REPORT

# Optimizing protected areas to boost the conservation of key protected wildlife in China

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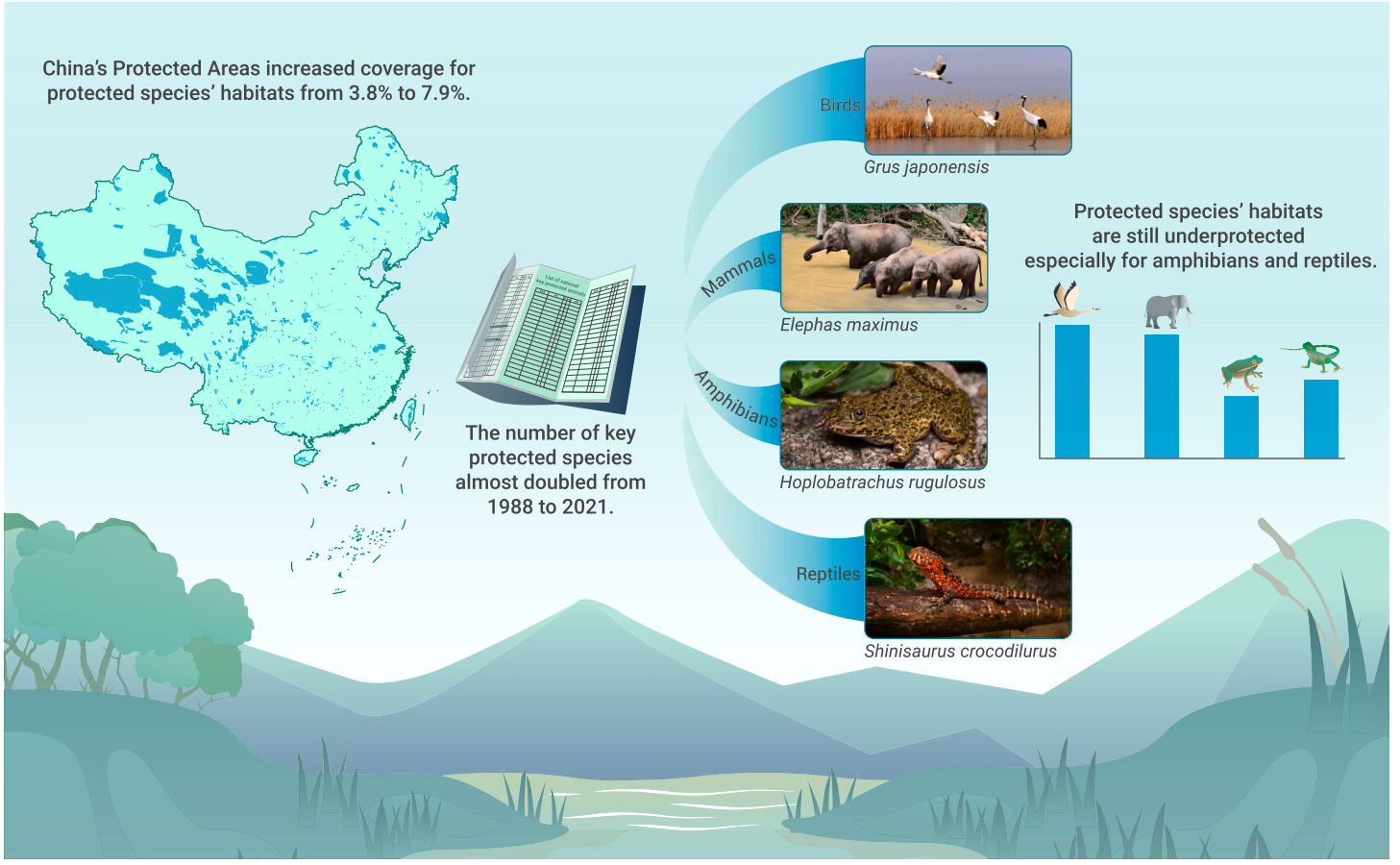
## GRAPHICAL ABSTRACT




## PUBLIC SUMMARY

- From 1988 to 2021, the number of protected species almost doubled, the area of protected areas increased 2.4 times.
- Over 92.8% of protected species are in protected areas, but 70.8% are not effectively protected.
- Amphibians and reptiles are significant additions to the protection list, but still least protected.
- Another 10.0% of China's land area is needed as protected areas to achieve the protection target.

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To meet the challenge of biodiversity loss and reach the targets of the proposed Post-2020 Global Biodiversity Framework, the Chinese government updated the list of national key protected wildlife in 2021 and has been continually expanding the protected areas (PAs). However, the status of protected wildlife in PAs remains unclear. In this study, we conducted a national assessment of the status of protected wildlife and suggested an optimization plan to overcome these shortcomings. From 1988 to 2021, the number of protected species almost doubled, and the area of PAs increased by 2.4 times, covering over 92.8% of the protected species. Nonetheless, 70.8% of the protected species are still not effectively protected by PAs, with some having less than 10% of their habitat included in PAs. Despite the significant addition of amphibians and reptiles to the latest protection list, they are the fewest species and are the least covered by PAs compared with birds and mammals. To fix these gaps, we systematically optimized the current PAs network by adding another 10.0% of China's land area as PAs, which resulted in 37.6% coverage of protected species' habitats in PAs. In addition, 26 priority areas were identified. Our research aimed to identify gaps in current conservation policies and suggest optimization solutions to facilitate wildlife conservation planning in China. In general, updating the list of key protected wildlife species and systematically optimizing PA networks are essential and applicable to other countries facing biodiversity loss.

