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ORIGINAL PAPER

Selecting priority areas for systematic conservation of Chinese *Rhododendron*: hotspot versus complementarity approaches

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Abstract
The use of quantitative measures to select priority areas for conservation has been in practice since the early 1980s. However, the relative efficiency of different methods for identifying priority areas is still the subject of debate. Here, using the distribution data of 556 *Rhododendron* species in China with high spatial resolution, we evaluated the performance of the two commonly used methods, i.e. hotspot and complementarity and selected the efficient method to select priority areas for the conservation of *Rhododendron* in China. By overlaying the priority areas map with the locations of protected areas, we also identified the regions not covered by current protected areas (i.e. conservation gaps). We found that the complementarity method selected less number of grid cells to capture an equivalent number of species and hence had higher efficiency and representativeness than the commonly used hotspot method. Moreover, the complementarity method was better at capturing the range-restricted species than the hotspot method. Based on the complementarity method, we identified 61 grid cells of 50 × 50 km as priority areas for *Rhododendron* conservation in China. Among these priority areas, only about 50% grid cells were located in the hotspot areas (e.g. Hengduan Mountains), and 14% grid cells were outside the current protected area network. Our findings suggest that, despite its popularity and ease of implementation, the sites selected by hotspot algorithm may not necessarily be the best sites to allocate conservation efforts. Since the identification of priority areas in China has largely been based on the hotspot method, the current study has revived the need to reassess the priority areas for other taxonomic groups too. More importantly, our findings have emphasized the need to expand the conservation priorities from Hengduan Mountains to south and southeast China as well.

Keywords Conservation gaps · Endemism · Hengduan Mountains · Protected areas · Species richness · Threatened species

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Introduction

An effective conservation begins with a systematic identification of high priority sites. However, in order to make the best use of the limited resources available for conservation, the identified priority areas should be as representative as possible (Fox and Beckley 2005). A prerequisite for preserving maximum biodiversity in a given biological domain is to identify priority areas that protect every possible species at the lowest possible cost (Margules et al. 1988). The best priority areas should, therefore, be comprehensive and representative and should provide a cost-effective conservation solution.

Numerous priority-setting approaches have been used to identify areas of exceptional conservation value. One of the most popular methods is the hotspots of richness and of rarity. Hotspot method assigns high priority to sites with a large number of species or with large numbers of rare, threatened or endemic species (Beger et al. 2003; Fox and Beckley 2005; Prendergast et al. 1993). Because of its simplicity to develop, implement and describe (Ribeiro et al. 2017), this method is popular and the most frequently used approach for site selection by conservationists (Prendergast et al. 1993). However, it is argued that this method can be inefficient because the diversity hotspots and the rarity hotspots usually do not overlap. For example, using richness data for British birds, Prendergast et al. (1993) showed that selecting a limited number of species rich areas (i.e. hotspot areas) may not be sufficient to protect the rare and range restricted species. As protecting all the regions where species occur could incur huge conservation costs and may not also be practically feasible, the site selection method should be as efficient as possible, and therefore minimize the required area, while still meeting the conservation targets (Fox and Beckley 2005).

The use of iterative algorithms that can identify optimal or near optimal solutions, in terms of the area and/or cost, to the problem of representing all the targeted natural features in a region, has been a recent development in the systematic conservation planning (Pressey et al. 1997). These algorithms incorporate the principle of complementarity by design (Pressey et al. 1993). The complementarity approach (Pressey et al. 1993, 1996; Vane-Wright et al. 1991), by definition, chooses areas of complementary richness i.e. areas that in combination have the highest species richness. Once a site with high conservation value is identified, this method selects other sites to complement the previous one, and thus replication of priority features is avoided. This approach has been used for the assessment of conservation priorities worldwide (e.g., Dobson et al. 1997; Fox and Beckley 2005; Kati et al. 2004; Margules et al. 1988; Pressey and Logan 1995; Pressey and Nicholls 1989; Williams et al. 2000, 1996) and is argued to provide a better conservation solution. The strength of this method, however, strongly depends on the availability of precise distribution data of the species. Therefore, despite several years of studies, the question of the best and the most efficient method for selecting priority areas is still the subject of debate.

China is one of the world's mega-biodiversity countries (Tang et al. 2006), and is home to over 30,000 plant species of which ca. 15,000 species are endemic (Yang et al. 2005). The dramatic land-use changes and habitat degradation in the recent years have caused rapid decline and/or extinction of many species in China. Recent evaluation suggests that ca. 5000 species are currently threatened or on the verge of extinction, which makes China one of the highest priorities for global biodiversity conservation (Volis 2016). Most previous studies in China have chiefly relied on the hotspot approach to identify priority areas for conserving endemic woody seed plants (Huang et al. 2012), endemic plants (López-Pujol et al. 2011), threatened plants (Zhang et al. 2015a), endemic genera and family of plants (Huang et al. 2016), evergreen broadleaved woody plants (Xu et al. 2017) and *Rhododendron* (Yu et al. 2017). Although few studies have used complementarity approach to identify priority areas in China (see, for example, Chi et al. 2017; Liu et al. 2017; Zhang et al. 2015b), exhaustive comparisons of the two methods have not been made so far. Moreover, whether the selected priority areas adequately protect the taxonomic group of interest and provide the best optimal solution in terms of area selection and cost-efficiency has rarely been evaluated in China.

