Post-Print of the Outline for the Classification of Tropical Forest Vegetation in Yunnan

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Abstract

Tropical forests constitute important vegetation types in Yunnan. Although systematic classification and research on Yunnan' s tropical forest vegetation have been documented in *Yunnan Vegetation* and numerous papers have been published, inconsistencies persist in the division, nomenclature, and interpretation of vegetation types, particularly regarding incomplete documentation of formations. This paper summarizes available research materials, references worldwide studies on analogous tropical forest vegetation, and systematically synthesizes the types, classification, species composition, and community characteristics of tropical forest vegetation in Yunnan. Yunnan' s tropical forest vegetation comprises three main vegetation types: tropical rainforest, monsoon forest, and seasonally moist forest. The tropical rainforest in Yunnan represents a type of tropical rainforest developed under the monsoon climate at the northern margin of tropical Asia, reaching limiting conditions in terms of moisture, heat, and distribution altitude; it is divided into two vegetation subtypes—tropical seasonal rainforest and its montane variant, tropical montane rainforest—with the former including 19 formations and the latter 12 formations. The tropical monsoon forest in this paper is defined according to its original definition as a tropical deciduous to semi-evergreen forest vegetation situated between tropical rainforest and savanna, whose distribution is primarily constrained by moisture conditions and represents non-zonal vegetation; these are divided into two vegetation subtypes—deciduous monsoon forest and semi-evergreen monsoon forest —with the former including 7 formations and the latter 3 formations. Regarding the tropical forest vegetation distributed in limestone mountains of southern Yunnan, which is referred to as "limestone monsoon forest" in some botanical literature, consideration of its evergreen to semi-evergreen physiognomic characteristics, special floristic composition, and the absence of a distinct leafless (deciduous) period in the tree layer (its deciduous phenomenon may be primarily attributable to local habitat dryness and historical factors rather than regional climatic drought) indicates that they do not conform to the original def-

inition of monsoon forest; this paper employs the name tropical seasonal moist forest to define this vegetation type occurring in the middle and upper parts of limestone mountains, on the tropical montane vertical belt above the tropical seasonal rainforest zone. Seasonally moist forest is also divided into two vegetation subtypes—seasonal evergreen moist forest and seasonal semi-evergreen moist forest—each including 2 formations.

Full Text

Preamble

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A Sketch of the Classification of Tropical Forest Vegetation in Yunnan
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Abstract

Tropical forests represent important vegetation types in Yunnan. Although foundational work was enumerated in the monograph *Vegetation of Yunnan* and numerous papers on local vegetation types have been published, the classification, terminology, and explanations of Yunnan' s tropical forests remain inconsistent and uncertain, particularly regarding the classification and circumscription of formations. This article synthesizes available research materials and references global studies on similar tropical forest vegetation to systematically summarize the types, classification, species composition, and community characteristics of Yunnan' s tropical forest vegetation. Yunnan' s tropical forest vegetation comprises three main vegetation types: tropical rain forest, monsoon forest, and seasonal moist forest. The tropical rain forest in Yunnan represents a type developed under monsoon climate conditions at the 极限 limits of rainfall, temperature, and altitude required by tropical Asian rain forests. It is divided into two vegetation subtypes: tropical seasonal rain forest on lowlands and its montane variant—tropical montane rain forest, with the former including 19 formations and the latter 12 formations. The tropical monsoon forest in this paper follows its original definition as a tropical deciduous to semi-evergreen forest vegetation type 介于 between tropical rain forest and savanna, whose distribution is primarily constrained by moisture conditions rather than latitudinal zonation. It is classified into two subtypes: deciduous monsoon forest with 7 formations and semi-evergreen monsoon forest with 3 formations. Tropical forest vegetation on limestone mountains in southern Yunnan, referred to as "limestone monsoon forest"in some botanical literature, exhibits evergreen to semi-evergreen physiognomy, distinctive floristic composition, and lacks a distinct leafless (deciduous) period in the tree canopy. The deciduous phenomenon appears to result primarily from local habitat dryness and historical factors rather than regional climatic drought, making it inconsistent with the original definition of monsoon forest. This paper employs the term "tropical seasonal moist forest" to define

this vegetation type occurring on middle and upper limestone slopes above the tropical seasonal rain forest zone. Seasonal moist forest is also divided into two subtypes: seasonal evergreen moist forest and seasonal semi-evergreen moist forest, each comprising 2 formations.

Keywords: vegetation, classification, forest, tropical, Yunnan

Introduction

China' s tropical regions are primarily distributed in southeastern Tibet, southern Yunnan, Guangxi, Guangdong, Taiwan, and Hainan Island, all belonging to the northern margin of tropical Asia. However, the largest and most typical tropical forest areas occur in Yunnan, distributed from the southwestern to southeastern parts of the province (Zhu, 2017; Zhu, 2017a, 2017b).

Tropical forest vegetation in Yunnan was first mentioned by Wang Qiwu in 1939 (Wang, 1939). Since the 1950s-60s, extensive survey and research work conducted by the Chinese Academy of Sciences and Yunnan University has produced numerous publications. Comprehensive studies were included in *Vegetation of Yunnan* (Wu, 1987), and Jin Zhenzhou et al. (1983) preliminarily described the characteristics of Yunnan' s tropical rain forest and monsoon forest vegetation, later publishing on the diversity of tropical rain forest community types in Xishuangbanna (Jin & Ou, 1997). To date, a substantial body of research has been published on various tropical forest communities in Yunnan (Zhu, 1992, 1993a, 1993b, 1993c, 1994, 2005, 2007, 2011; Zhu et al., 1996, 1997, 1998, 2000, 2001, 2002, 2004, 2006, 2007, 2011, 2015; Li et al., 1993, 1999; Wang & Zhu, 1990; Wang et al., 2001; Zhou et al., 2001; Zhou et al., 2006a, b; Li et al., 2007; Zhang et al., 2006; Gu & Zhu, 2015; Cao et al., 1997, 2006; Zhu, 1992, 1994, 1997, 2004, 2006, 2008a, 2008b; Zhu & Roos, 2004; Zhu et al., 1998, 2003, 2004, 2005, 2006a, 2006b, 2015), fully confirming the presence of Indo-Malaysian-type Asian tropical rain forests in Yunnan.

However, compared with major global tropical rain forest regions, Yunnan' s tropical areas have relatively low latitude and high altitude, characterized by mountainous plateau topography, relatively low mean annual temperature (approximately 21-22°C), and annual rainfall (averaging 1500 mm). Consequently, long-standing debate has persisted regarding whether true tropical rain forests exist in Yunnan. Some ecologists have traditionally considered any Yunnan rain forests to represent a type 介于 between Schimper' s (1903) definition of classic tropical rain forest and monsoon forest, or a subtropical rain forest type distinct from true tropical rain forest in many aspects (Richards, 1952). Early research preliminarily confirmed the presence of biogeographically true tropical rain forests (Fedorov, 1958) and tropical flora (Fedorov, 1957) in southern Yunnan, but still considered them a type distinct from Indo-Malaysian tropical rain forests. The discovery of typical Southeast Asian tropical rain forest indicator plants—such as Dipterocarpaceae species including Parashorea chinensis—in Yunnan' s tropical rain forests eventually led to international acceptance of the

presence of true Southeast Asian-type tropical rain forests in southern Yunnan (Whitmore, 1982, 1990). Because Yunnan's tropical rain forests represent a type developed at the 极限 limits of moisture, heat, and altitude requirements, with a certain proportion of deciduous tree species in the canopy, Chinese scholars have designated them as tropical seasonal rain forest (Wu, 1987) to distinguish them from evergreen tropical rain forests of equatorial lowlands in Asia.

In addition to research papers, scientific investigation reports from nature reserves in Yunnan' s tropical rain forest and monsoon forest distribution areas also contain descriptions of these vegetation and plant community types (Xu, 2001, 2003; Yang & Du, 2004, 2006).

The materials used in *Vegetation of Yunnan* primarily date from before the 1980s (mostly from 1960s surveys). Due to limited conditions at the time, research on Yunnan' s tropical forests was not comprehensive, and reference materials on Southeast Asian tropical forest vegetation were scarce, resulting in inconsistencies in vegetation classification, nomenclature, and interpretation. The interpretation and application of tropical monsoon forests, including those in Yunnan, have been inconsistent, particularly prone to confusion with tropical rain forests (Zhu, 2005, 2011). Yunnan represents a key and hotspot region for global biodiversity conservation (part of the Eastern Himalaya and Indo-Burma biodiversity hotspot and critical area) (Myers, 1998), attracting significant international academic attention. With deepening research on Yunnan' s tropical forest vegetation and expanded international academic exchange and collaborative research, new developments have emerged in vegetation type classification and terminology interpretation, making it necessary to further synthesize research materials and reference global studies on similar tropical forest vegetation to provide a comprehensive summary of Yunnan' s tropical forest vegetation types, classification, species composition, and community characteristics. Currently, as Yunnan Province delineates ecological conservation red lines, tropical rain forests and monsoon forests are priority targets.

