taxa and disjunct distribution at the two ends of the line, was therefore formed based on the geological history of the region. It was also emphasized by LI Heng that the area in the west of the “Ecogeographical Diagonal Line” was mainly derived from Gondwana. The close affinity between the tropical flora of southern Yunnan and the flora of SE Asia was suggested by ZHU based on the studies of the tropical flora and vegetation of southern Yunnan (ZHU, 1994, 1996, 1997, 2001; ZHU et al., 1997, 2000a, 2000b). The southern Yunnan was conjectured to be at similar latitude as the northeast India in some period of geological history based on the strongly floristic similarity between the south Yunnan and the northeast India. This is somewhere concordance with the idea of “Ecogeographical Diagonal Line”. In order to explore further these biogeographical patterns in Yunnan, four well treated regional floras from both sides of the “Tanaka Line” and both ends of the “Ecogeographical Diagonal Line” respectively, i.e. Dulongjiang Nature Reserve from the northwest of Yunnan, Tongbiguang Nature Reserve from the west, Xishuangbanna from the south and the regional flora of southeast Yunnan, are chosen as examples for making a comparative study. The floristic similarities among them at the family, generic and specific levels are also studied. Their geographical locations are showed in Fig. 1.

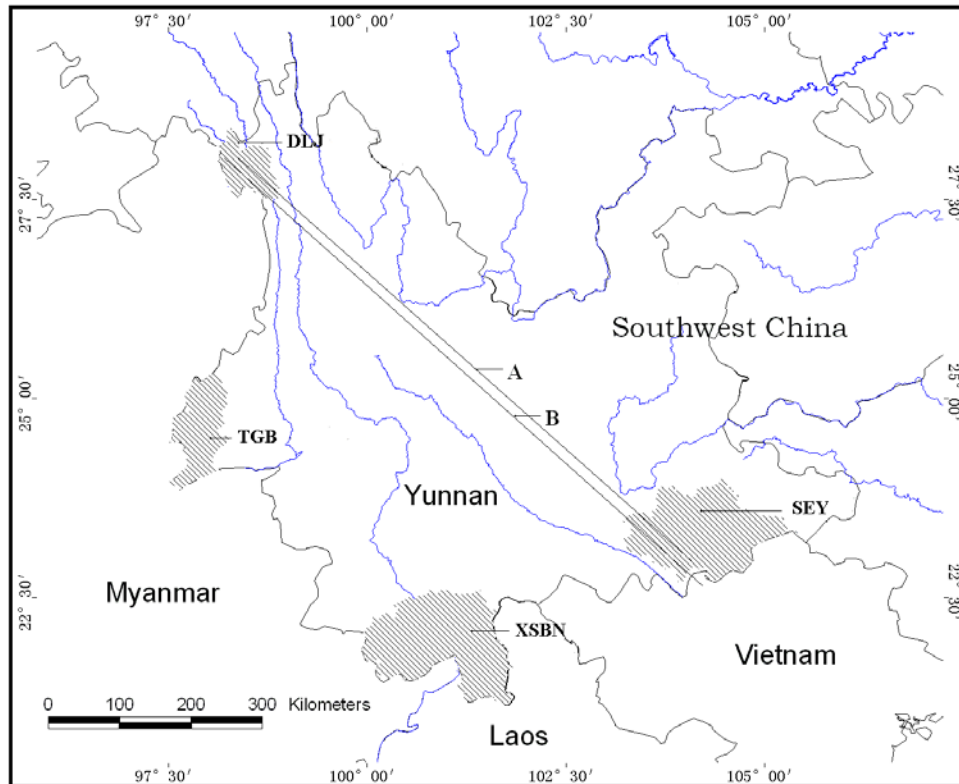


Fig. 1 The map showing the biogeographical lines and the locations of the four compared floras in Yunnan

A: Ecogeographical Diagonal Line (from LI Heng, 1994); B: Tanaka Line (from LI Xi-wen & LI Jie, 1992)

XSBN: Xishuangbanna; SEY: SE Yunnan; TGB: Tongbiguang Nature Reserve; DLJ: Dulongjiang Nature Reserve.

2 COMPARISON OF FLORISTIC SIMILARITIES

Dulongjiang Nature Reserve is in the northwest part of Yunnan and lies between 27° 40' and 28° 50' N, 97° 45' and 98° 30' E. It has an area of 1994 km². 1920 native species of 673 genera and 158 families of seed plants are recognized from the Nature Reserve (LI Heng, 1993, 1994b).

Tongbiguan Nature Reserve is located between 23° 54' and 24° 51' N, 97° 31' and 97° 46' E in western Yunnan. It covers an area of 307 km². 3475 species of 1229 genera and 214 families of seed plants are recognized from the Nature Reserve⁽¹⁾.

Xishuangbanna is the southern part of Yunnan and lies between 21° 09' and 22° 36' N, 99° 58' and 101° 50' E. The region has an area of 19690 km². 3336 native species of 1218 genera and 207 families of seed plants are recognized from the region.

The southeast Yunnan, which is here referred to the area of the southeastern part of Yunnan in the east of Wenshan country (c. 103° 30' E). 4777 species of 1397 genera and 236 families of seed plants are recognized from the database of the Institute of Botany of the Chinese Academy of Sciences.

Species authorities and taxa circumscription follow the Flora of China (Fl. Reip. Pop. Sin.). Comparisons of similarity at family, generic and specific levels among these four regional floras are made. The results are showed in Table 1.

At the family level, the similarities among these four regional floras are more than 93%. At the generic level, the similarities among them are over 60%. This indicates that these four regional floras are close affinity each other in floristic origin. It is interesting that the highest similarities at family and generic levels (98.7% and 78.6% respectively) among them is between the flora of Dulongjiang Nature Reserve and the flora of SE Yunnan although these two regions are the most distant away among the compared regional floras. This seems supporting the idea of the "Ecogeographical Diagonal Line".

The similarities at the family and the generic levels are supposed to imply the historic connection of regional floras, while the similarity at the specific level indicates more the present physiogeographical and ecological connections. The pattern of the similarity at the specific level shows a different picture. The specific similarities among these four regional floras vary from 19.1 to 43.1%. It is obvious that the specific similarities between regional floras are more related to their geographical distance and ecological habitats. For example, the highest

Table 1. The similarity coefficients at family, generic and specific levels between the four compared floras in Yunnan

Similarity coefficients at family level:				
Compared regional flora	Xishuangbanna	SE Yunnan	Tongbiguan	Dulongjiang
Xishuangbanna	100	94.3	93.9	93.4
SE Yunnan	94.3	100	97.2	98.7
Tongbiguan	93.9	97.2	100	94.9
Dulongjiang	93.4	98.7	94.9	100
Similarity coefficients at generic level:				
Compared regional flora	Xishuangbanna	SE Yunnan	Tongbiguan	Dulongjiang
Xishuangbanna	100	70.1	74.1	60.5
SE Yunnan	70.1	100	76.7	78.6
Tongbiguan	74.1	76.7	100	76.1
Dulongjiang	60.5	78.6	76.1	100
Similarity coefficients at specific level:				
Compared regional flora	Xishuangbanna	SE Yunnan	Tongbiguan	Dulongjiang
Xishuangbanna	100	39	43.1	19.1
SE Yunnan	39	100	40.9	32.2
Tongbiguan	43.1	40.9	100	34.5
Dulongjiang	19.1	32.2	34.5	100

species similarity among the compared regional floras is between Xishuangbanna and Tongbiguan. This correlates with the nearest locality and the most similar habitat (both tropical habitats) between them. On the other hand, the lowest specific similarity is found between Xishuangbanna and Dulongjiang. This correlates with relatively more

⁽¹⁾ Southwest Forestry University, Yunnan Forestry Bureau & Forestry Bureau of Dehong region (eds.), 2000. Yunnan Tongbiguan Nature Reserve.

distant away and different habitats (tropical in Xishuangbanna, subtropical –temperate in Dulongjiang) between them.

3 COMPARISONS IN THE DOMINANT AND THE ORIGINALLY REPRESENTED PLANT FAMILIES

The top twenty families with the most species richness from the four regional floras are enumerated in the table 2. The families with the most species richness from these regional floras are basically the same. They present the common floristic characters of the marginal tropical flora of Mainland SE Asia. Ericaceae is the commonly shared dominant family in both floras of SE Yunnan (7 genera, 63 species) and Dulongjiang (9 genera, 105 species). This seems indicating some particular connection between them.

Table 2. Comparison of dominant families of the four floras

Flora of SE Yunnan		Flora of Tongbiguan		Flora of Dulongjiang		Flora of Xishuangbanna	
Family	Gen. / sp.	Family	Gen. / sp.	Family	Gen. / sp.	Family	Gen. / sp.
Gramineae	115: 232	Orchidaceae	72: 194	Orchidaceae	50: 141	Orchidaceae	102: 354
Orchidaceae	80: 204	Compositae	70: 174	Compositae	45: 107	Gramineae	68: 180
Compositae	67: 164	Gramineae	78: 157	Ericaceae	9: 105	Papilionaceae	54: 177
Rubiaceae	48: 162	Papilionaceae	47: 150	Rosaceae	21:97	Rubiaceae	46: 155
Papilionaceae	50: 156	Rubiaceae	43: 118	Gramineae	39:65	Euphorbiaceae	39: 123
Lauraceae	14: 140	Labiatae	38: 99	Urticaceae	15: 56	Compositae	63: 110
Rosaceae	30: 133	Euphorbiaceae	31: 87	Rubiaceae	18: 45	Moraceae	7: 85
Urticaceae	17: 122	Rosaceae	22: 85	Scrophulariaceae	19:49	Lauraceae	12: 80
Labiatae	45: 113	Lauraceae	13: 81	Liliaceae	17: 45	Urticaceae	13: 74
Gesneriaceae	25: 106	Urticaceae	19: 71	Gentianaceae	8: 45	Zingiberaceae	17: 73
Fagaceae	5: 106	Moraceae	7: 69	Primulaceae	4: 39	Asclepiadaceae	27: 71
Euphorbiaceae	33: 100	Acanthaceae	36: 61	Araliaceae	10: 38	Labiatae	30: 63
Moraceae	7: 84	Gesneriaceae	16: 55	Labiatae	18:38	Cucurbitaceae	19: 59
Rutaceae	15: 82	Asclepiadaceae	22: 49	Lauraceae	8: 37	Annonaceae	16: 57
Cyperaceae	16: 81	Zingiberaceae	14: 49	Papilionaceae	19:36	Rosaceae	19: 55
Araliaceae	16: 77	Araliaceae	14: 46	Cyperaceae	12: 31	Apocynaceae	27: 54
Theaceae	9: 73	Cucurbitaceae	18: 42	Umbelliferae	12: 28	Acanthaceae	30: 52
Myrsinaceae	5: 71	Umbelliferae	18: 42	Salicaceae	2: 28	Palmae	15: 52
Verbenaceae	12: 63	Cyperaceae	11: 42	Vacciniaceae	2: 27	Fagaceae	7: 51
Ericaceae	7: 63	Theaceae	9: 42	Aceraceae	1: 26	Cyperaceae	15: 48

The flora of Xishuangbanna, in which the tropical families contribute the most in the dominant families, such as Annonaceae, Rubiaceae, Euphorbiaceae, Moraceae, Asclepiadaceae, Apocynaceae, Palmae, Acanthaceae, shows strongly tropical nature. If the dominant families are rearranged based on the percentage that the number of species of a family in the regional flora is divided by the number of total species of the family in the world, the families ranking ahead could be the most originally represented families in the floras. The supposed top fifteen originally represented families are enumerated in table 3. The family Urticaceae ranks in the first except in the second in Dulongjiang. This implies Urticaceae could be the most originally represented family in the marginal tropical flora of Mainland SE Asia. Again Ericaceae appears to be originally represented family in both floras of Dulongjiang and SE Yunnan. The flora of Xishuangbanna shares the most originally represented families with the flora of Tongbiguan, which implies both of them could have closer affinity in origin.

4 DISCUSSION

From the comparisons of the floristic similarities, the dominant families and the originally represented families among the four regional floras, it is revealed that the flora of Dulongjiang has closer affinity to the flora of SE Yunnan than others although it is the most distant away from SE Yunnan. The directly floristic migration between the northwestern and the southeastern Yunnan is difficult because there are huge Hengduan Mountains between them, which undoubtedly hinder the migration. One of the possible ways to explain the closer floristic affinity between

northwestern and southeastern Yunnan is from the geology and the tectonic theory of these regions. Recent studies on the geological history of SE Asia reveals that the west and south Yunnan could be derived from fragments of Gondwana (FORTEY *et al.*, 1998) (Fig. 2). During the proceeding of the northward thrusting of Indian plate to Asian continental plate and the uplift of the Himalayas and the Hengduan Mountains (Fig. 3), the Gondwana fragment of Yunnan had turned clockwise (Fig. 4).

