Diversity distribution patterns of Chinese endemic seed plant species and their implications for conservation planning

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Endemism is an important concept in biogeography and biodiversity conservation. China is one of the richest countries in biogeography and biodiversity conservation. China is one of the richest countries in biodiversity, with very high levels of plant endemism. In this study, we analysed the distribution patterns of diversity, the degree of differentiation, and the endemcity of Chinese endemic seed plants using the floristic unit as a basic spatial analysis unit and 11 indices. The analysis was based on distribution data of 24,951 native seed plant species (excluding subspecies and varieties) and 12,980 Chinese endemic seed plant species, which were sourced from both specimen records and published references. The distribution patterns of Chinese endemic flora were generally consistent but disproportionate across China for diversity, degree of differentiation and endemcity. The South Hengduan Mountains Subregion had the highest values for all indices. At the regional level, both the Hengduan Mountains and the Central China regions were highest in diversity and degrees of differentiation. However, both the rate of local endemic to native species and the rate of local to Chinese endemic species were highest in the Taiwan Region and the South Taiwan Region. The Hengduan Mountains Region and the Central China Region are two key conservation priority areas for Chinese endemic seed plants.

The Chinese flora has long attracted the attention of botanists and biogeographers1–8. China is one of the richest countries in terms of plant biodiversity9,10. The total number of vascular plant species in China is 31362 (Wu et al.11). The Chinese flora is also highly endemic12–14; a previous study found that endemic species account for 52.1% of all seed plant species8. China is also the only country in the world that supports vegetational continuity from tropical, to subtropical, temperate and boreal forests2,15. This continuous latitudinal gradient of forest vegetation, in combination with the many mountain ranges in China, presumably reduced rates of extinction during glaciations and increased rates of evolution and speciation for vascular plants2. China has attracted the attention of ecologists and conservationists because of the extraordinary richness of its flora16–20 and because it is among the countries with the highest numbers of threatened species in the world (Jenkins et al.21). Of the World Wildlife Fund’s Global 200 most Critical and Endangered Ecoregions, 17 are located in or intersect with China (Olson & Dinerstein22). Furthermore, of the 34 global biodiversity hotspots identified by Conservation International (Mittermeier et al.23), four either intersect with or are located within China. In total, 10 hotspot ecoregions22, 20 hotspots of endemic woody seed plant species20 and 8 hotspots of threatened plant species22 have been identified in China. By the end of 2014, China had established 2729 nature reserves26, but many were established opportunistically and do not fully represent and protect biodiversity priority areas27 or threatened plants28.

The flora in China is extremely rich and complex in species composition and distribution patterns. Thus, the regionalization of Chinese flora is also difficult and challenging. Wu was the first researcher to publish a comprehensive regionalization of Chinese flora based on pioneering works that had been published over decades. He

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classified Chinese flora into 2 kingdoms, 7 subkingdoms and 22 regions. Subsequently, the regionalization of Chinese flora was updated and refined into 4 kingdoms, 7 subkingdoms, 24 regions and 49 subregions. As described previously, many studies of biodiversity conservation have been conducted across China. However, they primarily used an administrative unit, particularly at the provincial level, as the spatial unit for analysis rather than a natural geographic or floristic unit. It is better to identify conservation priority areas on the basis of a natural geographic or floristic unit because such classifications substantially reduce the influence of and definition by human factors. Therefore, using the floristic unit as the basic unit of spatial analysis, we examined the distribution patterns, diversification and degrees of differentiation of Chinese endemic seed plants and identified conservation priority areas across the country for conservation planning and future effective conservation actions.

**Materials and Methods**

**Species data.** Based on a previously published list of Chinese endemic seed plant species, we compiled a data set of species distributions of Chinese endemic seed plants at the county level. The main sources used to compile the distribution dataset were as follows: (a) Flora of China and Flora Reipublicae Popularis Sinicae; (b) local flora, plant checklists and relevant monographs; (c) journal papers on plant taxonomy and distribution; and (d) specimens. Our research sources included 1044 flora, monographs, reports and theses; 516 papers; and 37 herbaria through the end of 2012. The references and herbaria are listed in Appendix A. The distribution data were extracted from the source data and compiled and unified to county level. Then, a geographic distribution database of Chinese endemic seed plant species was established. We compiled 789,004 records of 24,951 native seed plant species (excluding subspecies and varieties) with distribution information at the county level. Of these species, 12,980 (Appendix B) are endemic to China.

