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Policy analysis

Representativeness of threatened terrestrial vertebrates in nature reserves in China

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ABSTRACT

Habitat degradation and loss threaten the survival of many species, especially vertebrates. The establishment of nature reserves is an efficient approach to protect biodiversity. However, fulfilling conservation targets depends largely on the effectiveness of these nature reserves in capturing the targeted species. In this study, we developed a distribution database of threatened terrestrial vertebrates in China, then explored the patterns of the threatened terrestrial vertebrates and evaluated the effectiveness of current nature reserves in terms of their conservation, further identified the conservation priorities for these species in China. We found 452 threatened terrestrial vertebrates widely distributed across China, especially in mountainous and forested regions in southern China. The current nature reserve network is inadequate to capture the threatened vertebrate species. The nature reserves were found to cover 30.47% of the hotspots and 38.65% of the ranges of these species on average, with quite a few conservation hotspot and species gaps. We further propose to either systematically plan and fix current nature reserves or add new protected areas in Yunnan Province and mountainous regions in southeast China.

1. Introduction

Vertebrates are suffering from great threat of extinction across the world (Dirzo et al., 2014; McCauley et al., 2015; Grooten and Almond, 2018; Powers and Jetz, 2019), due mainly to conversion, degradation and fragmentation of habitats, climate change, over-exploitation and pollution caused by anthropogenic activities (Tittensor et al., 2014; Newbold et al., 2015; Zhang et al., 2019). Vertebrates are delicate and sensitive to habitat degradation and fragmentation, so that a minimal habitat change may have severe consequences for their survivals. Studies have shown that each 1% forest loss will increase the odds of threatened status by 5.06% on vertebrates in tropical rainforests (Betts et al., 2017). According to the International Union for Conservation of Nature (IUCN, 2019), 388 vertebrates had gone extinct and 27% of all assessed species had gone threatened with extinction since 1500, meanwhile, the population size of vertebrates had declined 60% from1970 to 2014 (Grooten and Almond, 2018). Besides the irreversible loss of vertebrates themselves, the extinction and declines in vertebrate population might change the species composition in local community and further cause great loss in ecosystem function (Dirzo et al., 2014; Tilman et al., 2014; Bello et al., 2015). In addition, threatened vertebrates are often used as umbrella species or surrogates of conservation (Wiens et al., 2008; Di Minin and Moilanen, 2014; Li and Pimm, 2016; Magg et al., 2019), because their critical attributes reflecting the complexity, uniqueness and endangerment of biodiversity (Bonn et al., 2002; Luo et al., 2015). A bunch of evidences have indicated that current species extinction rates are much higher than the natural background (Pimm et al., 2014; Ceballos et al., 2015), and the risk of species extinction is still increasing (IUCN, 2019). How the future extinction rate will change depends on how the threat expands and whether protection counters them (Pimm et al., 2014; McIntosh et al., 2017).

Several international initiatives have attempted to halt or even reverse biodiversity loss through multiparty cooperation, such as, the United Nation's Sustainable Development Goals 14 and 15 (SDGs, https://sustainabledevelopment.un.org/sdgs) specified natural conservation as a part of global sustainable development and the Aichi Targets of the international Convention on Biological Diversity (CBD, https://www.cbd.int/sp/targets/) referred to the improvement of protected areas (target 11), stopping the loss of natural habitats (target 5)

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and species extinction (target 12). To meet these goals, effective *in situ* conservation strategies under limited resources require protection that addresses high conservation values (Margules and Pressey, 2000; McIntosh et al., 2017). As cornerstones for local, regional and global strategies on natural conservation, the protected areas have covered 15% of the global landmass (UNEP-WCMC et al., 2018), but were inadequate for conserving biodiversity in some cases (Gaston et al., 2008; Hoffmann et al., 2010; Pimm et al., 2014; Johnson et al., 2017). To maximize conservation efficiency, it is theoretically possible to protect large fractions in relatively small areas with systematic conservation planning (Pimm et al., 2018). And this can be achieved by exploring the patterns of biodiversity distribution and identifying biodiversity hotspots, which were defined as areas harbouring exceptional concentration of species and experiencing exceptional loss of habitat (Myers et al., 2000; Wu et al., 2017; Rahbek et al., 2019). Other important issues include to identify the anthropogenic activities threatening the biodiversity and the conservation achievement, and to complete the global conservation system to fill the current conservation gaps (Jenkins et al., 2013; McIntosh et al., 2017).

China is one of the “mega-diverse” countries and harbours > 37,367 higher plants and 7300 vertebrates (The Biodiversity Committee of Chinese Academy of Sciences, 2019). However, 21.4% (932 of 4357 assessed) of vertebrates were assessed as threatened (Ministry of Ecology and Environment of the People's Republic of China and Chinese Academy of Science, 2015). China has faced up many ecological challenges including ecological degradation during the last four decades (Liu et al., 2018). Meanwhile, China has gradually constructed a national conservation system, including the Natural Forest Conservation Program, the Grain-to-Green Program, the Ecosystem Functional Conservation Areas, the Ecological Protection Redlines. The designated protected area in China, such as nature reserves, scenic sites, forest parks, community-based conservation areas, protected sites for wild plants, wetland parks, desert parks, geological parks, special marine protected areas and germplasm conservation farms, have contributed to sustaining the biodiversity, natural landscape and ecosystem function (Liu et al., 2008; Viña et al., 2016; Ministry of Ecology and Environment of the People's Republic of China, 2017b; Xu et al., 2019a). Among different types of protected areas, strictly managed nature reserves (NRs) play the predominant roles in protecting China's biodiversity (Wu et al., 2011; Zhang et al., 2017; Ma et al., 2019), China had established 2833 NRs by the end of 2017, covered 15.3% of the whole landmass (Ministry of Ecology and Environment of the People's Republic of China, 2017a; UNEP-WCMC and IUCN, 2019).