## INTRODUCTION

Our world is facing accelerated species extinction and biodiversity loss.[1–3] Timely implementation of management policies and achieving conservation targets such as protected area (PA) targets,[4,5] strategic conservation targets (eg, 30 × 30 initiative in the Post-2020 Global Biodiversity Framework),[6,7] and climate change targets[8,9] (e.g., 1.5°C target) are crucial for current and future biodiversity conservation. China is home to exceptional biodiversity and is actively working to meet the challenges of biodiversity loss.[10] To prevent future biodiversity loss, China plans to accelerate environmental protection with an ambitious blueprint for an ecological civilization.[11] The Chinese government has formulated new conservation policies such as integrating ecological civilization into the national strategy,[11] delineating the Ecological Conservation Redline (ECR),[12] implementing the National Park PA system,[13] and updating the list of national key protected wildlife.[14] Thus, biodiversity conservation in China is entering a new era.

One of the most important wildlife conservation policies in China is the publication of an updated list of wildlife under the national key protection. The Chinese government published the first protection lists for animals and plants in 1988, named "List of Key Protected Wild Animals in China" (hereafter List 1988) and "List of Key Protected Plants in China." People who kill, purchase, transport, or sell species included on these lists are sentenced to imprisonment and fined according to criminal laws in China.[15] The second protection list was published in February 2021 (hereafter List 2021). Hundreds of species were added to this updated list,[14] which is hoped to substantially improve the protection of wildlife in China. Another important wildlife protection policy is the establishment of a PA system.[13] PAs have been the cornerstone of global conservation strategies,[16,17] and, ideally, sufficient PAs should be safeguarded to guarantee the long-term persistence of the widest biodiversity, especially threatened species.[18,19] Since the first nature reserve was established in 1956, China has constructed more than 11,800 PAs, including 10 pilot National Parks established over the last 3 years, covering >18% of its land surface.[20]

To help guide future biodiversity conservation and management plans, we need to make better use of available conservation resources and establish more PAs (eg, National Parks) to promote the harmonious coexistence of humans and nature.[21] Based on the International Union for the Conservation of Nature (IUCN) Red List, several studies have examined the effectiveness of PAs in protecting biodiversity in China, including all species, endemic species, or threatened species.[22–24] Nonetheless, we argue that using the new list of key protected species (List 2021) is a better alternative to the IUCN list for describing the patterns currently threatening biodiversity in China. This is because List 2021 is based on an extensive collection of species data in China, rigorous scientific evaluation, and discussion by a government-selected panel of experts and scholars, together with suggestions from relevant departments and publicly solicited opinions across all relevant sectors of society.[14] In addition, most of the species listed on List 2021 are endangered in China. In contrast, species on the IUCN list might not be fully representative of the true threat to biodiversity in China because over 45% of species on the Protection List 2021 are categorized as species of Least Concern by the IUCN (Figure S1). For example, the Eurasian beaver (*Castor fiber*) is on the verge of extinction, with only approximately 700 individuals distributed across China.[25] Therefore, Eurasian beavers are ranked among those needing the highest level of protection (Class I) in the Key Protected Wild Animals list, yet are classified as species of Least Concern by the IUCN. List 2021 can be used to summarize the survival status of species in China and lays a solid foundation for future scientific protection and management policies. However, comprehensive analyses of the status of Key Protected Wild Animals in China's PAs are lacking.

Optimizing the current PA system is an efficient way to protect threatened wildlife. Species richness in PAs is often used to evaluate the conservation effectiveness of current PAs and to determine conservation priorities in China.[22,26,27] However, the identification of priority conservation areas based solely on species richness may ignore the protection of individual species,[28] especially small-range species.[29] To maximize the representation of each species, we need a coupled human and natural system approach that ensures the conservation of biodiversity hotspots and the distribution range of individual species.[28,30] In addition, to make realistic recommendations for the expansion of PAs, economic and opportunity costs should be considered alongside potential ecological value,[31] but have often been omitted in previous studies.[22–24] Considering conservation costs and human disturbances in the conservation planning model could minimize financial loss and avoid significant disturbances in conservation areas to promote conservation success in a more cost-efficient manner.[32–34] Therefore, a systematic conservation planning approach that considers species richness, distribution range, conservation costs, and human disturbances is necessary to optimize the current network of PAs.

Here, we examined the coverage of China's protected wildlife species by the PA system, and evaluated the effectiveness of PAs in China. To achieve this, we overlaid the PA map with habitat maps of key protected terrestrial vertebrate species including birds, mammals, reptiles, and amphibians. We then identified priority conservation areas by using systematic reserve design, and, lastly, we recommend two strategies for establishing a comprehensive National Park system to address the gaps between the wildlife protection requirements based on List 2021 and the current PA system.

