Postprint: Prediction of Potential Suitable Habitat for Arnebia euchroma in China under Climate Change

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Date: 2025-10-23T12:01:42+00:00

Abstract

This study investigates the potential suitable habitat distribution and ecological adaptability of Arnebia euchroma in China, aiming to provide a theoretical basis for the conservation and rational development and utilization of wild plant resources of A. euchroma. Based on the MaxEnt model and ArcGIS software, this research predicts the potential suitable habitats using 51 distribution points and 11 environmental factors for A. euchroma in China, explores the main environmental factors influencing its distribution, and forecasts its potential suitable habitats under current (1970–2000) and future (2021–2040, 2041–2060) climate scenarios. The results indicate that mean temperature of the wettest quarter (bio8), precipitation seasonality (bio15), mean precipitation of the warmest quarter (bio18), and elevation (elev) are the dominant environmental factors affecting the distribution of A. euchroma, with contribution rates of 36.2%, 13.9%, 10.1%, and 8.5%, respectively. Under current climate conditions, A. euchroma is mainly distributed in central Xinjiang and northwestern Tibet, with a total potential suitable habitat area of 96.26$×10^{4}$ km^2. Compared with the current period, the distribution of potential suitable habitats shows no significant change under four future climate scenarios, with the total suitable area showing a decreasing trend, while the area of highly suitable habitat slightly increases.

Full Text

Preamble

Arid Zone Research Vol. 42 No. 9 Sep. 2025

Prediction of Potential Suitable Areas for *Arnebia euchroma* in China Under Climate Change

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Abstract

This study investigated the potential distribution and ecological adaptability of *Arnebia euchroma* in China to provide a theoretical basis for the conservation and rational utilization of this wild plant resource. Using MaxEnt and ArcGIS software, we predicted potential suitable habitats based on 51 distribution points and 11 environmental factors across China, examined the dominant environmental factors influencing its distribution, and projected potential suitable areas under current (1970-2000) and future (2021-2040, 2041-2060) climate scenarios. The results demonstrated that mean temperature of the wettest quarter (bio8), precipitation seasonality (bio15), precipitation of the warmest quarter (bio18), and elevation were the primary environmental determinants, with contribution rates of 36.2%, 13.9%, 10.1%, and 8.5%, respectively. Under current climate conditions, *A. euchroma* is mainly distributed in central Xinjiang and northwestern Tibet, with a total potential suitable area of 96.26$×10^{4}$ km^2. Compared with the present, future climate scenarios showed no significant shift in distribution patterns, though the total suitable area decreased while the highly suitable area increased slightly.

Keywords: *Arnebia euchroma*; MaxEnt; potential suitable area prediction; climate change

Introduction

Climate change has emerged as one of the most pressing environmental challenges of the 21st century. Persistent increases in greenhouse gas emissions have driven significant global temperature rises, triggering a cascade of environmental problems including more frequent extreme weather events, sea-level rise, and accelerated glacier melting. These changes not only threaten human societies but also profoundly impact ecological balance, biodiversity, and species distributions. As climate shifts, species may no longer tolerate the environmental conditions in their historic ranges, leading to altered geographic distributions, population sizes, and genetic diversity patterns. For instance, warming temperatures and increasing precipitation have caused climate zones to shift poleward, pushing zonal vegetation boundaries toward higher latitudes or elevations. Consequently, some species have experienced range contraction, with endangered species facing heightened extinction risks. Predicting potential suitable habitats and identifying key ecological drivers under global climate change is therefore crucial for developing effective conservation strategies.

Species Distribution Models (SDMs) serve as essential tools for understanding spatial distribution patterns, potential suitable areas, and environmental drivers of species distributions. By integrating species occurrence data with climatic information and applying specific algorithms, SDMs can predict potential habitats and identify ecological factors influencing species distributions, thereby informing scientific management and conservation planning. Among these models, the Maximum Entropy (MaxEnt) ecological niche model stands out for its simple assumptions, operational convenience, minimal sensitivity to sample size, and robust stability. Requiring only species occurrence points and corresponding environmental data, MaxEnt has been widely applied to predict potential distributions of invasive plants, rare and endangered species, and medicinal plants. For example, Du et al. predicted the potential suitable areas for the invasive plant *Bidens frondosa* under different climate scenarios to inform early warning systems and integrated management. Chen et al. identified suitable habitats for the endangered wild lotus (*Nelumbo nucifera*), providing references for artificial transplantation and conservation. Lin et al. evaluated habitat suitability for the medicinal plant *Hedysarum polybotrys*, revealing that elevation, precipitation, and seasonal solar temperature variation were key factors, thereby guiding cultivation planning and resource protection.

