Predicting Suitable Habitat for Tetraena mongolica and GAP Analysis with Protected Areas: A Post-print

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Abstract

Clarifying the potential distribution areas of species and their gaps with current nature reserves is of great significance for rationally and efficiently conducting endangered species protection. To predict the distribution range of Tetraena mongolica in the contemporary period (2020s) and future (2060s, 2100s), as well as the current protection status of nature reserves for T. mongolica, this study utilized the maximum entropy model (MaxEnt) combined with 23 environmental variables to predict its potential suitable habitat in western Ordos of Inner Mongolia Autonomous Region and Ningxia Hui Autonomous Region, and conducted a conservation gap analysis with current T. mongolica nature reserves. The results showed: (1) The area under the receiver operating characteristic curve of the MaxEnt model was 0.977, indicating accurate predictions. (2) The primary environmental factor affecting the distribution of T. mongolica was precipitation in the wettest month, followed by precipitation in the driest month, distance to roads, isothermality, mean temperature of the coldest quarter, and slope. (3) The current suitable area for T. mongolica within the study region was 4,717 km^2; the potential distribution area of T. mongolica contracted from the 2020s to 2100s and shifted toward the northwest. (4) Based on the conservation gap analysis, only 14.88% of the suitable habitat for T. mongolica currently lies within protected areas, with large areas of suitable T. mongolica habitat not designated as nature reserves; these areas are mainly concentrated in Wuhai City of Inner Mongolia and Hanggin Banner of Ordos City. The research results aim to provide scientific guidance for the conservation of T. mongolica and the construction of its nature reserves.

Full Text

Preamble

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Potential Habitat Prediction of Tetraena mongolica and Its GAP Analysis with Nature Reserves

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Abstract: Clarifying the potential distribution of species and identifying gaps with current nature reserves is essential for rational and efficient conservation of endangered species. To predict the distribution range of *Tetraena mongolica* under contemporary (2020s) and future (2060s, 2100s) climate scenarios, and to assess the current conservation status within nature reserves, this study utilized the Maximum Entropy model (MaxEnt) with 23 environmental variables to predict potential suitable habitats in western Ordos, Inner Mongolia and Ningxia Hui Autonomous Region. A conservation gap analysis was then conducted with existing *T. mongolica* nature reserves. Results showed: (1) The area under the receiver operating characteristic curve (AUC) for the MaxEnt model was 0.977, indicating high prediction accuracy. (2) The primary environmental factor influencing *T. mongolica* distribution was precipitation in the wettest month, followed by precipitation in the driest month, distance from roads, isothermality, mean temperature of the coldest quarter, and slope. (3) The current suitable habitat area for *T. mongolica* in the study region was 4,717 km^2. (4) From the 2020s to 2100s, the potential distribution area contracted and shifted northwestward. (5) Based on gap analysis, only 14.88% of suitable habitats currently fall within protected areas, with large expanses of suitable habitat remaining unprotected, concentrated primarily in Wuhai City and Hangjin Banner of Ordos City. These findings provide scientific guidance for *T. mongolica* conservation and nature reserve planning.

Keywords: *Tetraena mongolica*; MaxEnt model; potential suitable area; GAP analysis

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Introduction

Faced with the severe prospect of a "sixth mass extinction," a critical component of biodiversity conservation is the rescue of endangered species. Climate change affects species carrying capacity in a given region, influences population dynamics and species geographic distribution, and drives patterns of biodiversity. Consequently, the impact of climate change on biodiversity has become a research hotspot. Predicting the potential distribution of endangered species under climate change scenarios provides important reference value for rational conservation planning.

Species distribution models are essential tools for studying how suitable habitats respond to climate change. These models estimate potential distribution areas that meet species' ecological requirements by analyzing geographic distribution data and environmental variables. Globally applied species distribution models include ecological niche factor analysis, genetic algorithm for rule-set production, regional environmental models, bioclimatic models, and maximum entropy models. Among these, MaxEnt (Maximum Entropy model software) demonstrates high prediction accuracy and can achieve relatively accurate results even with limited target species distribution points. Environmental factors for species distribution prediction typically include three categories: (1) climate factors such as temperature and precipitation; (2) topographic factors including elevation, slope, and aspect; and (3) human disturbance factors, often represented by distance from roads.

Establishing nature reserves for in-situ conservation is the most effective method for biodiversity protection, preserving ecosystem diversity, species diversity, and genetic diversity. However, the rationality of nature reserve planning requires clarification of species' potential distribution areas. MaxEnt models have been widely applied in endangered species conservation research. For example, Wan et al. effectively delineated priority conservation areas for *Taxus cuspidata* under climate change pressure, providing conservation solutions and evaluating the contribution of existing nature reserves.