Table 3. Comparison of the originally represented families of the four floras

Flora of SE Yunnan		Flora of Tongbiguan		Flora of Dulongjiang		Flora of Xishuangbanna	
Family	* (%)	Family	* (%)	Family	* (%)	Family	* (%)
Urticaceae	21.78	Urticaceae	12.68	Aceraceae	13.00	Urticaceae	13.21
Fagaceae	11.78	Araliaceae	6.57	Urticaceae	10.00	Cucurbitaceae	9.22
Theaceae	10.43	Cucurbitaceae	6.56	Ericaceae	7.78	Zingiberaceae	8.11
Rutaceae	9.11	Theaceae	6.00	Vacciniaceae	6.75	Moraceae	6.07
Myrsinaceae	7.10	Zingiberaceae	5.44	Araliaceae	5.43	Fagaceae	5.67
Rosaceae	6.65	Moraceae	4.93	Salicaceae	5.28	Apocynaceae	3.60
Verbenaceae	6.30	Rosaceae	4.25	Gentianaceae	5.00	Lauraceae	3.56
Lauraceae	6.22	Lauraceae	3.60	Rosaceae	4.85	Asclepiadaceae	3.55
Moraceae	6.00	Labiatae	2.83	Primulaceae	3.90	Rosaceae	2.75
Gesneriaceae	5.30	Gesneriaceae	2.75	Lauraceae	1.64	Annonaceae	2.71
Ericaceae	4.67	Asclepiadaceae	2.45	Scrophulariaceae	1.63	Rubiaceae	2.50
Labiatae	3.23	Acanthaceae	2.44	Liliaceae	1.22	Euphorbiaceae	2.46
Araliaceae	2.91	Rubiaceae	1.90	Labiatae	1.09	Acanthaceae	2.08
Rubiaceae	2.61	Euphorbiaceae	1.74	Umbelliferae	0.87	Palmae	2.08
Gramineae	2.32	Gramineae	1.57	Orchidaceae	0.83	Orchidaceae	2.08
Cyperaceae	2.03	Compositae	1.34	Compositae	0.82	Gramineae	1.80
Euphorbiaceae	2.00	Umbelliferae	1.30	Cyperaceae	0.78	Labiatae	1.80
Papilionaceae	1.30	Papilionaceae	1.25	Rubiaceae	0.73	Papilionaceae	1.48
Compositae	1.26	Orchidaceae	1.14	Gramineae	0.65	Cyperaceae	1.20
Orchidaceae	1.20	Cyperaceae	1.05	Papilionaceae	0.30	Compositae	0.85

** (%) : The number of species of the family in the regional flora/ the number of total species of the family in the world x 100%

From LI Heng's idea, the Dulongjiang region could be at the same latitude as the southeast Yunnan before the fragment turned clockwise. With the turning clockwise of the fragment, the Dulongjiang region moved northward about 4.5 latitudinal degrees, while the region of southeast Yunnan moved southward about 1-2 degrees. It can be further conjectured that the flora of Dulongjiang has derived from a background of tropical flora, and has developed into the present flora, which is dominated by worm-temperate floristic elements. On the other hand, the flora of SE Yunnan has derived from a flora with much subtropical characters. These conjectures are supported by the composition of geographical elements of the flora of Dulongjiang. The floristic elements of mainly Gondwana tropical origin contribute 52.8% of its total flora at generic level, while the temperate floristic elements contribute 83.54% of its total flora at specific level (LI Heng, 1994a). This implies that the flora of Dulongjiang has a tropical origin, but temperate characteristics.

Other studies on fern floras give some significant implications. It is revealed that the generic similarity between the fern flora of Nujiang, the northwestern Yunnan, and the fern flora of the southeastern Yunnan is 88.18% and the fern flora of Nujiang has closer affinity to the fern flora of the southeastern Yunnan than the fern flora of Xishuangbanna (ZHU, 1998). The Bozhu mountain, which is located in the south of The Tropic of Cancer in the southeastern Yunnan, has a fern flora with some subtropical to temperate characters (Lu, 1994). This seems supporting the idea of some southward movement of the region. I agree with the idea of "Ecogeographical Diagonal Line" because it is supported by some biogeographical and floristic studies as well as the geological history of these regions.

It is obvious that the "Tanaka Line" acts as a demarcation line separating Sino-Himalayan and Sino-Japanese subkingdoms in East Asia floristic kingdom. However, it is not evident that the "Tanaka Line" acts also as a line to separating the East Asia floristic elements from the Indo-Malaysia elements. Hainan Island of southeast China was considered to be in the east side of the "Tanaka Line" by TANAKA (1954). From WU Te-Lin *et al.* (1996), the floristic similarity coefficient at the generic level between the flora of S China Sea Islands (Hainan Island as its core area) and the Philippines is 78.2% and Java is 75.0%, and Guangdong of mainland China is 82.3%, as well as Taiwan is 70%. Although Hainan Island is almost connected to Guangdong of mainland China, the floristic similarity coefficient between them is just a little higher than the floristic similarity coefficient between Hainan and the far away Philippines and Java. This clearly supports that the flora of Hainan is part of Malesian flora and belongs to the Indo-Malesia floristic region.

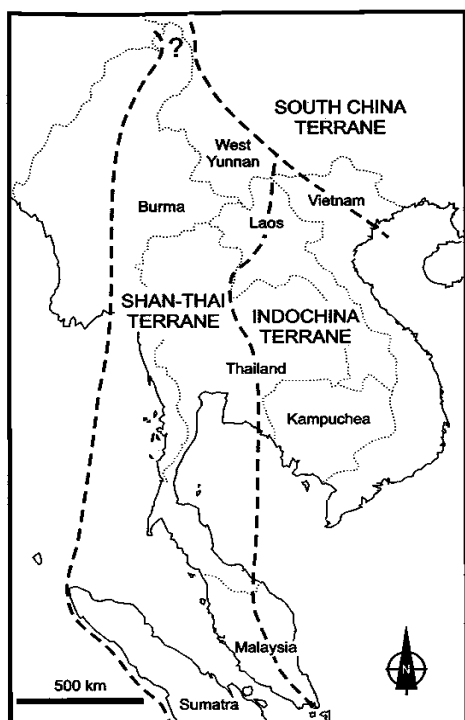


Fig. 2 The map showing the boundaries of the various terranes in SE Asia (from FORTEY *et al.*, 1998)

There are still some other interesting distribution patterns of plants in Yunnan. For example, the species *Dipterocarpus retusus* (a big tree species) is the characteristic species in the tropical rain forest of the southwestern Yunnan and the southeastern Yunnan, but strangely absent in the southern Yunnan. The shrubby oak forest with hard and thorny leaves which looks like the Mediterranean vegetation, occurs frequently in the center area of Yunnan and the species *Pistacia chinensis*, which is supposed to be Mediterranean origin, also occurs frequently on some lake bank in center Yunnan. In some dry and hot valleys, such as Yuanjiang and Jingshajiang, you can see the Savanna vegetation of the African affinity. You can see also some montane evergreen broad-leaved forests, which has a subtropical floristic composition but occur on a habitat of temperate climate. All these interesting biogeographical patterns could not be simply explained by only the diversity of ecological habitats found in Yunnan. The knowledge of geological history, tectonic theories and historical biogeography of the region should be taken into consideration.

REFERENCE

- AUDLEY-CHARLES M G, 1987. Dispersal of Gondwanaland: Relevance to evolution of the Angiosperms [A]. In: WHITMORE T C (ed.). *Biogeographical Evolution of the Malay Archipelago* [C]. Oxford: Clarendon Press, 5-25
- FORTEY R A & COCKS L R M, 1998. Biogeography and palaeogeography of the Sibumasu terrane in the

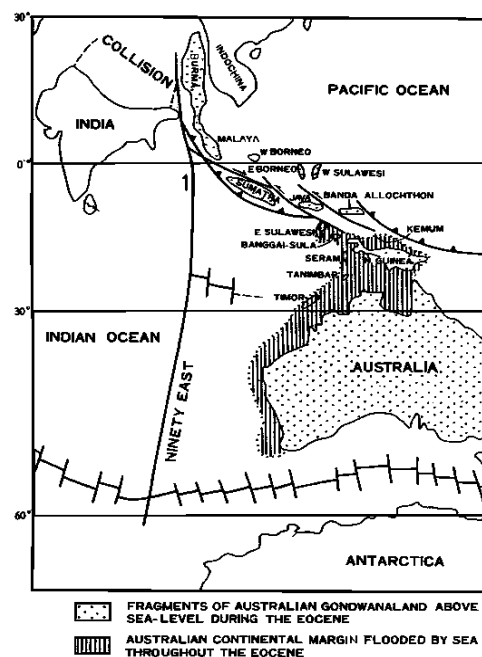


Fig. 3 Reconstruction of convergence zone between Australia-New Guinea and South-east Asia for 40 Ma early Eocene (from AUDLEY-CHARLES, 1987)

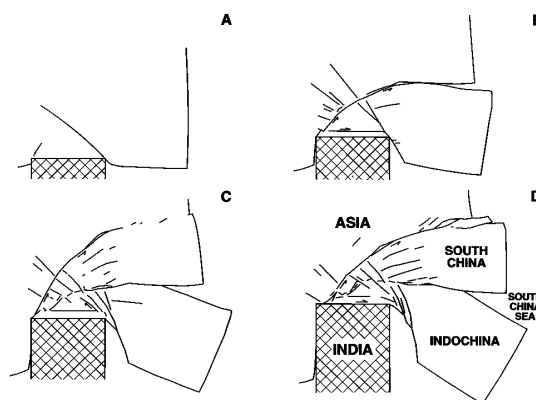


Fig. 4 The models of the impact of a rigid Indian indenter with Asia (from HALL, 1998)

- Ordovician: a review [A]. In: HALL R et HOLLOWAY J D (ed.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backbuys Publishers, 43-56.
- HALL R, 1998. The plate tectonics of Cenozoic SE Asia and the distribution of land and sea [A]. In: HALL R & HOLLOWAY J D (ed.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backbuys Publishers, 99-131.
- LANG Kai-yong, 1994. Studies on the distribution patterns of some significant genera in orchid flora [J]. *Acta Phytotaxon. Sin.* 32: 328-339 (In Chinese with English abstract).
- LI Heng, 1993. Plants of Dulongjiang region [M]. Kunming: Yunnan Science & Technology Press, 1-220 (In Chinese).
- LI Heng, 1994a. Delineation and feature of Dulongjiang region flora [J]. *Acta Bot. Yunn. Suppl.*, VI: 1-100 (In Chinese with English abstract).
- LI Heng, 1994b. The biological effect to the flora of Dulongjiang caused by the movement of Burma-Malaya Geoblock [J]. *Acta Bot. Yunn. Suppl.*, VI: 113-120 (In Chinese with English abstract).
- LI Heng, He Da-ming, Bartholomew B & Long Chun-lin, 1999. Re-examination of the biological effect of plate movement --- impact of Shan-Malay Plate displacement (the movement of Burma-Malay Geoblock) on the biota of the Gaoligong Mountains [J]. *Acta Bot. Yunn.* 21 (4): 407-425.
- LI Xi-wen & LI Jie, 1992. On the validity of Tanaka Line and its significance viewed from the distribution of eastern Asiatic genera in Yunnan [J]. *Acta Bot. Yunn.* 14 (1): 1-12 (In Chinese with English abstract).
- LI Xi-wen & LI Jie, 1997. The Tanaka-Kaiyong Line - an important floristic line for the study of the flora of East Asia [J]. *Ann. Missouri Bot. Gard.* 84: 888-892.
- LU Shu-gang, ZHANG Guang-fei, 1994. A Study on the Pteridoflora from Bozhu Mountain, SE Yunnan [J]. *Journ. Yunn. University (Natural Sciences)* 16 (3): 276-280 (In Chinese with English abstract).
- METCALFE I, 1998. Paleozoic and Mesozoic geological evolution of the SE Asia region: multidisciplinary constraints and implications for biogeography [A]. In: HALL R et HOLLOWAY J D (ed.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backbuys Publishers, 25-41.
- MORLEY J R, 1998. Palynological evidence for Tertiary plant dispersal in the SE Asian region in relation to plate tectonics and climate [A]. In: HALL R et HOLLOWAY J D (ed.). *Biogeography and Geological Evolution of SE Asia* [C]. Leiden: Backbuys Publishers, 221-234.
- SHI Ya-feng, LI Ji-yun, LI Bing-yuna et al., 1998. Uplift and environmental evolution of Qinghai-Xizang (Tibetan) plateau [A]. In: Sun Honglie, Zheng Du (ed.). Formation, evolution and development of Qinghai-Xizang (Tibetan) plateau [C]. Guangzhou: Guangdong Science and Technology Press, 73-138 (In Chinese).
- SHI Ya-feng, LI Ji-yun, LI Bing-yuna, et al., 1999. Uplift of the Qinghai-Xizang (Tibetan) plateau and East Asia environmental change during late Cenozoic [J]. *Acta Geogr. Sin.* 54 (1): 10-21 (In Chinese with English abstract).
- TANAKA T, 1954. Species problem in Citrus [M]. Tokyo: Japanese Society for the Promotion of Science, 58-69
- WU Telin, XING Fu-wu, YE Hua-gu et al. 1996. Study on the spermatophytic flora of South China Sea Islands [J]. *J. Trop Subtrop Bot.* 4 (1): 1~22; 4 (2): 1~11. (in Chinese).
- ZHU Hua, 1994. Floristic relationships between dipterocarp forest of Xishuangbanna and forests of tropical Asia and S China [J]. *Acta Bot. Yunn.* 16 (2): 97-106 (in Chinese with English abstract)
- ZHU Hua, 1996. On the floristic occurrence of the dipterocarp forest of Xishuangbanna [J]. *Collected Research Papers on the Tropical Botany* 4: 36-52 (in Chinese with English abstract)
- ZHU Hua, 1997. Ecological and Biogeographical Studies on the Tropical Rain Forest of South Yunnan, SW China with a Special Reference to Its Relation with Rain forests of Tropical Asia [J]. *Journ. Biogeogr.* 24: 647-662
- ZHU Hua, 2001. New Plants of *Lasianthus* Jack (Rubiaceae) from Kinabalu, Borneo and its biogeographical implication [J]. *Blumea* 46 (3): 447-455.
- ZHU Hua, Wang Hong & LI Bao-gui, 2000. *Gymnanthes* Sw. (Euphorbiaceae), new to China and its biogeographical implication [J]. *Acta Phytotaxon. Sin.* 38 (5): 462-463
- ZHU Hua, Wang Hong & LI Bao-gui, 2000. A new subspecies of the genus *Lasianthus* Jack (Rubiaceae) from Yunnan with a reference to its biogeographical implication [J]. *Acta Phytotaxon. Sin.* 38 (3): 282-285
- ZHU Hua, Wang Hong & LI Bao-gui, 1997. Floristic relationships between the limestone flora of Xishuangbanna and neighboring floras of tropical Asia and south China [J]. *Acta Bot. Yunn.* 19 (4): 357-365. (in Chinese with English abstract)
- ZHU Wei-ming, 1998. Pteridophyta [A]. In: Yunnan Forestry Bureau (ed.) Nujiang Nature Reserve [C]. Kunming: Yunnan Art Press. 270-317 (In Chinese).

Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia

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Abstract. Ecological and biogeographic analyses of the tropical rain forest in south Yunnan were made using data from seventeen sample plots and floristic inventories of about 1000 species of seed plants. The rain forest is shown to be a type of true tropical rain forest because it has almost the same profile, physiognomic characteristics, species richness per unit area, numbers of individuals in each tree species and diameter classes of trees as classic lowland tropical rain forests. As the area is at the northern margin of monsoonal tropics, the rain forest differs from equatorial lowland rain forests in having some deciduous trees in the canopy layer, fewer megaphanerophytes and epiphytes but more species of lianas as well as more species of microphylls. In its floristic composition, about 80% of total families, 94% of total genera and more than 90% of total species are tropical, of which about 38% of genera and 74% of species are tropical Asian. Furthermore, the rain forest has not only almost the same families and genera, but also the same families rank in the top ten both in species richness and in dominance of stems, as lowland forests in southeast Asia. It is indisputable that the flora of the rain forest is part of

the tropical Asian flora. However, most of the tropical families and genera have their northern limits in south Yunnan and most have their centre of species diversity in Malesia. More strictly tropical families and genera have relatively lower species richness and importance compared with lowland rain forests in tropical southeast Asia. Thus, the flora also shows characteristics of being at the margin of the tropics.

Based mainly on physiognomy and floristic composition the tropical rain forest of Yunnan is classified into two types, i.e. seasonal rain forest and wet seasonal rain forest, the latter is further divided into two subtypes, i.e. mixed rain forest and dipterocarp rain forest.

From analysis of geographic elements it is also shown that the tropical rain forest of Yunnan occurs at a geographical nexus with its flora coming mainly from four sources, i.e. Malesia, south Himalayas, Indochina and China.

Key words. Yunnan, tropical rain forests, ecology, biogeography.

INTRODUCTION

Climatically the tropical areas of south China are situated disjunctively in southeastern Xizang (Tibet); southern parts of Yunnan; Gunangxi; Taiwan and Hainan Island at the margin of tropics. The largest tropical area still covered by forests is in Yunnan province, the southwestern-most part of China. Yunnan is a region of exceptional interest to biologists, not only because it is in a transitional position from the southern Himalayas to east Asia and from tropical southeast Asia to subtropical China, but also because it is at the junction of the Indian and Burmese plates of Gondwanaland and the Eurasian plate of Laurasia (Audley-Charles, 1987).

Southern Yunnan is a mountainous area at the end of Hengduan Mountains (part of the Himalayas) at the northern margin of mainland southeast Asia. Geographically, it is at the northern margin of the tropics

(21°09'–24°40' N latitude). As a result, it has a slightly lower annual mean temperature (c. 22°C) and lower annual precipitation (average 1500 mm) in its tropical area (below 900 m altitude) in comparison with the main tropical rain forest areas of the world. For a long time there has been discussion as to whether there is true tropical rain forest in Yunnan. If there were tropical rain forest in the region, it would probably be intermediate between classic tropical rain forest and monsoon forest as defined by Schimper (1903), or be a type of subtropical rain forest which differs in various aspects from the true tropical rain forest of Richards (1952). Botanists' interests in the area were rekindled in 1974 by the finding of dipterocarps, which are characteristic of rain forests of tropical southeast Asia. However, the tropical rain forest of Yunnan has not been investigated in detail until recently because of poor access and security problems. Publications about the tropical rain forest in English are extremely rare although there are some in Chinese (Wu, 1980; Liu, 1987; Zhu, 1992a, 1993a, 1994a). The present paper describes the physiognomic, floristic and phytogeographic characteristics of the tropical rain forest, and its relationship with tropical rain forests of southeast Asia.

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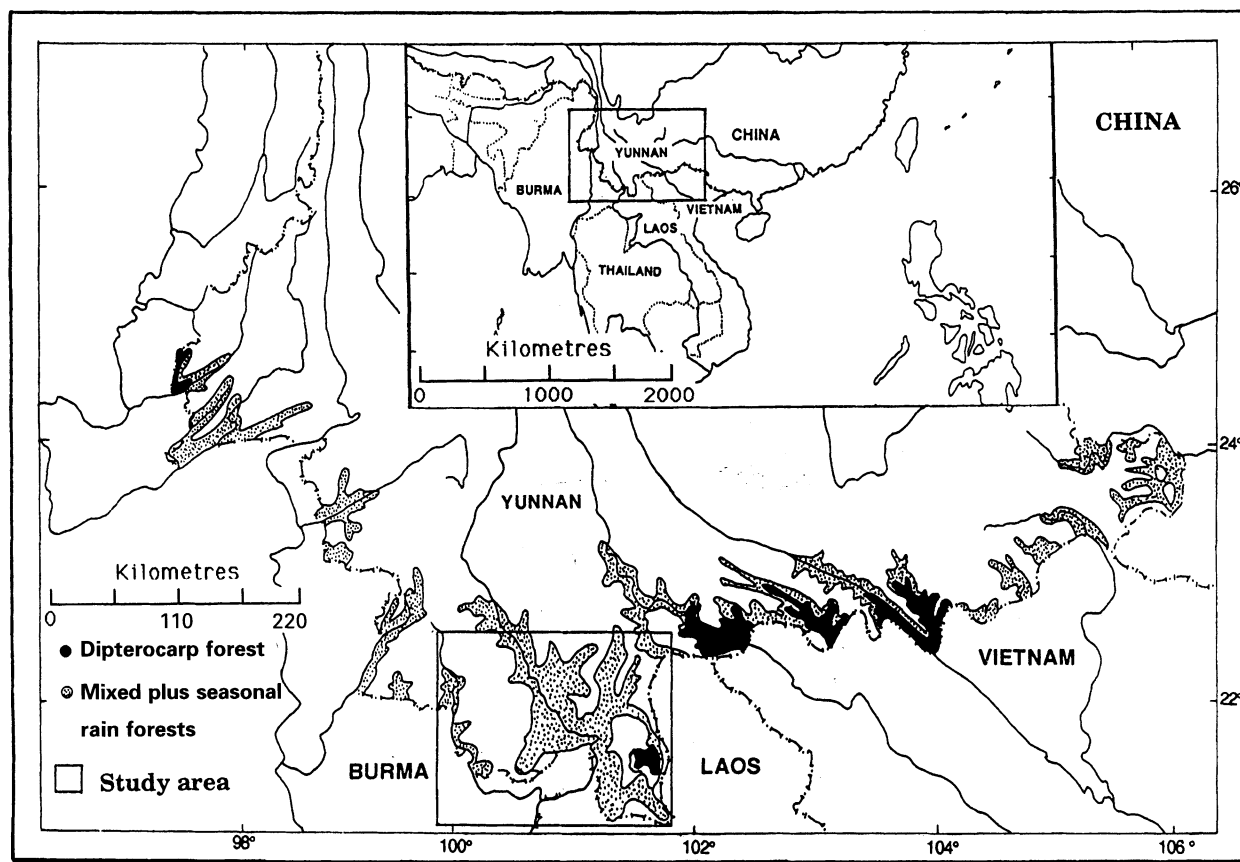


FIG. 1. Distribution of tropical rain forest in Yunnan, southwest China.

TABLE 1. Principal climatic factors of tropical areas of Yunnan.

County	Location	Altitude (m)	Annual mean temperature (°C)	Annual air relative humidity (%)	Lowest monthly humidity (%)	Annual precipitation (mm)	Average number of foggy days per year*
Hekou (SE Yunnan)	103°57' E, 22°30' N	137	22.8	86	82	1764	59
Jinghong (S Yunnan)	101°04' E, 21°33' N	553	21.7	83	69	1221	142
Mengdin (SW Yunnan)	99°05' E, 23°34' N	511	21.5	80	64	1488	97

(*Data from Liu (1987).)

GENERAL GEOGRAPHY

The tropical rain forest of Yunnan lies between 21°09' to 24°40' N and 97°34' to 106° E, and borders Burma to the west and southwest, Laos to the south and Vietnam to the southeast (Fig. 1). Basically, the area has a mountain-valley topography with the ridges running north-south with a falling southward. Altitude varies from 100 m at the bottom of the lowest valley in the south to 2900 m at the top of the highest mountain in the north. The region is controlled by a typical tropical monsoon climate. Climatic change with altitude is conspicuous. In those areas of lower hills and valleys covered by tropical forests, the annual mean temperature is 21°–22.8°C, and frost has never been recorded. The annual cumulative temperature (the sum of

daily temperature means where they are >10°C) is more than 7600°C. The annual precipitation varies from 1200 mm to 1800 mm of which more than 80% falls during the rainy season which starts in May and lasts till the end of October (Table 1).

Tropical rain forest occurs mainly in valleys and on lower hills below 900 m altitude, as intermittent tracts or patches in local habitats with a tropical moist climate that form due to particular topography. Tropical rain forest forms a mosaic pattern with montane evergreen forests and semi-evergreen forests. The Hengduan mountains to the north of the region act as a huge barrier keeping out the cold air from the north in winter. Dense fog always exists during the whole dry season on the lower hills and in the valleys (average 146 foggy days per year and 1 mm precipitation per foggy

day recorded in Mengla County in the south of the region) and this compensates for the insufficient precipitation so that a tropical moist climate can form in local habitats in spite of its relatively high latitude and elevation. The tropical moist climate in the region presumably did not form until the Hengduan Mountains were elevated after late Tertiary. This implies that the tropical rain forest of the region did not develop until late Tertiary.

The tropical rain forest of Yunnan occurs mainly on laterite soil developed from siliceous rocks, such as granite and gneiss. The pH values of soil are usually 4.5–5.5. The tropical rain forest occurs also in some wet valleys of limestone. However, the rain forest on limestone is almost the same as that on laterite soil in physiognomy and floristic composition. This paper deals with the rain forest on laterite of siliceous rocks.

METHODS

The most representative and best conserved tracts of the tropical rain forest of Yunnan are in the Xishuangbanna region of south Yunnan, so it was chosen as the principal study area (Fig. 1).

Several representative patches were chosen for plot and floristic investigation from each of three main forest types. In each patch, one to several plots were laid out depending on size and variance of the floristic composition of the patch. A total of seventeen plots were used in the paper. The size of plot was ideally 2500 m² (0.25 ha) which is considered to be close to the phytosociological minimum area for rain forest (Drees, 1954). In each plot, all trees were identified and their d.b.h. (minimum 5 cm), height and crown coverage measured. Each plot was roughly divided into five strips so that frequency of tree species could be calculated. In four to five subplots (in each plot) of 5 × 5 m, saplings were counted and seedlings, shrubs and herbaceous plant cover were estimated by Braun-Blanquet's degree of abundance (Braun-Blanquet, 1932). Epiphytes and Lianas were identified and abundance estimated by eye. Besides these sample plots, some other relatively small patches of forest were inventoried to analyse geographical elements more completely. Thus a (nearly) complete list of species for the about 800 ha of dipterocarp rain forest existing in Xishuangbanna was made. Seasonal rain forest was less extensively investigated, and only about 10 ha was studied floristically. Similarly in mixed rain forest of wet seasonal rain forest a complete floristic inventory was not made. For all species both from sample plots and from patches of forest, specimens were collected and identified; these are in the herbaria KUN and HITBC. Species authorities follow mainly *Flora Reipublica Populario Sinica*.

Releve or synthetic plot tables were obtained from four or five non-contiguous plots for each type and subtype of the rain forest. Life forms and leaf size classes were analysed based on all plant species in two almost contiguous plots in the dipterocarp forest. Species biogeographical affinities were analysed for (a) the dipterocarp rain forest of the wet seasonal rain forest (based on 800 ha) and (b) the seasonal rain forest (on about 10 ha).

RESULTS

Forest types, structure and floristic composition

Based mainly on physiognomy and floristic composition tropical rain forests of Yunnan were classified into two types, i.e. seasonal rain forest and wet seasonal rain forest.

Seasonal rain forest

The seasonal rain forest reaches 35–45 m high and has three or four inconspicuous tree layers. In the top tree layer with discontinuous crowns (coverage of 25–35%) of emergent trees, about half of individuals and one third of species are deciduous. The second layer, which is 15–30 m high and has a crown cover of 80%, consists of a mixture of evergreen species. The lower tree layer, 5–18 m high and with crown cover of 40–50%, consists of small evergreen trees and juveniles of species from the upper layers. There are 131 tree species in the plots (1.25 ha of cumulative area) of the forest type (Table 2). In the top layer, the most important deciduous species is *Antiaris toxicaria*. Another outstanding deciduous species is *Tetrameles nudiflora* with huge buttresses, which occurs locally and is usually the largest emergent tree in the forest. The dominant evergreen species in the emergent layer are *Gironniera subaequalis*, *Aphananthe cuspidata* and *Pouteria grandiflora*. In the second layer, the dominant species vary from site to site, but the characteristic species are *Polyalthia cheliensis*, *Nephelium lappaceum* var. *pallens*, *Garcinia xanthochymus*, *Walsura yunnanensis* and *Cryptocarya yunnanensis*. The commonest species in the lower layer are *Aporosa yunnanensis*, *Millettia leptobotrya*, *Acronychia pedunculata* and *Memecylon polyanthum*. The understorey, with a cover of 34–40%, consists mainly of saplings and young woody lianas. True shrubs are rare, the commonest species are *Lasianthus*, *Psychotria* and *Prismatomeris* of the Rubiaceae, and *Pandanus*. The herb layer is usually undeveloped in most sites except in gaps and at margins. Woody lianas are abundant, the commonest species are *Randia bispinosa*, *Strychnos nitida*, *Salacia polysperma* and *Combretum latifolium*. Epiphytes are relatively less abundant than in wet seasonal rain forest, and the common species are *Pothos chinensis*, *Rhaphidophora decursiva* as well as the fern *Pseudodrynaria coronans*. In a typical plot (0.25 ha, No. 93–12–6) of the forest type, forty-two sapling and seedling species (less than 5 cm d.b.h.), ten shrub species and fourteen herbaceous species were recorded from the understorey, and thirty-five climber species and six epiphyte species were recorded.

