Diversity patterns and conservation gaps of Magnoliaceae species in China

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ABSTRCAT

Magnoliaceae, a primitive group of angiosperms and distinguished ornamental plants with more than 100 species in China, is one of the most threatened plant family in the wild due to logging, habitat loss, over-collection and climate change. To provide a scientific guide of its conservation for policymakers, we explore the diversity patterns of 114 Magnoliaceae species in China using three diversity indices (species richness, weighted endemism, β-diversity) with a spatial resolution of 10 km by 10 km. Two methods, the top 5% richness algorithm and complementary algorithm, are used to identify diversity hotspots. Conservation gaps are recognized by overlapping the diversity hotspots with Chinese nature reserves. Our results indicate that Magnoliaceae species richness and weighted endemism are high in tropical to subtropical low montane forests in southern China, exceptionally high in southernmost Yunnan and boundary of Guizhou, Guangxi and Hunan. The β-diversity are scattered in southern China, suggesting a different species composition among grid cells. We identify 2524 grids as diversity hotspots for Magnoliaceae species in China, with 24 grids covered by three diversity indices (first-level diversity hotspots), 561 grids covered by two indices (second-level diversity hotspots) simultaneously and 1939 grids (76.8%) covered by only one index (third-level diversity hotspots). The first-level diversity hotspots include over 70% of the critically endangered Magnoliaceae species and are the priority areas for Magnoliaceae conservation. However, only 24% of the diversity hotspots fall in nature reserves and only ten grids are from the first-level diversity hotspots. Zhejiang, Guizhou and Fujian have less than 20% of diversity hotspots covered by nature reserves and need attention in future Magnoliaceae conservation. Using multiple diversity indices and algorithms, our study identifies diversity hotspots and conservation gaps and provides scientific basis for Magnoliaceae conservation in future.

Keywords: Magnoliaceae, Species richness, Weighted endemism, β diversity, Biodiversity hotspots, Priority conservation areas

HIGHLIGHTS

- Diversity hotspots were identified by three diversity indices and two algorithms
- Diversity hotspots were mainly distributed in southern China
- Only 24% of hotspots of Magnoliaceae covered by the Chinese nature reserves
- The first-level diversity hotspots can protect 70% of critically endangered species
- Conservation gaps of diversity hotspots were mainly in Zhejiang, Guizhou and Fujian

1. Introduction

Magnoliaceae is a family of flowering plants with ca. 300 species disjunctly distributed in the Americans and Aisa, known for its scientific, economic and ecological importance (Azuma et al., 2001; Sima and Lu, 2012; Kim and Suh, 2013; Shen et al., 2018). Species in this family have their stamens and pistils in spirals on a conical receptacle, a plesiomorphic character of flowering plants, which makes Magnoliaceae a good model system for botanists and evolutionary biologists to study the evolution of flowering plants. This family is also known to the public for its showy and delicate fragrant flowers (Xia et al., 2008; Schühly et al., 2011). Many Magnoliaceae species are valuable horticultural materials and are cultivated globally (Sima et al., 2001). Due to the high content of proanthocyanins, benzylisoquinoline and cyanogenic acid, many species have been used in traditional medicine for a long time (Schühly et al., 2011), such as *Houpoëa officinalis*, *Yulania liliiflora*, *Michelia figo, Oyama sinensis, etc.* (Pan et al., 2014; Wang et al., 2017). And some species, e.g., *Magnolia grandiflora*, and *Michelia figo* are essential components of lowland tropical and subtropical evergreen forests (Xia et al., 2008; Shen et al., 2018). However, Magnoliaceae remains one of the most threatened flowering plants families with most species occupied small areas with very small population sizes in the wild unfortunately (Rivers et al., 2016). According to the IUCN Red List of Magnoliaceae, around half of Magnoliaceae taxa are threatened with extinction in the wild by various threats such as logging, habitat loss, over-collection and climate change (Cicuzza et al., 2007; Rivers et al., 2016). Therefore, it is an urgent task to assess the conservation status and recognize the conservation priorities of wild Magnoliaceae species.

China, harboring ca. 120 Magnoliaceae species, is one of the diversity hotspots of this family (Xia et al., 2008). According to the China Biodiversity Red List, ca. 70% of the Magnoliaceae species in China are threatened with extinction in the wild due to biotic and abiotic reasons (http://www.iplant.cn/rep/protlist/4, Access date: 5 March 2020). Biotic causes, e.g., the decline in reproductive ability, low seed setting rate and low seed germination rate, have been reported in *Parakmeria omeiensis*, *Parakmeria lotungensis* and *Lirianthe championii* (Wang and Jiang, 2001; Wang, 2006; Chen et al., 2012). In addition, some medicinal species, e.g., *Yulania liliiflora* and *Houpoea officinalis*, are severely damaged in the wild because of the effects of habitat loss and over collection (Yang, 2019). To protect Magnoliaceae from extinction, many botanical gardens and research institutes, e.g., South China Botanical Garden, Shenzhen Fairy Lake Botanical Garden and Kunming Institute of Botany, have set up *Magnolia* gardens and have collected diverse Magnoliaceae species. These gardens have been also used it to carry out research improving the reproductive capacity of Magnoliaceae species (Liu et al., 1997; Wang, 2006). Besides *ex-situ* conservation, understanding the spatial patterns of Magnoliaceae species diversity and identifying conservation priority areas are important for the *situ* conservation of this family. Currently, the *in-situ* conservation studies of Magnoliaceae mainly focus on a few species, and populations (Wang, 2006; Cires et al., 2013; Budd et al., 2015), while the diversity patterns and conservation status of the entire family remain to be explored.