However, previous studies have shown that current reserves haven't performed well in conserving many aspects of biodiversity (Xu et al., 2017; Zhang et al., 2017). Current NRs showed limited conservation effectiveness on wildlife, such as threatened, small population sized, and medical plants (Zhang et al., 2015a, 2018; Chi et al., 2017; Y. Xu et al., 2019), migratory birds (Hu et al., 2017), and phylogenetic and functional diversity of terrestrial vertebrates (Quan et al., 2018). The coverages of NRs on the important ecoregions were also limited, for example, of the 23 cross-border WWF ecoregions, only six have a NR coverage of > 17% for the landmass of their China parts (Zhang et al., 2017). The NRs cover only 4.1% of the areas of an important ecoregion, the Southeast China-Hainan Moist Forest Region, one of the nine Global 200 priority Ecoregions for biodiversity (Olson and Dinerstein, 2002; Wu et al., 2011). In general, the current nature reserve network is not effective enough to capture the important components of biodiversity in China, including the vertebrates (Wu et al., 2011; Hu et al., 2017; Xu et al., 2017; Quan et al., 2018). There are still knowledge gaps on how the threatened vertebrates and their hotspots were distributed, and how they were conserved (J. Jiang et al., 2016; Jiang, 2016; Z. Jiang et al., 2016; Zhang et al., 2017).

In this study, we evaluated the effectiveness of current nature reserve network in China in conserving threatened terrestrial vertebrates. We first established a distribution database of threatened terrestrial vertebrates, which included species occurrence data and habitat preference information, collected by compiling records from existing databases and extracting from the literatures. Based on this database, we explored the distribution patterns of species richness of each taxonomic group, identified hotspots using three different algorithms and classified them into different levels of conservation priority. We also overlapped the spatial distribution of hotspots and each species with NRs to evaluate how they were conserved by the current nature reserve network, and specified conservation gaps. As China has been improving its protected area system by adding new protected areas and reforming management (W. Xu et al., 2019), we hope that the conservation gaps of threatened terrestrial vertebrates could be an important consideration when planning future protected areas.

2. Materials and methods

2.1. Species checklist and occurrence data

According to an assessment by the Ministry of Ecology and Environment of the People's Republic of China and Chinese Academy of Science (2015), 637 terrestrial vertebrates (including 146 birds, 178 mammals, 137 reptiles and 176 amphibians) were assessed as threatened, including 120 critically endangered (CR), 187 endangered (EN), and 330 vulnerable (VU) species (Table S1). In consideration of data availability and evaluation accuracy, migratory birds were not included in this study.

We collected distribution records of these threatened terrestrial vertebrates from the following five data sources: (1) species records from comprehensive investigation reports of 214 nature reserves (Supplementary 1), (2) specimen information from the National Specimen Information Infrastructure (NSII, http://www.nsii.org.cn/), (3) occurrence records from the Global Biodiversity Information Facility (GBIF, 2019, https://www.gbif.org/), (4) shapefiles from IUCN Spatial Data &Mapping Resources (https://www.iucnredlist.org/resources/spatial-data-download) and Birdlife (http://www.birdlife.org/), and (5) range maps from scientific articles on the species distribution (Table S1). The expert range maps, occurrence records and specimen data could be complementary for each other to reduce bias and were proper for exploring distribution patterns (Rondinini et al., 2006; Merow et al., 2017; Nualart et al., 2017).

2.2. Mapping distribution ranges

The above occurrence data are of different resolutions and accuracy; therefore, we filtered the raw occurrence data with habitat preferences (Early et al., 2008; Jenkins et al., 2013; Xu et al., 2017), which were defined as vegetation type and elevation range. For amphibians and some reptiles which relied on water, we took 1 km buffer around waterbody rather than vegetation type (Herrmann et al., 2005). We carefully extracted vegetation type for each species that occurred in > 20% of the GBIF points and species research papers to represent the habitat preferences of the species, so did the elevation range. Three types of data related to habitat preferences were introduced into our data processing: (1) vegetation map resampled from the MCD12Q1 product obtained from NASA (at a resolution of 500 m, https://modis.gsfc.nasa.gov/, Friedl and Sulla-Menashe, 2019), (2) elevation range based on a digital elevation model (DEM) obtained from the United States Geological Survey (at a resolution of 30 m, available at https://pubs.er.usgs.gov/publication/70038376), and (3) waterbody and river catchment derived from the Chinese Academy of Science (http://www.resdc.cn/data.aspx?DATAID=226, Xu, 2018). All the distribution records were converted to a grid map with a resolution of 10 $*$ 10 km, which was valid and practical for concrete conservation measure across extensive areas without field studies (Barbosa et al., 2010; Jenkins et al., 2013). For each gird cell, we extracted the maximum and minimum elevation from DEM and major vegetation type from the vegetation map, then defined grid cells that intersected with the elevation range of the species and matched the vegetation type as the actual habitats in which the species living. The habitat filtering process resulted in the distribution ranges of 452 threatened terrestrial vertebrate species, based on which we conducted our further analyses. We also identified the 5% richest grid cells as richness centres for each of the four taxonomic groups and their overlaps to explore their congruence (Tang et al., 2006; Jenkins et al., 2013), we calculated the surrogacy level of the single taxonomic group on the other groups, by comparing the percentages of groups captured by richness centres of the single taxonomic group with those captured by grid cells randomly selected from the collection of richness centres of each group (Rodrigues and Brooks, 2007).

2.3. Identification of hotspots

We first compared the numbers of species captured by hotspots identified with two different algorithms, the species-rich and the small-ranged algorithm (Zhang et al., 2015a). The species-rich algorithm, which aims to capture the highest number of species, selects the richest grid cells based on the 1%, 2.5%, 5%, 10%, 25% and 50% thresholds, respectively (Shrestha and Wang, 2018). The small-ranged algorithm, in contrast, which aims to capture more small-ranged species, starts by selecting grid cells in which the most narrowly ranged species occur, quantifies the percentages of missing species outside those grid cells, moves to the second most narrowly ranged species and so on, and then accumulates cells selected according to the same thresholds as the species-rich algorithm.