**Floristic regions of China.** We digitized the map of floristic regions of China using ArcGIS 9.3. The floristic regions of China were composed of 4 kingdoms, 7 subkingdoms, 24 regions and 49 subregions (Table 1 and Fig. 1). There are 9 regions without subregions. We used the floristic subregion as the basic unit for spatial analysis in this study. Thus, 58 spatial floristic units were examined (i.e., 49 subregions and 9 regions) (Table 1 and Fig. 1). Two of the 58 units — the Islands of East Guangdong along sea Subregion (IVG21b) and the Islands of South China Sea Subregion (IVG21e) — comprise multiple islands. We were unable to generate a checklist of plant species for these two units because high-precision species distribution data for them were not available. Therefore, 56 spatial floristic units were generated. We extracted centroids (latitude and longitude coordinates) for all counties using Data Management Tools in ArcGIS. These centroids were incorporated into 56 floristic units with Analysis Tools, and records of the floristic units for each species were then obtained. Distribution information regarding the presence or absence of each species was documented for each floristic unit.

**Data analysis.** Measurement of species diversity was based on species richness, i.e., the number of species in each spatial unit. Family diversity and genus diversity were calculated using family richness and genus richness, respectively, i.e., the number of families and genera in each spatial unit. In addition, the local endemic species (NLES) for each floristic unit were counted according to their distributions. The degrees of differentiation among endemic flora were represented by differentiation indices, which included a species differentiation index (D_s) and a genus differentiation index (D_g) and a species–family differentiation index (D_sf). The functions of the three indices are shown in Equations (1–3).

\[ D_s = \frac{N_s}{N_f} \]  
\[ D_g = \frac{N_g}{N_f} \]  
\[ D_{sf} = \frac{N_s}{N_f} \]

where \( D_s, D_g \) and \( D_{sf} \) are the species differentiation index, genus differentiation index and species–family differentiation index for a floristic unit, respectively, and \( N_s \) is the number of species endemic in China in a floristic unit, \( N_g \) is the number of genera of endemic flora in China in a floristic unit, and \( N_f \) is the number of families of endemic flora in China in a floristic unit.

Biodiversity conservation is closely associated with species distribution and biogeography. Generally, species that are confined to a limited area have an increased risk of extinction. Here, we calculated the weighted endemism for each floristic unit. The calculation of weighted endemism is shown in Equation (4).

\[ WE = \sum_{i=1}^{n} W_i \]  

where \( n \) is the number of species in a focal floristic unit and \( W_i \) is the weight of species \( i \), which is the inverse of its range (i.e., the number of floristic units in which species \( i \) occurs).

