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, and 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.

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 Paleotropical 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 Qiubei and Wenshan (103°30’E) part of the Southeast Yunnan Region into the Southeast Yunnan Limestone
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 Subregion 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 Lixinjiang. 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 florae 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.nsli.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 Buloxueshan 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
Table 1
The floristic delimitation of Yunnan and the number of stenochoric endemic plants (SEP) in each area.

| Floristic subregion                  | Number of the SEP within subregion | Floristic province                  | Number of the SEP within province |
|--------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| I: Central Yunnan Plateau Subregion  | 84                                  | I1: Zhaoyang Province              | 2                                   |
|                                      |                                     | I2: Yaoshan Province               | 12                                  |
|                                      |                                     | I3: Huize Dalai Province           | 4                                   |
|                                      |                                     | I4: East Yunnan Province           | 4                                   |
|                                      |                                     | I5: Jiaozishan Province            | 27                                  |
|                                      |                                     | I6: Songming Province              | 1                                   |
|                                      |                                     | I7: Kunming Province               | 13                                  |
|                                      |                                     | I8: Shilin Province                | 4                                   |
|                                      |                                     | I9: Longchuanjiang Province        | 0                                   |
|                                      |                                     | I10: Baicaoling Province           | 10                                  |
|                                      |                                     | I11: Chuxiong Province             | 7                                   |
| II: Jinsha River Subregion           | 114                                 | II1: Zhongdian Halba Province      | 27                                  |
|                                      |                                     | II2: Xiaoliangshan Province       | 7                                   |
|                                      |                                     | II3: Yulongxueshan Province       | 47                                  |
|                                      |                                     | II4: Laojunshan Province           | 5                                   |
|                                      |                                     | II5: Ma'ershan Province            | 19                                  |
|                                      |                                     | II6: Yongsheng-Huaping Province    | 3                                   |
|                                      |                                     | II7: Juzushan-Dapingzi Province    | 6                                   |
| III: West Yunnan Gorge Subregion     | 74                                  | III1: North Nushan Province        | 16                                  |
|                                      |                                     | III2: South Baimaxueshan Province  | 9                                   |
|                                      |                                     | III3: Middle Nushan Province       | 3                                   |
|                                      |                                     | III4: Yunling Province             | 6                                   |
|                                      |                                     | III5: South Nushan Province        | 1                                   |
|                                      |                                     | III6: Tanchi-Jingguang Province    | 2                                   |
|                                      |                                     | III7: Qingshuihangshan Province    | 0                                   |
|                                      |                                     | III8: Gangshan Province            | 32                                  |
|                                      |                                     | III9: South Baoshan Province       | 5                                   |
| IV: East Himalaya Subregion          | 172                                 | IV1: Bingzhongluo Province         | 9                                   |
|                                      |                                     | IV2: Dulongjiang Province          | 65                                  |
|                                      |                                     | IV3: Gongsan Cikai Province        | 19                                  |
|                                      |                                     | IV4: Fugong Province               | 15                                  |
|                                      |                                     | IV5: Lushui Province               | 22                                  |
|                                      |                                     | IV6: South Gaoligongshan Province  | 5                                   |
|                                      |                                     | IV7: Tengchong Province            | 30                                  |
|                                      |                                     | IV8: Longling Province             | 7                                   |
| V: Lancang-Honghe Midstream Subregion | 83                                | V1: Dingbu Province                | 4                                   |
|                                      |                                     | V2: Upper Lincang Province         | 6                                   |
|                                      |                                     | V3: Yongkedaxueshan Province       | 6                                   |
|                                      |                                     | V4: Wulangshan Province           | 35                                  |
|                                      |                                     | V5: Ailaoshan Province             | 5                                   |
|                                      |                                     | V6: Jinggu Province                | 1                                   |
|                                      |                                     | V7: Ning'er-Simao Province         | 16                                  |
|                                      |                                     | V8: Xiping-Yuangjiang-Eshan Province | 10  |
| VI: Yunnan-Myanmar-Laos Subregion    | 165                                 | VI1: Tongbighuan Province          | 18                                  |
|                                      |                                     | VI2: Dayingjiang Province          | 4                                   |
|                                      |                                     | VI3: Ruilijiang Province           | 6                                   |
|                                      |                                     | VI4: Mangshi Province              | 5                                   |
|                                      |                                     | VI5: Zhenkang Province             | 9                                   |
|                                      |                                     | VI6: Nangunhe Province             | 12                                  |
|                                      |                                     | VI7: Menglian-Ximeng Province      | 9                                   |
|                                      |                                     | VI8: Lancang Province              | 8                                   |
|                                      |                                     | VI9: Menghai Province              | 20                                  |
|                                      |                                     | VI10: Upper Jinghong Province      | 12                                  |
|                                      |                                     | VI11: Lower Jinghong Province      | 13                                  |
|                                      |                                     | VI12: Yiwu Province                | 4                                   |
|                                      |                                     | VI13: Menglin Province             | 18                                  |
|                                      |                                     | VI14: Mengla Province              | 22                                  |
|                                      |                                     | VI15: Jiangcheng Province          | 5                                   |
| VII: Yunnan-Vietnam Subregion        | 174                                 | VII1: Huanggianshan Province       | 14                                  |
|                                      |                                     | VII2: Jining, Fenhsuling Province  | 21                                  |
|                                      |                                     | VII3: Hekou Moist Rain Forest Province | 31  |
|                                      |                                     | VII4: Maguan Gulingqing Province   | 29                                  |
|                                      |                                     | VII5: Malipo Province              | 46                                  |
|                                      |                                     | VII6: Xichou, Fadou Province       | 21                                  |
|                                      |                                     | VII7: East Liuzhaoshan Province    | 12                                  |
| VIII: Southeast Yunnan Subregion     | 80                                  | VIII1: Honghe Middle Stream Province | 7   |
|                                      |                                     | VIII2: Mengzi Province             | 11                                  |
|                                      |                                     | VIII3: Gejue Manhai Province       | 5                                   |
|                                      |                                     | VIII4: Upper Daweishan Province    | 30                                  |
|                                      |                                     | VIII5: Mile-Luxi Province          | 3                                   |
|                                      |                                     | VIII6: yanshan Province            | 6                                   |
|                                      |                                     | VIII7: Wenshan Province            | 12                                  |