In addition to Yunnan, large areas of tropical forest vegetation also occur in southwestern and southern Guangxi and on Hainan Island. In southwestern and southern Guangxi, tropical forest vegetation primarily develops on limestone terrain, with numerous published papers on vegetation type and classification research, represented by works such as Su & Li (2003) and Wang et al. (1998). Wang et al. (2014) and Su et al. (2014) published comprehensive vegetation survey monographs covering all of Guangxi, with Su et al. (2014) recording 37 tropical seasonal rain forest formations, including 15 formations on limestone habitats. Research on Hainan' s tropical forests began relatively early, with systematic vegetation descriptions in Guangdong Institute of Botany (1976), followed by numerous papers on specific vegetation types and plant communities, particularly investigation reports from various nature reserves, though with varying terminology application. A more systematic classification of Hainan' s tropical forest vegetation appears in Wang & Zhang (2002). The classification principles, basis, units, and system for Yunnan' s tropical forest vegetation are

relatively similar to those for Guangxi's tropical forest vegetation, and align with earlier Hainan vegetation classification literature, but differ substantially from later Hainan vegetation classifications. This outline aims to provide reference materials not only for Yunnan' s ecological conservation red line demarcation and for researchers, forestry, and environmental protection workers, but also for tropical forest vegetation research in other regions of China.

1.1 Rainforest

Tropical rain forest refers to a class of evergreen, tall forest vegetation in humid or wet tropical regions (Schimper, 1903). Tropical rain forests possess distinctive physiognomy and structural characteristics that clearly distinguish them from other forest types worldwide. With extremely rich species composition, tropical rain forests represent the most biodiverse ecosystems on Earth. Due to favorable habitats in tropical humid regions, tropical rain forests develop into tall, multi-layered forest vegetation with three to four tree strata, the uppermost generally exceeding 30 meters in height. Large trees in tropical rain forests typically possess buttress roots, while some medium and small trees develop stilt roots from adventitious or aerial roots. Lianas and epiphytes are abundant, and understory herbs often have large leaves.

The scope and application of the term "tropical rain forest" have not been uniform. In tropical Asia, various vegetation types along tropical montane vertical belts have been categorized under the broad vegetation type of tropical rain forest as different subtypes (Whitmore, 1990). Most Chinese scholars adopt a classification consistent with Asian tropical rain forests, treating Yunnan' s tropical rain forest as a vegetation type divided into three subtypes: humid rain forest, seasonal rain forest, and montane rain forest, with the first two equivalent to lowland rain forests or general tropical rain forests in Southeast Asia, and the latter representing a montane variant of tropical rain forest (Wu, 1987).

Due to its occurrence on the northern margin of monsoon tropics with mountainous terrain, Yunnan' s tropical rain forest contains some deciduous tree species in its canopy, representing a tropical rain forest type developed under monsoon climate conditions. Previous botanical literature distinguished Yunnan' s lowland tropical rain forests into humid rain forest and seasonal rain forest subtypes based on distribution habitats and differences in indicator species. However, Yunnan' s humid rain forest and seasonal rain forest are ecologically and structurally similar, both containing more or less deciduous tree species in the canopy with minor compositional differences, and should be treated as the same vegetation subtype, both belonging to seasonal rain forest. Yunnan' s tropical rain forest represents a type developed at the 极限 limits of moisture, heat, and altitude requirements, belonging to latitudinal zonal vegetation. Based on general vegetation classification principles, criteria, and characteristics, Yunnan' s tropical rain forest is divided into two vegetation subtypes: tropical seasonal rain forest and its montane variant—tropical montane rain forest (Zhu, 2017a).

1.1.1 Tropical Seasonal Rainforest

Yunnan' s tropical seasonal rain forest exhibits the following characteristics:

(1) **Rich species composition**: Within a 2500 m^2 sample area, there can be 150-200 vascular plant species, including 44-63 tree species with diameter at breast height 5 cm (80-90 tree species if including saplings and seedlings), 30-40 liana species, 15-20 shrub species, 15-25 herb species, and 5-20 epiphyte species.

(2) **Complex stratification**: In well-developed stands, five basic layers can be distinguished: three tree layers (upper, middle, and lower), a sapling-shrub layer, and a herb layer. Layer transitions are indistinct (except for the upper layer).

(3) **Tall, straight upper canopy trees with high branching**: Generally 30-60 m tall, prominently emergent above the middle canopy. The middle tree layer has maximum coverage, forming the canopy layer.

(4) **Distinct seasonal changes**: The upper tree layer contains about 1/3-1/4 deciduous species that shed leaves primarily during the dry season, while middle and lower layers remain evergreen year-round.

(5) **Life form composition dominated by evergreen large and medium phanerophytes**, with simple, leathery, entire, medium-sized leaves being predominant.

(6) **Shrub layer dominated by tree saplings** with few true shrub species, which often grow in tree-like forms lacking basal branching.

(7) **Smooth, light-colored bark on trees**, with buttress roots common in upper canopy trees, cauliflory in middle and lower canopy trees, and drip tips frequent in lower layer plants.

(8) **Abundant epiphytes**, primarily from Orchidaceae, Araceae, Gesneriaceae, Asclepiadaceae, and ferns, with foliicolous mosses. Woody lianas are also abundant, including strangler plants.

(9) **Floristic composition dominated by tropical Southeast Asian elements**, with most upper and middle canopy trees shared with tropical rain forests of the Indochinese Peninsula. In Yunnan's tropical rain forests, dominant families by species richness include Euphorbiaceae, Lauraceae, Meliaceae, Moraceae, Sapindaceae, Combretaceae, and Annonaceae, while dominant families by importance value include Dipterocarpaceae, Euphorbiaceae, Lauraceae, Moraceae, Sapindaceae, Ulmaceae, Annonaceae, Meliaceae, and Anacardiaceae. More than 90% of genera and over 80% of species belong to tropical floristic elements, with approximately 75% of species being tropical Asian elements.

Yunnan' s tropical seasonal rain forest has approximately 80% of families, 90% of genera, and over 90% of species belonging to tropical elements, with about

40% of genera and 70% of species being tropical Asian distribution elements, undoubtedly representing a type of Southeast Asian tropical rain forest.

1.1.2 Tropical Montane Rainforest

Tropical montane rainforest represents the montane variant of tropical rain forest, with tropical rain forest components comprising about 60% of the community. Its physiognomy and structure mostly exhibit rain forest characteristics, but lacks scattered giant trees, with buttress roots and cauliflory being rare, and tree ferns abundant. Yunnan' s tropical montane rain forest is mainly distributed at elevations of 900-1200 m on moist mountains or at 1300-1800 m in some valleys affected by temperature inversion. Using Xishuangbanna's tropical montane rain forest as an example, community height reaches 22-30(35) m, scattered giant trees are not prominent, trees typically form two layers, pinnately compound-leaved species are relatively few (compared to seasonal rain forest), dominant leaf size among woody plants is medium, buttress roots and cauliflory are rare, and epiphytes are abundant. Dominant families in floristic composition include Lauraceae, Euphorbiaceae, Fagaceae, Fabaceae, Rubiaceae, and Theaceae, while dominant families by tree importance value include Lauraceae, Magnoliaceae, Euphorbiaceae, Fagaceae, and Mastixiaceae.

Based on in-depth research on the ecological-physiognomic characteristics and floristic composition of Yunnan' s tropical montane rain forest, montane rain forest communities described in *Vegetation of Yunnan* at elevations below 900 m are almost indistinguishable from tropical seasonal rain forest, while communities in areas above 1000 m are often confused with so-called monsoon evergreen broad-leaved forest. Here we adhere to the original definition of tropical montane rain forest from *Vegetation of Yunnan* to systematically review various so-called "montane rain forest" communities in Yunnan' s tropical regions, classifying communities in low-elevation areas indistinguishable from tropical seasonal rain forest as tropical seasonal rain forest community types, and communities confused with monsoon evergreen broad-leaved forest as corresponding monsoon evergreen broad-leaved forest communities.

Yunnan' s tropical montane rain forest is ecologically and physiognomically similar to lowland or submontane rain forests of tropical Asia and America (Grubb et al., 1964), and floristically similar to lowland rain forests of tropical Asia (Ashton, 2003), thus belonging to tropical Asian lowland rain forest in nature.

1.2 Monsoon Forest

Monsoon forest is a tropical deciduous forest vegetation type developed under tropical monsoon climate with distinct wet and dry seasons. In Southeast Asia, monsoon forest and seasonal rain forest are interdigitated and mosaic in some areas. According to Schimper' s (1903) definition, monsoon forest is a tropical deciduous forest vegetation type 介于 between tropical rain forest and savanna developed under tropical monsoon climate. In Yunnan, monsoon forest is mainly

distributed along open river sections and some broad valley basins below 1300 m where monsoon influence is strongest, such as sections of major rivers including the Lancang, Nu, and Yuan Rivers and their tributaries, as well as valleys of the Nanpan, Amo, Babian, Daying, Tengtiao, and Tuo Niang Rivers, occurring as discontinuous patches.

In some Chinese botanical literature, considering Yunnan' s location on the northern margin of monsoon tropics, evergreen and semi-evergreen tropical forest vegetation interdigitated with tropical seasonal rain forest in Yunnan has been termed tropical monsoon forest, considered a vegetation type distributed on the northern margin of the tropics that develops toward rain forest while transitioning to subtropical evergreen broad-leaved forest, representing a vegetation type 介于 between tropical rain forest and subtropical evergreen broad-leaved forest belonging to latitudinal zonal vegetation (Wu, 1980, 1987). Wang (1987), Lin et al. (1996), and Wang & Zhang (2002) proposed that according to Schimper' s (1903) concept and definition of monsoon forest (translated as "季雨林" in China), it is a vegetation type that is essentially leafless during the dry season, 介于 between rain forest and savanna, belonging to longitudinal zonal vegetation.

