STAND STRUCTURE, WOODY SPECIES RICHNESS AND COMPOSITION OF SUBTROPICAL KARST FORESTS IN MAOLAN, SOUTH-WEST CHINA

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ZHANG ZH, HU G, ZHU JD & NI J. 2012. Stand structure, woody species richness and composition of subtropical karst forests in Maolan, south-west China. Natural karst forests have long been degraded due to human disturbances in mountainous regions of south-west China. We analysed the woody species diversity, floristic composition and stand structure of subtropical karst forests in Maolan, Guizhou Province of south-western China. A census of all woody species with diameter at breast height ≥ 1 cm in two 1-ha plots was made. A total of 8138 individuals belonging to 278 species, 167 genera and 69 families were recorded in the two plots. The most ecologically significant families as determined by stem density were Lauraceae, Fagaceae and Juglandaceae. The tree species *Platycarya longipes* (Juglandaceae) was the most dominant species in Dongge plot and *Castanopsis carlesii* var. *spinulosa* (Fagaceae), in Gengzheng plot. Total basal area was 42.22 m^2 in the two plots, ranging from 18.60 to 23.62 m^2 per plot. Forest structure was characterised by a large number of saplings. Compared with subtropical non-karst forests in China and karst forests in the tropics, the Maolan karst forest had higher species diversity with different tree species compositions. This study improved our understanding of the species diversity, community structure and functions of karst forests in subtropical Asia.

Keywords: Limestone forest, rocky desertification, vegetation restoration, size class, stem density

ZHANG ZH, HU G, ZHU JD & NI J. 2012. Struktur dirian, kekayaan spesies berkayu dan komposisi hutan kars subtropika di Maolan, barat daya China. Hutan kars asli telah lama dinyah gred di kawasan bergunung-ganang di barat daya China akibat gangguan manusia. Kami menganalisis kepelbagaian spesies berkayu, komposisi flora dan struktur dirian hutan kars subtropika di Maolan, wilayah Guizhou di barat daya China. Banci dijalankan ke atas semua spesies berkayu yang mempunyai diameter aras dada ≥ 1 cm di dua plot yang luasnya masing-masing 1 ha. Sebanyak 8138 individu daripada 278 spesies, 167 genus dan 69 famili dicerap di kedua-dua plot. Famili yang paling signifikan dari segi ekologi berdasarkan kepadatan batang ialah Lauraceae, Fagaceae dan Juglandaceae. *Platycarya longipes* (Juglandaceae) merupakan spesies yang paling dominan di plot Dongge manakala *Castanopsis carlesic* var. *spinulosa* (Fagaceae) di plot Gengzheng. Jumlah luas pangkal ialah 42.22 m^2 di kedua-dua plot dengan julat antara 18.60 m^2/plot hingga 23.62 m^2/plot. Struktur hutan dicirikan oleh anak benih yang banyak. Hutan kars Maolan mempunyai kepelbagaian spesies yang lebih tinggi dengan komposisi spesies pokok yang berlainan berbanding dengan hutan bukan kars subtropika di China dan hutan kars tropika. Kajian ini menambah baik pemahaman kita tentang kepelbagaian spesies, struktur komuniti dan fungsi hutan kars di Asia subtropika.

INTRODUCTION

Karst is a distinctive topography created by rainfall and groundwater acting on carbonate bedrock such as limestone dolomite or marble (He et al. 2008). The karst landscape is distributed all over the world, occupying 22 million km^2 and accounting for 15% of the world land area (Yuan 1991). China has the largest and widest karst area in the world, which is mainly distributed in mountainous regions of south-western (SW) China (Li et al. 2002). Among them, Guizhou Province has the largest and most unique karst terrain dominated by limestone substrata.