Identifying priority areas for conservation is a robust way to improve the conservation efficiency with limited resources (Myers et al., 2000; Huang et al., 2012; Zhao et al., 2016). In the past decades, scientists have adopted various metrics to quantify biodiversity hotspots. Species richness is a standard metric used in previous studies, which identified biodiversity hotspots with the highest number of species as conservation priorities (Myers et al., 2000). Endemism is another metric estimated by the weighted endemism method (WE) (Williams and Humphries, 1994; Slatyer et al., 2010) that prioritizes conserving endemic species with limited range. By weighting each species within a given area by its range size, the WE method avoids defining endemic species arbitrarily by region or range size (Linder and HP, 2001; Rosauer et al., 2009). In addition, β-diversity is an important metric to assess the variation in species composition among different areas (Marsh et al., 2010). β diversity is higher when compared areas contain more different species, and β diversity is lower when the species are the same in the different areas (Harrison and Inouye, 2002). Therefore, β diversity can offer complementary information about species distribution and has recently been used in conservation studies (Yu et al., 2017). The complementary algorithm aims to identify the minimum area to protect most species minimizing the amount of resource while offering protection to the highest number of species. These different metrics and methods have their unique emphases, and the results of conservation priorities based on each of them are not necessarily spatially consistent (Yu et al., 2017). Therefore, combining multiple indices to identify diversity hotspots and conservation gaps are necessary for identifying priority areas.

Here, we compiled the distribution of 114 Magnoliaceae species in China with a resolution of 10 * 10 km and identified hotspots and priorities areas of Magnoliaceae diversity using multiple metrics including species richness, weighted endemism, β diversity, and complementary algorithm. By overlapping our results with the nature reserves of China, we further assessed the conservation status of Magnoliaceae species and identified existing conservation gaps. Specifically, we aim to: (1) explore the diversity patterns of Magnoliaceae from multiple aspects; (2) identify the diversity hotspots and conservation priorities of Magnoliaceae; and (3) recognize conservation gaps of Magnoliaceaea species based on multiple metrics.

2. Materials and methods

2.1. Distribution of Magnoliaceae in China

Records of Magnoliaceae species are mainly collected from the *Atlas of Woody Plant in China* (Fang et al., 2011), which compiled county-level distribution data from the national, provincial and local floras, and checklists of nature reserves. These country-level distribution data was updated using recently published literature, digital records of specimens from the China Virtual Herbarium (CVH, http://www.cvh.cn, Access date: 2 March 2020) and other resources. The nomenclature of the Magnoliaceae checklist follows *Flora of China* (volume 7, Xia et al., 2008. Available at http://www.efloras.org). Cultivated records, e.g. distribution records from botanical gardens, were excluded. The threatened status of each species was obtained from the China Biodiversity Red List (http://www.iplant.cn/rep/protlist/4, Access date: 5 March 2020).

We refined the county-level distribution of each species into 10 km by 10 km grids by the known elevation ranges and habitat types, here evergreen forest and mixed forest, on which the species relied. We first converted the range of each species into 10 km grids. Then, we refined species' range by selecting only grids, of which elevation range was overlapped with the suitable elevation for each species. We further refined the selected grids by selecting only grids containing preferred habitats of the focus species. The maximum and minimum elevation and habitat type of each species follow the description in the *Flora of China* (Xia et al., 2008).

All the above analyses were performed in ArcGIS 10.2 (ESRI, Redlands, CA). Atlas of county and provincial level administrative division of China was downloaded from the National Geomatics Center of China (http://www.ngcc.cn/ngcc/). Elevation range of each grid was extracted from the digital elevation model (DEM) obtained from the United States Geological Survey at a resolution of 30 arc seconds (https://Ita.Cr.Usgs.gov/GTOPO30) and habitats within each grid were extracted from vegetation map of China (1:1,000,000) (Editorial Committee of Vegetation Map of China, 2007).

2.2 Diversity metrics

We used three metrics (species richness, weighted endemism and β-diversity) and two algorithms (top 5% algorithm and complementary algorithm) to identify the diversity hotspots of Magnoliaceae. Species richness of Magnoliaceae was defined by the species number within each grid.

Weighted endemism was calculated by the species present in each grid, using the reciprocal of their occurrence frequency to weight each species, and then calculating the total score by cell (Herkt et al., 2016). For each grid,

$$\text{Weighted endemism} = \sum_{\{t \in T\}} \frac{1}{R_t}$$

where *T* stands for all species found in the grid; *t* is a species of *T*; R_t is the number of grids that species *t* occupied.

Beta diversity (*β*-diversity) was calculated by Simpson's beta index (β_{sim}), which emphasize the turnover and removes the differences of species richness between two grids (Lennon et al., 2001). In order to evaluate *β*-diversity for each grid, we first calculated β_{sim} between two grids as following,

$$\beta sim_{ij} = 1 - \frac{A}{A + min\,(B,C)}$$

where i and j is the identifier of two grids; A is the number of species found in both grid i and j. B and C are the number of unique species in grid i and j, respectively. We applied the moving window algorithm to calculate the β-diversity of each grid. To do that, we first set a moving window with size of 50 km by 50 km and using the focal grid as the center. Then we calculated β-diversity of the focal grid as the average βsim of the focal grid with each of the grids within the window (Lennon et al., 2001; Wang et al., 2012).

2.3 Identification diversity hotspots of Magnoliaceae

The "top 5% richness algorithm" defined the hotspots as the top 5% of the distribution ranges with the highest species richness (Prendergast et al., 1993). Similarly, we defined hotspots by the top 5% areas of species richness, β-diversity and weighted endemism, respectively.

Diversity hotspots selected by the top 5% algorithm represent three metrics of diversity. However, this method might miss some species that are distributed outside the diversity hotspots, especially species with small ranges. Therefore, we also adopted the "complementary algorithm", which defined diversity hotspots by identifying the minimum number of grids that could cover all species (Dobson et al., 1997). Specifically, we first selected the grid with the highest species richness and removed these species occurring in this grid from the Magnoliaceae species distribution database.

Then we found out the grid with the highest species richness again from the remaining grids and removed species in this grid from the database again. This process continued iteratively until no species were deleted from the database (Dobson et al., 1997). All grids selected by the "complementary algorithm" were designated as diversity hotspots.

