



## Notes on the key role of stenochoric endemic plants in the floristic regionalization of Yunnan



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## ABSTRACT

With the accumulation and accessibility of information about plant species, it is time to re-evaluate and further divide a global biodiversity hotspot region, Yunnan, located in southwestern China. In this study, we combined data on the distribution of 1010 stenochoric endemic seed plants, vegetation constitution, geological history and climate change, and used these to propose a new system of floristic regions. We identified 11 distinct floristic subregions and 84 floristic provinces within Yunnan. Our work confirmed some views emphasized by Wu Zhengyi that the stenochoric endemic species play a key role in defining floristic provinces; that stenochoric endemic plants with long collection and publication histories are more valuable; that greater attention should be paid to woody plants; and that for Yunnan, a border region, some trans-border distributed elements should be treated cautiously.

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Floristic regionalization results in a hierarchical system which categorizes geographic areas in terms of plant species and their various floristic elements (Engler and Diels, 1936; Kreft and Jetz, 2010). To determine floristic regions requires that the distribution of each plant group level (family, genus, and species) found in the area is known, as well as the distribution of any stenochoric endemic plants (SEP), the geological history, climate changes, and knowledge of the differences between areas, and their relationships with other regions. When these traits are known, regionalization can be carried out accordingly (Engler and Diels, 1936; Li et al., 2015; Zhang et al., 2016). The basic units for floristic regionalization are classified as kingdom, region, province, and district, while the determination of which unit to use in practice is decided by the size and scale of the area investigated, and the research data (Engler and Diels, 1936; Takhtajan, 1986). A floristic kingdom is characterized by a set of endemic families with a shared evolutionary history, and is mainly determined by paleogeographic factors. A floristic region is characterized by a set of endemic genera and subgenera and a certain number of dominant families; different regions have different geological ages and histories, and thus show distinct regional properties, and boundaries between

these regions tend to be consistent with the boundaries of geological structures, geomorphic units, or climatic zones. Floristic provinces and districts are characterized by sets of endemic species and subspecies, and are mainly based on the differences in geomorphology, climate, or soil.

Yunnan is one of the most botanically diverse terrestrial regions on Earth and forms part of the Himalaya biodiversity hotspot (Myers et al., 2000). It has a disproportionate amount of China's overall floristic diversity (51.6%), with more than 18,000 plant species (Yang et al., 2004), and includes high levels of endemism. Wu (1984) first divided the flora of Yunnan into 11 regions (actually the subregions according to the floristic classification of world seed plants), which provided significant information and support for plant protection, agriculture and forestry regionalization and land use in Yunnan. In 1996 and 2011, adjusted floristic systems for the seed plants of China were published successively (Wu and Wu, 1996; Wu et al., 2011). Two floristic kingdoms can be recognized in Yunnan: the East Asia Kingdom and the Paleotropic Kingdom. The East Asia Kingdom, which forms the dominant floristic composition of Yunnan, is further divided into the Sino-Japan Forest Subkingdom and the Sino-Himalaya Forest Subkingdom. Compared with Wu (1984), the new system merged the Liangshan Region and East Yunnan Region into the Guizhou Plateau Subregion; placed the east Qjubei and Wenshan (103°30'E) part of the Southeast Yunnan Region into the Southeast Yunnan Limestone

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Subregion; changed the boundary of the Lancang-Honghe Midstream Region and the Southeast Yunnan Region to a boundary along the Mo River; separated the Dulong River basin from the East Himalaya Region to construct the Dulong River-North Myanmar Subregion; in addition, the remaining parts of the East Himalaya Region, the West Yunnan Gorge Region, and part of the Sichuan-Tibet Plateau Region were combined into a Three Parallel Rivers Gorge Subregion, and the South Hengduan Mountains Subregion was formed by the combination of the Jingsha River Region with the rest of Sichuan-Tibet Plateau Region (Wu et al., 2011). Subsequently, Zhu (2011) suggested the boundary between the Yunnan-Myanmar-Laos-Vietnam Region and the Yunnan-Vietnam Region should be moved from the Red River eastward to the Lixianjiang. Recently, species distribution modeling (Zhang et al., 2012) and phylogenetic perspectives (Li et al., 2015) have been used to delineate the floristic regionalization of Yunnan, the results of both being in broad agreement with previously published floristic divisions of Yunnan (Wu, 1984; Wu et al., 2011).

Floristic studies of seed plants have been widely applied to environmental assessment and scientific surveys of conservation areas in Yunnan. Such studies are suitable for the large scale floristic analyses, e.g. for large river basins or mountains, however, detailed and in-depth demonstrations and annotations are needed for the evaluation of small areas. Historical studies involving floristic analysis for localized areas are known from several areas. Matthews (1937) analyzed the flora of the British Isles and classified it into 16 subregions. Birks and Deacon (1973) summarized the work on the British Isles and added a subregion to that of Matthews (1937). Wang (1997) divided the flora of north China into four subregions and 11 provinces. With the publication of *Flora Yunnanica*, *Flora of China*, and the floras of certain areas of Yunnan, as well as the accessibility of online specimen databases, we are now able to re-evaluate and subdivide the flora of Yunnan.

