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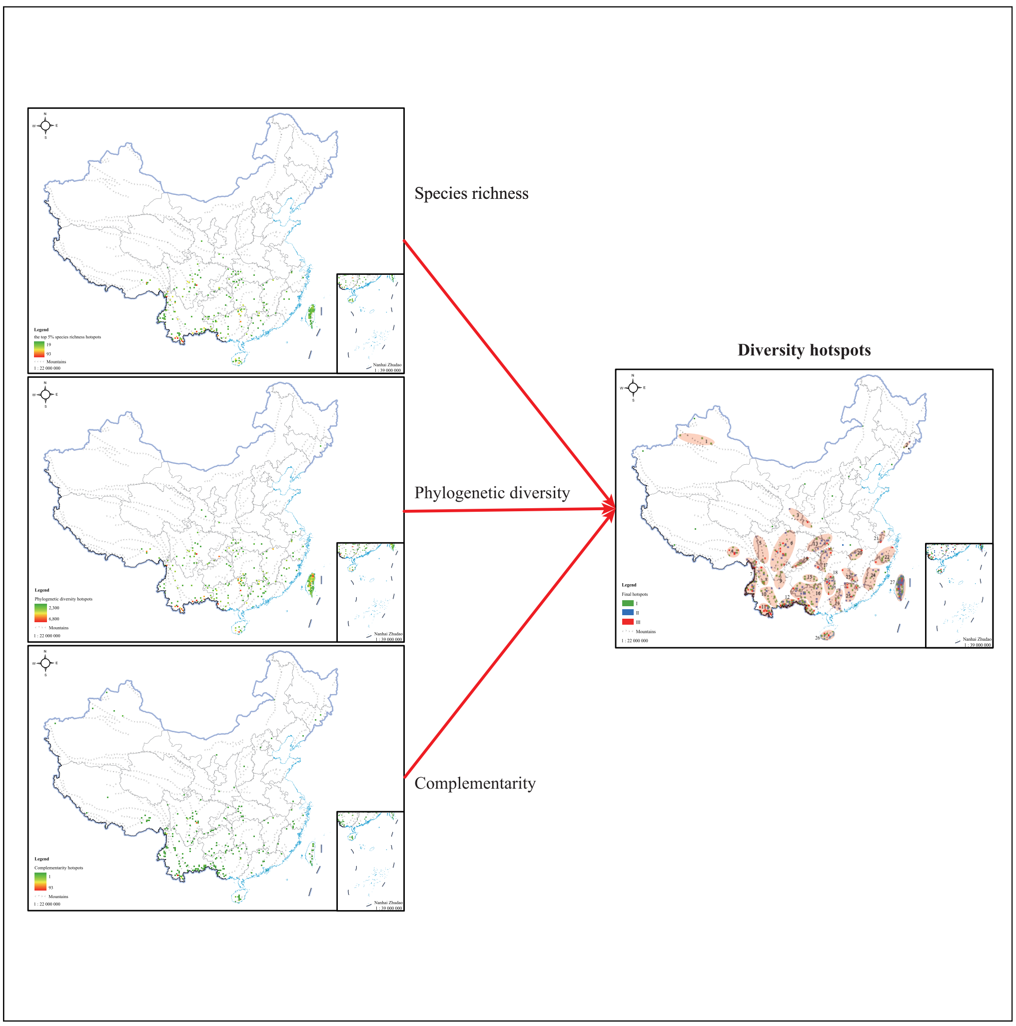

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Highlights

Twenty-seven diversity hotspots were identified by 3 algorithms

Diversity hotspots were mainly located in southwest and southern China

The conservation rate of national nature reserves in China is 61.49

The minimum area for protecting all species is 1.37% of the national land area

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SUMMARY

National key protected wild plants (NKPWPs) are considered flagship species for plant diversity conservation in China. Using data for 1101 species, we characterized NKPWPs distribution patterns in China and assessed conservation effectiveness and conservation gaps. In total, 4880 grid cells at a 20 × 20 km resolution were filled with occurrence records for NKPWPs. We identified 444 hotspot grid cells and 27 diversity hotspot regions, containing 92.37% of NKPWPs. However, 43.24% of these hotspot grid cells were fully or partially covered by national nature reserves (NNRs), where 70.21% of species were distributed. Approximately 61.49% of the NKPWPs species were protected by NNRs, but the populations or habitats of 963 species were partially or fully outside of NNRs. With global warming, the overall change in the extent of suitable habitats for NKPWPs is expected to be small, however, habitat quality in some areas with a high habitat suitability index will decrease.

INTRODUCTION

Plant diversity in China is among the highest in the world, with more than 41,000 species of higher plants alone,[1] of which about 50% are endemic.[2,3] With a population exceeding 1.4 billion, increasing demand for natural resources in China exerts substantial pressure on the environment and conservation.[4] Approximately 4000 species are assessed as threatened with a risk of extinction[3] due to habitat degradation or/and loss, over-collection, alien invasive species, climate change, or internal biological limitation.[3,5,6] To effectively protect plant diversity with limited resources, the National Forestry and Grassland Administration and the Ministry of Agriculture and Rural Affairs announced a revised list of national key protected wild plants (NKPWPs),[7] 22 years after the first version.[8] Species of NKPWPs were selected based on a combination of rarity, endangered status, and economic, cultural, scientific, genetic and ecological value[9] by more than 100 experts on plant diversity conservation and taxonomy as well as officials, with feedback from non-governmental organizations and the public. NKPWPs are widely considered flagship species for plant conservation in China[9,10] and are protected by national laws (https://www.gzzx.gov.cn/rdzt/kjyqgzzxzxd_1/fyygflfg/202106/P020210615548394847969.pdf) and regulations (http://www.gov.cn/zhengce/2020-12/26/content_5574904.htm). The major aims of NKPWPs are to strengthen the protection of plant diversity in accordance with law and regulation, ensure the sustainable utilization of wild plant resources and the health of ecosystems, and raise public awareness. NKPWPs are also major targets of *in situ* conservation, including national parks, national nature reserves (NNRs), provincial nature reserves, and natural parks (such as scenic and historic area, forest park, grassland park, wetland park, desert park, marine park, and geological park, in accordance with the taxonomy rule of protected areas in China) as well as *ex situ* conservation, including national botanical gardens.

Target 4 of the Kunming-Montreal Global Biodiversity Framework is to ''Ensure urgent management actions to halt human induced extinction of known threatened species and for the recovery and conservation of species, in particular threatened species, to significantly reduce extinction risk ...''.[11] To meet this target, it is important to understand the detailed distribution patterns and *in situ* conservation status based on available information.

The Chinese government established a natural protected areas system with national parks as its main body in 2019 (http://www.gov.cn/zhengce/2019-06/26/content_5403497.htm), and initiated integration and optimization strategies for natural protected areas. Among all protected areas, nature reserves are the most important type, accounting for 14.86% of the terrestrial land area of China, while all kinds of protected

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areas account for 18%.[12] The Chinese government also formulated the Overall Arrangement Plan of National Parks in 2022, which arranged 49 candidate national parks in China before 2035.[13] These current and potential national parks include about 700 protected areas and cover around 10% of terrestrial land in China and 80% of protected species.