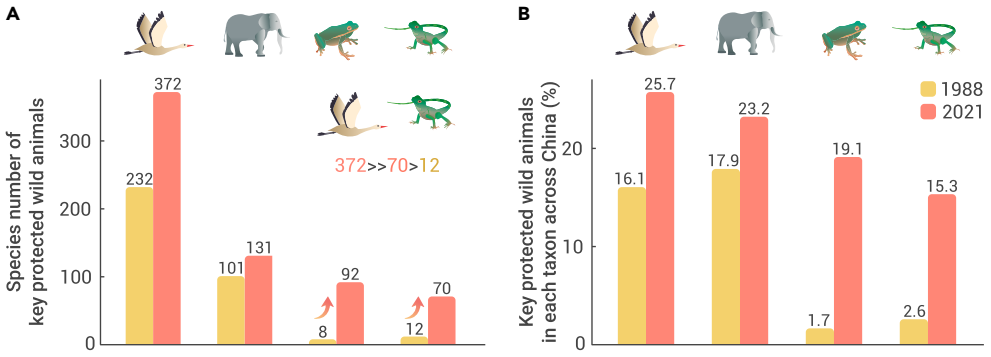


**Figure 1. Growth of key protected wild animals (protected species) in China** (A) The number of protected species within the four terrestrial vertebrate taxa (birds, mammals, amphibians, and reptiles) in List 1988 and List 2021. (B) The proportion of protected species within each of the four terrestrial vertebrate taxa in the List 1988 and 2021; the total number of species of the above four taxa distributed in China is referred to in Catalogue of Life China 2021.[35]

## RESULTS

### Updating the list of national key protected wild animals

The number of protected species in the protection list almost doubled from 353 in 1988 to 665 in 2021 (Figure 1A). Birds (232 species) and mammals (101 species) constituted the majority of the protected species on List 1988. Birds remained in the group with the highest number of protected species (372 species) on List 2021, while the number of protected amphibian and reptile species increased abruptly from 8 to 12 species in 1988 to 92 and 70 species in 2021, respectively (Figure 1A). The proportion of protected species relative to all species in China increased from 12.0% in 1988 to 22.6% in 2021. Notably, amphibians and reptiles rose sharply from 1.7% to 2.6%–19.1% and 15.3%, respectively, but remained the least represented groups of protected animals (Figure 1B).

### Distribution of protected species

Diversity hotspots of protected species on both List 1988 and List 2021 were mainly concentrated in the east and south of China, especially in the region south of the Yangtze River; PAs in these regions usually have small geographical ranges (Figures 2A and 2B). More species were included on List 2021 than on List 1988. The discrepancy between the number of species in the two lists was relatively large in southern China, including Guangdong, Guangxi, and Hainan provinces (Figure 2C). Distribution patterns varied significantly among the vertebrate taxa. The diversity hotspots for birds were in the south and east of China (Figures 2D1 and 2E1); whereas, for mammals, the diversity hotspots were located in southwest China and the transition zone from Sichuan to the Qinghai-Tibet Plateau (QTP) (Figures 2D2 and 2E2). The diversity hotspots for amphibians were mainly located in the south in 1988 but expanded to the transition zone from Sichuan to the QTP and to the northeast by 2021 (Figures 2D3 and 2E3). The diversity hotspots for reptiles were limited to southern China, mainly along the southern coastal areas (e.g., Guangdong, Guangxi, Fujian, and Hainan Provinces) and were largely located outside the PAs (Figures 2D4 and 2E4).

### Number and range coverage of protected species within PAs

We found that the expansion of PAs made little contribution to protected species on List 1988, with only a slight increase in the number ($\leq$2 species) and proportion ($\leq$2%) of protected species from 1988 to 2021 (Figures 3A and 3B; Table S1). The number of protected species within the PAs rose sharply from 331 in 1998 to 617 in 2021, whereas the proportion of protected species in the PAs decreased from 97.1% to 92.8%. Among the four vertebrate taxa, birds and mammals had the highest number of protected species and a larger proportion in PAs (216 and 98 species in 1988, 364 and 128 species in 2021, respectively; all proportions >97.0%). The number of protected amphibian species in PAs increased from 7 to 67, and that of reptile species increased from 10 to 58 from 1988 to 2021. However, the proportion of protected species in the PAs decreased during this period, especially amphibians (from 87.5% to 72.8%).

The percentage of the range covered by PAs for protected species on List 1988 almost doubled, from 3.8% in 1988 to 7.5% in 2021 (Wilcoxon test, $Z = -8.06$, $p < 0.001$; Figure 3C; Table S1). This percentage increased to 7.9% for the protected species on List 2021. Among the four vertebrate taxa, mammals had the largest habitat coverage by PAs (median $\geq$ 6.0%), whereas reptiles had the smallest habitat coverage by PAs (median $\leq$ 4.2%). The construction of PAs benefited mammals the most, resulting in the largest increase in range coverage in PAs (from 6.0% to 11.0%; Wilcoxon test, $Z = -4.99$, $p < 0.001$); range coverage for amphibians and reptiles only increased from 3.7% to 2.3%–5.7% and 3.6%, respectively for List 1988 (Wilcoxon test, both $p > 0.05$), and later increased to 8.5% and 4.2%, respectively for List 2021.

### Optimization for the current PAs network

Approximately 70.8% of the protected species did not achieve target protection (Figure 3C; Data S1). We found that another 10.0% of China's terrestrial land would be needed to capture the 10% goal for all protected species (Figures 4A and 4B), resulting in a PA system covering 24.5% of China's land surface and protecting a median of 37.6% of the protected species' geographic ranges, more than 4.7 times the current coverage (Figure 4C; Table S2). Among the four vertebrate taxa, amphibians benefitted the most from the optimization solution, with their median habitat coverage increasing from 8.5% to 100% (Figures 4B and 4C). In addition, to achieve the 15% or 30% goal, we need to protect another 11.0% or 20.3% of China's land surface (Figure S3), which could protect a median of 37.8% or 45.4% of the protected species' habitats (Data S1).

