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PREDICTION OF POTENTIAL DISTRIBUTIONS OF *RANUNCULUS TERNATUS* THUNB. BASED ON MAXENT MODEL

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Abstract

Based on distribution data of 140 sites and 10 environmental factors of *Ranunculus ternatus* Thunb. The MaxEnt model and geographic information system (GIS) were used to predict potentially suitable habitats of the species. The results showed that the area under the curve (AUC) value of the area under the receiver operation characteristic curve (ROC) was 0.92, indicating that the model prediction results were reliable. The highly suitable areas of *Ranunculus ternatus* Thunb. in China are mainly concentrated in the provinces of the Yangtze River Basin including the southern Henan province central and southern Anhui province, southern Jiangsu province, Shanghai, eastern and northern Zhejiang province northern Jiangxi province southern Hubei province and central Hunan province, part of Chongqing and north of Taiwan, covering an area of about 3.39 of China's land area. The dominant environmental factors affecting the distribution of *Ranunculus ternatus* Thunb. were related to precipitation and temperature, including precipitation in March, seasonal changes of precipitation, isotherm and standard deviation of seasonal changes in temperature. These results are consistent with the actual distribution and biological characteristics of *Ranunculus ternatus* Thunb. and can provide a reference for its promotion and planting.

Introduction

Ranunculus ternatus Thunb., commonly known as Cat's paw herb, is an annual herbaceous plant belonging to the family Ranunculaceae (Rabee *et al.* 2020). The name is derived from its clustered, fleshy rootlets, which resemble a cat's paw in form, it is also known by other vernacular names such as "Little Buttercup" and "Golden Flower Herb." This species is predominantly distributed across various regions of China, including Guangxi, Taiwan, Jiangsu, Zhejiang, Jiangxi, Hunan, Anhui, Hubei, and Henan (Han *et al.* 2024). It typically thrives in moist lowland meadows or uncultivated lands along field margins. Adorned with delicate golden-yellow blossoms, Cat's-paw herb possesses significant ornamental value as a groundcover plant (Kaltner *et al.* 2020). Notably, it can coexist naturally with *Cynodon dactylon* (Bermuda grass) during the winter season, making an excellent choice for evergreen turf mixtures in urban landscapes during colder months. Current research on *Ranunculus ternatus* Thunb. predominantly focuses on the extraction processes of its various constituents, the identification of bioactive compounds and their clinical applications, the variation in the quality of these active ingredients across different areas or habitats, its biological characteristics, and cultivation techniques (Zhang *et al.* 2025). Additionally, some studies delve into population genetic differentiation (Fang *et al.* 2020). Among the key factors influencing the growth, development, and effective composition of medicinal herbs, climate stands out as a crucial determinant, directly impacting both the geographical distribution and agricultural cultivation of these plants (Zhang and Tian 2007).

With the advancement of geographic information science and the deepening exploration of climate change, Species Distribution Models (SDMs) have emerged as an essential tool for examining the influence of climatic variables on species' geographical ranges (Yang *et al.* 2022).

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These models predict the probability of a species' occurrence across diverse ecological landscapes by analyzing the relationships between species presence and environmental factors. In recent years, SDMs have been extensively applied in biodiversity conservation, assessing species' responses to climate change, forecasting and managing invasive species, and predicting the distribution and conservation strategies for rare and endangered flora (Brown 2014). Increasingly, these techniques are also being utilized to simulate the potential spatial patterns of suitable habitats for traditional Chinese medicinal plants, offering critical insights to underpin the optimization of planting zoning schemes. The Maximum Entropy Model (MaxEnt) stands as one of the most widely used species distribution models for its robust predictive performance even with limited occurrence data (Liu and Huang 2024). Accordingly, this study harnesses MaxEnt modeling in conjunction with Geographic Information Systems (GIS) to forecast the optimal distribution range of *Ranunculus ternatus* Thunb. within China. By compiling and analyzing the natural occurrences of the species, the research further identifies the key environmental variables influencing its survival and distribution, thereby offering a theoretical foundation for the promotion, cultivation, and conservation of this valuable medicinal herb.

Materials and Methods

Source and processing of distributed data: The geographical distribution data of *Ranunculus ternatus* Thunb. were primarily obtained from the National Specimen Information Infrastructure (NSII; http://www.nsii.org.cn) and relevant literature, resulting a total of 1,583 distribution records. After excluding entries with missing coordinates, duplicate records, or evidently erroneous data points, a refined dataset comprising 140 valid distribution sites across 18 provinces was compiled, and formatted into a. csv file for further analysis.