Several challenging questions need to be addressed for effective biodiversity conservation. For example, how can control zones and boundaries of protected areas be adjusted to ensure the conservation purpose while also considering the livelihood of the local community? Which areas need to be covered by nature reserves to address habitat fragmentation and conservation gaps? How many protected areas are reasonable in China?

Species distributions are the result of long-term interactions between biotic and abiotic factors.[14] Understanding patterns of biodiversity and the underlying determinants is a critical step for effective conservation and sustainable resource utilization.[15,16] Many studies use provincial-level or county-level administrative districts or large grid cells as geographical sample uniting to analyze the distribution patterns of biodiversity.[17–20] Mountain ranges, such as the Andes, Himalayas, Hengduan Mountains, and Qinghai-Tibet Plateau, are characterized by rich biodiversity.[21–25] However, in mountainous areas with large topographic variation, the use of large geographic sampling units may not appropriately reflect the status of species. Biodiversity-rich areas attract the attention of a large number of researchers and the species distribution data are more detailed than in other areas, they are not fully representative of the threatened status of all populations of the species. In addition, species discovered in these well-studied areas are not necessarily the representatives of all NKPWPs species. Recent studies have evaluated species distribution patterns by georeferencing distribution records at the county-level or previous based on herbarium specimens or flora databases.[26–28] Using this approach, the concentration of multiple species collected within a region,[29] particularly for a large area, may bias the formulation of conservation strategies, limiting the precise protection of species.[30] Therefore, smaller geographic sampling units and precise geographic coordinates are helpful in understanding species distributions and establishing effective conservation strategies.

Algorithms based on species richness,[31,32] complementarity,[33–35] and phylogenetic diversity[36–39] are frequently used to identify biodiversity hotspots, providing a good research basis for top-down management decisions. Moreover, methods combining multiple algorithms can effectively determine hotspots.[40,41] These hotspots combined with the existing network of nature reserves can be used to determine priority protection areas, and provide new insights and suggestions for the scientific protection and management of these species.

Climate change is a major driver of changes in global species ranges.[42–44] It has been a major factor in biodiversity loss and species extinction since the beginning of the 21st century.[45,46] Most NKPWPs have small populations and a restricted geographical distribution, and are threatened due to habitat degradation, fragmentation and/or loss. Climate change may impact habitat quality, leading to changes in species distributions. It is therefore necessary to consider the impact of climate change in conservation planning.

Using data for the geographic distribution of 1101 species of NKPWPs in China and 32 environmental variables, our aims are to: (1) clarify the distributions of NKPWPs and identify species diversity hotspots, (2) assess conservation effectiveness and conservation gaps based on the existing NNRs network, (3) compare the effects of environmental variables on the distribution of species diversity, (4) predict current and future potentially suitable habitat areas under global warming trends, and (5) provide scientific information for optimizing the establishment of NNRs and national parks.

RESULTS

Distribution patterns and hotspots of NKPWPs

In total, 4880 of 23984 grid cells were filled with occurrence records for NKPWPs, accounting for approximately 20.54% of the land area in China. Species richness and phylogenetic diversity of NKPWPs was highly heterogeneous (Figures 1 and 2). In particular, species richness was highest in southwestern and southern China, Taiwan, and Hainan Island. NKPWPs were highly concentrated in the eastern Himalayas, Hengduan Mountains, Hunan-Guizhou-Guangxi border region, and boundary regions in southern China. Grid cells with the highest diversity had 93 species; however, more than 37% of the grid cells had a single species. Similarly, hotspot grid cells with the top 5% of values for species richness (Figure 3A) and phylogenetic

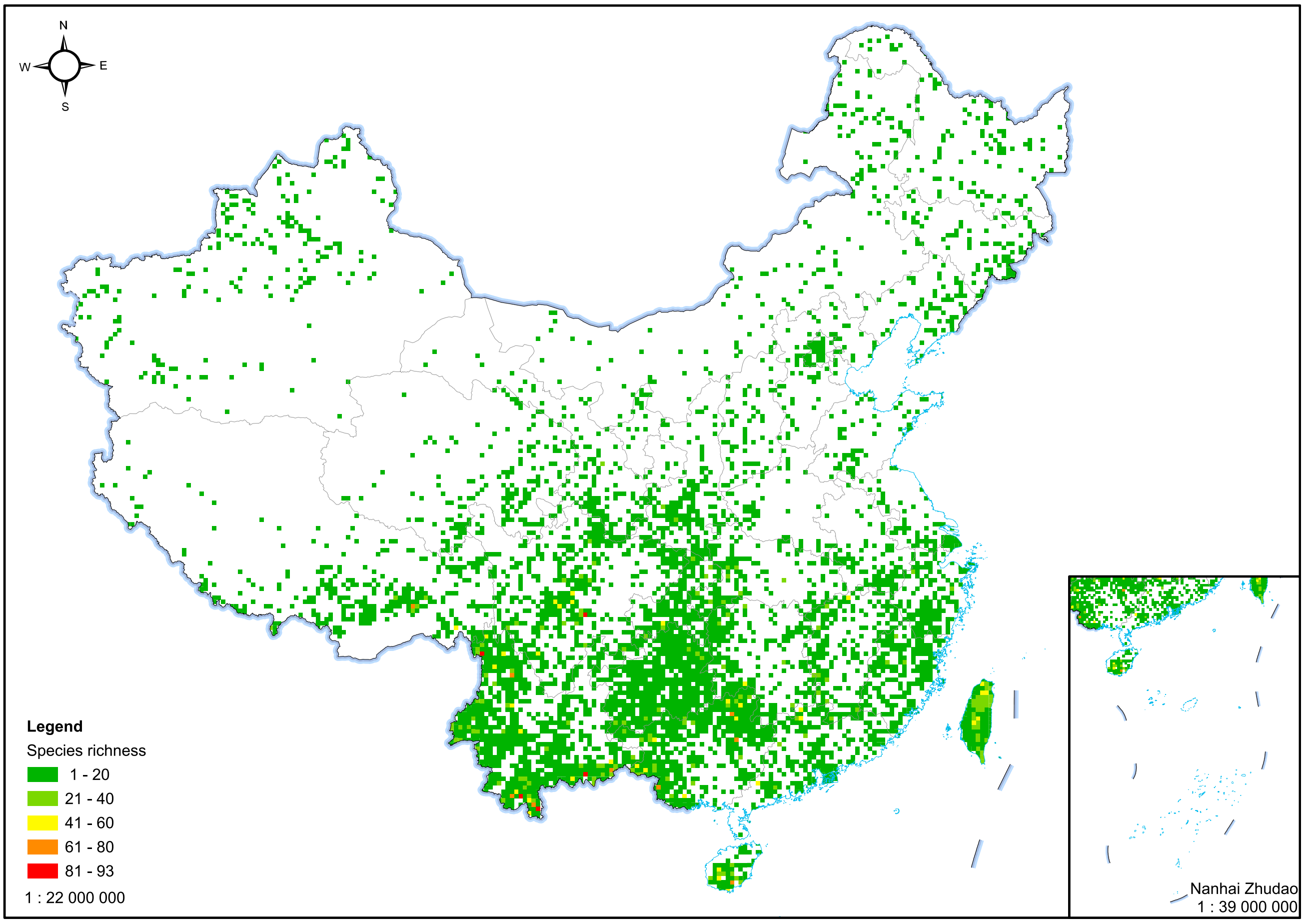

Figure 1. Distribution of species richness of NKPWPs

diversity (Figure 3B) were also mainly distributed in these regions and were relatively concentrated, containing 810 (73.57%) and 791 (71.84%) species, respectively, and accounting for 1.02% and 1.03% of the area of China. Although the distribution of grid cells with high species complementarity was generally consistent with those for the other two algorithms, the complementarity-based approach showed a relatively dispersed distribution (Figure 3C), with 1017 NKPWPs (92.37%) covering approximately 1.02% of the area, including all species obtained by the other two algorithms.

