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Original Research Article

Species richness and conservation gap analysis of karst areas: A case study of vascular plants from Guizhou, China

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ABSTRACT

Guizhou province, famous for its karst landforms and rich biodiversity, is facing exceptional threats by intensive human activities, like many areas in China. As a result, Guizhou is a critical and priority area for biodiversity conservation. In this research, herbarium collections were used for evaluating the present protection effectiveness of Nature Reserves. 103,783 herbarium specimen records, belong to 7505 native vascular plant species were used as different layers in ArcGIS software at 0.15 × 0.15-degree grid resolution. In addition, 129 natural reserves were used in the aim of exploring biodiversity patterns, identifying species richness centers, endemism centers, and for biodiversity gap analysis. As a result, nine distinct critical biodiversity areas were recognized based on high species richness, high endemic and endangered species: eight patches with highest species number (>1000 species), four patches with high areas of endemism species (>15 species), and three small areas with high percentage of endangered species (>50 species). Results showed that some species richness centers and endemism centers are protected by the current Nature Reserve network in China. However, comparing the nine distinct biodiversity critical areas and current Nature Reserves, many gaps exist, and some places with high endemism or endangered species still need further attention. More Nature Reserves should be established to protect the gap areas. This research provided an overview of approaches to establishing biodiversity conservation priorities, and of strategies for filling gaps in the existing reserve network, and also can shed light on conservation tasks for other similar karst landform regions.

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1. Introduction

China harbors the largest areas of karst landforms in the world, with an area of 1.3 million square kilometers (Lin et al., 2016). The karst forest ecological systems of southern China are well known for their high biodiversity and ecosystem fragility. This area contains numerous rare, endangered, endemic and economically important species (Davis et al., 1995; Yu and Qin, 2014; Yu et al., 2014, 2017). Several thousands of indigenous plant species have been documented, and a number of new species are published each year, including some species already facing extinction due to over collecting, even before they were scientifically described and documented (Ying et al., 1993; Zhang and Wu, 2016). The contradictions between biodiversity conservation and economic development have become more and more serious with the rapid increase of human explorations (Médail and Quézel, 1999; Mittermeier et al., 2005; Samways and Grant, 2007).

Guizhou, as the east portion of the Yunnan−Guizhou Plateau (Chinese: 云贵高原; pinyin: Yúnguì Gāoyuán) is a highland region located in southwest China, characterized by mixed broadleaf forests (Guizhou Plateau broadleaf and mixed forests. Global Species. Myers Enterprises II. Retrieved 31 July 2017). Guizhou owns an averaging 61.92% karst landforms, it is also called as “karst province”, this province has the largest proportion of rocky desertification and karst landforms in China (Huang and Cai, 2006).

It was listed as one biodiversity hotspot in China, with high endemism for plants. Over 37.9% of all Chinese endemic genera appear here, including *Davidia*, *Cercidiphyllum*, *Metasequoia* etc. (Ying, 2001); Southern Guizhou, as well as Wuling Mt. (Guizhou part), are very rich in biodiversity (Liu et al., 2013; Chi et al., 2017). The flora of Guizhou is characterized by distinct zonality in the context of karst distribution patterns (Academic Divisions of CAS, 2003). Both calciphobous and calciphilous plants are recorded in Southeast Guizhou karst areas (Gao et al., 2015). Orchid species are more diverse in the southwestern part, e.g. Maolan Nature Reserve, which have been founded especially for orchid conservation. Gymnosperm species are mostly distributed in the southeastern part, and *Rhododendron* species in the western and northeastern high mountains, mirroring the eco-zonation driven by karst alkalescent soil and other environmental factors (Liu et al., 2005; Zhang et al., 2006).

Guizhou is also famous for its traditional ethnic culture, with 49 ethnic groups, including Buyi, Dong, Gelao, Miao, Shui, and Yao, most of them maintaining their traditions (The Third Surveying and Mapping Institute of Guizhou Province & Guangdong province map press 2002). Their culture and tradition were always isolated due to the difficult accessibility of the karst mountain systems in the historical period, which resulted in low levels of local economic development, compared with other provinces in China (Wang and An, 2014).

For a long time, local people's livelihoods heavily relied on plant resources, which lead to high pressure on plant resources and habitat fragmentation (Gaston, 2000; Hou et al., 2010), such as overcollection of medicinal plants, orchids, and luxury foods, cutting trees for firewood; and cultivating small pockets of soil leading to desertification.

Many species are becoming endangered due to human's exploitation and economic development, and frequent fires lead to desertification and rapid biodiversity lose (Pimm et al., 1995; Olson and Dinerstein, 1998; Balmford et al., 2003; Jenkins et al., 2003; Huang et al., 2011), causing tremendous species loss (Gaston, 2000). By 2012, the area of land destruction caused by mineral resources development in Guizhou was 47,544 hm^{2,} especially exploring the limestone to make cement, of which the area of excavation damage was 3037 hm^2, accounting for 63.18% of the total area of destruction. Land destruction will cause serious ecological problems, including: ecological landscape, waste rock, dust, noise and earthquake waves (Hou et al., 2015).

These problems have received extensive attention, and the local government issued a list of conservation planning strategies, informed several national natural reserves, and carried out some conservation projects (Myers et al., 2000; Burgess et al., 2005; Joppa et al., 2013). As one example, the comprehensive rehabilitation of rock desertification in karst areas of Guizhou, Guangxi and Yunnan was included in the 10th Five-Year plan for National Economic and Social Development. Research showed the habitat sensitivity distributions in Guizhou are mainly composed of a highly sensitive area (covering an area of 93579. 40 km^2, accounting for 53.15%) and not sensitive area (covering an area of 39071. 14 km^2, accounting for 22.19%) (Wang et al., 2004). At the same time, the Sixth International Karst Correlation Project (Yuan, 2001) also emphasized the importance of Karst biological conservation. The government increased the protection for this region by establishing several new Nature Reserves. Currently there are 129 reserves in Guizhou, in which eight are national, four provincial, and 107 are at the country level.

The main aim of this study is to determine the biodiversity hotpots of Guizhou by analyzing the geographic distribution patterns of native species, especially endemic and endangered species, and to check their conservation status in Guizhou, to shed light on the distribution patterns in karst areas, and provide a framework for future conservation planning. In addition, we have attempted to provide suggestions to resolve large conservation challenges, faced by most of subtropical and tropical karst areas in Asia. In combination with Wild Plant protective regulations of the PRC implemented on Jan 1, 1997, we try to: 1) show the biological diversity and the plant geographical distribution patterns in Guizhou; 2) analyze the gaps in biological diversity conservation in Guizhou; 3) make suggestions for the biological diversity protection of karst landforms in Guizhou and China as a whole.