More importantly, in terms of optimization solutions for the 10% goal, we identified 26 priority areas with connected habitats (Figure S4), with approximately 3.3% of China's land surface or 22.9% of the current PAs (Figure 4A). These regions are shown in Figure 4A: (A) west of northern Tianshan Mountain, (B–D) north bank of Tarim River, (E) west of Changbai Mountains, (F) east of the Tanggula Mountains and north of Hengduan Mountains, (G) Daxue Mountains and Daliang Mountains, (H) Daba Mountains, (I) east of Qingling Mountains, (J) Wulin Mountains, (K) Wu Mountains, (L) northeast of Hunan, (M) Dabie Mountains, (N) southeast of Himalaya Mountains, (O) north and west of Yunnan, (P) Xishuangbanna, (Q) south of Yunnan, (R) west of Guizhou, (S) southwest of Guangxi, (T) southeast of Guizhou, (U) northeast of Guangxi, (V) northeast of Guangdong, (W) northeast of Fujian, (X) east of Fujian; (Y) Taiwan Island, (Z) Hainan Island. Including these regions in the current PA network would meet the coverage target of 72.5% of species and a median of 25.8% of the species' current geographic ranges (3.3 times the current; Table S2). Among the four taxa, amphibians would benefit the most, with the number of species in PAs increasing by 12.0% and the median habitat coverage of PAs increasing to 62.6% (Figures 4B and 4C). Most of these 26 priority areas were also identified when the conservation target was 15% or 30%, or when the current PAs were not forced to be included as conservation areas (Figure S3). Moreover, when the protection goal was 30%, more areas showed large connections, particularly in eastern China (Figure S3D).

## DISCUSSION

China published two lists of Key Protected Wild Animals in 1988 and 2021 and has continued to develop and improve the PA network since 1956. The majority ($\geq$92.8%) of the protected species were included in PAs as of 2021; China's PA system expanded the coverage of species habitats (from 3.8% to 7.9%). These achievements provide wild animals and their natural habitats with increased protection in PA systems; however, more conservation efforts are needed to adequately protect biodiversity in China. Our study revealed that a spatial mismatch exists between the protected species and the current PA layout and that the habitats of over 70% of the protected species are still under insufficient conservation. Furthermore, among terrestrial vertebrates, amphibians and reptiles are still relatively under-protected compared with mammals and birds. To optimize the effectiveness of the current PA system, additional PAs must be added to meet the requirements of the latest list of the protected species.

