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Diversity hotspots and conservation gaps for the Chinese endemic seed flora

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ABSTRACT

The flora in China is highly endemic. Decisions about conservation and management of biodiversity based on hotspots and conservation gaps of endemic seed plant species diversity in China are essential. In this paper, based on a species distribution data set with 12,824 Chinese endemic plants, we measured Chinese endemic seed plant diversity using five indices: endemic species richness (ER), weighted endemism (WE), phylogenetic diversity (PD), phylogenetic endemism (PE), and biogeographically weighted evolutionary distinctiveness (BED). Five percent of China's total land area with the highest biodiversity was used to identify hotspots for each index. In total, 19 hotspots covering 7.96% of China's total land area were identified. Most hotspots are located in mountainous areas, mainly in the Qinling Mountains and further south or in the Hengduan Mountains and to the east in China. Nine hotspots are identified with all five indices. These hotspots include the Hengduan Mountains, the Xishuangbanna Region, the Qinling Mountains, southwest Chongqing, and five mountainous areas (located in east Chongqing and west Hubei; in east Yunnan and west Guangxi; in north Guangxi, southeast Guizhou and southwest Hunan; in north Guangdong and south Hunan; and in southeast Tibet, respectively). Furthermore, we detected conservation gaps for hotspots of Chinese endemic seed flora by overlaying national nature reserves with the identified hotspots, and we designated priority conservation gaps for hotspots by overlaying global biodiversity hotspots with conservation gaps for hotspots. Most hotspots for Chinese endemic seed plant species are badly protected. Only 26.48% of the hotspot areas of Chinese endemic seed plant species were covered by nature reserves. We suggest that it is essential to pay more attention to herbaceous plants in biodiversity conservation, and to promote a network function of nature reserves within these hotspots in China.

1. Introduction

Endemism in biology is the restriction of a taxon to a defined area (Anderson, 1994; Gaston, 1994; Williams et al., 2002). It is central to the study of biogeography (Good, 1974) and is the key content of biodiversity studies (He and Ma, 1997; Lamoreux et al., 2006; Ying and Zhang, 1994). Endemism has commonly been regarded as an important criterion for biodiversity conservation at the global scale and even at a national as well as local scale (Lamoreux et al., 2006; Myers et al., 2000; Riemann and Ezcurra, 2005). The pattern of endemism is strongly scale-dependent (Crisp et al., 2001), and quantitative indices of endemism have been widely used in the management of biodiversity resources, particularly in the identification of priority areas for biodiversity conservation (Kier and Barthlott, 2001).

Biodiversity is distributed unevenly in space, and therefore, prioritizing areas is essential to protect biodiversity (Brooks et al., 2006). Hotspots (Myers et al., 2000) and gap analyses (Scott et al., 1993) have become important and popular approaches for the selection of priority areas (Brooks et al., 2006). In past decades, researchers paid much attention to species information to detect biodiversity priority areas (Brummitt and Lughadha, 2003; Orme et al., 2005; Reid, 1998). However, in recent years, much attention has been focused on evolutionary information. Consequently, some measures combining the phylogenies and geographical distribution of species have been proposed. Some of these measures focus on phylogenetic diversity (Faith, 1992; Forest et al., 2007) or taxonomic distinctiveness (Redding and Mooers, 2006; Vane-Wright et al., 1991). Others combine phylogenetic features and weighted endemism measures (Cadotte et al., 2010; Isaac et al., 2007; Rosauer et al., 2009). Two metrics are used to identify hotspots with this combination: one is phylogenetic endemism (Rosauer et al., 2009), and the other, biogeographically weighted evolutionary distinctiveness (Cadotte et al., 2010).

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China is one of the world's mega-biodiversity countries and one of the richest countries in terms of plant biodiversity (Hong and Blackmore, 2013; McNeely et al., 1990; Mittermeier et al., 1997). The total number of vascular plant species in China is 31,362 (Wu et al., 2012). The flora in China is highly endemic (Wu et al., 1993; Wu and Wang, 1983). Endemic species account for 52.1% of the total seed plant species (Huang et al., 2011). Moreover, China is one of the countries with the highest number of threatened species in the world (Jenkins et al., 2003). According to the latest assessment, 3767 vascular plant species in China are threatened, accounting for 10.93% of the total number of native vascular pants (Ministry of Environment Protection of China, 2013). Of the World Wildlife Fund's Global 200 most Critical and Endangered Ecoregions, 46 are located in or intersect with China (http://www.worldwildlife.org/biomes). Furthermore, among the 34 global biodiversity hotspots identified by Mittermeier et al. (2005), four either intersect with or are located in China.

Although many studies on endemism of Chinese flora have been conducted, data are still not sufficient to provide systematic guidance for biodiversity conservation in China. In a previous study (Huang et al., 2012), we identified hotspots of endemic woody seed plant species in China by using five indices, including endemic species richness (ER), weighted endemism (WE), phylogenetic diversity (PD), phylogenetic endemism (PE) and biogeographically weighted evolutionary distinctiveness (BED). In this paper, endemic herbaceous seed plant species in China were added. Based on endemic woody and herbaceous seed plants in China, we identify hotspots of endemic seed plant species in China using the same five indices as in our previous study on Chinese endemic woody seed plants (Huang et al., 2012). Moreover, conservation gaps of Chinese endemic seed plants are detected by overlaying the map of the hotspots of Chinese endemic seed plants and the map of China's nature reserves, which are the areas within the hotspots of Chinese endemic seed plant species but not covered by China's nature reserves. Furthermore, priority conservation gaps of Chinese endemic seed plants are also detected by overlaying the map of conservation gaps of Chinese endemic seed plants and the map of global biodiversity hotspots, which are the areas within both the hotspots of Chinese endemic seed plant species and the global biodiversity hotspots but not covered by China's nature reserves. We then analyze the conservation gaps and priority conservation gaps of hotspots of Chinese endemic seed plant species by overlaying hotspots of Chinese endemic seed plant species, China's nature reserves, and global biodiversity hotspots. Finally, we discuss the potential causes of the patterns revealed in this study and propose suggestions for Chinese flora protection.