Richards (1996) classified climates with annual rainfall 1200 mm and 4-6 dry months as tropical wet-dry (marked by dry season), and those with annual rainfall 700 mm and 6-8 dry months as tropical wet-dry with long dry season. Corresponding vegetation types are: tropical wet-dry climate—semi-evergreen seasonal forest, and tropical wet-dry with long dry season—deciduous seasonal forest. This is similar to Schimper' s (1903) classification of tropical forest vegetation types, with his deciduous seasonal forest equivalent to Schimper' s (1903) monsoon forest (Monsoon forest). Both treat tropical monsoon forest or tropical deciduous seasonal forest as vegetation types with the same heat requirements as tropical rain forest but different moisture factors, 介于 between tropical rain forest and savanna.

According to Richards and Schimper' s classifications, Yunnan' s tropical climate should be 介于 between tropical wet-dry and tropical wet-dry with long dry season, with zonal vegetation theoretically being semi-evergreen seasonal forest and deciduous seasonal forest. However, due to Yunnan' s special topography and landforms, dense fog during the dry season and moist soil under local topography partially compensate for precipitation deficiency, creating locally more humid microclimates than regional climate. In these habitats, semi-evergreen seasonal forests have relatively fewer deciduous components and develop rain forest characteristics, becoming a type of tropical rain forest—tropical seasonal rain forest. In broader basins and valleys strongly influenced by monsoons, deciduous seasonal forests develop, i.e., monsoon forest as defined by Schimper (1903). Therefore, Yunnan' s monsoon forest, interdigitated horizontally with tropical seasonal rain forest and transitioning to tropical montane evergreen broad-leaved forest, is mainly controlled by moisture factors, consistent with Schimper' s (1903) definition of a vegetation type with the same heat requirements as tropical rain forest but different moisture factors, 介于 between tropical

rain forest and savanna (Zhu, 2011).

Yunnan' s monsoon forest is characterized by relatively short community height, generally 20-30 m, simple structure, typically one to two tree layers, with upper layer species shedding leaves during the dry season or both upper and lower layer species becoming leafless, i.e., having a distinct leafless period. Upper canopy trees typically have umbrella-shaped crowns with large crown widths, low branching, thick and crooked branches, thick and rough bark, and buttress roots. The forest interior is noticeably drier with fewer woody lianas and epiphytes. Representative tree species include *Bombax ceiba*, *Chukrasia tabularis* var. *velutina*, *Erythrina stricta*, *Lannea coromandelica*, *Sterculia pexa*, *Albizia odoratissima*, *Pterocarya tonkinensis*, *Albizia chinensis*, *Eriolaena kwangsiensis*, *Dalbergia obtusifolia*, *Lagerstroemia intermedia*, *Phyllanthus emblica*, *Bauhinia variegata*, *Dalbergia fusca*, *Anogeissus acuminata*, *Grewia eriocarpa*, *Colona floribunda*, *Spondias pinnata*, *Mayodendron igneum*, and *Mitragyna brunonis*.

In terms of life form composition, woody plants constitute the largest proportion at 48%, followed by herbaceous plants at 35%, and lianas at 16%. The entire community is dominated by phanerophytes, particularly medium phanerophytes at 28%, followed by small phanerophytes at 14%. Among herbaceous plants, hemicryptophytes dominate at 17%, followed by geophytes at 7%, annuals at 6%, herbaceous phanerophytes at 4%, and chamaephytes are the least at 1%.

Yunnan' s monsoon forest is dominated by families including Fabaceae, Asteraceae, Euphorbiaceae, Poaceae, Rubiaceae, Moraceae, Urticaceae, and Tiliaceae. In floristic composition, tropical distribution genera account for 80% of total genera. Among tropical distribution genera, pantropical distribution is highest at 34% of total genera, tropical Asian distribution accounts for 18%, tropical Asia to tropical Africa distribution for 10%, and Old World tropical distribution also for 10%.

Typical monsoon forest is a tropical deciduous forest vegetation type developed under tropical monsoon climate, 介于 between tropical rain forest and savanna, primarily controlled by moisture factors. Due to habitat moisture differences, Yunnan' s monsoon forest is interdigitated with tropical seasonal rain forest. Although typical monsoon forest is deciduous, transitional types in areas bordering seasonal rain forest exhibit some evergreen species, particularly in lower canopy layers. This transitional type has been defined by some scholars as semi-evergreen monsoon forest, and I agree with treating such semi-evergreen tropical forests transitional to seasonal rain forest as semi-evergreen monsoon forest. Thus, tropical monsoon forest is divided into two vegetation subtypes: deciduous monsoon forest (typical type) and semi-evergreen monsoon forest (transitional type).

In some Chinese botanical literature, evergreen or semi-evergreen tropical forests on limestone mountains have been termed "limestone monsoon forest" (Monsoon forest on limestone). I refer to these evergreen or semi-evergreen tropical forests on limestone mountains as "tropical seasonal moist forest" (Zhu et al., 1998,

2003, 2006a; Zhu, 2006, 2005, 2011; Zhu et al., 2015). Although such forests show deciduous components to varying degrees due to obvious seasonal drought effects, they differ in many aspects from Schimper' s (1903) defined monsoon forest. Schimper' s monsoon forest concept clearly refers to forest types where trees shed leaves simultaneously and completely during the dry season due to macroclimate. Seasonal drought in southern Yunnan is partially compensated by fog, dew, and low temperatures during these months. Seasonal moist forests on limestone mountains lack a distinct leafless period; some trees shed leaves at the end of the dry season, some even during the rainy season, and some grow new leaves while old leaves are falling. Therefore, deciduous phenomena in seasonal moist forests likely result primarily from local habitat dryness and historical factors rather than regional climatic drought. Adopting Schimper' s (1903) monsoon forest concept, this type of forest distributed on middle and upper limestone mountains in southern Yunnan, above the tropical seasonal rain forest zone at foothills and gullies, cannot be classified as monsoon forest. They represent a vegetation type on limestone mountain vertical belts. Their community physiognomy differs from monsoon forest, their floristic composition differs from tropical montane evergreen broad-leaved forest, and they develop on limestone mountains above the tropical seasonal rain forest zone. Based on their ecological-physiognomic characteristics, floristic composition, and habitat features, we consider "tropical seasonal moist forest" a more appropriate term for this evergreen or semi-evergreen limestone mountain forest type. Due to the special characteristics of their community physiognomy and floristic composition, we recommend treating them as a separate vegetation type in Yunnan' s vegetation classification system, representing a vegetation type on the vertical belt of limestone mountains in northern tropical Southeast Asia.

1.3 Seasonal Moist Forest

Tropical seasonal moist forest in southern Yunnan typically reaches 20-25 m in height, though some partially deciduous large trees may reach 30 m locally. The tree layer usually has two distinct strata; on sites with relatively rich, moist soils, a small tree layer about 2-3 m tall composed of saplings of upper layer trees may be visible below the main tree layer. Woody lianas are abundant, thick-leaved vascular epiphytes are common, and buttress roots and cauliflory are relatively rare. Due to maximum variation in topography and habitat on limestone slopes, these forests show obvious differences in physiognomy and floristic composition. This forest type appears evergreen on shady slopes, low hilltops, and upper portions of higher hills, but semi-evergreen in broader, drier limestone valleys and dry sunny slopes of middle and low hills.

These forests are dominated by Euphorbiaceae, Ulmaceae, Oleaceae, and Agavaceae.

Based on the proportion of deciduous tree species, they can be divided into two vegetation subtypes: tropical seasonal evergreen moist forest and tropical seasonal semi-evergreen moist forest. Seasonal evergreen moist forest occurs on

middle and lower slopes of limestone mountains at 600-1300 m elevation, from gentle hills to hilltops, with bedrock exposure often exceeding 90%. The forest is evergreen, 20-25 m tall, with abundant woody lianas and common small, thick-leaved vascular epiphytes. Seasonal semi-evergreen moist forest occurs on drier middle and lower slopes of limestone mountains and in broad mountain valleys, appearing semi-evergreen with deciduous tree species comprising 30-60% of upper tree layer species and 35-60% of importance value, with numerous small woody lianas and relatively low frequency of vascular epiphytes.

2 Distribution of Tropical Forest Vegetation in Yunnan

In Yunnan, tropical rain forest is mainly distributed in humid tropical regions with annual accumulated temperature 10°C 7500°C, mean temperature of the coldest month 15°C, and multi-year average of absolute minimum annual temperature 5°C. Tropical rain forest occurs on both acidic soils and limestone substrate soils; although community floristic composition differs, their ecological-physiognomic characteristics are similar. At higher classification levels, such as tropical seasonal rain forest, they represent the same type regardless of soil substrate. Yunnan' s tropical rain forest is mainly distributed in border areas from southwestern to southern to southeastern Yunnan, bordering Myanmar to the southwest, Laos to the south, and Vietnam to the southeast. Climate varies significantly with altitude in this region. Tropical seasonal rain forest is primarily distributed in locally moist habitats below 900-1000 m elevation, typically as discontinuous patches. Tropical montane rain forest may occur locally above the tropical seasonal rain forest zone.

Yunnan' s complex topography, with changes in terrain and landforms from southeastern to southwestern Yunnan, leads to obvious climate differentiation. Consequently, tropical seasonal rain forest shows some variation in species composition and ecological-physiognomic characteristics from southeastern to southwestern Yunnan, forming different community types of tropical seasonal rain forest, particularly differing in indicator species among various community types.