Wet seasonal rain forest

Wet seasonal rain forest has fewer deciduous trees in both species and individuals, and conspicuously more individuals and species of epiphyte. Based mainly on floristic composition this forest type was further classified into two subtypes, i.e. the mixed rain forest and dipterocarp rain forest.

The mixed rain forest, which has almost the same profile as the former type, has an emergent layer of mixed species. There are 140 tree species in the plots (1.46 ha cumulative area) of the subtype (Table 2). The dominant evergreen

TABLE 2. The tree species (average importance value index over 5 or presence classes over II in at least one forest type) of mixed rain forest (MRF) and dipterocarp rain forest (DRF) of wet seasonal rain forest (WSRF), and seasonal rain forest (SRF) in south Yunnan with their importance value and presence.

Type of forest	WSRF				SRF					
Subtypes	MRF		DRF							
Cumulative area (ha)	1.46		1.04		1.25					
Number of plots	5		4		5					
Number of tree species	140		125		131					
No. of indiv. (>5 cm DBH)	698		892		954					
	A.IVI	Pr.	A.IVI	Pr.	A.IVI	Pr.				
<i>Pometia tomentosa</i>	29.8	V	12.2	V	5.9	II	A	E	Me	C
<i>Terminalia myriocarpa</i>	14.8	V	+	+	—	—	A	E	Me	S
<i>Lasiococca comberi</i> var.										
<i>pseudoverticillata</i>	11.8	IV	6.07	II	3.8	I	B	E	Me	S
<i>Dracontomelon macrocarpa</i>	9.9	II	0.83	I	—	—	A	E	Me	C
<i>Garuga floribunda</i> var. <i>gamblei</i>	8.3	V	2.93	IV	+	+	A	D	Me	C
<i>Shorea chinensis</i>	—	—	68.1	V	—	—	A	E	Me	S
<i>Pittosporopsis kerrii</i>	0.98	II	13.1	V	4.0	III	C	E	Me	S
<i>Garcinia cowa</i>	5.21	V	12.5	V	7.5	V	B	E	Me	S
<i>Baccaurea ramiflora</i>	6.09	IV	9.1	V	6.4	IV	B	E	Me	S
<i>Antiaris toxicaria</i>	0.52	I	+	+	17.3	IV	A	D	Me	S
<i>Gironniera subaequalis</i>	0.58	I	3.38	IV	16.5	IV	A	E	Me	S
<i>Cryptocarya yunnanensis</i>	0.22	I	+	+	20.9	II	B	E	Me	S
<i>Barringtonia macrostachya</i>	3.22	III	3.47	IV	11.9	III	B	E	Me	S
<i>Tetrameles nudiflora</i>	+	+	+	+	8.1	II	A	E	Me	S
<i>Aphananthe cuspidata</i>	—	—	—	—	6.7	IV	A	E	Me	S
<i>Pouteria grandiflora</i>	0.93	I	+	+	5.15	V	A	E	Me	S
<i>Syzygium latilimbium</i>	3.52	V	3.04	V	0.89	I	C	E	Me	S
<i>Horsfieldia pandurifolia</i>	3.99	V	1.28	II	—	—	C	E	Ma	S
<i>Knema furfuracea</i>	3.01	V	4.64	V	5.92	IV	B	E	Ma	S
<i>Aphonsea monogyna</i>	3.17	IV	+	+	4.56	III	B	E	Me	S
<i>Semecarpus reticulata</i>	2.16	IV	3.32	V	1.32	III	A	E	Me	S
<i>Cleidion bracteosum</i>	6.06	IV	3.05	IV	+	+	C	E	Me	S
<i>Vitex quinata</i> var. <i>puberula</i>	5.47	IV	+	+	0.61	I	C	E	Me	C
<i>Mayodendron igneum</i>	1.96	IV	2.95	IV	1.07	III	B	D	Me	C
<i>Ficus lankokensis</i>	4.24	III	6.18	IV	2.20	II	C	E	Me	S
<i>Diospyros xishuangbannensis</i>	5.82	III	2.16	IV	0.30	I	C	E	Me	S
<i>Pseuduvaria indochinensis</i>	4.37	III	3.67	V	1.79	I	B	E	Me	S
<i>Ailanthus fordii</i>	3.28	III	+	+	0.41	I	A	E	Me	C
<i>Drypetes cumingii</i>	3.22	III	+	+	1.15	I	C	E	Mi	S
<i>Celtis timorensis</i>	3.26	III	+	+	1.73	III	C	E	Mi	S
<i>Dysoxylum lukii</i>	1.53	III	+	+	4.12	III	B	E	Me	C
<i>Ulmus lanceifolia</i>	1.68	III	+	+	+	+	C	E	Mi	S
<i>Bischofia javanica</i>	1.24	III	+	+	+	+	C	E	Me	C
<i>Alstonia scholaris</i>	1.07	III	1.63	IV	—	—	A	E	Me	S
<i>Neonauclea tsaiana</i>	5.44	II	+	+	3.33	II	A	E	Me	S
<i>Pterospermum lanceaefolium</i>	6.44	II	+	+	2.76	III	A	E	Me	S
<i>Lithocarpus fohaiensis</i>	—	—	5.75	III	—	—	B	E	Me	S
<i>Cinnamomum bejolghota</i>	0.6	II	5.19	V	0.64	I	B	E	Me	S
<i>Castanopsis indica</i>	+	+	4.17	IV	1.05	II	A	E	Me	S
<i>Sapium baccatum</i>	+	+	3.97	IV	0.83	I	A	D	Me	S
<i>Chisocheton siamensis</i>	1.51	I	3.58	V	3.70	I	C	E	Me	C
<i>Aglaia pervridis</i>	0.62	II	3.36	V	0.60	I	C	E	Me	C
<i>Diospyros hassellii</i>	3.04	II	3.29	V	—	—	B	E	Me	S
<i>Phoebe lanceolata</i>	+	+	3.32	IV	0.90	I	C	E	Me	S
<i>Knema cinerea</i> var. <i>glauca</i>	0.34	I	3.04	IV	0.60	I	C	E	Me	S
<i>Pterospermum monglunensis</i>	1.67	I	2.37	III	—	—	A	E	Me	S
<i>Litsea dilleniaefolia</i>	1.79	I	2.29	III	—	—	B	E	Ma	S
<i>Neonauclea griffithii</i>	+	+	2.11	III	0.42	I	A	E	Me	S
<i>Beilschmiedia purpurascens</i>	+	+	1.92	III	—	—	C	E	Me	S
<i>Nephelium lappaceum</i> var. <i>pallens</i>	1.34	II	1.85	III	2.51	V	B	E	Me	C
<i>Harpullia cupanioides</i>	0.97	II	1.88	III	3.02	III	B	E	Me	C
<i>Dysoxylum binectariferum</i>	0.91	II	1.83	III	1.15	II	B	E	Me	C

contd

TABLE 2. *contd*

	A.IVI	Pr.	A.IVI	Pr.	A.IVI	Pr.				
<i>Xanthophyllum siamensis</i>	0.68	I	1.71	III	3.95	III	C	E	Me	S
<i>Pygeum latifolium</i> var. <i>macrocarpa</i>	1.08	II	1.90	III	—	—	B	E	Me	S
<i>Millettia leptobotrya</i>	+	+	+	+	4.72	III	C	E	Me	C
<i>Phoebe puwenensis</i>	0.93	II	1.04	I	3.69	III	B	E	Me	S
<i>Mitrephora thorelii</i>	1.44	I	+	+	2.69	III	B	E	Me	S
<i>Acer garrettii</i>	—	—	+	+	2.44	IV	C	E	Me	S
<i>Walsura yunnanensis</i>	0.52	I	0.96	I	2.84	IV	B	E	Me	C
<i>Garcinia xanthochymus</i>	+	+	+	+	3.37	III	B	E	Ma	S
<i>Polyalthia cheliensis</i>	1.0	II	+	+	6.86	III	B	E	Me	S
<i>Acronychia pedunculata</i>	0.6	I	+	+	4.97	III	C	E	Me	S
<i>Syzygium chathayensis</i>	+	+	+	+	4.45	III	C	E	Me	S
<i>Homalium laoticum</i>	+	+	+	+	1.82	III	A	E	Me	S
<i>Gomphandra tetrandra</i>	+	+	+	+	0.91	III	C	E	Mi	S
<i>Memecylon polyanthum</i>	—	—	+	+	1.19	III	C	E	Mi	S
<i>Machilus tenuipilis</i>	0.66	II	2.79	II	3.72	III	A	E	Me	S
<i>Aporosa yunnanensis</i>	+	+	+	+	5.84	III	C	E	Me	S

Average importance value index = $\frac{\text{Cumulative importance value from all plots}}{\text{number of plots}}$

A.IVI: Average Importance Value Index = cumulative importance value from all plots. Number of plots. Importance value index = relative density + relative dominance (Basal area) + relative frequency. Pr.: Presence Classes (from Braun-Blanquet), V (presence in 81–100% of plots), IV (61–80%), III (41–60%), II (21–40%), I (<20%).

Numbers in bold: the top five most important species in each forest type.

— The species is not in plots but present in the forest type.

— The species is generally absent in the forest type.

E, Evergreen; D, Deciduous; A, mainly in the first (top) layer; B, mainly in the second (middle) layer; C, mainly in the third (lower) layer; Mi, Microphyll; Me, Mesophyll; Ma, Macrophyll; (Raunkiaer, 1934) C, Compound leaves; S, Simple leaves.

species in the emergent layer are *Pometia tomentosa* and *Terminalia myriocarpa*, and the commonest deciduous tree is *Garuga floribunda* var. *gamblei*. Characteristic species in the second layer are *Lasiococca comberi* var. *pseudoverticillata*, *Dracontomelon macrocarpa*, *Diospyros xishuangbannensis* and *Pseuduvaria indochinensis*. Common species in the lower layer are *Syzygium latilimbum*, *Cleidion bracteosum* and *Horsfieldia pandurifolia*. The understorey is similar to the former type in species composition, but has higher species richness. The epiphytes are also more abundant than in seasonal rain forest in number of

individuals. Fifty-eight sapling and seedling species, fourteen shrub species (Raunkiaer, 1934), and twenty-four herbaceous species, twenty-five liana and seven epiphyte species were recorded from a typical plot (0.25 ha, No. 940101) of the forest subtype.

The dipterocarp rain forest is taller than both the former subtype and the seasonal rain forest, reaching up 60 m and has four tree layers. The top layer is 30–60 m tall with very uneven, discontinuous crowns covering about 30%. The second layer with a crown cover of 80%, is the main canopy. There are 125 tree species in the plots (1.04 ha of cumulative

TABLE 3. The top fifteen families with most accumulative importance of tree species from tropical rain forest in south Yunnan.

Seasonal rain forest	IVI	Wet seasonal rain forest (MRF)	IVI	Wet seasonal rain forest (DRF)	IVI
Lauraceae	39.05	Euphorbiaceae	37.67	Dipterocarpaceae	68
Moraceae	26.35	Sapindaceae	32.11	Lauraceae	25.27
Ulmaceae	26.07	Combretaceae	19.17	Euphorbiaceae	24.24
Annonaceae	24.3	Moraceae	19.13	Sapindaceae	15.9
Euphorbiaceae	23.31	Anacardiaceae	16.55	Meliaceae	15.41
Meliaceae	16.87	Annonaceae	14.96	Moraceae	15.29
Sapindaceae	14.95	Lauraceae	14.28	Fagaceae	14.44
Barringtoniaceae	11.85	Myristicaceae	11.25	Guttiferae	14.36
Rubiaceae	11.58	Ebenaceae	9.91	Icacinaceae	13.94
Guttiferae	11.31	Ulmaceae	8.76	Myristicaceae	9.69
Myristicaceae	10.81	Burseraceae	8.64	Ebenaceae	7.46
Datisaceae	8.1	Sterculiaceae	8.11	Anonaceae	6.69
Papilionaceae	7.73	Meliaceae	7.1	Rubiaceae	5.13
Myrtaceae	7	Bignoniaceae	5.79	Burseraceae	4.71
Rutaceae	5	Verbenaceae	5.47	Dichapetalaceae	4.70

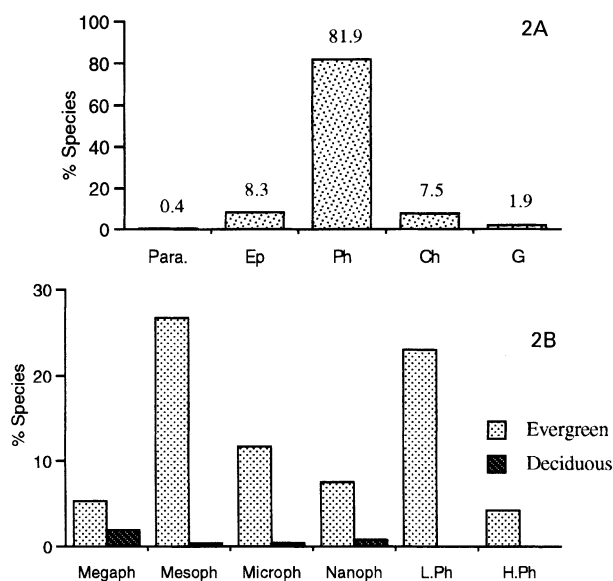


FIG. 2. Life form spectrum of the seasonal rain forest of south Yunnan (A) for the total 265 vascular plant species in a 0.5 ha area; (B) for 217 phanaerophytes of them. Para., parasite; Ep., epiphyte; Ph., phanaerophyte; Ch., chamaephyte; G., geophyte; L.Ph, Liana phanaerophyte; H.Ph, Herbaceous phanaerophyte.

area) of the subtype (Table 2). *Shorea chinensis* is characteristic and has the biggest emergent trees with semiorbicular crowns. Somewhat smaller than the *Shorea*, but still emergents are *Pometia tomentosa*, *Neonauclea griffithii* etc. as in the mixed rain forest. The characteristic species in the second layer are *Garcinia cowa*, *Cinnamomum bejolghota*, *Symphyllia siletiana* and *Knema furfuracea*. The third layer is 10–20 m high and the dominant species is *Baccaurea ramiflora*. The fourth layer is 6–10 m high with the dominant species *Pittosporopsis kerrii*. The understorey is also almost the same as the former subtype. Lianas are very abundant in species. The dominant species are *Tetracera scandens*, *Parameria laevigata* and *Byttneria integrifolia*. Epiphytes are also abundant in both species and individuals. In a typical plot (0.25 ha), forty-five seedling and sapling species, nineteen shrub species, twenty-eight herbaceous species, nineteen epiphyte species and forty-one liana species were recorded.