Geographic range size and how it changes through time is one of the fundamental ecological and evolutionary characteristics of a species, and substantial for species surviving and persisting (Harris and Pimm, 2007; Gaston and Fuller, 2009; Shrestha and Wang, 2018). However, the prioritization approaches based on richness can't always lead to the sufficient coverages of species ranges (Veach et al., 2017; Astudillo-Scalia and de Albuquerque, 2019). According to the IUCN Red List Categories and Criteria (Version 3.1, IUCN, 2001), we took the range size of 20,000 km^2 as a threshold for a fully protected species. To do this, we first designed species richness hotspots using the species richness algorithms. For species which were covered < 20,000 km^2 by the species richness hotspots, we applied a supplementary algorithm to increase their hotspot coverage to 20,000 km^2. The supplementary algorithm identified the grid cell with most less-covered species as hotspots, then recalculated the coverages of species by hotspots and removed the species were covered > 20,000 km^2, these processes were repeated until all the species were fully covered.

In addition, in consideration of the CBD Aichi Targets, we incorporated a collection of gird cells in high conservation value occupying 17% of the entire landmass (Xu et al., 2019). The hotspots we defined should have priority over other areas in conservation planning of threatened terrestrial vertebrates, because they captured high species richness or have been essential habitats for species surviving. In consideration of the differential conservation urgency of species, we further divided our hotspots, i.e., the 17% area of the landmass, into three priority levels, as they captured species of different threat levels (following the IUCN Red List categories). We defined grid cells that captured at least five CR species as first-priority areas, that captured more than five CR or EN species altogether (but less than five CR species) as second-priority areas, and the rest as third-priority areas.

2.4. Hotspot and species conservation gaps

By the end of 2017, China had established 2833 NRs to protect biodiversity, including 463 national, 855 provincial and 1432 municipal NRs in Mainland China and 83 in the Taiwan Province, among them, 526 were designed for wild animal protection (Ministry of Ecology and Environment of the People's Republic of China, 2017a). Here, we used the relatively well-managed national and provincial NRs, which accounted for up to 91.3% of the areas of all NRs in China (Chi et al., 2017; Zhang et al., 2015b). We also collected information on 83 NRs in Taiwan from the World Database on Protected Areas (WDPA, https://www.protectedplanet.net/).

We overlapped the range of NRs with our hotspots to identify the hotspot conservation gaps. Hotspot gaps were identified as having a conservation need but not covered by any NRs. We also overlapped the NRs with the distribution of the threatened species to identify the species conservation gaps.

All the spatial analyses were carried out in ArcGIS 10.4.1, and the statistical analyses were carried out with the packages of RPostgreSQL (Joe et al., 2017) for data management and access, dplyr (Hadley et al., 2020) for data integration and ggplot2 (Wickham, 2016) for generating figures in R (version 3.5.3, http://www.r-project.org/).

3. Results

3.1. Distribution of threatened terrestrial vertebrates in China

The threatened terrestrial vertebrates were mainly distributed in 52,873 grid cells (68.70% of the total landmass, Table 1), concentrated in the southern and western China, together with the Greater and Lesser Khingan Mountains, the Changbai Mountain of the northeast China and the Taihang Mountains in northern China (Fig. 1a, h). The endemic species were mainly distributed in the eastern part of the Qinghai-Tibet Plateau, Nanling Mountains and Wuyi Mountains, especially in the Mt. Min, Mt. Qionglai and Minya Konka lying between the Qinghai-Tibet Plateau and the Sichuan Basin (Fig. 1b). The four taxonomic groups are similar in hotspots of their richness, but inconsistent in the overall patterns (Fig. 1c, d, e, f). The richness of overall species was commonly high in Qinghai-Tibet Plateau, Yunnan and Hainan Provinces. However, the patterns of different taxonomical groups varied remarkably, mammals and non-migratory birds gathered in the Hengduan Mountains, while reptiles were scattered across China; amphibians were mostly distributed in the southern China, mainly in Guizhou and Guangdong Provinces (Fig. 1).

Altogether, 8746 grid cells were identified as the richest for at least one taxonomic group. Among these cells, 4234 (48.41% of the total) were identified as richness centres for all four groups, 3607 (41.24%) for three groups, 571(6.53%) for two groups and 334 (3.82%) for only one group (Fig. 2). However, the surrogacy of single taxonomic group on the other groups wasn't significant, as their richness centres haven't captured more species of the other taxonomic group than the grid cells randomly selected (Fig. S1, pairwise *t*-test: $p > 0.05$).

Table 1
Statistics of the studied species.

Taxonomic group	Red List categories	No. of species	Distributed areas (grid cells)	Mean range area (km^2)	Mean NR coverage
Mammals	CR	45	15,369	95,687.9	39.5%
	EN	42	25,473	184,544.1	39.9%
	VU	53	23,976	258,766.6	37.3%
Non-migratory birds	CR	10	2525	69,660.9	36.0%
	EN	28	19,545	162,107.8	37.3%
	VU	49	38,107	193,090.3	35.3%
Reptiles	CR	22	1742	14,533.7	51.8%
	EN	29	5437	57,731.1	47.0%
	VU	46	8558	44,440.0	45.2%
Amphibians	CR	12	1320	14,424.5	30.2%
	EN	30	2462	12,142.9	39.4%
	VU	86	18,067	80,858.9	32.2%
Total		452	52,873	115,194.2	38.7%

Abbreviations for IUCN Red List categories: CR = Critically Endangered, EN = Endangered, VU = Vulnerable.