Southwestern and southern Yunnan are mainly influenced by the Indian Ocean monsoon, with similar tropical rain forest formations; southeastern Yunnan is also influenced by the East Asian monsoon, with relatively wetter climate, especially in mountainous areas with annual precipitation mostly above 2000 mm, possessing tropical rain forest formations somewhat different from southwestern and southern Yunnan.

Tropical rain forest formations in southeastern Yunnan are mainly distributed in lower reaches of the Nanxi, Yuan, Tengtiao, Lixian, and Xiaohei Rivers. In valley areas, mean annual temperature is 22-23°C and annual rainfall reaches 2000 mm. Zonal soils below 500 m elevation are mainly latosolic soil and yellow latosolic soil, at 500-1000 m are latosolic red soil, and above 1000 m are mountain yellow soil. Tropical seasonal rain forest in this region is mainly distributed in gully sections below 900 m elevation, while tropical montane rain forest occurs

on mountains above 900 m with abundant orographic rain, frequent cloud and fog, and high humidity.

Tropical rain forest in southern Yunnan is mainly distributed in Xishuangbanna Autonomous Prefecture and southwestern Simao region. Tropical seasonal rain forest generally occurs below 900-1100 m elevation and between 500-800 m in valley basins. Tropical montane rain forest is distributed in some mountainous moist habitats above 1000 m elevation. Mean annual temperature in this region is 20-22°C, annual rainfall is 1200-1500 mm with 80% concentrated in the rainy season, distinct wet and dry seasons, but heavy fog and dew during the dry season with annual average relative humidity around 80%. Below 800 m elevation, soils are latosolic soil, above 800 m are latosolic red soil, with brown and red limestone soils in local limestone areas.

Tropical rain forest in southwestern Yunnan is mainly distributed in areas bordering Myanmar, including parts of Dehong Prefecture and southwestern Lincang region. The entire area lies at the southern extension of the Nushan and Gaoligong Mountains of the Hengduan Mountain system, with terrain gradually decreasing from northeast to southwest. Most mountains are below 2000 m elevation, with valley basins at 400-850 m. Climate is controlled by the southwest monsoon, with mean annual temperature 19-21°C and annual rainfall 1200-1700 mm, 90% concentrated in the rainy season, with distinct wet and dry seasons. Soils below 900 m are latosolic soil, with black limestone soil in limestone areas, and red soil above 900 m. Tropical seasonal rain forest is mainly distributed in shady, moist gullies and low slopes below 800-900 m, while tropical montane rain forest occurs on mountains and in valleys above 800-900 m. This region' s tropical seasonal rain forest represents the northernmost tropical rain forest type in Yunnan, now mainly remaining in Nangun River National Nature Reserve and Yunnan Tongbiguan Nature Reserve.

Major seasonal rain forest formations in southeastern Yunnan include *Dipterocarpus retusus-Pometia tomentosa* forest, *Pometia tomentosa-Saraca dives* forest, *Parashorea chinensis* forest, and *Lysidice rhodostegia-Garcinia paucinervis* forest. In Xishuangbanna, southern Yunnan, major formations include *Antiaris toxicaria-Pouteria grandiflora* forest, *Pometia tomentosa-Terminalia myriocarpa* forest, and *Parashorea chinensis* forest. In southwestern Yunnan, major formations include *Duabanga grandiflora-Amoora tetrapetala* forest and *Shorea assamica* forest.

Tropical montane rain forest in southern Yunnan is dominated by formations such as *Mastixia euonymoides-Phoebe megacalyx* forest, *Parakmeria yunnanensis-Gymnanthes remota* forest, and *Calophyllum polyanthum-Semecarpus reticulata* forest; in southeastern Yunnan by *Madchuca pasquierii-Altingia yunnanensis* forest; and in southwestern Yunnan by *Alstonia scholaris-Semecarpus reticulata* forest.

Yunnan' s monsoon forest is mainly distributed below 1300 m elevation along open sections of major rivers and in broad valley basins strongly affected by

monsoons, such as sections of the Lancang, Nu, and Yuan Rivers and their tributaries, and valleys of the Nanpan, Amo, Babian, Daying, and Tengtiao Rivers, occurring as discontinuous patches. No obvious regional differentiation exists between monsoon forests in southeastern, southern, and southwestern Yunnan.

Yunnan' s tropical seasonal moist forest is typically distributed on middle and upper limestone mountains in southern Yunnan, above the tropical seasonal rain forest zone at foothills and gullies, representing a vegetation type on limestone mountain vertical belts.

3 Principles, Criteria, Units, and System for Classifying Tropical Forest Vegetation in Yunnan

Vegetation of Yunnan (Wu, 1987) employed the principle of integrating various basic characteristics of plant communities, emphasizing vegetation physiognomy, morphology, structure, and ecological features for higher classification units, and emphasizing species composition for middle and lower classification units. Based on the classification principles and criteria adopted in *Vegetation of Yunnan*, we believe that combining community ecological-physiognomic characteristics, species composition, and habitat features as vegetation classification principles and criteria can more objectively reflect the internal ecological relationships and external ecological expressions of Yunnan' s tropical forest plant communities, providing clearer identification features (Zhu et al., 2006a; Zhu, 2006, 2007; Zhu et al., 2015). This differs somewhat from the ecological classification principle emphasizing community physiognomy of the Anglo-American school (Warming, 1909), the floristic classification principle emphasizing species composition of the French-Swiss school (Braun-Blanquet, 1932), and the community classification emphasizing habitat and dynamic succession (Clements, 1916; Tansley, 1920). For higher classification units—vegetation types (including vegetation subtypes)—ecological-physiognomic (structural) characteristics are used, while for middle classification units—formations—species composition features are the main classification criteria.

Consistent with the classification units, system, and division standards of *Vegetation of Yunnan* (Wu, 1987), we continue to employ the classic three-level vegetation classification system: vegetation type (higher unit), formation (middle unit), and plant association (basic unit). Similarly, following general vegetation classification principles, if a vegetation type includes diverse and complex community types, auxiliary units are established as needed, i.e., vegetation subtypes below vegetation type. Vegetation subtypes are distinguished within vegetation types based on differences in community dominant synusia (in ecological-physiognomic characteristics) caused by habitat differences such as topography and altitude.

Due to species diversity in tropical rain forests, Aubréville (1938) proposed that upper canopy tree species composition in rain forest communities changes

continuously in time and space at local scales—the so-called mosaic or cyclical theory of regeneration. This theory later developed into the gap-phase regeneration theory, which considers tropical rain forests as mosaics of forest patches in three growth phases: gap phase, building phase, and mature phase, with the canopy always in a continuous state of floating floristic composition (Whitmore, 1989, 1990). In other words, in mixed tropical rain forest communities (non-single dominant communities), upper canopy floristic composition is variable, and as Richards (1952) stated, no true associations (formations) can be recognized within a large area of mixed rain forest—the entire mixed forest must be considered a single association (formation) with floating floristic composition. Therefore, classification of tropical rain forest communities is extremely difficult with no recognized standard. Classification and recognition of Yunnan' s tropical forest community types are also varied. Based on years of survey and research, we can only attempt classification at higher units (vegetation types) and middle units (formations), striving to provide clear and relatively stable identification features for each formation. Thus, based on available data, Yunnan' s tropical forest vegetation discussed in this paper can be divided into three main vegetation types: tropical rain forest, monsoon forest, and seasonal moist forest, including 45 relatively typical formations.

I. Tropical Rain Forest (Vegetation Type)
Ia. Tropical Seasonal Rain Forest (Vegetation Subtype)
- Form. *Lasiococca comberi* var. *pseudoverticillata* + *Celtis philippensis* var. *wightii*
- Form. *Pometia pinnata* + *Celtis philippensis* var. *wightii*
- Form. *Garuga floribunda* var. *gamblei* + *Pometia tomentosa*

Ib. Tropical Montane Rain Forest (Vegetation Subtype)
- Form. *Schima noronhae-Phoebe puwenensis*

II. Monsoon Forest (Vegetation Type)
IIa. Deciduous Monsoon Forest (Vegetation Subtype)
- Form. *Bauhinia variegata* + *Albizia chinensis*
- Form. *Eriolaena kwangsiensis* + *Sterculia pexa*

IIb. Semi-evergreen Monsoon Forest (Vegetation Subtype)
- Form. *Tetrameles nudiflora–Ulmus lanceaefolia*

III. Tropical Seasonal Moist Forest (Vegetation Type)
IIIa. Tropical Seasonal Evergreen Moist Forest (Vegetation Subtype)
- Form. *Lasiococca comberi* var. *pseudoverticillata–Cleistanthus sumatranus*
- Form. *Osmanthus polyneurus–Dracaena cochinchinensis*

IIIb. Tropical Seasonal Semi-evergreen Moist Forest (Vegetation Subtype)
- Form. *Bombax insignis–Garcinia bracteata*

Note: "+" indicates co-dominant species in the same tree layer, "–" indicates co-dominant species in different tree layers.

4.1.1 Tropical Seasonal Rainforest

(1) *Pometia tomentosa-Saraca dives* Forest
Mainly distributed in the Lixian River watershed of southeastern Yunnan, with *Pometia tomentosa* as the dominant upper canopy species, *Saraca dives* as the dominant middle canopy species, and *Sumbaviopsis albicans* as the dominant lower canopy species (see Zhou et al., 2001 for details).