2. Methods

2.1. Study locality

Guizhou lies on eastern margin of the Yunnan-Guizhou Plateau between 24°30′-29°13′N and 103°31′-109°30′E in southwestern China. It covers an area of about 170,000 km^2 and 61.9% of the area is covered with karst landforms (Huang et al., 2011). The local karst landforms are considered to be a natural karst landscape museum, because they have completely developed and classical karst topographic features (Wang et al., 2004). There are forty-nine ethnic groups with a population of 37.10 million occurred in this area, taking up 34.7% of the whole population, including Miao, Dong, Buyi, Chuanqing etc. The last published flora contains 5800 species (Flora of Guizhou Editorial Committee, 1982–2004), and many new species or new records have been reported since then (He et al. 2011, 2013; Zhang et al. 2012, 2015). A total of 129 Nature Reserves for plant conservation have been established, but very few evaluations of their protection efficiency have been carried out.

2.2. Date collection and treatment

Our specimen data mainly come from the Chinese Virtual Herbarium (http://www.cvh.org.cn/), compiled from 13 major herbaria: CDBI, HENU, HIB, HITBC, HNWP, IBK, IBSC, IFP, KUN, LBG, NAS, PE, WUK with Guizhou plant collections (the acronyms follow Fu, 1993). The geographical coordinates of the herbarium specimen records were geo-referenced on SQL Server Management Studio, according to China gazetteers, and manually fine-tuned by consulting maps. Specimen records lacking detailed locality information were excluded from this study. We carried out data cleaning of the specimen database, and taxonomic name resolution based on *Flora of China* (http://www.efloras.org/flora_page.aspx?flora_id=2) and Species 2000 China node (http://www.sp2000.org.cn/) (All our statistics including species and intraspecies).

A total of 103,783 specimen records were used to analyze the species richness, endemic and endangered plants in Guizhou province, cultivated or alien species were excluded. After removing entries with invalid date 83,458 records were used for the final calculations. Threatened plants were classified from China Biodiversity Red list (Ministry of Environmental Protection of the People's Richardson et al., 2001), including VU (Vulnerable), EN (Endangered), CR (Critically endangered), RE (Regional extinct), and EW (Extinct in the wild) species. A total of 400 plant species fall into China Biodiversity Red list category. A total of 171 endemic species from the red list were recognized in Guizhou, accounting for 21.94% of the total number in China.

2.3. Biodiversity mapping

Guizhou province was divided into 827 grid cells based on 0.15 × 0.15-degree latitude/longitude grid size for mapping species richness and endemism. 87 cells located at the border with less than 50% area presented were removed. Each cell covered an area of approximately 256 km^2. A larger scale would have been too coarse, while a smaller scale would have amplified the effect of sampling artifacts, such as the occurrence of artificially empty grid squares and mapping errors (Crisp et al., 2001; Linder, 2001). In order to detect the biodiversity hotspots, the number of species, endemic species and endangered species were measured separately within each grid cell. In the end, we synthesized the above results by overlaying layers together, and got a new richness layer. Because cells overlap the coast and provincial boundaries have only a small proportion of land, those cells will have an inaccurate index if we calculating any variables related with area of land. As a result, it will be preferable to omit these cells from the analysis (Morawetz and Raedig, 2007). The concept of endemism followed Anderson (1994) referring to species restricted to Guizhou province. We used DIVA-GIS 5.0 to visualize the species richness and distribution patterns (Hijmans et al., 2005), which has been successfully used for analogous analysis (e.g. Hijmans and Spooner, 2001; Ganeshaiah et al., 2003; Miller and Knouft, 2006; Parthasarathy et al., 2006). The patterns obtained for both parameters were examined to detect aggregates of cells with high amounts of species, endangered species and endemic species (i.e. Centers of distribution), as commonly done in biodiversity distribution surveys (Crisp et al., 2001; Linder, 2001; Morawetz and Raedig, 2007).

2.4. Conservation gap analysis

A GIS document of the China Nature Reserve network was downloaded from the World Database on Protected Area (WDPA) (https://protectedplanet.net/), with 129 Nature Reserves in polygon or point type (Some nature reserves have smaller areas, they were designed to protect one single species, named “small protect areas”, they can only be shown as points rather than polygons on the distribution map) available for conservation gap analysis. We used a map from the National Catalogue Service for Geographic Information. In this study, we overlapped the Nature Reserve network on the layer of species richness of all the species, endemic and endangered taxa, rather than vice versa to generate maps of the current protection efficiency by recognizing un-overlapped priority conservation areas (Hou et al., 2010; Zhang et al., 2015). The final results of the conservation gap analysis were obtained by synthesizing the results of all species, endemic and endangered species.

2.5. Floristic similarity analyses

This Jaccard coefficient can compare two areas' floristic similarity as long as both areas’ plant inventory were investigated (Qian et al., 2005). We can rank all the cells by floristic similarity, those cells with the highest floristic similarity with cells already set up as Nature Reserves should also be considered to be protected in the future.

The Jaccard coefficient (Muller-Dombois and Ellenberg, 1974; Qian et al., 1998) was considered as similarity index (*SI*):

$$SI = C / (A + B - C)$$

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Where *A* is the number of species in area *i*, B is the number of species in area *j*, and C is the number of species common to both areas of *i* and *j*. Low or high of the *SI* indicated areas *i* and *j* are character of low or high similarity. We could confirm which diversity center should be treated as priority conservation area in the context of understanding the heterogeneity or homogeneity of those diversity centers.

3. Results

3.1. Floristic statistics

Overall, 264 plant families with 1667 genera and 7505 vascular plants species were inventoried from Guizhou province (Table 1). There were 17 families with more than 300 species (Table 2), including Asteraceae (412 species), Rosaceae (369 species), Poaceae (366 species), Fabaceae (316 species). In total, 740 grid cells were sampled, comprising 83,458 occurrence records for 7505 species-level taxa. Around 19.59% of the grid cells showed a total absence of species, while more than half presented less than 400 species and eight cells more than 1000 species (Table 3). From the observation, eight distinct richness centers were identified in Guizhou, namely Fanjing mountain (No. 1), Kaili (No. 2), Guiyang (No. 3), Leigong mountain (No. 4), Xingren (No. 5), Xingyi (No. 6), Anlong (No. 7), Ceheng (No. 8) (Fig. 1).