Tetraena mongolica is a relict endangered plant from the ancient Mediterranean flora, designated as a second-class nationally protected plant in China, and celebrated as a "living fossil" and the "giant panda" of the plant kingdom. Numerous scholars have conducted extensive research on *T. mongolica* conservation, including molecular marker development, population genetic structure, community composition, and species diversity. Studies have shown significant differences in seedling growth and photosynthetic rates under different climate conditions, confirming climate as a key factor affecting its distribution. Currently, two nature reserves have been established to protect *T. mongolica*: the Helan Mountain Nature Reserve and the West Ordos Nature Reserve. However, the rationality of these reserves under current and future climate change remains unclear. Therefore, based on current distribution data and meteorological data, this study employed MaxEnt software and GIS 10.8.1 spatial analysis technology to identify dominant environmental factors affecting *T. mongolica* distribution, model its potential distribution range under current (2020s) and future (2060s, 2100s) climate scenarios, and conduct a protection gap analysis with current nature reserves to provide guidance for conservation planning.

1 Study Area

The study area encompasses western Ordos in Inner Mongolia (106°43 –111°27 E, 39°23 –49°51 N) and Ningxia Hui Autonomous Region (104°17 –107°39 E, 35°14°–37°35 N). The region has a temperate continental climate with an average annual temperature of 6–9°C, average annual precipitation of 150–330 mm, and a frost-free period of 120–180 days. The northern part consists of the Urad Grassland, the southern area lies within the Yellow River system, the western part is the western foothills of the Helan Mountains, and the eastern part is the Ordos Plateau. The region is rich in natural forest resources, dominated by natural shrub forests including *Tetraena mongolica*, *Zygophyllum xanthoxylon*, *Ammopiptanthus mongolicus*, and *Nitraria tangutorum*. *T. mongolica* is mainly distributed in western Ordos City, Wuhai City, southern Bayannur, eastern Alxa, and Shizuishan City in Ningxia. Two national *T. mongolica* nature reserves are located within the study area: the Helan Mountain Nature Reserve and the West Ordos Nature Reserve, both established in 1992 and upgraded to national-level reserves in 1995.

2 Methods

2.1 Sample Data Acquisition and Processing

Current distribution samples of *T. mongolica* were identified through literature retrieval. Using the keyword "Tetraena mongolica" in CNKI (China National Knowledge Infrastructure), 42 papers were retrieved as of December 31, 2021, with 16 papers containing detailed sample location information (Table 1). A total of 42 *T. mongolica* sample records with longitude, latitude, and elevation data were obtained and used as actual distribution data for MaxEnt software (Figure 1).

[Figure 1: see original paper]

2.2 Environmental Variable Data Acquisition

This study employed 23 environmental factors across three categories. First, 19 climate factors related to temperature and precipitation under current and future climate conditions (Table 2) were obtained from the WorldClim global climate database (http://www.worldclim.org) at 2.5-minute resolution for contemporary (1970–2000) and future periods. Second, three topographic factors were included: elevation, aspect, and slope. Elevation data were downloaded from the Geospatial Data Cloud (http://www.scloud.cn), with slope and aspect derived from elevation data using ArcGIS spatial analysis tools. Third, distance from roads was used as a human disturbance factor, obtained from the National Geographic Information Resources Directory Service System (https://www.webmap.cn) at 1:1,000,000 scale. Road vector data were processed in ArcGIS using Euclidean distance calculations to determine the shortest distance from each sample point to roads. All environmental variables were resampled into ASCII raster format and unified under the WGS1984 projection coordinate system.

2.3 Nature Reserve Data

Nature reserve data for *T. mongolica* were obtained from the Resources and Environmental Sciences and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn). Two *T. mongolica* nature reserves exist within the study area: the West Ordos Nature Reserve located in western Otog Banner and Wuhai City of Inner Mongolia, and the Ningxia Helan Mountain National Nature Reserve situated on the eastern slope of the Helan Mountains in western Ningxia. The nature reserve boundaries were overlaid with the suitable habitat map to identify suitable habitats not included within protected areas.

2.4 MaxEnt Model Construction

To avoid overfitting, a 10 km buffer zone was established around species distribution points, removing redundant points within buffers, resulting in 42 filtered distribution points. The model used 75% of distribution points as training data and 25% as test data. Model prediction accuracy was evaluated using the area under the receiver operating characteristic curve (AUC). The jackknife method was used to determine the weight of each environmental factor.

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3 Results

3.1 Model Evaluation and Prediction Accuracy

The receiver operating characteristic (ROC) curve in MaxEnt reflects model accuracy, with the area under the curve (AUC) ranging from 0 to 1. Values closer to 1 indicate higher precision. An AUC of 0.5–0.6 indicates poor predictive performance; 0.6–0.7 indicates poor results; 0.7–0.8 indicates average results; 0.8–0.9 indicates good results; and >0.9 indicates excellent accuracy. The AUC for *T. mongolica* prediction was 0.977, demonstrating high model accuracy suitable for assessing habitat suitability in the study area.

3.2 Environmental Factors Affecting Habitat

The contribution rates of environmental factors affecting *T. mongolica* distribution were analyzed. Precipitation in the wettest month showed the highest contribution rate (22.9%), followed by precipitation in the driest month, distance from roads, isothermality, mean temperature of the coldest quarter, and slope. The top six factors accounted for over 85% of total contribution. Response curves revealed the optimal environmental conditions: precipitation in the wettest month of 30–70 mm, higher precipitation in the driest month, isothermality of 25%–29%, and mean temperature of the coldest quarter below 0.192–0.462°C.