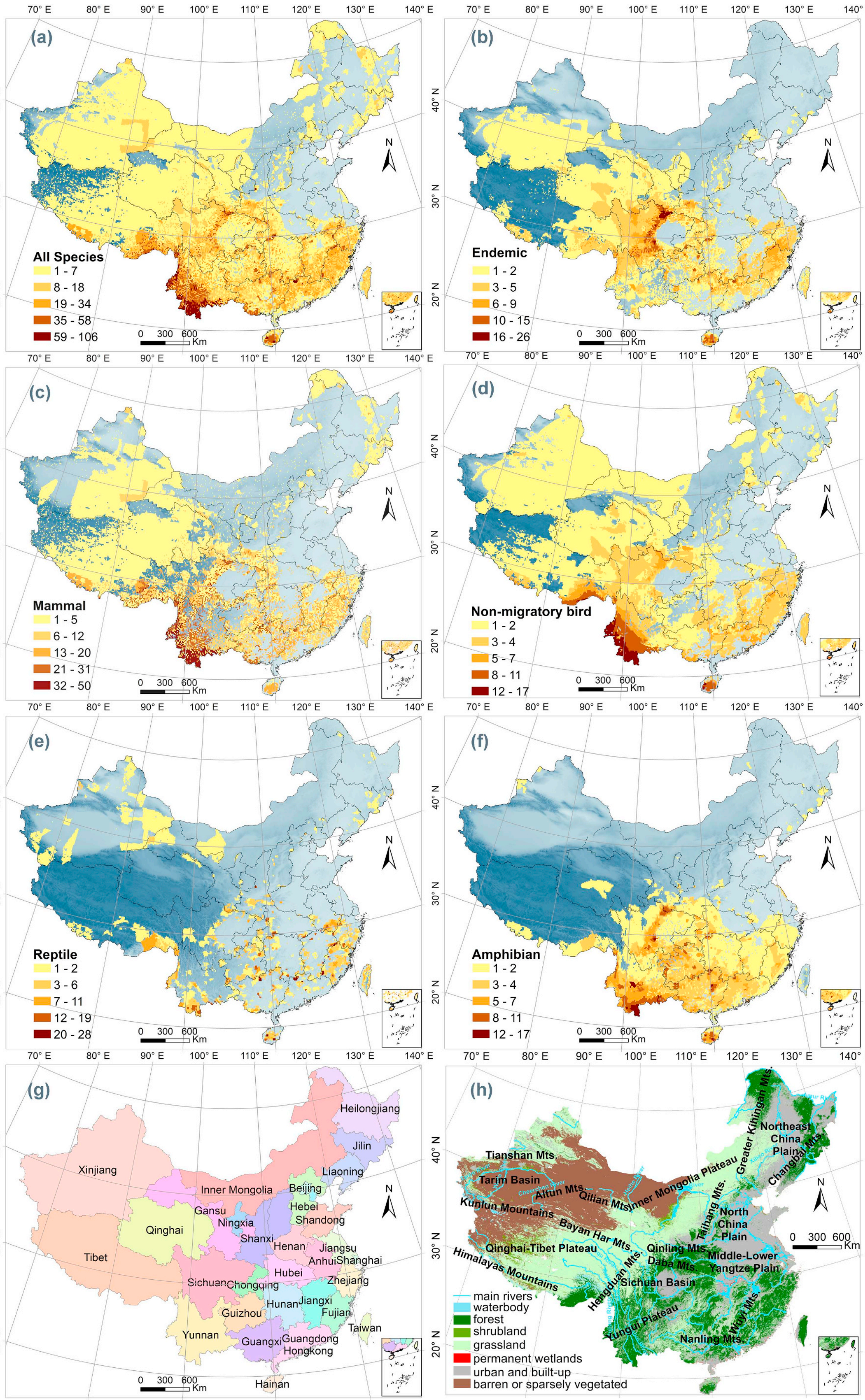

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Fig. 1. Distribution of threatened terrestrial vertebrate richness in China: (a) overall, (b) endemics to China, (c) mammals, (d) non-migratory birds, (e) reptiles, (f) amphibians. The blue background indicates the elevation of China according to a DEM. Sub-figures (g) and (h) illustrates the provincial administration and land cover of China, respectively.

3.2. Conservation hotspots of the threatened terrestrial vertebrates in China

For both of the species-rich and small-ranged algorithms, the number of species captured by the hotspots depended on the threshold we defined, with the number of missed species decreasing remarkably as the threshold increased (Fig. 3). For the same threshold, the small-ranged algorithm always captured more species (fewer missed species), indicating that the small-ranged algorithm was more effective than the species-rich algorithm. The species-rich algorithm identified the southern part of China as a hotspot (Fig. 3a), and 10% of the landmass area captured 424 species (93.81% of the total). In contrast, the hotspots identified by the small-ranged algorithm were scattered across all parts of China (Fig. 3b), and they captured 451 species (99.78%). Altogether, the two algorithms identified 11,534 grid cells as representing hotspots, with an overlap of 3416 grid cells (54% of the cells at 10% threshold), with 451 species captured in the hotspots they identified. Based on this result, our conservation hotspots, i.e., 17% of the landmass of China, were composed of the following three parts: the small-ranged algorithm identified 10% of the landmass capturing 99.78% of species, the supplementary algorithm identified another 1.84% of the landmass to ensure the essential range area (i.e., 20,000 km^2) for each species, and the additional 5.16% consist of grid cells with relatively high richness. The regions identified by supplementary algorithm were mostly located in northern China, where is relatively low in biodiversity (Fig. 4). Our conservation hotspots were congruent with the topography and forest distribution in China (Figs. 4 &1h), indicating that mountainous regions and forests could be a valuable ecosystem for biodiversity conservation.

Following the criteria of species richness in different threatened status, the first-priority hotspots with most CR species were mainly distributed in the Yunnan Province and the southeast edge of the Qinghai-Tibet Plateau, the second-priority hotspots with CR and EN species in the Nanling Mountains and the mountains around the Sichuan Basin, and the third-priority areas were scattered across the whole nation (Fig. 5).