We recognized 171 endemic species from 40 families and 91 genera (Table 1). Some families with more than 10 species had high percentages of endemism (Fig. 2, Table 2), e.g. Gesneriaceae (21 species), Rosaceae (16 species), Poaceae (12 species), Asteraceae (12 species), Primulaceae (11 species). Four endemic centers were identified (Fig. 2): Fanjing mountain (No. 1), Guiyang (No. 2), Libo (No. 3), Anlong (No. 4). The Fanjing mountain (No. 1), Guiyang (No. 3) and Anlong (No. 7) are also species richness centers (Fig. 1).

Table 1
The amounts of endangered and endemic species.

Ranking	Family	Genera	Species	Endemic species
Total	264	1667	7505	171
VU	77	158	235	18
RE	1	1	1	0
EW	1	1	1	0
EN	49	93	125	16
CR	23	31	38	10
proportion (%)	61.38	17.04	5.33	25.73

Table 2
The endemic and endangered species of families with more than 100 species.

Family (>100 Species)	Number of Species	Number of Endemic Species	Number of Endangered Species	Proportion of Endemic Species (%)	Proportion of Endangered Species (%)
Asteraceae	412	12	0	7.02	3
Rosaceae	369	16	11	9.36	4
Poaceae	366	12	8	4.68	3
Fabaceae	316	3	14	8.19	0.73
Orchidaceae	284	8	85	49.71	2
Thelypteridaceae	182	0	5	2.92	0
Liliaceae	171	0	5	2.92	0
Lauraceae	169	5	16	9.36	1.25
Lamiaceae	166	6	5	2.92	1.42
Ericaceae	136	4	7	4.09	1
Rubiaceae	133	0	0	0	0
Cyperaceae	128	0	0	0	0
Euphorbiaceae	126	1	3	1.75	0.25
Theaceae	125	5	7	4.09	1.25
Scrophulariaceae	119	8	2	1.17	2
Ranunculaceae	119	2	3	1.75	0.5
Polypodiaceae	116	0	1	0.58	0
Total	3437	82	171	1	20.4

Table 3
Species richness calculation by cells.

Number of Species	0	1–199	200–399	400–699	700–999	1000–1457
Cells	145	470	71	35	11	8
%	19.59	63.51	9.59	4.73	1.49	1.22

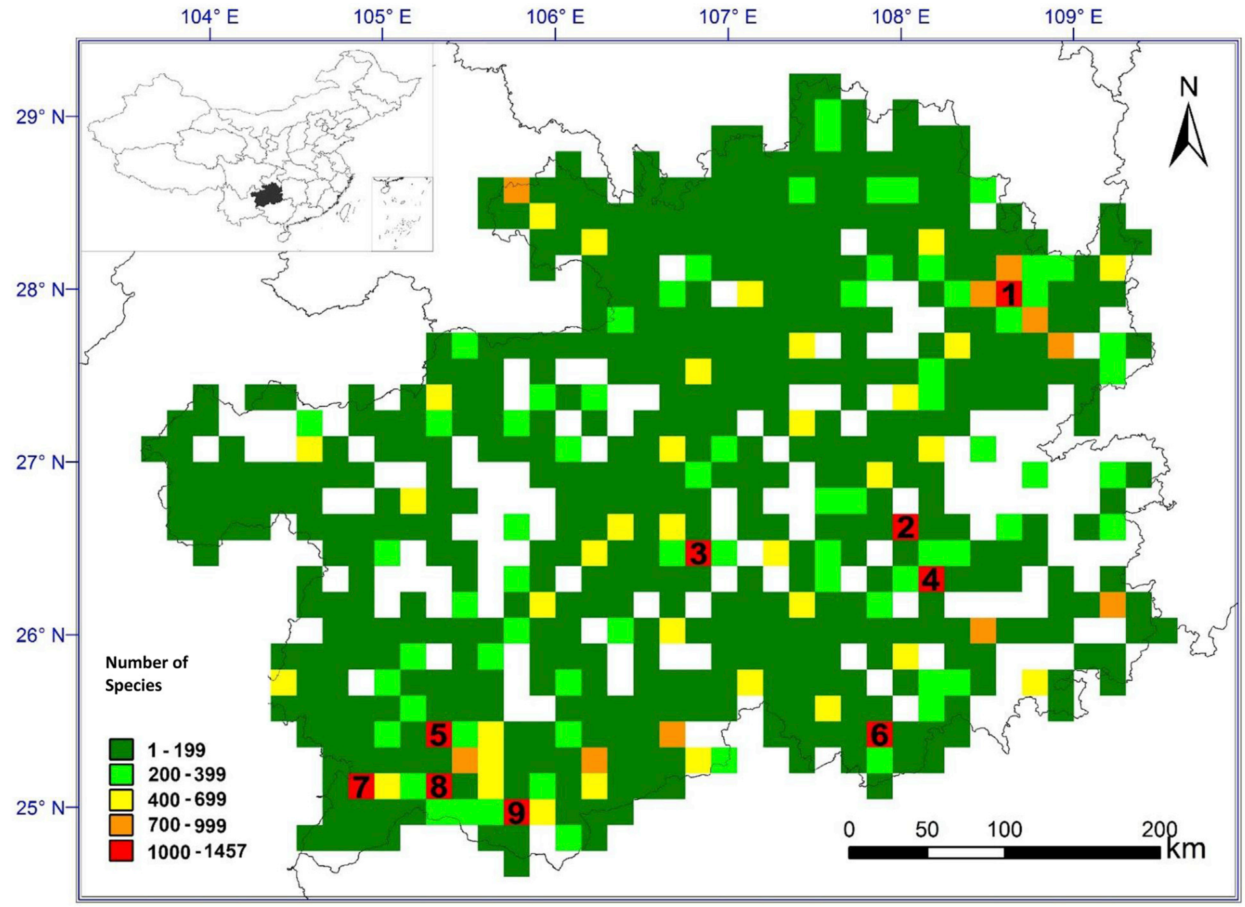

Fig. 1. Species richness mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to the centers of species richness. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Four hundred species with 2233 specimen records were included in China Biodiversity Red list (Ministry of Environmental Protection of the People's Richardson et al., 2001), accounting for 5.33% of Guizhou flora (Table 1). Including 38 CR species, 125 EN species, and 235 VU species. Most of these endangered species were mainly distributed in Fanjing mountain, Libo, Leigong mountain, Guiyang, Southwest of Guizhou (Fig. 3), with three cells harboring the highest number of endangered species, namely, Libo (No. 1), Xingyi (No. 2), Anlong (No. 3) (Fig. 3).

