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The Tropical Forests of Southern China and Conservation of Biodiversity

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Abstract Species-rich tropical forests once occurred along much of China's southern border, from southeastern Xizang (Tibet) and southern Yunnan to southwestern Guangxi, southern Taiwan and Hainan, mainly south of 22°30'N latitude. These Chinese forests are similar to Southeast Asian lowland tropical forests in their profiles and physiognomic characteristics, floristic composition and species richness. Studies of these southern forests in China are reviewed. Complete vegetation studies on the physiognomy and floristic composition have been done in southern Yunnan, Hainan and southwestern Guangxi. Forest fragmentation, dispersal patterns of trees, and the maintenance, population dynamics, phylogenetic community structure, tree functionality and phylogenetic diversity and conservation of these tropical Chinese forests have also been studied. Major changes in land use in China have resulted in an increase in rubber and *Eucalyptus* plantations and a decrease in the extent of southern forests. The direct results have been fragmentation and loss of biodiversity. The underplanting of economic crops in native forests also threatens to destroy saplings and seedlings, causing the forest to lose its regenerative capacity. Limiting further expansion of monoculture tree plantations, restricting underplanting, and promoting multi-species agroforestry systems are needed in China to conserve the biodiversity of its forests.

Keywords Forests · Ecology · Biogeography · Conservation; review · China

Introduction

Southern China, including southeastern Xizang (Tibet), southern Yunnan, southwestern Guangxi, southern Taiwan, and Hainan, has generally been recognized as being on the northern edge of the Asian tropics. However, the use of different criteria has resulted in multiple definitions of the tropical areas in China (Zhu, 2013). This uncertainty in the northern boundary of the Chinese tropical zone hinders objective definition of regions for vegetation classifications, defining distribution of crops, and physical geography.

Historically, species-rich forests have existed along much of China's southern border. These forests are similar in ecology and floristics to forests in SE Asia, occur on the lowland below 1000–1200 m alt., and are defined as tropical forests. These tropical forests are considered to be an extension of the SE Asian forests (Zhu, 1997; Zhu, 2008a; Zhu & Roos, 2004; Zhu et al., 2006a), but they represent SE Asian tropical forest at its latitudinal and altitudinal limits. However, in Chinese botanical references, the explanations and applications of the term "tropical forest" have not been consistent. Here we review studies of the tropical forest in China in order to define its characteristics and circumscription.

Three main factors resulting in the loss of biodiversity of the tropical forest in southern China have been recognized: 1. rubber and pulp plantations replacing the forests; 2. fragmentation of the forests and 3. economic plant cultivation in the forest understory. The major land-use change impacting tropical forests in southern China has been an increase in monoculture rubber (*Hevea brasiliensis*) or pulp (*Eucalyptus* spp.) plantations in natural forest habitat (Li et al., 2007; Zhai et al., 2012; Xu et al., 2014). The direct results are decreased tropical forest area and increased fragmentation of the remaining forest, leading to a loss of biodiversity (Zhu et al., 2004, 2010). Planting economic plants in the forest understory is also a potential threat to biodiversity in SW China (Zhu et al., 2002).

In this article, the northern boundary of the frost-free areas in China will be discussed; studies of southern forests in China will be reviewed; and current threats to biodiversity in the forests will also be highlighted.

Frost-Free Areas in China

The distribution of tropical forests in China is limited to frost-free areas. The frost-free region in China, including southeastern Xizang (Tibet), southern Yunnan, southwestern Guangxi, southern Taiwan, and Hainan, has generally been recognized as lowland areas on the northern edge of tropical Asia (Zhu, 1997). Both climatic and physical zonation indicate that the tropical zone (designated "marginal tropical zone") is generally south of the Tropic of Cancer, except for parts of southwest China (National Committee of Atlas Compilations, 1999), although the precise demarcation line for the tropical area has been debated and variously applied (Zhu, 2013).

Climatically, the Nanling mountains have been suggested as the tropical demarcation, roughly south of 24°–25°N in southern China (Guangxi and Guangdong provinces), and up to 26°N in southeastern China (Fujian province) (Zhu & Wan, 1963). However, vegetation and soil have been considered to be better indicators of bioclimate than a single climatic factor (Ren & Xiang, 1963; Ren & Zeng, 1991). Further south, a line at c. 21°30'N, with the annual effective accumulative temperature of 8000 °C, daily mean temperature of >10 °C, and mean temperature of the coldest month >16 °C, has also been suggested to be the northern boundary of the tropical area in southern China (Institute of Geography, Chinese Academy of Sciences, 1959; Qiu & Lu, 1961; Qiu, 1986; Huang, 1991; National Committee of Atlas Compilations, 1999), and has been widely used in studies of the geography and climate of China. In a narrow sense, the tropical area has been considered to be limited to southern Hainan and the southern margin of Taiwan according to the Köppen-Geiger climate classification of the equatorial monsoon region (Kottek et al., 2006; Peel et al., 2007), which was supported by some Chinese ecologists (Fang, 2001; Fang et al., 2002).

A line at c. 22°30'N has been suggested as the northern boundary of the tropical zone in south and southeastern China based on the biogeographical patterns of Chinese seed plants, since south of this line regional floras are dominated by tropical genera (Zhu et al., 2007a; Zhu, 2013). This line corresponds well with the currently recognized northern boundary of the tropical monsoon and rain forests of China (Wu, 1980; Hou, 1981, 1988; Cao et al., 2006; Zhang, 2007). Although there is a slightly lower annual cumulative temperature in the area of the line at c. 22°30’N, strictly tropical lowland plants, such as rubber, coffee, jackfruits, pepper, and pineapples, generally grow well in these regions, and tropical genera account for more than 80% of the total genera in the floras of these regions (Zhu et al., 2007a; Zhu, 2013). A tropical southeast Asian flora is found south of the 22°30’N line in southern China (Zhu, 1997, 2008a, 2008b; Zhu & Roos, 2004). In the floristic regions of the World (Takhtajan, 1978), the line corresponds well to the demarcation between the East Asiatic Kingdom (Wu & Wu, 1996) or Holarctic Kingdom and the Paleotropical Kingdom. Although the boundary of the tropical climate is still uncertain, southern China has a marginal tropical climate (Domroes, 2003), and 22°30’N provides a suitable biogeographical boundary for the tropical areas in south and southeastern China. The forests reviewed here lie below this boundary.

Frost-Free Forests in China

Vegetation zones of China were mapped by Wu (1980) and incorporated into the National Geographical Atlas (National Committee of Atlas Compilations, 1999). In this vegetation zonation, the tropical monsoon forest and rain forest regions are located in the southern-most parts of China. The tropical vegetation of China was further partitioned into eastern tropical monsoon forest and rain forest with a humid bias, and western tropical monsoon forest and rain forest with a dry bias (Sun, 1998). Eastern tropical vegetation includes humid rain forest zones in southern Taiwan, southern Guangdong, southwestern Guangxi, and Hainan. Western tropical vegetation includes seasonal rain forest zones in southern, southwestern Yunnan and in southeastern Tibet, extending to 29°N along the Yalong Tsangpo River below 1000 m altitude.

The tropical forests of China in the strict sense do not include tropical monsoon forests (Zhu, 2011) but include tropical rain forests in lowlands and tropical montane rain forests, which were classified as a sub-type of forest (Wu, 1987; Zhu, 2006; Zhu et al., 2015a). These forests have almost the same forest profile and physiognomic characteristics as equatorial lowland rain forests and are a type of true tropical lowland rain forest (Zhu, 1997; Zhu et al., 2006a). The distribution of the frost-free forests in China is shown in Fig. 1 (Cao et al., 2006). They occur mainly in the lowlands in wet valleys and on lower hills below 1000 m altitude in Yunnan and Xizang (Tibet) of southwestern China, extending to southwestern Guangxi, southern Taiwan and Hainan.