Soils in karst terrain are typically shallow and experience strong seasonal drought and rapid drainage. They have high levels of calcium and magnesium, relatively high pH and organic

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matter content compared with other subtropical and tropical soils (Crowther 1987, Zhou 1987). The karst terrain has steep and irregular ground surface with frequent rock outcrops, and thin and less continuous soil cover, forming a complex mosaic of heterogeneous habitats (Crowther 1987). Due to the edaphic condition and changing topography, the vegetation on limestone is extremely diverse and rich in endemic taxa. However, few studies have investigated in detail the original subtropical forests on limestone bedrock partly due to the difficultly of working in karst terrain (Han et al. 2010, Song et al. 2010, Zhang et al. 2010). Given that tree species diversity is fundamental to forest biodiversity, inventory and monitoring of tree diversity and forest structure are key prerequisites for understanding and managing the world's forest ecosystems (Noss 1990, Novotny et al. 2006), especially the less investigated subtropical karst forests.

Karst forests in SW China play very important roles in maintaining regional and local ecosystem service including water and soil conservation (Ran et al. 2002), provision of important animal and wildlife habitats, maintenance of biological diversity (Zhou 1987) and development of ecotourism (Su et al. 2001). However, karst forests are more vulnerable to environmental changes due to the relatively dry, fragmentised habitat and shallow soils which sometimes are irreversible once damaged (Tuyet 2001). Many areas of SW China have been degraded under different kinds of human disturbances such as agriculture firewood production and livestock overgrazing (Zhu 2002b, Brewer et al. 2003). The rocky desertification, a desert-like landscape covered by rocks, often happens in this area after karst forest degradation. Thus, more attention is needed on the research and conservation of karst forests in SW China.

Natural karst forests are scare in the world because of long human impacts (Brewer et al. 2003). The last undisturbed remnant of original karst forests in China (or even in the world), the mixed evergreen deciduous broadleaved forest, is mainly located in Maolan National Natural Reserve in southern Guizhou Province. Maolan has unique geographical location (northern edge of mid-subtropical region), climatic condition (mid-subtropical moist monsoon climate) and geological factor (typical karst landscape consisting of pure limestone and dolomite rocks). This makes the mixed evergreen and deciduous forest the only zonal vegetation in subtropical China where evergreen broadleaved forests are broadly distributed (Long & Yu 2008). This forest has specific habitat, complex community structure and rich biodiversity (Zhang et al. 2010). There are over 1200 vascular species in Maolan, comprising approximately 4% of China's total plant diversity (Lan et al. 2009). Compared with subtropical forests in non-limestone soils in China (e.g. Zhu et al. 2008, Yang et al. 2011), we know little of the vegetation structure and functions of original subtropical karst forests. What are the unique features of mixed forest in karst terrain? Are they different from pure evergreen non-karst forests in stand structure and species composition? What are the reasons leading to such differences?

In this paper we analyse the community structure and composition of karst forests in Maolan. The aims of this study were to: (1) assess the species richness, taxonomic composition and stand structure of the subtropical karst forests and (2) compare the subtropical karst forest of Maolan with other karst forests and non-karst forests in subtropical and tropical regions. This study will provide a botanical reference for future ecological research and conservation efforts of karst forests in subtropical Asia.

MATERIALS AND METHODS

Study area

The Maolan National Nature Reserve (25° 09' –25° 20' N, 107° 52'–108 °05 ' E) is located in Libo County of southern Guizhou Province in SW China. It joined the World Biosphere Reserve Network under the UNESCO Man and the Biosphere Programme in 1996. The total area of this reserve is about 20,000 ha, with altitude ranging from 430 to 1078.6 m. The karst geomorphology is composed mainly of pure limestone and dolomite rocks, forming a typical outcrop karst type called the typical karst habitat. Mean temperature ranges from 8.3 °C in January to 26.4 °C in July with an annual mean of 15.3 °C. Average annual precipitation is 1320.5 mm and the annual evaporation is 1343.6 mm. The annual mean relative humidity is 83%. The shallow black limestone soil has low water-holding capacity but is rich in organic matter and nutrients (N, P, K and Ca).

