

## Prediction of Suitable Distribution Areas of *Panzerina lanata* in China under Climate Change: Postprint

**Authors:** Yanfen Zhao, Wang Chuncheng, Pan Borong

**Date:** 2025-10-23T12:01:28+00:00

### Abstract

*Panzerina lanata* possesses significant medicinal and ecological value, playing an important role in maintaining human health and ecosystem balance. To investigate the distribution pattern of suitable habitats for this species and its response to climate change, this study utilized 86 natural distribution points of *P. lanata* and 20 environmental variables to simulate and predict the suitable habitats and their dynamic changes under current and future (2041-2060, 2081-2100) climate change scenarios using the Max Ent model. The importance of key environmental factors was evaluated using a combination of comprehensive contribution rates and the Jackknife method, and the diffusion pathways of *P. lanata* were simulated using the least-cost path method based on chloroplast haplotype data from 27 populations of *P. lanata* and distribution model simulation data from different time periods. The results indicate that: (1) The main environmental factors influencing the geographical distribution of *P. lanata* are maximum temperature of the warmest month, elevation, precipitation of the wettest month, and temperature seasonality. (2) Under current climate conditions, the potential high-suitability habitat area of *P. lanata* in China is approximately  $21.04 \times 10^4$  km<sup>2</sup>, mainly distributed in Ulanqab, Ordos, and eastern Alxa of Inner Mongolia, northern Ningxia, northern Shaanxi, and Gansu Province. (3) Under two typical concentration pathway climate scenarios (SSP1-2.6 and SSP5-8.5) in the future (2081-2100), the total suitable habitat area and high-suitability habitat area of *P. lanata* both show an increasing trend, with its core distribution area still located in Inner Mongolia. The east-west direction along the northern edge of the Mu Us Sandy Land represents an important diffusion pathway during population migration of *P. lanata*, and the connectivity among populations is strongest in the Alxa Left Banner and Ordos regions.

## Full Text

# Predicting the Suitable Distribution Areas of *Panzerina lanata* in China under Climate Change

ZHAO Yanfen<sup>1</sup>, WANG Chuncheng<sup>2</sup>, PAN Borong<sup>3</sup>

<sup>1</sup>College of Resources and Environment, Shanxi University of Finance and Economics, Taiyuan 030006, Shanxi, China

<sup>2</sup>Central South University of Forestry and Technology, Changsha 410004, Hunan, China

<sup>3</sup>Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China

## Abstract

*Panzerina lanata* holds significant medicinal and ecological value, playing an important role in maintaining human health and ecosystem balance. To investigate the distribution patterns of suitable habitats for this species and its response to climate change, this study employed the MaxEnt model to simulate and predict the suitable distribution areas of *P. lanata* under current and future climate scenarios. Based on 86 natural distribution points and 20 environmental variables, we assessed the importance of key environmental factors by combining comprehensive contribution rates with the jackknife method. Additionally, using chloroplast haplotype data from 27 populations and distribution model simulation data from different periods, we simulated the dispersal pathways of *P. lanata* using the least-cost path method. The results indicate: (1) The primary environmental factors influencing the geographical distribution of *P. lanata* are the maximum temperature of the warmest month, elevation, precipitation of the wettest month, and temperature seasonality. (2) Under current climate conditions, the potential highly suitable area for *P. lanata* in China covers approximately  $21.04 \times 10^4 \text{ km}^2$ , mainly distributed in Ulanqab, Ordos, and eastern Alxa in Inner Mongolia, as well as northern Ningxia, northern Shaanxi, and parts of Gansu Province. (3) Under future climate scenarios (2041-2060, 2081-2100), both the total suitable area and highly suitable area of *P. lanata* show an increasing trend, with the core distribution region remaining in Inner Mongolia. The east-west corridor along the northern fringe of the Mu Us Sandy Land represents an important dispersal pathway during population migration, with the strongest connectivity between populations in the Alxa Left Banner and Ordos regions.