Several species have high importance and presence in

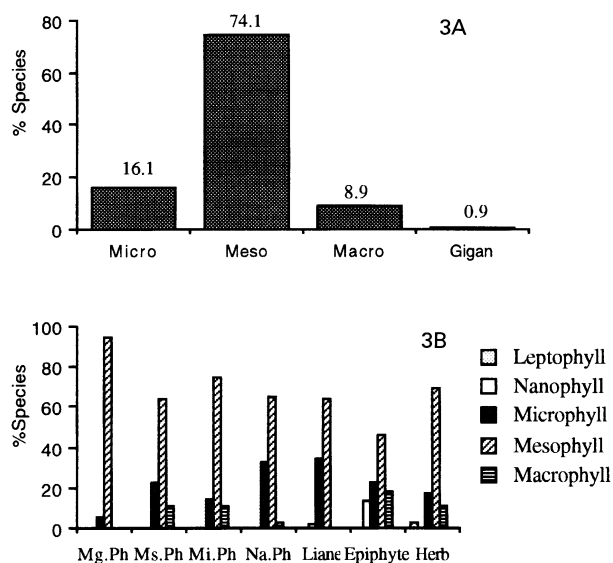


FIG. 3. Leaf size spectra. (A) Leaf size spectrum of tree species; (B) Leaf size spectrum in different life forms. Mg.Ph, Mega-phanaerophyte; Ms.Ph, meso-phanaerophyte; Mi.Ph, micro-phanaerophyte; Na.Ph, nano-phanaerophyte. Raunkiaer (1934).

all rain forest types. They are *Garcinia cowa*, *Baccaurea ramiflora*, *Barringtonia macrostachya* and *Knema furfuracea*. The top fifteen families with greatest cumulative importance of tree species in each rain forest type are shown in Table 3. Among them, seven were common to all three types, a further five occurred in two and the remaining were in the top 15 in only one.

The seasonal rain forest occurs mainly on lower hills and lower slopes of mountains surrounding wide depressions. The wet seasonal rain forest occurs in wetter habitats of valleys and lower hills. The dipterocarp rain forest occurs in the wettest habitats in the southernmost part of the region where annual average relative humidity is more than 80% and mean annual temperature and precipitation are the highest in Yunnan.

The floristic composition of each rain forest type varies to some extent from southeastern to southwestern Yunnan, especially in characteristic species. For example *Dipterocarpus tonkinensis*, *Hopea mollissima*, *Lysidice rhodostegia*, *Saraca thaipingensis*, *Amesiodendron chinensis* and *Eberhardia tonkinensis* occur in the dipterocarp rain forest

TABLE 4. Composition of leaf type, leaf texture, leaf margin and leaf apex of 145 species of phanaerophyte in 0.5 ha dipterocarp rain forest, south Yunnan.

Life form	Leaf type		Leaf texture		Leaf margin		Leaf apex	
	Simple (%)	Compound (%)	Leather (%)	Paper (%)	Entire (%)	Not entire (%)	Drip tip (%)	Not drip tip (%)
Megaphyll	68.4	31.4	73.7	26.3	73.7	26.3	10.5	89.5
Mesophyll	80.6	19.4	55.6	44.4	81.9	18.1	15.3	84.7
Microphyll	75.0	25.0	28.1	71.9	75.0	25.0	3.1	96.9
Nanophyll	86.4	13.6	13.6	86.4	86.4	13.6	13.6	86.4
All	78.6	21.4	45.5	54.5	80.0	20.0	11.7	88.3

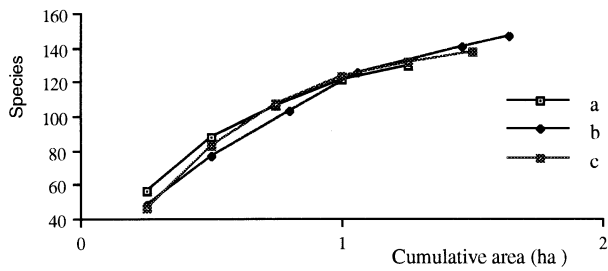


FIG. 4. Species/area curves for the tropical rain forests of south Yunnan. (a) Dipterocarp rain forest; (b) mixed rain forest; (c) seasonal rain forest.

of southeastern part; while *Shorea assamica*, *Dipterocarpus turbinatus*, *Arenga pinnata*, *Taraktogenos kurzii* occur in the dipterocarp rain forest of the southwestern part.

Although floristic composition and the proportion of deciduous trees vary to some extent from place to place and from type to type, the forest profiles are almost always the same within a forest type at altitudes from 400 m to 1000 m.

Physiognomy

The tropical rain forest of south Yunnan is dominated by phanerophytes (Figs 2 and 3). The liana phanerophytes are especially abundant, making up 23% of total species. Deciduous species which are mainly megaphanerophytes make up 6.2% of total species, and about 25% of megaphanerophytes. In leaf size spectra, mesophylls made up 74% of tree species and have the highest percentage in upper (top) tree layer; while microphylls have relatively high percentages amongst shrubs and lianas. Diversity of leaf size appears mainly in epiphytes and herbaceous plants. Among 145 woody plant species, 21.4% have compound leaves (Table 4) and the frequency was the highest amongst megaphanerophytes, supporting the idea that compound leaves are adaptive for rapid vertical growth of trees (Givnish, 1978). Leathery leaves make up 73.7% of megaphanerophytes but only 13.6% of nanophanerophytes. Leaf apex was often changed as trees grew larger. Leaves with drip tips are common in saplings and seedlings of mega and mesophanerophytes and leaf apex becomes acuminate and obtuse in mature trees.

TABLE 6. Frequency of tree species in plots of the tropical rain forest.

No. of Plot	No. of Individual	1	2-5	6-10	11-20	>20
94-1-3	No. of species	31	19	8	0	2
	%	51.7	31.7	13.3	0	3.3
94-1-2	No. of species	27	17	4	0	0
	%	56	35	9	0	0
931206	No. of species	25	18	6	2	1
	%	48.1	34.6	11.5	3.8	1.9
94-1-1	No. of species	28	18	1	1	0
	%	58	37.5	2.1	2.1	0
92-1	No. of species	18	20	2	3	3
	%	39	43	4.3	6.5	6.5

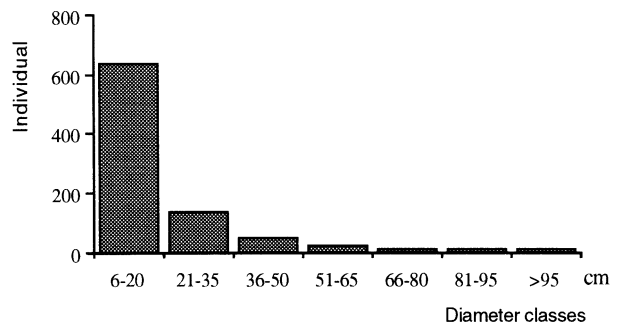


FIG. 5. Distribution of trees in different diameter classes (from 1.04 ha dipterocarp rain forest).

Species area, individual/species and diameter classes

There are 150–200 species of vascular plants of which trees over 5 cm d.b.h. are forty-four to sixty-three species (or eighty to ninety species including saplings and seedlings), lianas are thirty-four to forty species, shrubs fifteen to twenty, herbaceous plants fifteen to twenty-five, and epiphytes five to twenty in a plot of 0.25 ha, based on ten plots of 0.25 ha each from typical forest sites (both WSRF and SRF forest types). The cumulative tree species/area (over 5 cm d.b.h.) curves from non-contiguous plots (some of them in the same forest patch or stand, but most of them in different patches) for each of the rain forest types are shown in Fig. 4. These curves tend to flatten at about 1 ha.

TABLE 5. Individual species in different tree strata of the mixed seasonal rain forest.

Plot	Area (ha)	Upper tree layer (>30 m height)			Middle tree layer (18–30 m height)			Lower tree layer (5–18 m height)			All trees (>5 m)
		N.I.	N.S.	I./S.	N.I.	N.S.	I./S.	N.I.	N.S.	I./S.	
94-1-3	0.25	34	18	1.9	84	35	2.4	76	27	2.8	3.4
94-1-2	0.25	31	14	2.2	48	28	1.7	29	21	1.4	3.7
931206	0.25	22	6	3.6	91	31	2.9	69	35	2.0	3.5
94-1-1	0.25	24	14	1.7	31	21	1.5	41	26	1.6	2.0
92-1	0.25	45	17	2.6	72	25	2.9	90	26	3.5	4.5
Total	1.25	156			326			305			
Average				2.4			2.3			2.3	3.4

* N.I., number of individuals; N.S., number of species; I./S., number of individuals per species.

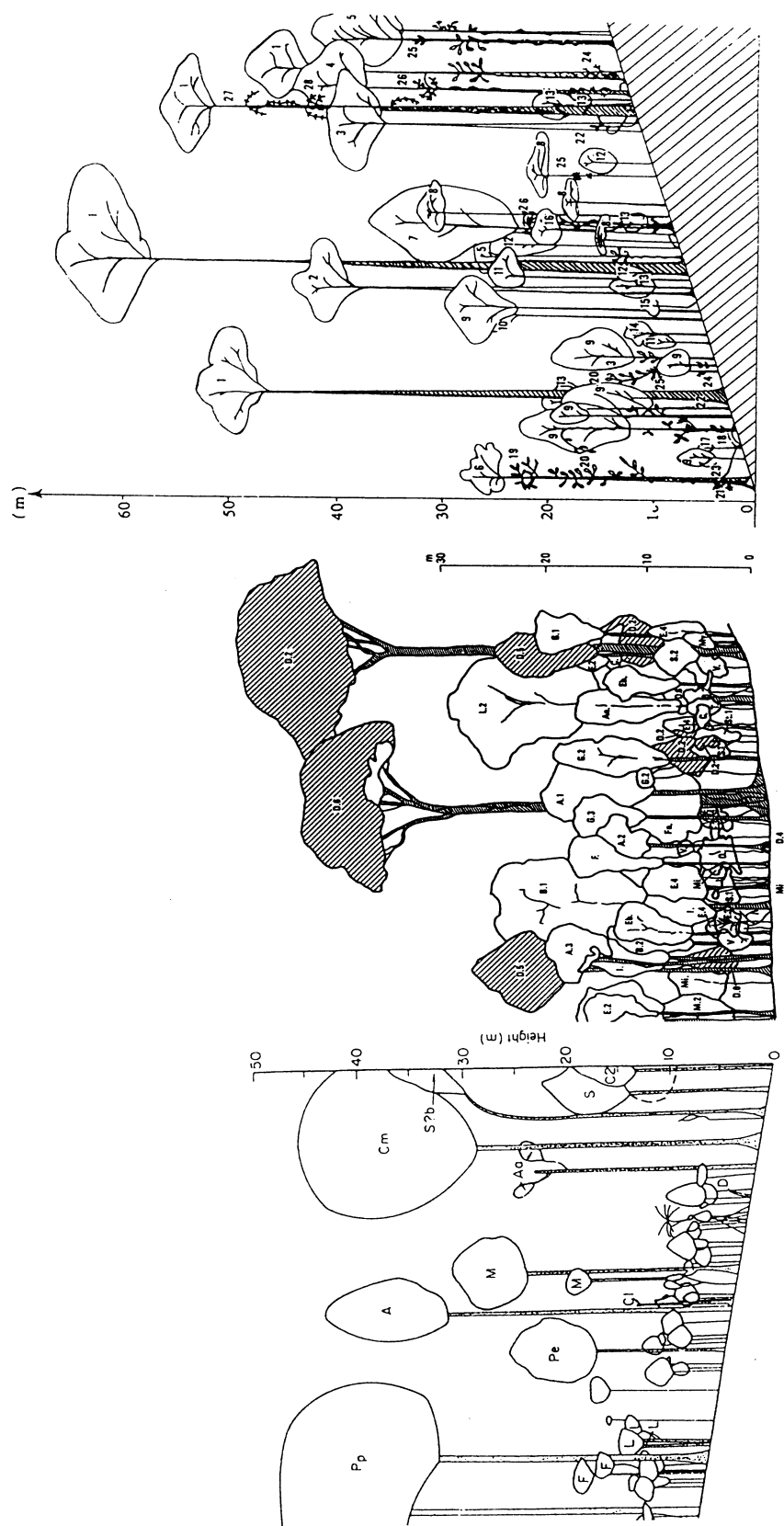


FIG. 6. Comparison of profile diagram between the tropical rain forest of south Yunnan and those in Malaysia. Left: rain forest in New Guinea, 600 m alt. (Pajmians, 1970, Fig. 5); middle: lowland rain forest in Brunei (Whitmore, 1975, Fig. 2.1); right: rain forest in south Yunnan, southwest China, 700 m altitude (Zhu, 1992b, Fig. 1).