The spatial congruence of diversity hotspots identified by the above four methods (three diversity metrics and complementary algorithm) was estimated by counting the total number of methods identifying a grid as diversity hotspot. The total number of critically endangered (CR), endangered (EN) and vulnerable (VU) species occurred in these diversity hotspots were counted.

2.4. Conservation status and gaps

By overlapping the diversity hotspots of Magnoliaceae identified by the above four metrics with the range of Chinese nature reserves (Fig. 1d), we defined the grids that were not covered by nature reserves as conservation gaps. The conservation gaps of diversity hotspots, especially those containing threatened species, in each province were assessed. Conservation status of each species was also evaluated by overlapping the species' range with Chinese nature reserves and the number of protected grids were counted for each species.

The spatial database of nature reserves (Ministry of Ecology and Environment of the People's Republic of China, 2017) was digitalized and updated by Zhao et al., (2013), Chi et al., (2017), Bai et al., (2020), Zhang et al., (2020).

3. Results

3.1. Distribution and diversity patterns of Magnoliaceae in China

The final database contains 20,709 occurrences of 114 Magnoliaceae species at a 10 km by 10 km resolution. On the whole, Magnoliaceae species are mainly distributed in lowland to middle altitude evergreen forests in southern China (Fig. 1b). Only seven species are distributed up to 3000 meters and 25 species up to 2000 meters above the sea level (Table S1). The areas with more than 20 species are mainly located in southern Yunnan, northern of Guangdong and Guangxi, southwestern of Hunan and Guizhou. Particularly, there are more than 30 species in Wenshan county, Yanshan county, and Xichou county in the southernmost YN. On the contrary, in the vast northern China, Magnoliaceae species are absent from some provinces, such as Heilongjiang Inner Mongolia, Xinjiang, Qinghai and Ningxia.

Generally, spatial patterns of weighted endemism and β-diversity are similar to species richness with high diversity in southern China. For example, the areas with the highest species richness (> 25), weighted endemism (> 0.05) and β-diversity (> 0.408) are all located in southern China. Specific to weighted endemism, it is exceptionally high in southern Yunnan, northern Guangdong and southwestern Guizhou (Fig. 1c), with the highest number of endemic species in Maguan county and Wenshan county of Yunnan and Ruyuan county of Guangdong. Compared to species richness and weighted endemism, the grids with high β-diversity are scattered across southern China, suggesting a dissimilar species composition among grid cells.

3.2. The diversity hotspots of Magnoliaceae

According to "the top 5% richness algorithm", 1034 grids are regarded as hotspots areas of Magnoliaceae with over 13 species in each grid, covering about 149 counties from 12 provinces (Fig. 2a). The hotspots of species richness mainly distribute in two almost continuous areas in southernmost Yunnan (Fig. 2(a)1) and mountain ranges in northern of Guangxi and Guangdong (Fig. 2(a)2). The distribution of hotspots identified by the top 5% weighted endemism is similar to top 5% species richness. However, five hotspots in central Yunnan (Fig. 2(b)3), Sichuan (Fig. 2(b)7), Guangdong (Fig. 2(b)4), Fujian and Zhejiang (Fig. 2(b)5), and the boundary between Hubei and Hunan (Fig. 2(b)6) are not covered by species richness hotspots. The top 5% beta diversity hotspots were scattered across southern China. The complementary algorithm recognizes 31 grids as hotspots, including all Magnoliaceae species in China and accounting for only 0.15% of the distribution range of Magnoliaceae in China. Specifically, the 17 most species-rich grids contain 100 species, accounting for 87.7% of the Magnoliaceae species (Fig. 2d, Fig. S1).

3.3. Spatial congruence of diversity hotspots

In total, there are 2524 grids identified as diversity hotspots by at least one diversity index. Among these grids, spatial congruence analysis finds that no grids can be identified as hotspots by the four indices simultaneously. We identified only 24 grids (< 1%) covered by three indices (first-level diversity hotspots), 561 grids (22.2%) covered by two indices (second-level diversity hotspots) simultaneously and 1939 grids (76.8%) covered by only one index (third-level diversity hotspots) (Fig. 3). The first-level and second-level diversity hotspots are mainly concentrated in the southern Yunnan, southeastern Guizhou, southwestern Hunan and northern of Guangdong and Guangxi.

3.4. Conservation gaps

Existing nature reserves partly protect the distribution range and diversity hotspots of Magnoliaceae species in China. The nature reserves have about 4, 711 grids covering the distribution range of Magnoliacae, accounting for 23 % of the total area of Magnoliaceae (Fig. 4a), and about 617 (24%) grids covering the all three levels of diversity hotspots (Fig. 4b). Among the 24 first-level diversity hotspots, only ten grids are covered by natures reserves. The second-level diversity hotspots have 160 (28.5%) grids overlapped with nature reserves. The third-level diversity hotspots have 447 (23.1%) grids in common with nature reserves.

The distribution and conservation status of diversity hotspots are different among provinces (Table 1). Among all provinces where Magnoliaceae species are present, only 19 provinces contain diversity hotspots. In eight provinces, including the most species-rich provinces Yunnan, Guizhou and Hunan (species richness > 25), less than 24% of diversity hotspots are in common with nature reserves, which is lower than the overall diversity hotspots protection ratio. Among these eight provinces, Zhejiang, Guizhou and Fujian have the lowest protection ratio, with less than 20% diversity hotspots in common with nature reserves. Among the other eight provinces containing over 24% diversity hotspots covered by nature reserves, Hainan and Chongqing have the highest protection ratio, with over 40% diversity hotspots in common with nature reserves. Guangxi, Henan and Gansu also have more than 30% diversity hotspots in common with nature reserves.