**Keywords:** *Panzerina lanata*; climate change; MaxEnt model; potential suitable distribution; dispersal pathway

## Introduction

Global climate change has intensified ecosystem degradation and biodiversity loss, triggering “warming” phenomena in species distributions, altering geograph-

ical ranges, and causing habitat degradation, all of which pose severe challenges to species' adaptive capacities [1]. According to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), global surface temperature is projected to increase by 1.5–4.3°C within the next century [2]. This level of warming will expose species in terrestrial ecosystems to high extinction risks; when the temperature increase reaches 4.3°C, 29.7% of species will face extinction risks [3]. Medicinal plants are important plant resources closely related to human life, playing a significant role in safeguarding human health. However, under the influence of global climate change and intensified human activities, the production areas of authentic medicinal materials in China have shifted, and the number of wild medicinal plant resources has decreased sharply, making population regeneration unsustainable [4]. Predicting suitable habitat changes for medicinal plants under climate change is of great significance for their conservation and sustainable utilization.

Species Distribution Models (SDMs) can estimate species' actual and potential distribution areas and have become a hot tool in research fields such as biogeography and regional ecology [5]. Among numerous distribution models, the Maximum Entropy Model (MaxEnt) has been widely applied in endangered species conservation and invasion biology due to its simple operation and good simulation performance [6], providing a theoretical basis for selecting priority protection areas, investigating plant resource inventories, and introducing cultivation. In recent years, domestic and international scholars have extensively used the MaxEnt model to study the potential suitable distribution areas of medicinal plants, as the model can map spatial distribution ranges based on species distribution points and environmental variable data [7]. However, species distribution models still have certain limitations in identifying species dispersal pathways and geographical isolation barriers. In recent years, with the support of molecular sequencing data, species distribution models can reveal species' potential migration routes and dispersal corridors by integrating genetic sequencing data and SDM simulations, providing new ideas for effective species conservation [8].

*Panzerina lanata* belongs to the Lamiaceae family and is a perennial herb. In China, *P. lanata* is mainly distributed in ecologically fragile regions such as Inner Mongolia, northern Shaanxi, northern Ningxia, and Gansu [9]. The whole plant is used medicinally, possessing important medicinal value [10] and significant ecological functions in windbreak and sand fixation [11]. Due to climate change and human activity destruction in recent years, the wild population of *P. lanata* has gradually decreased and is becoming endangered. Current research on *P. lanata* has mainly focused on chemical composition studies [12], pharmacological activity research [13], and phylogeography [14]. However, studies on the potential geographical distribution range of *P. lanata* and the impact of future climate change on its distribution are limited. Among them, Yang et al. [15] discussed the potential distribution of *P. lanata* in China under current and a single climate scenario based on 19 climatic factors, but large-scale predictions of its potential geographical distribution under multiple extreme emission scenarios and its migration corridors are rarely reported. Therefore, this study

utilized the MaxEnt model to simulate and analyze the suitable distribution range and area changes of *P. lanata* in China under current and future climate scenarios (low emission scenario SSP1-2.6 and high emission scenario SSP5-8.5), exploring the key environmental factors affecting its geographical distribution and potential migration dispersal pathways, to provide a scientific basis for the effective conservation and artificial cultivation of *P. lanata*.

## Methods

### 1.1 Distribution and Sequencing Data Sources

Distribution data for *P. lanata* were obtained from the Global Biodiversity Information Facility (GBIF, <https://www.gbif.org/>), the China National Specimen Resource Platform (<http://www.nsi.org.cn/>), and field surveys. The `dismo` package in R was used to filter the obtained distribution points, retaining only one valid distribution point per  $5 \text{ km} \times 5 \text{ km}$  grid cell for habitat simulation, resulting in 86 distribution data points (Figure 1). The distribution data mainly came from field surveys conducted in 2021, primarily distributed in Inner Mongolia (Hongqinghe Town, Yijinhuluo Banner, Xinjie Town, Tuke Town, Aolezhaoqi Town, Mukainuoer Town, Bayanhaote Town, Duguitala Town, Engebei Town, Saihan Town, Hongshitou Village, Xuejiawan Town, Saiwusu Town, Wusitai Town), Shaanxi (Erlintu Town, Baijie Town, Mahe Town, Jingbian County, Dingbian County), Ningxia (Ningdong Town, Lingwu City), and Gansu (Liangzhou District, Gulang County). Chloroplast gene fragment (*rpoB*) haplotype data were derived from published literature [14].