Research on tropical forests of China started in southern Yunnan, southwestern China (Wang, 1939). This initial work suggested that tropical rain forests existed in southern Yunnan, but these forests were considered to be different from those in Indo-Malaysia (Fedorov, 1957, 1958) because of the lack of representatives of the Dipterocarpaceae, which dominates rain forests in tropical Asia. Members of the Dipterocarpaceae were found in southernmost Yunnan in the 1970s, indicating that extensions of the Indo-Malaysian forests were present in the region. It was later confirmed that true evergreen rain forests occur in the southern fringes of China (Whitmore, 1982, 1984, 1990). Further biogeographical and ecological studies on the

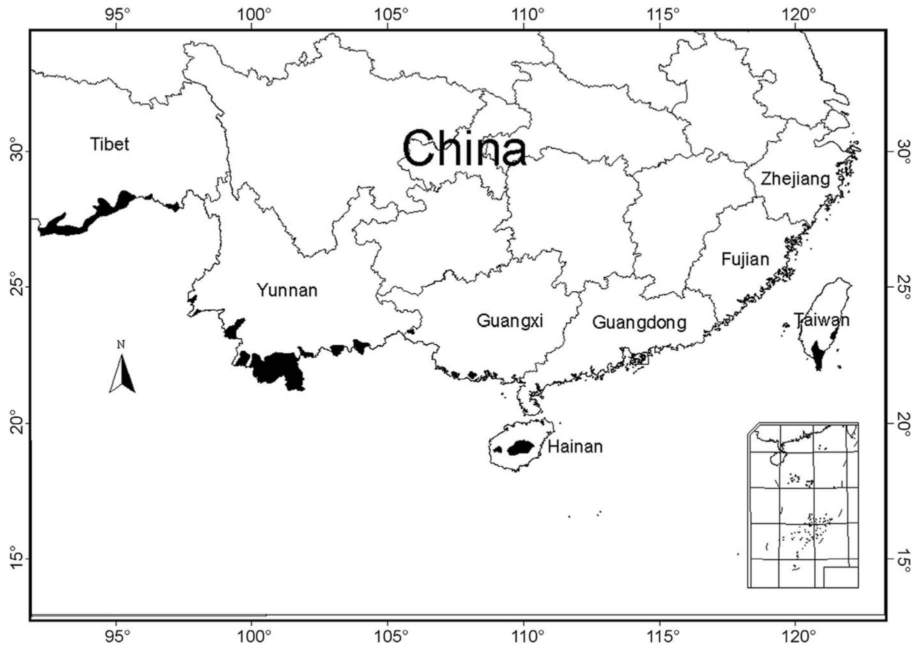

Fig. 1 Distribution of the tropical rain forest in China (dark patches showing the distribution areas of the tropical rain forest) (redraw from Cao et al., 2006, Fig. 1)

vegetation and flora of southern Yunnan revealed that in this region forests with physiognomic and floristic similarities to the Indo-Malaysian forests are at their northern climatic limits (Zhu, 1992a, 1992b, 1993a, 1993b, 1994a, 1994b, 1997, 2004, 2006, 2008a, 2008b; Zhu et al., 1998a, 1998b). As the forest at such climatic limits has a clear change in physiognomy between different seasons, Chinese botanists refer to them as 'tropical seasonal rain forest' in southern Yunnan (Wu, 1980, 1987).

Frost-free forests throughout southern China have almost the same physiognomic characteristics, but vary in species diversity. The common physiognomic features are that they have three tree layers in profile: the top layer is composed by emergent trees, and the second layer is the main canopy with the greatest density of individuals. These are the typical profile features of equatorial lowland forests (Robbins, 1968; Paijmans, 1970; Kartawinata et al., 1981; Proctor et al., 1983; Richards, 1983; Richards, 1996). Like equatorial lowland forests, these forests have phanerophytes and tree species with mesophyllous leaves contributing the greatest number of species to the forests' life-form and leaf size spectra (Zhu et al., 1998b). However, species diversity varies significantly among these forests across China. For example, in southern Yunnan there were 150 tree species with DBH > 5 cm recorded from a 1 ha sampling plot (Cao et al., 1996) and 468 tree species with dbh > 1 cm recorded from a 20 ha sampling plot (Lan et al., 2012). In Nonggang, Guangxi, 223 tree species with dbh > 1 cm were recorded in a 15 ha northern tropical karst rain forest plot (Wang et al., 2014a). In the Wuzhi mountain in Hainan 249 tree species with dbh >1.5 cm were present in a 1 ha plot in a tropical lowland rain forest (Hu & Li, 1992), and 177 tree species with dbh > 2.5 cm in a 1 ha plot in a tropical montane rain forest (An et al., 1999a). In forests in Jianfengling on Hainan, 171 tree species with dbh > 5 cm were found in a 1 ha plot (Fang et al., 2004), but 290 tree species (excluding 61 unidentified individuals) in a 60 ha forest dynamics plot in a tropical montane rain forest in Jianfengling (Xu et al., 2015). From these statistics of species diversity, the forest in Yunnan had lower tree species diversity than Hainan in a 1 ha plot, but had much more diversity in a larger sample plot.

Despite similar physiognomy, the tropical forests in China have conspicuous variations in floristic composition from region to region. The forest in southern Yunnan is characterized by species of *Pometia* (Sapindaceae), *Terminalia* (Combretaceae), *Shorea* (Dipterocarpaceae), *Antiaris* (Moraceae), and *Gironnieria* (Ulmaceae), and in southeastern Yunnan and southwestern Guangxi by species of *Lysidice* (Fabaceae), *Burretiodendron* (Tiliaceae), *Eberhardtia* (Sapotaceae), *Cephalomappa* and *Deutzianthus* (Euphorbiaceae), although they are also dominated by *Shorea*, *Hopea,* and *Vatica* (Dipterocarpaceae), *Canarium* and *Garuga* (Burseraceae), *Knema* and *Horsfieldia* (Myristicaceae), and *Antiaris* and *Artocarpus* (Moraceae), as in the tropical rainforest in southeastern Yunnan. In Hainan, the tropical forest is characterized by *Vatica* and *Hopea (*Dipterocarpaceae), *Heritiera (*Sterculiaceae), *Amesiodendron* (Sapindaceae), *Homalium* (Salicaceae), *Alphonsea* (Annonaceae), *Gironniera* (Ulmaceae), *Dillenia* (Dilleniaceae) and *Ancistrocladus* (Ancistrocladaceae).

Despite variations in species and genera across tropical forests in China, their family compositions are very similar (Fig. 2). The families with most species in the forest in southern Yunnan are ranked as Lauraceae, Euphorbiaceae, Moraceae, Rubiaceae, Meliaceae, Fabaceae, Elaeocarpaceae and Annonaceae. The families with most species in the forest on limestone in southwestern Guangxi are ranked as Euphorbiaceae, Moraceae, Sterculiaceae, Rubiaceae, Verbenaceae, Meliaceae, Annonaceae and Sapindaceae, while in Hainan the dominant families are Lauraceae, Euphorbiaceae, Rubiaceae, Annonaceae, Fagaceae, Moraceae, Myrtaceae and Meliaceae. Some families have only a small number of species, but they are the dominant families in phytosociological importance, having the most individuals in the forests (Fig. 3), such as Icacinaceae and Dipterocarpaceae in southern Yunnan, and Dipterocarpaceae, Sapindaceae, Sterculiaceae and Ebenaceae in Hainan.

The biogeographical elements of the forests of southern China are similar. Most species have tropical distributions, and the tropical Asian element contributes the highest proportion, followed by the pantropic element, based on Wu's classification of geographical elements (Fig. 4) (Wu, 1991a). However, a higher proportion of the tropical Asian element is found in Yunnan, while a higher proportion of the pantropical element is found in Hainan (Fig. 4). In south Yunnan, genera with a tropical distribution contribute 94.2% of the total genera. Among these, genera of tropical Asian distribution have the highest percentage of all biogeographical types, contributing 42.3%, while genera of pantropical distribution contribute 19.6%. In Hainan, genera with a tropical distribution contribute 93.9% of the total genera, but genera with a pantropic distribution have the highest percentage, contributing 27.3%, while genera with a tropical Asian distribution have 26.7% in the lowland forest (Chen et al., 2005).

This review of Chinese tropical forests shows that the forests of China have almost the same forest profile and physiognomic characteristics as equatorial lowland rain forests (Richards, 1996). They also have similar families with most species similar to those in the tropical Asian rain forests. This review indicates that these Chinese forests