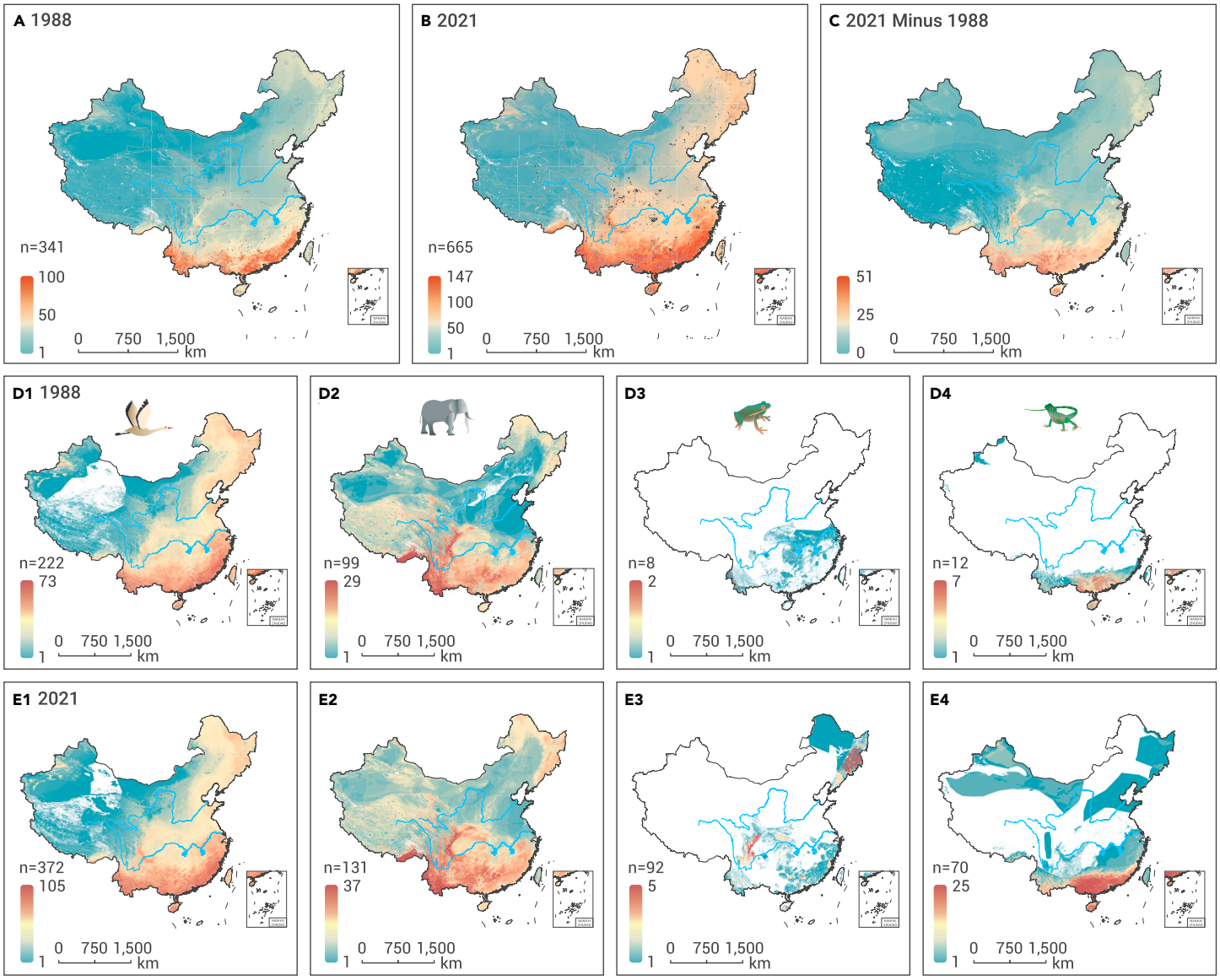


**Figure 2. Spatial distribution of PAs and key protected wild animals (protected species) in 1988 and 2021** (A) The spatial distribution of all protected species on List 1988 overlaid by PAs in 1988. (B) The spatial distribution of all protected species on List 2021 overlaid by PAs in 2021. (C) The spatial distribution of species richness change between List 1988 and List 2021. (D and E) (D1 and E1) The spatial distribution of birds on List 1988 and 2021, (D2 and E2) the spatial distribution of mammals on List 1988 and 2021, (D3 and E3) the spatial distribution of amphibians on List 1988 and 2021, and (D4 and E4) the spatial distribution of reptiles on List 1988 and 2021. The color gradient from blue to red indicates increasing species richness.

## Spatial mismatch of current PAs and protected species

Although the land coverage of PAs has expanded to 14.5% of China's land surface over the past few decades, PAs cover only 7.9% of the habitats of protected species. This is mainly due to the spatial mismatch between the protected species and the location of the current PAs. Currently, PA coverage is higher in western and northern China and lower in eastern and southern China. However, the majority of protected species are distributed in southern and eastern China (Figure 2).[38] Thus, current PAs do not adequately represent or protect national biodiversity.[23] For instance, Guangxi, Guangdong, and Hainan provinces are hotspots for protected reptiles (Figure 2), with 55.7% of protected reptiles distributed in these provinces, and 59.6% of the land area being home to over 10 reptile species. However, the PAs in these three provinces cover only 4.0% of the land area and only 1.3% of China's total PA system. A similar mismatch was found in the US, whose PA system is recognized as one of the oldest and most sophisticated in the world.[39] Most PAs in the US are in the west, whereas vulnerable species are largely in the southeast.[39]

The spatial mismatch we identified in China's PA system may be due to a lack of top-level design[40] and inadequate systematic planning[23] of PAs, because the early PAs in China were specifically designed to rescue critically endangered species from extinction.[23,40] This method of PA establishment has resulted in other problems such as the spatial overlap of different types of PAs, fragmentation and isolation of PAs, and ineffective management.[41] In addition, spatial mismatches may be driven by changes in the patterns of threatening processes that affect wildlife due to environmental perturbations and human activities. For example, the yellow-breasted bunting, *Emberiza aureola* experienced a global population collapse over the past three decades because of illegal trapping.[42] This species was not included in List 1988 but, because of the increased risk of endangerment, it has since been assigned the highest protection level (Class I) on List 2021.

The coverage of PAs in the east and south of China is not only relatively low but is also affected by higher rates of habitat fragmentation, population pressure, and economic dispatch pressure[43]; thus, these PAs are also more vulnerable to climate change.[44] Therefore, the protection requirements in eastern and southern China are higher than those at the national level.[43] Recently, the aim of China's PA system has shifted to the broader goals of protecting the natural environment, conserving natural resources, protecting biodiversity and landscape diversity, maintaining the health and stability of natural ecosystems, and improving ecosystem service functions.[13] Fixing the problem of spatial mismatch between