(continued on next page)
the Lixianjiang. The flora of Yunnan–Myanmar–Laos Subregion is more related to Indo-Malaysia Flora, with 165 SEP.

7) Yunnan–Vietnam Subregion VII: As mentioned above, the western boundary of Yunnan–Vietnam Subregion has been moved to the Lixianjiang. It is more related to the Eastern Asia Flora, with 174 SPE.

8) Southeast Yunnan Subregion VIII: This subregion presents some extent of palaeo-endemism and has affinity with Yunnan-Guizhou-Guangxi region, south China Region and Beibu Gulf Region. A total of 80 SEP was recorded.

9) Northeast Yunnan Subregion IX: The flora of this subregion is more similar to the Central China Region of the Sino-Japan Forest Subkingdom, especially the floristic properties and identity at higher taxonomic group level. Therefore, this subregion is a special area in the flora of Yunnan, with ten SEP.

10) Liangshan Subregion X: Based on its close relationship with the flora of the Central China as well as its transitionality to the Northwest Liangshan, Wu (1984) suggested establishing the Liangshan Subregion. Within this subregion, many Jinsha River Valley elements are characterized by compatibility and transitionality. There are only six SEP recorded.

11) Sichuan-Tibet Plateau Subregion XI: This subregion is actually part of the Kangzang Plateau Region, and is an area dominated historically by coniferous forests. This subregion has different subalpine and alpine

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Table 1 (continued)

| Floristic subregion          | Number of the SEP within subregion | Floristic province         | Number of the SEP within province |
|------------------------------|------------------------------------|----------------------------|-----------------------------------|
| IX: Northeast Yunnan Subregion | 10                                 | VIII: Guanhai-Qubei Province | 2                                 |
|                              |                                    | IX1: Luoping-Shizong Province | 4                                 |
|                              |                                    | IX2: Yiliang Xiaoaoa Province | 5                                 |
|                              |                                    | IX3: Tuchubu Province         | 4                                 |
| X: Liangshan Subregion       | 6                                  | X1: Yongshan Province         | 3                                 |
|                              |                                    | X2: Suijiang-Shufu Province    | 3                                 |
| XI: Sichuan-Tibet Plateau Subregion | 48                                | XI1: Shikashan Province        | 8                                 |
|                              |                                    | XI2: Upper Zhongdian Province  | 10                                |
|                              |                                    | XI3: North Baishuzheng Province| 13                                |
|                              |                                    | XI4: Meiluixueshan Province    | 9                                 |
|                              |                                    | XI5: Deqin Province            | 11                                |

Fig. 1. The floristic delimitation of Yunnan. Cartographic lines represent the Subregion boundaries and dashed lines represent the Province boundaries. Codes refer to Table 1.
coniferous forests formed by various Larix, Abies, and Picea species. Some deciduous elements, especially forests with obvious seasonal change formed by Sorbus, Acer, etc. are dispersed in this area. There are 48 SPE recorded.