Combining the results of the three algorithms, we obtained 444 hotspot grid cells (Figure 3D; Table S1) containing 1017 (92.37%) species, accounting for approximately 1.86% of the land area of the country. There were 233 grid cells in category III with 729 species (66.21%) and 134 grid cells in category II with 646 species (58.67%). Category I had only 77 grid cells but 718 species (65.21%). In addition, the minimum number of grid cells required to contain all species was 328 (Figure S1), corresponding to approximately 1.37% of the total land area. According to the main mountain range, climate, floristics, and administrative boundaries, we identified 27 diversity hotspots (Figure 3D): (1) Tianshan Mountains, (2) Changbai Mountains, (3) Qinling Mountains, (4) the eastern Himalayas, (5) Que'er-Shaluli Mountains, (6) northern Hengduan Mountains, (7) Gaoligongshan-Nujiang Mountains, (8) Yunling-Cangshan Mountains, (9) Luoji Mountains-Pudu River area, (10) Ailao-Wuliang Mountains, (11) Xishuangbanna Region, (12) limestone border regions between China and Vietnam, (13) eastern Dabashan-Wushan Mountains, (14) western Daloushan Mountains, (15) Miaoling Mountains, (16) Yunnan, Guizhou and Guangxi limestone Mountains, (17) eastern Daloushan-Wuling Mountains, (18) western Nanling Mountains, (19) Darongshan-Yunkai-Yunwu Mountains, (20) Mufu Mountains, (21) Tianmu Mountains, (22) Tiantaishan-Xianxialing Mountains, (23) Hengshan-southern Luoxiao Mountains, (24) Wuyi-Lianhua Mountains, (25) eastern Nanling-Jiulian Mountains, (26) south-central Hainan Island, and (27) Central Mountain Range, Taiwan Island.

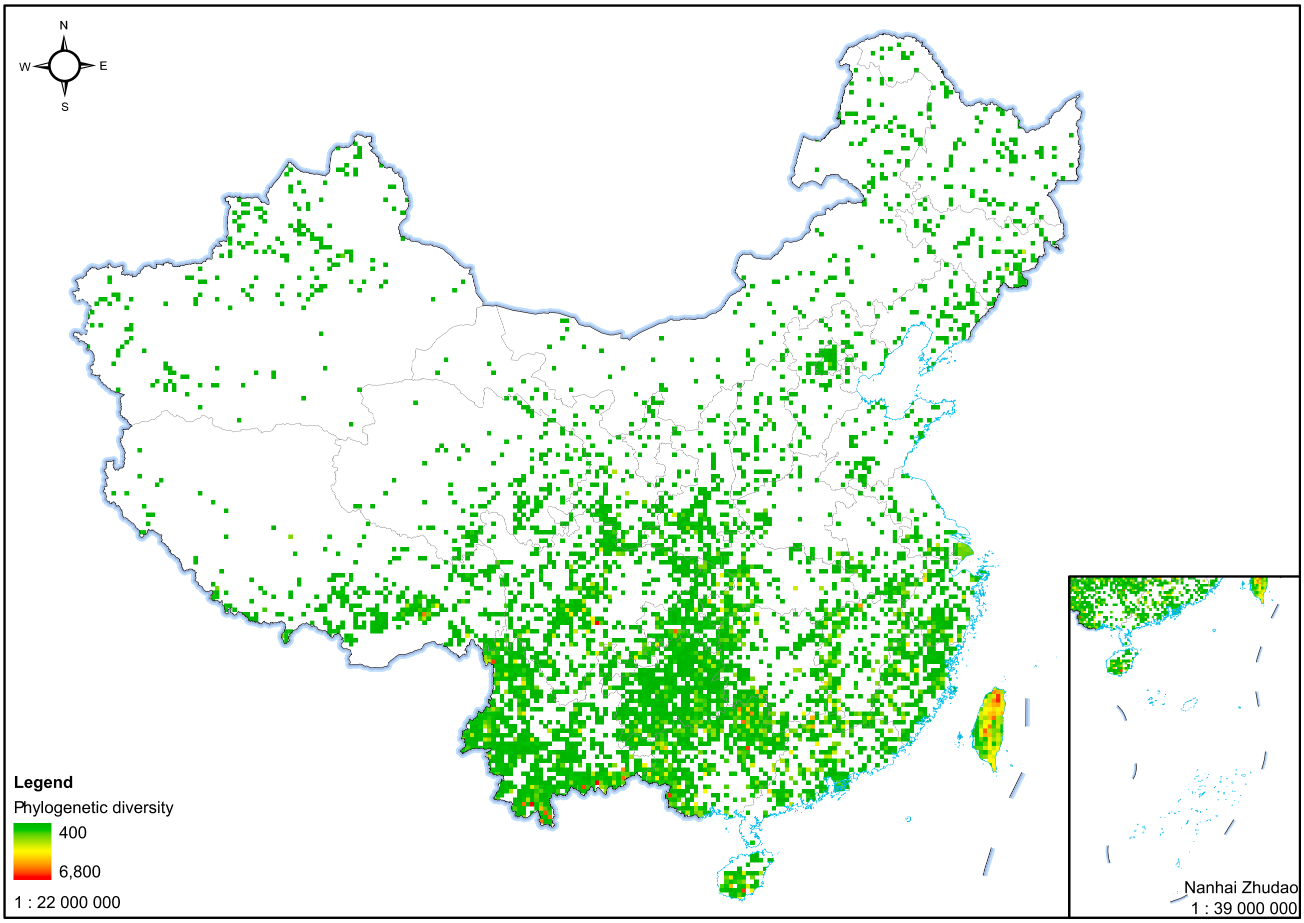

Figure 2. Distribution of phylogenetic diversity of NKPWPs

Conservation effectiveness and gaps of NKPWPs in NNRs

Combining NNRs with species distribution data revealed that the current NKPWPs conservation efficiency is approximately 61.49% (677 species). The conservation efficiencies for first-level and second-level protected plants were 53.72% and 62.45%, respectively. Of all grid cells with occurrence records, at least 1212 (24.84%) were partially or fully covered by NNRs, and these contained 873 species (79.29%). Among the screened hotspot grid cells, at least 192 (43.24%) were partially or fully covered by NNRs, containing 773 species (70.21%). Rare and endangered woody taxa, such as *Abies*, *Cycas*, Dipterocarpaceae, *Pinus*, and *Taxus*, were largely covered by NNRs. However, many herbaceous taxa of NKPWPs with high medicinal or economic value (e.g., *Fritillaria*, *Paris*, and *Tulipa*), were not covered by NNRs.