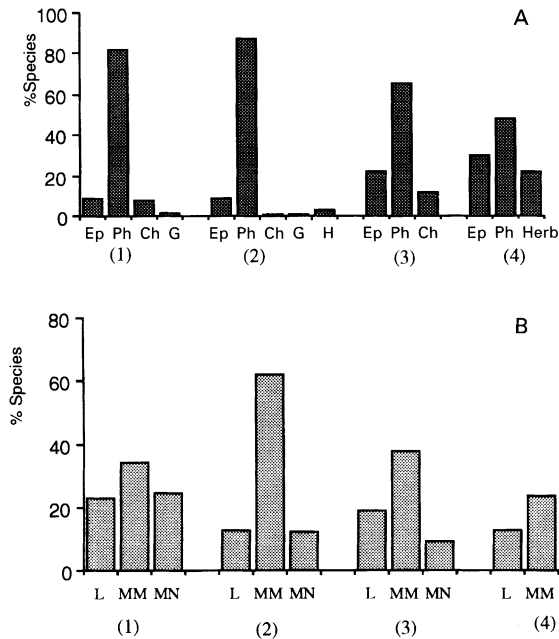


FIG. 7. Comparison of life form spectra. (A) For all vascular plant species in the communities; (B) For phanaerophytes of them. (1) Tropical seasonal rain forest, south Yunnan; (2) lowland rain forest, Brazil (Cain *et al.*, 1959); (3) Lowland rain forest, Guiana (Richards, 1952); (4) montane rain forest, west Java (Meijer, 1959). Ep, epiphyte; Ph, phanaerophyte; Ch, chamaephyte; H, hemicryptophyte; G, geophyte; L, liana; MM, mega and mesophanaerophyte; MN, micro and nanophanaerophyte.

This means the floristic composition of a forest type can be obtained from plots totalling 1 ha.

From five plots of the same size in mixed seasonal rain forest, the average ratio of individual/species is 2.4 for upper and middle layer trees, 3.4 for all trees over 5 cm d.b.h.

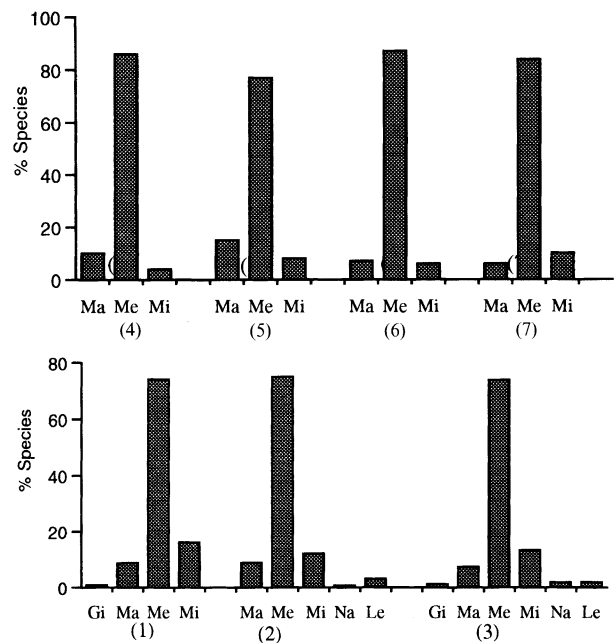


FIG. 8. Comparison of leaf size classes. (1) Tropical rain forest, south Yunnan; (2) equatorial rain forest, Mucambo para, Brazil; (3) rain forest, terra firme, Brazil; (4) dipterocarp forest, Philippines; (5) lowland rain forest, Borneo; (6) lower montane rain forest, Philippines; (7) wet evergreen forest, Nigeria. Gi, gigantophyll; Ma, macrophyll; Me, mesophyll (*sensu lato*); Na, nanophyll; Le, leptophyll. References: (2) & (3) Cain & Oliveira Castro (1959); (4), (6) & (7) Richards (1952); (5) Vareschi (1980).

(Table 5). In dipterocarp rain forest, the ratio is about 4 for upper and middle layer trees and 7.1 for all trees (from four plots). The frequency of tree species in plots is that 40–60% of species have only one individual each, 30–45% of species two to five individuals each, less than 15% of

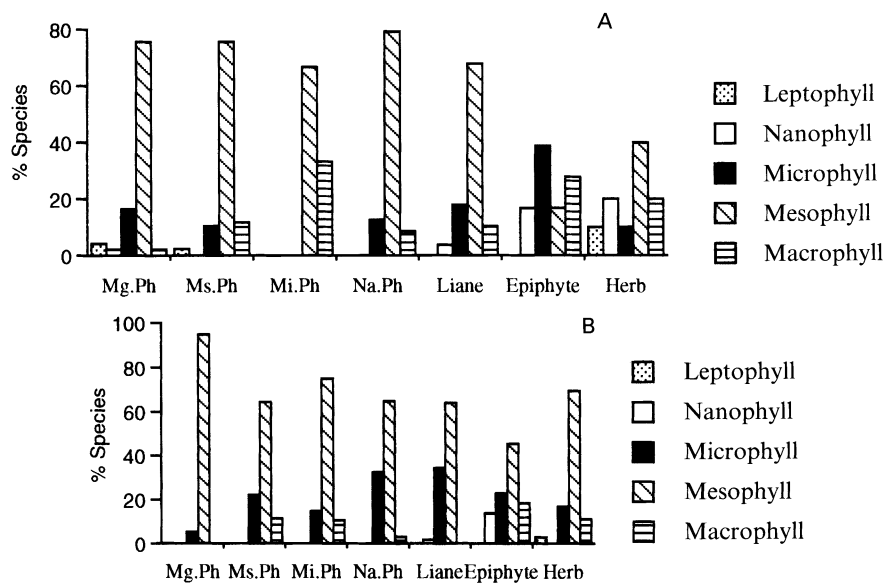


FIG. 9. Leaf size spectra in different life forms. (A) Equatorial rain forest, Brazil (Cain & Oliveira Castro 1959); (B) tropical rain forest, south Yunnan. Mg.Ph; mega-phanaerophyte; Ms.Ph, meso-phanaerophyte; Mi.Ph, micro-phanaerophyte; Na.Ph, nanophanaerophyte.

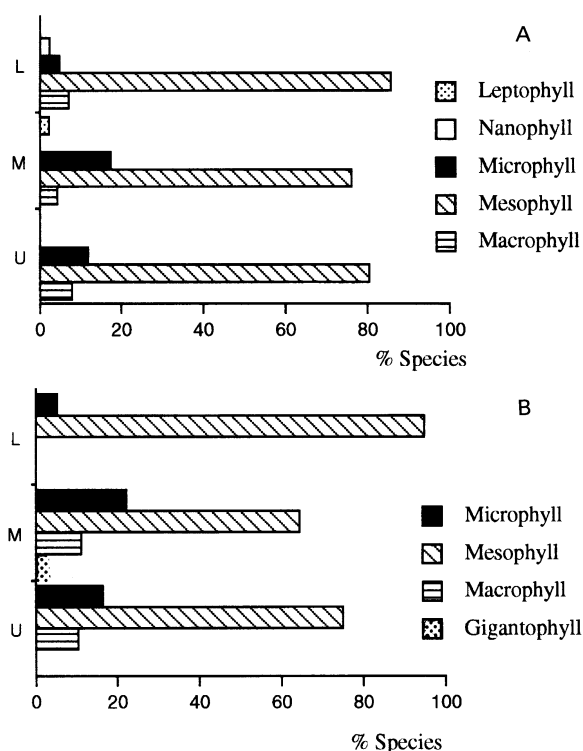


FIG. 10. Comparison of leaf size spectra in different tree layers. (A) Evergreen seasonal forest, Trinidad (Richards, 1952); (B) The seasonal rain forest, south Yunnan. U, upper tree layer; M, middle tree layer; L, lower tree layer.

species six to ten individuals each, and less than 10% of species have more than ten individuals each (Table 6). The distribution of d.b.h. classes was shown in Fig 5 in the example of the dipterocarp forest.

DISCUSSION

Comparison with lowland rain forests of equatorial area

Profiles

The use of rain forest profiles was emphasized in classifying rain forest types by Robbins (1968) and Richards (1983).

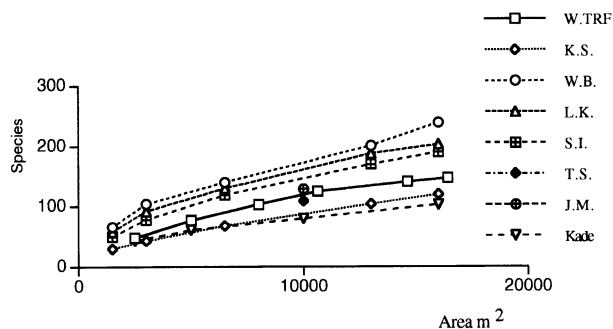


FIG. 11. Comparison of species-area curves, data for Ghana and Yunnan are from non-contiguous plots, for the others are from contiguous plots. W.TRF, wet seasonal rain forest, south Yunnan; K.S., Ketambe, Sumatra; W.B., Wanariset, Borneo; L.K., Lempake, Kalimantan; S.I., Sekundur, Indonesia; T.S., Toraut, Sulawesi; J.M., Jaro, Malaysia; Kade, Ghana. (W.TRF: trees over 5 cm d.b.h.; Others: over 10 cm d.b.h.). Ref.: K.S., W.B., L.K. and S.I. from Kartawinata (1990); T.S. and J.M. from Whitmore & Sidiyasa, (1986); Kade from Hall & Swaine (1981).

The rain forest of Yunnan, although occurring at relatively higher altitude and latitude, has almost the same profile as equatorial lowland rain forest (Fig. 6). Its canopy is constituted mainly of the second tree layer which has the biggest coverage. Its top tree layer of uneven discontinuous crowns of emergent trees is conspicuous.

Life form spectrum

The rain forest of Yunnan has also a similar life form spectrum to lowland rain forests (Fig. 7). It differs from the latter only in having more abundant woody lianas and fewer mega and mesophanaerophytes. Abundant lianas may be a characteristic of rain forest in monsoon climate. Fewer mega and mesophanaerophytes may be a result of the fact that it occurs at the climatic limit and shows some tendency toward subtropical and montane rain forests.

Leaf size

The tropical rain forest of Yunnan has a very similar leaf size spectrum to equatorial lowland rain forest (Fig. 8) and differs from the latter only in having a relatively higher percentage of microphylls. Furthermore, the comparison of leaf size spectra from different life forms (Fig. 9) shows that

TABLE 7. Comparison of compound leaves in several tropical rain forests.

Forest type	Megaphyll comp. %	Mesophyll comp. %	Microphyll comp. %	Nanophyll comp. %	All Ph comp. %
Seasonal rain forest, S. China	31.6	19.4	25.0	13.6	21.4
Dipterocarp forest, Philippines ¹	32	17	13	—	—
Tropical rain forest, Brazil ¹	37	27	—	14	27.9
Tropical rain forest, New Guinea ²	—	—	—	—	23.0

References: ¹Givnish (1978); ²Paijmans (1970).

TABLE 8. Comparison of number of individuals in different d.b.h. classes.

Forest type	Alt. (m)	Area (ha)	d.b.h. classes (cm)				
			>10	>20	>40	>50	>80
Dipterocarp forest, S China	700–900	1.04	660	254	95	62	22
Alluvial forest, Sarawak	50	1.0	615	197	52	26	8
Dipterocarp forest, Sarawak	200–250	1.0	778	327	101	57	8
Heath forest, Sarawak	170	1.0	708	269	73	45	13
Limestone forest, Sarawak	300	1.0	644	219	64	43	5
Lowland rain forest, Sulawesi	100	1.0	408	237	44	–	–
Tropical rain forest, New Guinea	600–1125	1.0	575	222	–	–	–
Montane rain forest, W Java	1450	1.0	283	162	80	59	13

References: Sarawak from Proctor, *et al.* (1983); Sulawesi from Whitmore & Sidiyasa (1986); New Guinea from Pajmans (1970); W Java from Meijer (1959).

TABLE 9. Comparison of number of individual/species in different d.b.h. classes.