Here, we test these two priority-setting approaches for their efficiency at identifying areas of conservation importance for *Rhododendron* in China. *Rhododendron* is one of the largest flowering plant genera with ca. 1000 species globally (Milne et al. 2010). It is a horticulturally significant genus and forms an important component of the montane ecosystem in the subalpine and alpine regions of the Himalaya (Yu et al. 2017). The genus is represented by about 571 species in China (Wu et al. 2005) with an exceptional number of endemics (Huang et al. 2011). Of the 571 species, 405 species are endemic to China (Ma et al. 2014); many of which are also rare and threatened (Gibbs et al. 2011). The study by Ma et al. (2014) has pointed the need to reassess the conservation status of Chinese *Rhododendron* owing to the fact that most species are under greater threat than has been acknowledged. Habitat degradation and an increasing pressure on land to meet the demands of an expanding population have placed some of the species of *Rhododendron* in China at risk of extinction (Ma et al. 2014). Therefore, identifying areas of high conservation importance for Chinese *Rhododendron* is urgently required to effectively monitor and conserve them, particularly in a scenario where global change is imposing great threat to species' survival. Using only 212 species (<40% of known species in China), Yu et al. (2017) explored the priority areas for *Rhododendron* conservation in China using hotspots of richness and weighted endemism. Due to the low species coverage, especially the low coverage on narrow-ranged species, the efficiency and representativeness of these priority areas remain unclear. In the present study, we used a much larger (near complete) and finely scrutinized dataset that include the distribution records for 556 *Rhododendron* species in China (ca. 98% species) to identify priority areas for the conservation of this genus. Specifically we aim to (1) evaluate the performance of the two priority-setting methods: hotspots of richness/rarity and complementarity approach, (2) use the most efficient of these methods to prioritize areas of high conservation importance and (3) identify the protection gaps for Chinese *Rhododendron*.

Materials and methods

Distribution data

The distribution data of *Rhododendron* species were compiled from (1) specimen records available from the National Specimen Information Infrastructure (NSII, http://nsii.org.cn), (2) all available national, provincial and local floras including the *Atlas of Woody Plants in China* (Fang et al. 2011), and (3) field sampling conducted in the mountain forests in China (Fang et al. 2012). The intraspecific taxa were merged to species level and the species names were standardized using the updated online version of *Flora of China* (available at http://www.efloras.org/). The final dataset included the distribution records for 556 *Rhododendron* species out of 571 species occurring in China (Wu et al. 2005). The database of *Rhododendron* distributions used in this study reflects the most comprehensive distribution data for this genus in China. The county-level distribution were then transferred into gridded distributions at a spatial resolution of 50 × 50 km by overlaying the distribution map of each species with the grid in ArcGIS (ESRI, Redlands, CA) (see Wang et al. 2009 for details). We further divided our data into endemic species, rare species and threatened species. Species occurring only in China were designated as endemic species. A species was considered rare if its distribution range (i.e. the number of grid cells where species occurs) was within the lowest quartile of range sizes of all *Rhododendron* species (see Liu et al. 2017; Shrestha et al. 2017 for details). The definition of rare species used in our study sufficiently covers the species enlisted in the National List of Plant Species with Extremely Small Populations (PSESP) in China. Threatened species were identified from *The Red List of Rhododendron* (Gibbs et al. 2011) and *Biodiversity Red List in China—the Volume of Higher Plants* (Ministry of Environmental Protection of China 2013). We treated species with the following IUCN categories as threatened species: extinct in the wild (EW), critically endangered (CR), endangered (E), vulnerable (VU) and near threatened (NT). In total, our dataset included 402 endemic species, 143 rare species and 177 threatened species.

Hotspot analysis

The term hotspot was initially used by Myers (1990, 1988) for areas world-wide that (1) have exceptional concentrations of species richness, (2) have exceptional concentrations of narrow endemics, and that (3) face exceptional degrees of threat (Williams et al. 1996). However, this term has been widely used to denote any areas with high scores on any scale of conservation metrics (see, for example, Beger et al. 2003; Huang et al. 2012, 2016; Tang et al. 2006). Here, we followed a more general approach and used the term hotspots to denote areas with high species diversity. In particular, the following two steps were used to select hotspots for each group. (1) We arranged all grid cells in the study area in descending order of the species diversity within grid cells of each species group (all species, endemic species, rare species and threatened species) respectively. (2) The hotspots of each species groups were defined using the arbitrary threshold of upper 1, 2.5, 5 and 10% grid cells following previous studies (Chi et al. 2017; Grenyer et al. 2006; Huang et al. 2012, 2016; López-Pujol et al. 2011; Prendergast et al. 1993; Tang et al. 2006; Yu et al. 2017). We then calculated the number of unique species included by each threshold and the minimum number of grid cells that could include all species.

Complementarity analysis

We used the sorting algorithm based on the principle of complementary subsets as proposed by Dobson et al. (1997). This algorithm first selects the grid with the greatest number of species. The species included by that grid are then removed from the distribution matrix. The algorithm then searches for the grid cell with the greatest number of species that are not already selected. This process continues iteratively until all the listed species are included. This algorithm selects the minimum required grid cells to include all the listed species.

Comparison between the efficiency of hotspot and complementarity methods

In order to check congruence between the hotspot and complementarity methods for selecting conservation priorities, we first calculated the total number of overlapping and non-overlapping grid cells selected by two algorithms. We then evaluated the performance of the two approaches using following steps. First, we calculated the cost required to protect all the listed species. We used the land area that should be conserved (i.e. the number of equal-size grid cells) as a surrogate of cost (Williams et al. 1996). We used this approach because the number of grid cells (land area) required to protect the listed species is directly proportional to the cost needed to protect them. For example, if the hotspot approach requires n times more grid cells than the complementarity approach to protect all the listed *Rhododendron* species, the operating cost for protecting hotspot grid cells is n times more than complementarity grid cells. Second, we evaluated how many species could be protected if we chose an equivalent number of grid cells using these two algorithms. Third, we calculated the efficiency of the two methods for each species group using the following formula (Pressey and Nicholls 1989).

$$\text{Efficiency(E)} = 1 - \left(\frac{N}{T}\right)$$

where N is the number of grid cells needed to protect all the listed species (conservation target) and T is the total of grid cells where species occur. The value close to 1 indicates high efficiency, which means that the method is cost-effective because it requires proportionally low land area (i.e. grid cells) to meet the conservation target. Similarly, the value close to 0 indicates low efficiency, which means that the method requires proportionally more land area to meet the conservation target.