3.2. Plant biodiversity hotspots in Guizhou

Based on the results of the species richness analysis, eight grids had more than 1000 species (Fig. 1, Table 3). On the level of endemics, four diversity areas cells harbored with more than 15 endemic species (Fig. 2, Table 5). For endangered taxa, three diversity areas with more than 50 endangered species (Fig. 3). The three richness layers were then overlapped, and the resulting synthesized layer comprised eight patches with highest species number (>1000 species), four patches with high areas of endemism species (>15 species), and three small areas with high percentage of endangered species (>50 species) corresponding to nine critical regions: Fanjing mountain (No. 1), Kaili (No. 2), Guiyang (No. 3), Leigong mountain (No. 4), Xingren (No. 5), Libo (No. 6), Xingyi (No. 7), Anlong (No. 8) and Ceheng (No. 9) (Fig. 4, Table 5).

3.3. Conservation gaps and similarity of diversity areas for priority conservation

Based on the results of the conservation analysis, six of nine critical regions in three different levels were found to be outside the current nature conservation network. These gap areas were Kaili (No. 2), Guiyang (No. 3), Xingren (No. 5), Xingyi (No. 6), Anlong (No. 7) and Ceheng (No. 8) (Fig. 5). For endemic species, three areas with high richness were found to be outside the current nature conservation network (Fig. 6), and three high species richness areas of endangered species were also found outside the nature conservation network (Fig. 7). When overlapping the layer from above mentioned taxa it resulted that more than a half the species richness areas were outside the conservation areas (Fig. 5).

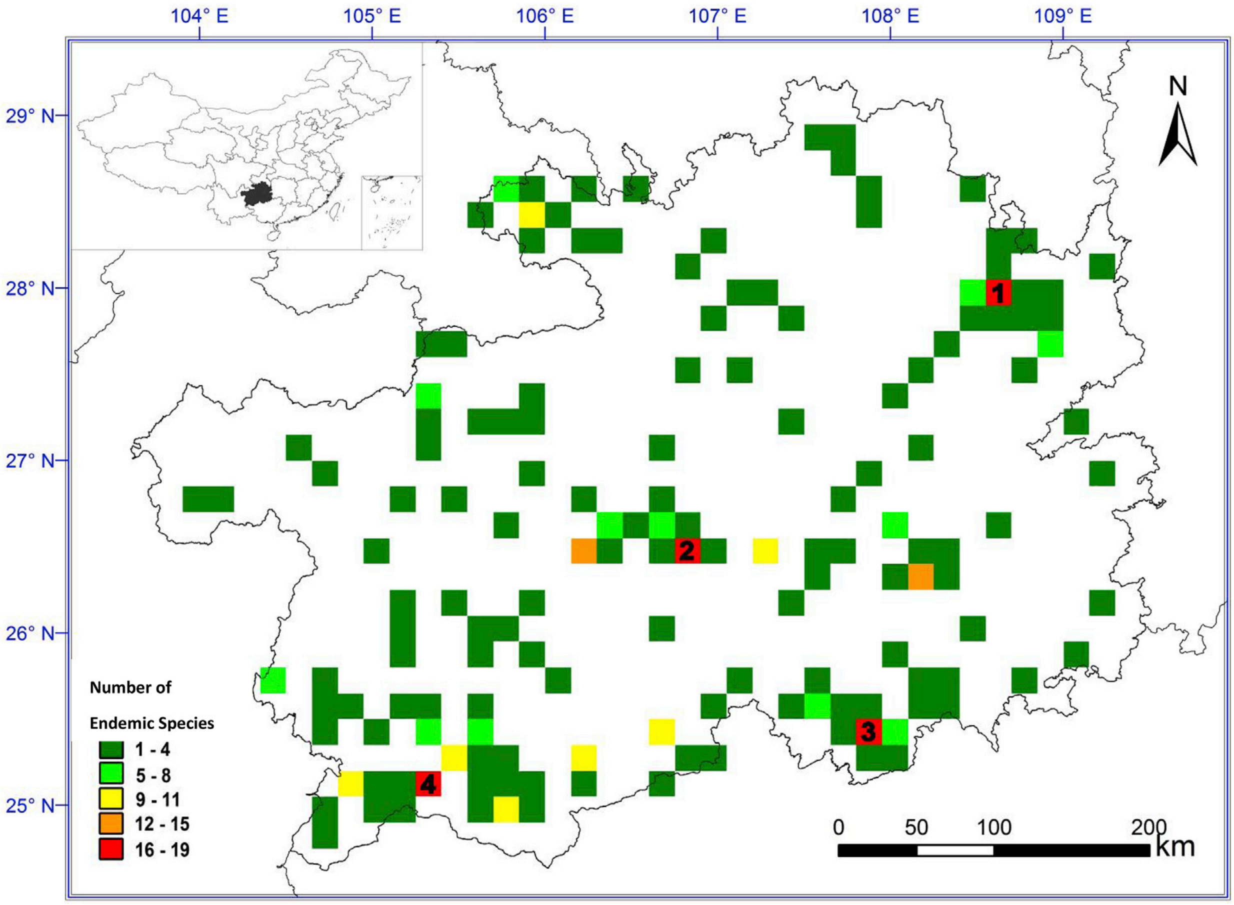

Fig. 2. Endemism mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to the centers of endemism. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Similarity analysis showed that Xingren (No. 5), Xingyi (No. 6), Anlong (No. 7), and Ceheng (No. 8) (Fig. 5) had a high similarity exceeding 27%, while Guiyang (No. 3) and Anlong (No. 7) have a low similarity (under 10%, Table 4; Fig. 5). Xingren (No. 5, Fig. 5) was not only the center of species richness, but also very rich for endemic species, with many species endangered. Given the limited budget to establish Nature Reserve, it would be better to select new sites with lower similarities, and thus Kaili (No. 2), Guiyang (No. 3) and Xingren (No. 5) should be given priority in conservation (Fig. 5).

4. Discussion

Under-sampled assessment and Controlling of sampling bias to ensure the reliability of macroecological inferences.

According to Yang's assessment, 91% (n = 2161) of Chinese counties are under-sampled. Assuming that a minimum of 5914 specimens should be collected for each county (i.e. the average number of specimens of well-sampled counties), all of the 88 counties in Guizhou are under-sampled (Yang et al., 2013). There are even 66 counties in Guizhou with only less than 1000 specimens collected in the past. A roughly estimated total of 420,000 specimens are still required to accomplish a near complete survey of all counties.