[Figure 2: see original paper]

[Figure 3: see original paper]

3.3 Potential Suitable Distribution Range

Natural breaks classification was used to categorize four types of suitable habitats, with the most suitable and moderately suitable habitats collectively defined as suitable habitats. The total suitable habitat area for *T. mongolica* was 4,717 km^2 under current conditions. From the 2020s to 2100s, the suitable area showed a trend of initial decrease followed by slight increase: decreasing from 4,717 km^2 in the 2020s to 4,556 km^2 in the 2060s, then increasing to 4,678 km^2 in the 2100s. The most suitable habitat area decreased from 1,665 km^2 in the 2020s to 1,461 km^2 in the 2060s, then increased to 1,604 km^2 in the 2100s. Moderately suitable habitat decreased from 3,052 km^2 in the 2020s to 3,095 km^2 in the 2060s, then decreased further to 3,074 km^2 in the 2100s. Overall, the potential distribution area contracted and shifted northwestward under future climate scenarios.

[Figure 4: see original paper]

3.4 GAP Analysis of Nature Reserves

Conservation gap analysis revealed that only 14.88% of suitable habitats were located within nature reserves in the 2020s, leaving 85.12% unprotected. These gaps were concentrated in Wuhai City and Hangjin Banner of Ordos City. In the 2060s, 16.75% of suitable habitats were protected, with 83.25% outside reserves. In the 2100s, 16.82% were protected, with 83.18% remaining unprotected.

[Figure 5: see original paper]

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4 Discussion

Biodiversity Conservation Implications

Tetraena mongolica plays an irreplaceable role in local ecological protection and ecosystem stability. In recent years, intense human disturbances including mining, logging, grazing, land development, and urbanization, combined with simple community structure and fragile ecosystems, have caused habitat islandization, leading to reduced distribution area, declining population numbers, and deteriorating age structure. This study found that precipitation in the wettest month is the dominant factor affecting suitable habitat distribution, consistent with studies on other drought-resistant plants in arid regions such as *Hippophae* *rhamnoides* and *Picea meyeri*. Precipitation patterns significantly impact vegetation growth and distribution, confirming the critical role of moisture for *T. mongolica*.

Climate change impacts on species distribution are widely documented. Ran et al. demonstrated similar effects on relict plants, while Wu et al. showed that desert plant ranges may initially expand then contract under climate change. This study indicates that *T. mongolica* suitable habitat will contract and shift northwestward, likely due to regional warming and drying trends in Inner Mongolia that align with the species' growth characteristics.

The gap analysis reveals that only 14.88% of suitable habitats are currently protected, with large unprotected areas in Wuhai City and Hangjin Banner. These regions feature dense road networks, extensive farmland, and frequent human activity, making reserve establishment challenging and potentially costly with limited effectiveness. Hangjin Banner contains high-quality farmland where conversion to conservation could impact local economies. Therefore, conservation strategies should protect *T. mongolica* without compromising economic development or local livelihoods through targeted, site-specific measures.

Conservation Recommendations

1. **Adjust Reserve Boundaries**: Fill conservation gaps in Wuhai City and Hangjin Banner to reduce destruction from mining, logging, grazing, and urbanization. When constructing roads or cultivating within reserves, avoid occupying *T. mongolica* habitats and maintain connectivity between populations.

2. **Climate-Adaptive Management**: Adjust reserve boundaries according to climate-driven northwestward shifts in suitable habitat. Consider ex-situ conservation for populations in areas becoming unsuitable.

3. **Long-term Monitoring**: Integrate *T. mongolica* plots into monitoring systems using GPS, remote sensing, and GIS technologies to track growth status, assess environmental changes, and establish genetic resource banks.

4. **Policy and Enforcement**: Strengthen legal frameworks and management measures, remove illegal factories and enterprises from reserves, and use modern media to raise public awareness about *T. mongolica* conservation.

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5 Conclusions

This study employed ArcGIS spatial analysis and MaxEnt modeling to evaluate environmental variables affecting *Tetraena mongolica* distribution and predict suitable range changes through 2100s. Key conclusions include:

1) The MaxEnt model demonstrated high accuracy (AUC = 0.977) and is widely applicable for predicting and evaluating habitat selection factors and suitable area distribution for *T. mongolica*.
2) Appropriate precipitation is the primary factor affecting *T. mongolica* growth, with precipitation in the wettest month being the most critical environmental variable.
3) From the 2020s to 2100s, suitable habitat area will first decrease then slightly increase, but remain below current levels overall, with distribution contracting and shifting northwestward.
4) Conservation gap analysis indicates that only 14.88% of suitable habitats are currently protected. We recommend incorporating suitable habitats in Wuhai City and Hangjin Banner of Ordos City into the nature reserve system.

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