Selection of priority areas

Based on hotspot algorithm, we designated the upper 1%–10% richness grid cells as priority areas following previous studies. Similarly, based on complementarity algorithm, the complementary grid cells that could cover all species of specific species groups were selected as priority areas. Of the two methods, we chose an efficient one to generate the final priority area map for Chinese *Rhododendron*. The grid cells selected for each species group were examined for possible overlaps. The priority level of each grid cell was then evaluated based on the number of overlaps. For example, the grid cells which were selected by all four species groups were designated as “Very high priority areas”. These grid cells are not only species rich but also harbor a high number of rare, endemic and threatened species. Similarly, the grid cells selected by at least three species groups were designated as “High priority areas”, while the grid cells selected by at least two species groups were designated as “Moderate priority areas”.

Conservation gaps for *Rhododendron* in China

A database of nature reserve (NS) distribution in China and a digitized spatial map thereof were compiled from Zhao et al. (2013). In total, there are 2640 terrestrial nature reserves in China, among which 319 are national nature reserves and 835 are provincial nature reserves covering approximately 14% of the total landmass (Zhang et al. 2015a). By overlaying the priority grid cells with the distribution of nature reserves in China, we identified the grid cells that were outside the protected area network. These grid cells represent the gaps in protecting high priority sites for *Rhododendron* species in China. Since we did not have the spatial distribution data for nature reserves in Taiwan, we excluded the grid cells in Taiwan during the gap analysis.

Results

Diversity pattern of *Rhododendron* species

The diversity of overall *Rhododendron* species is the highest in southwest China particularly along the mountain ridges of southeast Xizang, northwest Yunnan and central and south Sichuan (Fig. 1a). The diversity of endemic species and threatened species also peak along the same regions (Fig. 1b, d). Rare species have a more scattered distribution compared to other groups and they are confined mainly in south China (Fig. 1c). The diversity of rare species is highest in northwest Yunnan.

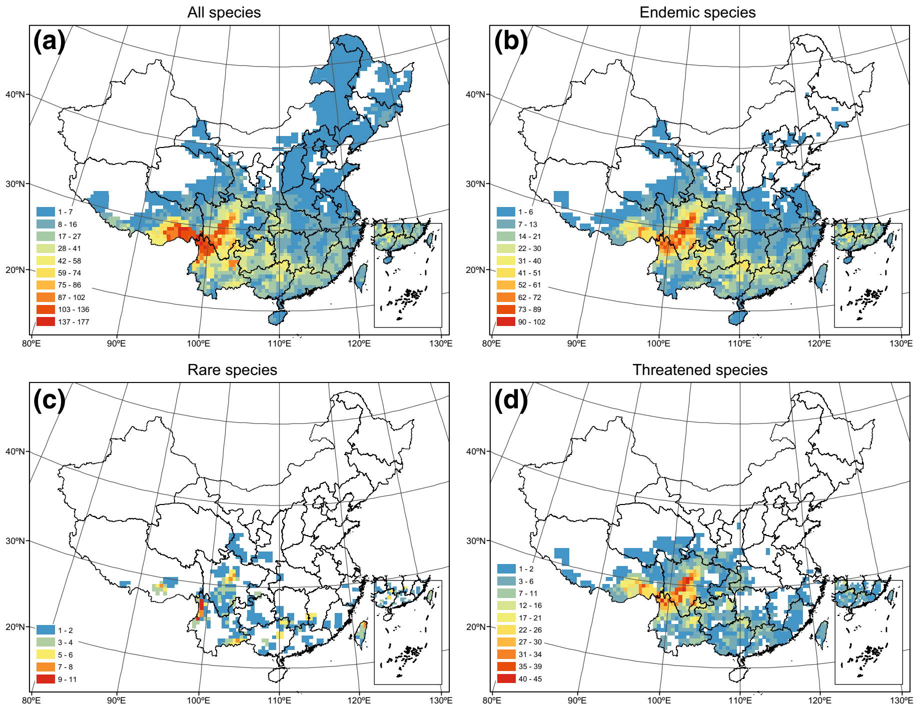

Fig. 1 Diversity patterns of *Rhododendron* species in China estimated in 50×50 km grid cells. **a** All species, **b** endemic species, **c** rare species and **d** threatened species. The pattern of all species has been adapted from Shrestha et al. (2017)

Hotspots of *Rhododendron* diversity

The hotspot algorithm based on the top 1, 2.5, 5 and 10% grid cells selected the Hengduan Mountain area in central and southeast Sichuan and northwest Yunnan, central and northeast Yunnan, southwest Xizang, Wuling Mountain region in east Guizhou, Nanling Mountain region along the border of Guangxi and Hunan, Jinfo Mountain along the border of Guizhou and Chongqing, Yungui Plateau in Yunnan, central Guangxi, and northwest Guangdong as the hotspots of *Rhododendron* diversity (Fig. 2). The total number of grid cells selected as priority areas for all *Rhododendron* species were 24, 60, 120 and 240 grid cells based on 1, 2.5, 5 and 10% thresholds, respectively. However, not all *Rhododendron* species were covered by these priority grid cells. For example, the 10% threshold only included about 85% of all species, 80% of endemic species, 50% of rare species and 70% of threatened species (Fig. 3). The coverage was much worse for the 5% threshold and other lower thresholds. Interestingly, the species missed by these commonly used thresholds (1–10%) in hotspot analyses represent the rarest species in each group indicating inefficiency of the method in capturing range restricted species. The mean range sizes of species missed by each threshold were significantly lower than those of the included species (see Fig. 4), which indicates that the hotspot approach often fails to include species with the most restricted distribution.