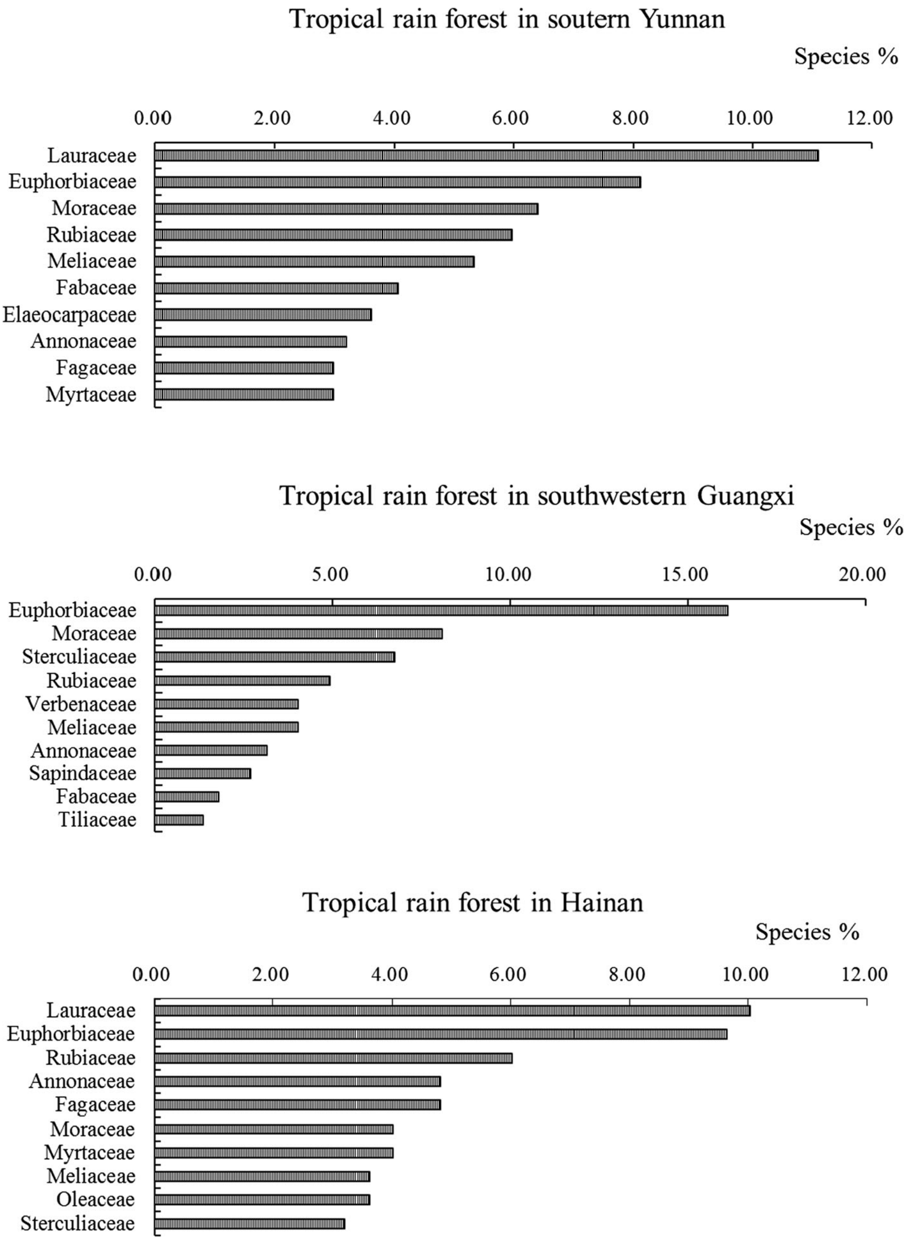

Fig. 2 Comparison of abundant families from tropical forests across China. Species %: The number of species in the family is divided by the total number of species in the plot. Upper: Tropical rain forest in southern Yunnan from a 20 ha plot (Lan et al., 2012); Middle: Tropical rain forest in southwestern Guangxi from a 15 ha plot in Longgan karst area (Wang et al., 2014b); Lower: Tropical rain forest in Hainan from a 1 ha plot (Hu & Li, 1992)

are tropical forests. In terms of physiognomy, the tropical forest of China is similar to the evergreen seasonal forest of tropical America (Beard, 1944, 1955), which was reclassified by Richards (1996) as a sub-formation of forest. Chinese tropical forests

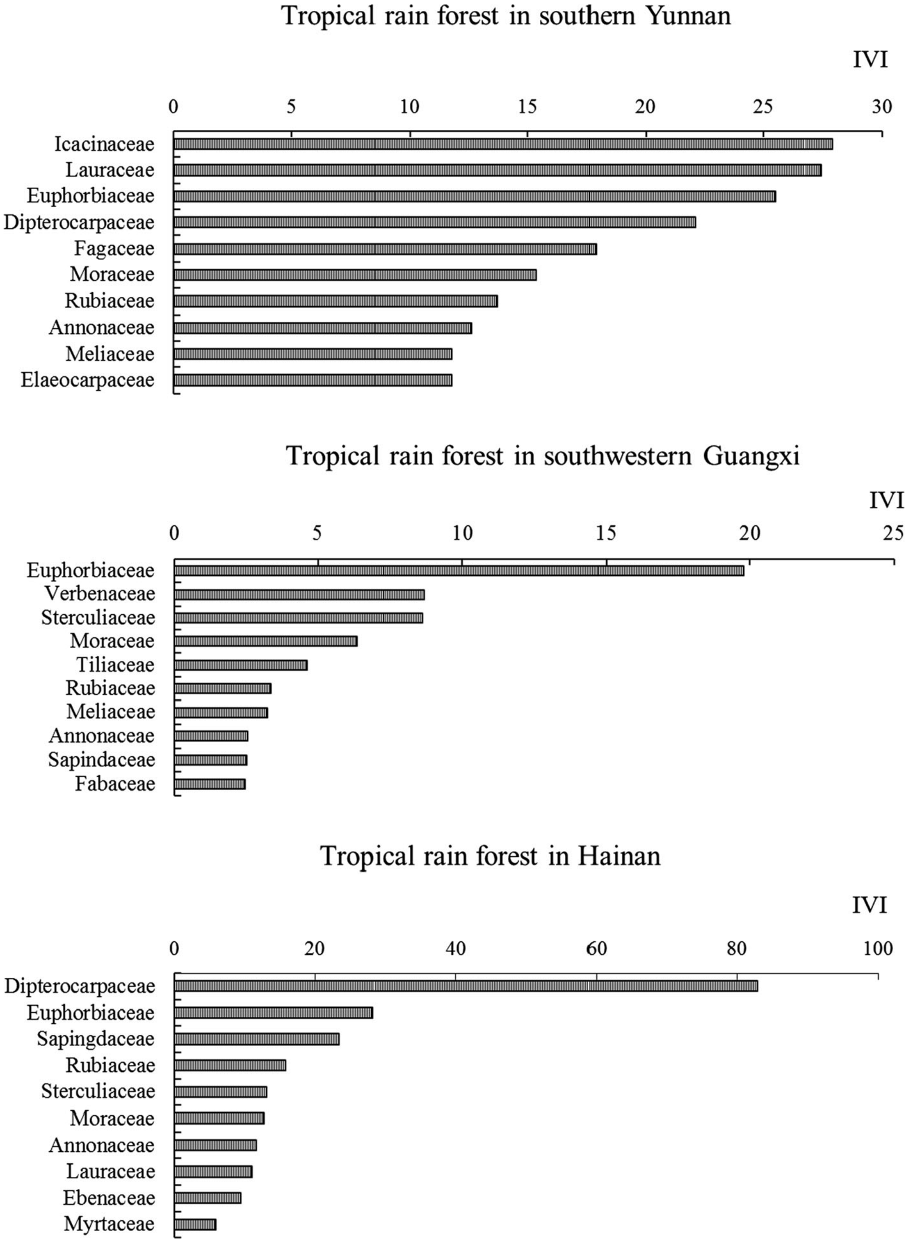

Fig. 3 Comparison of dominant families from tropical forests in China. IVI: Importance Value Index. Upper: Tropical rain forest in southern Yunnan from a 20 ha plot (Lan et al., 2012); Middle: Tropical rain forest in southwestern Guangxi from a 15 ha plot in Longgan karst area (Wang et al., 2014b); Lower: Tropical rain forest in Hainan from a 1 ha plot (Hu & Li, 1992)

also resemble the moist evergreen type of African forest (Hall & Swaine, 1976), the mesophyll vine forest of Australian rain forest (Webb, 1959), and the semi-evergreen rain forest (Walter, 1971). However, Chinese tropical forests are most equivalent to the semi-evergreen rain forests of Southeast Asia (Whitmore, 1984).