3.3. Conservation of the threatened terrestrial vertebrates in China

The NRs covered 15.30% of the whole landmass, while covered only 30.47% of the conservation hotspots. The NR coverages were 32.10%, 32.17% and 27.88% for the first to third priority levels, respectively. The hotspot conservation gaps were mainly distributed in Yunnan Province and the Nanling and the Wuyi Mountains (Fig. 5).

The protected coverage varied remarkably among species. On average, NRs covered 38.65% (std = 22.43%) of our evaluated species' ranges, with 16 species (Table S2) not covered by any national or provincial nature reserves (Fig. 6a). The average coverage of NRs for the threatened species was 40.91% for CR, 40.90% for EN, and 36.56% for VU species. For the four taxonomic groups, the reserve coverages differed significantly in a pairwise manner in all cases except when the coverages for the non-migratory birds were compared to that for mammals and amphibians (Fig. 6b, Wilcoxon test: $p < 0.05$), and coverage was higher for reptiles (47.20%) than for the other groups (38.80% for mammals, 36.14% for birds and 33.17% for amphibians) on average. In each group, the coverage did not differ significantly among species from different IUCN Red List categories (Fig. 6b).

A substantial part of the region harboured great richness of threatened terrestrial vertebrates that haven't been protected, such as the Yunnan Province, the eastern Himalaya and Nanling and Wuyi Mountains in southeast China (Fig. 5).

4. Discussion

4.1. Distributions of threatened terrestrial vertebrates in China

We found that the richness centres of the threatened terrestrial vertebrates gathered in southern, southwestern, and central China, especially in Yunnan Province, the Hengduan Mountains and the mountainous regions in southern China, nearly similar hotspots with previous studies on threatened species (Luo et al., 2015; Xu et al., 2017). This pattern is inconsistent with the overall biodiversity pattern (Tang et al., 2006; Quan et al., 2018), partly because of the different mechanisms driving the diversity pattern between the threatened

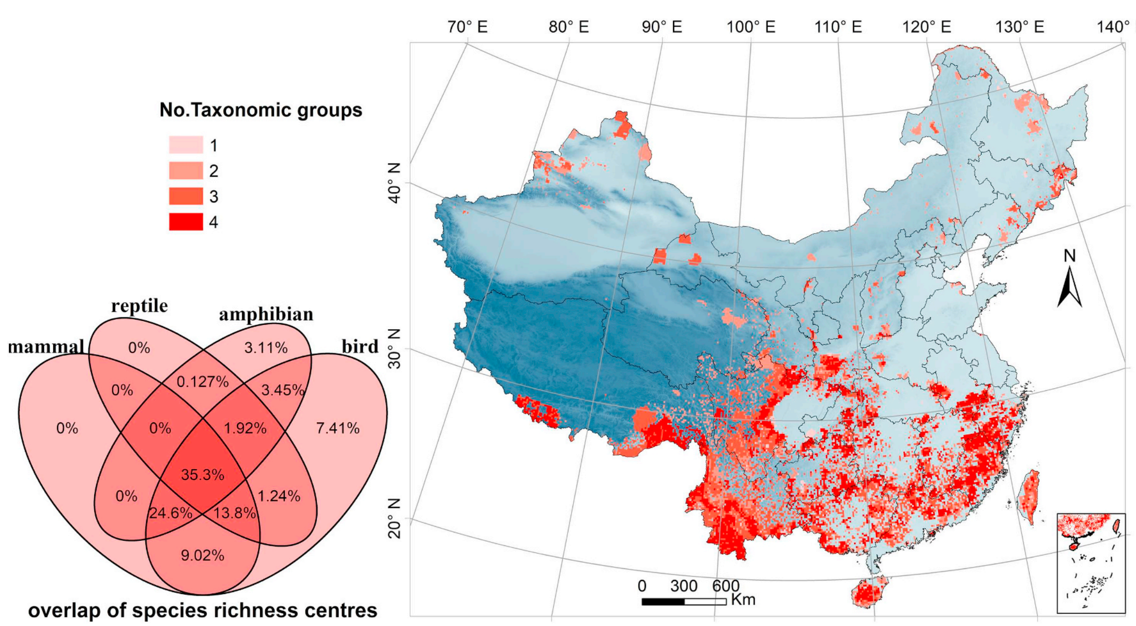

Fig. 2. Distribution of the 5% richest grid cells for each taxonomic group; the Venn diagram shows the overlaps of the different taxonomic groups.