Proportions of endemism were calculated to compare the distribution patterns of endemic flora in China. These proportions included the rate of Chinese endemic to native species (RCENS), the rate of local endemic to native species (RLENS) and the rate of local to Chinese endemic species (RLCES).
| Code | Subregion code | Subregion name | Kingdom code | Kingdom name | Subkingdom code | Subkingdom name | Region code | Region name |
|------|----------------|----------------|--------------|--------------|----------------|----------------|-------------|-------------|
| 1    | IA1            | Da Hinggan Ling Region | I           | Holarctic Kingdom | IA            | Eurasian Forest Subkingdom | IA1        | Da Hinggan Ling Region |
| 2    | IA2            | Altai Region       | I           | Holarctic Kingdom | IA            | Eurasian forest Subkingdom | IA2        | Altai Region |
| 3    | IA3            | Tianshan Region    | I           | Holarctic Kingdom | IA            | Eurasian forest Subkingdom | IA3        | Tianshan Region |
| 4    | IB4a           | Northeast Plain forest steppe Subregion | I           | Holarctic Kingdom | IB            | Eurasian Steppe Subkingdom | IB4        | Inner Mongolia Grassland Region |
| 5    | IB4b           | Eastern Inner Mongolia grassland Subregion | I           | Holarctic Kingdom | IB            | Eurasian Steppe Subkingdom | IB4        | Inner Mongolia Grassland Region |
| 6    | IB4c           | Ordos, Shensi-Kansu-Ningia desert grassland Subregion | I           | Holarctic Kingdom | IB            | Eurasian Steppe Subkingdom | IB4        | Inner Mongolia Grassland Region |
| 7    | IIC5a          | Tacheng and Yili Subregion | II          | Tethys Kingdom | IIC           | Central Asia Desert Subkingdom | IIC5       | Junggar Region |
| 8    | IIC5b          | Junggar Subregion   | II          | Tethys Kingdom | IIC           | Central Asia Desert Subkingdom | IIC5       | Junggar Region |
| 9    | IIC6a          | Southwest Inner Mongolia Subregion | II          | Tethys Kingdom | IIC           | Central Asia Desert Subkingdom | IIC6       | Kashgar Region |
| 10   | IIC6b          | Qaidam Basin Subregion | II          | Tethys Kingdom | IIC           | Central Asia Desert Subkingdom | IIC6       | Kashgar Region |
| 11   | IIC6c          | Kashi Subregion     | II          | Tethys Kingdom | IIC           | Central Asia Desert Subkingdom | IIC6       | Kashgar Region |
| 12   | IIID7          | Northeast China Region | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID7      | Northeast Region |
| 13   | IIID8a         | Liaoning, Shandong Peninsula Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID8      | North China Region |
| 14   | IIID8b         | North China Plain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID8      | North China Region |
| 15   | IIID8c         | North China Mountain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID8      | North China Region |
| 16   | IIID8d         | The Loess Plateau Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID8      | North China Region |
| 17   | IIID9a         | Huanghuai Plain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID9      | East China Region |
| 18   | IIID9b         | Jianghan Plain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID9      | East China Region |
| 19   | IIID9c         | South Zhejiang Mountain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID9      | East China Region |
| 20   | IIID9d         | South Jiangxi-East Hunan Hills Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID9      | East China Region |
| 21   | IIID10a        | Qinling-Bashan Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID10     | Central China Region |
| 22   | IIID10b        | Sichuan Pendi Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID10     | Central China Region |
| 23   | IIID10c        | Sichuan, Hubei and Hunan Border Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID10     | Central China Region |
| 24   | IIID10d        | Guizhou Plateau Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID10     | Central China Region |
| 25   | IIID11a        | North Fujian Mountain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID11     | Lingnan Mountains Region |
| 26   | IIID11b        | North Guangdong Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID11     | Lingnan Mountains Region |
| 27   | IIID11c        | East Section of Nanling Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID11     | Lingnan Mountains Region |
| 28   | IIID11d        | Guangdong-Guangxi Mountain Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID11     | Lingnan Mountains Region |
| 29   | IIID12a        | Guizhou-Guangxi Border Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID12     | Yunnan, Guizhou and Guangxi Region |
| 30   | IIID12b        | Hongshuihe River Basin Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID12     | Yunnan, Guizhou and Guangxi Region |
| 31   | IIID12c        | Southeast Yunnan Limestone Subregion | III         | Eastern Asiatic Kingdom | IIID         | China-Japan Forest Plant Subkingdom | IIID12     | Yunnan, Guizhou and Guangxi Region |

Continued
To summarize, the 11 indices were as follow: the number of species (N_s), the number of genera (N_g), the number of families (N_f), the number of local endemic species (NLES), the degree of species differentiation (D_s), the degree of genus differentiation (D_g), the degree of species–family differentiation (D_sf), weighted endemism (WE), the rate of Chinese endemic to native species (RCENS), the rate of local endemic to native species (RLENS).