Currently, based on our data, we found the northwest part and south part of Guizhou still need more collections for further composing of Flora of Guizhou, Zunyi (14 counties altogether 10044 specimens, with an average of 717 specimens collected in each county), Bijie (7 counties altogether 3841 specimens, with an average of 548 specimens collected in each county); Qianan (12 counties, Luodian and Libo have relatively better collections,while other ten counties altogether have 5746 specimens, with an average of 574 specimens collected in each county), Qiandongnan (16 counties, Leishan, Rongjiang and Kaili have relatively better collections,while other thirteen counties altogether have 5335 specimens, with an average of 413 specimens collected in each county). Luckily, some counties with rich biodiversity with relatively higher number of specimens collected, such as Yinjiang (4923 specimens for 1916 species), Kaili (1808 specimens for 1145 species), Xingren (2443

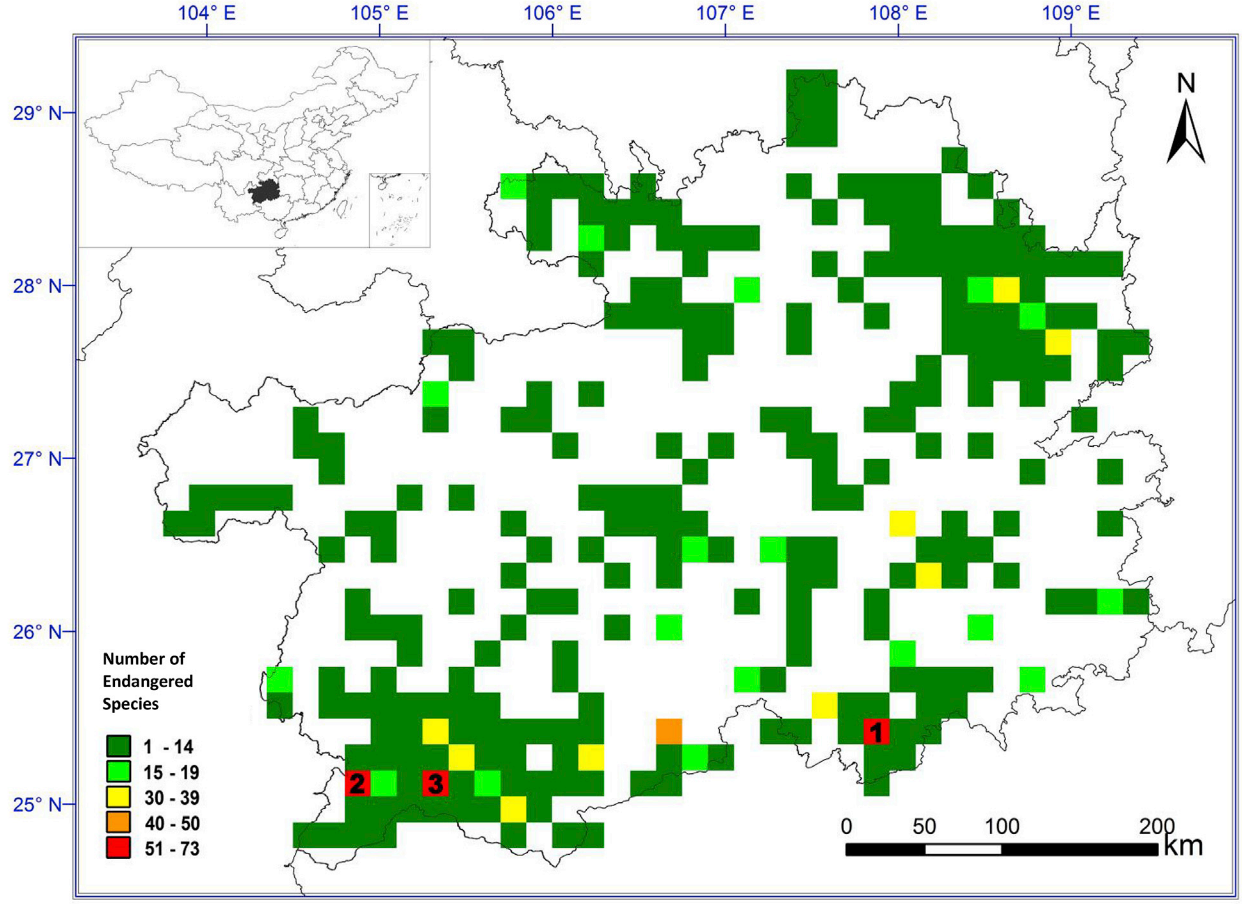

Fig. 3. Endangered mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to the centers of endangered species. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Similarity analysis of the six areas with rich biodiversity.

Locality	Number of Species	Kaili	Guiyang	Xingren	Xingyi	Anlong	Ceheng
Species		1031	1162	1114	1457	1317	1137
Kaili	1031	1	23.06%	21.94%	18.65%	20.10%	17.70%
Guiyang	1162		1	14.49%	24.36%	5.70%	20.75%
Xingren	1114			1	32.46%	30.08%	27.90%
Xingyi	1457				1	35.58%	31.47%
Anlong	1317					1	30.32%
Ceheng	1137						1

Table 5
Top scoring species richness centers in Guizhou.

Hotspot no.	Location	Species richness	Rank in Species richness	Number of Endemic species	Rank in endemic species richness	Vegetation type
1	Fanjingshan	1358	2	20	1	Coniferous forest
2	Kaili	1031	8	1	7	Thickets and coppice forest
3	Guiyang	1162	5	18	2	Broad-leaved forest
4	Leigongshan	1283	7	16	3	Broad-leaved forest
5	Xingren	1114	8	0	8	Subtropical evergreen forests
6	Libo	880	9	20	1	Broad-leaved forest
7	Xingyi	1457	1	9	6	Coniferous forest
8	Anlong	1317	3	16	4	Coniferous forest
9	Ceheng	1137	6	11	5	Thickets and coppice forest