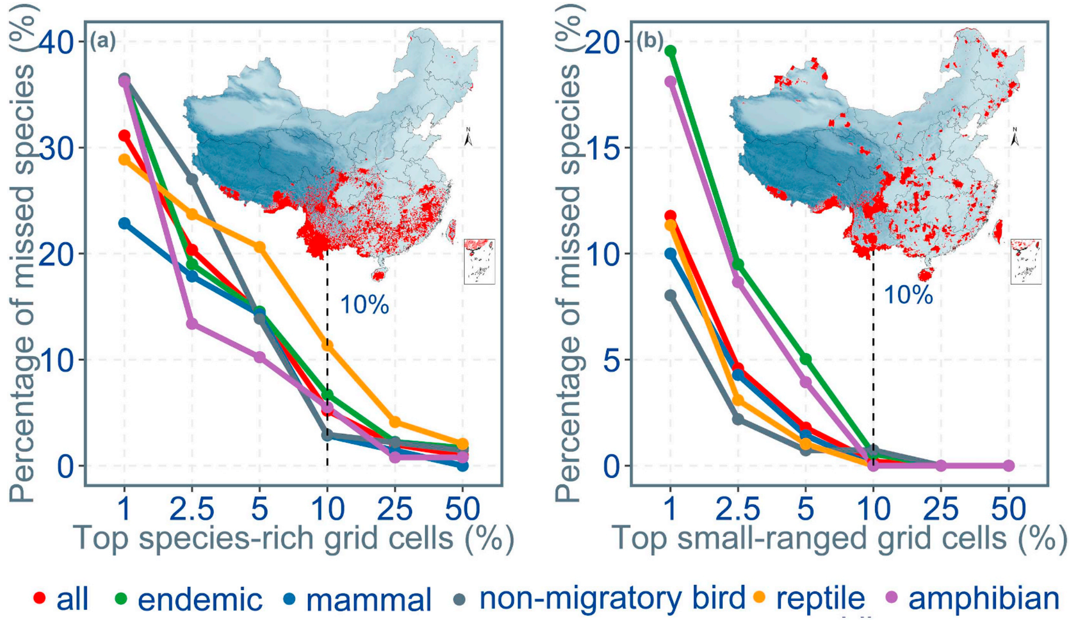

Fig. 3. Proportions of species missed by the hotspot thresholds identified with (a) species-rich algorithm and (b) small-ranged algorithm. The insets in the upper right are maps of the identified top 10% of grid cells.

species and the common species (Xu et al., 2008). Factors shaping actual ranges of species are complicated, such as habitat requirements, population dynamic, evolutionary characteristics, anthropogenic activities, can change the patterns dramatically (Kindsvater et al., 2018). In general, biodiversity patterns of common species were driven by geographical history, regional climate and topography (Shade et al., 2018), while those of the threatened species were more susceptible to the anthropogenic disturbance than common species (Marco and Santini, 2015; Newbold et al., 2015; Gossner et al., 2016). Distribution patterns of threatened terrestrial vertebrates generally followed the topographical features, mountainous regions show high richness owing to the abundant microhabitats generated by the heterogeneity in

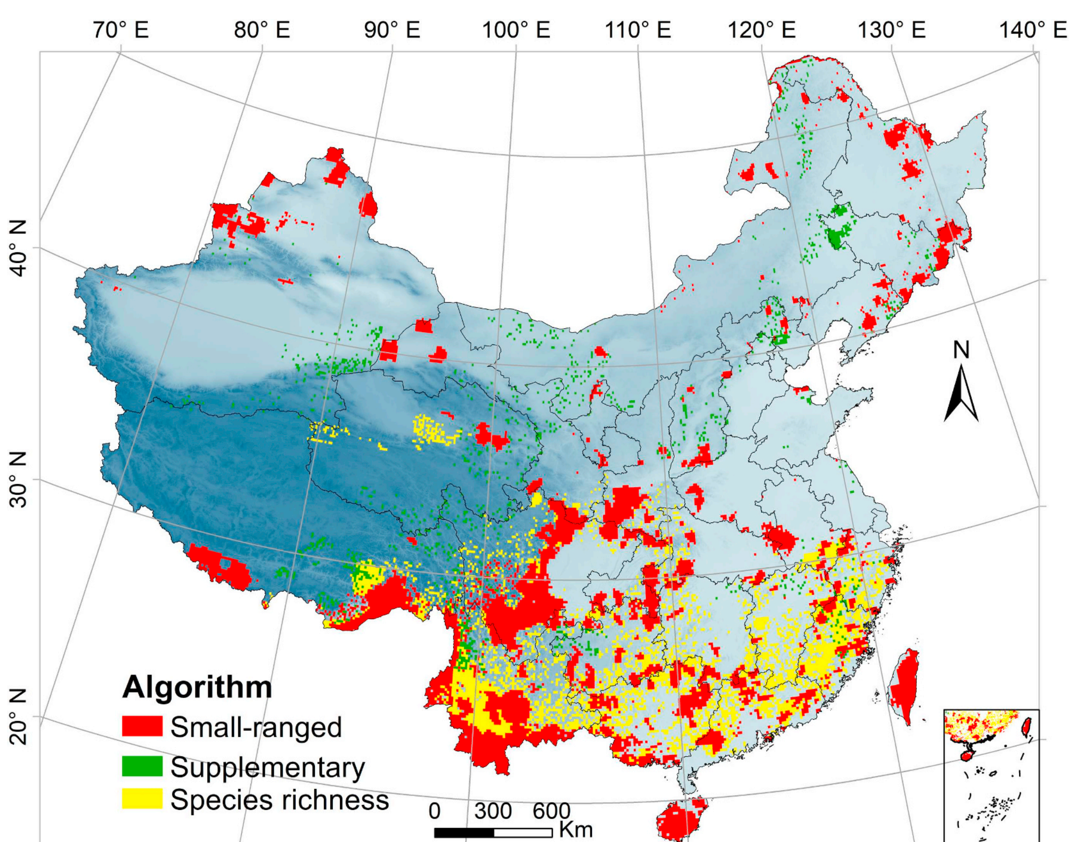

Fig. 4. Distribution of identified hotspots and coverage by nature reserves in China; the accumulated proportions of each priority level and species are shown in the right subfigures.