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Field sampling

In July 2008, two 1-ha (100 m × 100 m) permanent plots were established in the core zone of Maolan National Nature Reserve. The first plot is located in the Dongge site (25° 18' N, 107° 57' E; altitude 876 m). This plot was established on a steep south-east-facing slope from valley bottom to hill top covered by thin soil and more bare rocks. The second plot was located on the top of another low mountain at the Gengzheng site (25° 18' N, 107° 57' E; altitude 915 m), with relatively thick soil and less outcrop rock. Detailed information of the two plots can be found in Zhang et al. (2010). Forests in these two plots have less human disturbances and are representatives of subtropical karst forests in Maolan according to field surveys. Using a compass, each plot was divided into 100 contiguous 10 m × 10 m subplots as workable units. All free-standing woody plants in the plot with diameter at breast height (dbh) ≥ 1 cm were investigated. The species names, relative location of each individual, dbh and height within each subplot were recorded. Nomenclature followed the Editorial Board for Flora of Guizhou (1982).

Data analysis

The basal area, relative density, relative frequency, relative dominance and importance value index were quantified following Curtis and Cottam (1962). In addition, family relative diversity, relative density, relative dominance and family importance value were calculated according to Mori et al. (1983). To determine species richness, the lists of woody species registered for each subplot were pooled together. The Shannon–Winner index (H') and Simpson index (D) for species diversity were calculated according to $H' = -\sum p_i \log p_i, D = 1 - \sum p_i^2$ where p_i is the proportion of importance value of the i^{th} species ($p_i = n_i / N$, n_i is the importance value index of i^{th} species and N is the importance value index of all species) (Magurran 1988). The Pielou evenness index was calculated according to the formula $E = H'/\ln S$ where S is the total number of species (Magurran 1988). The Student's t-test (Waite 2000) was used to test significant difference of the indices between the two plots. Similarity between two plots was assessed using the Jaccard's coefficient of similarity and the Sørenson index of similarity (Small et al. 2004). A species–area curve of each 1-ha plot was calculated by the sequence of combining and expanding sample as nest-shape. The frequency distribution of stem density in various size classes in two plots was compared using Kolmogorov–Smirnov one-sample test (Zar 1999). The rank abundance curve was obtained by plotting the logarithm of the relative abundance of species against the species rank (Magurran 2004).

RESULTS

Species richness

A total of 8138 stems were recorded across the two plots of subtropical karst forest in Maolan (Table 1). They represented 278 woody species in 167 genera and 69 families. The Dongge plot had 199 species in 140 genera and 63 families. The numbers of the free-standing woody species in 10 m × 10 m subplots ranged from 10 to 32, with an average of 21 species (results not shown). In the Gengzheng plot, 191 species were found and species numbers in all 10 m × 10 m subplots were between 8 and 33, with an average of 19 species (results not shown) ($p < 0.05$). The Shannon–Weiner index and Pielou's evenness index values were slightly greater in Gengzheng than Dongge but insignificant ($p > 0.05$). However, they both had the same Simpson index value.

Table 1 Tree species richness and floristic diversity in two 1-ha plots of subtropical karst forest in Maolan, SW China

Plot	Stem (dbh ≥ 1cm)	Basal area (m^2)	Species	Genus	Family	H'	D	E
Dongge	4281	18.60	199	140	63	4.11	0.98	0.77
Gengzheng	3857	23.62	191	121	58	4.15	0.98	0.79
Total	8138	42.22	278	167	69	–	–	–

dbh = Diameter at breast height; H' = Shannon–Wiener index; D = Simpson index; E = Pielou's evenness index

The number of species for each plot showed a relatively sharp increase initially with increasing area. Then the increasing trend became slow and stable. Species–area curves revealed that species increment was similar for both plots and the curves approached an asymptote at 0.4 ha (Figure 1).

The Sørenson and Jaccard's coefficient indices revealed high similarities between the Dongge and Gengzheng plots at the family level, moderate at the genus level and lowest at the species level (Table 2). Both plots had 52 families, 95 genera and 101 species overlapping.