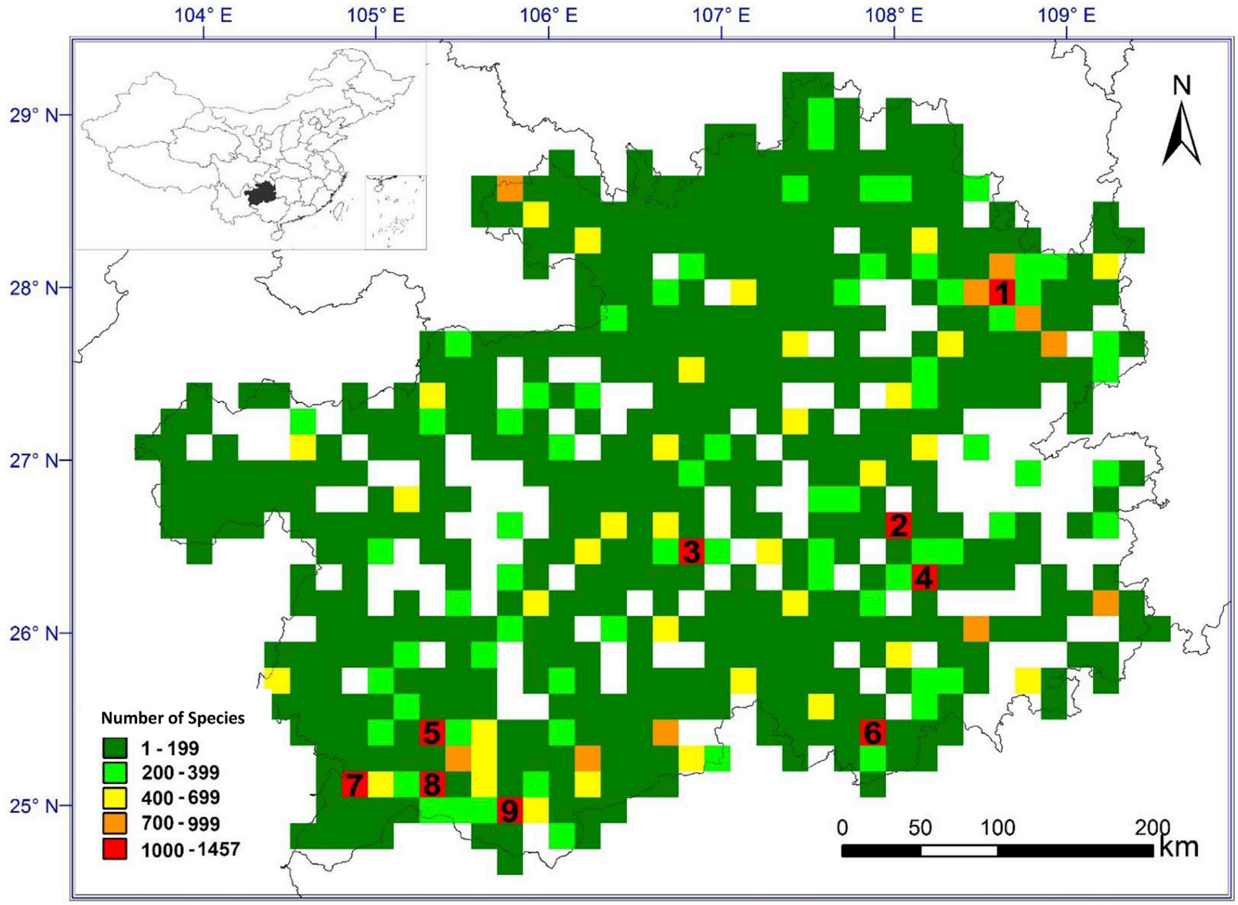

Fig. 4. Combined data of species richness, endemism and endangered species mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to critical areas of biodiversity. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

specimens for 1443 species), Xingyi (2742 specimens for 1747 species), Anlong (4555 specimens for 2114 species), Ceheng (2659 specimens for 1533 species).

While, when we try to locate each specimen's georeferenced data into the grid, some specimens' occurrence data were only recorded to county level, so the georeferenced data only can be point to the center of the county. So, we have some blank grid without one single specimen record, it could probably due to two reasons: 1.the area is not rich in biodiversity, or has experienced extensive vegetation explorations by human beings, so very few specimens have been collected in that area; 2. due to the complexity or absent of locality names on the specimen label, many records were georeferenced in the center of a county, rather at the actually position.

To ensure the robustness of results, we suggest including in analyses only well-sampled units. The blank ones won't affect the macroecological modeling results.

Yang's study (2013) showed inferences can be scaled up may depend on how well the well-sampled units represent the whole study area. 73% of the environmental variance (expressed by elevational range, PET and annual wet days) in China is still covered by the well sampled counties. Collecting effort has been usually concentrated on regions with the highest species richness or number of endemics. So, we think our around 20% absence of specimens' data in the grid should be acceptable to reflect the biodiversity pattern of karst areas in Guizhou.

4.1. Sampling representative mirrored insufficiency of previous investigation

Although of 103,783 specimen records surveyed, and 83,458 georeferenced entries included in the final analysis, we encountered some vacant grid cells at the species richness layer. That may be the result of two major reasons: First, in China, the specimen digitization projects are just at the beginning, thus only 103,783 digitized specimens from 13 herbaria had been uploaded on the Chinese Virtual Herbarium, representing only a fractional historical collection of Guizhou province. Second, historical collections did not cover Guizhou province sufficiently, and most collections were confined to famous mountains and great rivers (Table 5), e.g. there were 4923 collections from Fanjing mountain and from Leigong mountain. To some