2. Materials and methods

2.1. Data set

After referring to a list of Chinese endemic seed plant species, we compiled a species distribution database that included all Chinese endemic seed plant species (Huang et al., 2011, 2014). The database was based on a large number of literature sources including floras, checklists, monographs, journal articles and atlases pertinent to the flora of China, as well as on a large number of herbarium specimens. The major sources documenting Chinese plants include *Flora Reipublicae Popularis Sinicae*, (Editorial Committee of Flora Reipublicae Popularis Sinicae 1961–2004), *Flora of China* (Wu et al., 2012), *Sylva Sinica* (Zheng 1983–2004), and many local flora, monographs and articles. Specifically, we acquired data from 1044 floras, monographs, reports or theses; 516 articles; and 37 herbaria by the end of 2012. All lists of references and herbaria are provided in Appendix A. The county was used as the basic spatial analysis unit because species distribution data at the county level is the most comprehensive, and it is also the basic spatial unit of species distributions in references. The other half was sourced from specimens. The geographical coordinate point is the basic unit of the species in the specimens. In order to combine the two types of data, all geographical distributions of specimens were converted into a spatial unit at county level according to their spatial affiliations. China has 23 provinces, five autonomous regions (equivalent to a province in China) and four municipalities (Fig. 1a). These provinces, autonomous regions and municipalities consist of 2377 counties (Fig. S1). Distribution information for the presence of each species was documented for each county. In our study, 12,824 Chinese endemic species were obtained with a total of 247,886 occurrence records at the county level. A checklist of Chinese endemic seed plant species is provided in Appendix B.

As of 2014, 2729 nature reserves existed in China, covering a total area of 1,469,9 00 km^2 (Ministry of Environment Protection of China, 2015). Each nature reserve is administered by one of four different levels of a government from the highest to lowest: national, provincial (or autonomous region), municipal, and county. Among the 2729 nature reserves, 428 are national nature reserves. Nature reserves overseen by higher levels of government are usually managed more rigorously and receive more manpower and funding; thus, they provide information that is more accurate. In contrast, information from the nature reserves overseen by lower levels of government is usually incomplete. Therefore, we collected a georeferenced or spatially referenced dataset of 2139 nature reserves by integrating the most recent official list of nature reserves published by China's Ministry of Environment Protection and ProtectedPlanet.net (the World Database on Protected Areas: http://www.protectedplanet.net/). The global biodiversity hotspots dataset was downloaded from Conservation International (http://www.conservation.org/How/Pages/Hotspots.aspx).

2.2. Measures of diversity

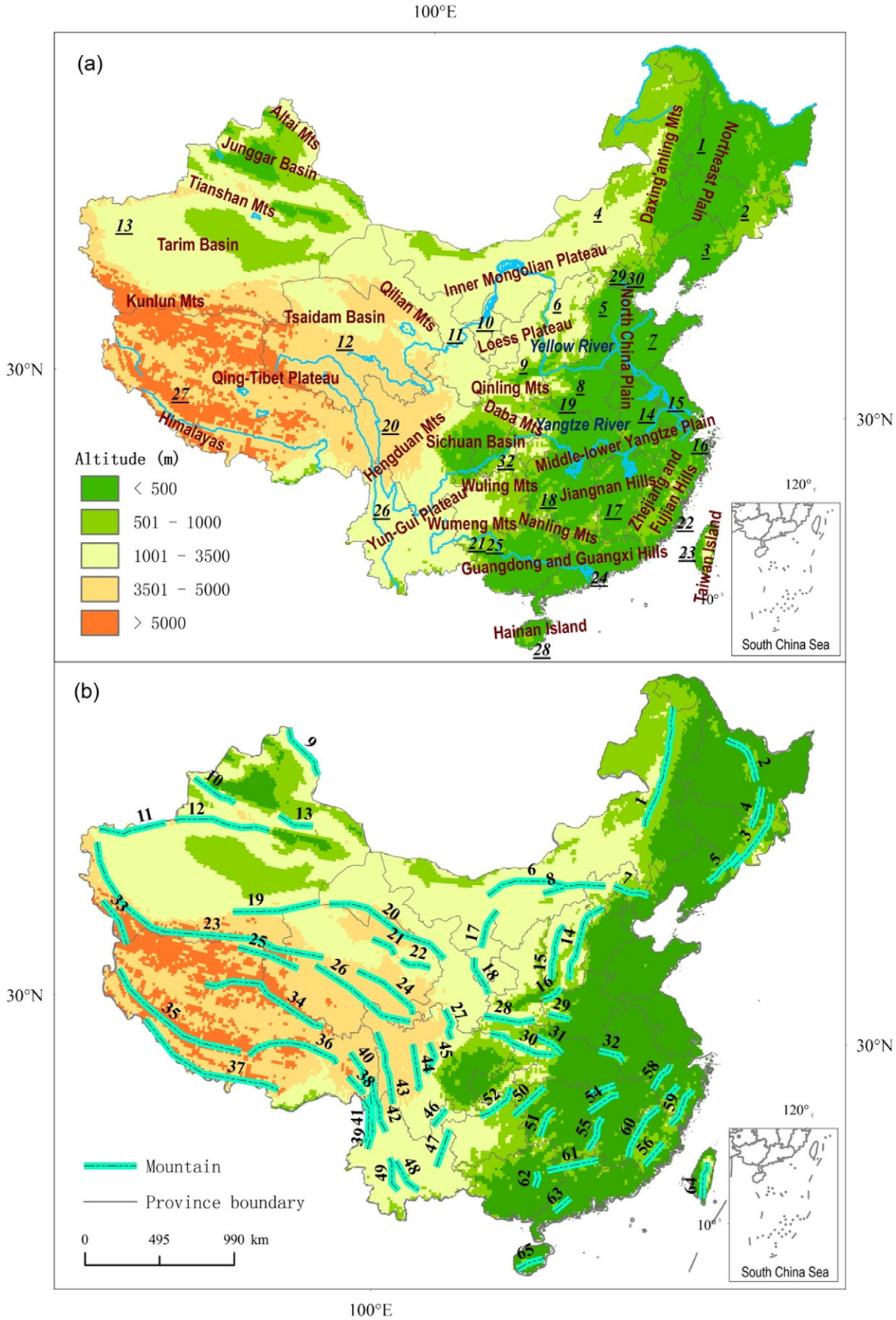
To detect the distribution patterns of Chinese endemic seed flora, we calculated the above-mentioned five indices separately: ER, WE, PD, PE and BED. Equations and corresponding details of all indices are listed in Table 1. Among these indices, endemic species richness is one of the widely used indices and is a core index for identifying global biodiversity hotspots (Myers et al., 2000). WE combines range weighting and the number of species. PD emphasizes the phylogenetic diversity. PE combines the phylogenetic diversity and range size. BED combines the phylogenetic evolutionary distinctiveness and range size.