3.5. Conservation of endangered species of Magnoliaceae

Among all 114 Magnoliaceae speices we studied, 74 are recorded as threatened species in the Chinese red list, including 10 Critically endangered (CR), 26 Endangered (EN) and 38 Vulnerable (VU) species (Table S1). Conservation status assessment showed that there are eight species not covered by any nature reserves, including four endangered species (*Manglietia obovalifolia, Manglietia ovoidea, Manglietia caveana, and Yulania viridula*), one vulnerable species (*Manglietia hongheensis*), and three non-threatened species.

Spatially, these threatened species are mainly distributed in southern China, especially in the diversity hotspots of southern Yunnan, northern Guangxi, and southeastern Xizang (Fig5 and Table 1). Generally, the protected ratio of diversity hotspots that contains endangered species is generally higher than that of all diversity hotspots in each province except Shannxi. However, the protection ratios of seven provinces are lower than 24%, the overall diversity hotspots protection ratio, especially in Shanxi (SN), Anhui and Zhejiang province with protected ratio less than 15% (Table 1).

By overlapping the three levels of diversity hotspots with the distribution of threatened species, our results indicate that 70% of CR, 80.77% of EN, 81.58% of VU, and 80.7% of all species are distributed in first-level diversity hotspots, respectively. These findings suggested that the conservation of only first-level diversity hotspots (24 grids) can protect most threatened species. When considering the second-level diversity hotspots (561 grids) as conservation areas, the protected proportion reaches 100% for CR, 96.15% for EN, 97.37% for VU, and 96.49% for all species, respectively. The protected proportion reaches 100% for threatened species, when including the third level hotspots.

4. Discussion

4.1. Distribution and diversity patterns of Magnoliaceae in China

To the best of our knowledge, this is the first study to explore the distribution and diversity patterns of 114 Magnoliaceae species in China with a spatial resolution of 10 km by 10 km. Most Magnoliaceae species are evergreen species distributed in the evergreen broad-leaved forest from lowland up to 3000 meters above sea level in the southern China. The diversity of Magnoliaceae estimated by species richness, weighted endemism and β-diversity is generally high in southern China. Species richness and weighted endemism are extra-ordinarily high in the southernmost part of Yunnan and the bordering regions of Guizhou, Guangxi and Guangdong, and β-diversity is high in mountain regions of southern parts of Magnoliaceae's distribution. These regions have been regarded as the diversitiy centre of Magnoliaceae species (Liu et al. 1997). These patterns are different from the diversity patterns of Chinese woody plants (Wang et al., 2011), Chinese endemic seed plants (Huang et al., 2016b), *Rhododendron* (Yu et al. 2017; Shrestha et al., 2018; Shrestha and Wang 2018), and herbaceous groups, e.g. Primulaceae (Bai et al. 2020), Gesneriaceae (Liu et al., 2017; Xu et al., 2017), which showed the highest species richness in southwestern China, especially in the alpine regions of the Hengduan Mountains and eastern Himalayas. These distinct diversity patterns might be attributed to the inability of tropical evergreen species to adapt to the cool climate. Recent studies also suggested that southern China did not widespread glaciers during the Quaternary, and acted as museum for many species (Lu et al., 2018; Tang et al., 2018). Therefore, ancient groups, such as Magnoliaceae, could survive periods of global climate cooling in this region.

4.2. Diversity hotspots and conservation gaps

It is crucial to identify diversity hotspots to improve conservation efficiency of the expansion of nature reserves (Ma et al., 2003; Heywood and Dulloo 2005; Zhao et al. 2016). Until 2017, the Chinese government has set up over 2750 nature reserves (including 463 national, 856 provincial and 1424 local nature reserves), which cover over 14.87% of the Chinese land areas and represent various natural ecosystems (Ministry of Ecology and Environment of the People's Republic of China, 2017). Despite the wide range of nature reserves, some specific rare and endangered taxa are still not protected due to the spatial mismatch of nature reserves and diversity hotspots. Conservation gaps were already identified for various taxonomic groups, such as orchid (Zhang et al., 2015), *Rhododendron* (Yu et al. 2017; Shrestha and Wang 2018), endemic seed plants (Huang et al., 2016a), and rare and endangered species (Huang et al. 2016b). However, the areas of conservation gaps varied among different groups. For example, over 40% of the diversity hotspots of *Rhododendron* identified by any of the three diversity indices, such as species richness, β-diversity and weighted endemism, can be protected by nature reserves considering the top 5% grid cells as diversity hots spots (Yu et al., 2017). However, only 29.2% of species richness hotspots, 19.9% β-diversity hotspots and 27.2% weighted endemism hotspots of Magnoliaceae can be protected by the current nature reserves, suggesting a low protection rate. These significant conservation gaps of Magnoliaceae diversity hotspots might result from the lower coverage of nature reserves in tropical and subtropical evergreen broad-leaved forest ecosystems (8.66% and 6.43%, respectively) compared with other ecosystems (Sun et al., 2020). Spatially, in only two provinces, Chongqing and Hainan, current nature reserves cover over 40% of the diversity hotspots of Magnoliaceae. In contrast, in Zhejiang, Fujian and Guizhou provinces, the current nature reserves cover less than 20% of the diversity hotspots of Magnoliaceae and hence natures reverse expansion is needed in these regions to preserve the species of Magnoliaceae.

4.3. The forest of southern China: conservation priority areas

Among the 74 threatened species, only fifteen threatened species are distributed in regions over 1600 meters above sea level (Table S1). Habitat loss due to land-use change, high human impact, and low coverage of nature reserves in lowland forests might exacerbate the extinction risk of Magnoliaceae species, especially the threatened species with limited ranges and narrow niches. Therefore, establishing new nature reserves or protected areas and conserving the whole ecosystem in lowlands might be the most effective way to improve the conservation status of the threatened Magnoliaceae species (Wang and Jiang, 2001).