(2) *Parashorea chinensis* + *Pometia tomentosa* Forest
Mainly distributed in low mountain gullies of Gulinqing, Maguan County and Nanxi River, Hekou County. The community reaches 45 m in height, with *Parashorea chinensis* as scattered emergent trees towering above the canopy. Beneath the *Parashorea* canopy, *Pometia tomentosa* is dominant, accompanied by *Canarium bengalense*, *C. album*, etc. The middle canopy is dominated by *Diospyros kerrii*, with common species including *Drypetes perreticulata*, *Deutzianthus tonkinensis*, *Pavieasia anamensis*, *Lysidice brevicalyx*, and *Garcinia paucinervis*. The lower canopy is dominated by *Trigonostemon thyrsoideum*, with other species including *Syzygium brachyanthrum* and *Arenga pinnata*.

(3) *Lysidice rhodostegia* + *Garcinia paucinervis* Forest
Mainly distributed on limestone mountains in Maguan and Hekou counties of southeastern Yunnan. The community reaches 30 m in height, with *Lysidice rhodostegia*, *Garcinia paucinervis*, and *Arenga pinnata* as dominant tree species.

(4) *Dipterocarpus retusus-Crypteronia paniculata* Forest
Mainly distributed in deeply incised, secluded gorges in the hinterland of Daweishan. Upper canopy trees reach 40 m, dominated by *Dipterocarpus retusus*, *Pometia tomentosa*, and *Litsea dilleniifolia*. Middle and lower canopy species mainly include *Crypteronia paniculata*, *Euodia rutaecarpa*, *Amesiodendron chinense*, *Aphanamixis polystachya*, *Caryota ochlandra*, *Barringtonia paniculata*, *Artocarpus petelotii*, *Mitrephora thorelii*, *Pseuduvaria indochinensis*, *Dysoxylum gobara*, *Dimocarpus longan*, and *Nephelium chryseum*.

(5) *Dipterocarpus retusus* + *Altingia excelsa* Forest
Mainly distributed in Jinping Fenshuiling Nature Reserve at 800-1000 m elevation. The community reaches 30-40 m in height, with *Dipterocarpus retusus* and *Altingia excelsa* as indicator species. Other common species include *Cyclobalanopsis austro-cochinchinenesis*, *Terminalia myriocarpa*, *Barringtonia paniculata*, and *Garcinia xanthochymus* (cited from Xu, 2002).

(6) *Antiaris toxicaria* + *Pouteria grandiflora* Forest
This formation is mainly distributed below 800 m on acidic soil mountains, hills, and terraces in Xishuangbanna, such as "dragon forests" preserved near villages. Due to rich species composition and diverse community types, even when formations are divided according to upper canopy indicator or dominant species, there are considerable differences in species composition, particularly among sub-dominant trees, among communities within the same formation. The up-

per canopy is dominated by *Antiaris toxicaria*, with *Pouteria grandiflora* and *Gironniera subaequalis* as sub-dominants. *Tetrameles nudiflora*, *Canarium album*, *Amoora dasyclada*, and *Neonauclea griffithii* may dominate in some communities or local sites, while *Pometia tomentosa* appears in gully sites with greater dominance or importance value. The middle canopy includes *Barringtonia paniculata*, *Garcinia cowa*, *Knema furfuracea*, and *Nephelium lappaceum* var. *pallens* with high presence and dominance. The lower canopy shows maximum presence of *Baccaurea ramiflora*, followed by *Aporosa yunnanensis*, *Acronychia pedunculata*, and *Ostodes paniculata*; *Pittosporopsis kerrii* and *Arytera littoralis* also dominate locally.

(7) *Lasiococca comberi* var. *pseudoverticillata* + *Celtis philippensis* var. *wightii* Forest

This formation reaches about 30 m in height with distinct stratification, co-dominated by *Lasiococca comberi* var. *pseudoverticillata* and *Celtis philippensis* var. *wightii*. Other common species include *Sumbaviopsis albicans*, *Cleidion spiciflorum*, *Alphonsea mollis*, *Caryota urens*, and *Metadina trichotoma*. Deciduous species in the tree layer include *Chukrasia tabularis*, *Garuga pinnata*, and *Tetrameles nudiflora*. This is the most common limestone mountain seasonal rain forest type.

(8) *Pometia tomentosa* + *Terminalia myriocarpa* Forest

This formation is mainly distributed along gullies on narrow valley slopes at 550-900 m elevation in southern Yunnan, most concentrated at 600-700 m in gullies. It occurs in Xishuangbanna and Nangun River Nature Reserve in Cangyuan, with relatively few deciduous species in the upper canopy and significantly more epiphytes and large woody lianas. The formation is indicated by *Pometia tomentosa* and *Terminalia myriocarpa*, with *Pometia tomentosa* as the upper canopy dominant and *Terminalia myriocarpa* as sub-dominant or locally dominant. Upper canopy deciduous representative species is mainly *Garuga floribunda* var. *gamblei*. Middle canopy species with maximum presence include *Garcinia cowa* and *Knema furfuracea*, while *Lasiococca comberi* var. *pseudoverticillata*, *Barringtonia fusicarpa*, *Mitrephora maingayi*, *Pseuduvaria indochinensis*, and *Neonauclea tsaiana* may dominate locally. Lower canopy species with high presence include *Horsfieldia pandurifolia* and *Syzygium latilimbum*, with *Baccaurea ramiflora* and *Cleidion brevipetiolatum* as sub-dominants.

(9) *Pometia pinnata* + *Celtis philippensis* var. *wightii* Forest

This formation is distributed in the most humid limestone gully bottoms or lower slopes, usually with rich soils. Community height is typically 35-40 m, dominated by *Pometia pinnata*, with *Celtis philippensis* var. *wightii*, *Lasiococca comberi* var. *pseudoverticillata*, and *Alphonsea monogyna* as sub-dominants or co-sub-dominants in different sites. The physiognomy and vertical structure of this formation are essentially the same as non-limestone mountain moist seasonal rain forest, with the vast majority of species shared between the two types except for a few endemic components. Due to rock distribution in limestone mountain soils, tree density is lower, making the forest interior appear more open.

(10) *Acrocarpus fraxinifolius* + *Duabanga grandiflora* Forest
This formation is mainly distributed in steep gully slopes in Nabang River Basin National Nature Reserve (Guomenshan Station). It represents a transitional type between seasonal rain forest and monsoon forest. The tree layer is divided into three strata. The upper layer reaches 30-50 m, with mosaic-connected crowns covering 70%, featuring *Acrocarpus fraxinifolius* as scattered emergent trees up to 50 m tall with umbrella-shaped, even crowns as a deciduous species. *Duabanga grandiflora* is the dominant species with maximum importance value. The middle layer at 15-30 m is dominated by *Syzygium megacarpum*, accompanied by *Cryptocarya yunnanensis*, *Turpinia pomifera*, and *Knema erratica*, covering 40-50%. The lower layer at 5-15 m includes *Alseodaphne petiolaris*, *Baccaurea ramiflora*, and *Gomphandra tetrandra*.

(11) *Dracontomelon macrocarpum* + *Pometia pinnata* Forest
This formation is mainly distributed in valley bottoms of Xiaonanman River, Longmen Yakouqing, Nanmuha River in Shangyong sub-reserve, and Mandan Reservoir, Nanbang River in Mengla sub-reserve of Xishuangbanna. Community height is 35-45 m. Upper canopy coverage is 30-35%, dominated by *Dracontomelon macrocarpum* and *Pometia pinnata*, followed by *Semecarpus reticulatus* and *Canarium album*. Middle canopy coverage is 35-40%, dominated by *Wrightia laevis* and *Beilschmiedia pauciflora*, followed by *Dysoxylum gotadhora* and *Walsura pinnata*. Lower canopy coverage is 40-45%, dominated by *Baccaurea ramiflora* and *Diospyros xishuangbannaensis*, followed by *Oreocnide frutescens* and *Ficus cyrtophylla*.

(12) *Sapium baccatum* + *Pouteria grandifolia* Forest
This formation is mainly distributed in moist gullies and lower slopes below 1000 m in Damenglong area of Xishuangbanna. Upper canopy species include *Sapium baccatum*, *Pometia pinnata*, *Pouteria grandiflora*, *Cinnamomum glanduliferum*, *Artocarpus nitidus*, *Nephelium chryseum*, and *Mangifera sylvatica*. The middle canopy is dominated by *Walsura pinnata*, with abundant *Mayodendron igneum*. Lower canopy dominants include *Aidia yunnanensis*, *Phoebe lanceolata*, *Baccaurea ramiflora*, *Dichapetalum gelonioides*, and *Pittosporopsis kerrii*.

(13) *Parashorea chinensis* Forest
Yunnan' s southern *Parashorea chinensis* forest is only distributed in about 20 km² of Bubeng District, Mengla County, intermittently along several tributaries and moist gullies at 700-950 m elevation. It is primarily a single-dominant community with *Parashorea chinensis* (Dipterocarpaceae) as the upper canopy dominant, *Pometia pinnata* as sub-dominant, middle layer dominated by *Garcinia cowa*, and lower layer dominated by *Pittosporopsis kerrii* and *Pittosporopsis kerrii*. This community is the most tropical, species-rich, and rain forest-characteristic community in Xishuangbanna' s seasonal rain forest (see Zhu, 1992 for details).

(14) *Vatica guangxiensis* Forest
In addition to the single-dominant *Parashorea chinensis* community, another

dipterocarp, *Vatica guangxiensis* (called "qingmei forest"), occurs as a characteristic or indicator species on steep slopes of several tributaries at 800-1100 m elevation. *Vatica* forest still belongs to tropical seasonal rain forest in nature, but due to relatively high distribution altitude and special habitat, represents a transitional type between seasonal rain forest and montane rain forest, as well as an altitudinal 极限 limit type of seasonal rain forest in northern tropical regions.