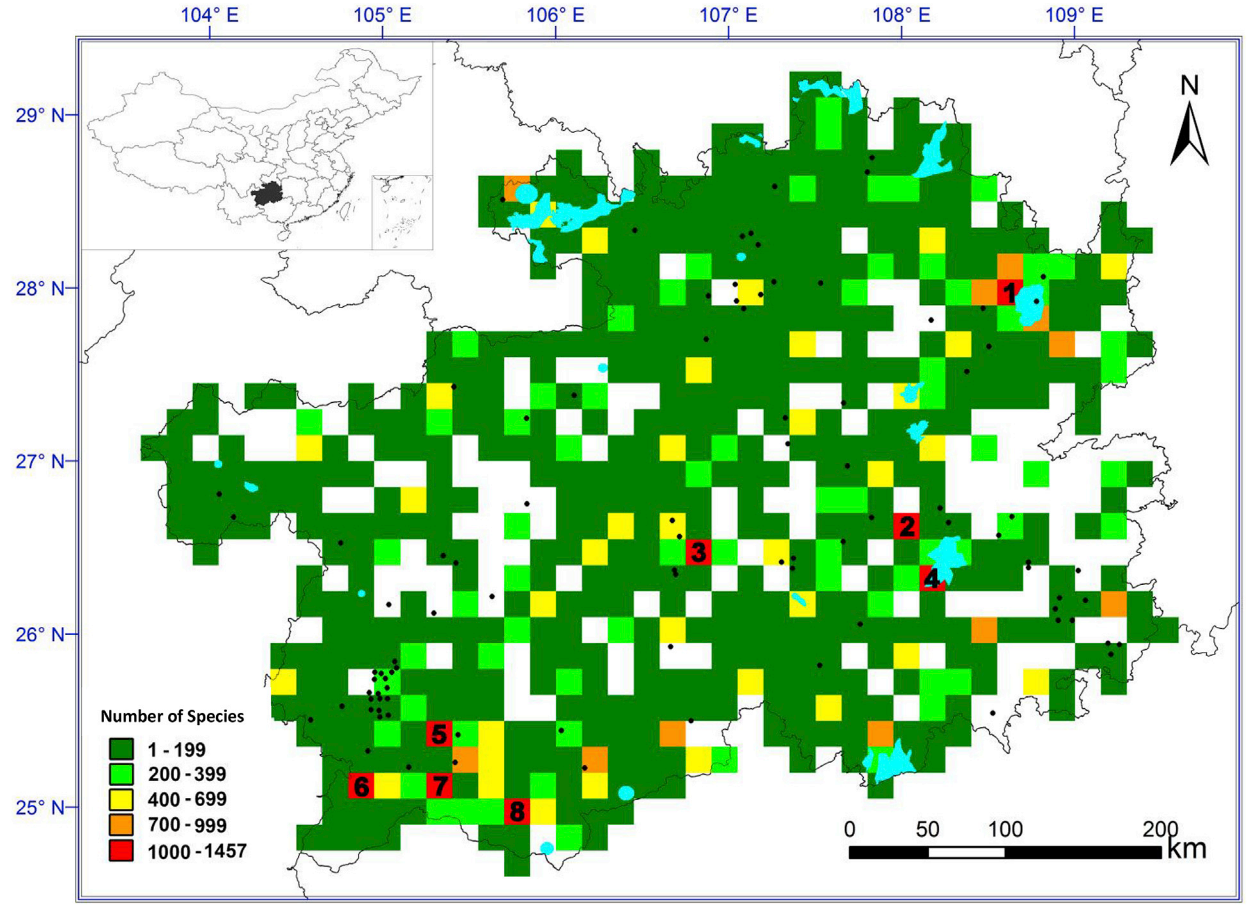

Fig. 5. Species richness mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to the centers of species richness. The black points are small protect areas and the blue litter areas are Nature Reserves. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

extent, the distribution patterns of specie richness indicated historical collections are unevenly distributed. We collected all available specimen data for Guizhou, try to provide a good outline of species distribution.

4.2. Further optimization of nature conservation network

After our GAP analysis based on data on species richness, endemic species percentage and endangered species distribution etc., we found many of these biodiversity hotspots were already incorporated into existing reserve networks, however, we also exposed some problems due to insufficiency of existing reserves. For example, the southwest Guizhou is one species richness center, as well as an endemic species center, and harbors many endangered species, but not enough Nature Reserves set up to protect the fragile ecosystem.

Most high species richness areas were confined to southern, central and eastern Guizhou, which are the marginal transition zones with hyper heterogeneity of habitats of the Yunnan-Guizhou plateau. Most of these areas included mountain ranges, which may be attributed to the high heterogeneity of topographical and environmental features (Richardson et al., 2001; Tzedakis et al., 2002; Orme et al., 2005).

Comparing this to the existing nature conservation network, it appears that western and northern of Guizhou have established sufficiently effective nature conservation networks; while, many gaps shown on the central and southwestern Guizhou in a less efficient reserve network. The distributions of diversity areas of different taxa level are congruent with each other; undoubtfully the typical karst areas of southwestern Guizhou indicated that the high species richness needs more efficient protection.

It is important to determine priority areas for biodiversity conservation and take effective measure to cope with limited human and material resources (Araujo, 1999; Ferrier, 2002). Combined with high species richness areas and conservation gap analysis, some diversity points in the karst areas of southwestern Guizhou were found without Nature Reserves. The similarity coefficient showed the absence of conservation areas and determined gaps in grids Kaili (No. 2), Guiyang (No. 3),