Our study identified three levels of diversity hotspots considering species richness, β-diversity, weighted endemism and complementary algorithm to improve the conservation status of the threatened species of Magnoliaceae. The first level diversity hotspots covering only 2400 km^2 (24 grid cells) contain 70% of critically endangered species, 80.77% of endangered species and 81.58% of vulnerable species. Moreover, the second-level diversity hotspots contain over 90% of the threatened species. We, therefore, propose that the grid cells located in the Wenshan county and Maguan county of Yunnan, and the bordering region of Guizhou, Guangxi and Guangdong are the top priority areas for the conservation of Magnoliaceae. These areas are also not fully explored by botanists and many new species were also described from these areas recently (Chen, 1988; Sima et al., 2020; Yang et al., 2021). Our results emphasize the importance of protecting the lowland forest in southern China for the conservation of Magnoliaceae species and probably other similar tropical evergreen plant groups.

4.4. Uncertainties

We here explored the diversity patterns of Magnoliaceae and identified the diversity hotspots and conservation gaps, providing a scientific basis for the further conservation of this family. However, uncertainties of our results might exist due to the following reasons. First, we compiled species occurrences based on records from literature, specimens and existing database. Due to the dynamic change of distribution range, these records probably reflect the historical distribution range not the current distribution range. Second, we refined the distribution of Magnoliaceae species from the county level to a 10 km grid using the elevation range and habitat of each species, which might overestimate species range size and consequently species richness. Therefore, the actual conservation status of Magnoliaceae might be worse than the results we reported here. Regular field investigations are needed in monitoring species distribution and conservation planning of Magnoliaceae, especially for the threatened species.

5. Conclusion

Magnoliaceae is one of the most primitive and endangered flowering plant groups with extensive use for ornamental plants and indigenous herbal medicine (Sánchez-Velásquez et al., 2016). We estimated the patterns of species richness, weighted endemism and β-diversity of Magnoliaceae species in China with a spatial resolution of 10 km by 10 km and evaluated the protection status of these species. Our results indicate that the hotspots of species richness and weighted endemism patterns are similar and high in the southernmost of Yunnan and Guangxi while the hotspots of β-diversity are scattered in the south of China. Conservation gaps analysis indicate that only 24.4% of diversity hotspots are covered by Chinese nature reserves, suggesting large conservation gaps, especially in Guizhou, Fujian and Zhejiang where less than 20% of diversity hotspots are covered by nature reserves. The diversity hotspots identified by all three diversity indices only contains 24 grid cells but contain over 70% threatened species, which are probably the top priority areas in further conservation planning of Magnoliaceae.

Author contributions

X.X. and J.W. conceived the idea and designed the study. Y.T., H.X. and J.F. performed the analysis. H.X., X.X., J.W., W.D. and Y.T. collected the data. H.X. write the first draft with contributions from all authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (#31770566), National Key Research and Development Program of China (#2017YFC0505203), Biodiversity Survey, Observation and Assessment Program of Ministry of Ecology and Environment of China.

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Supplementary files

Table S1 Threaten status, elevation range, habitat and conservation status for Magnoliaceae species of China.

Fig. S1 The accumulative conservation rate of complementarity analysis.

Data accessibility

All data necessary to reproduce the analyses presented in this study are included in the Supporting Information.

Table

Table 1 Richness and conservation status of diversity hotspots for all species and **threatened** species in each province. No. grids, the total number of grid cells of the diversity hotspots. Pro. grids. hotspot, protected grid cells of diversity hotspots. Pro. ratio, protection ratio of the diversity hotspots.

Province	All species			Threatened species		
	Species Richness	No. grids Hotspot	Pro.ratio	Species Richness	No. grids Hotspot	Pro.ratio
YN	38	712	23%	27	712	23%
GX	27	368	34%	16	322	38%
GZ	27	295	15%	14	283	16%
HN	26	231	23%	11	192	26%
GD	22	130	23%	10	130	23%
CQ	20	30	43%	7	30	43%
HB	19	62	21%	5	32	28%
JX	19	112	30%	7	62	45%

SC	16	137	29%	9	134	29%
FJ	15	151	17%	6	102	22%
HI	15	20	45%	10	20	45%
ZJ	15	75	13%	5	70	14%
AH	11	9	22%	3	8	13%
HA	11	59	31%	2	24	33%
XZ	10	6	-	8	6	-
SN	7	93	29%	2	39	10%
XG	7	-	-	4		-
GS	6	30	37%	2	14	57%
SD	5	-	-	-		-
JS	4	1	-	1	0	-
LN	3	-	-	1		-
TW	2	3	-	-	0	-
BJ	1	-	-	-	-	-
HE	1	-	-	-	-	-
JL	1	-	-	-	-	-
SX	1	-	-	1	-	-

Figure legends

Fig. 1. Spatial patterns of Magnoliaceae species richness (a), weighted endemism (b) and β-diversity (c) of Magnoliaceae species and nature reserves and provincial map of China (d). Abbreviation of province names: BJ, Beijing; TJ, Tianjin; HE, Hebei; SX, Shanxi; NM, Inner Mongolia; LN, Liaoning; JL, Jilin; HL, Heilongjiang; SH, Shanghai; JS, Jiangsu; ZJ, Zhejiang; AH, Anhui; FJ, Fujian; JX, Jiangxi; SD, Shandong; HA, Henan; HB, Hubei; HN, Hunan; GD, Guangdong; GX, Guangxi; HI, Hainan; CQ, Chongqing; SC, Sichuan; GZ, Guizhou; YN, Yunnan; XZ, Tibet; SN, Shaanxi; GS, Gansu; QH, Qinghai; NX, Ningxia; XJ, Xinjiang; TW, Taiwan.