2.3. Constructing the phylogenetic tree

We used Phylomatic (Webb and Donoghue, 2005) to construct a phylogenetic supertree for the Chinese endemic seed plants. The latest Angiosperm Phylogeny Group classification in Phylomatic was used as the backbone of the supertree. The branch lengths of our phylogenetic tree were adjusted by using the BLADJ algorithm (Webb et al., 2008) with known molecular and fossil dates (Wikstrom et al., 2001). The "known" molecular and fossil dates used to calibrate the supertree are estimates, but they improve the robustness of phylogenetic analyses of endemism in comparison to the alternative, which is to use nodal distances (Webb, 2000). The phylogenetic tree constructed for the Chinese endemic seed plant species in this study is provided in Appendix C.

2.4. Detecting patterns of diversity and identifying hotspots

All five diversity indices were calculated by using two R packages, Ape (Paradis, 2006) and Picante (Kembel et al., 2010), in R 3.1.2 (R Core Team, 2014), and the resulting maps were generated with ArcGIS 9.0 (ESRI, Redlands, CA, USA). The consistency between the patterns of diversity characterized with the different indices was analyzed using Spearman's correlation coefficient for each pair of indices. The related p-value was corrected for the spatial autocorrelation with Dutilleul's (1993) method and implemented with Legendre's Fortran program modttest (http://www.bio.umontreal.ca/casgrain/en/labo/mod_t_test.html).


100°E
(a)
Altai Mts
Junggar Basin
Tianshan Mts
Tarim Basin
Kunlun Mts
Tsaidam Basin
Qilian Mts
Inner Mongolian Plateau
Daxing'anling Mts
Northeast Plain
North China Plain
Loess Plateau
Yellow River
Qing-Tibet Plateau
Qinling Mts
Daba Mts
Yangtze River
Himalayas
Hengduan Mts
Sichuan Basin
Middle-lower Yangtze Plain
Wuling Mts
Jiangnan Hills
Zhejiang and Fujian Hills
Yun-Gui Plateau
Wumeng Mts
Nanling Mts
Guangdong and Guangxi Hills
Taiwan Island
Hainan Island
South China Sea
Altitude (m)
< 500
501 – 1000
1001 – 3500
3501 – 5000
> 5000
30°N
120°
(b)
Mountain
Province boundary
0 495 990 km
South China Sea
100°E

Hotspots were identified with each diversity index as indicated hereafter. The county with the maximum value for the index was identified, and one more county with the maximum value for the index among the remaining counties was added until the total area of the selected counties reached 5% of China's total land area, which has been considered an optimal scale (Huang et al., 2012). To detect the effect of the spatial analysis unit size on the hotspot identification, a power function $D = bA^c$ was fitted with nonlinear regression, where D is a diversity index and A is the area of the county for which the diversity is calculated. The residuals from this model can be considered as the diversity after removing the area effect. The correlation between these residuals and the original diversity values for each diversity index was analyzed with Spearman's correlation coefficient ρ (with spatial autocorrelation-corrected P-value) (Dutilleul, 1993). The counties with high (positive) residuals were considered having high diversity irrespective of areas.

2.5. Analysis of the conservation gaps

To identify conservation gap areas for the hotspots of endemic seed plant species, their map was overlapped with the distribution of nature reserves and further with the global biodiversity hotspots across China. As a result, the gap areas of hotspots of Chinese endemic seed plant species indicate areas where conservation efforts should be prioritized. In this paper, we named areas covered by hotspots of endemic seed plant species but not covered by nature reserves as "conservation gaps" of hotspots of endemic seed plant species. Similarly, areas covered by hotspots of endemic seed plant species and global biodiversity hotspots but not covered by nature reserves were named as "priority conservation gaps".