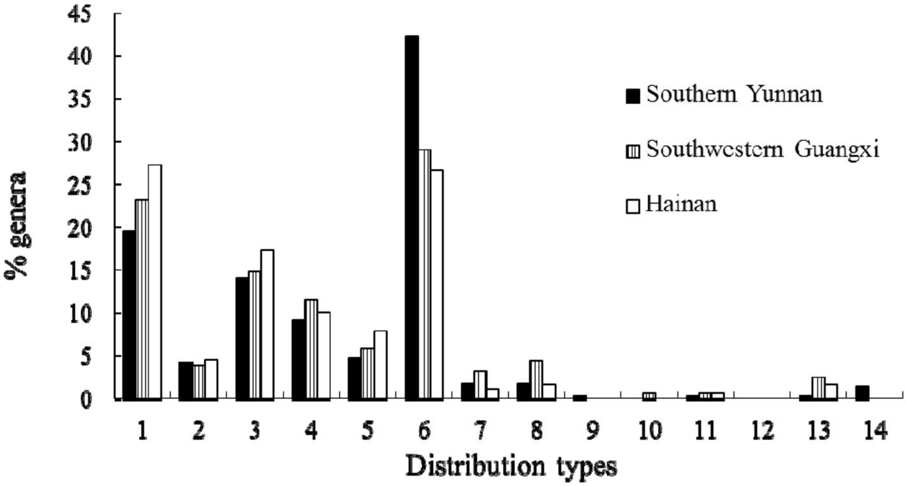

Fig. 4 Comparison of biogeographical elements of the tropical forests in China. Data are from tropical forest in southern Yunnan (Zhu et al., 2015b); tropical forest in Guangxi from a 15 ha plot in the Longgan karst area (Wang et al., 2014b); tropical forest in Hainan from a 2600 m^2 plot in Tongtielin, Hainan (Chen et al., 2005). Biogeogrphic types: 1 Pantropic, 2 Tropical Asia and Tropical America disjunct, 3 Old World Tropics, 4 Tropical Asia to Tropical Australia, 5 Tropical Asia to Tropical Africa, 6 Tropical Asia, 7 North Temperate, 8 East Asia and North America disjunct, 9 Old World Temperate, 10 Temperate Asia, 11 Mediterranean region, West to Central Asia, 12 Central Asia, 13 East Asia, 14 Endemic to China

Review of Studies of the Tropical Forests in Southern China

There have been many vegetational and biogeographical studies of the tropical forest in southern Yunnan (Jin, 1983; Zhu, 1992a, 1992b, 1993a, 1993b, 1994a, 1994b, 1997, 2004, 2006, 2008a, 2008b, 2011; Zhu & Roos, 2004; Zhu & Yan, 2009; Zhu et al., 1998a, 1998b, 2003, 2004, 2005, 2006a, 2006b, 2015a, 2015b). These have shown that these forests have physiognomic and floristic similarities to the Indo-Malaysian rain forests and are a type of tropical Asian rain forest at the climatic limits on the northern edge of the tropical zone.

A synthetic study on the tropical vegetation of southern Yunnan has been published recently (Zhu et al., 2015a). In this work, 32 vegetation formations, belonging to 7 vegetation types, including tropical rain forest, were recognized (Table 1).

In addition to studies of physiognomy and floristic composition, the species diversity, fragmentation, species dispersal patterns of trees and their maintenance, phylogenetic community structure, tree functional and phylogenetic diversity and conservation of tropical forest in southern Yunnan have also been studied (Cao & Zhang, 1997; Zhu et al., 1998c, 2000, 2004, 2010; Zhu & Zhou, 2002; Liang et al., 2010; Lan et al., 2011, 2012; Mo et al., 2011, 2013; Yang et al., 2014, 2015; Liu & Zhu, 2014). Studies of forest fragmentation and biodiversity changes have found that for species composition, the abundance of some species and the dominant ranks of some families have changed with fragmentation (Zhu et al., 2004, 2010). Additionally, the total number of species per plot has been reduced in fragmented forests and the more seriously disturbed the fragment has, the more species richness has diminished (Zhu et al., 2004, 2010). In life form spectra, liana and microphanerophyte species have increased, but epiphyte, megaphanerophyte, mesophanerophyte and chamaephyte species have been reduced

Table 1 Tropical rain forest and its formations in southern Yunnan

Vegetation type	Subtype	Formation*
Tropical rain forest	A. Tropical lowland rain forest	*Antiaris toxicaria* + *Pouteria grandiflora* forest
		Lasiococca comberi var. *pseudoverticillata* + *Celtis philippensis* var. *wightii* forest
		Pometia pinnata + *Terminalia myriocarpa* forest
		Pometia pinnata + *Celtis philippensis* var. *wightii* forest
		Acrocarpus fraxinifolius + *Duabanga grandiflora* forest
		Dracontomelon macrocarpum + *Pometia pinnata* forest
		Sapium baccatum + *Pouteria grandifolia* forest
		Shorea wantianshuea forest
		Vatica guangxiensis forest
	B. Tropical montane rain forest	*Metadina trichotoma -Syzygium cathayense* forest
		Metadina trichotoma -Pittosporopsis kerrii forest
		Mastixia euonymoides -Phoebe megacalyx forest
		Parachmeria yunnanensis -Gymnanthes remota forest
		Calophyllum polyanthu -Phoebe nanmu forest

*: "+" indicates co-dominant tree species in the same tree layer; "-" indicates co-dominant tree species in the different tree layers

in fragmented forests (Zhu et al., 2004, 2010). Plant species diversity was generally lower in fragmented forests than in primary forest, although some life forms could more abundant (Zhu et al., 2004, 2010). Tree species with small populations were often lost first in the process of rain forest fragmentation (Zhu et al., 2004, 2010). Heliophilous or pioneer tree species increased and the shade-tolerant species were reduced in fragmented forests (Zhu et al., 2004, 2010).

In some cases, however, species diversity did not decrease with forest fragment size and further isolation of the remnant. In a study on a remnant tropical forest followed for 48 years, Zhu et al. (2010) found that species could condense into the limited natural habitats of remnant forest upon the loss of surrounding natural vegetation, but there was a significant shift in floristic composition and a conspicuous shift in the relative representation of mature-forest and light-demanding species: the former decreased, and species loss was balanced by new migrants across life forms.

After fragmentation, forest community phylogenetic structure changed distinctly from clustered to dispersed, which was related to the relatively drier conditions in the forest following fragmentation, resulting in an increase of phylogenetically remote heliophytes and the loss of more closely related sciophytes from the forest (Liu & Zhu, 2014). In another case, the phylogenetic community structure changed from clustered to over-dispersed during succession, and finally became random in old-growth forest (Mo et al., 2013).

The population structure, spatial distribution patterns and the changes in spatial pattern across the growth stages in a fragmented forest were also studied using point pattern analysis with Ripley's L-function (Lan et al., 2009). This research showed that Janzen-Connell effects are a potential mechanism for the maintenance of forest diversity in southern Yunnan (Lan et al., 2009) and that the topography could explain 20%, 24% and 5% of the total variation of species abundance for saplings, poles and adults, respectively (Lan et al., 2011).

In southwestern Guangxi, the tropical forest occurs mainly on limestone. The earliest study on the forest was made by Hu and Wang (1980), followed by a number of subsequent studies on community ecology (Su, 1981; Wang & Hu, 1982; Su et al., 1988; Su & Li, 2003; Wu, 1991b; Wang et al., 1998; Huang et al., 2013a; Wang et al., 2014a). Synthetic studies on the vegetation of Guangxi province (Su et al., 2014) identified 14 vegetation types, including 301 formations, of which 22 formations were tropical seasonal rainforests on acid soil and 15 formations were tropical seasonal rainforests on limestone. At the same time, another monograph on vegetation from the data-based local records of Guangxi vegetation was also published (Wang et al., 2014b).

Survey of a 15 ha karst seasonal rain forest dynamic plot (22.43°N, 106.95°E) in Nonggang, Guangxi, has provided information on species diversity and spatial patterns (Wang et al., 2014a). A total of 223 species, 157 genera and 56 families were recorded. In the plot, 11 species with the greatest numbers of individuals represented 51.64% of the total individuals, and the 58 species with the greatest numbers of individuals represented 90.19% of the total individuals. This study suggested that the strong habitat heterogeneity and special geological background of the area may be important for regulating species composition and spatial distribution of trees in the karst seasonal rain forest.

Studies on the forest in Hainan began in the 1960's (Chang, 1963a, 1963b), and these forests were described and classified into tropical rain forest (including montane rain forest as its subtype) and tropical monsoon forest vegetation types (Guangdong Institute of Botany, 1976). Subsequent articles on these tropical forests have differed in the forest names and physiognomy (Huang et al., 1986; Lu et al., 1986; Li, 1997; Hu, 1997; Yang et al., 2005; Zhang et al., 2005; Liu et al., 2009; Long et al., 2011), as well as estimates of plant diversity (An et al., 1999a; Wang & An, 1999; Hu & Din, 2000; Zang et al., 2001; Zang et al., 2002; Fang et al., 2004). Hu and Li (1992) recognized the lowland rain forest below 900 m altitude, including 5 formations, with all types dominated by *Vatica* and *Hopea*. Wang and Zhang (2002) reviewed the classification of tropical forest vegetation on Hainan Island and concluded that the tropical forests could be classified into 7 vegetation types, 4 vegetation subtypes, 35 formations, 21 subformations and 109 association groups or associations, among which a tropical seasonal rain forest was recognized. This forest type was represented by *Hopea hainanensis* and *Hopea exalata* of the Dipterocarpaceae, *Heritiera parvifolia* of the Sterculiaceae, *Amesiodendron chinense* of the Sapindaceae, *Homalium hainanense* of the Salicaceae, *Alphonsea monogyana* of the Annonaceae, and *Gironniera subaequalis* of the Ulmaceae. This vegetation type was widely distributed in southeastern, southern and southeastern Hainan in the lowlands below 700–900 m. However, the tropical montane rain forest was recognized to be the largest tropical forest in Hainan. It occurs widely on Diaoluo Mountain, Wuzhi Mountain, Jianfengling, Limuling, and Bawanling above 700–1300 m and is represented by *Dacrydium pierrei* of the Podocarpaceae, *Syzygium araiocladum* of the Myrtaceae, *Lithocarpus fenzeliaus* of the Fagaceae, *Pentaphylax euryoides* of the Pentaphylacaceae, and *Altingia obovata* of the Hamamelidaceae. The floristic composition (Zhang et al., 2007), community patch and tree species diversity dynamics (Zang et al., 2002; Zang et al., 2005), competition and facilitation processes of tree individuals (Long et al., 2013) and forest recovery (Huang et al., 2013b) of the Hainan forest have also been investigated.