Forest type	Altitude (m)	Area (ha)	No. of species (No. of individuals per species) d.b.h. classes (cm)			
			>10	>20	>35	>40
Dipterocarp forest, S China	800	1.04	116 (5.7)	97 (2.6)	40 (2.9)	33 (2.9)
Lowland rain forest, Sulawesi	100	1.0	109 (3.7)	72 (3.2)	43 (1.7)	26 (1.5)
Alluvial rain forest, Sarawak ²	50	1.0	223 (2.7)	–	–	–
Dipterocarp forest, Sarawak ²	200	1.0	213 (3.7)	–	–	–
Heath forest, Sarawak ²	170	1.0	123 (5.7)	–	–	–
Mixed rain forest, Guyana ³	200	1.5	91 (7.1)	55 (6.0)	–	32 (2.8)
Rain forest, Guyana ³		1.49	61 (7.1)	221 (5.8)	–	21 (2.9)
Mixed rain forest, Sarawak ³	150	1.5	–	98 (2.7)	–	32 (1.9)
Montane rain forest, W Java ⁴	1450	1.0	59 (4.8)	47 (3.6)	–	22 (3.6)
Tropical rain forest, Africa ³	550	1.0	52 (53.4)	33 (10.9)	–	11 (6.3)
Rain forest, Nigeria ¹		1.49	47 (8.3)	34 (6.3)	–	21 (2.2)

References: ¹Whitmore & Sidiyasa (1986); ²Proctor *et al.* (1983); ³Richards (1945); ⁴Meijer (1959).

the rain forest of Yunnan has less diversity of leaf size in each life form and more abundant microphylls in lianas, shrubs, and the trees of middle and small sizes. For example, in lowland rain forest of Brazil, megaphanaerophytes have five leaf sizes varying from leptophyll to megaphyll, while in the rain forest of Yunnan, megaphanaerophytes have only mesophyll and microphyll. This suggests that monsoon climate may have strong selection on physiognomy of rain forest. The rain forest of Yunnan is very close to evergreen seasonal forest of Trinidad in physiognomy. Both of them are affected by seasonal dryness. However, in the rain forest of Yunnan, microphylls make up a relatively higher percentage in each tree layer (Fig. 10). This suggests that the rain forest of Yunnan which occurs at relatively higher latitude and altitude, is affected not only by seasonal dryness of climate, but also by low temperature.

The percentage of compound leaves in the rain forest of Yunnan is slightly less than that in equatorial lowland rain forests (Table 7) despite the slightly seasonal climate. The suggestion by Givnish (1978) that compound leaves can be an adaptation to seasonal drought is not supported by these data from Yunnan.

Species/area, individual/species and d.b.h. classes

The rain forest of Yunnan has relatively lower number of species per area than typical lowland rain forests in southeast Asia, but higher than rain forest of Africa (Fig. 11).

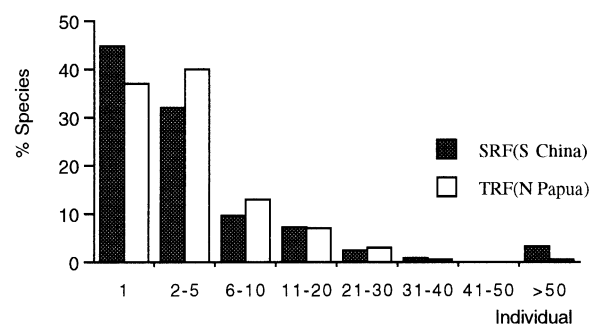


FIG. 12. Comparison of the number of individuals in each tree species between seasonal rain forest of Yunnan and lowland rain forest of Papua New Guinea. SRF: seasonal rain forest, south Yunnan; TRF, tropical rain forest, north Papua (from Pajmans, 1970).

TABLE 10. Geographic elements of tropical rain forest of southern Yunnan.

Geographic elements of genera	DRF* % gen.	SRF* % gen.	Geographic elements of species	DRF % sp.	SRF % sp.
1. Pantropic	19.6	25.3	1. Pantropic	—	0.3
2. Tropical Asia to Tropical America disjuncted	4.3	4.6	2. Tropical Asia & Tropical America disjuncted	—	0.3
3. Old World Tropic	14.0	13.7	3. Old World Tropic	0.3	0.6
4. Tropical Asia to Tropical Australia	9.2	10.2	4. Tropical Asia to Tropical Australia	2.9	3.2
5. Tropical Asia to Tropical Africa	4.8	7.3	5. Tropical Asia to Tropical Africa	—	2.2
6. Tropical Asia	42.3	33.2	6. Tropical Asia and its subtypes	(73.3)	(74.6)
7. N. Temperate	1.8	1.9	6.1. India–Malaysia	21.4	26.7
8. E Asia & N America disjuncted	1.8	1.5	6.2. Mainland SE Asia to Malaysia	7.5	8.3
9. Old World Temperate	0.3	—	6.3. S Asia to Mainland SE Asia	21.3	19.4
10. Mediterranean–W Asia to C Asia	0.3	—	6.4. Mainland SE Asia to S China	23.7	19.4
11. E Asia	0.3	1.5	7. S. China	8.2	10.1
12. Endemic to China	1.5	0.6	8. Endemic to Yunnan	15.4	8.6
Total	100	100	Total	100	100

*DRF: Dipterocarp rain forest (analysis based on 587 species of seed plant in about 800 ha); SFR: Seasonal rain forest (analysis based on 380 species of seed plant in about 10 ha). The Tropical is of geographical conception.

The density and frequency of the distributions of trees across the diameter classes of the rain forest are very similar to those of lowland rain forests of Malesia (Table 8). The number of individuals per species in different diameter classes of the rain forest is also close to those of lowland rain forests (Table 9). However, in bigger diameter classes, the number of species per unit area of the forest is not lower than those of lowland rain forests in Malesia. Furthermore, the numbers of individuals in each tree species of the seasonal rain forest is quite similar to that of lowland rain forest of Malesia (Fig. 12).

Biogeography

Geographic elements

Based on the distributions of genera of Chinese seed plants (Wu, 1991) and analysis of geographic elements of the tropical rain forest of Xishuangbanna (Zhu, 1993c, 1994b), twelve generic level and eight specific level distributional types (geographic elements) can be recognized from the rain forest of Yunnan (Table 10). At the generic level, the tropical distribution types (1–6) contribute about 94% of the total, while the temperate distribution types (7–11) contribute only 3–4%. At the specific level, the tropical Asian make up 73–75% of total species. The strictly tropical species make up 76–80%, and if the ones of tropical margin of south China are included, tropical species contribute more than 90% of the flora. Therefore, the flora of the Yunnan rain forest is undoubtedly tropical and part of the tropical Asian flora.

On the other hand, although tropical species dominate,

most of them have their northern limits of distribution here. Among the tropical families most of them range more or less beyond tropics, while only a small portion are strictly tropical and have their northern limits here (Fig. 13). Both groups have their centre of species diversity in Malesia.

It is also suggested from analysis of geographic elements that the region of south Yunnan is a geographical nexus. The Malesian element (making up about 30% of total species) from south, the one of south Asia or south Himalayas (making up about 20%) from west, the one of Indochina-south China (about 20%) from southeast and the one of China (c. 10%) from northeast, converge in the region.

Affinity to rain forests of tropical Asia

The rain forest of Yunnan has the same family composition and almost the same generic composition as rain forests in tropical Asia. It differs from the latter only in being somewhat less species rich in strictly tropical families and genera. In species richness, the top ten families of the forest are similar to the top ten families in rain forests of southeast Asia and most of them are at the same rank (Table 11). In importance, seven of the top ten families of the forest are in the top ten families of rain forests of southeast Asia too (Table 12). Compared with rain forests of southeast Asia, Elaeocarpaceae, Ulmaceae, Sapindaceae have relatively higher species richness per unit area and Ulmaceae, Combretaceae, Icacinaceae, Lauraceae, Meliaceae and Fagaceae show relatively higher importance in the rain forest of Yunnan; while more strictly tropical families, such as Dipterocarpaceae, Sapotaceae, Guttiferae, Palmae, Myristicaceae, Myrtaceae, Melastomataceae and

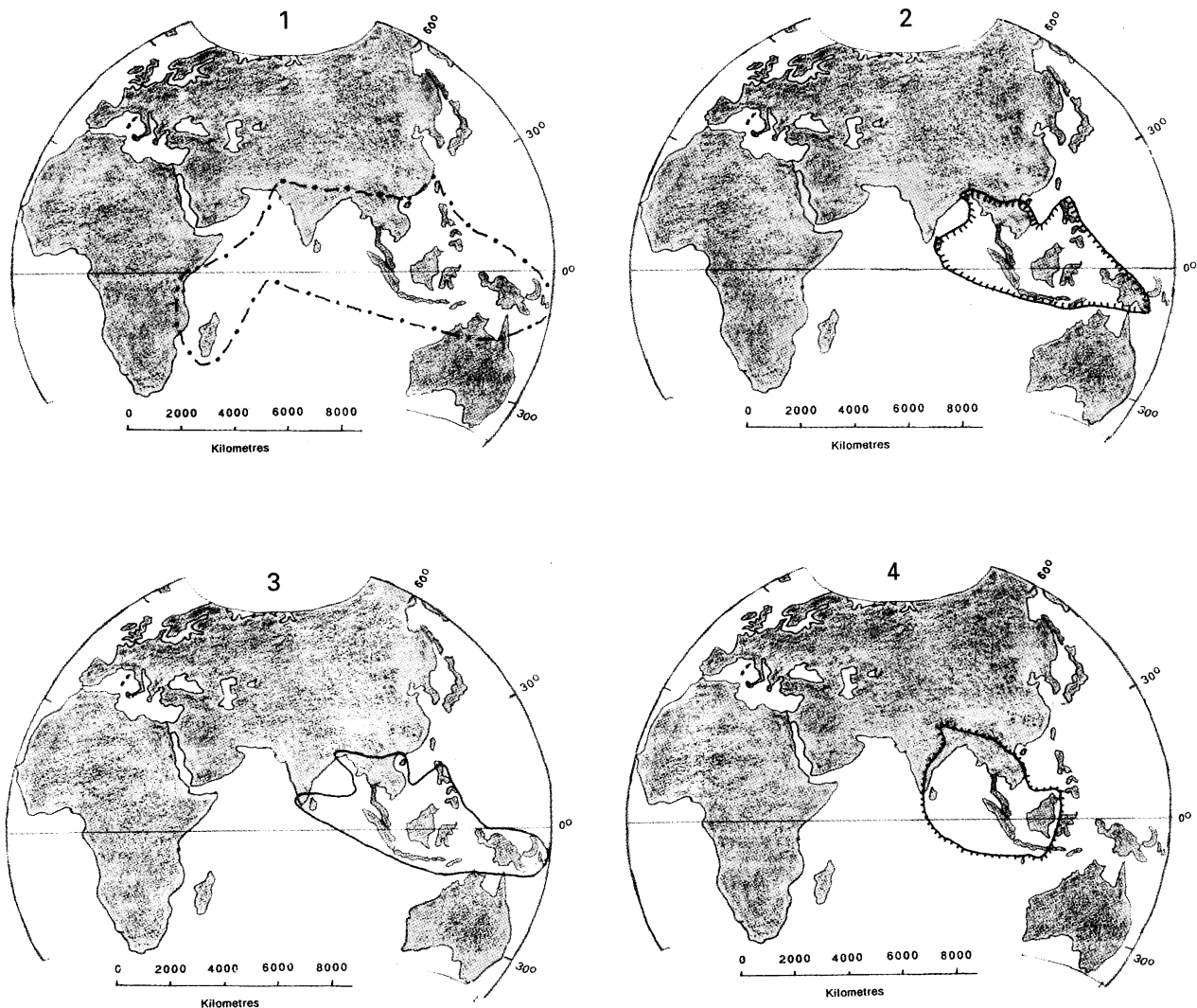


FIG. 13. Distribution of four tropical families. 1, Barringtoniaceae; 2, Crypteroniaceae; 3, Mastixiaceae; 4, Tetrameleaceae.

Anacardiaceae usually have higher species richness and importance in rain forests of southeast Asia.

CONCLUSION

The tropical rain forest in south Yunnan has almost the same forest profile, physiognomic characteristics, species richness per unit area, numbers of individual in each tree species and diameter classes of trees as equatorial lowland rain forests. It is undoubtedly a type of true tropical rain forest. This was also confirmed by Whitmore after his short visit to the region (1982, 1984). As the tropical rain forest of Yunnan occurs at the extreme condition of rainfall and temperature usually required by tropical rain forest, it differs slightly from lowland rain forests in equatorial areas in having some deciduous trees in the canopy layer, fewer megaphanerophytes and epiphytes but more abundant lianas as well as more microphylls. It is considered that these differences are a result of the slight seasonal dryness

as well as the relatively low temperature found at this relatively high latitude and altitude.

In its floristic composition, about 80% of total families, 94% of total genera and more than 90% of total species are tropical, of which about 38% of genera and 74% of species are tropical Asian. Furthermore, the rain forest of Yunnan has not only almost the same families and genera, but also the same top ten families, both in species richness and importance of stems, as some lowland rain forests in southeast Asia. It is indisputable that the flora of the rain forest is tropical and part of tropical Asian flora. However, in Yunnan at the margin of tropics, most of the tropical families and genera of the flora are at their northern limits of distribution and most have their centre of species diversity in Malesia. More strictly tropical families and genera show relatively lower species richness and importance in the Yunnan rain forest compared with southeast Asia. Thus, the flora has characteristics of the tropical Asian flora at the northern limit.

TABLE 11. The top ten families from rain forests of Yunnan and their status in rain forests of South East Asia with reference to their number of species and rank.