3. Results

3.1. Distribution patterns of diversity

Chinese endemic seed plant species are mainly distributed in the Qinling Mountains and farther south and in the eastern portion of the Qinghai-Tibet Plateau and to the east of that plateau, and more than 90% of the total Chinese endemic seed plant species occur in these regions (Fig. 1). The five diversity indices calculated by county throughout the country are highly significantly correlated with each other (Table 2). After the area effect has been accounted for, i.e., each diversity index has been regressed against the corresponding county area according to the power function, the residual from this function is still highly significantly correlated with the original corresponding diversity index (Table 3). Therefore, whether the area effect is considered or not, the five diversity indices show a similar trend across the country.

3.2. Distribution patterns of the hotspots

The hotspots identified with ER are roughly distributed in 13 distinct centers (Fig. 2a, Table 4). These include the Hengduan Mountains (Anderson, 1994); eight other mountainous areas (these include east Chongqing and west Hubei (2); east Yunnan and west Guangxi (Brooks et al., 2006); north Guangxi, southeast Guizhou, and southwest Hunan (Brummitt and Lughadha, 2003); north Guangdong and south Hunan (Cañadas et al., 2014); southeast Tibet (Cadotte and Davies, 2010); southeast Anhui and northwest Zhejiang (Chen, 1998); south Zhejiang, northwest Fujian, and southeast Jiangxi (Crisp et al., 2001); and west Henan (Editorial Committee of Flora Reipublicae Popularis Sinicae, 1961–2004)); the Xishuangbanna region (Cadotte et al., 2010); the Qinling Mountains (Dutilleul, 1993); southwest Chongqing (Essl et al., 2009); and the source of Lancang River (ESRI, 2004).

Among the 13 hotspot centers, five are major centers (Fig. 2a, centers 1 through 4, and 6). The hotspots identified with WE are mainly located in 14 areas (Fig. 2a, Table 4); these include 11 of the above 13 centers (i.e., centers 1 through 12, except 11) and three other centers Hainan Island (Faith, 1992), Taiwan Island (Forest et al., 2007), and the mountainous areas of central and north Guangdong (Fu et al., 1993). Centers 1 through 4, 6, and 14 through 16 are major ones. Those centers identified with PD are the same as ER (Fig. 2a, Table 4) but lack center 13. The hotspots identified with PE include 15 centers (Fig. 2a, Table 4); these include 12 of the above 15 centers (i.e., centers 1 through 16 except 8, 9, 11 and 13) and three more centers west of Longzhong Plateau (Gaston, 1994), Yarkant River in west Kunlun Mount (Good, 1974), and the Nielamu region (He and Ma, 1997). Five (i.e., centers 1, 3, 6, 14, and 15) of the 15 centers are major ones. Those identified with BED have the same centers as WE (Fig. 2a, Table 4), and they have the same major centers as WE except center 16.

The geographic distributions of the hotspots identified with ER and PD are very similar, as are those identified with WE and BED. Hotspots identified by both pairs have the highest correlation coefficients (Table 2) and have the most common hotspots (Table 4). Some differences exist between the geographic distributions of the hotspots identified for the former two indices and for the latter two indices. The most prominent difference can be seen in the three centers: 14–16. These three centers are apparently highlighted by WE and BED. The hotspots identified with PE are the least similar to those identified with the other indices. The most conspicuous difference can be seen in two centers: 8–9. Both centers are identified as centers with four indices: ER, WE, PD and BED. However, these centers are obscured in the hotspots identified by PE (Table 4). Another difference between the hotspots identified with PE and with the other four indices is the three small centers that are only identified with PE. They are centers 17–19.

A total of 19 hotspot centers (Table 4) are identified with at least one of the five diversity indices. These centers cover an area of approximately 767,000 km^2, or 7.96% of the total land area, and contain 11,691 Chinese endemic seed plant species, or 91.17% of total Chinese endemic seed plant species. We regarded these 19 centers as the hotspots for Chinese endemic seed plant species. Nine out of the 19 centers, including centers 1–7, 10 and 12, are commonly identified with all five indices. They cover an area of approximately 250,600 km^2, accounting for 2.60% of China's total land area, and harbor 9171 Chinese endemic seed plant species, or 71.51% of the total Chinese endemic seed plant species (12,824 species).

3.3. Conservation gap of Chinese endemic seed flora

The spatial distributions of 2139 nature reserves and hotspots of endemic seed plant species in China are significantly different (Fig. 2a, b).