### 1.2 Environmental Data Sources and Screening

Current and future (2041–2060, 2081–2100) climate data were downloaded from WorldClim (<http://www.worldclim.org/>), including 19 bioclimatic variables (Bio1–Bio19) and elevation data, all at a spatial resolution of 2.5 arc-minutes. Future climate data were selected from the Sixth International Coupled Model Intercomparison Project (CMIP6) under two typical emission scenarios: SSP1-2.6 (low emission scenario) and SSP5-8.5 (high emission scenario).

To reduce multicollinearity among environmental variables, the `Hmisc` package in R was used to calculate Pearson correlation coefficients for all environmental factors. For pairs with  $|r| \geq 0.8$ , the factor with lower contribution was removed based on the species' ecological characteristics [16]. Ultimately, 11 environmental factors were retained as modeling data (Table 1). The regularized training gain of environmental variables on the distribution of *P. lanata* was assessed using the jackknife tool in MaxEnt 3.4.1 software, combined with environmental variable contribution rates and permutation importance values, to comprehensively determine the main environmental variables affecting its distribution.

### 1.3 MaxEnt Model Construction and Result Evaluation

The MaxEnt 3.4.1 model was used to simulate the current and future potential distribution areas of *P. lanata* based on its ecological niche requirements. In model construction, 75% of the data were randomly selected as the training set, with the remaining 25% as the test set, with 10 replicate runs. The Area Under the Receiver Operating Characteristic Curve (AUC) was used to evaluate model prediction accuracy, with values ranging from 0 to 1; values closer to 1 indicate higher prediction accuracy [17]. The current potential geographical distribution simulation results for *P. lanata* in China showed an AUC value of 0.978, indicating good model fit and high prediction accuracy, making it suitable for predicting the potential distribution range of *P. lanata* in China.

### 1.4 Suitable Area Classification and Centroid Migration Analysis

The natural breaks method was used in combination with field survey conditions to classify the suitable distribution areas of *P. lanata* into four categories: highly suitable area (0.6-1.0), moderately suitable area (0.4-0.6), low suitable area (0.2-0.4), and unsuitable area (0-0.2) [18]. Suitable area changes under different climate scenarios were then calculated and statistics compiled. The geometric center of *P. lanata* distribution areas under different climate scenarios was calculated using ArcGIS 10.5 to analyze migration trends of suitable area centroids under climate change, thereby determining spatial pattern changes in its geographical distribution.

### 1.5 Dispersal Pathway Analysis

Based on the least-cost path analysis method, species haplotype data and species distribution simulation data were integrated to visualize the dispersal pathways of *P. lanata* under current and future climate scenarios. First, the ArcGIS reclassification tool was used to convert current and future potential distribution data into a species habitat resistance model. Second, SDMtoolbox v2.0 was used to create cost distance rasters for each sample location using the resistance layer of *P. lanata*. Simultaneously, based on shared haplotypes in the cpDNA data, pairwise comparisons were conducted among populations sharing haplotypes to calculate migration route layers between sites. Finally, all individual path layers were overlaid to visualize the dispersal pathways of *P. lanata*.

## Results

### 2.1 Current Suitable Distribution Areas and Influencing Factors of *P. lanata* in China

Under current climate conditions, the highly suitable area for *P. lanata* covers approximately 2.19% of China's land area, mainly distributed in Ordos, Bayannur, Wuhai City, and eastern Alxa in Inner Mongolia; Shizuishan, Yinchuan, Wuzhong, and Zhongwei in Ningxia; Yulin in Shaanxi; Baiyin in Gansu; and

a small area in the Aksu region of Xinjiang. Except for the Aksu region in Xinjiang, the highly suitable areas align well with field survey results. The moderately suitable area is concentrated at the periphery of highly suitable areas, covering approximately 3.77% of China's land area. The low suitable area is mainly located in eastern Alxa, Bayannur, Baotou, Ulanqab, and Hohhot in Inner Mongolia; Yan'an in Shaanxi; Qingyang in Gansu; northern Shanxi Province; and scattered areas in the Aksu region of Xinjiang (Figure 1, Table 2).