An analysis of conservation gaps revealed 424 species (38.51%) that are not protected by any NNR, including 55 species in first-level and 369 in second-level, 247 threatened species (58.25%), 270 endemic species (63.68%), and 160 species (37.74%) recorded at a single site. In addition, the grids not covered by NNRs contained 963 species (87.47%), while 252 hotspot grid cells lacked any protection and contained 815 species (74.02%) (Figures 4A and 4B). These unprotected hotspot grid cells were mainly located in the Tianshan Mountains, Changbai Mountains, Hengduan Mountains, China's borders with Vietnam and Myanmar, upper Hongshui River region, Nanling Mountains, and Wushan-Dalou Mountains.

Relationships between species richness and environmental variables

In a spatial autocorrelation test of species richness, Moran's I was 0.22, which exceeded the significance level of 0.001, and the z-value was 61.49, much higher than the critical value of 2.58 at this confidence level, indicating significant positive spatial autocorrelation. After removing multicollinearity, we obtained five

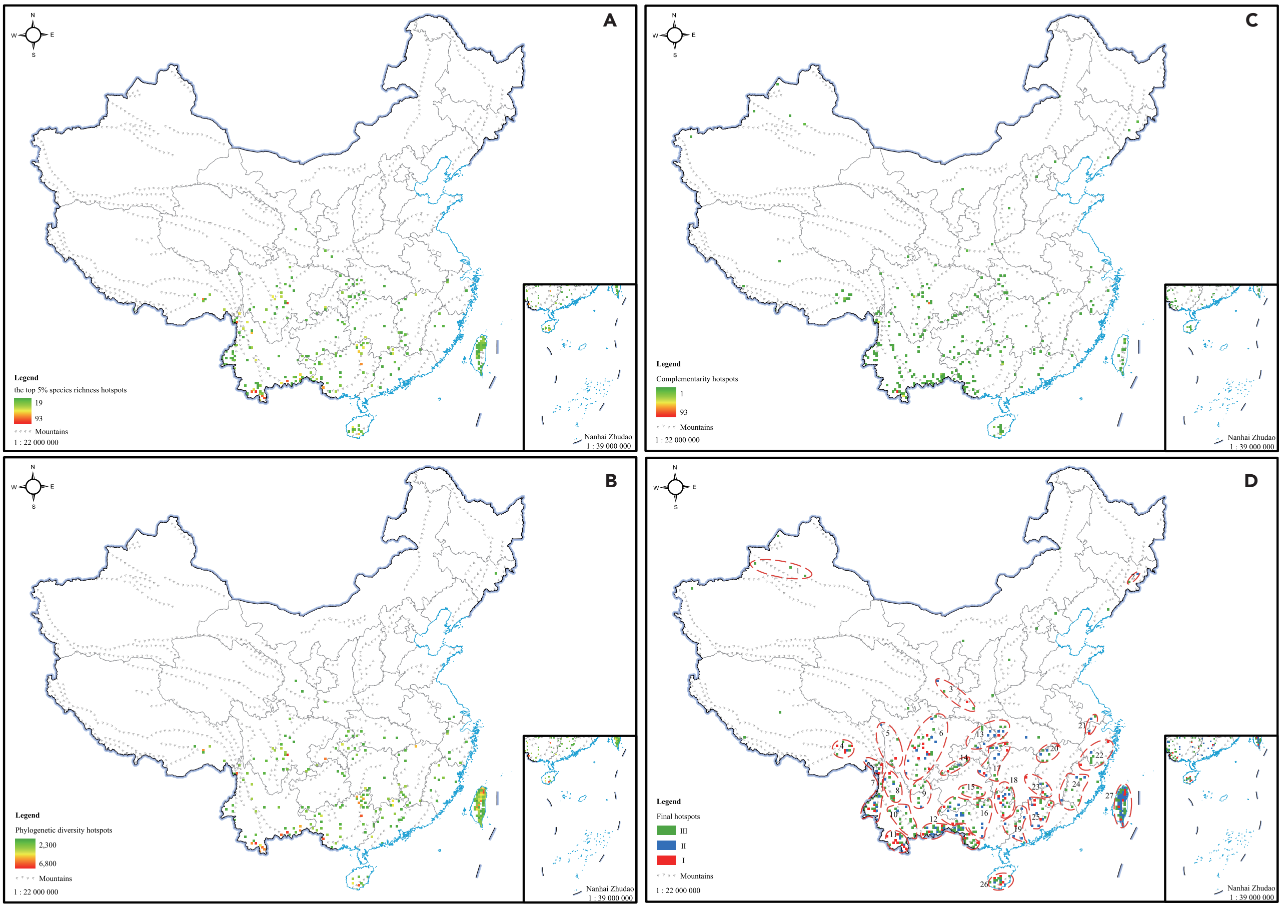

Figure 3. Distribution of hotspot grid cells of NKPWPs

(A–D) (A) Hotspot grid cells identified based on species richness, (B) Hotspot grid cells identified based on phylogenetic diversity, (C) Hotspot grid cells identified based on complementarity, (D) Hotspot grid cells identified by all three algorithms.

1. Tianshan Mountains, 2. Changbai Mountains, 3. Qinling Mountains, 4. the eastern Himalayas, 5. Que'er-Shaluli Mountains, 6. northern Hengduan Mountains, 7. Gaoligongshan-Nujiang Mountains, 8. Yunling-Cangshan Mountains, 9. Luoji Mountains-Pudu River area, 10. Ailao-Wuliang Mountains, 11. Xishuangbanna Region, 12. limestone border regions between China and Vietnam, 13. Eastern Dabashan-Wushan Mountains, 14. western Daloushan Mountains, 15. Miaoling Mountains, 16. Yunnan, Guizhou and Guangxi limestone Mountains, 17. eastern Daloushan-Wuling Mountains, 18. western Nanling Mountains, 19. Darongshan-Yunkai-Yunwu Mountains, 20. Mufu Mountains, 21. Tianmu Mountains, 22. Tiantaishan-Xianxialing Mountains, 23. Hengshan-southern Luoxiao Mountains, 24. Wuyi-Lianhua Mountains, 25. eastern Nanling-Jiulian Mountains, 26. south-central Hainan Island, and 27. Central Mountain Range, Taiwan Island.

significant environmental variables, temperature seasonality, precipitation seasonality, precipitation of the warmest quarter, elevation range, and road length (significance less than 0.001 and VIF less than 7.5) (Table 1).

The GWR model explained 39.12% of the variance in the spatial distribution of species richness, which was markedly superior to the OLS model, which explained only 20.02% of the variance (Table 2). The relative advantage of GWR was corroborated by other goodness-of-fit indices, such as adjusted R^2 and Akaike information criterion (AICc) values. Therefore, GWR was the most effective approach for identifying the environmental determinants of the spatial distribution of NKPWPs. We found that the environmental variables differed substantially in their modes and degrees of influence on species richness at different spatial locations (Figure S2). Except for precipitation seasonality, the overall performance was dominated by grid cells with a positive effect, where the intensity of the effects of temperature seasonality, precipitation seasonality, precipitation of the warmest quarter, and elevation range were all below 0.1. Interestingly, in 98.22% of the grid cells, road length had a positive effect on the diversity of NKPWPs, although the effect was generally weak.