Fig. 1. Maps of administrative provinces, topography and major mountain ranges in China. (a) Locations of administrative province and major morphostructures (Scarlet text). Black number with underline identifies administrative province: 1 Heilongjiang, 2 Jilin, 3 Liaoning, 4 Inner Mongolia, 5 Hebei, 6 Shanxi, 7 Shandong, 8 Henan, 9 Shaanxi, 10 Ningxia, 11 Gansu, 12 Qinghai, 13 Xinjiang, 14 Anhui, 15 Jiangsu, 16 Zhejiang, 17 Jiangxi, 18 Hunan, 19 Hubei, 20 Sichuan, 21 Guizhou, 22 Fujian, 23 Taiwan, 24 Guangdong, 25 Guangxi, 26 Yunnan, 27 Tibet, 28 Hainan, 29 Beijing 30, Tianjin, 31 Shanghai, 32 Chongqing. According to Chinese physical geography (Editorial Committee for China's Physical Geography, 1985), the topography is shown as five types, including plains (elevation <500 m), low mountains (elevation of 500–1000 m), middle mountains (elevation of 1000–3500 m), high mountains (elevation of 3500–5000 m) and very high mountains (elevation >5000 m). (b), Black number indicates main mountain ranges (Numbers are consistent with Table S1). The terrain of China from west to east forms a flight of three steps, commonly called "Three Steps". The First Step mainly includes Qing-Tibet Plateau, northern to Kunlun, Aerjin, and Qilian Mountains and eastern to Min, Qionglai, Daxue and Hengduan Mountains. The Second Step lies between the Hengduan Mountains to the west and Daxing'anling, Taihang, Funiu, and Xuefeng Mountains to the east, including mainly inner Mongolian Plateau, Loess Plateau, Qinling Mountains, Sichan Basin, and Yun-Gui Plateau. The Third Step scans all regions the Second Step to the east, which covering Northeast Plain, North China Plain, Middle-lower Yangtze Plain, Jiangnan Hills, Nanling Mountains, Guangdong and Guangxi Hills, Zhejiang and Fujian Hills as well as Taiwan and Hainan islands. The inset in the right bottom of the figure shows the south boundary of China, includes all islands in the South China Sea. Albers projection.

Table 1
Five indices of measuring diversity for Chinese endemic seed plant species.

Index	Equation	Corresponding details	Characteristics	Reference
Endemic species richness	$ER = S$	S is the number of Chinese endemic seed plant species represented in a spatial unit.	The most straightforward and universal index	
Weighted endemism	$WE = \sum_{i=1}^{n} W_i$	n is the number of Chinese endemic seed plant species in a spatial unit, and W_i is the weighting of species i, which is the inverse of its range.	Combining number of species and range size of them	(Linder, 2001)
Phylogenetic diversity	$PD = \sum_{(c \in C)} L_c$	C is the set of branches in the minimum spanning path joining the species to the root of the tree, c is a branch in the spanning path, and L_c is the length of branch c.	The sum of the lengths of all branches that are members of the corresponding minimum spanning path and is a simple measure of evolutionary diversity	(Faith, 1992)
Phylogenetic endemism	$PE = \sum_{(c \in C)} L_c / R_c$	C, c and L_c are the same as in PD, R_c is the clade range.	Combining PD and WE based on the length and geographic range size for each branch on a phylogeny	(Rosauer et al., 2009)
Biogeographically weighted evolutionary distinctiveness	$BED = \sum_{i=1}^{n} \sum_{j=1}^{m} L_j / N_j / R_i$	n is the number of taxa, m is the number of branches, L_j is the length of branch j, N_j is the numbers of terminal species descended from branch j, and R_i is the range of species i.	Combining species evolutionary distinctiveness and species spatial extent	(Cadotte and Davies, 2010)

Table 2
Spearman's correlation coefficient ρ (with spatial autocorrelation-corrected P-value) between a pair of diversity indices. ER: Chinese endemic seed plant species richness, WE: weighted endemism, PD: phylogenetic diversity, PE: phylogenetic endemism, BED: biogeographically weighted evolutionary distinctiveness.

Index 1	Index 2	Spearman's ρ	*P*-value
ER	WE	0.9238	<0.001
ER	PD	0.9959	<0.001
ER	PE	0.8673	<0.001
ER	BED	0.8847	<0.001
WE	PD	0.9310	<0.001
WE	PE	0.9248	<0.001
WE	BED	0.9931	<0.001
PD	PE	0.8734	<0.001
PD	BED	0.8968	<0.001
PE	BED	0.9176	<0.001

These reserves and hotspots have common areas of 2031 km^2 which occupy 11.64% of the total area of China's nature reserves. The 73.52% of the hotspot areas were not covered by nature reserves. Therefore, most hotspots of Chinese endemic seed plant species are not well protected, and thus form conservation gaps (Fig. 2c).

Seven of the 19 hotspots of Chinese endemic seed plant species fall into global biodiversity hotspots. They are centers 1, 3, 6, 7, 14, 16 and 19, amounting to 384,700 km^2. They account for 50.15% of the total area of all hotspots and contain 77.43% (9929 species) of the total number of Chinese endemic seed plants in China. The remaining 12 hotspots harbor 6993 Chinese endemic seed plant species, accounting for 54.53% of the total Chinese endemic seed plant species.

Priority conservation areas to alleviate for conservation gaps of Chinese endemic seed plant species include centers 1, 3, 6, 7, and 14 (Fig. 2d). China's nature reserves, hotspots of Chinese endemic seed plant species, and global biodiversity hotspots have common areas with 108,200 km^2 and account for only 6.20% of the total area of China's nature reserves.