Environmental factors with contribution rates greater than or close to 10% were, in descending order: maximum temperature of the warmest month (30.4%), elevation (26.7%), precipitation of the wettest month (20.5%), and temperature seasonality (18.7%), with temperature-related factors contributing a cumulative 49.1%. Environmental factors with permutation importance values greater than or close to 10% were precipitation of the wettest month, maximum temperature of the warmest month, elevation, and temperature seasonality. The jackknife test further confirmed that these four factors significantly influence *P. lanata* distribution (Figure 3). These results indicate that temperature, precipitation, and elevation are the main environmental variables affecting *P. lanata* distribution.

## 2.2 Future Potential Distribution and Centroid Changes of *P. lanata* in China

Under the two climate scenarios, *P. lanata* suitable areas showed different trends (Figure 4). From current to low-emission scenario SSP1-2.6 during 2041-2060, the total suitable area increased by 12.6%, with highly suitable area increasing by 13.2% and moderately and low suitable areas decreasing. During 2081-2100 under SSP1-2.6, the total suitable area increased by 15.8% compared to current, with highly suitable area increasing by 17.4% and moderately and low suitable areas showing increasing trends. From current to high-emission scenario SSP5-8.5 during 2041-2060, the total suitable area increased by 13.5%, but highly suitable area decreased by 2.1% while moderately and low suitable areas increased slightly. During 2081-2100 under SSP5-8.5, the total suitable area increased by 16.3% compared to current, with highly suitable area increasing by 15.5% and moderately and low suitable areas showing increasing trends (Table 2). With climate warming, both total suitable area and highly suitable area of *P. lanata* maintain relatively stable trends, with distribution still primarily in current provinces.

The centroid of current suitable areas for *P. lanata* is located in Otog Banner. Under future climate scenarios, centroid migration distances vary between the two scenarios. Under SSP1-2.6, from current to 2041-2060, the centroid migrates northeast; by 2081-2100, it migrates northwest. Under SSP5-8.5, from current to 2041-2060, the centroid migrates northeast; by 2081-2100, it migrates southwest (Figure 5).

### 2.3 Dispersal Pathways of *P. lanata*

Under current climate conditions, *P. lanata* primarily disperses from east to west along the northern fringe of the Mu Us Sandy Land. Under future climate scenarios, *P. lanata* continues this east-west dispersal pattern along the northern fringe of the Mu Us Sandy Land, though the magnitude of migration decreases significantly. Alxa Left Banner and Ordos serve as important pathways connecting eastern and western populations of *P. lanata*, with the strongest connectivity between populations in these regions.

## Discussion

### 3.1 Influence of Environmental Factors on the Potential Geographical Distribution of *P. lanata*

In China's arid regions, the richness of perennial herbaceous plants is mainly affected by precipitation, temperature, and soil nutrients [19], though different species respond differently to climate change [20]. This study shows that the main environmental factors affecting *P. lanata* distribution, in order of contribution rate, are maximum temperature of the warmest month, precipitation of the wettest month, elevation, and temperature seasonality. The cumulative contribution rate of temperature factors approaches 50%, and precipitation contributes 26.7%, consistent with Yang et al. [15], confirming that temperature and precipitation are the dominant environmental factors affecting *P. lanata* distribution, which also aligns with its ecological characteristics of preferring warmth and tolerating humidity [21]. Additionally, elevation is an important factor affecting potential distribution, with a contribution rate of 20.5%. *P. lanata* is mainly distributed on sandy lands at 900–1350 m elevation, with field surveys finding most populations at 1000–1400 m, consistent with jackknife validation results. Overall, climatic factors (temperature and precipitation) and elevation jointly play important roles in the suitable distribution of *P. lanata*.

This study focused on the effects of environmental factors and elevation on the potential geographical distribution of *P. lanata*, without considering soil factors, human activities, or interspecies interactions. Therefore, subsequent studies should incorporate more biotic and abiotic factors to improve model prediction accuracy and more accurately assess the potential distribution range of *P. lanata* under climate change scenarios.