| Code | Subregion code | Subregion name                  | Kingdom code | Kingdom name                  | Subkingdom code | Subkingdom name                  | Region code | Region name                  |
|------|----------------|---------------------------------|--------------|--------------------------------|-----------------|---------------------------------|-------------|--------------------------------|
| 32   | IIIE13a        | Central Yunnan Plateau Subregion| III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE13      | Yunnan Plateau Region         |
| 33   | IIIE13b        | East Yunnan Subregion           | III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE13      | Yunnan Plateau Region         |
| 34   | IIIE13c        | Southwest Yunnan Subregion      | III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE13      | Yunnan Plateau Region         |
| 35   | IIIE14a        | Sanjiang valley Subregion       | III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE14      | Hengduan Mountains Region     |
| 36   | IIIE14b        | South Hengduan Mountains Subregion| III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE14      | Hengduan Mountains Region     |
| 37   | IIIE14c        | North Hengduan Mountains Subregion| III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE14      | Hengduan Mountains Region     |
| 38   | IIIE14d        | Taohe-Minshan Subregion         | III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE14      | Hengduan Mountains Region     |
| 39   | IIIE15a        | Dulongjiang River-North Myanmar Subregion| III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE15      | East Himalayan Region         |
| 40   | IIIE15b        | Southeast Tibet Subregion       | III          | Eastern Asiatic Kingdom       | IIIE            | China-Himalayan Plant Subkingdom| IIIE15      | East Himalayan Region         |
| 41   | IIIF16a        | Qilian Mountains Subregion      | III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF16      | Tanggute Region                |
| 42   | IIIF16b        | Animaqing Subregion             | III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF16      | Tanggute Region                |
| 43   | IIIF16c        | Tanggula Subregion              | III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF16      | Tanggute Region                |
| 44   | IIIF17a        | Upper and Middle of Yarlung Zangbo River Subregion| III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF17      | Tibet-Pamir-Kunlun Region      |
| 45   | IIIF17b        | Qiangtang Plateau Subregion     | III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF17      | Tibet-Pamir-Kunlun Region      |
| 46   | IIIF17c        | Pamir-Karakoram-Kunlun Subregion| III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF17      | Tibet-Pamir-Kunlun Region      |
| 47   | IIIF18         | Himalayan Region                | III          | Eastern Asiatic Kingdom       | IIIF            | Qing-Tibet Plateau Subkingdom   | IIIF18      | Himalayan Region               |
| 48   | IVG19a         | Taiwan high mountain Subregion  | IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG19       | Taiwan Region                  |
| 49   | IVG19b         | Taipei Subregion                | IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG19       | Taiwan Region                  |
| 50   | IVG20          | South Taiwan Region             | IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG20       | South Taiwan Region            |
| 51   | IVG21a         | West Guangdong-North Hainan Subregion| IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG21       | South Sea Region               |
| 52   | IVG21b         | Islands of east Guangdong along sea Subregion| IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG21       | South Sea Region               |
| 53   | IVG21c         | Southwest Hainan Subregion      | IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG21       | South Sea Region               |
| 54   | IVG21d         | Central Hainan Subregion        | IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG21       | South Sea Region               |
| 55   | IVG21e         | Islands of South China Sea Subregion| IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG21       | South Sea Region               |
| 56   | IVG22          | Beibu Gulf Region               | IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG22       | Beibu Gulf Region              |
| 57   | IVG23          | Yunnan, Myanmar and Thailand Border Region| IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG23       | Yunnan, Myanmar and Thailand Border Region|
| 58   | IVG24          | South edge of eastern Himalayan Region| IV           | Paleotropic Kingdom           | IVG             | Malaysia Subkingdom             | IVG24       | South edge of eastern Himalayan Region|

Table 1. Floristic regionalization of China.
and the rate of local to Chinese endemic species (RLCES). These 11 indices were standardized by dividing their maxima and then summed to produce a total value. All floristic units were ranked according to their total value, and conservation priority areas for Chinese endemic seed plants were identified according to each unit's rank. The spatial floristic unit was used to prioritize conservation areas, and the units with the highest total values were the top-ranked areas because higher values were determined by greater endemic species richness and the degree of differentiation and endemism. In this study, the top eight floristic units were designated conservation priority areas.