4. Discussion

4.1. Hotspots of Chinese endemic seed plant species

The 19 hotspots of Chinese endemic seed plant species identified in this study cover most of the previously defined key areas for biodiversity conservation in China. They include 11 of the 14 terrestrial key areas for conservation of China's biodiversity proposed by Wang et al. (1993); the 10 hotspot ecoregions identified by Tang et al. (2006); eight of the 11 terrestrial critical regions for conservation of China's biodiversity proposed by Chen (1998); 16 of the 32 terrestrial priority areas for biodiversity conservation in China launched by the Ministry of Environment Protection of China (2011); seven of the 12, which are located in or around China, of the WWF's Global 200 most critical and endangered terrestrial ecoregions; 13 of 20 centers of plant endemism in China (Lopez-Pujol et al., 2011); 15 of 20 centers of hotspots of Chinese endemic woody seed plants (Huang et al., 2012); all eight hotspots of China's threatened plants (Zhang and Ma, 2008); all three

Table 3
Spearman's correlation coefficient ρ (with spatial autocorrelation-corrected P-value) between a diversity index and the residual from a nonlinear regression in which the index is a power function of the county area. ER: Chinese endemic seed plant species richness, WE: weighted endemism, PD: phylogenetic diversity, PE: phylogenetic endemism, BED: biogeographically weighted evolutionary distinctiveness.

Index	Spearman's ρ	P-value
ER	0.9996	<0.001
WE	0.9942	<0.001
PD	0.9998	<0.001
PE	1.0000	<0.001
BED	1.0000	<0.001

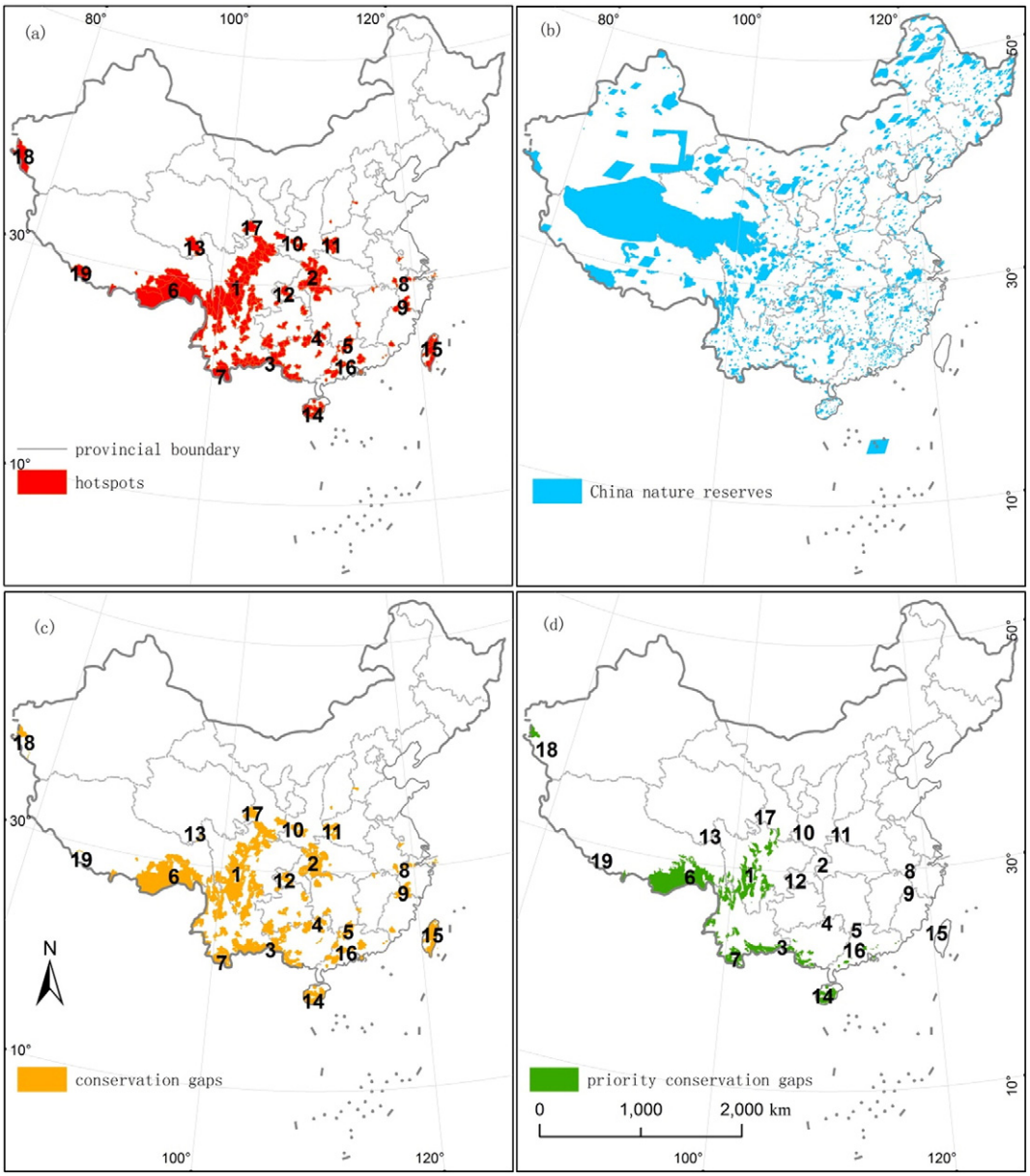


Fig. 2. Geographic distributions of hotspots and conservation gaps of Chinese endemic seed plant species and China nature reserves, (a) hotspots of Chinese endemic seed plant species, (b) China nature reserves, (c) conservation gaps of hotspots of Chinese endemic seed plant species and (d) priorities conservation gaps of hotspots of Chinese endemic seed plant species. Albers projection. Hotspot center codes are consistent with Table 4.

centers of China flora (Ying, 2001); and all three centers of endemic genera of China (Ying and Zhang, 1994). Among the 19 hotspots of Chinese endemic seed plant species, 16 hotspots were overlapped with areas that are rich in woody plant in China (Wang et al., 2011). Thus, the hotspots of Chinese endemic seed plant species encompass most key areas for biodiversity conservation in China.