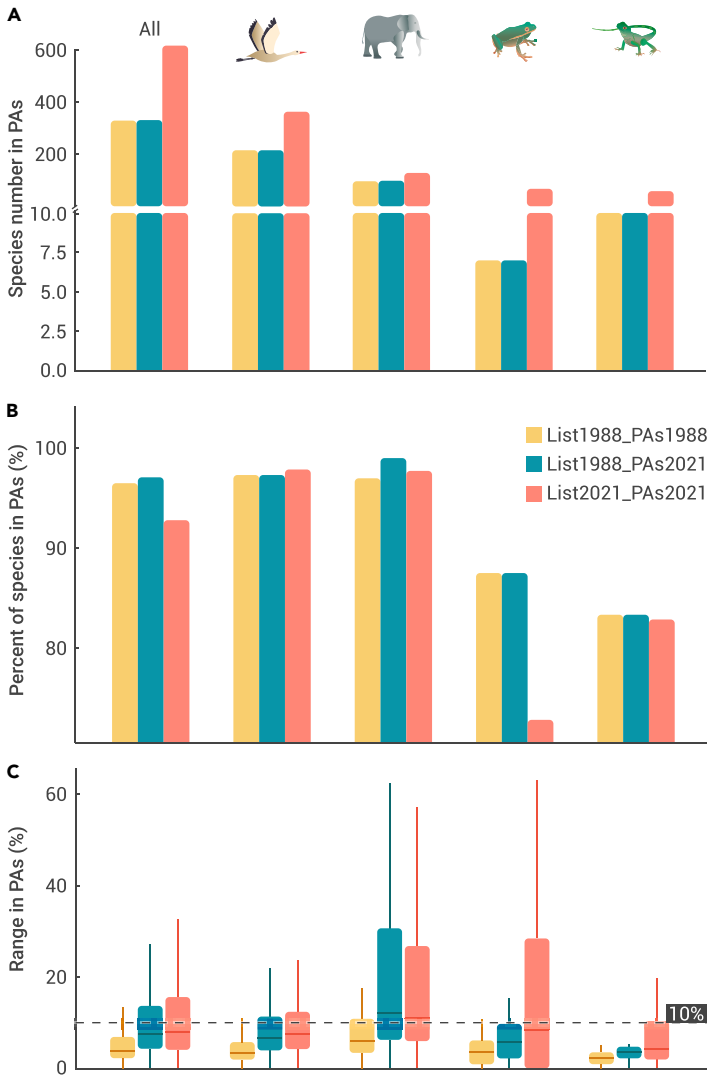


**Figure 3. Species number and range in PAs** (A) The number of species in PAs. (B and C) (B) The proportion of species in PAs and (C) the percentage of each species' range coverage in PAs for species on List in 1988 and 2021. The yellow, red, and blue columns represent List 1988 for interaction with PAs in 1988, List 1988 for interaction with PAs in 2021, and List 2021 for interaction with PAs in 2021, respectively. The black dashed line in (C) shows the minimum 10% conservation target adopted by Watson et al.[36] and Rondinini et al.[37]

current PAs and protected species is a critical step in achieving these broad goals. In particular, the biodiversity hotspots in the east and south of China deserve additional protection to adequately protect China's biodiversity overall.

Furthermore, even if a species on the protection list is found within PAs, it may not be exempt from human activities because there are local residents within and near many PAs.[45,46] This phenomenon is also common in many PAs in other developing countries, such as Nepal.[47,48] Thus, it is necessary to assess the impacts of PAs on wildlife.[49,50]

## Protection of amphibians and reptiles is insufficient

As indicator species of environmental quality, amphibians and reptiles are more sensitive and vulnerable to environmental variation and human interference than are mammals and birds.[51–54] Globally, approximately 41% of amphibian and 21% of reptile species are classified as threatened by the IUCN,[55,56] with 43.1% of amphibian and 29.7% of reptile species listed as threatened in China.[57,58] The number of protected amphibian (from 8 to 92) and reptile species (from 12 to 70) in China increased sharply from 1988 to 2021. The increasing number of protected amphibians and reptiles is not only due to the increasing endangerment of species described before 1988, but is also attributable to more new species discovered after 1988 than those of birds and mammals. In List 2021, amphibians and reptiles accounted for 47.6% and 36.3% of the new species discovered after 1988, respectively, whereas birds and mammals only accounted for 2.9% and 16.7% of the new species, respectively. However, the ratio of the number of protected amphibian and reptile species to the total number of reptile and amphibian species in China was much lower than that of birds and mammals (19.1% and 15.3% vs. 25.7% and 23.2% in 2021). In addition, the proportion of protected amphibians and reptiles within the PAs in China was lower than that of birds and mammals, and the habitat coverage for amphibians and reptiles in the PAs was small (Figures 3B and 3C). Therefore, we strongly recommend that more amphibian and reptile species be included on future protection lists, especially species threatened with the highest risk of extinction in China, such as those in the orders Caudata (amphibians) and Crocodylia and Testudines (reptiles), of which 63.4%, 100%, and 91.2% of species are threatened, respectively.[57,58] To avoid more species going extinct, such as the Asian giant softshell turtle (*Pelochelys cantorii*)[59,60] and the Yangtze giant softshell turtle (*Rafetus swinhoei*),[61] we need to invest more resources and strengthen policies to provide greater protection for amphibians and reptiles, and improve public awareness of wildlife conservation.

A recent study found that efforts aimed at protecting threatened tetrapods likely also benefited many other threatened reptiles globally.[56] However, on a regional scale, such as in China, we found that the distributions of the four vertebrate taxa did not overlap (Figure 2). This means that PAs that are important for some groups (eg, mammals or birds) may not ensure the protection of others (eg, amphibians or reptiles). For example, the Giant Panda National Park in Sichuan Province is a hotspot for protected birds and mammals, but only a few reptiles are distributed in this area (Table S3). This situation arose because a large proportion of China's PAs were initially established for birds and mammals and rarely for amphibians and reptiles.[22] This underplayed the level of adequate protection required for these two taxa, especially when considering how strongly they are affected by ongoing global changes.

In addition, a recent conservation study assessed the conservation effectiveness of PA expansion for wildlife (especially for IUCN-threatened species), biomes, and ecoregions in China.[24] This study found that species with small geographical ranges that had the highest risk of extinction in China were better protected than expected. In contrast, our study found that key protected amphibian and reptile species with a smaller range (Figure S7) were less protected than birds and mammals. This between-study discrepancy is because we made a comparison among the four lineages of terrestrial vertebrates, whereas the previous study compared small- and large-range species within each lineage. In addition, given that most threatened species in China are not effectively protected by PAs (Figure 4), a systematic optimization of PA networks is needed.