Correlations between the values of indices and the geographic distance from focal floristic units to the centre floristic unit with the highest value for each index were identified using the Mantel test37. All calculations were carried out using the R statistical software package, version 3.2.238. All geographic distribution patterns of Chinese endemic flora were mapped using ArcGIS 9.3 software.

**Results**

**Composition and distribution of Chinese endemic seed plant species.** Families and genera of Chinese endemic seed plant species were unevenly distributed across the country. At the family level, the South Hengduan Mountains Subregion (IIIIE14b) and the Central Yunnan Plateau Subregion (IIIIE13a) contained the most families (Table 2 and Fig. 2a). These two subregions were followed by the Southeast Yunnan Subregion (IIIIE13b), the Guizhou-Guangxi Border Subregion (IIID12a) and the Guizhou Plateau Subregion (IIIIE13b). The South Hengduan Mountains Subregion (IIIIE14b) and the Central Yunnan Plateau Subregion (IIIIE13a) were the richest in genera of Chinese endemic seed plant species, with 813 and 785 genera, respectively (Table 2). These subregions were followed by the Guizhou Plateau Subregion (IIID10d), the Yunnan-Myanmar-Thailand Border Region (IVG23), the Sanjiang Valley Subregion (IIIIE14a), the Guizhou-Guangxi Border Subregion (IIID12a), the Southeast Yunnan Subregion (IIIIE13b), the Guangdong-Guangxi Mountain Subregion (IIID11d), the Sichuan-Hubei-Hunan Border Subregion (IIID10c) and the Beibu Gulf Region (IVG22) (Table 2 and Fig. 2b).

Chinese endemic seed plant species were also unevenly distributed across the country. The South Hengduan Mountains Subregion (IIIIE14b) was the richest, with 5177 species of Chinese endemic seed plants, which was followed by the Central Yunnan Plateau Subregion (IIIIE13a), with 3688 species (Table 2). The Pamir-Karakoram-Kunlun Subregion was the least rich in Chinese endemic species richness and has only 64 species (Table 2). At the region level, the distribution of Chinese endemic seed plants was concentrated mainly in the Hengduan Mountains Region (IIIIE14), followed by the Yunnan Plateau Region (IIIIE13), the Yunnan-Guizhou-Guangxi Border Region (IIID10), the Lingnan Mountains Region (IIID11), the Central China Region (IIID10), the Yunnan-Myanmar-Thailand Border Region (IVG23) and the Beibu Gulf Region (IVG22) (Fig. 2c).

The distribution patterns of Chinese endemic flora at family, genus and species levels across the country were generally consistent (Fig. 2a–c). The patterns were significantly correlated (P < 0.001), and all correlation coefficients were greater than 0.80. The South Hengduan Mountains Subregion (IIIIE14b) and the Central Yunnan Plateau Subregion (IIIIE13a), which bordered each other, were centres of Chinese endemic flora because they had the highest numbers of endemic taxa. The number of families, genera and species of Chinese endemic seed flora decreased with increasing distance from focal floristic units to the centre floristic unit with the highest value for each index (Fig. 2a–c), but the number of families and genera decreased significantly (P < 0.05).

**Species differentiation.** The degree of differentiation among endemic seed plant species was unevenly distributed across China (Fig. 2d–f). The highest species differentiation was in the South Hengduan Mountains Subregion (IIIIE14b), with a value of 6.37, followed by the North Hengduan Mountains Subregion (IIIIE14c), with a value of 5.56 (Table 2). The lowest degree of species differentiation was in the Tacheng and Yili Subregion, with a value of 1.24 (Table 2). The genus differentiation among Chinese endemic seed plant species was the highest (5.57) in the South Hengduan Mountains Subregion (IIIIE14b) and the lowest (1.86) in the South Taiwan Region (IVG20), with a value of 1.24 (Table 2). The genus differentiation among Chinese endemic seed plant species was the highest (5.57) in the South Hengduan Mountains Subregion (IIIIE14b) and the lowest (1.24) in the South Taiwan Region (IVG20). The pattern for the species–family differentiation index was similar to that observed for genus differentiation (Table 2).