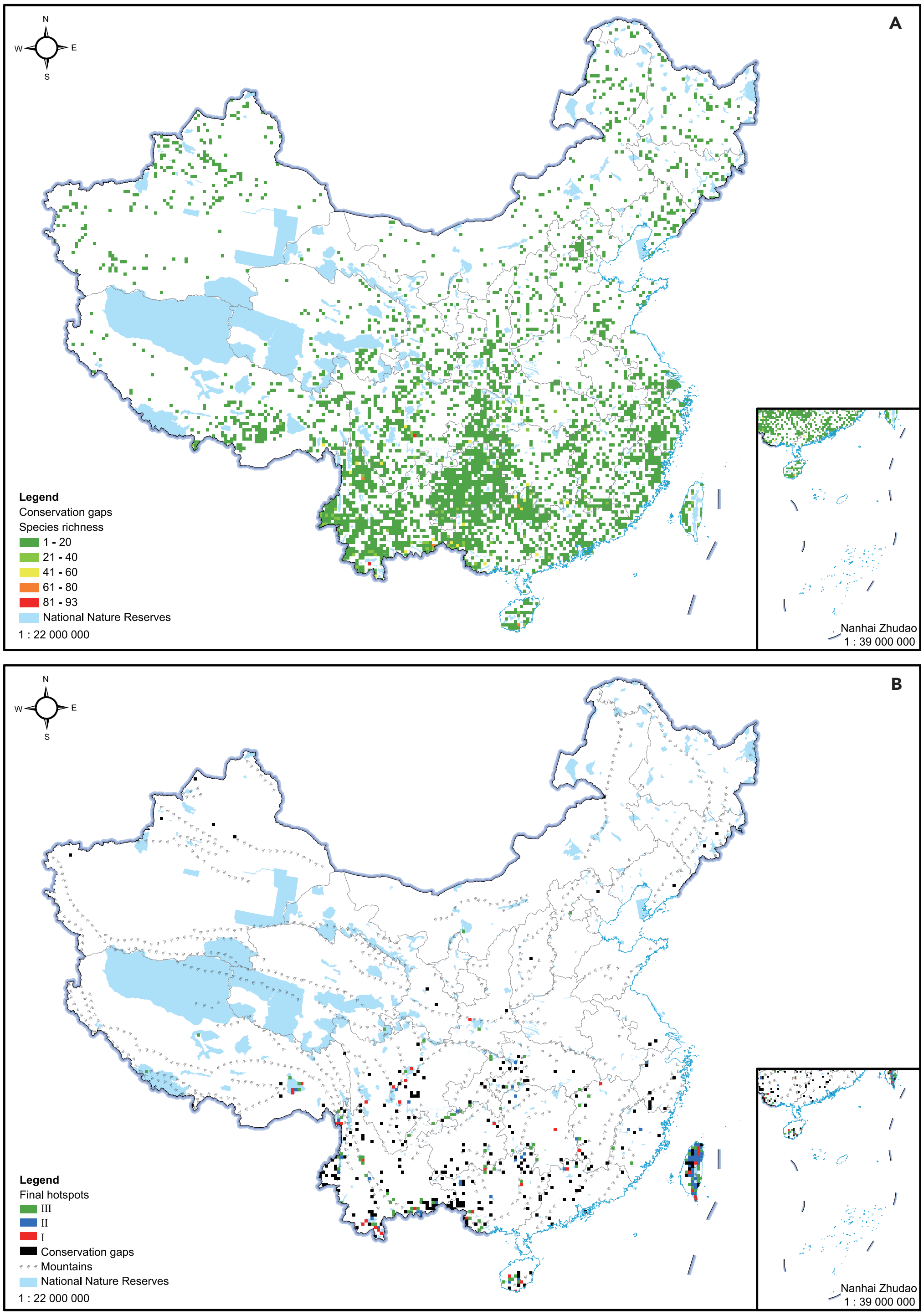

Figure 4. Conservation gaps of NKPWPs

(A) Species richness of grid cells not covered by NNRs, (B) Conservation gaps in hotspot grid cells.

Suitable distribution of NKPWPs in the future

Models for the current situation and four future SSPs showed areas under the curve (AUC) of > 0.9 for all species, with high prediction accuracy. The prediction results for the current scenario showed that the main suitable habitats of NKPWPs are concentrated in the southwestern and southern regions of China,

Table 1. Variance inflation factors and summary of ordinary least-squares regression results

Variables	Coefficient	p	VIF
Temperature Seasonality (BIO4)	−0.000126	0.001	2.21
Precipitation Seasonality (BIO15)	−0.002276	0.001	1.11
Precipitation of Warmest Quarter (BIO18)	0.000557	0.001	1.75
Elevation Range	0.000119	0.001	1.41
Road Length	0.010065	0.001	1.11

mainly including the eastern Himalayas, Hengduan Mountains, border areas of southern China with Myanmar and Vietnam, south-central Hainan Island, and Central Mountain Range of Taiwan Island; the most suitable areas were mainly concentrated in Xishuangbanna, south-central Hainan Island, and the Central Mountain Range of Taiwan (Figure 5). In the four future SSPs, there were little changes in the overall suitable habitat areas (Figure 6). However, areas with a high suitability index tended to shift toward the southern boundary area, with decreases in habitat quality in the Daloushan-Wushan Mountains, the upper reaches of Hongshui River area, parts of the Hengduan Mountains, and the Wuyi Mountains. Areas with a high suitability index in Guangxi and Guangdong Provinces were predicted to increase, and the eastern Himalayas were predicted to become highly suitable for NKPWPs (Figure S3).

DISCUSSION

Distribution patterns and conservation effectiveness of NKPWPs

Our results indicate that NKPWPs generally show a heterogeneous distribution in which species richness was high in the west and low in the east, and high in the south and low in the north, in agreement with the distribution of higher plants in China[1] and previous results.[47] These results were also consistent with the high biodiversity in southwestern mountainous areas with the high habitat heterogeneity and relatively little disturbance in China.[48] The NKPWPs diversity hotspots identified in this study were basically distributed within the priority areas for biodiversity conservation in China announced by the Ministry of Ecology and Environment of the People's Republic of China in 2015 (https://www.mee.gov.cn/gkml/hbb/bgg/201601/W020160106364696044586.rar), further validating the prioritization of areas for biodiversity conservation in China. However, our results provide new insights into the distribution and conservation effectiveness of NKPWPs in comparison with previous results based on studies of specific taxa (e.g., Orchidaceae[49] and Rhododendron[50]) or NKPWPs based on specimens[51] or large grids.[47] We detected a higher species conservation rate (61.49%) than previous estimates (44.70%)[47] and a lower minimum area required to conserve all species (1.37%) (Figure S1) than previous estimates (4.8%).[47] Twenty-seven hotspot regions included about 424 of 444 hotspot grid cells, containing 987 species and occupying about 89.65% of the total area. We identified seven new hotspot regions, including the Changbai Mountains, southern Wuyi Mountains, the Hengshan-southern Luoxiao Mountains, Mufu Mountains, eastern Nanling-Jiulian Mountains, Ailao-Wuliang Mountains, and Que'er-Shaluli Mountains. The newly identified hotspot regions were mainly located in eastern and southern China. Most of the 77 category I hotspot grid cells were concentrated in eleven hotspot regions. One part of the border region between China and Myanmar did not have any hotspot grid cells, which may be explained by a lack of botanical surveys. These new insights can be attributed to the accuracy of the data obtained by fieldwork and smaller grid cells than those used in previous studies.