## Optimization of the current PA network

To optimize China's PA system, we first need to identify priority conservation areas outside the current PAs. If new PAs are established to include these priority areas along with existing PAs, then all protected species would be effectively protected ($\geq$10% of habitats within new PAs). The median habitat coverage would increase over 4.7 times for all species, and 11.8 and 8.2 times for amphibians and reptiles in particular (Figure 4C). The new PAs would account for 24.5% of China's land area, which is close to China's ECR policy target of more than 25% of China's land area being under legal protection.[12] Our research indicates that if we continue to systematically expand the current PAs network, 25% of China's land surface could effectively conserve all protected species. This aligns with the main aim of the proposed ECR policy, which is to limit anthropogenic alterations to areas critical for national ecological security and essential ecosystem services, thereby providing stronger protection for vulnerable species and fragile ecosystems.[62,63]

Based on the principle of high habitat connectivity, where large areas reduce the problems of low habitat connectivity and isolation,[22] our Marxan analyses identified 26 priority conservation areas (Figure 4A) that together account for 22.9% of the land area of current PAs in China. These regions have increased the area of species habitat within PAs by 226% in general and by 640% and 280% for amphibians and reptiles, respectively. In addition, we found that these regions have different species assemblages (Figure S5; Table S4) that need to be considered. For example, birds reside in the west and south of Yunnan (O–Q), breed on the north bank of the Tarim River (A–D), and stop or overwinter in the west of the Changbai Mountains (E). Mammals mainly inhabit the southwest

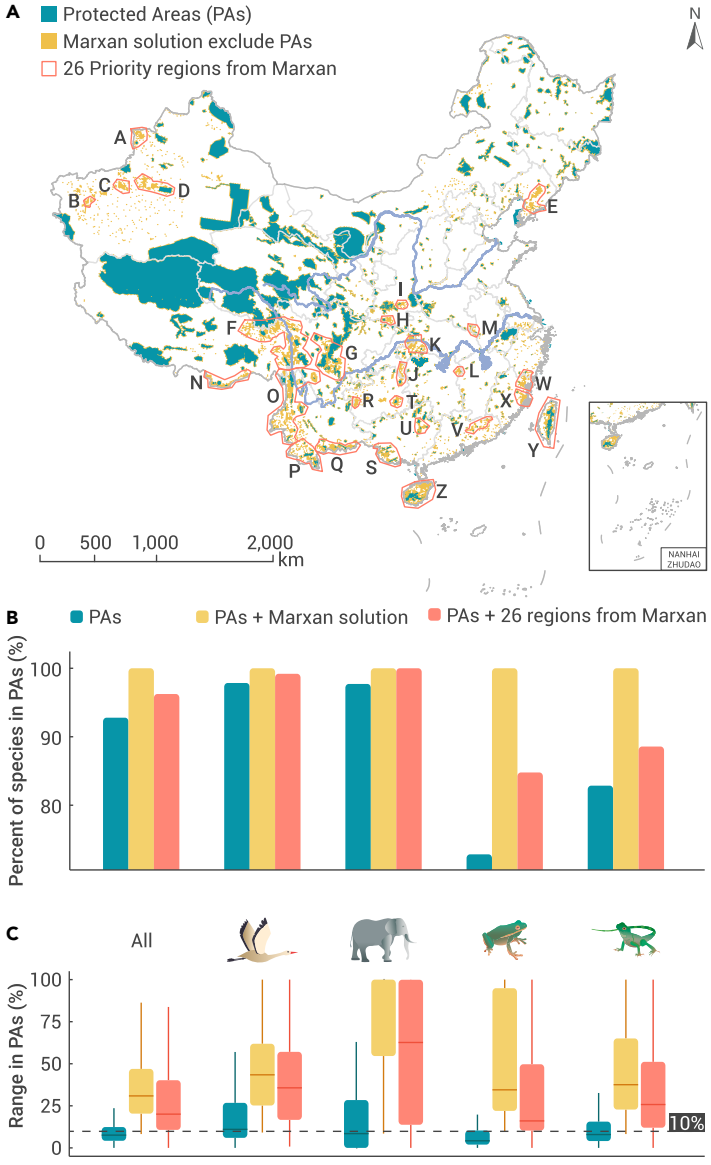


**Figure 4. Optimized solutions for the current PA system based on the target of 10% of each species' habitat covered by PAs** (A) The spatial distribution of Marxan solutions and current PAs. (B and C) (B) The proportion of species number and (C) the percentage of each species' range coverage for species on List 2021 within PAs in current PAs and two Marxan solutions. The yellow hexagons within pink polygons in (A) indicate the location of priority conservation regions. The black dashed line in (C) shows the minimum 10% conservation target adopted by Watson et al.[36] and Rondinini et al.[37] Letters in (A) indicate the priority areas: A, west of northern Tianshan Mountain; B–D, north bank of Tarim River; E, west of Changbai Mountains; F, east of the Tanggula Mountains and north of Hengduan Mountains; G, Daxue Mountains and Daliang Mountains; H, Daba Mountains; I, east of Qlinging Mountains; J, Wulin Mountains; K, Wu Mountains; L, northeast of Hunan; M, Dabie Mountains; N, southeast of Himalaya Mountains; O, north and west of Yunnan; P, Xishuangbanna; Q, south of Yunnan; R, west of Guizhou; S, southwest of Guangxi; T, southeast of Guizhou; U, northeast of Guangxi; V, northeast of Guangdong; W, northeast of Fujian; X, east of Fujian; Y, Taiwan Island; Z, Hainan Island.

of China, such as the east of Tanggula Mountains (F), and from the Hengduan Mountains to the west and south of Yunnan (O–Q). Amphibians are mainly distributed in the middle and south of China, including the Daxue and Daliang Mountains (G), Wulin Mountains (J), and Wu Mountains (K). Reptiles are mainly located in southern China, such as southwestern and northeastern Guangxi (S and U), northeastern Guangdong (G), and Hainan Island (H). It is noteworthy that the southeast of the Himalayan Mountains (N), the Hengduan Mountains to the west and south of Yunnan (O–Q), and the southwest of Hainan Island (Z) are also hotspots where small-range protected species are found (Figure S6).