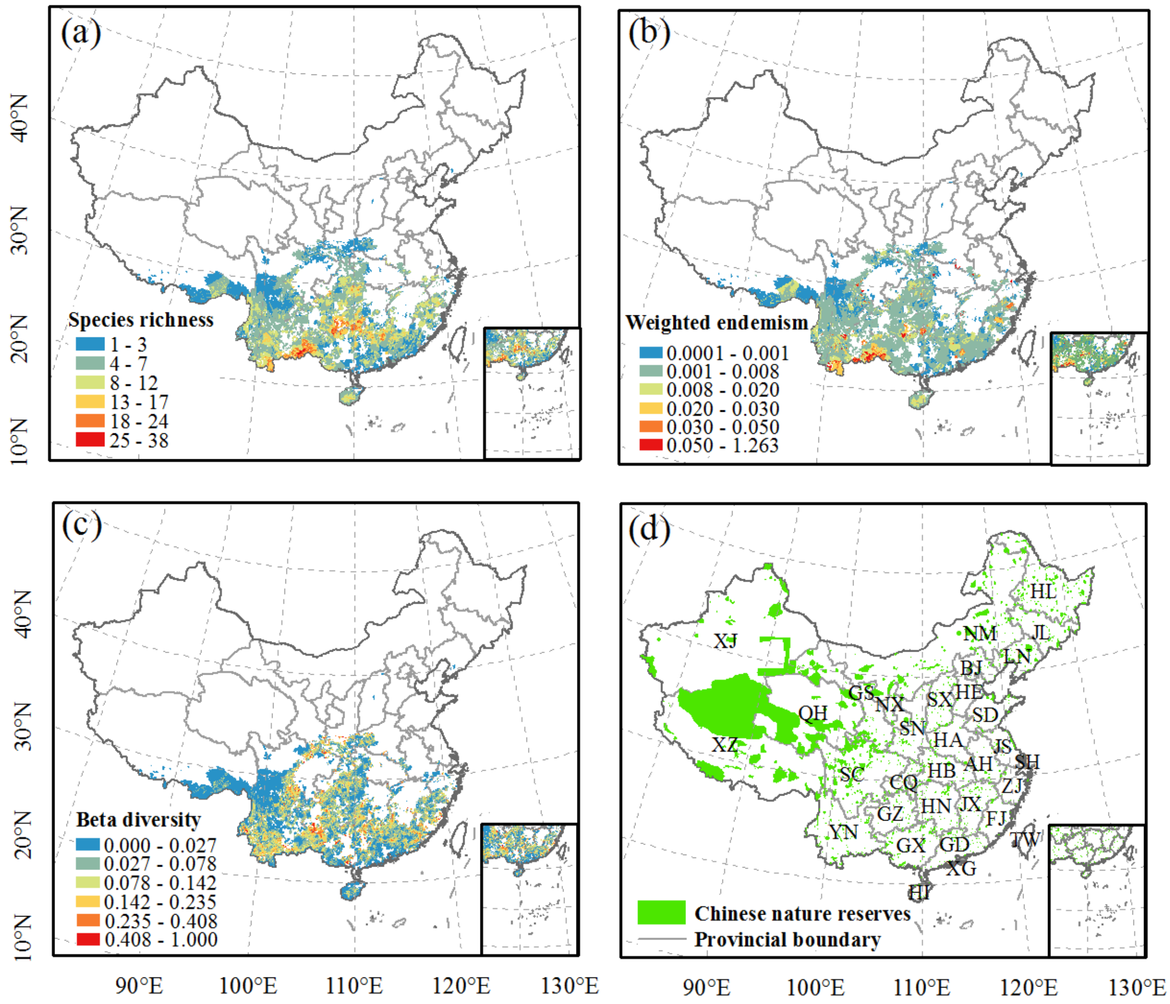
Fig. 2. Hotspots identified by the "top 5% algorithm" based on species richness (a), weighted endemism (b) and β diversity (c), and the "complementary algorithm" (d). There are two hotspots identified by species richness, five new hotspots identified by weighted endemism, and β diversity hotspots are scattered.

Fig.3. The spatial congruence of diversity hotspots identified by species richness, weighted endemism, β diversity, and complementary algorithm of Magnoliaceae.

Fig. 4. Protected and gap areas in the whole Magnoliaceae distribution areas (a) and in the hotspots areas of Magnoliaceae(b).

Fig. 5. Diversity patterns for threatened species (a) and the accumulated percentage of critically endangered species (CR), endangered species (EN), venerable species (VU), and all species (All) through three levels of diversity hotspots (b).

Fig. 1.


(a)
Species richness
1 - 3
4 - 7
8 - 12
13 - 17
18 - 24
25 - 38
(b)
Weighted endemism
0.0001 - 0.001
0.001 - 0.008
0.008 - 0.020
0.020 - 0.030
0.030 - 0.050
0.050 - 1.263
(c)
Beta diversity
0.000 - 0.027
0.027 - 0.078
0.078 - 0.142
0.142 - 0.235
0.235 - 0.408
0.408 - 1.000
(d)
HL
NM
JL
XJ
BJ
LN
GS
NX
SX
HE
QH
SN
SD
XZ
HA
JS
SC
CQ
HB
AH
SH
ZJ
GZ
HN
JX
FJ
YN
GX
GD
TW
XG
HI
Chinese nature reserves
Provincial boundary
40°N
30°N
20°N
10°N
90°E
100°E
110°E
120°E
130°E