Tropical forest occurs also in the Motuo region in the valley of the Yarlung Zangbo River below 1000 m in southern Tibet (Xizang) of southwestern China. There are few studies on tropical forest in this region. A single reference (Yang & Zhou, 2015) has described a forest dominated by *Terminalia myriocarpa* as a forest type.

In southeastern China, tropical forest occurs in the south of Taiwan. Several studies reported the forest on limestone, such as the Kenting Karst Forest (Wu et al., 2011; Wang et al., 2004). Ebenaceae and Euphorbiaceae are the dominant families in the forest in Kenting. *Diospyros maritima* is the most common species, followed by *Bischofia javanica, Drypetes littoralis, Pisonia umbellifera, Laportea pterostigma, Aglaia formosana, Palaquium formosanum, Gonocaryum calleryanum* and *Pouteria obovata.* There are 113 tree species with dbh $\geqq$ 1 cm in a 10-ha permanent plot in Kenting Karst Forest. This karst tropical forest is low in tree species diversity compared to other rain forests of China.

Biodiversity Loss in the Tropical Forests of Southern China

Three main factors that contribute to loss of biodiversity in the tropical forests in southern China are expansion of rubber and *Eucalyptus* plantations, forest fragmentation, and underplanting forests with economic plants (Zhu et al., 2007b).

Rubber and Eucalyptus Replacing Natural Forests

The major recent land use change in tropical areas in China has been an increase in rubber and *Eucalyptus* plantations and a decrease in the natural forests. The direct results are loss and fragmentation of the native forest, leading to loss of biodiversity. For example, the tropical seasonal rain forest in southern Yunnan decreased from a cover of 10.9% of the total area of the region in 1976 to 3.6% in 2003, mainly due to planting rubber after removing natural forest (Li et al., 2007). By 2010, rubber covered 22.14% of the total area of the region (Xu et al., 2014). Zhou et al. (2012) investigated species diversity of understory vegetation of rubber plantations of different ages at different elevations and with different management modes in southern Yunnan. They found that there were more than 340 plant species from 241 genera and 87 families under rubber plantations; Poaceae, Fabaceae, Asteraceae, Euphorbiaceae and Rubiaceae often had the most species and individuals. They also found that the understory species diversity decreased with increase in plantation age. Compared to natural forest, floristic composition changed conspicuously in rubber plantations, although they still have species diversity to some extent.

Lan et al. (2014) investigated a 1-ha dynamic rubber plantation plot after natural management in Hainan, and found a total of 183 plant species belonging to 155 genera and 69 families. Also, 475 sample plots were used to investigate undergrowth in rubber plantation in 19 counties in Hainan (Liu et al., 2006b). This study found 207 species of vascular plants belonging to 113 genera and 61 families in these plots. The dominant family was Poaceae, and the dominant species were *Cyrtococcum patens*, *Eupatorium odoratum*, *Urena lobata*, *Ottochloa nodosa*, *Elephantopus scaber*, *Borreria articulalis*, *Phyllanthus simplex*, and *Mimosa pudica.* These dominant plants in rubber plantations are mostly heliophilic plants and weeds.

Apart from rubber plantations, *Eucalyptus* has also been widely planted on Hainan Island. Since 1995, rubber and *Eucalyptus* plantations have displaced different types of natural forest (Zhai et al., 2012). Only 224 vascular plant species were recorded in a total 153 plots of 100 m^2 of *Eucalyptus* plantations on the island, which included 88 woody plants, and 136 herbs and lianas. Most of these plants were weeds and roadside heliophytes (Yang et al., 2008).

The natural forests undoubtedly lost their tree species diversity after they were replaced by monoculture rubber and *Eucalyptus* plantations. Although there is a flora composed largely by shrub and herbaceous plants underneath these plantations, it is much less diverse than that of natural forests (Yang et al., 2008). If the expansion of rubber or *Eucalyptus* plantations continues in China, the natural tropical forest will be lost, and consequently, most of the regional biodiversity, which is distributed mainly in the forest, will also be lost. Limiting further expansion of rubber and *Eucalyptus* plantations will be necessary for conservation of the Chinese rain forest flora and fauna.

Fragmentation of Tropical Forest

With fragmentation of forests, species diversity is usually reduced, and the smaller the fragment is, the greater the reduction. In addition, the more seriously disturbed the fragment, the more species richness diminishes (Zhu et al., 2004). Tree species with small populations are lost first in the process of fragmentation. However, how biodiversity changes with fragmentation is complicated, based on disturbances and human activities. For example, three fragmented rain forests and one primary forest were sampled with plots in southern Yunnan (Zhu et al., 2010). The total number of species per plot was reduced in the fragmented forests, and the more seriously disturbed the fragment, the more species richness diminished. Heliophilous or pioneer tree species increased, and shade-tolerant species were reduced. Although species diversity could not reduce with diminution and further isolation of the remnant, there was a conspicuous shift in the relative representation of mature-forest and light-demanding species: the former decreased. The floristic composition and ecological species groups changed through the time. This implies that the essential flora of the forest could not be maintained in the remnant. We will fail to protect the flora of Chinese tropical forest from impoverishment if only fragmented forests are conserved in the region.

Although human activities affect tree diversity and composition of tropical rainforests, the forest has considerable regeneration potential. Species diversity in forests disturbed by slash and burn agriculture were studied by Mo et al. (2011). Their study showed that these secondary forests play a unique role in biodiversity conservation, not only for their rich biodiversity, but also for their abundant timber and other useful species (Mo et al., 2011).

Economic Plant Plantations underneath the Tropical Rain Forest

Planting of cardamom (*Amomum villosum*) underneath the lowland rain forest is a potential threat to forest biodiversity in SW China. Cardamom was introduced into south and south-west Yunnan in 1963 as a traditional Chinese medicine

(Zhou, 1993).Its cultivation is as widely practiced as rubber planting in southern Yunnan. This practice poses a serious threat to natural regeneration of forests, because harvesting cardamom fruit requires complete clearing of young trees, saplings, seedlings and shrubs (Zhu et al., 2002; Liu et al., 2006a). Tropical forests regenerate from their sapling-seedling bank, especially species in the lower tree layer and sapling-shrub layer. If clearing takes place, it destroys the sapling-seedling bank of the rain forest, which causes the forest to lose its regeneration capability. The cultivation of cardamom in tropical rainforest has led to biodiversity decrease, however, the number and richness of plants increased after removal of cardamom in an ecological restoration experiment carried out from 1998 to 2001 (Gao & Liu, 2003, 2009).

Conclusions

In the past, species-rich tropical forests covered much of China's southern border, from southeastern Xizang (Tibet) to southern Yunnan, extending to southwestern Guangxi, southern Taiwan and Hainan mainly south of 22°30'N latitude. With conspicuous similarity in ecological and floristic characters to the forests of southeast Asia, the forests in southern China are considered to be a northern extension of those Asian forests. The forests of southern China share similar physiognomic characteristics, but vary in floristic composition and species diversity. As the forest nears its climatic limits, a change in physiognomy occurs between seasons. Chinese botanists have used the term 'tropical seasonal rain forest' for this type of forest.

Southern Chinese forests have been well-studied, starting from southern Yunnan. There have also been studies on the tropical forests in Taiwan (Wu et al., 2011; Wang et al., 2004). However, southern Tibet (Xizang) forest studies are largely lacking but urgently needed. Southern tropical forests with the most species have lost tree diversity after rubber and *Eucalyptus* plantations replaced them. The major change in land use in southern China has been an increase in rubber and *Eucalyptus* plantations and a decrease in natural forests. The direct results are biodiversity loss and forest fragmentation. A largely ignored threat to the natural regeneration of forests is underplanting with economic plants such as cardamon. Although no trees are cut down in this practice, the loss of saplings and seedlings causes the forest to lose its regeneration capability. This potential threat should be highlighted.