Effects of environmental variables on NKPWPs

We detected significant spatial heterogeneity in the effects of environmental variables on the diversity of NKPWPs (Figure S2); however, the magnitudes of the effects were low. Contrary to our expectation, road

Table 2. Comparison on the performance of ordinary least squares (OLS) and geographical weighted regression (GWR)

Model	R^2	Adjusted R^2	AICc
OLS	0.20	0.20	4921.65
GWR	0.39	0.33	4264.95

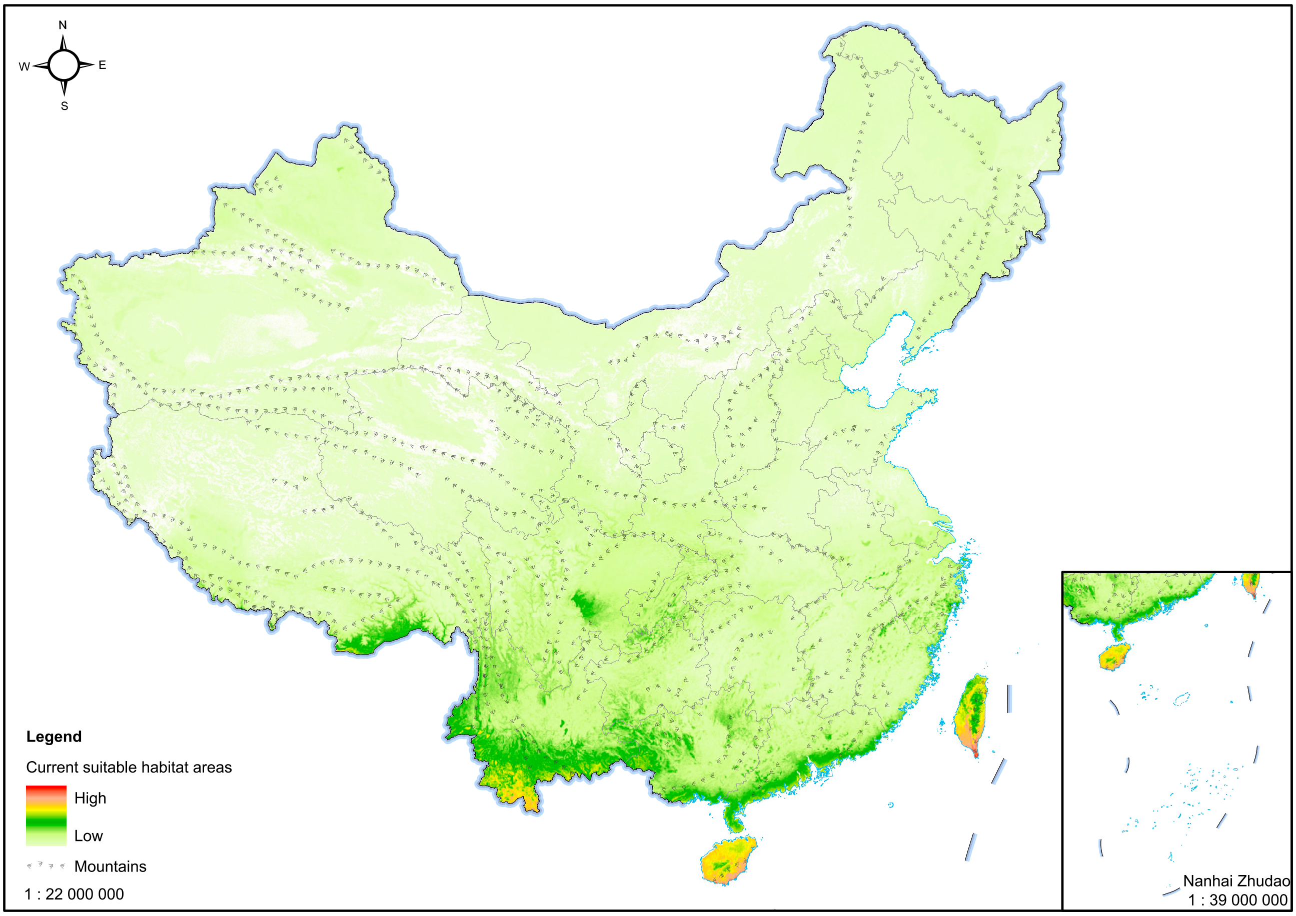

Figure 5. Current suitable habitat areas for NKPWPs

length was positively related to the abundance of NKPWPs in areas, with an impact coefficient greater than 0.1. This may be explained by the high forest coverage in these areas, with better vegetation or higher habitat heterogeneity combined with low anthropogenic disturbance or human accessibility; thus increasing road length may facilitate the discovery of NKPWPs.

With climate warming, the overall change in the extent of suitable habitats for NKPWPs was not significant. However, the suitability index was predicted to decrease in some areas with a high suitability index and was predicted to increase significantly in some areas along the coast of Guangdong and subregions of Guangxi, explaining the northward shift in the suitable habitat of species distributed in Hainan due to global warming. However, this is an important economic development region in China, with a high population density and limited area for the growth and protection of NKPWPs. Therefore, the development of conservation strategies that account for economic development in the context of climate change will be a major challenge.

Conservation recommendations

Identify priority protection areas and key biodiversity areas

Our results indicated that NKPWPs are a very good proxy for plant biodiversity in China. With limited available resources, identifying priority protection areas is an important aim. Among 27 hotspot areas (Table S2), we recommend nine as priority areas containing 822 species (74.66%) for conservation, including the limestone border region between China and Vietnam (358 species), Gaoligongshan-Nujiang Mountains (263 species), Xishuangbanna Region (228 species), Yunnan, Guizhou, and Guangxi limestone Mountains (224 species), northern Hengduan Mountains (200 species), western Nanling Mountains (153 species),

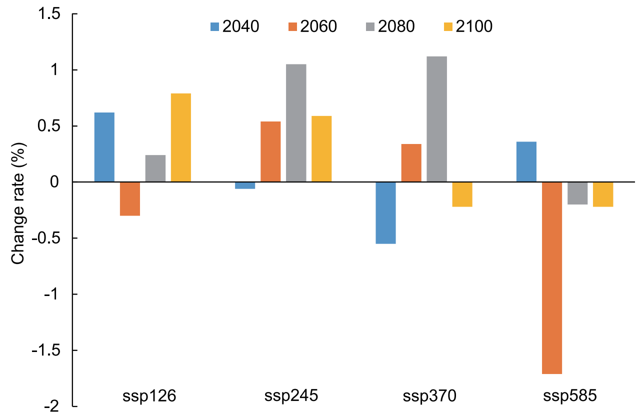

Figure 6. Rate of change (%) in the area of suitable habitats for NKPWPs under different climate scenarios and time periods

Central Mountain Range of Taiwan Island (152 species), Ailao-Wuliang Mountains (143 species), and south-central Hainan Island (140 species). For example, Hainan Province and Xishuangbanna had 153 and 228 NKPWPs species, respectively; however, only 68 (44.44%) and 135 species (59.21%) were protected by NNRs. Hainan Island is the largest tropical island in China, with the highest concentration of NKPWPs; it is the most well-preserved, largest contiguous area of tropical rainforest and has the most mangrove species in China. It harbors the richest tropical plant diversity in China. Xishuangbanna is part of the Indo-Myanmar biodiversity hotspot and has been listed as a key area and hotspot area[22,52] for biodiversity conservation in the world, characterized by tropical mountains and tropical valley rainforests with rich plant diversity. Both regions are included in the current list of national parks in China. An inventory of plant diversity in the region, regular monitoring, and species-specific studies are recommended to improve the efficiency of plant conservation in the region.