The community reaches about 45 m in height with three tree layers. The upper layer at 30-45 m consists of scattered *Vatica guangxiensis* emergent trees and other large trees with spherical or umbrella-shaped, non-connected crowns creating an uneven canopy with 40-60% coverage. The middle layer at 18-30 m comprises mixed species with mostly elliptical crowns, greater density, nearly continuous canopy, and 50-70% coverage. The lower layer at 5-20 m consists of saplings of upper and middle layer species and mixed small trees with conical, non-connected crowns and 40-50% coverage. Upper canopy trees are basically evergreen except for a few semi-deciduous species with obvious leaf exchange periods, while middle and lower canopy trees are entirely evergreen (see Zhu, 1993c for details).

(15) *Duabanga grandiflora* + *Amoora tetrapetala* Forest
Mainly distributed in narrow bands along gullies and steep river banks in Ruili area. This tropical seasonal rain forest community reaches about 30 m in height, with main tree species including *Duabanga grandiflora*, *Amoora tetrapetala*, *Pterospermum kingtungense*, *Canarium album*, *Sapium baccatum*, *Artocarpus lacucha*, *Carallia brachiata*, *Knema cinerea*, *Garcinia xanthochymus*, and *Baccaurea ramiflora*.

(16) *Shorea assamica* Forest
This formation is mainly distributed in shady, moist gullies and low slopes below 800-900 m in Yingjiang Tongbiguan Nature Reserve, also occurring in gullies of Ruili Moli Forest Park. The community reaches 35-40 m in height, with *Shorea assamica* as the indicator species in the upper canopy. Species with high importance values include *Dracontomelon macrocarpum* and *Gironniera subaequalis*, with *Dipterocarpus retusus* also present. Other tree layer species include *Knema furfuracea*, *Taraktogenos annamensis*, *Saraca griffithina*, *Sumbaviopsis albicans*, and *Baccaurea ramiflora*.

(17) *Pometia tomentosa* + *Hydnocarpus banhongensis* Forest
This formation appears in gullies below 1000 m in Nangun River Nature Reserve, Cangyuan. The community reaches 40-45 m in height, with *Hydnocarpus banhongensis* as the most dominant species and *Pometia tomentosa* as sub-dominant. Other tree species include *Cinnamomum bejolghota*, *Horsfieldia kingii*, *Syzygium latilimbum*, and *Pittosporopsis kerrii* (cited from Yang & Du, 2004).

(18) *Syzygium tetragonum* + *Pometia tomentosa* Forest
This formation appears on valley slopes below 900 m in Nangun River Nature Reserve, Cangyuan. The community reaches 40 m in height, dominated

by *Syzygium tetragonum*. Other common species include *Pometia tomentosa*, *Tetrameles nudiflora*, *Terminalia myriocarpa*, *Gironniera subaequalis*, *Chukrasia tabularis*, *Elaeocarpus varunua*, *Garcinia xanthochymus*, *Litsea panamonja*, *Dysoxylum lenticellatum*, *Syzygium latilimbum*, and *Cleidion spiciflorum* (cited from Yang & Du, 2004).

(19) *Garuga floribunda* var. *gamblei* + *Pometia tomentosa* Forest
This formation is mainly distributed in moist gully bottoms below 1200 m in Caiyanghe Nature Reserve, Simao, occurring in strips along gullies. The community reaches over 35 m in height, with massive buttress roots on upper canopy trees that tower above the main canopy as scattered emergent trees 25-35 m tall with about 50% crown cover, dominated by *Garuga floribunda* var. *gamblei* and *Pometia tomentosa*. Associated species include *Duabanga grandiflora*, *Terminalia myriocarpa*, *Semecarpus reticulatus*, and *Sapium baccatum*. The middle layer at 10-25 m height has 50% coverage, composed of evergreen species dominated by *Alphonsea monogyna*, accompanied by *Garcinia cowa*, *Cinnamomum bejolghota*, *Mitrephora maingayi*, *Horsfieldia kingii*, *Mayodendron igneum*, *Celtis timorensis*, *Lithocarpus grandifolius*, and *Garcinia xanthochymus*. The lower layer at 3-10 m height has 50% coverage, dominated by *Cleidion spiciflorum*, with common species including *Baccaurea ramiflora*, *Ostodes paniculata*, *Phoebe puwenensis*, *Trigonostemon thyrsoideum*, *Pittosporopsis kerrii*, *Phoebe lanceolata*, *Turpinia pomifera*, and *Saprosma ternandra*.

4.1.2 Tropical Montane Rainforest

(1) *Hopea mollissima–Nephelium chryseum* Forest
This formation is mainly distributed in gullies at 800-1100 m elevation. Community height is 25-30 m, with the upper canopy forming a relatively dense, sometimes roughly continuous canopy layer. Main species include *Hopea mollissima*, *Nephelium chryseum*, *Gironniera subaequalis*, *Alniphyllum eberhardtii*, *Castanopsis megaphylla*, *Rehderodendron membranifolium*, and *Styrax argentifolia*. Other common species include *Garcinia cowa*, *Pellacalyx yunnanensis*, *Litchi chinensis*, *Cinnamomum tonkinense*, *C. bejolghota*, *Schefflera delavayi*, *Cinnamomum iners*, *Lipisunthes sengalensis*, *Memecylon polyanthum*, and *Macaranga henryi*.

(2) *Altingia excelsa* Forest
Mainly distributed at 800-1100 m elevation in Daweishan Nature Reserve. The community reaches 35 m in height, forming a single-dominant community composed of *Altingia excelsa*. Other tree species include *Exbucklandia populnea*, *Betula alnoides*, *Machilus bombycina*, *Michelia balansae*, *Schima wallichii*, *Cinnamomum austro-yunnanensis*, *Amoora tetrapetala*, and *Schefflera hoi*.

(3) *Madchuca pasquierii* + *Altingia yunnanensis* Forest
This formation is mainly distributed above 1000 m elevation in Daweishan and Huangliangshan. Height reaches 30-40 m, with *Madchuca pasquierii* and *Altingia yunnanensis* as upper canopy dominants. Other common species in-

clude *Podocarpus imbricatus*, *Eberhardtia aurata*, *Mytilaria laosensis*, *Rhodoleia paivipetala*, *Beilschmiedia fasciata*, *Michelia foveolata*, *Lithocarpus truncatus*, and *Castanopsis tonkinensis*. Lower canopy species commonly include *Fokienia hodginsii*, *Cinnamomum tonkinense*, *Actinodaphne forrestii*, *Elaeocarpus subpetiolatus*, *Carallia diphpetala*, *Tutcheria spectabilis*, *Rhoiptelea chiliantha*, *Cryptocarya depauperata*, *Macaranga henryi*, *Lithocarpus megaphylla*, and tree ferns.

(4) *Metadina trichotoma–Syzygium cathayense* Forest
This formation is mainly distributed in southern Yunnan, with three relatively distinct tree layers. The upper layer at 25-40 m consists of tall trees with 70-80% coverage, mainly umbrella-shaped crowns forming the canopy layer. Main species include *Metadina trichotoma*, *Canarium album*, *Elaeocarpus austroyunnanensis*, *Paramichelia baillonii*, *Actinodaphne henryi*, *Beilschmiedia purpurascens*, and *Podocarpus neriifolius*. The middle layer at 10-25 m has 50-70% coverage, dominated by *Syzygium cathayense*, with other species including *Knema erratica*, *Syzygium forrestii*, *Streblus indicus*, *Garcinia cowa*, *Harpullia cupanioides*, and *Arytera littoralis*. The lower layer at 5-10 m has 30-40% coverage, dominated by *Oxyceros griffithii* and *Aporosa yunnanensis*, with other species including *Dichapetalum gelonioides* and *Turpinia montana*.

(5) *Metadina trichotoma–Pittosporopsis kerrii* Forest
This formation is mainly distributed in southern Yunnan. The upper layer at 25-35 m has 70-80% coverage, dominated by *Metadina trichotoma* and *Castanopsis mekongensis*, with other species including *Schima wallichii*, *Garuga floribunda* var. *gamblei*, *Alseodaphne petiolaris*, *A. andersonii*, *Semecarpus reticulatus*, *Homalium ceylanicum*, *Neonauclea griffithii*, and *Paramichelia baillonii*. The middle layer at 10-25 m has 50-70% coverage, dominated by *Phoebe puwenensis*, *Baccaurea ramiflora*, *Knema furfuracea*, *Machilus bombycina*, and *Lithocarpus truncatus*. The lower layer at 5-10 m has 30-40% coverage, dominated by *Pittosporopsis kerrii*, with other species including *Phoebe lanceolata*, *Syzygium forrestii*, *Aporosa yunnanensis*, *Actinodaphne henryi*, and *Turpinia pomifera*.

(6) *Mastixia euonymoides–Phoebe megacalyx* Forest
This formation is mainly distributed in southern Yunnan along mountain gullies, with three relatively distinct tree layers. The upper layer at 22-35 m has over 80% coverage, forming the canopy layer with main species including *Mastixia euonymoides*, *Nyssa wenshanensis*, *Manglietia hookeri*, *Michelia cavaleriei*, *Alcimandra cathcartii*, *Michelia hedyosperma*, and *Calophyllum polyanthum*. The middle layer at 11-20 m has 70-80% coverage, dominated by *Phoebe megacalyx*, *Dysoxylum gotadhora*, *Syzygium globiflorum*, and *Helicia pyrrhobotrya*. The lower layer at 5-10 m has 40-50% coverage, dominated by *Cylindrokelupha kerrii*, *Cryptocarya rolletii*, *Litsea cangyuanensis*, *L. verticillata*, and *Ardisia thyrsiflora*.