The decrease in area and the consequent fragmentation of southern forests due to the expansion of rubber (in Yunnan and Hainan) and *Eucalyptus* (in Hainan) monocultures have been the principal factors leading to loss of biodiversity. The high price of rubber encourages expansion of rubber plantations. Limiting further expansion of rubber and *Eucalyptus* plantations and promoting multispecies agroforestry systems are needed in the southern tropical forests of China.

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Literature Cited

An, S.Q., J.F. Wang, F.J. Zeng, H.D. Zhang & B.S. Wang. 1999a. Biodiversity of tropical montane rain forest on Diaoluo Mountain, Hainan. Acta Scientiarum Naturalium Universitatis Sunyatseni 38(6): 78–83. (in Chinese with English abstract)

———, X.L. Zhu, J.F. Wang, D.G. Campbell, G.Q. Li & X.L. Chen. 1999b. The plant species diversity in a tropical montane rain forest on Wuzhi Mountain, Hainan. Acta Ecologica Sinica 19: 803–809. (in Chinese with English abstract)

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.

Cao, M. & J. H. Zhang. 1997. Tree species diversity of tropical forest vegetation in Xishuangbanna, SW China. Biodiversity and Conservation 6:995–1006.

———, ———, Z. L. Feng, J. W. Deng & X. B. Deng. 1996. Tree species composition of a seasonal rain forest in Xishuangbanna, Southwest China. Tropical Ecology 37(2):183–192.

———, X. M. Zhou, M. Warren & H. Zhu. 2006. Tropical forests of Xishuangbanna, China. Biotropica 38(3): 306–309.

Chang, H.T. 1963a. Scheme of vegetation classification of Hainan Island. Acta Phytoecologica et Geobotanica Sinica 1(1): 141. (in Chinese with English abstract)

———. 1963b. The *Vatica* forest from Hainan. Acta Phytoecologica et Geobotanica Sinica 1(1): 142. (in Chinese with English abstract)

Chen, H. F., Y. H. Yan, X. S. Qin & F. W. Xin. 2005. Study on characteristics of the tropical lowland rainforest in Tongtieling, Hainan Island. Acta Botanica Boreali-Occidentalia Sinica 25(1): 103–112. (in Chinese with English abstract)

Domroes, M. 2003. Climatological characteristics of the tropics in China: climate classification schemes between German scientists and Huang Bingwei. Journal of Geographical Science 13: 271–285.

Fang, J. Y. 2001. Re-discussion about the forest vegetation zonation in eastern China. Acta Botanica Sinica 43: 522–533. (in Chinese with English abstract)

———, Y. C. Song, H. Y. Liu & S. L. Piao. 2002. Vegetation-climate relationship and its application in the division of vegetation zone in China. Acta Botanica Sinica 44(9): 1105–1122. (in Chinese with English abstract)

———, Y.D. Li, B. Zhu, G. H. Liu & Zhou G. Y. 2004. Community structures and species richness in the montane rain forest of Jianfengling, Hainan Island, China. Biodiversity Science, 12: 29–43. (in Chinese with English abstract)

Fedorov, An. A. 1957. The flora of southwestern China and its significance to the knowledge of the plant world of Eurasia (in Russia). Komarov Chten 10: 20–50.

———. 1958. The tropical rain forest of China (in Russia with English summary). Botanicheskii Zhurnal S.S.S.R. 43: 1385–1480.

Gao, L. & H. M. Liu. 2003. Restoration of tropical rainforest after re-moving *Amomum villosum* in Xishuangbanna. Acta Phytoecologica Sinica 27. 366–372. (in Chinese with English abstract)

———, ———. 2009. Rotation system for cardamom planting and forest regeneration in the tropical rainforest of south-West China. Journal of Tropical Forest Science 21(3): 190–197.

Guangdong Institute of Botany. 1976. Vegetation of Guangdong. Beijing: Science Press, pp. 41–97. (in Chinese)

Hall, J. B. & M. D. Swaine. 1976. Classification and ecology of closed-canopy forest in Ghana. Journal of Ecology 64: 913–953.

Hou, X.Y. 1981. A further discussion on the principle and scheme for vegetation regionalization of China. Acta Phytoecologica et Geobotanica Sinica 5**:** 290–301. (in Chinese).

——— 1988. Physical geography of China—plant geography, part II, Vegetation Geography of China. Beijing, Science Press. Pp. 112–113. (in Chinese)

Hu, Y.J. 1997. The dipterocarp forest of Hainan Island, China. Journal of Tropical Forest Science 9(4): 477–498.

______ & X.Q. Din. 2000. A study on the plant species diversity of tropical natural forest in Bawangling, Hainan Island. Chinese Biodiversity 8(4): 370–377. (in Chinese with English abstract)

——— & Y. X. Li. 1992. The tropical rain forest of Hainan Island. Guangzhou: Guangdong High Education Press pp. 1–332. (in Chinese with English abstract)

Hu, S. S. & H. P. Wang. 1980. The phytocoenological feature of seasonal rain forest of limestone region in Guangxi**.** Journal of North-Eastern Forestry Institute 4: 12–36. (in Chinese with English abstract)

Huang, B.W. 1991. Climatic division and physiogeographic division of China: retrospects and prospects. In: Yoshino. M: Studies on Tropical and Subtropical Climates and Their Impacts. Climatol. Notes (Univ. of Tsukuba. Japan) 4 l:3–10.

Huang, Q., Y. D. Li, D. Z. Zheng, J. C. Zhang, L. L. Wang, Y. X. Jiang & Y. M. Zhao. 1986. Study of tropical vegetation series in Jianfengling region, Hainan Island. Acta Phytoecologica et Geobotanica Sinica 10: 90–105. (in Chinese with English abstract)

Huang, Y. S., W. H. Wu, R. H. Jiang, S. Y. Liu, Y. Liu & X. K. Li. 2013a. Primary study on species diversity of plant in Longgang National Nature Reserve of Guangxi. Guihaia 33: 346–355. (in Chinese with English abstract)

Huang, Y. F., X. H. Lu, R. G. Zang, Y. Ding, W. X. Long, J. Q. Wang, M. Yang & Y. T. Huang. 2013b. Community assembly during recovery of tropical lowland rain forest from abandoned shifting cultivation lands on Hainan Island, China. Chinese Journal of Plant Ecology 37 (5): 415–426. (in Chinese with English abstract)

Institute of Geography, Chinese Academy of Sciences. 1959. Integrated Physiogeographical regionalization of China (preliminary draft). Beijing, Science Press (in Chinese).

Jin, Z. Z. 1983. The characteristics of tropical rain forest and monsoonal forest in Yunnan. Journal of Yunnan University 1-2:197–205. (in Chinese with English abstract)

Kartawinata, K., R. Abdulhadi & T. Partomihardjo. 1981. Composition and structure of a lowland dipterocarp forest at Wanariset, East Kalimantan. Malayan Forester 44: 397–406.

Kottek, M., J. Grieser, C. Beck, B. Rudolf & F. Rubel. 2006. World map of Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15(3): 259–263.

Lan, G.Y., H. Zhu, M. Cao, Y. H. Hu, H. Wang, X. B. Deng, S. S. Zhou, J. Y. Cui, J. G. Huang, Y. C. He, L.Y. Liu, H. L. Xu & J. P. Song. 2009. Spatial dispersion patterns of tree in a tropical rainforest in Xishuangbanna, Southwest China. Ecological Research 24:1117–1124.

———, Y. H. Hu, M. Cao & H. Zhu. 2011. Topography related spatial distribution of dominant tree species in a tropical seasonal rain forest in China. Forest Ecology and Management 262: 1507–1513.

———, H. Zhu & M. Cao. 2012. Tree species diversity of a 20-ha plot in a tropical seasonal rain forest in Xishuangbanna, Southwest China. Journal of Forest Research 17: 432–439.

———, Z. X. Wu & G. S. Xie. 2014. Characteristics of plant species diversity of rubber plantation in Hainan Island. Biodiversity Science 22 (5): 658–666. (in Chinese with English abstract)

Li, Y.D. 1997. Community characteristics of tropical mountain rain forest in Jiangfengling, Hainan island. Journal of Tropical and Subtropical Botany 5(1): 18–26. (in Chinese with English abstract)

Li, H. M., T. M. Aide, Y. X. Ma, W. J. Liu & M. Cao. 2007. Demand for rubber is causing the loss of high diversity rainforest in SW China. Biodiversity and Conservation 16, 1731–1745.

Liang, J., H. Zhu & Y. X. Ma. 2010. Land use, land cover change and conservation in the dipterocarp rain forest area of southern Yunnan, China. Gardens Bulletin Singapore 61 (2): 343–357.