Stand structure and floristic composition

The population structure of the two forest stands was reverse J-shaped (Figure 2). A comparison of size-class distribution of species density across two plots did not show significant variation $p > 0.05$). The number of individuals per 0.01 ha subplot ranged from 20 to 76, with an average of 43 individuals in the Dongge plot (results not shown). It ranged from 12 to 94 and the average was 38 individuals in Gengzheng plot (results not shown) ($p < 0.05$). However, total volume

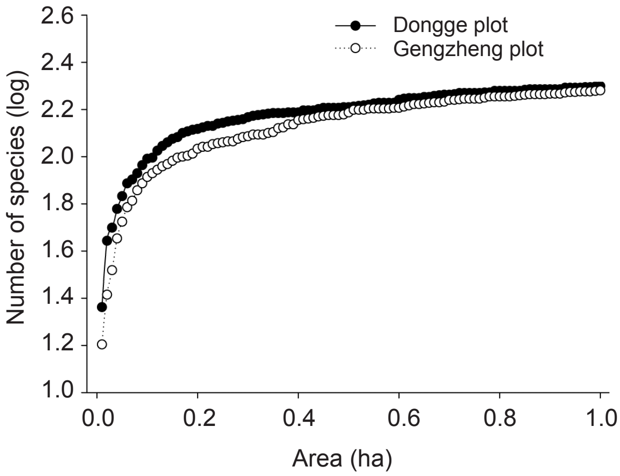

Figure 1 Species–area curves for two subtropical karst forest plots in Maolan, SW China

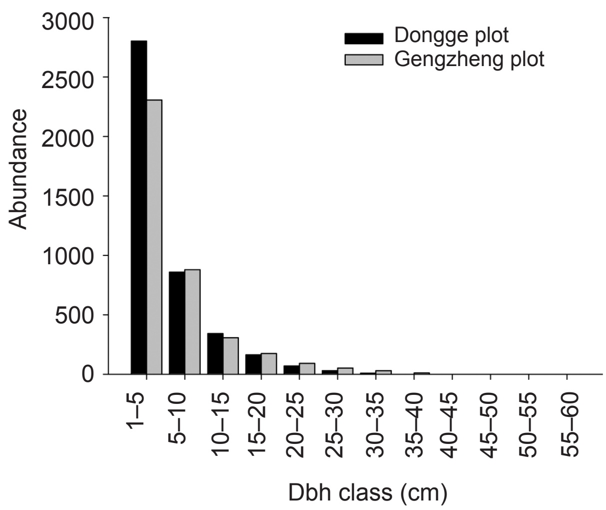

Figure 2 Diameter class distribution of woody species for two subtropical karst forest plots in Maolan

in the Gengzheng plot was greater (basal area 23.62 m^2) than the Dongge plot (basal area 18.60 m^2) ($p < 0.01$). More than 82% individuals had stems with dbh < 10 cm in the two plots. Individuals with dbh > 40 cm were rare (Figure 2). The rank–abundance curves of two plots displayed similar distribution patterns (Figure 3). Single individual species accounted for 21% (Gengzheng plot) to 28% (Dongge plot) of the total number of species. A total of 37.7 and 35.1% species had less than two stems in Dongge and Gengzheng plots respectively.

The 10 most important species accounted for about 40% of the total importance value in each plot (Table 3). *Platycarya longipes* was the most important species in Dongge plot due to the highest basal area of stems. *Acer wangchi* and *Clausena dunnianai* were the second and third most important species due to higher stem density and basal area respectively. *Castanopsis carlesii* var. *spinulosa* with the highest basal area and second highest stem density stems was the most important species in Gengzheng plot. No single species clearly dominated each plot.