641 **Fig. 2.**

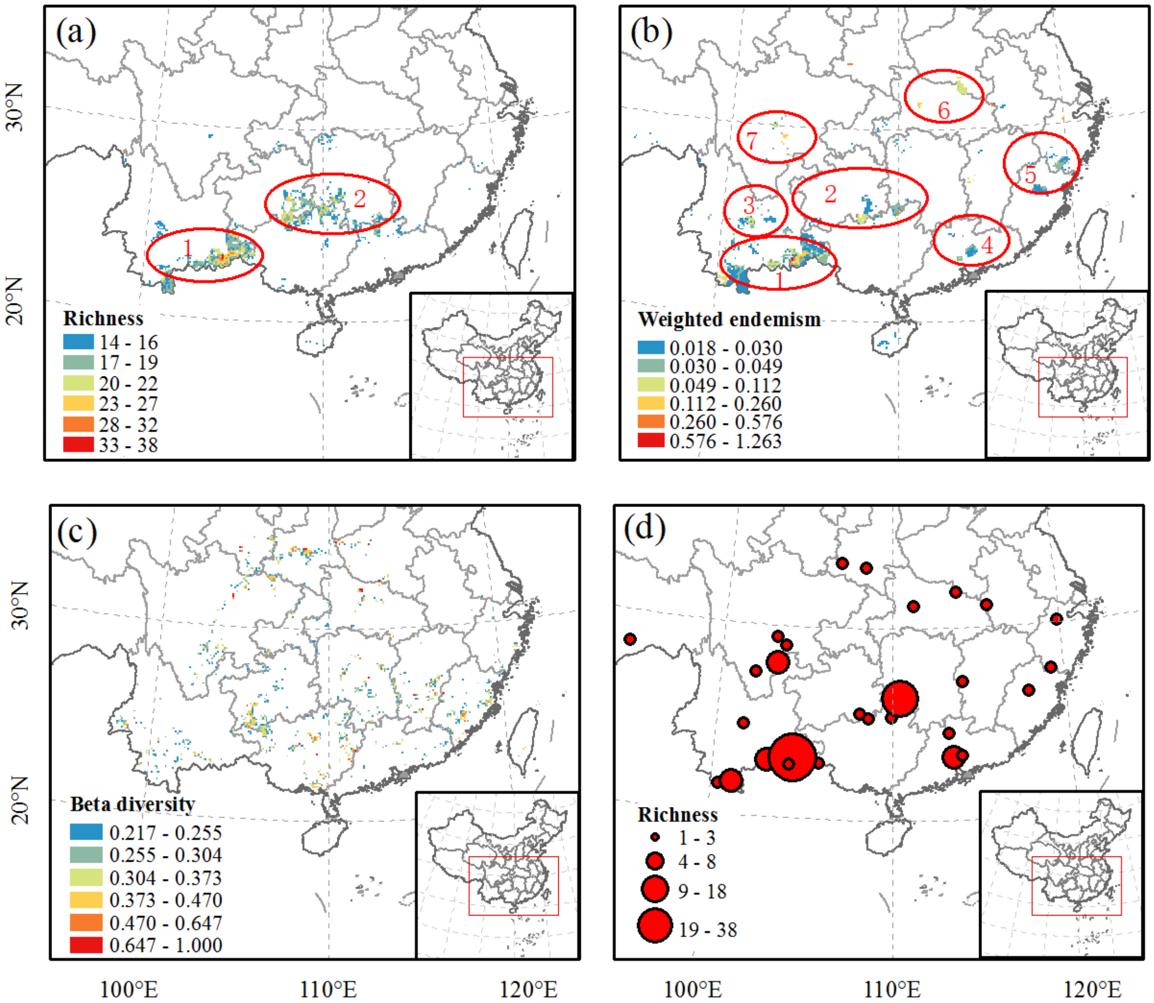

(a)
30°N
20°N
1
2
Richness
14 - 16
17 - 19
20 - 22
23 - 27
28 - 32
33 - 38
(b)
1
2
3
4
5
6
7
Weighted endemism
0.018 - 0.030
0.030 - 0.049
0.049 - 0.112
0.112 - 0.260
0.260 - 0.576
0.576 - 1.263
(c)
30°N
20°N
Beta diversity
0.217 - 0.255
0.255 - 0.304
0.304 - 0.373
0.373 - 0.470
0.470 - 0.647
0.647 - 1.000
(d)
Richness
1 - 3
4 - 8
9 - 18
19 - 38
100°E
110°E
120°E
100°E
110°E
120°E

Fig. 3.

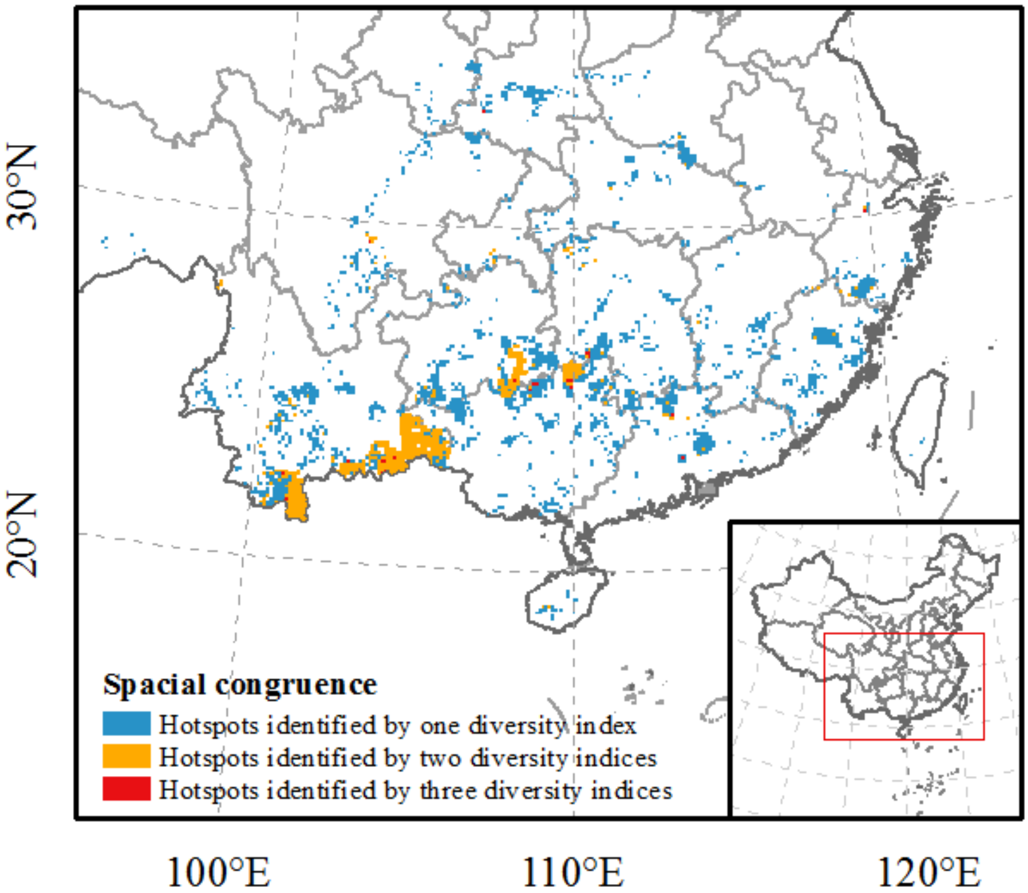

30°N
20°N
100°E
110°E
120°E
Spacial congruence
Hotspots identified by one diversity index
Hotspots identified by two diversity indices
Hotspots identified by three diversity indices

Fig.4.