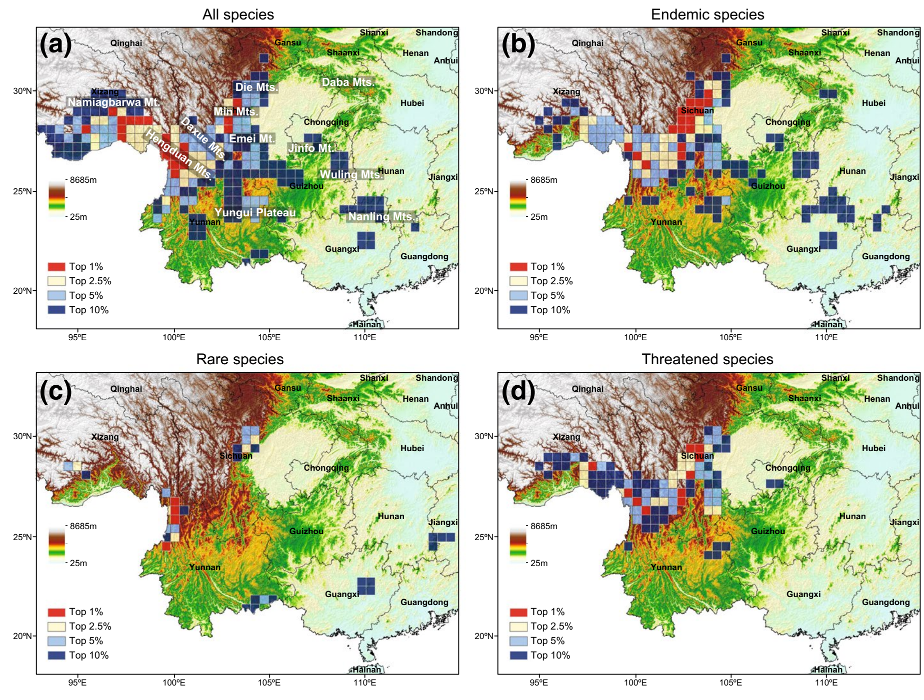

Fig. 2 Hotspot areas (top 1–10% species rich grid cells) of *Rhododendron* diversity in China for four species groups. **a** All species, **b** endemic species, **c** rare species and **d** threatened species

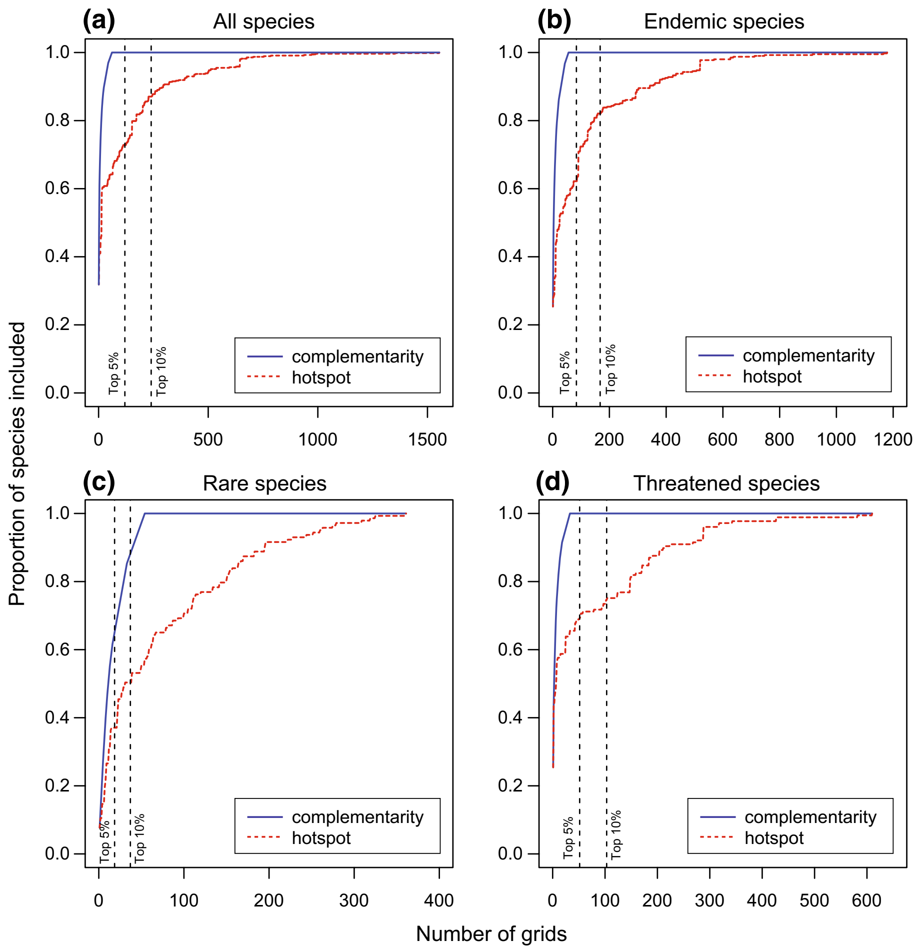

Fig. 3 Species accumulation curves as functions of the increase in conservation area for *Rhododendron* species in China evaluated by the two alternative methods: hotspot (red dotted lines) and complementarity (blue solid lines). **a** All species, **b** endemic species, **c** rare species and **d** threatened species

Priority areas based on complementarity

The complementarity algorithm selected a total of 61 grid cells that included all *Rhododendron* species, 56 grid cells that included all endemic species, 54 grid cells that included all rare species and 33 grid cells that included all threatened species (see Fig. 5). Unlike hotspot algorithm, the complementarity algorithm selected scattered grid cells in south China as priority areas. These regions were east Zhejiang, mountainous region along the border of southeast Zhejiang and northeast Fujian, mountainous areas in Fujian, west Jiangxi, west Hubei, south Guangxi and southwest Guangdong.