(7) *Parakmeria yunnanensis–Gymnanthes remota* Forest
This formation is mainly distributed in southern Yunnan. The upper layer at 20-25 m is dominated by *Parakmeria yunnanensis*, with other species includ-

ing *Acer laurinum*, *Podocarpus neriifolius*, *Craibiodendron stellatum*, *Manglietia insignis*, *Nyssa wenshanensis*, and *Alcimandra cathcartii*. The middle and lower layers at 5-20 m have 70-80% coverage, mainly composed of medium and small diameter trees. Dominant species include *Gymnanthes remota*, with other species including *Xanthophyllum yunnanense*, *Syzygium globiflorum*, *Gomphandra tetrandra*, *Calophyllum polyanthum*, *Dimocarpus yunnanensis*, *Cinnamomum bejolghota*, and *Lindera metcalfiana* var. *dictyophylla*.

(8) *Semecarpus reticulatus* + *Calophyllum polyanthum* Forest
This formation is mainly distributed at 1000-1500 m elevation in southern Yunnan. The community reaches 30 m in height, with the upper canopy dominated by *Semecarpus reticulatus* and *Calophyllum polyanthum*, accompanied by *Alstonia scholaris*, *Cinnamomum bejolgota*, and *Reevesia siamensis*. The lower canopy mainly includes *Phoebe nanmu*, *Knema globularia*, *Garcinia xanthochymus*, *Beilschmiedia robusta*, *Acronychia pedunculata*, and *Turpinia pomifera*.

(9) *Sladenia celastrifolia*–*Lithocarpus randifolius* Forest
This formation is mainly distributed above 900 m in Tongbiguan Nature Reserve. The community reaches 20-30 m in height, with the upper canopy dominated by *Sladenia celastrifolia* and *Lithocarpus randifolius*. Other common species include *Castanopsis rockii*, *Phoebe puwenensis*, *Helicia nilagirica*, *Calophyllum polyanthum*, and *Schima wallichii* (cited from Yang & Du, 2006).

(10) *Altingia excelsa* + *Artocarpus pithecogallus* Forest
This formation is mainly distributed above 900 m in Tongbiguan Nature Reserve. The community reaches 20-25 m in height, with the upper canopy dominated by *Altingia excelsa* and *Artocarpus pithecogallus*. Other common species include *Beilschmiedia robusta*, *Cryptocarya yunnanensis*, *Lithocarpus truncatus*, *Helicia clivicola*, *Schima wallichii*, and *Meliosma arnottiana* (cited from Yang & Du, 2006).

(11) *Alstonia pachycarpa* + *Semecarpus reticulata* Forest
This formation is distributed above 900 m in both Xishuangbanna and Tongbiguan Nature Reserve, southwestern Yunnan. The community reaches 20-25 m in height, with the upper canopy dominated by *Alstonia pachycarpa* and *Semecarpus reticulata*. Other common species include *Dysoxylum hainanensis*, *Ailanthus fordii*, *Lithocarpus randifolius*, *Knema furfuracea*, *Phoebe puwenensis*, and *Beilschmiedia robusta* (cited from Yang & Du, 2006).

(12) *Schima noronhae*–*Phoebe puwenensis* Forest
This formation occurs in mountainous areas at 1200-1350 m elevation in Nangun River National Nature Reserve. The community reaches 30 m in height, with *Schima noronhae* as the dominant tree species and *Phoebe puwenensis* as subdominant. Other common species include *Lithocarpus randifolius*, *Paramichelia baillonii*, *Cinnamomum bejolghota*, *Garcinia cowa*, *Beilschmiedia robusta*, *Manglietia fordiana*, *Pterospermum yunnanensis*, *Sapindus rarak*, *Chisocheton siamensis*, and *Harpullia cupanioides* (cited from Yang & Du, 2004).

4.2.1 Deciduous Monsoon Forest

(1) *Pterocarya tonkinensis* Forest
Pterocarya tonkinensis (Juglandaceae) is a common species in riparian monsoon forests of tropical Southeast Asia, forming narrow, linear bands along major river banks as typical single-dominant communities. As a special tropical riparian type, it represents a characteristic community type of riparian deciduous monsoon forest. For example, typical *Pterocarya tonkinensis* forest occurs on riverine alluvial or flood terraces at 480-650 m elevation along open sections of the Luosuo River in southern Yunnan.

The *Pterocarya tonkinensis* community shows distinct seasonal changes, representing a typical tropical riparian vegetation type developed under tropical monsoon climate conditions. The tree layer is deciduous during the dry season, presenting typical deciduous monsoon forest physiognomy. Community height is about 25 m with total coverage of about 80%.

(2) *Bombax ceiba* Forest
Bombax ceiba is a characteristic species of monsoon forest and savanna in tropical Asia, usually scattered or occurring in mixed deciduous forests, but forming relatively large areas on alluvial, flood, or colluvial terraces of some valleys in Yunnan.

(3) *Anogeissus acuminata* Forest
Anogeissus acuminata is a characteristic species of mainland Southeast Asian tropical deciduous monsoon forest, often forming single-dominant communities in semi-humid regions of the Indo-Burma area. It occurs in monsoon forest in the Jieyang River valley, Yingjiang, southwestern Yunnan, and the Mengyang area, southern Yunnan, forming large single-dominant communities in the Xiaoxianggan Lancang River valley, southern Yunnan.

Anogeissus acuminata forest has typical monsoon forest physiognomy, with two distinct tree layers. The first layer reaches 25-30 m, with umbrella-shaped, non-connected crowns covering about 40%, absolutely dominated by *Anogeissus acuminata*. The second layer at 10-15 m forms a closed canopy dominated by *Dendrocalamus* species. Associated species in both layers include *Sterculia villosa*, *Dalbergia obtusifolia*, *D. yunnanensis*, *Grewia eriocarpa*, *Lannea coromandelica*, and *Dalbergia cultrata* (see Wang & Zhu, 1990 for details).

(4) *Lannea coromandelica* + *Albizia odoratissima* Forest
This formation is distributed in the lower Luozha River valley, Yunnan County, at 950-1200 m elevation. The community reaches 15-20 m in height. The first tree layer is composed of deciduous *Lannea coromandelica*, *Albizia odoratissima*, and *Bombax cambodiense* with pure white flowers, with occasional individuals exceeding 20 m. The second layer at 5-10 m includes *Mallotus philippensis*, *Phyllanthus emblica*, *Colona floribunda*, and *Eriolaena spectabilis*.

(5) *Bauhinia variegata* + *Albizia chinensis* Forest
This formation is mainly distributed along the Nanwan River banks in Ruili at

800-900 m elevation. The tree layer is dominated by *Bauhinia variegata* and *Albizia chinensis*, with other common species including *Bombax ceiba*, *Schima wallichii*, *Stereospermum tetragonum*, *Toona ciliata* var. *pubescens*, *Colona floribunda*, and *Morus macroura* (cited from Yang & Du, 2006).

(6) *Lannea coromandelica* + *Garuga forrestii* Forest
This formation is widely distributed on slopes at 560-800 m elevation in the Lüzhi River valley, a tributary of the Yuan River. Community height is 15-20 m with distinct seasonal changes. The tree layer has two obvious strata. The first layer forms a continuous canopy with over 90% closure, with umbrella-shaped, large crowns. Main species include deciduous *Lannea coromandelica*, *Garuga forrestii*, *Haldina cordifolia*, *Chukrasia tabularis* var. *velutina*, and evergreen *Albizia odoratissima*. The second layer at 5-10 m has about 30% closure, mainly composed of evergreen *Cipadessa cinerascens* and *Pistacia weinmannifolia*, *Polyalthia cerasoides*, plus deciduous *Sapium insigne*, *Woodfordia fruticosa*, and *Phyllanthus emblica*.

(7) *Eriolaena kwangsiensis* + *Sterculia pexa* Forest
This formation is distributed on low mountains and hills along both banks of the Sinan River and its tributaries. Community height is about 20 m, with the tree layer mainly composed of deciduous *Eriolaena kwangsiensis*, *Sterculia pexa*, *Colona floribunda*, *Albizia chinensis*, *Lagerstroemia intermedia*, *Phyllanthus emblica*, *Stereospermum colais*, and *Kydia calycina*. Evergreen species in the tree layer include *Dalbergia obtusifolia*, *Pistacia weinmannifolia*, and *Cipadessa cinerascens*, with *Dendrocalamus membranaceus* present in severely disturbed communities.

4.2.2 Semi-evergreen Monsoon Forest

(1) *Lannea coromandelica* + *Sterculia pexa* Forest
The semi-evergreen forest on both banks of the lower Lancang River, with deciduous *Lannea coromandelica* and *Sterculia pexa* as dominant and indicator species, represents a monsoon forest type. It has the basic structure and characteristics of monsoon forest, but due to relatively high distribution altitude and latitude and its location in the transition zone between humid-hot and dry-hot valleys of the Lancang River, it differs somewhat from typical monsoon forest in community characteristics, containing a certain number of evergreen species as a semi-evergreen monsoon forest. Although *Lannea coromandelica* + *Sterculia pexa* forest is distributed in valleys of the middle and lower Lancang River and its tributaries, most has been destroyed and replaced by secondary bamboo forest dominated by *Dendrocalamus membranaceus*. Only a few well-preserved forest communities dominated by *Lannea coromandelica* and *Sterculia pexa* remain in Nuozhadu Nature Reserve along the Lancang River. They are mainly distributed on low hills and mountains below 900 m elevation along both banks of the Lancang River and its tributaries.