Liu, Y. Y. & H. Zhu. 2014. Phylogenetic and floristic changes over 48 years in a tropical rainforest remnant in Xishuangbanna, SW China. Ecotropica 20: 15–34.

Liu, H. M., L. Gao, Z. Zheng & Z. L. Feng. 2006a. The impact of *Amomum villosum* cultivation on seasonal rainforest in Xishuangbanna, Southwest China. Biodiversity and Conservation 15: 2971–2985.

———, J. S. Jiang & S. L. Dong. 2006b. Study on biodiversity of the tropical rubber plantation in Hainan. Journal of Nanjing Forestry University (Natural Sciences Edition): 30(6): 55–60. (in Chinese with English abstract)

Liu, W. D., R. G. Zang & Y. Ding. 2009. Community features of two types of typical tropical monsoon forests in Bawangling nature reserve, Hainan Island. Acta Ecologica Sinica 29(7): 3465–3476. (in Chinese with English abstract)

Long, W. X., R. G. Zang & Y. Ding. 2011. Community characteristics of tropical montane evergreen forest and tropical montane dwarf forest in Bawangling National Nature Reserve on Hainan Island, South China. Biodiversity Science 19 (5): 558–566. (in Chinese with English abstract)

———, ———, ——— & Y. F. Huang. 2013. Effects of competition and facilitation on species assemblage in two types of tropical cloud forest. PLoS ONE 8(4): e60252.

Lu, Y., M. G. Li, Y. W. Huang, Z. H. Chen & Y. J. Hu. 1986. Vegetation of Bawangling gibbon nature reserve, in Hainan Island. Acta Phytoeologica et Geobotanica Sinica 19(6): 803–809. (in Chinese with English abstract)

Mo, X. X., H. Zhu, Y. J. Zhang, J. W. F. Slik & J. X. Liu. 2011. Traditional forest management has limited impact on plant diversity and composition in a tropical seasonal rain forest in SW China. Biological Conservation 144: 1832–1840.

———, **L. L. Shi, Y. J. Zhang, H. Zhu & J. W. F. Slik.** 2013. Change in phylogenetic community structure during succession of traditionally managed tropical rainforest in Southwest China. PLoS ONE 8(7): e71464.

National Committee of Atlas Compilations. 1999. National nature atlas of People's republic of China. Beijing, map Press of China. Pp. 64-80, 116–120 (in Chinese).

Paijmans, K. 1970. An analysis of four tropical rain forest sites in new Guinea. Journal of Ecology 58 (1): 77–101.

Peel, M.C., Finlayson B. L. & T. A. Mcmahon. 2007. Updated world map of the Köppen -Geiger climate classification. Hydrology and Earth System Sciences 4: 439–473

Proctor, J., J. M. Anderson, P. Chai & H. W. Vallack. 1983. Ecological studies in four contrasting rain forests in Gununm Mulu National Park, Sarawak. I. Forest environment, structure and floristics. Journal of Ecology 71**:** 237–360.

Qiu, B. J. 1986. A new discussion on the regionalization of agro-climate in China. Acta Geographica Sinica 41: 202–209 (in Chinese with English abstract).

——— **& Q. R. Lu.** 1961. Agroclimatic division of tropical and southern subtropical regions in China. Acta Geographica Sinica 27: 28–37 (in Chinese).

Ren, M. E. & R. Z. Xiang. 1963. On some theoretical problems of the physical regionalization in China from a contradictory opinion—re-discussion on the physical regionalization in China. Journal of Nanjing University (Natural Sciences) 3: 1–12 (in Chinese).

——— **& Z. X. Zeng.** 1991. The extent of tropical zone in China. Scientia Geographica Sinica 11(2): 101–108 (in Chinese with English abstract).

Richards, P. W. 1983. The three-dimensional structure of tropical rain forest. In: Sutto, S. L. de. Tropical rain forest: ecology and management. Oxford: Blackwell Sci. Pub.: 3–10.

———. 1996. The tropical rain forest, an ecological study. Second edition. London: Cambridge University Press.

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.

Su, Z. M. 1981. Classification of the limestone forests in Nonggang, Guangxi. Guihaia 1(2): 122–130. (in Chinese)

——— **& X. K. Li.** 2003. The types of natural vegetation in karst region of Guangxi and its classified system. Guihaia 23, 289–293. (in Chinese with English abstract).

———, **T. L. Zhao & Q. C. Huang.** 1988. The vegetation of Longgang Natural Reserve in Guangxi. Guihaia (Suppl. 1): 188–214. (in Chinese with English abstract)

———, **X. K. Li, D. Din, S. J. Nin, W. L. Chen & Mo, X. L.** 2014. The vegetation of Guangxi. Beijing: China Forestry Press. Pp. 757. (in Chinese)

Sun, S. Z. 1998. Concerning the vegetation Chinese regionalization map as part of in the natural geographical atlas of the Peoples Republic of China. Acta Phytoecologica Sinica 22(6): 523–537. (in Chinese with English abstract)

Takhtajan, A. 1978. Floristic rejoins of the World. Leningrad: Soviet Sciences Press. Chinese version, Translated by Huang G C, 1988. Beijing, Science Press. 203–229.

Walter, H. 1971. Ecology of tropical and subtropical vegetation. Edinburgh: Oliver & Boyd.: 207–236.

Wang, C. W. 1939. A preliminary study of the vegetation of Yunnan. Bulletin of the Fan Memorial Institute of Biology 9 (2): 65–125.

Wang, J. F. & S.Q. An. 1999. Biodiversity of the montane rain forest in Diaoluo Mountain, Hainan. Acta Ecologica Sinica 19(1): 61–65. (in Chinese with English abstract)

Wang, H. P. & S. S. Hu. 1982. The phytocoenological features of seasonal rain forest of acid soil region in Guangxi. Acta Botanica Boreali-Occidentalia Sinica 2(2): 69–86. (in Chinese with English abstract)

Wang, B. S. & W. Y. Zhang. 2002. The groups and features of tropical forest vegetation of Hainan Island. Guihaia 22(2):107–115. (in Chinese with English abstract)

Wang, H. P., S. Z. Sun & X. X. Li. 1998. Study of limestone seasonal rain forest classification in Guangxi. Bulletin of Botanical Research 17(4): 52–84. (in Chinese with English abstract)

Wang, H. H., I. F. Sun, C. T. Chien, F. J. Pan, C. F. Kuo, M. H. Yu, H. L. Ku, S. H. Wu, Y.P. Cheng, S. Y. Chen & Y. C. Kao. 2004. Tree species composition and habitat types of a karst forest in Kenting, southern Taiwan. Taiwan Journal of Forest Science 19: 323–335. (in Chinese with English abstract).

Wang, X.P., K. Ge & Y.G. Wen. 2014a. Local records of Guangxi vegetation (Guangxi Zhibei Zhiyao). Beijing: Higher Education Press, pp. 1–2084. (in Chinese)

Wang, B., Y. S. Huang, X. K. Li, W. S. Xiang, T. Ding, F. Z. Huang, S. H. Lu, W. H. Han, S. J. Wen & L. J. He. 2014b. Species composition and spatial distribution of a 15 ha northern tropical karst seasonal rain forest dynamics study plot in Nonggang, Guangxi, southern China. Biodiversity Science. 22 (2): 141–156. (in Chinese with English abstract)

Webb, L. J. 1959. A physiognomic classification of Australian rain forests. Journal of Ecology 47: 551–570.

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

———. 1984. Tropical rain forest of the far east. Second Edition, Oxford: Clarendon Press.

———. 1990. An introduction to tropical rain forests. Oxford: Clarendon Press.

Wu, Z. Y. 1980. Vegetation of China. Beijing: Science Press: 363–397. (in Chinese)

———. 1987. Vegetation of Yunnan. Pp.143–163. Beijing: Science Press. (in Chinese).

———. 1991a. The areal-types of Chinese genera of seed plants. Acta Botanica Yunnanica Supp. 4: 1–139. (in Chinese with English abstract)

Wu, C. L. 1991b. Classification and ordination of tropical limestone seasonal forest of Guangxi. Acta Phytoecologica et Geobantanica Sinica 15: 17–26. (in Chinese with English abstract).

Wu, Z. Y. & S. G. Wu. 1996. A Proposal for a new floristic kingdom (realm) —— the Asiatic kingdom, its delineation and characteristics. In: Zhang A L, Wu S G (editors). Floristic characteristics and diversity of east Asian plants. Beijing, China Higher Education and Springer Press pp. 3–42.

Wu, S. H., Z. Y. Hseu, Y.T. Shih, I. F. Sun, H. H. Wang & Y. C. Sen. 2011. Kenting karst Forest dynamics plot: tree species characteristics and distribution patterns. Taiwan Forestry Research Institute, Taipei. 1–306.