In this study, endemic species refer to the species that occur naturally in China and nowhere else in the world. Therefore, the poor state of floristic information in several of the surrounding countries may inflate the number of endemic Chinese flora. Eight hotspots are located beside the border of China, and may be artificially affected by the factors below. Endemism itself is a scale-dependent and relative concept. The locations identified as hotspots of Chinese endemic seed plants are only tentative. The main reason for the uncertainty is the poor state of the floristic information in several of the surrounding countries, a situation that probably inflates the number of apparent endemics. As comprehensive and deep floristic surveys occur, the number of Chinese endemic plants may change, so hotspots of Chinese endemic seed plants may also change accordingly. Therefore, to obtain accurate locations of hotspots of Chinese endemic plants, communication and information sharing with our neighboring countries about the acquisition of plant data must be strengthened on the one hand; on the other hand, constant and timely update of the species checklist and distribution database of Chinese endemic seed plants is necessary.

4.2. The hotspots in the major mountain ranges and their potential causes

Chinese endemic seed plant species are unevenly distributed across the country. All the hotspots for these species other than Centers 13, 17, 18 and 19, are located in mountainous areas, mainly in the Qinling Mountains and further south or the Hengduan Mountains and to the East in China (Fig. 1). These areas correspond broadly to the regions with subtropical evergreen broad-leaved forest, tropical monsoon forest, and rain forest vegetation (Wu, 1980). Almost every hotspot embraces several mountain peaks (Table 4). Mountainous areas are important to the distribution of Chinese endemic seed plant species (Cañadas

Table 4
Hotspot centers for Chinese endemic seed plant species found in the present study and their main ranges, and for comparison with the critical regions of biodiversity in China. ++: major center; +: minor center; −: no center.

Hotspot centers	Main ranges (Summit (m asl))*	Present study					Wang et al. (1993) key biodiversity regions	Huang et al. (2012) biodiversity hotspots for Chinese endemic woody plant	Lopez-Pujol et al. (2011) Centers of plant endemism in china
		ER	WE	PD	PE	BED			
1. Hengduan Mountains	Gaoligong Mountains (3374), Shaluli Mountains (Que'ershan, 6168), Nu Mountains (Biluoxueshan, 4379), Meilixueshan (6740), Yulongxueshan (5596), Daxue Mountains (Gonggashan, 7556), Qionglai Mountains (Siguliangshan, 6250), Min Mountains (Xuebaoding, 5588)	++	++	++	++	++	+	++	++
2. Mountainous areas of east Chongqing and west Hubei	Daba Mountains (Shengnongding, 3105), Wudang Mountains (1612)	++	++	++	+	++	+	++	++
3. Mountainous areas of east Yunnan and west Guangxi	Transition areas of vegetation, Yun-Gui Plateau and Guangdong and Guangxi Basin	++	++	++	++	++	+	++	++
4. Mountainous areas of north Guangxi, southeast Guizhou and southwest Hunan	Transition areas of vegetation, Yun-Gui Plateau, Guangdong and Guangxi Hills and Jiangnan Hills, Leigong Mountains (2178), Jiuwanda Mountains, Xuefeng Mountains (1934)	++	++	++	+	++	−	++	++
5. Mountainous areas of north Guangdong and south Hunan	Nanling Mountains (1902)	+	+	+	+	+	+	++	++
6. Mountainous areas of southeast Tibet	Edge of Qing-Tibet Plateau	++	++	++	++	++	+	++	+
7. Xishuangbanna Region	Valleys of Lancangjiang River	+	+	+	+	+	+	++	+
8. Mountainous areas of southeast Anhui and northwest Zhejiang	Tianmu Mountains (1787), Huang Mountains (1873)	+	+	+	−	+	−	+	+
9. Mountainous areas of south Zhejiang, northwest Fujian, and southeast Jiangxi	E-China Mountains, Xianxialing Mountains (1621), Wuyi Mountains (2157),	+	+	+	−	+	+	+	−
10. Qinling Mountains	Qinling Mountains (Taibaishan, 3767)	+	+	+	+	+	+	+	+
11. Mountainous area of west Henan	Funiu Mountains (2212), Zhongtiao Mountains	+	−	+	−	−	−	+	−
12. southwest Chongqing	Dalou Mountains (Jinfoshan, 2251)	+	+	+	+	+	−	−	+
13. Lancang River source	Tanggula Mountains (5200)	+	−	−	−	−	−	−	−
14. Hainan Island	Wuzhi Mountains (1867)	−	++	−	++	++	+	++	+
15. Taiwan Island	Yu Mountains (3952)	−	++	−	++	++	+	++	+
16. Mountainous areas of central and west Guangdong	Yunwu Mountains (1703), Yunkaida Mountains	−	++	−	+	+	−	+	++
17. west of Longzhong Plateau	Liupan Mountains (Longshan, 2928)	−	−	−	+	−	−	−	−
18. Yarkant River in west Kunlun Mount	Karakoram Range (Qiaogelifeng, 8611)	−	−	−	+	−	−	−	−
19. Nielamu region	South edge of Himalaya	−	−	−	+	−	−	+	−