We found that 15 of the 26 priority areas from the Marxan solution are located within biodiversity conservation priority areas across China.[64] In Northwest China, region (A) is located in Tianshan, southwest of Junggar Basin, regions (B–D) belong to the Tarim River Basin priority areas, region (H) lies in the Daba Mountain priority area, and region (I) lies within Qinling. In Southwest China, region (G) lies in Min Mountains—the north section of the Hengduan Mountains, (J) is located in Wulin Mountains, (N) is in the southeast of the Himalayan Mountains, the north part of the region (O) lies in the south section of Hengduan Mountains priority area, regions (P) and (Q) are located in the Xishuangbanna, (S) lies in the southwestern mountainous region of Guangxi. In East China, region (M) lies in the Dabie Mountains. In South China, region (T) lies in the Nanling priority area and (Z) encompasses the priority areas of South Central Hainan Island. However, the other 11 regions are not yet covered by the current biodiversity conservation priority areas. China is striving to establish a natural PA system composed mainly of National Parks[13] to promote the harmonious coexistence of humans and nature and improve awareness of biodiversity conservation.[21] The priority conservation regions identified may be included in the development of a future National Park system to protect wildlife in China.

Identifying potential priority areas for wildlife conservation depends on the species of interest and the methodology of assessment. We focused on the conservation effectiveness of PA expansion for the National Key Protected Species of vertebrates in China and identified 26 priority conservation areas across China. A previous study assessed how well Chinese endemic birds, mammals, and amphibians are protected by existing PAs and identified priority conservation areas in central and southern China (i.e., central Sichuan, central Yunnan, Nan Mountain, and central and western of Hainan Island).[26] We found a wider distribution and more priority areas than those in a previous study. This discrepancy could be attributed to several factors. First, previous research focuses on endemic species,[26] which usually inhabit a limited area, such as a mountain range, lake, or island[65]; endemic species in China are mainly distributed in the middle and south of China.[26] Our priority areas were based on the distribution of protected species on List 2021, which included both endemic and wide-range species. The wide distribution of priority areas identified in the current study could contribute to the conservation of key protected species widely distributed across China. Therefore, the optimal PA network for key protected species may differ from that for endemic and IUCN-categorized threatened species in China. Second, the two studies used different methods to identify priority areas. Li and Pimm[26] identified priority areas mainly based on species richness, whereas we used an optimized method to highlight the requirement that at least 10% of a species' range should be within PAs and considered conservation costs and human disturbance as well. Conservation studies based on species richness may fail to account for small-range species, because species richness relies on a large number of distribution records of wide-ranging species. This leads to a disproportionate contribution to species richness counts,[29] and small-range species are frequently more threatened by environmental changes.[66,67] For example, in our study, the spatial distribution pattern of all protected species (665 species) was highly correlated with the distribution pattern of widespread species (332 species; Pearson's R = 0.997), but least correlated with small-range species (333 species; Pearson's R = 0.594; Figure S6). Moreover, by considering conservation costs and human disturbance in the optimization solution for current PAs, we can make realistic recommendations for conservation policies.[31]

Our results show that some priority conservation regions (eg, Hainan Island) include farmlands and urban areas even after considering human pressure and conservation costs. This suggests that these regions are important for the efficient conservation of key protected wildlife at lower costs. Protecting the biodiversity of farmland and urban areas could supplement the current biodiversity conservation networks in China. For example, European countries have implemented the Common Agricultural Policy since 1992.[68] The protection of urban biodiversity involves dealing with the aggravation of pollution, loss of natural habitats, and biological invasion, thereby reducing the negative impacts of urbanization on biodiversity.[69] Moreover, the ecosystem services provided by urban biodiversity conservation can significantly improve citizens' health and well-being.[70]

## CONCLUSION

The policy of updating the list of protected species and expanding the PA network included 665 protected animals and covered 14.5% of the land surface in China. However, we are still far from achieving the goal of adequate wildlife (e.g., amphibians and reptiles) protection in China. New National Parks are also being established in China. Thus, the systematic expansion of the current PA network and timely updating of the protection list are urgently needed to

maximize the design and effectiveness of PAs and National Parks. The identified conservation gaps and priority areas may ultimately contribute to improving biodiversity conservation, achieving ecological civilization policy targets in China, and protecting up to 30% of the planet by 2030. Furthermore, we recommend that updated lists of protected species for each country are essential, as is the need for continuous and systematic optimization of global PA networks to increase the effectiveness of biodiversity conservation worldwide.

## MATERIALS AND METHODS

See supplemental information for details.

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## AUTHOR CONTRIBUTIONS

C.M. and W.D. conceived the research idea. C.M., K.S., and L.M. designed the study. C.M. conducted the main analysis. C.M. and W.D. wrote the manuscript. J.X., B.S., Y.S., and J.L. reviewed and edited the manuscript.

## DECLARATION OF INTERESTS

The authors declare no competing interests.

## DATA AND MATERIALS AVAILABILITY

Data supported the conclusions are present in the paper, and the supplemental information (Data S1); protected species distribution data are available in https://doi.org/10.6084/m9.figshare.22138346.

## SUPPLEMENTAL INFORMATION

It can be found online at https://doi.org/10.1016/j.xinn.2023.100424.

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