Table 2 Sørenson index and Jaccard's coefficient between the two plots of subtropical karst forest in Maolan

Plot	Sørenson index			Jaccard's coefficient		
	Family	Genus	Species	Family	Genus	Species
Dongge–Gengzheng	0.842	0.677	0.457	0.739	0.568	0.312

The 10 most important families accounted for 50–60% of the total family importance value (FIV) in each plot (Table 4). In Dongge plot, Lauraceae was the most important family (FIV 8.9) due to its higher species richness (17 species) and number of individuals (510). Aceraceae also had high number of individuals (454) and was thus the second most abundant family. These two and three other families (Juglandaceae, Rutaceae and Fagaceae) had more than 48% of the total FIV. In Gengzheng plot, Fagaceae was the most important family with FIV of 16.9 because many Fagaceae individuals had large basal area (8.2 m^2), representing 34.5% of the entire basal area of this plot (Table 4). Lauraceae was the second most important family in Gengzheng plot due to its higher species richness (20 species) and number of individuals. The other important families were Rubiaceae, Juglandaceae and Ericaceae. The top five families accounted for 42.8% of the total FIV.

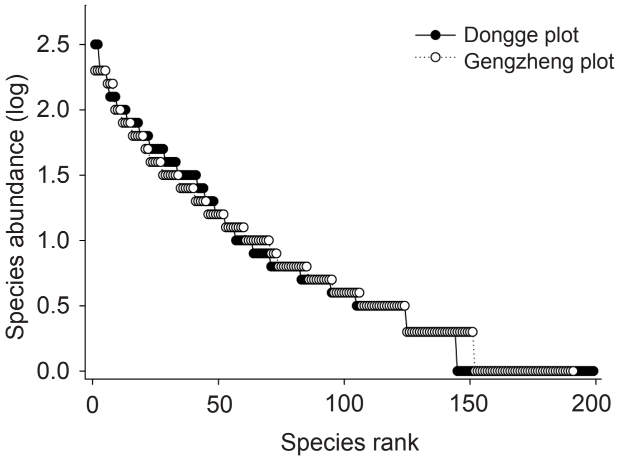

Figure 3 Rank–abundance curves of woody species from two subtropical karst forest plots in Maolan

DISCUSSION

The species richness in Maolan karst forest (Table 1) was higher than that in Mulun, a neighbouring natural reserve south of Maolan (200 species with dbh ≥ 1 cm) (Song et al. 2010) and much higher than the tropical karst forest in Kenting, Taiwan (113 species with dbh ≥ 1 cm) (Wang et al. 2004). Compared with subtropical non-karst forests (all woody species with dbh ≥ 1 cm),

Table 3 The 10 most important woody species (≥ 1 cm dbh) according to decreasing order of IVI in Dongge and Gengzheng plots

Plot	Species	D	F	BA	RDe	RF	RDo	IVI
Dongge	*Platycarya longipes*	81	36	2.55	1.89	1.69	13.72	5.77
	Acer wangchii	285	78	1.11	6.66	3.66	5.98	5.43
	Clausena dunniana	206	60	1.60	4.81	2.81	8.61	5.41
	Celtis biondii	90	53	1.55	2.10	2.48	8.35	4.31
	Cyclobalanopsis glauca	289	69	0.38	6.75	3.23	2.06	4.02
	Mahonia duclouxiana	215	85	0.47	5.02	3.98	2.53	3.84
	Viburnum brachybotryum	215	45	0.60	5.02	2.11	3.25	3.46
	Pittosporum crispulum	165	76	0.51	3.85	3.56	2.75	3.39
	Swida parviflora	138	41	0.65	3.22	1.92	3.48	2.88
	Carpinus pubescens	68	35	0.81	1.59	1.64	4.36	2.53
Gengzheng	*Castanopsis carlesii* var. *spinulosa*	206	63	4.56	5.34	3.26	19.32	9.31
	Cyclobalanopsis myrsinaefolia	87	46	2.01	2.26	2.38	8.50	4.38
	Distylium myricoides	201	51	1.14	5.21	2.64	4.83	4.23
	Rhododendron latoucheae	174	37	1.23	4.51	1.92	5.20	3.88
	Osmanthus fragrans	183	50	0.99	4.74	2.59	4.22	3.85
	Platycarya longipes	74	38	1.57	1.92	1.97	6.63	3.51
	Engelhardtia roxburghiana	221	68	0.26	5.73	3.52	1.11	3.45
	Rapanea neriifolia	205	55	0.26	5.32	2.85	1.11	3.09
	Aidia canthioides	168	53	0.26	4.36	2.75	1.08	2.73
	Sloanea sinensis	97	45	0.78	2.51	2.33	3.29	2.71