### 3.2 Geographical Distribution Patterns of *P. lanata* under Different Climate Scenarios

Previous studies have shown that herbaceous plants, with shorter generation cycles than woody plants, are more flexible in changing climates and have stronger adaptability to climate change [22]. Currently, the highly suitable areas for *P. lanata* are mainly concentrated in Inner Mongolia, with small distributions in northern Ningxia, northern Shaanxi, and parts of Gansu. Under future cli-

mate scenarios, the potential distribution of *P. lanata* remains primarily in current distribution regions, with no significant changes in total suitable area and highly suitable area compared to current conditions. This is basically consistent with Yang et al. [15], though the predicted potential suitable area in this study is smaller than in some related studies, possibly due to differences in selected environmental factors and suitable area classification standards. Under the low-emission scenario SSP1-2.6, the highly suitable area of *P. lanata* shows an increasing trend compared to current conditions. Under the high-emission scenario SSP5-8.5, the highly suitable area decreases during 2041–2060 but increases during 2081–2100, with new suitable areas emerging in Alxa Left Banner, Bayannur, Baotou, Ulanqab in Inner Mongolia, and Shaanxi Province.

Under both climate scenarios, the suitable area of *P. lanata* increases compared to current conditions, possibly related to the warming and wetting trend in northwestern arid regions of China under global warming [23], with potential suitable areas of *P. lanata* increasing with changes in temperature and precipitation. This also suggests that climate warming has a positive effect on *P. lanata* distribution, potentially providing more habitats for future colonization. The centroid migration results show that under different emission scenarios, the distribution center of *P. lanata* will migrate to higher altitude areas by 2081–2100, possibly related to increasing precipitation in western Ordos in the future, allowing *P. lanata* to disperse and migrate to this region.

Affected by climate change, many desert plants in northwestern China show large-scale population expansion along deserts and Gobi [24]. *P. lanata* grows well in sandy environments of desert areas and typical steppes, especially on gravelly plains and dry riverbeds. The dispersal pathways obtained through least-cost path analysis are consistent with its suitable distribution areas, with the northern fringe of the Mu Us Sandy Land becoming an important dispersal corridor. Under current climate conditions, *P. lanata* disperses westward along Alxa Left Banner and eastward to western Ordos along the optimal corridor. Migration corridors connecting fragmented habitats can increase gene flow among populations in different habitats, thereby increasing species genetic diversity [25]. Populations distributed in the Alxa Left Banner and Ordos regions have low genetic diversity, while populations around Helan Mountain have high genetic diversity [14]. Therefore, maintaining migration corridors between eastern and western highly suitable areas and connecting fragmented populations through dispersal pathways is essential for scientifically and effectively protecting wild resources and genetic diversity of *P. lanata*. We recommend establishing priority nature conservation areas in highly suitable regions of Alxa Left Banner and Ordos in Inner Mongolia to implement in-situ conservation measures, addressing resource depletion and genetic erosion of *P. lanata* caused by climate change and human activities, thereby protecting biodiversity and ecological stability in northwestern arid regions. This study simulated dispersal pathways of *P. lanata* based on only two chloroplast fragments, which may have limitations; future studies should consider multi-source data to improve the accuracy of dispersal pathway inference.

## Conclusion

The main environmental factors affecting the geographical distribution of *P. lanata* are the maximum temperature of the warmest month, temperature seasonality, and precipitation of the wettest month, with elevation also exerting a synergistic effect. Currently, the potential suitable areas of *P. lanata* are mainly distributed in ecologically vulnerable regions of northwestern China, including Inner Mongolia, Ningxia, Shaanxi, and Gansu. Under future climate scenarios (2041–2100) for both low-emission and high-emission pathways, the potential distribution range of *P. lanata* remains primarily in current provinces, with both total suitable area and highly suitable area showing increasing trends compared to current conditions. The core distribution area is located in Inner Mongolia, where the east-west corridor along the northern fringe of the Mu Us Sandy Land (Alxa Left Banner and Ordos region) represents an important dispersal corridor during population migration. Based on these findings regarding suitable area changes and dispersal pathways, this study proposes conservation strategies for the wild resources of this species.