**Local endemic species and their endemcity.** The spatial distribution patterns of Chinese endemic plant species, local endemic species and weighted endemism were significantly correlated (P < 0.001) (Fig. 3a–c), and all correlation coefficients were greater than 0.75. The South Hengduan Mountains Subregion (IIIIE14b) was the richest in local endemic species, with a value of 429. The Yunnan-Myanmar-Thailand Border Subregion ranked second, with 194 local endemic species.

The endemic rates were also unevenly distributed across the country (Fig. 3d–f). The rate of Chinese endemic to native plant species (RCENS) was highest in the South Hengduan Mountains Subregion (IIIIE14b) and the North Hengduan Mountains Subregion (IIIIE14c). Both the rate of local endemic to native species (RLENS) and the rate of local to Chinese endemic species (RLCES) were the highest in the Taiwan Region (VG19) and the South Taiwan Region (IVG20). The rate of local to Chinese endemic species (RLCES) was also very high in the Altai Region (IA2) and the Pamir-Karakoram-Kunlun Subregion (IIIIF17c), followed by the South Taiwan Region (IVG20).

**Priority areas of floristic regions for Chinese endemic seed plant species.** The South Hengduan Mountains Subregion (IIIIE14b), the Central Yunnan Plateau Subregion (IIIIE13a), the Sanjiang Valley Subregion (IIIIE14a) and the North Hengduan Mountains Subregion (IIIIE14c) had the highest total values of all floristic units (Fig. 4). These subregions, with the exception of the Central Yunnan Plateau Subregion (IIIIE13a), are in the geographic space of the Hengduan Mountains Region (Table 1). The subregions that followed those with
the highest values were the Guizhou Plateau Subregion (IIID10d), the Sichuan-Hubei-Hunan Border Subregion (IIID10c), the Qinling-Bashan Subregion (IIID10a), and the Taohe-Minshan Subregion (IIIE14d). Of these regions, the first three are in the Central China Region (Table 1), and the Taohe-Minshan Subregion is also in the Hengduan Mountains Region (Table 1).

Discussion
Species differentiation. The degree of species differentiation among Chinese endemic seed plants was unevenly distributed across the country. Although the degree of differentiation was not high in many parts of China, it was particularly high in the Hengduan Mountains12, which indicated that the Hengduan Mountains are the centre of differentiation for Chinese endemic seed plants39. This result is consistent with the hypothesis that Southwest China is the differentiation centre of the Chinese flora1,2,7. The Hengduan Mountains are the core part of Southwest China in terms of biological diversity and differentiation7. Therefore, the Hengduan Mountains are the centre of biological diversity and differentiation in China.

Endemicity. The rate of Chinese endemic to native plant species was highest in the South Hengduan Mountains Subregion (IIIE14b), followed by the North Hengduan Mountains Subregion (IIIE14c). Based on this result, endemicity of flora in the Hengduan Mountains is very high across China. However, the South Hengduan Mountains Subregion and the North Hengduan Mountains Subregion differ in endemicity. The terrain of China from west to east forms a flight of three steps, commonly called the “Geomorphological Three Steps”. The First Step mainly encompasses the Qinghai-Tibet Plateau, north to the Kunlun, Aierchin, and Qilian mountains and east to Min, Qionglai, Daxue and Hengduan mountains. The Second Step lies between the Hengduan Mountains to the west and the Daxing’anling, Taihang, Funiu, and Xuefeng mountains to the east, primarily including the Inner Mongolian Plateau, Loess Plateau, Qinling Mountains, Sichuan Basin, and Yun-Gui Plateau. The Third Step covers the entire area east from the Second Step, and includes the Northeast China 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 Hainan20. The floristic endemicity was higher in the South Hengduan Mountains than that in the North Hengduan Mountains Subregion, most likely because the Hengduan Mountains are topographically located along the border of the Second Step and the Third Step in China, and the warm, moist airflows