D = density, F = frequency, BA = basal area (m^2), RDe = relative density, RF = relative frequency, RDo = relative dominance, IVI = importance value index

Table 4 The 10 most important families of woody plants according to decreasing order of FIV in Dongge and Gengzheng plots

Plot	Family	NS	NI	BA	RDi	RDe	RDo	FIV
Dongge	Lauraceae	17	510	1.14	8.54	11.91	6.11	8.86
	Aceraceae	6	454	1.41	3.02	10.61	7.60	7.07
	Juglandaceae	2	186	2.63	1.01	4.34	14.13	6.49
	Rutaceae	6	220	1.62	3.02	5.14	8.70	5.62
	Fagaceae	7	359	0.73	3.52	8.39	3.94	5.28
	Ulmaceae	2	107	1.82	1.01	2.50	9.78	4.43
	Cornaceae	4	191	0.96	2.01	4.46	5.19	3.89
	Rosaceae	9	161	0.57	4.52	3.76	3.07	3.79
	Sapindaceae	3	47	0.99	1.51	1.10	5.32	2.64
	Betulaceae	3	72	0.82	1.51	1.68	4.42	1.99
Gengzheng	Fagaceae	8	458	8.16	4.19	11.87	34.54	16.88
	Lauraceae	20	500	1.30	10.47	12.96	5.50	9.64
	Rubiaceae	11	374	0.75	5.76	9.70	3.16	6.21
	Juglandaceae	2	295	1.83	1.05	7.65	7.74	5.48
	Ericaceae	5	202	1.38	2.62	5.24	5.84	4.56
	Hamamelidaceae	4	213	1.38	2.09	5.52	5.84	4.48
	Oleaceae	5	205	1.16	2.62	5.32	4.90	4.28
	Rosaceae	12	90	0.45	6.28	2.33	1.92	3.51
	Aquifoliaceae	8	74	1.05	4.19	1.92	4.42	3.51
	Elaeocarpaceae	3	123	0.89	1.57	3.19	3.76	2.84

NS = number of species, NI = number of individuals in a family, BA = basal area (m^2), RDi = relative diversity, RDe = relative density, RDo = relative dominance, FIV = family importance value

the species richness in Maolan was also higher than those in southern subtropical evergreen broadleaved forest in Dinghushan, Guangdong Province (123 species, Kong et al. 1998) and in mid-subtropical evergreen broadleaved forest in Gutianshan in Zhejiang Province (159 species, Zhu et al. 2008). In the moist and temperate environments, climate is not a constraint factor of species richness. The unique and combined geomorphologic configuration in Maolan forms more heterogeneous habitats (Long 2007). This creates diverse environments within the subtropical karst landscape. For example, the proportion of exposed bedrock varied between 4 and 93% in the 100 subplots in Gengzheng plot, while the average soil depth ranged from 0.8 to 96.4 cm. Therefore, various soil depth and its vertical distribution, frequent rock outcrops and diverse microhabitats (e.g. stone face, stone groove, stone gap and soil surface) had created microclimates and trophic condition (Zhang et al. 2011), contributing to the higher woody species diversity (Zhu 2002a).