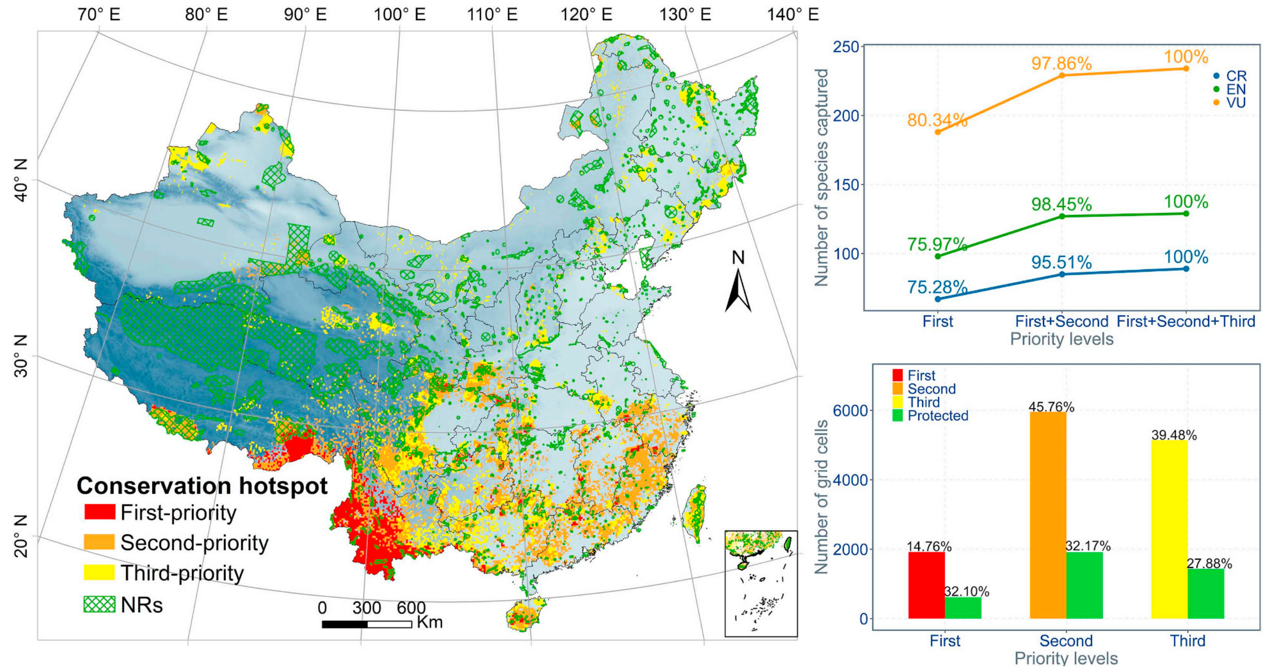

Fig. 5. Distribution of identified hotspots and coverage by nature reserves in China; the accumulated proportions of each priority level and species are shown in the right subfigures.

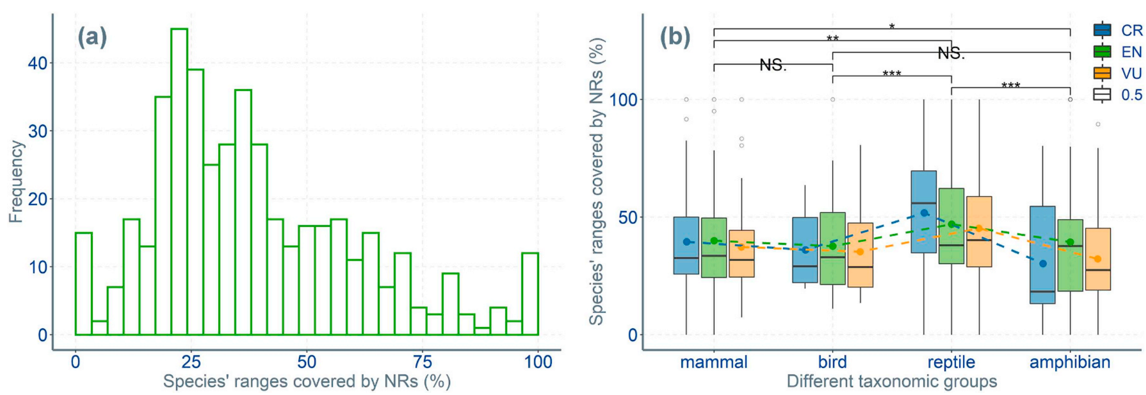

Fig. 6. Percentages of the distributions of all vertebrate species: (a) range of percentages, (b) percentages of the distributions of all vertebrate species (mammals, non-migratory birds, reptiles and amphibians) in different IUCN Red List categories covered by nature reserves. The black lines indicate the medians, the boxes the lower and upper quartiles, and whiskers and indicate 99% coverage of the data, respectively. Potential outliers are shown as circles, means are shown as darker points and linked with dashed lines for each category. Significant (pairwise) differences ($^{NS.}p > 0.05$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$) between taxonomic groups are shown as black brackets with asterisks above the boxes. Abbreviations for IUCN Red List categories: CR = Critically Endangered, EN = Endangered, VU = Vulnerable.

climate, rapid elevational changes and varying aspects of slope direction (Spehn and Körner, 2005; Tang et al., 2006). In addition, the Hengduan Mountains also represents the intersection of the Sino-Japanese and Oriental Kingdoms, and historical processes and the divergence of species have also contributed to the high diversity and endemism (Holt et al., 2013; Rueda et al., 2013).

Species richness, endemism, and taxonomic distinctiveness are often taken as different dimensions of measuring biodiversity (Myers et al., 2000; Jenkins et al., 2013). Although the richness hotspots overlapped a lot, the patterns of species richness were incongruent among different taxonomic groups (Fig. 1c–f). Multiple taxonomic groups should be considered for the identification of conservation areas according to their different ecological requirements and life histories (Xu et al., 2018). In this study, small-ranged algorithm was more efficient in capturing biodiversity, almost twice as species-richness (Fig. 3). It is widely acknowledged that most species' ranges are small, and those species often concentrated in regions without greatest species numbers (Pimm and Jenkins, 2010). Comparing with the species-rich and small-ranged algorithm, the priority identified by the supplementary algorithm showed an inconsistent pattern and mostly located in northern China, these regions were often neglected in conservation planning due to relatively low biodiversity. As many species lack of information about their life history or population size, the range size becomes a key factor in evaluating their threatened status and being corresponded by conservation planning, thus the size of species' range under protection should be regarded as an alternative measure in species conservation planning (Harris and Pimm, 2007; Gaston and Fuller, 2009).