## 1. Materials and methods

### 1.1. Study area

Yunnan is located in southwestern China between 21°8'32"–29°15'8"N, and 97°31'39"–106°11'47"E. It is a transitional zone, characterized by strong environmental gradients, between tropical, sub-tropical, temperate and alpine vegetation types, with the flora of tropical Indochina, mixing with the subtropical East Asian flora. It lies between major floristic regions, with the Sino-Japanese Floristic Region in the east and the Sino-Himalayan Floristic Region in the west (Li and Li, 1997; Zhu et al., 2006).

The region is one of the most botanically diverse terrestrial regions on Earth and includes nearly 18,000 plant taxa. The richness of the flora can be attributed to the geologic, topographic, and climatic diversity found within the area (Li and Walker, 1986). There is also great diversity in the topography of the area, with many peaks exceeding 4000 m a.s.l. and deep valleys in this area. This topographical complexity presents substantial barriers to dispersal, and is thought to have been critical to the formation and development of the flora in this region (Li, 1985; Wu, 1987). Furthermore, some parts of Yunnan have been identified as refugia during the Pleistocene (López-Pujol et al., 2011).

### 1.2. Data sources

Traditionally, floristic units were delimited based on taxonomic composition and species distributions, which relied on the experience and knowledge of botanists (Takhtajan, 1986). Nowadays, increasing numbers of databases are available online, depositing detailed information on species taxonomy and plant distributions.

Therefore, some quantitative methods for defining floristic units have been developed, including clustering and ordination (Kreft and Jetz, 2010; Li et al., 2015; Zhang et al., 2016), phylogenetic perspectives (Webb et al., 2002; Cavender-Bares et al., 2009; Li et al., 2015) and species distribution modeling (Zhang et al., 2012). Meanwhile, researchers have consistently emphasized the key role of the SEP in floristic regionalization. In this study, 1010 SEP recorded only from Yunnan and from only one site, were selected from the Flora of China (*Flora of China Editorial Committee, 1994–2011*) (see species list Appendix 1). The circumscriptions of families and genera were consistent with the APG III classification system (Angiosperm Phylogeny Group, 2009). These endemic species can be assigned to 354 genera and 104 families. Species distribution data were recorded either from the original publications or from online databases (<http://www.db.kun.ac.cn>; <http://www.nsii.org.cn>). Although many of these records did not have latitude and longitude data, we were able to geo-reference collections within Yunnan at the county or town level, using the location descriptions on the labels.

### 1.3. Data analysis

Collection sites with coordinates were marked on the topographic map of Yunnan using ArcGIS10.2. Because of its wide use, Wu Zhengyi's floristic regions of Yunnan (Wu, 1984) were selected as the backbone for further division of the floristic regions into province level areas. Areas with at least two endemic species were designated as a province. Geological history, vegetation constitution and climate change were also considered.

## 2. Results

A total of 11 subregions and 84 provinces are erected for the flora of Yunnan (Table 1, Fig. 1) and the numbers of SEP in each subregion and province are summarized in Table 1. Here, we will briefly describe each subregion. 1) Central Yunnan Plateau Subregion I: The Central Yunnan Subregion, together with the Lancang-Honghe Middle Stream Subregion and the Southeast Yunnan Subregion form the Yunnan Plateau Region. It is the largest subregion, and has 84 SEP. Based on its abundant endemic elements (especially on the generic level), the flora of Yunnan Plateau Region was considered to be a very natural one in floristic delimitation and may be the birthplace the flora of Sino-Himalaya Subkingdom (Wu, 1984, Wu et al., 2011; Li, 1993). 2) Jinsha River Subregion II: Figuratively speaking, the Jinsha River Subregion, looks like a 'W', and is an area with high flora diversity with 114 SEP. Some provinces within this subregion are actually natural mountains. 3) West Yunnan Gorge Subregion III: It is a subregion of the southern parts of the Hengduan Mountains with 74 SEP. Within this area, some tropical elements are dispersed northward to the river valleys, while Himalayan and temperate elements extend southward to the mountaintop, forming a rare pattern where southern and northern elements coexist in the same area. 4) East Himalaya Subregion IV: Following Wu (1984) and Kingdon-Ward (1927, 1935), the Biluoxueshan is set to the eastern boundary of the East Himalaya Subregion, which is a higher endemic area with 172 SEP. 5) Lancang-Honghe Midstream Subregion V: The Lancang-Honghe Middle Stream Subregion is the second largest subregion, with 83 SEP. It is a transitional area, located in central Yunnan. It has many tropical elements in the river valley and temperate elements, such as *Abies* and *Tsuga*, on the mountaintop. Thus, distinctive vertical zones of vegetation can often be found in this subregion. 6) Yunnan-Myanmar-Laos Subregion VI: Following the suggestion of Zhu (2011), the boundary between Yunnan-Myanmar-Laos Subregion and the Yunnan-Vietnam Subregion has been moved westward to

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