Subtropical karst forests are usually characterised by an abundance of species with low frequency of occurrence (Zhou 1987). In this study, more than 35% of woody species were represented by only one or two individuals (Figure 1). The richness of rare species in the subtropical karst forests may be attributed to habitat heterogeneity and fragmentation of karst morphology (Zhu & Wei 1993). Karst forests in Maolan have few dominant species, which contrast to the non-karst subtropical evergreen forests (Zhu 2002b). Moreover, the composition of dominant species in our study was quite different from other karst forests. For example, *Diospyros maritima* was the dominant species in tropical karst forest in Taiwan (Wang et al. 2004). *Cleistanthus sumatranus* and *Lasiococca comberi* were the dominant species in tropical karst forest in Xishuangbanna on the northern edge of tropical South-East Asia (Tang et al. 2011). Furthermore, karst forests in Maolan had different leading families compared with karst forests of tropical Asia. In Maolan, Lauraceae, Fagaceae and Juglandaceae were the most important families. However, in limestone forest in South-East Asia (e.g. Sarawak and Indonesia), Dipterocarpaceae or Myrtaceae was the most important family (Proctor et al. 1983, Polak 2000). Euphorbiaceae was the most important family in karst forests in the Xishuangbanna (Tang et al. 2011). Similarly, Lauraceae and Fagaceae also dominated the subtropical non-karst forests in China (Wei et al. 2010, Gong et al. 2011, Yang et al. 2011). However, unlike tropical karst and subtropical non-karst forests, Juglandaceae has played a significant role in the evolution of karst forest in Maolan. All these results suggested that floristic composition of subtropical karst forest in Maolan was more or less different from karst forests in tropical Asia and subtropical non-karst forests.

In terms of stem density, subtropical karst forest in Maolan was lower than tropical limestone forest in Kenting, Taiwan (5196 stems ha^{-1}) (Wang et al. 2004). It was also lower than those of evergreen broadleaved forests in Gutianshan (5563 stems ha^{-1}) (Zhu et al. 2008) and Tiantong (4730 stems ha^{-1}) (Yang et al. 2011), China. However, stem densities of woody plants with dbh ≥ 5 cm in this study (1479 ha^{-1} and 1551 ha^{-1} for the Dongge and Gengzheng plots respectively) were much higher than those of tropical limestone forests in Sarawak (644 ha^{-1}, Proctor et al. 1983) and Xishuangbanna (998 ha^{-1}, Tang et al. 2011). The basal area values of woody plants (dbh ≥ 1 cm) of subtropical karst forest in Maolan (18.6 m^2 in Dongge and 23.6 m^2 in Gengzheng) were lower than the subtropical non-karst forests in Dinghushan (30.2 m^2) (Ye et al. 2008) and Gutianshan (36.9 m^2) (Zhu et al. 2008), and also much lower than that of a tropical karst forest in Taiwan (44.3 m^2) (Wang et al. 2004). Moreover, the basal area of woody plants with dbh ≥ 5 cm in our plots (17.1–22.3 m^2) was much lower than tropical karst forests in Gunung Mulu of Sarawak (37.0 m^2 ha^{-1}) (Proctor et al. 1983) and Xishuangbanna (33.5 m^2 ha^{-1}) (Tang et al. 2011). The differences in basal area between different forests could be due to differences in size structure of trees, species composition, habitat conditions, degree of disturbance and successional stages of the stands (Swamy et al. 2000). In this study, 83% of individuals belonged to the diameter class of 1–10 cm. In Kenting, Taiwan, however, the diameter class of < 10 cm accounted for 72% of individuals (Wang et al. 2004). Moreover, these comparisons suggested that the rigorous habitats (e.g. shallow soils, frequent rock outcrops and low water retention capacity) in subtropical karst forests in Maolan caused relatively slow growth of tree diameter.

The size structure of a species reflects regeneration processes (Takahashi et al. 2001) and can provide insight into forest dynamics (Hou et al. 2004). The typical reverse-J-shaped growing population in the dbh distribution curves (Figure 3) for both Dongge and Gengzheng plots revealed that forest stands in the two study sites had good recruitment patterns with rich sapling bank.

Our knowledge about species diversity of subtropical karst forest communities is still insufficient. This paper reveals that subtropical karst forests in Maolan have rich species and differ significantly in floristic composition and structure as indicated by species composition and species rank–abundance curve from subtropical non-karst and tropical karst forests. As a natural treasure and unique forest type, the karst forest should be protected. Karst forests in Maolan National Nature Reserve have been well protected but the other reserves are at great risks of being destroyed by human disturbances such as grazing, fuelwood collection and other economic activities. Thus, further research and conservation initiatives on these vulnerable karst ecosystems are needed in order to better manage and restore the forest resource, and to prevent the increase of rocky desertification.

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