Although we tried our best to collect data, we cannot exhaust all the distribution areas of all the species. The possible incompleteness and inaccuracies of data might affect the reliability of our results (Yang et al., 2013). The habitat requirements, life histories, population dynamics, evolutionary characteristics and dispersal ability are lacking, thus the distribution ranges we mapped might be imprecise (Butchart and Bird, 2010). More accurate data and ecological niche models may improve the reliability (Guillera-Arroita, 2017). Detecting the biodiversity pattern, using the species richness may disregard other aspects of biodiversity, such as phylogenetic diversity, functional diversity and genetic diversity, the mixed measurement could better represent biodiversity features (Devictor et al., 2010; McIntosh et al., 2017; Quan et al., 2018).

4.2. Conservation effectiveness of threatened terrestrial vertebrates in China

Among different the landscape types, we found that most hotspots of threatened terrestrial vertebrates were covered by forests. These results further emphasized the importance of forests in conserving terrestrial vertebrates (Barlow et al., 2016; Betts et al., 2017; Magg et al., 2019). China has 2.08 million km^2 of forest. However, most forests in China are highly fragmented and only 3.4% are categorized as intact (Li et al., 2017). Meanwhile the country has the largest reforestation programs in the world, which increased forest cover from 9% to 20% in the past half century (Xu, 2011). However, these planted forests were mostly monocultures and failed to support the high level of biodiversity found in the primary forests (Hua et al., 2016). On the positive side, the National Forest Protection Program (NFPP) launched in 2000 has decreased the annual deforestation rate from 2.7% in 2000 to 0.62% in 2010 in the NFPP provinces (Ren et al., 2015). The national conservation system China has devoted to reform has contributed in sustaining the ecosystem function (Ouyang et al., 2016; Viña et al., 2016), but were inadequate in representing the biodiversity hotspots (Xu et al., 2017; Xu et al., 2019).

In general, the current NR network represents low richness, ranges, and hotspots of threatened terrestrial vertebrates in China, NRs in the southern China of high species richness are too small to capture the threatened terrestrial vertebrates, and the number of NRs falls short of meeting the need of species conservation (Fig. 5). Our study highlights Yunnan Province, mountainous regions in the southeast China and regions around the Sichuan Basin as hotspots of conservation priority. The first two harbours high richness of threatened vertebrates, but with disproportional areas being protected and currently suffering from human disturbance such as agricultural expansion and urbanization (Li et al., 2017; Liu et al., 2019); regions around the Sichuan Basin were relatively well protected, partly due to, the giant panda, the famous flagship species occurred here (Li and Pimm, 2016). These regions together with the other fractions constitute the 17% landmass as hotspots of threatened terrestrial vertebrates, but only 30.47% of them are protected. Most of China's large size NRs are located in relatively remote and wild places where sparse population, such as the Qinghai-Tibet plateau. These NRs have played important roles in maintaining ecosystem functions (Chen et al., 2013), but harboured relatively fewer species. Future opportunities for NR expansion should be provided in southern China to address hotspots of biodiversity conservation.

The delineation of NRs is influenced not only by the ecological pattern, but also by long-term consequence of social politic. It is necessary to consider the ecosystem services and health, the impacts of invasive species, the economic costs, benefits and conservation will of local residents for improving the conservation effectiveness (Luo et al., 2015; McIntosh et al., 2017; Zhang et al., 2017). A comprehensive, representative and cost-effective conservation solution should be provided through systematic planning (Margules and Pressey, 2000; Shrestha and Wang, 2018). China has devoted to reforming its national conservation system (Zhang et al., 2017; Bryan et al., 2018; W. Xu et al., 2019), such as the Ecological Red Lines and the National Park System, which have contributed to maintaining ecosystem services and function. These programs also could contribute to biodiversity conservation, overall conservation planning could recategorize all the landscapes for conservation to meet the requirements of biodiversity and ecosystem services (Ouyang et al., 2016; Viña et al., 2016; W. Xu et al., 2019).

The connectivity, the shape or size of conservation areas also affected the conservation effectiveness. For example, the fragmentation of habitat in southern China where many small-sized NRs located, the optimizing also should focus on adjustment and management of current NRs (Wu et al., 2014; McIntosh et al., 2017). From the time of designation until 2015, NRs along the coast of the Yellow Sea have lost one-third of their area because of boundary adjustment, along with 54.6% decrease of the important ecosystem in these NRs, the tidal wetlands (Ma et al., 2019). The total areas of nature reserves in China even decreased by 3% although the number increased between 2007 and 2014, due partly to the downsizing and degazettement of the existing NRs in competing against socioeconomic development (Ma et al., 2019). NRs in China were managed by multiple administrative agencies (Zhang et al., 2017), which may have overlapping management responsibilities and potential conflicts. Furthermore, NRs are established for different primary objectives, including wildlife, ecosystem and geodiversity features (Ministry of Ecology and Environment of the People's Republic of China, 2017a). The lack of effective legal mechanism for different types of NRs, which determines the roles of management authority, the resource allocation and criteria of management, would impair the conservation effectiveness (W. Xu et al., 2019). Based on our study, we propose the following suggestions to optimize the current NR network in China. First to systematically plan and fix current nature reserves, and to establish comprehensive spatial planning of NRs that considers the hotspots of representative species, ecosystem across the nation, and that makes good use of the conservation programs as a supplement for species conservation. Second to add new protected areas in southern China, especially in the Yunnan Province and mountainous regions in southeast China of conservation priority, to fill the conservation gaps. Finally, to develop feasible and effective management strategies for current nature reserves, with specified criteria for different conservation objectives.

CRediT authorship contribution statement

Si-Yi Zhang: Conceptualization, Methodology, Software, Data curation, Writing - original draft.**Gheyur Gheyret:**Data curation, Writing - review & editing.**Xiulian Chi:**Investigation, Resources.**Yun-Hao Bai:**Data curation.**Chengyang Zheng:**Resources, Data curation.**Zhiyao Tang:**Supervision, Project administration, Funding acquisition, Writing - review & editing.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2020.108599.

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