Figure 1. Distribution of floristic regionalization of China. Albers projection. The subregion codes on the map are consistent with those provided in Table 1. The map was generated using ArcGIS 9.3 (ESRI, Redlands, CA, USA; http://www.esri.com).
| Floristic region code | Composition of Chinese endemic flora | Indices of differentiation | Number of local endemic species | Value of weighted endemism | Rate of Chinese endemic to native species | Rate of local endemic to native species | Rate of local to Chinese endemic species |
|----------------------|-------------------------------------|-----------------------------|-----------------------------|----------------------------|------------------------------------------|---------------------------------------------|---------------------------------------------|
| IA1                  | 27 72 127                            | 1.76 2.67 4.70             | 3                          | 18                         | 0.10                                    | 0.00                                        | 0.02                                        |
| IA2                  | 28 64 91                             | 1.42 2.29 3.25             | 17                         | 29                         | 0.06                                    | 0.01                                        | 0.19                                        |
| IA3                  | 43 139 268                           | 1.93 3.23 6.23             | 26                         | 72                         | 0.11                                    | 0.01                                        | 0.10                                        |
| IB4a                 | 46 108 164                           | 1.52 2.35 3.57             | 4                          | 24                         | 0.11                                    | 0.00                                        | 0.02                                        |
| IB4b                 | 48 146 277                           | 1.90 3.04 5.77             | 4                          | 41                         | 0.16                                    | 0.00                                        | 0.01                                        |
| IB4c                 | 65 223 527                           | 2.36 3.43 8.11             | 4                          | 69                         | 0.25                                    | 0.00                                        | 0.01                                        |
| IIC5a                | 56 128 159                           | 1.24 2.29 2.84             | 7                          | 28                         | 0.08                                    | 0.00                                        | 0.04                                        |
| IIC5b                | 33 83 132                            | 1.59 2.52 4.00             | 5                          | 32                         | 0.07                                    | 0.00                                        | 0.04                                        |
| IIC6a                | 83 321 1083                          | 3.37 3.87 13.05            | 16                         | 161                        | 0.37                                    | 0.01                                        | 0.01                                        |
| IIC6b                | 70 140 200                           | 2.00 2.06 4.12             | 0                          | 17                         | 0.26                                    | 0.00                                        | 0.00                                        |
| Table 2. Composition, diversity, degree of differentiation, and endemicity of endemic seed plants for each floristic unit in China.
in summer occur primarily in the South Hengduan Mountains Subregion and have only a limited influence if they arrive in the North Hengduan Mountains Subregion. By contrast, the North Hengduan Mountains Subregion is often influenced by dry and cold airflows. The altitude range is mainly between 2000 and 3000 m in the South

Figure 2. Distribution of biodiversity and differentiation indices across Chinese floristic units. 
(a) $N_f$ = number of families of Chinese endemic seed plants, (b) $N_g$ = number of genera of Chinese endemic seed plants, (c) $N_s$ = number of species of Chinese endemic seed plants, (d) $D_s$ = degree of species differentiation among Chinese endemic seed plants, (e) $D_g$ = degree of genus differentiation among Chinese endemic seed plants, and (f) $D_{sf}$ = degree of species–family differentiation of Chinese endemic seed plants. Five levels for each index were categorized using the Natural Breaks (Jenks) method in ArcGIS. Albers projection. The subregion codes on the map are consistent with those provided in Table 1. The map was generated using ArcGIS 9.3 (ESRI, Redlands, CA, USA; http://www.esri.com).
Hengduan Mountains Subregion, which is the altitude characterized by a rapid increase in the rate of Chinese endemic seed plants.

The rate of local endemic to native plant species was highest in the Taiwan Region (IVG19) and the South Taiwan Region (IVG20), which indicates that the flora of Taiwan is distinctive. The rate of local to national
endemic plant species was the highest in the Taiwan Region (IVG19), the South Taiwan Region (IVG20), the Altai Region (IA2) and the Pamir-Karakoram-Kunlun Subregion (III17c). This result shows that the island of Taiwan, the Altai Region (IA2) and the Pamir-Karakoram-Kunlun Subregion (III17c) have different flora that might be influenced by trans-boundary flora from neighbouring countries.