In total, the complementarity approach identified 61 grid cells as priority sites for all four species groups combined, among which 12 grid cells in the mountainous region along the border of southeast Zhejiang and northeast Fujian, southeast Yunnan, northwest Yunnan, southeast Xizang and south Sichuan were identified as "*Very high priority*

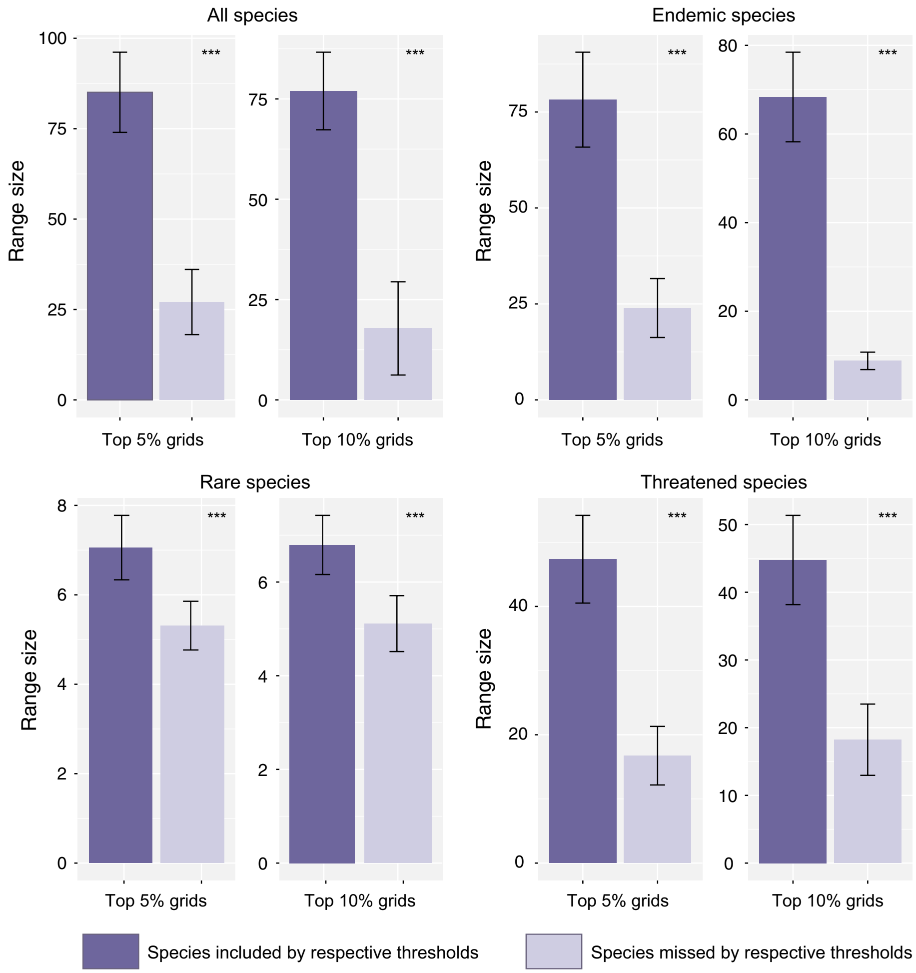

Fig. 4 Range size of included and missed species by 5% and 10% hotspot threshold for four species groups of *Rhododendron* in China. The mean range size of the included species was significantly larger (***$P < 0.001$) than that of the missed species

areas". Similarly, 23 grid cells in central and southwest Sichuan, northeast Yunnan, south Guizhou, northeast Chongqing, and continuous mountain range along the border of southeast Guizhou, north Guangxi, Hunan and Guangdong were identified as "*High priority areas*" and 26 grid cells in the mountainous regions of southeast Xizang, central Sichuan, northeast Yunnan, Guizhou, Chongqing, Guangxi, Hunan, Guangdong and Jiangxi were identified as "*Moderate priority areas*" (Fig. 6).

Congruence of two methods and their efficiency

The grid cells selected by hotspot and complementarity approaches did not overlap completely with each other for any species group (Fig. 7). A large number of grid cells selected

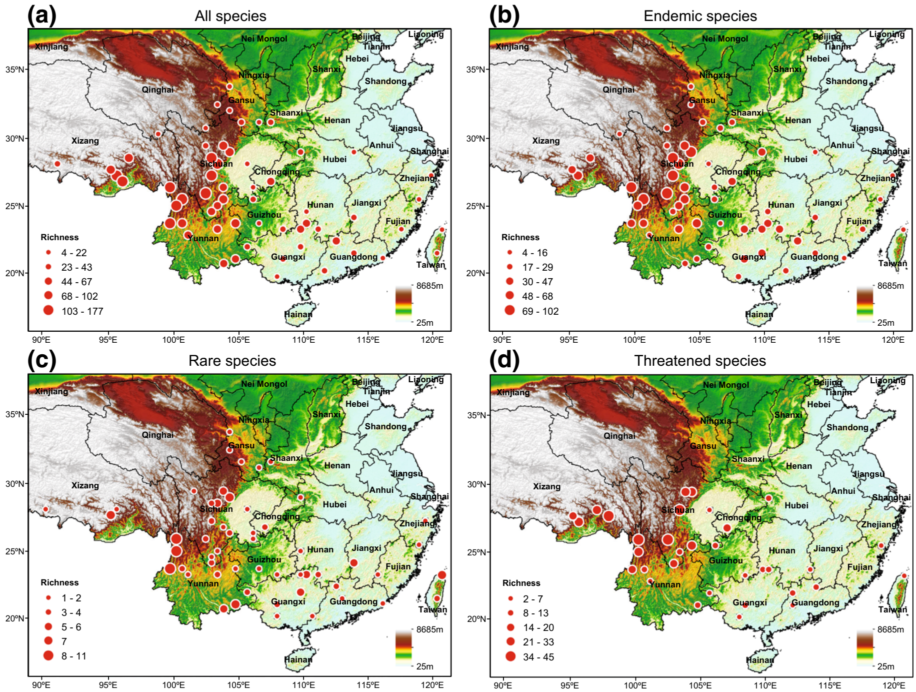

Fig. 5 Priority areas for the conservation of *Rhododendron* in China identified by the complementarity method. **a** All species, **b** endemic species, **c** rare species and **d** threatened species. The size of the red dots represents species richness