Arnebia euchroma is a perennial herbaceous plant in the Boraginaceae family, commonly known as Xinjiang purple grass. In China, it occurs exclusively in Xinjiang and Tibet, typically inhabiting gravelly slopes, alluvial fans, grasslands, and meadows. The species exhibits excellent cold, drought, and barren tolerance. Its roots are widely used in traditional medicine for clearing heat, cooling blood, detoxification, and antibacterial purposes, making it a valuable medicinal resource both domestically and internationally. *A. euchroma* is officially listed as a medicinal source in the *Pharmacopoeia of the People' s Republic of China*. However, escalating market demand has led to overexploitation, causing a dramatic decline in wild populations. The species is now classified as a nationally protected second-class wild plant. Understanding its spatial distribution and dynamics under current and future climate scenarios is fundamental for developing effective conservation strategies. This study compiled distribution points and environmental data for *A. euchroma* across China, employing MaxEnt and ArcGIS to model potential suitable areas under current (1970–2000) and future climate scenarios (2021–2040, 2041–2060), and to identify dominant environmental factors influencing its distribution. The findings aim to support resource conservation, artificial cultivation, and sustainable utilization of *A. euchroma*.

Materials and Methods

1.1 Species Distribution Data Acquisition and Processing

Distribution data for *A. euchroma* were obtained from the National Plant Specimen Resource Center (NPSRC, https://www.cvh.ac.cn), the Global Biodiversity Information Facility (GBIF, https://www.gbif.org), relevant literature, and field surveys conducted by our research team. After initial collection, duplicate records were removed, yielding 51 distribution points across China. To avoid model overfitting from multiple points within the same grid cell, we performed spatial autocorrelation analysis using the "Spatially Rarefy Occurrence Data for SDMs" tool in ArcGIS with a 2.5 km resolution, retaining 51 spatially independent occurrence points for subsequent analysis [Figure 1: see original paper].

1.2 Environmental Variable Acquisition and Screening

Current environmental data (1970–2000) and future climate projections (2021–2040, 2041–2060) were sourced from WorldClim (www.worldclim.org), including 19 bioclimatic variables and elevation data at 2.5 km resolution. Using ArcGIS, we derived three topographic variables (slope, aspect, and elevation) from the digital elevation model. Assuming topographic factors remain constant over the coming decades, we used current topographic data for all future scenarios. Future climate data were selected from the medium-resolution climate model BCC-CSM2-MR under the sixth phase of the Coupled Model Intercomparison Project (CMIP6), encompassing four Shared Socioeconomic Pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5). To reduce multicollinearity, we performed Pearson correlation analysis on the 19 bioclimatic and 3 topographic variables in SPSS 25.0. When correlation coefficients exceeded $|0.80|$, we retained the variable with higher contribution in the MaxEnt model. This process selected seven variables: mean diurnal temperature range (bio2), temperature seasonality (bio4), max temperature of the warmest month (bio5), mean temperature of the wettest quarter (bio8), mean temperature of the driest quarter (bio9), precipitation seasonality (bio15), precipitation of the driest month (bio14), precipitation of the warmest quarter (bio18), slope, and aspect.

1.3 MaxEnt Model Construction and Parameter Optimization

We imported the 51 distribution points and selected environmental variables into MaxEnt version 3.4.4. Model parameters were set as follows: 75% of occurrence points for training and 25% for testing; feature types including quadratic, hinge, and threshold features; 10 replicate runs with cross-validation; other parameters remained default. Outputs were generated in ASCII format. We used the Jackknife test to evaluate variable contributions and the Area Under the Receiver Operating Characteristic Curve (AUC) to assess model performance. AUC values range from 0 to 1, with higher values indicating greater accuracy and reliability. Model predictions are considered excellent when AUC > 0.9, good when 0.8-0.9, and fail when < 0.7. The mean AUC for *A. euchroma* was 0.945 ± 0.021, indicating excellent predictive performance and high reliability.