Xu, J. C., R. E. Grumbine & P. Beckschäfer. 2014. Landscape transformation through the use of ecological and socioeconomic indicators in Xishuangbanna, Southwest China, Mekong region. Ecological Indicators 36: 749–756.

Xu, H., Y. D. Li, M. X. Lin, J. H. Wu, T. S. Luo, Z. Zhou, D. X. Chen, H. Yang, G. J. Li & S. R. Liu. 2015. Community characteristics of a 60 ha dynamics plot in the tropical montane rain forest in Jianfengling, Hainan Island. Biodiversity Science 23 (2): 192–201. (in Chinese with English abstract).

Yang, N. & X. W. Zhou. 2015. Plants of Motuo. Beijing: Chinese Forestry Press, 1–232. (in Chinese with English abstract)

Yang, X.B., Q.S. Wu, Y.L. Li, X.Y. Wu, Q.H. Chi & S.N. Wang. 2005. Characteristic of tropical forest composition in north of Hainan Island. Scientia Silvae Sinicae 41(3): 19–24. (in Chinese with English abstract)

Yang, Z. H., X. B. Yang, Y. L. Li, X. B. Yu & Q. S. Wu. 2008. Species component and biomass of understory vegetation in eucalyptus plantation in Hainan Island. Journal of Northeast Forestry University 36(5): 25–27. (in Chinese with English abstract)

Yang, J., G. Zhang, X. Ci, N. G. Swenson, L. Sha, C. C. Baskin, J. Li, M. Cao, J. W. F. Slik & L. X. Lin. 2014. Functional and phylogenetic assembly in a Chinese tropical tree community across size class, spatial scales and habitats. Functional Ecology. 28:520–529.

———, N. G. Swenson, G. Zhang, X. Ci, M. Cao, L. Sha, J. Li, J. W. F. Slik & L.X. Lin. 2015. Local-scale partitioning of functional and phylogenetic beta diversity in a tropical tree assemblage. Scientific reports 5: 12731

Zang, R. G., Y. C. Yang & Y. X. Jiang. 2001. Community structure and tree species diversity characteristics in a tropical montane rain forest in Bawan-gling natural reserve, Hainan Island. Acta Phytoecologica Sinica 25: 270–275. (in Chinese with English abstract)

———, Y.X. Jiang & S.X. Yu. 2002. The forest cycle and tree species diversity dynamics in a tropical montane rain forest of Hainan island, South China. Acta Ecologica Sinica 22(1): 24–32. (in Chinese with English abstract)

———, J. P. Tao & C. Y. Li. 2005. Within community patch dynamics in at tropical montane rain forest of Hainan Island, South China. Acta Oecologica 28:39–48. (in Chinese with English abstract)

Zhai, D. L., C. H. Cannon, J. W. F. Slik, C. P. Zhang & Z. C. Dai. 2012. Rubber and pulp plantations represent a double threat to Hainan's natural tropical forests. Journal of Environmental Management 96: 64–73.

Zhang, X. S. (editor in chief), 2007. Vegetation map of the People's Republic of China. Beijing, Geological Publishing House. P. 12 (in Chinese).

Zhang, R.J., X. S. Qin & F. W. Xing. 2005. Features of *Lasiococca comber* var. *pseudoverticillata* Community in limestone areas in Changjiang, Hainan Island. Acta Scientiarum Naturalium Universitatis Sunyatseni 44 Sup.: 283–290. (in Chinese with English abstract)

———, F. W. Xing, L. P. Siu, Y. Liu, Y. S. Ye, Ng. Saichit, H. F. Cheng & Wang, F. G. 2007. Spermatophyte flora of Yinggeling Mountain, Hainan. Biodiversity Science 15 (4): 382–392. (in Chinese with English abstract)

Zhou, S.Q. 1993. Cultivation of *Amomum villosum* under tropical rainforest. Forest Ecology and Management 60: 157–162.

Zhou, H. P., X. S. Yan, H. D. Zhang, L.Q. Zhang & L. P. Wei. 2012. Species diversity of understory vegetation in rubber plantations in Xishuangbanna. Chinese Journal of Tropical Crops 33: 1444–1449. (in Chinese with English abstract)

Zhu, H. 1992a. Research of community ecology on *Shorea chinensis* forest in Xishuangbanna. Acta Botanica Yunnanica 14 (3): 237–258. (in Chinese with English abstract)

———. 1992b. The tropical rainforest vegetation in Xishuangbanna. Chinese Geographical Science 2 (1): 64–73.

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

———. 1993b. Floristic plant geography on the dipterocarp forest of Xishuangbanna. Acta Botanica Yunnanica 15 (3): 233–253. (in Chinese with English abstract)

———. 1994a. The floristic characteristics of the tropical rain forest in Xishuangbanna. Chinese Geographical Science 4 (1): 174–185.

———. 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)

———. 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.

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

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

———. 2008a. The tropical flora of southern Yunnan, China, and its biogeographical affinities. Annals of the Missouri Botanical Garden 95: 661–680.

———. 2008b. Advances in biogeography of the tropical rainforest in southern Yunnan, southwestern China. Tropical Conservation Science 1: 34–42.

———. 2011. Tropical monsoon forest in Yunnan with comparison to the tropical rain forest. Chinese Journal of Plant Ecology 35 (4): 463–470.

———. 2013. Geographical elements of seed plants suggest the boundary of the tropical zone in China. Palaeogeography, Palaeoclimatology, Palaeoecology 386:16–22.

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

Zhu, K. Z. & M. W. Wan. 1963. Phenology. Beijing, Scientific Education Press (in Chinese), 234–293.

Zhu, H. & L.C. Yan. 2009. Biogeographical affinities of the flora of southeastern Yunnan, China. Botanical Studies 50(4): 467–475.

——— **& H. X. Zhou.** 2002. A comparative study on the tropical rain forests in Xishuangbanna and Hainan. Acta Botanica Yunnanica 24 (1): 1–13. (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. Gardens' Bulletin Singapore 50: 5–33.

———, ——— & ———. 1998b. Research on the tropical seasonal rainforest of Xishuangbanna, South Yunnan. Guihaia 18 (4): 37–384. (in Chinese with English abstract)

———**, B. G. Li, H. Wang & Z. F. Xu.** 1998c. 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)

———**, Z. F. Xu, H. Wang & Li B. G.** 2000. Effects of fragmentation on the structure, species composition and diversity of tropical rain forest in Xishuangbanna, Yunnan. Acta Phytoecologica Sinica 24(5): 560–568. (in Chinese with English abstract)

———, ———, ——— & ———. 2002. A discussion on the loss of biodiversity of tropical rain forest by *Amomum* planting underneath in South Yunnan. Guihaia 22(1): 55–60. (in Chinese with English abstract)

———**, H. Wang, B.G. 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.

———**, Z. F. Xu, H. Wang & Li B. G.** 2004. Tropical rain forest fragmentation and its ecological and species diversity changes in southern Yunnan. Biodiversity and Conservation 13: 1355–1372.

———**, J. P. Shi & C. J. Zhao.** 2005. Species composition, physiognomy and plant diversity of the tropical montane evergreen broad-leaved forest in southern Yunnan. Biodiversity and Conservation 14: 2855–2870.

———**, M. Cao & H. B. Hu.** 2006a. Geological history, flora, and vegetation of Xishuangbanna, southern Yunnan, China. Biotropica 38(3): 310–317.

———, **H. Wang & B. G. Li.** 2006b. Floristic composition and biogeography of tropical montane rain forest in southern Yunnan of China. Gardens' Bulletin Singapore 58: 81–132.
———, **Y. X. Ma, L. C. Yan & H. B. Hu.** 2007a. The relationship between geography and climate in the generic-level patterns of Chinese seed plants. Journal of Systematics and Evolution 45(2): 134–166.
———, **H. M. Li & Y.X. Ma.** 2007b. Biodiversity Loss in Xishuangbanna with the Changes of Land Use and Land Cover over 27 Years. BCI International Symposium Proceedings. P. 69–72.
———, **H. Wang & S. S. Zhou.** 2010. Changes in species diversity, floristic composition and physiognomy in a rain forest remnant over 48 years in southern Yunnan, China. Journal of Tropical Forest Science 22(1): 49–66.
———, ———, **B. G. Li, S. S. Zhou & J. H. Zhang.** 2015a. Studies on the forest vegetation of Xishuangbanna. Plant Science Journal 33(5): 641–726
———, **Y. Chai, S. S. Zhou, H. Wang & L.C. Yan.** 2015b. Vegetation, floristic composition and species diversity in a tropical mountain nature reserve in southern Yunnan, SW China with implications to conservation. Tropical Conservation Science 8(2): 528–546.