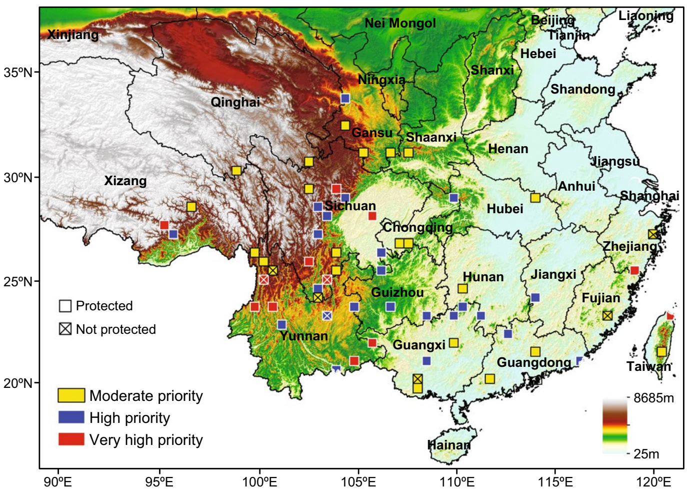

Fig. 6 Priority areas identified by the complementary method for the systematic conservation of *Rhododendron* in China. Complementarity algorithm was used to identify priority areas because of its high efficiency. The priority areas were classified into moderate priority, high priority and very high priority areas based on the number of overlaps between the priority grid cells for four species groups. The grid cells not currently within the protected area network are marked with a black cross (X) inside

as priority areas by one method were not selected by the other method. For example, out of 61 grid cells prioritized by complementarity algorithm for the group of "all *Rhododendron* species", only 17 grid cells were selected by the 5% threshold of the hotspot analysis and 29 grid cells by the 10% threshold of the hotspot analysis (Fig. 7). The congruence between the two methods was even lower for the groups of endemic, rare and threatened species (Fig. 7). Compared with hotspot analysis, complementarity approach was much more cost-effective. The cost of protecting hotspot grid cells that could include all *Rhododendron* species was 25 times higher than the cost of protecting all complementarity grid cells covering all *Rhododendron* species. Similarly, the cost of hotspot analysis was 21, 7 and 18 times higher that complementarity approach to protect all endemic, rare and threatened species, respectively. At the same cost of complementarity grid cells, hotspot grid cells could only protect 64% total species, 58% endemic species, 57% rare species and 65% threatened species. The efficiency of the hotspot approach (10% richness algorithm) for four species groups ranged between 0.03 and 0.41, while that of the complementarity approach ranged between 0.85 and 0.97 (Table 1).

Conservation gaps for *Rhododendron* in China

We evaluated the protection status of 61 grid cells identified as priority areas by complementarity algorithm. We chose complementarity over hotspot grid cells because the efficiency of the complementarity approach was higher than the hotspot approach (see Table 1). The overlap between remaining 59 priority grid cells and nature reserves revealed that about 14% of the grid cells were not covered by any nature reserve in China. Two of these unprotected grid cells were very high priority areas, one was high priority area and five were moderate priority areas based on our analyses (Fig. 6).

Discussion

The use of quantitative measures to select areas of high conservation importance has been in practice since the early 1980s. However, the question of the most efficient method for identifying priority areas is still the subject of debate (Fox and Beckley 2005). Here, we show that the iterative complementarity method is more efficient than the commonly used hotspot method in choosing priority areas for the conservation of *Rhododendron* in China (see Table 1). We found that the cost of protecting hotspot grid cells that could include all *Rhododendron* species was 25 times higher than the cost of protecting all complementarity grid cells covering all species of the same group. Similarly, at the same cost of protecting complementarity grid cells, only about half of the *Rhododendron* species would be protected by the hotspot grid cells. Similar results have been found for British birds (Williams et al. 1996), South African coastal fishes (Turpie et al. 2000), Papua New Guinean corals and fishes (Beger et al. 2003) and Western Australian coastal fishes (Fox and Beckley 2005).

The priority areas selected by one method did not correspond well with the priority areas selected by the other method, which indicates that the designation of conservation areas using these two methods result in protecting completely different regions and hence different features (e.g. species). This is particularly due to differences in their site selection principles. For example, hotspot method assigns high priority to areas with high species richness, while complementarity method chooses sites to complement the previously

Fig. 7 Overlap between the priority areas selected by the hotspot (blue circles) and complementarity (green circles) algorithms for the four species groups of *Rhododendron* in China. The sizes of priority areas are represented by the number of grid cells (i.e. the numbers within the circles). The left column represent the overlap between top 5% hotspot grid cells and complementarity grid cells, while the right column represent the overlap between top 10% hotspot grid cells and complementarity grid cells

chosen sites as fully as possible (Pressey et al. 1996). Although, the commonly used thresholds of 1–10% in hotspot approach were able to fully capture areas with high species richness (or high endemism or rarity), we found that the selected sites in the hotspot method were not as representative as the ones selected by complementarity in order to protect all species. Furthermore, the number of required grid cells to protect all the listed species of *Rhododendron* in each group was much higher in the hotspot method compared to the complementarity method. More importantly, the hotspot method failed to include the range restricted species, while the common species were repeatedly included in the hotspot grid cells. Even when using the hotspots of the rare species, the algorithm failed to include the rarest of these rare species (see Fig. 4), which suggests an inefficient spatial solution of the hotspot method (Pressey and Nicholls 1989). For all the species groups used in our analysis, hotspot method was unable to capture 15–50% of the *Rhododendron* species. The missed species in all the groups were usually those with much narrower ranges, i.e. species that require the most conservation attention, which indicates that irrespective of the dataset or groups used, the range-restricted species are always excluded by the hotspot method. The principles of minimization and representativeness are violated when hotspot method is used to prioritize areas, which suggest that the sites selected by hotspot algorithm may not necessarily be the best sites to allocate conservation efforts (Ribeiro et al. 2017).