The top ten provinces with the most SEP are the Dulongjiang Province IV2 (65 species), the Yulongxueshan Province III3 (47 species), the Malipo Province VII5 (46 species), the Wuliangshan Province V4 (35 species), the Gangnan-Qiubei Province VIII8 (35 species), the Upper Daweishan Province VII4 (29 species), and the Mabinong Province IX3 (27 species). Numbers of the SEP in the Shilin Province I8, the Jinggu Province V6, the Tuchubu Province IX3, the Longchuanjiang Province I9, and the Qingshuijiangshan Province III7 are less than three, of which the Longchuanjiang Province I9 and the Qingshuijiangshan Province III7 have no SEP recorded.

3. Discussion

SEP, which have a lower re-collection frequency relative to that of widespread species, play a key role in the floristic regionalization. Take the genus Aconitum for example: Aconitum coriophyllum Hand.-Mazz. collected by H. Handel-Mazzetti in 1916 and Aconitum acutiusculum H.R. Fletcher & Lauener collected by G. Forrest in 1917, which are both much more valuable than the species found more recently, such as Aconitum bracteosum W. T. Wang (found in 1976) and Aconitum parcelliuum Q. E. Yang & Z. D. Fang (found in 1987). This is because former specimens were published much earlier and have never been found anywhere else, while the distributions of the latter still need to be confirmed. Another well-known example is Orophea yunnanensis B.T. Li, which was first collected by K. Z. Hou near Mt. Bijia in Chengjiang County in 1940. The type specimen of O. yunnanensis was, until recently, still the only known collection. We carried out a survey on O. yunnanensis in Mt. Bijia during 2014–2015 and found that the species grows in an extremely isolated site (Ren et al., 2016). So, these data, combined with those of three other SEP, namely Eulaia przunosa B. S. Sun & M. Y. Wang, Petrosocrema shilinensis Y. M. Shui & H. T. Zhao, and Salvia breviconnectivata Y. Z. Sun, lead to our suggesting the creation of a representative species of the Menghai Province VI-9, was collected in 1929 by R. C. Ching in Malutang, Mt. Cang. It was not collected again until 73 years later that Y. S. Chen found the species again in the Cang District.

Wu emphasized the floristic value of woody plants while carrying out floristic studies of China, especially for the SEP (Wu, 1984; Wu et al., 2011). Acer yangbiense Y. S. Chen & Q. E. Yang was first collected in 1929 by R. C. Ching in Malutang, Mt. Cang. It was not until 73 years later that Y. S. Chen found the species again in the same locality and published the species. Currently, A. yangbiense is only known from western Mt. Cang, thus it is plausible to divide the Mt. Cang Province III–8 into the West Mt. Cang District and East Mt. Cang District.

Twenty-five counties in Yunnan share borders with Myanmar, Laos, or Vietnam. The florae of these three countries are still incomplete, and it is therefore difficult to decide whether a species collected in the bordering counties is a stenochoric endemic or not. Adiantandra latifolia L. K. Ling was collected from the basin of the Dulong River nearly 80 years ago. If no further collection records are reported, the species may be regarded as convincing evidence for the high species richness of the Dulong River Province IV-2. But we cannot exclude the possibility that A. latifolia may appear in the Upper Myanmar, which is geographically close to the Dulong River. Similarly, we are not sure whether the tropical floristic element of Alseodaphne huanlianshanensis H. W. Li & Y. M. Shui can be found in the neighboring countries.

However, the situation can be different for temperate species. Arctous microphyllus C. Y. W is a representative floristic element of the Upper Zhongdian Province XI-2. Most of the taxa closely related to this plant are distributed throughout the temperate regions of the Northern Hemisphere, with some even extending to the Arctic. Thus, as a convincing stenochoric endemic species, A. microphyllus is almost impossible to be found in tropical area.

On the whole, our recent work on the floristic regionalization of Yunnan further confirms some views emphasized by Wu (1984) and Wu et al. (2011) in that SEP play a key role in defining a province: SEP with long collection and publication history are more valuable; more attention should be paid to the woody plants; and we need to be cautious while analyzing the flora of border areas.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.pld.2016.11.011.

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