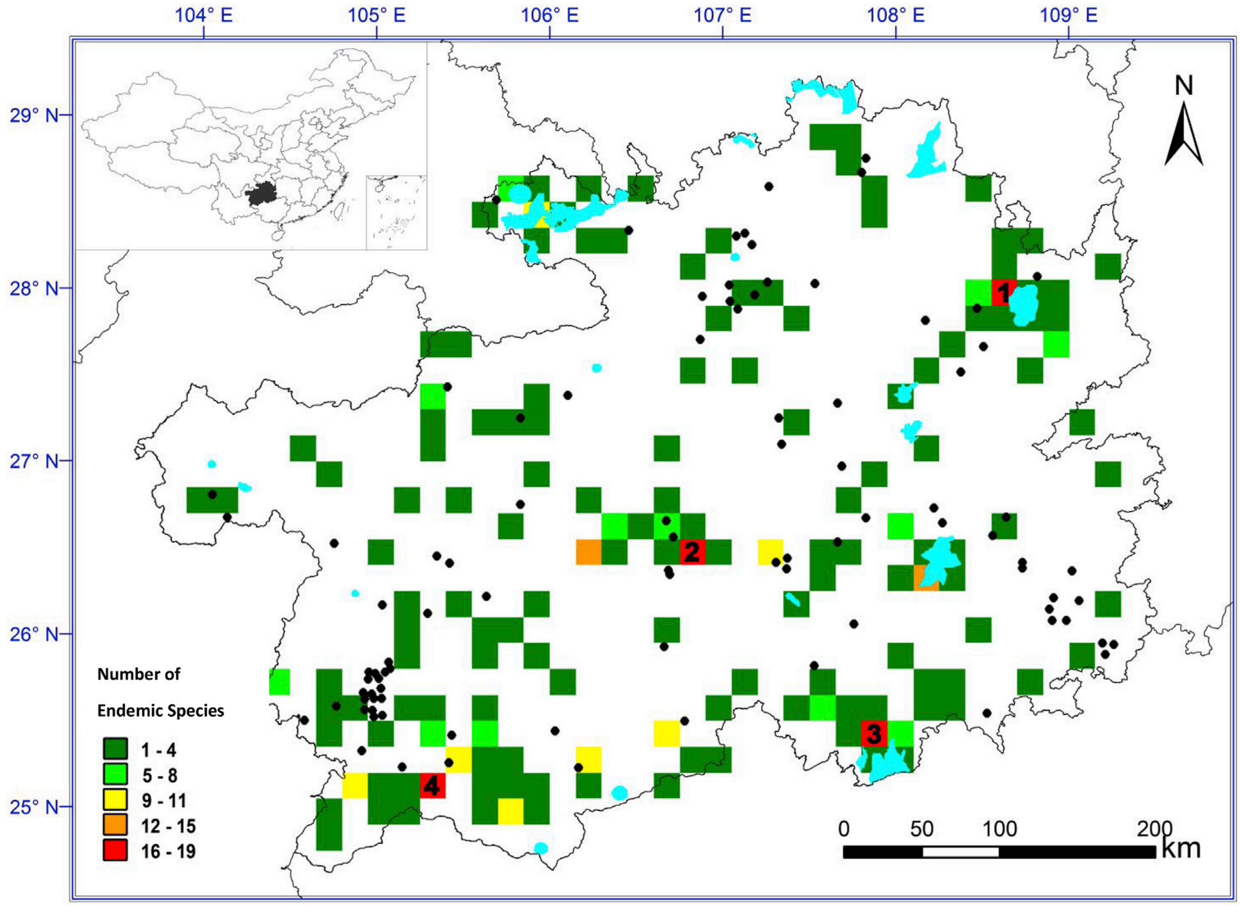

Fig. 6. Endemic species mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to the centers of endemic species. The black points are small protect areas and the blue areas are Nature Reserves. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Xingren (No. 5), Xingyi (No. 7), Anlong (No. 8), and Ceheng (No. 9) (Fig. 4), which had higher floristic heterogeneity than others. Xingren (No. 5), Xingyi (No. 7), Anlong (No. 8), and Ceheng (No. 9) showed high similarity, and Guiyang (No. 3), Kaili (No. 2), Anlong (No. 8) expressed low similarity (Fig. 4; Table 4). The Grid of Xingren (No. 5, Fig. 4) not only is center of species richness, but also center of endemic species and center of endangered species. Kaili (No. 2, Fig. 4) and Guiyang (No. 3, Fig. 4) were also considered to be the priority conservation areas due to its floristic heterogenicity.

4.3. Biodiversity conservation and ethnic minority culture

In this study, we concluded that high diversity areas of Southwest Guizhou (including Xingren (No. 5), Xingyi (No. 7), Anlong (No. 8), and Ceheng (No. 9) (Fig. 4)), especially the karst mountainous areas, needed more attention in future conservation plans. The species richness analysis confirmed several highest diversity hotspots at all of the three levels (Fig. 4). Most of them confined to southern and eastern parts of Guizhou. Plant diversity was overall higher and better conserved in South, Northeast, and Central Guizhou, while massive population pressure, and heavy human activities have already severely destroyed the original vegetation in the North, and very few endangered or endemic species occurred in these areas (Fig. 4).

This plant biodiversity distribution pattern was very similar to the occurrence of ethnic minorities (Fig. 4). Local people helped to conserve the biodiversity. The local ethnic groups in Guizhou have developed a profound knowledge for utilizing plants, and developed their own management of ecosystem; local people traditionally use plants for food, herbal medicine, ornament, religious worship and culture.

The minorities kept their customs, in most of the remote areas, including their traditional cultural utilization and management of local plant diversity. Their traditional management towards the natural resources are sustainable. They not only ensure the consumption of resources, but also their associated impacts do not exceed the carrying capacity of the environment and breaking the linkages between economic growth and resource use.

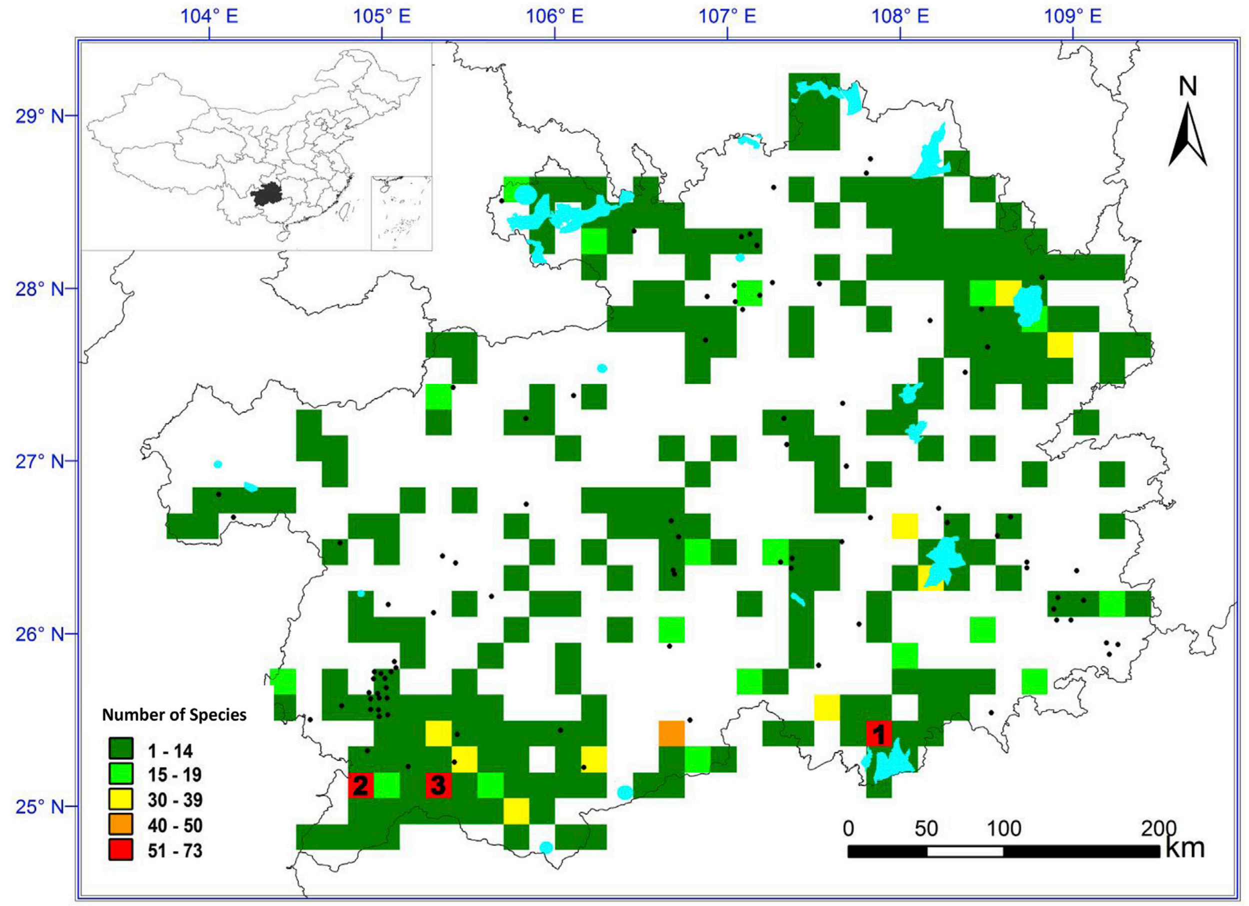

Fig. 7. Endangered species mapped in 0.15 × 0.15-degree grid cells. Red grid cells in the map correspond to the centers of endangered species. The black points are small protect areas and the blue areas are Nature Reserves. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

We suggest that the indigenous resource management knowledge and culture diversity should be conserved and extensively studied.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2018.e00460.

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