Results

2.1 Influence of Major Environmental Factors on *A. euchroma* Distribution

Contribution rates revealed that mean temperature of the wettest quarter (bio8) was the most important factor, alone accounting for 36.2% of the model contribution, followed by precipitation seasonality (bio15, 13.9%), precipitation of the warmest quarter (bio18, 10.1%), and elevation (8.5%). Other factors included precipitation of the driest month (bio14, 4.8%), mean diurnal temperature range (bio2, 4.1%), temperature seasonality (bio4, 3.8%), max temperature of the warmest month (bio5, 3.3%), mean temperature of the driest quarter (bio9, 2.9%), slope (2.5%), and aspect (0.6%) [Figure 3: see original paper].

Jackknife tests showed that elevation, mean temperature of the wettest quarter, max temperature of the warmest month, precipitation of the warmest quarter, and slope had high regularized training gains when used as single variables, with elevation producing the highest gain. When these variables were omitted, mean diurnal temperature range, elevation, precipitation seasonality, mean temperature of the wettest quarter, and precipitation of the warmest quarter significantly reduced training gains. Combined results from contribution rates and Jackknife tests identified mean temperature of the wettest quarter, precipitation seasonality, precipitation of the warmest quarter, and elevation as the dominant environmental factors.

Response curves illustrated relationships between dominant factors and species occurrence probability [Figure 5: see original paper]. Mean temperature of the wettest quarter showed optimal suitability at 8-11 °C, with probability declining sharply above 13.5 °C. Precipitation seasonality was optimal at 11.5–70 mm, with probability decreasing significantly when exceeding 95 mm. Precipitation of the warmest quarter was most suitable at 110-180 mm, with probability dropping sharply above 180 mm and approaching zero beyond 600 mm. Elevation showed increasing suitability up to 2500–4100 m, where probability approached 1, but declined precipitously above 4100 m. These curves indicate that optimal conditions for *A. euchroma* are: mean temperature of wettest quarter 8–11 °C, precipitation seasonality 11.5–70 mm, precipitation of warmest quarter 110–180 mm, and elevation 2500–4100 m.

2.2 Current Potential Suitable Areas for *A. euchroma* in China

Under current climate conditions, the total potential suitable area for *A. euchroma* in China is 96.26$\times10^{4}$ km^2, representing 10.03% of China' s total area [Figure 6: see original paper]. Low-suitability areas (68.12$\times10^{4}$ km^2, 70.77% of total suitable area) are widespread across northern Xinjiang (Altai Mountains), eastern Xinjiang (Bogda Mountains), central and eastern Tibet, and central Qinghai. Medium-suitability areas (17.75$\times10^{4}$ km^2, 18.44%) are concentrated in northwestern Xinjiang. High-suitability areas (10.39$\times10^{4}$ km^2, 10.79%) are primarily located in the central Tianshan Mountains, western Karakoram Mountains, and northwestern Himalayas in Tibet.

2.3 Future Potential Suitable Areas Under Climate Scenarios

Future projections using 2021-2040 and 2041-2060 climate data under four SSP scenarios revealed similar spatial patterns to current conditions, with medium- and high-suitability areas remaining in central Xinjiang and northwestern Tibet [Figure 7: see original paper]. However, total suitable area decreased across all scenarios while high-suitability area increased slightly [Figure 8: see original paper]. Compared with current conditions:

- **SSP1-2.6**: Total area decreased by 10.39% (86.32$\times10^{4}$ km^2) and 10.33% (86.25$\times10^{4}$ km^2) for 2021-2040 and 2041-2060, respectively; high-suitability area increased by 1.73% and 8.96%.
- **SSP2-4.5**: Total area decreased by 14.10% (82.68$\times10^{4}$ km^2) and 10.40% (86.25$\times10^{4}$ km^2); high-suitability area increased by 0.36% and 6.20%.
- **SSP3-7.0**: Total area decreased by 6.22% (90.29$\times10^{4}$ km^2) and 6.25% (90.27$\times10^{4}$ km^2); high-suitability area increased by 2.17% and 3.35%.
- **SSP5-8.5**: Total area decreased by 15.30% (81.53$\times10^{4}$ km^2) and 17.46% (79.45$\times10^{4}$ km^2); high-suitability area increased by 0.24% and 0.06%.

2.4 Centroid Migration of Potential Suitable Areas

Low-suitability areas are most extensive, and their distribution centers shifted under climate change. The current centroid is located in northwestern Qinghai (38.489°N, 91.692°E). Under future scenarios, centroids migrate northwestward to southeastern Xinjiang and northwestern Qinghai (38.648°-38.781°N, 91.271°-91.679°E) [FIGURE:9, TABLE:1]. Migration distances range from 23.5 km to 56.8 km across different scenarios, indicating consistent northwestward and upward elevation shifts.