Despite its low efficiency, the priority-setting approaches in China have mostly relied on the hotspot algorithm (e.g., Huang et al. 2012; López-Pujol et al. 2011; Tang et al. 2006; Xu et al. 2017; Yu et al. 2017). These studies have, therefore, always identified areas of high species richness, high endemism or high rarity as the priority areas for conservation, irrespective of complementarity of the chosen sites. This raises an important concern about the efficiency of the prioritized areas for other taxonomic groups in China. Our findings raise two major questions on the performance of the hotspot method. First, are the targeted groups adequately represented by the designated priority areas? Second, does the chosen method optimize the cost in terms of the number of sites selected? The current study shows that this is not the case here. We found that the commonly used hotspot method selects more areas but protects less species. This indicates that the priority areas identified previously for the conservation of endemic woody seed plants (Huang et al. 2012), endemic plants (López-Pujol et al. 2011), endemic plant genera and families (Huang et al. 2016), evergreen broadleaved woody plants (Xu et al. 2017) and *Rhododendron* (Yu et al. 2017) based on hotspot method may not be adequate to fully achieve the given conservation target.

A possible solution to this problem would be to find areas of complementary richness so as to make the selected priority sites as representative as possible (Pressey et al. 1993; Stewart et al. 2003). An optimal priority area selection approach, such as the complementarity could, therefore, be useful here. Indeed we found that the iterative complementarity method is more efficient and representative than the hotspot method, in identifying priority areas for Chinese *Rhododendron*. The complementarity method identifies the smallest set of sites, i.e. lowest number of grid cells or total area, needed to represent a targeted group in a region (Pressey et al. 1996) and hence, provides an efficient and cost-effective conservation solution. Since this method follows the key principles of systematic conservation

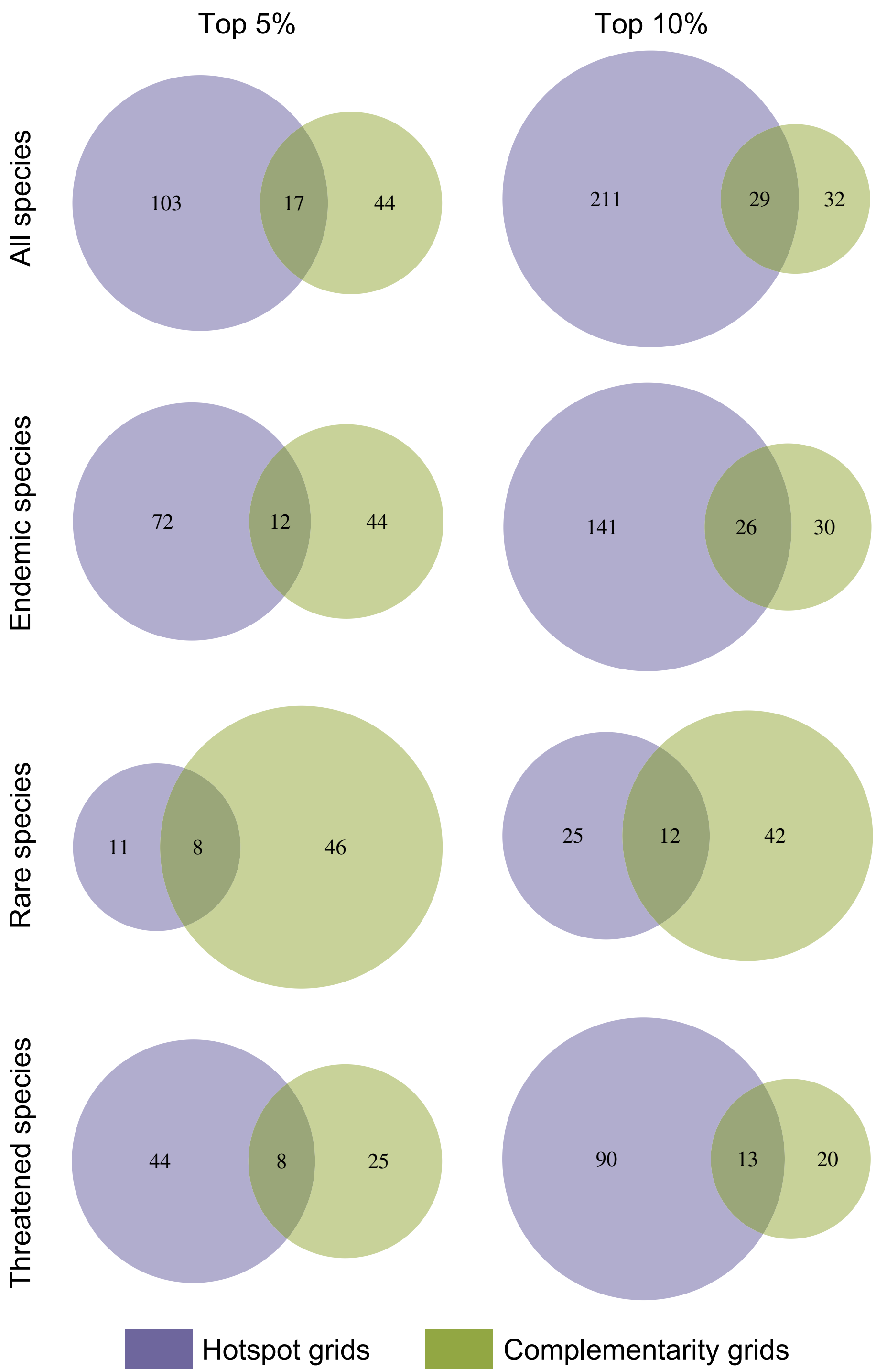
Top 5%
Top 10%
All species
103
17
44
211
29
32
Endemic species
72
12
44
141
26
30
Rare species
11
8
46
25
12
42
Threatened species
44
8
25
90
13
20
Hotspot grids
Complementarity grids