Promote the optimization and adjustment of nature reserves

Based on current conditions and future climate change projections, it is necessary to optimize and adjust nature reserves to effectively protect the most species possible with limited resources. We hope to establish cross-border protected areas and conservation corridors in southwest China, including the Hengduan Mountains, Gaoligong Mountains, Xishuangbanna region, limestone area on the border between China and Vietnam, upper Hongshui River region, and Nanling Mountains, to address the small and fragmented nature reserves, and thereby improve the effectiveness of species conservation[53,54] while reducing costs. Moreover, the establishment of conservation corridors will increase the habitat options for wildlife and improve wildlife populations.

Strengthen the protection of endangered species

For species not covered by NNRs or other protected areas, it is very important to establish conservation communities or carry out *ex situ* conservation to protect wild populations or genetic resources. Target 3 of the Kunming-Montreal Global Biodiversity Framework addresses the importance of other effective area-based conservation measures (OECMs) in addition to traditional protected areas for *in situ* conservation.[11] In southern China, local communities have rights to land, and OECMs might be a good option. A recently established action plan involves the construction and improvement of about 500 protected communities of different sizes in areas containing more than 110 species of NKPWPs, including populations that are not convenient for large-scale *in situ* conservation. This will greatly increase the protection rate of NKPWPs and provides a new model for conservation in addition to protected areas. The effectiveness of protected communities should be assessed in 10 years or three generations according to IUCN Red List criteria (https://www.iucn.org/resources/publication/guidelines-application-iucn-red-list-ecosystems-categories-and-criteria). Species with restricted distributions and/or small populations, such as *Cypripedium subtropicum* and *Paphiopedilum wardii*, should be listed as top priorities in *ex situ* conservation actions, including the conservation of seeds, plant organs, and tissues. In cases of severe habitat degradation or loss, plant introduction and cultivation are necessary. In addition, it is very important to reintroduce seedlings to expand wild populations with the help of national and regional botanical gardens, formulate key conservation plans for these species and other seriously threatened species, implement rescue conservation actions, and conduct regular monitoring.

In the face of shrinking areas with high habitat suitability, methods to conserve species in diversity hotspots are an urgent issue. In particular, effective species conservation in the Qinling-Wushan Mountains, Daloushan-Wuling Mountains, upper reaches of the Hongshui River area, eastern part of the Nanling Mountains, and Wuyishan Mountains after declines in habitat quality will be a major challenge. Therefore, it is necessary to prioritize recovery actions for species in these regions, involving appropriate *ex situ* conservation, population expansion, seed nursery technology research, and reintroduction. We also suggest regular monitoring of these species to avoid disturbances caused by external factors.

Botanical surveys

Plant distribution information is an essential component of management decisions.[55] We found that among 283 species of orchids, the conservation efficiency of NNRs for orchids (73.14%) was significantly higher than the average value for NKPWPs (61.49%), and this may be related to data from an ongoing national survey of wild orchid resources. In addition, we detected 27 hotspots of plant diversity, of which seven were newly discovered. However, we identified a plant diversity knowledge gap between hotspots 7 and 11 along the border region between China and Myanmar. Our examination of specimens in CVH and GBIF indicated that there is very little information for these regions. Botanical surveys are urgently needed to address this gap and provide solid data support for subsequent conservation work.

Limitations of study

Our analyses were mainly based on available species distribution data of NKPWPs and results may be improved with botanical surveys in the future. Our results on the relationships between species richness and environmental variables do not reveal dominant factors influencing species distribution due to many factors, including specific ecological niche of each species and the influence of human activities.

Conclusion

Based on extensive distribution data and a variety of statistical methods, we obtained 444 hotspot grid cells and found that they were largely located within priority areas for biodiversity conservation in China, covering 9.10% of grid cells containing NKPWPs and containing 92.37% of target species. However, there are still large conservation gaps in these areas, and these gaps should be prioritized when optimizing nature reserves in the future. In addition, under global warming, habitat suitability for NKPWPs is expected to gradually improve in the eastern Himalayas and the southern part of Hengduan Mountains to Xishuangbanna; increasing the number and area of nature reserves in these regions may improve the long-term survival and population growth of NKPWPs. Finally, species surveys are needed, especially in areas where historical surveys are insufficient but where species richness is high.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

- KEY RESOURCES TABLE
- RESOURCE AVAILABILITY
  - Lead contact
  - Materials availability
  - Data and code availability
- METHOD DETAILS
  - Checklist and database of occurrence data for NKPWPs
  - Evaluation of species richness and identification of hotspots
  - Conservation effectiveness and gap analysis
  - Relationships between species richness and environment factors
  - Prediction of suitable habitat areas for NKPWPs
- QUANTIFICATION AND STATISTICAL ANALYSIS

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2023.107364.

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AUTHOR CONTRIBUTIONS

Conceptualization, C.Y., Z.Z., and X.J.; Methodology, C.Y.; Software, C.Y.; Validation, C.Y.; Formal analysis, C.Y.; Investigation, C.Y. and X.J.; Resources, H.L., Z.Z., and X.J.; Data Curation, C.Y., H.L., and X.J.; Writing - Original Draft, C.Y.; Writing - Review & Editing, H.L., H.Q., J.S., Z.Z., and X.J.; Visualization, X.J.; Supervision, H.L. and X.J.; Project administration, X.J.; Funding acquisition, X.J.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
List of National Key Protected Wild Plants	https://www.gov.cn/zhengce/zhengceku/2021-09/09/content_5636409.htm	Table S3
Software and algorithms		
ArcGIS Pro (Version 2.7)	ESRI	https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview
R (Version 4.2.2)	R Core Team	https://cran.r-project.org/bin/windows/base/old/4.2.2/
MaxEnt (Version 3.4.4)	Maxent software for modeling species niches and distributions	http://biodiversityinformatics.amnh.org/open_source/maxent/

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled by the lead contact, Xiaohua Jin (xiaohuajin@ibcas.ac.cn).

Materials availability

This study did not generate new unique reagents or materials.

Data and code availability

- All data reported in this paper will be shared by the lead contact upon request.
- This paper does not report original code.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

METHOD DETAILS

Checklist and database of occurrence data for NKPWPs

According to the list of NKPWPs published in 2021,[9] referring to species name in the *Catalogue of Life China* (http://www.sp2000.org.cn) and recent references on plant taxonomy and phylogeny (e.g., *Cycas*,[56] *Dendrobium*[57] and *Paris*[58]), 1101 species of NKPWPs were evaluated (Table S3). Occurrence records with precise latitude and longitude information were obtained from the Chinese Virtual Herbarium (CVH, https://www.cvh.ac.cn/), Global Biodiversity Information Facility (GBIF, https://www.gbif.org/). In addition, our field records over the last 20 years were included. After removing invalid data, including cultivation records, coordinates outside China, and geographical information at the country level, 60819 georeferenced points were retained for the analysis of distribution patterns of NKPWPs.