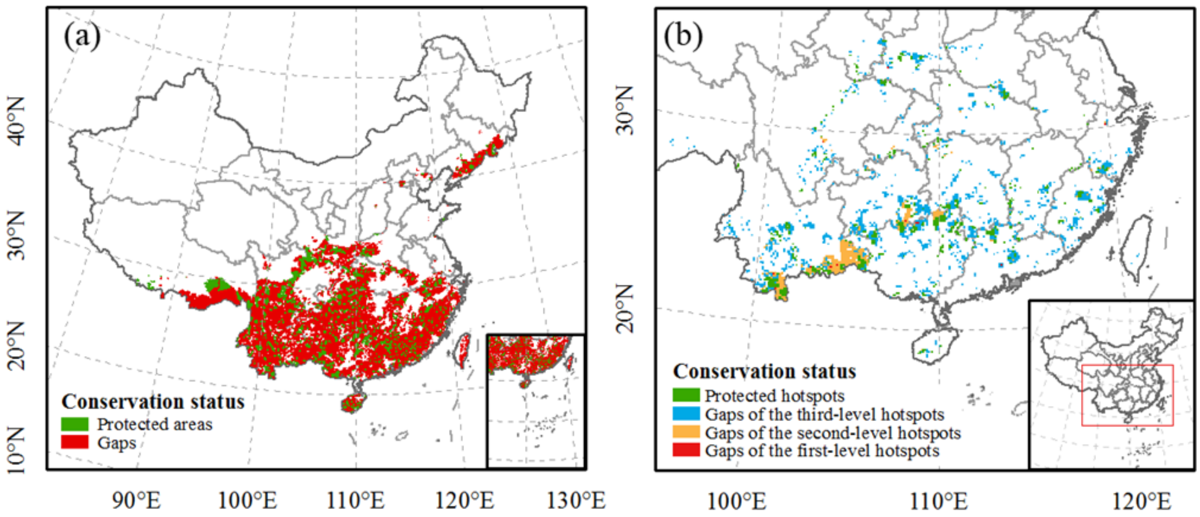

(a)
Conservation status
Protected areas
Gaps
40°N
30°N
20°N
10°N
90°E
100°E
110°E
120°E
130°E
(b)
Conservation status
Protected hotspots
Gaps of the third-level hotspots
Gaps of the second-level hotspots
Gaps of the first-level hotspots
30°N
20°N
100°E
110°E
120°E

Fig. 5.

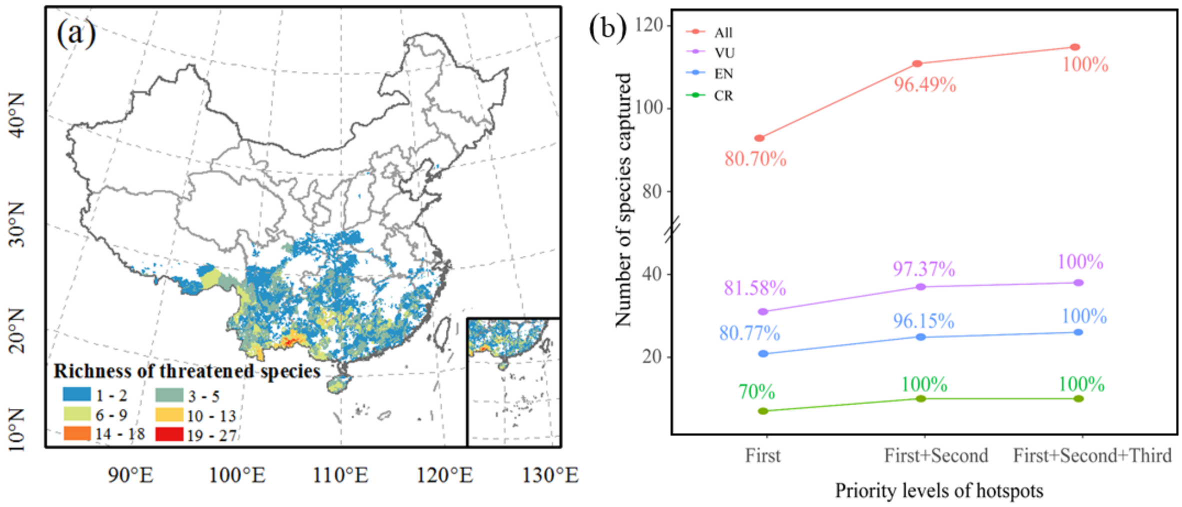

(a)
Richness of threatened species
1 - 2
3 - 5
6 - 9
10 - 13
14 - 18
19 - 27
40°N
30°N
20°N
10°N
90°E
100°E
110°E
120°E
130°E
(b)
All
VU
EN
CR
Number of species captured
120
100
80
40
20
80.70%
96.49%
100%
81.58%
97.37%
100%
80.77%
96.15%
100%
70%
100%
100%
First
First+Second
First+Second+Third
Priority levels of hotspots

Table S1 Threaten status of IUCN Red List, elevation and habitat for each species of China Magnoliaceae.

Fig. S1 The accumulative conservation rate of complementarity analysis.