Table 1 Comparison of efficiency in identifying priority areas between the hotspot analysis and complementarity approaches

Species groups	Hotspot (10%)			Complementarity		
	N	*T*	Efficiency	*N*	*T*	Efficiency
All species	1554	2399	0.35	61	2399	0.97
Endemic species	1179	1674	0.30	56	1674	0.97
Rare species	361	371	0.03	54	371	0.85
Threatened species	610	1031	0.41	33	1031	0.97

N is the number of required grid cells to protect all the listed species (conservation target) and *T* is the total number of grid cells where species occur. For ease of comparison, only 10% hotspot approach has been shown. Efficiency was calculated following the method of Pressey and Nicholls (1989)

i.e. comprehensiveness, adequacy, representation and cost-efficiency (Ribeiro et al. 2017), it is being increasingly used globally to prioritize areas for the protection of biodiversity, including ecosystems, biological assemblages, species and populations (Margules and Pressey 2000).

The priority areas for *Rhododendron* identified in the present study using complementarity method (Fig. 5) and the priority areas for other taxonomic groups identified in previous studies (e.g., Chi et al. 2017; Liu et al. 2017; Zhang et al. 2015b) correspond very well with each other. This indicates that the areas required for the systematic conservation of different plant groups in China are more or less similar. The grid cells chosen by the hotspot method here (see Fig. 2) and in previous studies (e.g., Huang et al. 2012, 2016; Xu et al. 2017; Yu et al. 2017) were, however, heavily biased towards south-west China, particularly the Hengduan Mountain region. As a global biodiversity hotspot (Myers et al. 2000), Hengduan Mountain is one of the most species rich regions in China and hence the hotspot algorithm assigns high priority to it. On the contrary, the grid cells selected by complementarity method were uniformly distributed throughout the mountainous regions of south China. Particularly, many grid cells in east China and south-east China not selected by the hotspot approach were prioritized by the complementarity method. For example, previous study based on hotspot method (Yu et al. 2017) failed to identify southeast Yunnan, south Guangxi, southwest Guangdong, southeast Gansu, southwest Shaanxi, and east Fujian as priority areas for *Rhododendron*. Although these grid cells are low in species richness, they represent sites of high complementarity. Failure to protect these grid cells could lead to loss of many rare species as shown by our analysis (see Fig. 4). In fact, some of these grid cells are outside the protected area network, which further indicates that the rare species occurring in these grid cells may be already under threat. Overall, our results suggest that in order to achieve the highest conservation target (i.e. protect maximum species at lowest cost), the identification of priority areas in China should be based on the method that could provide a quantified and reliable measure of its performance.

Despite its inefficiency, the usefulness of the hotspot method cannot be fully denied. In absence of a spatially explicit data of species distributions, for example, the hotspot method is still useful in defining conservation priority. However, when data insufficiency is not the case, the output from complementarity is more reliable, explicit and efficient (Ribeiro et al. 2017). The precise data on the spatial distributions of species can greatly aid their conservation, and are urgently needed for the groups with high conservation concerns. The distribution data for *Rhododendron* in China is based on herbarium specimens as well as all national-level floras including *Flora Reipublicae Popularis Sinicae*, *Flora of China*, more than 120 volumes of provincial floras, and a great number of local floras and inventory reports across the country (Fang et al. 2011). Therefore, our dataset provides the most comprehensive distribution records for the genus in China. The validity of our approach and the output it provides is, hence, justified.

Although complementarity method is an efficient priority setting method than the hotspot analysis, we acknowledge that the priority areas selected herein for the conservation of *Rhododendron* may have some limitations. First, our results are based on the analyses at a broad spatial scale (50×50 km). While many reserves in China have areas smaller than this, it may not be practically possible to designate such large conservation areas based on this coarse scale analysis. Such scale mismatch between distribution data and nature reserves may add some uncertainties in the gap analysis. Nevertheless, our results provide a rough estimation of priority areas that lie outside the protected area network and therefore, these findings could be useful in developing future management plans for *Rhododendron* conservation in China. Second, the identification of priority areas is based on species composition alone. Therefore, the change in species' identity or a discovery of new species in the entire region may, though slightly, alter the map of the priority areas due to change in diversity measure. However, this will have effect only on the species poor regions and a major part of the map will still remain intact. Third, we did not incorporate information of the evolutionary history of species into our analyses. Evolutionary history has been widely believed to be important for biodiversity assessment and the identification of priority areas (Faith et al. 2004). However, this was beyond the scope of our study. While the approach we followed here implicitly provides equal status to each species, the phylogenetic approach assigns values to species based on evolutionary distinctness (Faith 1992). Comparative studies could be made in the future by including phylogenetic diversity over species diversity to evaluate consistency in the selected priority areas.

To sum up, the present study identified areas of high conservation importance for *Rhododendron* in China. Although two methods were employed to identify the priority areas for the conservation of this genus, the iterative complementarity method had higher efficiency and representativeness than the commonly used hotspot method. Besides, to achieve the given conservation target, the complementarity algorithm selected much lesser areas than the hotspot. This indicates that despite its popularity and ease of implementation, the sites selected by hotspot algorithm may not necessarily be the best sites to allocate conservation efforts. Instead, if we prioritize areas based on complementarity, we can achieve a much efficient (low-cost) conservation solution. Because the identification of priority areas in China has chiefly been based on the hotspot method, the current study has revived the need to reassess the priority areas for other taxonomic groups. Our findings have also emphasized the need to expand the conservation priorities from the Hengduan Mountains to south and southeast China as well.

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