Evaluation of species richness and identification of hotspots

To better visualize NKPWPs diversity hotspots and identify priority conservation areas, the map of China was divided into 23984 grid cells with a 20 km × 20 km resolution using ArcGIS Pro 2.7. Three different algorithms, including the species richness algorithm, complementarity algorithm, and phylogenetic diversity algorithm, were used to analyze the distributions of NKPWPs. The top 5% of grid cells with respect to species richness were identified as diversity hotspots, following previous studies.[59–61] For comparisons, the top 5% of grid cells with the highest species complementarity and phylogenetic diversity were also selected as hotspots.

Complementarity algorithms aim to contain the maximum number of species in the minimum area.[33] All grid cells were sorted by species richness, and the grid cells with the greatest species richness were selected, while eliminating species in this grid cell from the species database. Then, the remaining grid cells were sorted, and the grid cell with the highest species richness was selected. This process was repeated until the selected grid cells contained all species.

Phylogenetic diversity, reflecting the evolutionary history among taxa, may provide a better measure than species richness alone for conservation assessment.[62,63] To calculate phylogenetic diversity, a phylogeny was generated for 1084 species, excluding mosses, algae, and fungi, using the "V. PhyloMaker" package[64] in R, and then the function "build.nodes.1" was used to extract the genus-level root and the corresponding basal node information from the backbone tree. This method is still a good way to calculate phylogenetic diversity in the absence of sufficient molecular data, although it has some potential pitfalls, such as the fact that many taxa are places on the tree without using real data, branch lengths are all scaled to the same length. Phylogenetic diversity was calculated for each grid cell using Biodiverse 3.1.[65]

Finally, hotspots detected by the three algorithms were combined to obtain 444 unique hotspot grid cells. The grid cells identified by all three algorithms were assigned to category I, the grid cells detected by any two algorithms were assigned to category II, and the grid cells detected by a single algorithm were assigned to category III.

Conservation effectiveness and gap analysis

Nature reserves are the most effective means of *in situ* biodiversity conservation.[51,66] In particular, NNRs are the core of biodiversity conservation[67] owing to their good financial support, large areas, professional support of scientists, strong legislation support, and mature management systems. Other types of nature reserves or natural parks are often not well maintained or managed due to insufficient funds, small areas, inappropriate conservation planning, weak legislation, and inadequate infrastructure and management organization.[68–70] The 5 national parks nominated in 2021 are combination of some NNRs, provincial nature reserves or natural parks, which haven't determine their detail boundaries yet. Therefore, we used the distributions of species and data for 474 NNRs (https://www.resdc.cn/) established to date to assess conservation effectiveness and gaps of NKPWPs. However, the database does not include nature reserves in Taiwan Province; accordingly, data for 92 nature reserves in Taiwan were downloaded from The World Database on Protected Areas (WDPA, https://www.protectedplanet.net/) database for analysis.

Relationships between species richness and environment factors

We selected 32 variables to explore environmental factors influencing the abundance of NKPWPs in China, including 21 climatic variables (19 bioclimatic and two evapotranspiration variables), six habitat heterogeneity variables (elevation range, mean annual temperature range, mean annual precipitation range, vegetation type, net primary productivity of vegetation, and normalized difference vegetation index), and five human activity variables (population density, gross domestic product, arable land area, road length, and night-time lights).

The 19 bioclimatic variables (1970–2000,WorldClim, version 2.0) were obtained from the WorldClim database (http://www.worldclim.org/) at a spatial resolution of 30 arc-seconds. Data for potential evapotranspiration (PET, mm) and actual evapotranspiration (AET, mm) were downloaded from the CGIAR-CSI website (https://cgiarcsi.community/) with 30 arc-seconds resolution. Elevation range (ER, m) was extracted from Digital Elevation Model (DEM, m) with 30 arc-seconds resolution (http://www.webgis.com/terr_world_02.html). Mean annual temperature range (RMAT, °C) and mean annual precipitation range (RMAP, mm) were extracted from annual mean temperature and mean annual precipitation data. Vegetation type (VEG), net primary productivity of vegetation (NPP, $gC/m^2 \cdot a$), normalized difference vegetation index (NDVI), and nighttime light data were downloaded from the Resource and Environmental Science and Data Centre, Chinese Academy of Sciences (https://www.resdc.cn/), with an accuracy of 1km. Gross domestic product and arable land area were obtained from the National Qinghai-Tibet Plateau Scientific Data Centre (http://data.tpdc.ac.cn/zh-hans/), with an accuracy of 1km. Population density was downloaded from the WorldPop database website (https://hub.worldpop.org/), with an accuracy of 30 arc-seconds. Road length was downloaded from the OpenStreetMap (https://www.openstreetmap.org/) website.

The mean, range, and sum of all variables were evaluated within a 20 × 20 km grid cell using ArcGIS Pro 2.7, followed by normalization. Logarithmic transformation was applied to species richness data. Spatial autocorrelation of species richness was examined using Moran's I, and multicollinearity among environmental variables was removed based on ordinary least squares (OLS) regression and variance inflation factors (VIF). Geographically weighted regression (GWR) models were used to visualize the effects of environmental variables on species richness at different locations.

Prediction of suitable habitat areas for NKPWPs

MaxEnt is the most widely used ecological niche model and accurately predicts the distribution of species with small geographical distribution ranges and limited environmental tolerance.[71,72] MaxEnt (version 3.4.4)[73] was used to predict the present and future suitable distribution areas for NKPWPs. First, species with fewer than five presence locations were excluded. In total, 59,161 locations for 687 species were used for the prediction of potential distribution areas.

Elevation, slope, aspect and 19 historical climate parameters (1970-2000, WorldClim, version 2.0) were used to predict the current potential distribution of NKPWPs. Additionally, 19 bioclimatic variables were used to predict the potential future distributions under four Shared Socio-economic Pathway (SSP) scenarios, based on the BCC-CSM2-MR model from the Coupled Model Intercomparison Project Phase 6 (CMIP6). The resolution of all variables was 30 arc-seconds. To avoid the influence of multicollinearity on model prediction, the caret package[74] in R was used to exclude one of the two variables with Pearson correlation coefficients greater than 0.8. Finally, we obtained eight environmental variables (i.e., BIO2, BIO4, BIO8, BIO14, BIO15, BIO18, slope, and aspect) for the prediction of the present and future potential distributions of NKPWPs (Figure S4).

For all species, cross-validation with 10 replications was used. The jackknife method and response curve were used to assess the importance and contribution of environmental factors to species distributions, and other parameters were set to default values. Finally, the mean value of 10 replications was determined for each species. Grid cells with suitability values greater than 0.75 for each species were extracted in ArcGIS Pro to obtain the suitable distribution area,[75] and the values for the grid cells for all species were summed to obtain the final suitable distribution areas of the NKPWPs.

QUANTIFICATION AND STATISTICAL ANALYSIS

Quantification and statistical analysis are presented in method details.