Conservation priority areas. The four top conservation priority areas were identified; the South Hengduan Mountains Subregion (IIIE14b), the Central Yunnan Plateau Subregion (IIIE13a), the Sanjiang Valley Subregion (IIIE14a) and the North Hengduan Mountains Subregion (IIIE14c). Most of these subregions are in the geographical terrain of the Hengduan Mountains. The Hengduan Mountains are rich in mountainous flora and are thus a key area for studies of the relationships among Laurasian, Gondwanian and Tethyan flora. Vegetation with both horizontal and vertical replacement is markedly dominant in the Hengduan Mountains. Moreover, new and old endemic plant species coexist, although the new endemic species are dominant in this region. The flora of this region is divided into three geographical elements based on ancient geographical environments: Boreal, Tethys and Gondwana. Studies of the trade-offs among these geographical elements over space and time are beneficial in clarifying the relationships between the development of flora and the movements of tectonic plates.

Conservation International listed the montane areas of Southwest China as one of the 34 global biodiversity hotspots.

Three other top conservation priority areas were identified; the Guizhou Plateau Subregion (IIID10d), the Sichuan-Hubei-Hunan Border Subregion (IIID10c) and the Qinling-Bashan Subregion (IIID10a). These three subregions are in the Central China Region. The flora of this region comprises direct and nearly intact descendants of a Tertiary ancient flora for several reasons. First, the Ancient Central China region did not suffer transgression after Indosinian movement in the Triassic period. Second, montane refuges that were widespread during the Pleistocene glacial period were less affected in this region. In the glacial periods throughout the glacial-interglacial cycles, some plants migrated between the north and south and between low and high elevations near the Hengduan Mountains. Third, this region is completely surrounded by mountains and has an enclosed terrain that is complex and varied. All of these factors are closely related to the preservation of old endemic species, and to the differentiation of new endemic species. Therefore, we suggest that more attention...
should be paid to this region for its protection. In our study, the conservation priority areas identified for Chinese endemic seed plants were highly consistent with the key flora of China that were identified in previous studies. In addition, in this study, conservation priority areas were identified for the first time by using a floristic unit as the basic unit of spatial analysis across China. With this approach, the artificial impact of the unit of spatial analysis on the distribution patterns of species was substantially weakened because the bounded floristic subregion depended much more on natural factors than on human factors. Consequently, determination of conservation priority areas for Chinese endemic seed plants of the China flora is more credible when a floristic unit is the basic unit for spatial analysis.

**Conclusion**

The diversity and degrees of differentiation among Chinese endemic seed plants are unevenly distributed across the country. Both the Hengduan Mountains and Central China regions are diversity centres that also have the highest degrees of differentiation. Moreover, the Hengduan Mountains Region and the Central China Region are two key conservation priority areas for Chinese endemic seed plants based on diversity, degrees of differentiation and endemicity. In addition, the Taiwan Region, the Altai Region and the Pamir-Karakoram-Kunlun Subregion have unique endemic flora, and greater attention should be paid to the flora of these regions or subregions in future conservation planning and actions.

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Acknowledgements
We are particularly grateful to the associate editor and anonymous reviewers for their valuable comments on the manuscript. This research was supported by the National Natural Science Foundation of China (41471048), the National Nonprofit Institute Research Grant of the Chinese Academy of Forestry (CAFYBB2014MA005) and the National Nonprofit Institute Research Grant of the Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry (CAFIFEEP2015B02).

Author Contributions
Jihong Huang, Jianhua Huang and K.M. designed the study. Jihong collected data. Jihong Huang and Jianhua Huang carried out the data analysis and wrote the manuscript. Jihong Huang, Jianhua Huang, K.M. and X.L. reviewed the manuscript.

Additional Information
Supplementary information accompanies this paper at http://www.nature.com/srep

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Huang, J. et al. Diversity distribution patterns of Chinese endemic seed plant species and their implications for conservation planning. Sci. Rep. 6, 33913; doi: 10.1038/srep33913 (2016).

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