## References

- [1] Fang Jingyun, Zhu Jiangling, Shi Yue. The responses of ecosystems to global warming[J]. Chinese Science Bulletin, 2018, 63(2): 136-140.
- [2] Urban M C. Climate change extinctions[J]. Science, 2024, 386(6726): 1123-1128.
- [3] IPCC AR6. Future global climate based on projection under scenarios and on near-term information[J]. Climate Change Research, 2021, 17(6): 652-663.
- [4] Sun Meng, Zhang Zilong. Research progress in medicinal plants response to climate change[J]. Journal of Biology, 2015, 32(5): 84-88.
- [5] Li Guoqing, Liu Changcheng, Liu Yuguo, et al. Advances in theoretical issues of species distribution models[J]. Acta Ecologica Sinica, 2013, 33(16): 4827-4835.
- [6] Ouyang Zeyi, Ouyang Shulong, Wu Jiyu, et al. Progress of the application of prediction of potential suitable distribution of plants based on Maxent[J]. Hunan Forestry Science & Technology, 2022, 49(1): 83-88.
- [7] Guo Yanlong, Zhao Zefang, Qiao Huijie, et al. Challenges and development trend of species distribution model[J]. Advances in Earth Science, 2020, 35(12): 1292-1305.
- [8] Yu Haibin, Zhang Yili, Li Shicheng, et al. Predicting the dispersal routes of alpine plant *Pedicularis longiflora* (Orobanchaceae) based on GIS and species distribution models[J]. Chinese Journal of Applied Ecology, 2014, 25(6): 1669-1673.

- [9] Zhao Yizhi, Zhao Liqing, Cao Rui. *Flora Intramongolica*[M]. Hohhot: Inner Mongolia People's Press, 2020: 220-221.
- [10] Lei Qifen, Zhao Xiangpei, Zhu Dan. Progress of Mongolian herb *Panzeria alaschanica* in chemical components and clinical application[J]. *China Journal of Traditional Chinese Medicine and Pharmacy*, 2017, 32(7): 3083-3085.
- [11] Zheng Yafu, Yin Wei, Lin Lili, et al. Advances in studies on *Panzeria alaschanica*[J]. *Chinese Traditional and Herbal Drugs*, 2007, 38(9): 1434-1436.
- [12] Zhao Yizhi. *Rare and Endangered Plants in Inner Mongolia*[M]. Beijing: China Agricultural Science and Technology Press, 1992: 56.
- [13] Mi Yingying. *Study on Pharmacognosy and Anti-inflammatory Activity of Mongolian Medicine Panzerina alaschanica*[D]. Beijing: Minzu University of China, 2021.
- [14] Zhao Y F, Zhang H X, Pan B R, et al. Intraspecific divergences and phylogeography of *Panzerina lanata* (Lamiaceae) in Northwest China[J]. *PeerJ*, 2019, 7: e6264.
- [15] Yang Kang, Zhao Xiangpei, Zhang Xun, et al. Prediction of potential distribution of Mongolian medicine *Panzerina lanata* based on MaxEnt niche model[J]. *Journal of Chinese Medicinal Materials*, 2021, 44(8): 1827-1831.
- [16] Zhu Biao. *Variation Characteristics of Vapor, Potential Evapotranspiration and Extreme Temperature and Precipitation under the Background of Warming-wetting in Northwest China*[D]. Lanzhou: Lanzhou University, 2023.
- [17] Phillips S J, Dudík M. Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation[J]. *Ecography*, 2008, 31(2): 161-175.
- [18] Brown J L, Bennett J R, French C M. SDMtoolbox 2.0: The next generation python based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses[J]. *PeerJ*, 2017, 5: e4095.
- [19] Yao S R, Wei G H, Ming F J, et al. Distribution, species richness, and relative importance of different plant life forms across drylands in China[J]. *Plant Diversity*, 2025, 47(2): 273-281.
- [20] Wang Siyu, Wu Jianguo. Research progress on the changes in geographical distributions of plant species under future climate change scenarios in China[J]. *Guihaia*, 2025, 45(3): 500-516.
- [21] Cheryomushkina V A, Astashenkov A Y. Morphological adaptation of *Panzerina sojak* (Lamiaceae) species to various ecological conditions[J]. *Contemporary Problems of Ecology*, 2014, 7(5): 520-525.
- [22] Sun Y, Sun Y, Yao S R, et al. Impact of climate change on plant species richness across drylands in China: From past to present and into the future[J]. *Ecological Indicators*, 2021, 132: 108288.