Discussion

3.1 Model Reliability

In MaxEnt modeling, higher AUC values indicate greater predictive accuracy. Our mean AUC of 0.945 ± 0.021 demonstrates excellent model performance, reliably reflecting the actual distribution of *A. euchroma* in China. This represents an improvement over previous studies, such as Ye et al.' s prediction of suitable areas in Xinjiang, by incorporating broader geographic coverage and more occurrence points. We reduced overfitting through spatial rarefaction and Pearson correlation analysis, and our use of multiple SSP scenarios and time periods provides robust predictions of future distribution patterns under climate change.

3.2 Dominant Environmental Factors

Species distributions are influenced by multiple factors that vary among taxa. Our results identify mean temperature of the wettest quarter, precipitation seasonality, precipitation of the warmest quarter, and elevation as the primary constraints on *A. euchroma* distribution. Temperature of the wettest quarter contributed most (36.2%), with optimal suitability at 8–11 °C. Literature and herbarium records confirm that *A. euchroma* primarily inhabits mountainous regions of central-western Xinjiang and northwestern Tibet, where the wettest quarter corresponds to summer. Thus, summer temperature critically affects its growth and survival.

Precipitation seasonality (bio15) was the second most important factor (13.9% contribution), representing seasonal precipitation distribution. Optimal suitability occurred at 11.5–70 mm, indicating that *A. euchroma* prefers regions with relatively consistent seasonal precipitation. Ma et al. reported that *A. euchroma* seeds exhibit dormancy that can be broken under appropriate water and temperature conditions, but excessive temperature and moisture inhibit germination and growth. Our findings align with Ye et al., who identified elevation, precipitation of the driest month, and mean temperature of the warmest month as key factors.

Elevation contributed 8.5% to the model, with optimal suitability at 2500–4100 m, consistent with *Flora of China* records (2500–4200 m). This confirms that *A. euchroma* prefers cool, moist, high-elevation environments. The combined contributions of precipitation and elevation factors (32.5%) validate its preference for humid, cold, high-altitude habitats. While climate and topography are primary drivers, soil, vegetation, solar radiation, and human activities also influence distribution, suggesting future studies should incorporate additional biotic and abiotic variables to improve predictive accuracy.

3.3 Distribution Patterns Under Climate Scenarios

Future projections show stable spatial patterns with northwestward centroid migration and decreasing total suitable area but increasing high-suitability area. High-suitability areas remain concentrated in the Tianshan, Karakoram, and Himalayan mountains—high-elevation regions with minimal human disturbance that match the species' habitat requirements. This aligns with Ding et al.' s resource surveys. However, predicted suitable areas in northern Xinjiang, central-eastern Tibet, and central Qinghai lack documented occurrences, likely because our model considered only climate and topography, excluding soil properties, anthropogenic impacts, and interspecific interactions. Additionally, limited dispersal capacity, low reproductive rates, and historical overexploitation have prevented colonization of potentially suitable habitats. Field observations confirm that while historical records document *A. euchroma* at ~1900 m, current populations are only found above 2200 m in areas with reduced human pressure.

The northwestward migration trend and increasing high-suitability area reflect climate warming impacts. As temperatures rise, high-elevation areas become more favorable, facilitating upward expansion. Similar patterns have been observed in other species. However, the fluctuating area changes across scenarios underscore the complexity of climate change impacts. To prevent further resource decline, we recommend establishing protected areas within high-suitability zones and integrating genetic diversity analyses to prioritize conservation of distinct lineages. Artificial cultivation in suitable areas could also reduce pressure on wild populations.

Conclusion

Using MaxEnt and ArcGIS, we identified mean temperature of the wettest quarter, precipitation seasonality, precipitation of the warmest quarter, and elevation as the dominant factors controlling *A. euchroma* distribution. Under current climate, medium- and high-suitability areas are concentrated in central Xinjiang and northwestern Tibet. Future climate scenarios project relatively stable spatial patterns with decreased total suitable area, slightly increased high-suitability area, and northwestward/upward elevation shifts in distribution centroids. These results demonstrate *A. euchroma*' s adaptive capacity and positive response to climate warming, providing a critical theoretical foundation for conservation and sustainable utilization strategies.

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