Forest type	WSRF (MRF)	WSRF (DRF)	SRF	T.S.	W.B.	L.B.	K.S.	B.T.S.	H.M.
Area (ha)	1.46	1.04	1.25	1.0	1.6	1.6	1.6	3.2	0.5
Name of family	spp. (rank)	spp. (rank)	spp. (rank)	spp. (rank)	spp. (rank)	spp. (rank)	spp. (rank)	spp. (rank)	spp. (rank)
Euphorbiaceae	13 (1)	9 (3)	13 (1)	6 (4)	26 (1)	32 (1)	25 (1)	22 (1)	3 (6)
Lauraceae	13 (1)	14 (1)	12 (2)	12 (1)	14 (2)	18 (3)	11 (2)	13 (2)	7 (3)
Moraceae	13 (1)	10 (2)	7 (4)	6 (4)	8 (8)	5 (9)	10 (3)	6 (13)	1 (15)
Meliaceae	9 (4)	9 (3)	10 (3)	6 (4)	13 (4)	13 (5)	8 (4)	5 (16)	2 (10)
Annonaceae	8 (5)	4 (6)	6 (5)	3 (11)	8 (8)	22 (2)	5 (7)	10 (7)	1 (15)
Fagaceae	5 (7)	7 (5)	2 (*)	*	*	*	*	6 (13)	2 (10)
Myristicaceae	4 (9)	4 (6)	5 (8)	5 (7)	12 (5)	10 (7)	6 (5)	7 (10)	5 (5)
Sapindaceae	3 (12)	3 (9)	6 (5)	*	*	*	*	7 (10)	2 (10)
Ebenaceae	3 (12)	4 (6)	2 (*)	5 (7)	*	*	*	4 (18)	1 (15)
Rubiaceae	4 (9)	3 (9)	6 (5)	1 (17)	8 (8)	15 (4)	5 (7)	7 (10)	3 (6)
Elaeocarpaceae	4 (9)	3 (9)	*	*	*	*	*	4 (18)	1 (15)
Ulmaceae	5 (7)	2 (14)	4 (10)	*	*	*	*	2 (11)	1 (15)
Burseraceae	2 (*)	3 (9)	3 (11)	11 (7)	9 (8)	4 (9)	13 (2)	6 (4)	
Guttiferae	3 (12)	3 (9)	2 (*)	10 (2)	*	*	*	8 (8)	9 (2)
Anacardiaceae	6 (6)	2 (14)	3 (12)	7 (3)	*	*	*	6 (7)	3 (6)
Myrtaceae	2 (*)	2 (14)	5 (8)	*	*	*	*	13 (2)	11 (1)

*Rank <20.

H.M., Halmahera, Moluccas (Whitmore, Sidiyasa & Whitmore, 1987). T.S., Toraut, Sulawesi; W.B., Wanariset, Borneo; L.B., Lempake, Borneo; K.S., Ketambe, Sumatra (Whitmore & Sidiyasa, 1986). B.T.S., Bukit Timah, Singapore (Wong, 1987). WSRF (MRF), Wet seasonal rain forest (subtype mixed rain forest); WSRF (DRF), wet seasonal rain forest (subtype Dipterocarp rain forest); SRF, seasonal rain forest.

TABLE 12. The top ten dominant families from two rain forest types of Yunnan and their status in rain forests of South East Asia with reference to their importance and rank.

Forest type	MRF IVI (rank)	DRF IVI (rank)	H.M. Stems % (rank)	B.T.S. Stems % (rank)	A.F.S1 B.A. % (rank)	A.F.S2 B.A. % (rank)	D.F.S. B.A. % (rank)	H.S. B.A. % (rank)
Dipterocarpaceae	—	68.2 (1)	2.7 (8)	14.1 (1)	13.0 (1)	11.5 (2)	43.2 (1)	42.9 (1)
Euphorbiaceae	30.5 (1)	24.2 (3)	8.4 (3)	7.8 (3)	8.9 (3)	10.8 (3)	2.9 (6)	3.0 (5)
Lauraceae	26.2 (2)	25.6 (2)	8.4 (3)	2.9 (12)	5.5 (5)	8.6 (5)	2.6 (7)	1.5 (12)
Sapindaceae	23.5 (3)	15.9 (4)	1.3 (12)	1.1 (19)	1.3 (16)	2.5 (11)	0.6 (13)	0.2 (17)
Moraceae	22.7 (4)	15.3 (6)	*	5.5 (6)	*	*	*	*
Meliaceae	11.9 (7)	15.4 (5)	0.8 (17)	1.2 (17)	2.1 (13)	4.2 (9)	*	0.1 (18)
Ulmaceae	17.4 (6)	3.4 (17)	*	1.4 (16)	*	*	*	*
Fagaceae	2.2 (*)	14.4 (7)	6.2 (6)	1.1 (19)	1.7 (15)	2.0 (12)	2.6 (7)	0.9 (14)
Guttiferae	9.3 (11)	14.4 (8)	28 (1)	2.1 (15)	5.2 (6)	5.4 (7)	2.2 (1)	17.0 (2)
Annonaceae	19.6 (5)	7.0 (12)	*	2.2 (14)	2.0 (14)	1.3 (14)	0.5 (14)	2.6 (7)
Myristicaceae	11.0 (8)	9.7 (10)	4.9 (7)	*	2.7 (10)	1.9 (13)	2.4 (9)	1.1 (13)
Icacinaeae	2.9 (20)	14 (9)	*	*	*	*	*	*
Combretaceae	9.8 (9)	2.1 (*)	*	*	—	—	—	—
Anacardiaceae	9.7 (10)	4.1 (16)	0.8 (18)	6.5 (4)	4.2 (9)	4.0 (9)	1.5 (12)	2.1 (8)

*Rank <20.

MRF, Mixed rain forest, south Yunnan; DRF, Dipterocarp rain forest, south Yunnan; H.M., Halmahera Moluccas (Whitmore, 1987). B.T.S., Bukit Timah, Singapore (Wong, 1987). A.F.S1, Alluvial forest, Sarawak; A.F.S2, Alluvial forest, Sarawak; D.F.S., Dipterocarp forest, Sarawak; H.F.S., Heath forest, Sarawak (Proctor *et al.*, 1983). IVI=Importance Value Index (see Table 2).

From analysis of geographic elements it can also be seen that the flora of the tropical rain forest of Yunnan came mainly from four sources, i.e. Malesia, south Himalayas, Indochina and China.

The rain forest of Yunnan, in terms of physiognomy and structure, is similar to: Evergreen seasonal forest of tropical America of Beard (1944, 1955) which was reclassified by

Richards (1952) as a subformation of tropical rain forest; or the Moist Evergreen type of African tropical rain forest of Hall & Swaine (1976, 1981); or Mesophyll Vine Forest of Australian rain forest of Webb (1959); as well as Semi-evergreen rain forest of Walter (1971) etc. However, it is most equivalent to Semi-evergreen rain forests of SE Asia of Whitmore (1975, 1984). Since the rain forest occurs at

the latitudinal and altitudinal limits of tropical rain forest and has a clear change of physiognomy between different seasons, Chinese botanists prefer the term tropical seasonal rain forest (Wu, 1980; Liu, 1987; Zhu, 1996), which nonetheless belongs to the tropical rain forest formation of SE Asia and is a type of semi-evergreen rain forest from the northern edge of the tropical zone.

The tropical rain forest of Yunnan though surprisingly far from the equator and at a high altitude is not the northern-most type of tropical rain forest because tropical rain forest was recorded in northern Burma at about 27°30' N latitude (Kingdon-Ward, 1945). However, the tropical rain forest is still of high scientific significance not only for the biogeography and ecology of rain forests but also for floristic relationships between tropical South East Asia and subtropical China as well as the South East Himalayas. It is unfortunate that the tropical rain forest of the region is still little known (and not shown in maps of tropical rain forest of the world) and facing extinction.

ACKNOWLEDGMENTS

This project was partly funded by the Chinese Academy of Sciences and The National Foundation for Natural Science of China. I thank Mr Wang Hong and Mr Li Bao-gui for much help with field work, Professor Xu Ziafu, director of Xishuangbanna Tropical Botanical Garden for his great help with my research and Professor Wu Zheng-yi and Professor Li Hen who are my academic advisors. I also wish to acknowledge the Department of Plant Sciences, University of Cambridge and especially the Ecology Group in the Department for help of various kinds. I particularly thank Dr E. Tanner and Dr P. Grubb for their great assistance in analysing my data and writing this paper during a visiting scholar year at the University of Cambridge. Finally I particularly thank Dr T. C. Whitmore who has greatly supported and helped me in my research.

REFERENCES

- Audley-Charles, M.G. (1987) Dispersal of Gondwanaland: relevance to evolution of the angiosperms. *Biogeographical evolution of the Malay Archipelago* (ed. by T.C. Whitmore), pp. 5–21. Clarendon Press, Oxford.
- Beard, J.S. (1944) Climax vegetation in tropical America. *Ecology*, **25**, 127–158.
- Beard, J.S. (1955) The classification of tropical American vegetation types. *Ecology*, **36**, 359–412.
- Braun-Blanquet, J. (1932) *Plant sociology*, pp. 52–58. McGraw, London.
- Cain, S.A. & Oliveira Castro, G.M. (1959) *Manual of vegetation analysis*, pp. 255–284.
- Drees, E.M. (1954) The minimum area in tropical rainforest with special reference to some types in Bangka (Indonesia). *Vegetatio*, **5–6**, 517–523.
- Givnish, T.J. (1978) *Tropical trees as living systems* (ed. by P. B. Tomlinson and M. H. Zimmerman), pp. 351–380. Cambridge University Press, Cambridge.
- Hall, J.B. & Swaine, M.D. (1976) Classification and ecology of closed-canopy forest in Ghana. *J. Ecol.* **64**, 913–953.
- Hall, J.B. & Swaine, M.D. (1981) Distribution and ecology of vascular plant in a tropical rain forest – Forest vegetation in Ghana. *Geobotany*, **1**, (ed. by M.J.A. Werger, Dr W. Junk, The Hague).
- Kartawinata, K. (1990) A review of natural vegetation studies in Malesia with special reference to Indonesia. *The plant diversity of Malesia* (ed. by P. Baas, K. Kalkman and R. Geesink), pp. 121–132. Kluwer Academic, Dordrecht.
- Kingdon-Ward, F. (1945) A sketch of the botany and geography of north Burma. *J. Bombay Nat. Hist. Soc.* **45**, 16–30.
- Liu, L.H. (1987) Rain forest. *Vegetation of Yunnan* (ed. by C.Y. Wu), pp. 97–134. Science Press (in Chinese), Beijing.
- Meijer, W. (1959) Plant sociological analysis of montane rain forest near Tjibodas, West Java. *Acta Bot. Neerl.* **8**, 277–291.
- Paijmans, K. (1970) An analysis of four tropical rain forest sites in New Guinea. *J. Ecol.* **58**, 77–101.
- Proctor, J., Anderson, J.M., Chai, P. & Vallack, H.W. (1983) Ecological studies in four contrasting rain forests in Gunung Mulu National Park, Sarawak. I. Forest environment, structure and floristics. *J. Ecol.* **71**, 237–360.
- Raunkiaer, C. (1934) *The life forms of plants and statistical plant geography*. Oxford University Press, Oxford.
- Richards, P.W. (1945) The floristic composition of primary tropical rain forest. *Biol. Rev. Camb. Philos. Soc.* **20**, 1–13.
- Richards, P.W. (1952) *The tropical rain forest* Cambridge University Press, Cambridge.
- Richards, P.W. (1983) The tree dimensional structure of tropical rain forest. *Tropical rain forest: ecology and management* (ed. by S.L. de Sutto), pp. 3–10. Blackwell Scientific Publications, Oxford.
- Robbins, R.G. (1968) The biogeography of tropical rain forest in SE Asia. *Proc. Symp. Recent. Adv. Trop. Ecol.*, **1968**, 531–535.
- Schimper, A.F.W. (1903) *Plant-geography upon a physiological basis*. Oxford University Press, Oxford.
- Vareschi, V. (1980) *Vegetationsökologie der tropen* pp. 141–148.
- Walter, H. (1971) *Ecology of tropical and subtropical vegetation* pp. 207–236. Oliver & Boyd, Edinburgh.
- Webb, L.J. (1959) A physiognomic classification of Australian rain forests. *J. Ecol.* **47**, 551–570.
- Whitmore, T.C. (1975) *Tropical rain forests of the Far East*. Clarendon Press, Oxford.
- Whitmore, T.C. (1982) Fleeting impressions of some Chinese rain forests. *Commonw. For. Rev.* **61**, 51–58.
- Whitmore, T.C. (1984) *Tropical rain forests of the far east* 2nd. edn., Clarendon Press, Oxford.
- Whitmore, T.C. & Sidiyasa, K. (1986) Composition and structure of a lowland rainforest at Toraut, northern Sulawesi. *Kew Bull.* **41**, 747–755.
- Whitmore, T.C. Sidiyasa K. & Whitmore, T.J. (1987) Tree species Enumeration of 0.5 hectare on Halmahera. *Gard. Bull. Sing.* **40**, 31–34.
- Wong, Y.K. (1987) Ecology of the trees of Bukit Timah Nature Reserve. *Gard. Bull. Sing.* **40**, 45–76.
- Wu, C.Y. (1980) *Vegetation of China*, pp. 363–379. Beijing Science Press (in Chinese), Beijing.
- Wu, C.Y. (1991) The areal-types of Chinese genera of seed plants. *Acta Bot. Yunn. Supp.* **IV**.
- Zhu, H. (1992a) Research of community ecology on Shorea chinensis forest in Xishuangbanna. *Acta Bot. Yunn.* **14**, 237–258. (in Chinese with English abstract).
- Zhu, H. (1992b) Tropical rain forest vegetation in Xishuangbanna. *Chinese Geogr. Sci.* **2**, 64–73.
- Zhu, H. (1993a) A comparative study of phytosociology between Shorea chinensis forest of Xishuangbanna and other closer forest types. *Acta Bot. Yunn.* **15**, 34–46 (in Chinese with English abstract).

- Zhu, H. (1993b) A phytocoenological study on Vatica forest in Xishuangbanna. *Guihaia*, **13**, 48–60 (in Chinese with English abstract).
- Zhu, H. (1993c) Floristic plant geography on the dipterocarp forest of Xishuangbanna. *Acta Bot. Yunn.* **15**, 233–253 (in Chinese with English abstract).
- Zhu, H. (1994a) Floristic relationships between dipterocarp forest of Xishuangbanna and forests of tropical Asia and S China. *Acta Bot. Yunn.* **16**, 97–106 (in Chinese with English abstract).
- Zhu, H. (1994b) The floristic characteristics of the tropical rain forest in Xishuangbanna. *Chinese Geogr. Sci.* **4**, 174–185.