- [23] Ding Yihui, Liu Yanju, Xu Ying, et al. Regional responses to global climate change: Progress and prospects for trend, causes, and projection of climatic warm-wetting in Northwest China[J]. *Advances in Earth Science*, 2023, 38(6): 551-562.
- [24] Qiu J S, Zhang J W, Wang Y N. PPDC: An online platform for the prediction of plant distributions in China[J]. *Journal of Plant Ecology*, 2024, 17(6): 1-11.
- [25] Rana H K, Luo D, Rana S K, et al. Geological and climatic factors affect the population genetic connectivity in *Mirabilis himalaica* (Nyctaginaceae): Insight from phylogeography and dispersal corridors in the Himalaya-Hengduan biodiversity hotspot[J]. *Frontiers in Plant Science*, 2020, 10: 1721.
- [26] Zhang Dan, Ma Songmei, Wei Bo, et al. Historical distribution pattern and driving mechanism of *Haloxylon* in China[J]. *Biodiversity Science*, 2022, 30(1): 42-51.
- [27] Ma S M, Nie Y B, Jiang X L, et al. Genetic structure of the endangered, relict shrub *Amygdalus mongolica* (Rosaceae) in arid Northwest China[J]. *Australian Journal of Botany*, 2019, 67(2): 128-139.
- [28] Sun Zhixia. Dispersal Corridors for Plant Species in Poyang Lake Basin Identified by Integration of Genetic and Geospatial Data[D]. Nanchang: Jiangxi Agricultural University, 2017.
- [29] Fan Yuke, Ren Ju, Wang Runlong, et al. Prediction of potential suitable distribution area of *Pinus bungeana* in China under the background of climate change[J]. *Arid Zone Research*, 2024, 41(10): 1719-1730.
- [30] Yang Z B, Bai Y, Alatalo J M, et al. Spatio-temporal variation in potential habitats for rare and endangered plants and habitat conservation based on the maximum entropy model[J]. *Science of the Total Environment*, 2021, 784: 147080.
- [31] Qu Yuyang, Wen Tiantian, Liu Jiamin, et al. Potential geographic distribution of the three species of *Cuscuta* in China under climate scenarios[J]. *Arid Zone Research*, 2025, 42(1): 97-107.
- [32] Cha Suna, Qi Bore, Hu Hongxia, et al. Prediction of the potential distribution area of endangered medicinal plant *Gymnadenia conopsea* in China under the background of climate change[J]. *Chinese Journal of Applied Ecology*, 2024, 35(11): 3023-3030.
- [33] Wang Qingli, Wang Rulin, Zhang Liping, et al. Climatic ecological suitability and potential distribution of *Tricholoma matsutake* in western Sichuan Plateau, China based on MaxEnt model[J]. *Chinese Journal of Applied Ecology*, 2021, 32(7): 2525-2533.
- [34] Chen Yuguang, Le Xingui, Chen Yuhan, et al. Identification of potential distribution area of *Cunninghamia lanceolata* in China under climate change

based on the MaxEnt model[J]. Chinese Journal of Applied Ecology, 2022, 33(5): 1207-1214.

[35] Zhuo Z H, Xu D P, Pu B, et al. Predicting distribution of *Zanthoxylum bungeanum* Maxim. in China[J]. BMC Ecology, 2020, 20(1): 1-11.

[36] Zhao X F, Lei M, Wei C H, et al. Assessing the suitable regions and the key factors for three Cd-accumulating plants (*Sedum alfredii*, *Hylotelephium spectabile*, and *Phytolacca americana*) in China using MaxEnt model[J]. Science of the Total Environment, 2022, 852: 158202.

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv –Machine translation. Verify with original.*