Lannea coromandelica + *Sterculia pexa* forest reaches about 20-25 m in height,

typically with 1-2 tree layers. The first layer is mainly composed of deciduous *Lannea coromandelica*, *Sterculia pexa*, *Stereospermum colais*, and *Albizia odoratissima*, with over 80% coverage. The second layer mainly includes evergreen *Pistacia weinmanniifolia* and *Cipadessa baccifera*, plus deciduous *Eriolaena kwangsiensis*, *Dendrocalamus membranaceus*, and *Phyllanthus emblica*, with 20-30% coverage.

(2) *Bombax insignis-Dalbergia burmanica* Forest
This formation is mainly distributed in the Daying River valley at 330-600 m elevation. The community reaches 20-30 m in height, with deciduous components accounting for 65%, dominated by *Bombax insignis* and *Dalbergia burmanica*. Other species include *Protium serratum*, *Dalbergia obtusifolia*, *Stereospermum neuranthum*, and *Terminalia hainanensis* (cited from Yang & Du, 2006).

(4) *Trameles nudiflora-Ulmus lanceaefolia* Forest
This formation is distributed in Nangun River Nature Reserve. The tree layer is dominated by *Tetrameles nudiflora*, with other species including *Terminalia myriocarpa*, *Engelhardtia spicata*, *Ulmus lanceaefolia*, *Lannea coromandelica*, *Mayodendron igneum*, and *Kydia calycina* (cited from Yang & Du, 2004).

4.3.1 Seasonal Evergreen Moist Forest

(1) *Lasiococca comberi* var. *pseudoverticillata-Cleistanthus sumatranus* Forest
This formation occurs on dry limestone middle and lower mountain slopes at 600-800 m elevation in Menglun and Mengxing areas of southern Yunnan. The community typically reaches 20-25 m in height. Deciduous large trees in the upper canopy such as *Tetrameles nudiflora*, *Garuga pinnata*, and *Chukrasia tabularis* var. *velutina* are sparsely distributed with large crowns covering about 30%. The lower tree layer at 5-16 m has over 80% coverage, absolutely dominated by *Cleistanthus sumatranus*, followed by *Lasiococca comberi* var. *pseudoverticillata*, accompanied by *Celtis philippensis*, *Glycosmis esquirolii*, *Mayodendron igneum*, and *Alphonsea monogyna*. On hilltops with more rock than soil, *Cleistanthus* individuals are dwarfed, forming hilltop dwarf forests with *Pistacia weinmannifolia*. In some moist mountain gullies and terraces, *Lasiococca comberi* var. *pseudoverticillata* is most dominant, followed by *Cleistanthus sumatranus* and *Croton crassifolius*.

(2) *Osmanthus polyneurus-Dracaena cochinchinensis* Forest
This formation is distributed on mountains or upper hill slopes above 1000 m elevation in Jinuo Mountain area of southern Yunnan. The community reaches about 20 m in height, with the upper canopy dominated by *Osmanthus polyneurus*. The lower canopy is dominated by *Dracaena cochinchinensis*, with other common species including *Tarenna attenuata*, *Wrightia arborea*, *Sterculia villosa*, and *Murraya tetramera*.

4.3.2 Seasonal Semi-evergreen Moist Forest

(1) *Bombax insignis-Colona floribunda* Forest

This formation is mainly distributed on dry limestone slopes below 1200 m elevation in southern Yunnan, with 30-50% bedrock exposure and relatively large forest area. The community reaches 20-25 m in height, with the upper canopy indicated or dominated by *Bombax insignis*. Associated species mainly include *Erythrina subumbrans*, *Acrocarpus fraxinifolius*, *Ulmus lanceifolia*, and *Spondias pinnata*. The lower canopy is dominated by *Colona floribunda*, with other common species including *Kydia calycina*, *Schima wallichii*, *Mallotus philippensis*, and *Ehretia tsangii*; on completely rocky sites, *Pistacia weinmanniifolia* is dominant.

(2) *Bombax insignis-Garcinia bracteata* Forest

This formation is mainly distributed on typical limestone middle and upper slopes in Mengyuan-Mankang River area of southern Yunnan, at 900-1300 m elevation, in dry habitats with basically no soil, where trees grow in rock crevices. The upper canopy is dominated by *Bombax insignis*, typically 20-25 m tall but reaching 40 m in large rock crevices. Other species include *Tetrameles nudiflora* and *Garuga floribunda* var. *gamblei*. The lower canopy is dominated by *Garcinia bracteata* and *Dracaena cochinchinensis*, with other common species including *Dendrocnide sinuata*, *Glycosmis esquirolii*, *Celtis timorensis*, *Sumbaviopsis albicans*, and *Dysoxylum lukii*.

5 Discussion and Conclusions

Yunnan' s tropical forest vegetation includes three main vegetation types: tropical rain forest, monsoon forest, and seasonal moist forest. Following international classification conventions for similar vegetation, tropical rain forest is divided into two vegetation subtypes based on distribution, habitat, and characteristics: lowland rain forest and its montane variant—montane rain forest. Yunnan' s lowland rain forest occurs on the northern margin of monsoon tropics, containing a certain proportion of deciduous tree species in the canopy layer with relatively obvious seasonal changes in physiognomy, representing a tropical rain forest type developed at the 极限 limits of moisture, heat, and altitude requirements. Chinese scholars have designated it as tropical seasonal rain forest. In previous botanical literature, some scholars distinguished lowland rain forest in southeastern Yunnan as humid rain forest, differentiating it from seasonal rain forest in southern and southwestern Yunnan. However, the so-called humid rain forest in southeastern Yunnan differs significantly from lowland humid rain forest in non-seasonal areas of tropical Asia, while being ecologically and physiognomically similar to seasonal rain forest in southern and southwestern Yunnan. Both occur on the northern margin of monsoon tropics, contain more or less deciduous tree species in the canopy layer, and show minor compositional differences, and should be treated as the same vegetation subtype, both belonging to tropical seasonal rain forest. This paper recommends eliminating the designation of so-called humid rain forest in southeastern Yunnan.

Yunnan' s monsoon forest, like Southeast Asian monsoon forest, is a tropical deciduous or semi-evergreen forest vegetation type developed under tropical monsoon climate with distinct wet and dry seasons. In some Chinese botanical literature, "monsoon forest" is broadly used to refer to a vegetation type distributed on the northern margin of China's tropics, considered a vegetation type 介于 between tropical rain forest and subtropical evergreen broad-leaved forest belonging to latitudinal zonal vegetation, though some scholars have questioned this usage. The term monsoon forest was proposed by Schimper (1903) to refer to a tropical deciduous forest vegetation type developed under tropical monsoon climate, 介于 between tropical rain forest and savanna, also called deciduous seasonal forest (Richards, 1996). Based on Schimper' s definition, this paper treats tropical deciduous forest vegetation mainly distributed along open sections of major rivers and broad valley basins strongly affected by monsoons as typical monsoon forest, and treats semi-evergreen tropical vegetation in areas bordering seasonal rain forest that contains some evergreen species, particularly in lower canopy layers, as semi-evergreen monsoon forest, a subtype of monsoon forest vegetation. This paper also applies the term "tropical seasonal moist forest" to evergreen or semi-evergreen tropical forest vegetation on limestone mountains previously called "limestone monsoon forest" in some Chinese botanical literature, because their canopy lacks a distinct leafless period, and their deciduous phenomenon likely results primarily from local habitat dryness and historical factors rather than regional climatic drought, differing in many aspects from Schimper' s (1903) defined monsoon forest where trees shed leaves simultaneously and completely during the dry season due to macroclimate. Seasonal semi-evergreen moist forest in tropical seasonal moist forest is ecologically and physiognomically similar to semi-evergreen monsoon forest, but seasonal semi-evergreen moist forest typically occurs on middle and upper limestone mountains in southern Yunnan, above the tropical seasonal rain forest zone at foothills and gullies, representing a vegetation type on limestone mountain vertical belts, while semi-evergreen monsoon forest is horizontally transitional with seasonal rain forest, a type 介于 between tropical rain forest and savanna, with obvious differences in floristic composition.

Yunnan's tropical forest vegetation classification is relatively similar to Guangxi' s tropical forest vegetation classification and early Hainan vegetation classification, but differs substantially from various later Hainan vegetation classifications. We recommend that researchers systematically review Hainan' s tropical forest vegetation classification system.

Yunnan' s topography and landforms are extremely complex, with climate and natural vegetation changing dramatically over short distances, creating a complex distribution pattern of various vegetation types. Regardless of latitude, tropical vegetation is typically distributed in areas below 1200-1300 m elevation. The tropical forest vegetation summarized in this paper is based only on available survey and research materials, and does not include all formations of Yunnan's tropical forest vegetation. We believe that continued in-depth surveys will continuously add new formations and gradually improve research on Yun-

nan' s tropical forest vegetation. As stated in the preamble, this paper provides a comprehensive summary of Yunnan' s tropical forest vegetation for reference in Yunnan' s ecological conservation red line demarcation, research on Yunnan and neighboring tropical forest vegetation, and for forestry and environmental protection workers.

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Note: Figure translations are in progress. See original paper for figures.