et al., 2014; Essl et al., 2009; Ying and Chen, 2011). The high level of heterogeneity in the topography, which is also more complex than the other areas in China, especially in areas of mountain uplift, probably provides a stimulus for plant speciation and thus has promoted the great species diversity and high degree of endemism (Qian and Ricklefs, 1999). The Qinling Mountains and Hengduan Mountains are two natural physical barriers. The both barriers changed the atmospheric circulation, and arouse increase in precipitation and moderation in temperature in the subtropical evergreen broad-leaved forest or tropical monsoon/rain forest regions, and thus contributed to maintain greater variety of habitats. These conditions thus may accelerate the speciation and species differentiation, and facilitate species preservation in these areas (Latham and Ricklefs, 1993) because structurally complex habitats may provide more niches and diverse ways of exploiting the environmental resources, thereby increasing the species diversity (Rosenzweig, 1995). Meanwhile, these natural physical barriers also restrict north-south and east-west plant migration and interchange, forming a geographically isolated area (Wu and Wang, 1983), thereby facilitating the speciation and differentiation of endemics. Furthermore, the lack of major ice caps during the Quaternary may have contributed to the maintenance of exceptional plant species richness in subtropical and tropical forest areas in China (Hsu, 1984; Latham and Ricklefs, 1993; Wu and Wang, 1983). All of these hotspots correspond to those regions that contribute greatly to the survival, speciation and evolution of vascular plants in China (Axelrod et al., 1996; Qian, 2002). Many endemic and relict genera of vascular plants are only found in these regions (Axelrod et al., 1996; Wu and Wang, 1983; Ying and Zhang, 1994). Alternatively, other factors may not play a decisive role but do play prominent roles in some local regions, such as in transitional areas (Axelrod et al., 1996; Wu, 1980; Wu and Wang, 1983) and in the isolation of islands from the continent (Lomolino et al., 2006). Consequently, we infer that the concentration of Chinese endemic seed plant species in the subtropical evergreen broad-leaved forest and tropical monsoon forest and rain forest vegetation regions may mainly result from the heterogeneous terrain, geological history and contemporary environments in these regions.

4.3. Suggestions for protection of the endemic flora of China

The identification of hotspots for flora has been reported using the ER, WE, PD, PE and BED indices. For example, ER has been used to identify global biodiversity hotspots (Myers et al., 2000); WE has been used to identify centers of endemism in sub-Saharan tropical Africa (Linder, 2001); PD has been used to identify biodiversity hotspots with evolutionary potential of flora in the Cape of South Africa (Forest et al., 2007); PE has been used to detect geographical concentrations of evolutionary history (Rosauer et al., 2009); and BED has been used to measure phylogenetic diversity for ecological communities (Cadotte et al., 2010). However, the use of all five indices together to identify hotspots of flora has not been reported previously (except in Huang et al. in 2012). In this study, we identified hotspots of Chinese endemic flora using five indices and based on comprehensive collections of endemic species distribution data of both woody and herbaceous seed plants. We think it is necessary to add herbaceous seed plants when identifying hotspots of Chinese endemic flora because more herbaceous plants than woody ones exist in China. However, the acquisition of accurate data for woody species is easier than for herbaceous ones. Fifteen hotspots of Chinese endemic woody seed plants are also hotspots of Chinese endemic seed plants. Among the 19 hotspots of Chinese endemic seed plants, four are not shared with endemic woody seed plants. These four hotspots are southwest Chongqing (center 12), the source of the Lancang River (center 13), west of Longzhong Plateau (center 17) and the Yarkant River in west Kunlun Mount (center 18). These hotspots indicate that endemic herbaceous seed plants contribute more to them than endemic woody seed plants. Consequently, we suggest that herbaceous plants in biodiversity conservation should be given adequate attention in the near future.

Our study shows that the hotspots of Chinese endemic seed plants are less protected, for example, by the current network of nature reserves in most tropical or subtropical mountainous vegetation, such as centers 1–17 except 13 (Fig. 2c). It should be noted that Taiwan Island (center 15 in Fig. 2c) is one of the major conservation gaps of the Chinese endemic flora according to this study. However, it may not be a fact. In fact, there are many protected areas in the island. We did not access nature reserves data about this island due to limited data sharing between Taiwan Island and mainland China. Although many nature reserves are distributed in the above regions, the areas covered by these reserves are very limited. In short, although China has established a large number and areas of nature reserves, the protection effectiveness of these reserves is extremely low (Wu et al., 2011). This mainly results from the lack of systematic planning at the beginning (Wu et al., 2011). Consequently, we suggest that the protection effectiveness of the established nature reserves should be promoted in the conservation gap areas of Chinese endemic seed plants. Geographical regions should serve as an important spatial unit to protect biodiversity. According to this study, conservation effort should be focus on the five priority conservation gaps of Chinese endemic seed plants: the Hengduan Mountains (center1), the mountainous areas of east Yunnan and west Guangxi (center 3), the mountainous areas of southeast Tibet (center 6), the Xishuangbanna Region (center 7), and Hainan Island (center 14).

5. Conclusions

Different diversity indices revealed similar distribution patterns of plant diversity at the national extent. The hotspots identified with weighted endemism and biogeographically weighted evolutionary distinctiveness have higher levels of diversity than those identified with the other indices. Nineteen hotspots of endemic seed plant species were identified with the five diversity indices in China. All of these hotspots are located in the mountainous areas, and most of them have been proposed as key areas for protecting China's biodiversity in previous studies. Although China has established more than 2000 nature reserves, over 70% of the hotspot areas of Chinese endemic seed plant species are not covered by current nature reserve system. Consequently, the purpose of the nature reserves network has yet to be achieved.

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