Acquisition and preprocessing of environmental variables: In this study, a total of 32 environmental variables were selected, comprising 19 bioclimatic factors, 12 monthly precipitation metrics, and elevation. All environmental data were retrieved from the WorldClim database (http://www.worldclim.org/), with a spatial resolution of 30 arc-seconds (approximately 1 km^2) (Chahouki and Sahragard 2015). The retrieved variables were imported into ArcGIS, clipped to the boundaries of China and subsequently converted into .asc format for further analysis. To mitigate the risk of multicollinearity among environmental variables, which could lead to model overfitting and reduced predictive accuracy. This study employed a two-step screening process based on correlation analysis and variable contribution. First, MaxEnt version 3.3.3 was used to assess the relative contributions of the 32 variables; then, ArcGIS 10.2 was utilized to extract the environmental values at the 140 occurrence points, followed by Pearson correlation analysis using SPSS software (Busqué and Gutiérrez 2011).

In the selection of environmental variables, priority was given to those with a correlation coefficient below 0.75. In cases where the coefficient exceeded or equaled 0.75, the variable with the higher contribution value was retained for model construction. Based on these criteria, ten key environmental variables (Table 1) were ultimately chosen to predict the suitable habitat range for *Ranunculus ternatus* Thunb.

Species distribution model and parameter settings: After organizing the 140 distribution points, they were input into the MaxEnt software. Utilizing the selected ten environmental variables, 75% of the samples were designated as a training subset, while the remaining 25% were reserved for model validation. The model was constructed with a maximum of 10,000 iterations and repeated 10 times. The accuracy of the model's predictions was assessed using the Receiver Operating Characteristic (ROC) curve and the Area Under the Curve (AUC). The predicted results from the MaxEnt model were converted into raster data using ArcGIS software, with the raster values representing the probability of survival (P) of *Ranunculus ternatus* Thunb. in the given distribution zone (Li *et al.* 2024). These values were then reclassified using the natural breaks (Jenks) method, allowing the habitat suitability to be artificially divided into four categories: $0 < P \leq 0.10$ as unsuitable habitat, $0.10 < P \leq 0.25$ as low suitability, $0.25 < P \leq 0.50$ as moderate suitability, and $0.50 < P \leq 1.00$ as high suitability. ArcGIS was then employed to analyze the layers of habitat suitability and calculate the area of each suitable zone for *Ranunculus ternatus* Thunb. Additionally, based on the relative contribution values of each environmental variable in the MaxEnt model's predictions, the primary environmental factors influencing the distribution and growth of *Ranunculus ternatus* Thunb. were assessed.

Table 1. Ten environmental variables used in MaxEnt model.

Environment variables	Variable deseription	Unit
Bio_02	Monthly average temperature difference between day and night	°C
Bio_03	Isothermal property	°C
Bio_04	Standard deviation of seasonal temperature variation	°C
Bio_06	The lowest temperature in the coldest month	mm
Bio_08	Average temperature of the wettest quarter	mm
Bio_15	Seasonal variation of precipitation	mm
Bio_03	Precipitation in March	mm
Bio_07	Precipitation in July	mm
Bio_08	Precipitation in August	mm
Ele	altitude	m

Results and Discussion

Prediction of the current potential distribution area: The area under the curve (AUC) ranges from 0 to 1.0, with values closer to 1.0 indicating higher model reliability. An AUC between 0.9 and 1.0 signifies excellent discriminative ability; between 0.8 and 0.9 denotes strong reliability; between 0.7 and 0.8 reflects moderate accuracy; while an AUC of 0.7 or less indicates low predictive credibility. In this study, the average AUC value of the predictive model was 0.92, suggesting that the model can accurately forecast the potential suitable distribution range of the species *Ranunculus ternatus* Thunb., offering significant reference value. The prediction results revealed that the optimal habitat for *Ranunculus ternatus Thunb.* lies within the plains of the Yangtze River Basin, spanning several provinces and municipalities, including Jiangsu, Shanghai, Zhejiang, Anhui, southern Henan, Hubei, Jiangxi, Hunan, Chongqing, and Guizhou. Based on ArcGIS calculations of each distribution type area, the highly suitable habitat covers approximately 317,500 km², accounting for about 3.3% of China's land area, while the moderately suitable habitat spans roughly 595,600 km², representing around 6.2% of the national territory.

The primary environmental factors influencing the distribution of *Ranunculus ternatus* Thunb. were identified through Jackknife analysis within the species distribution model. This method revealed both the contribution values of individual environmental variables to the model and their relative influence on the plant's geographic distribution. Synthesizing the results (Fig. 1 and Table 2), four dominant environmental variables emerged: March precipitation (Prec_03), precipitation seasonality (Bio_15), isothermality (Bio_03), and temperature seasonality, expressed as the standard deviation of temperature (Bio_04). Collectively, these factors account for a cumulative contribution rate of 89.8%, with two variables related to precipitation and two to temperature. Additionally, elevation (Ele) also plays a significant role, whereas the mean temperature of the wettest quarter (Bio_08) and July precipitation (Prec_07) exert relatively minor influence on the species' distribution range.

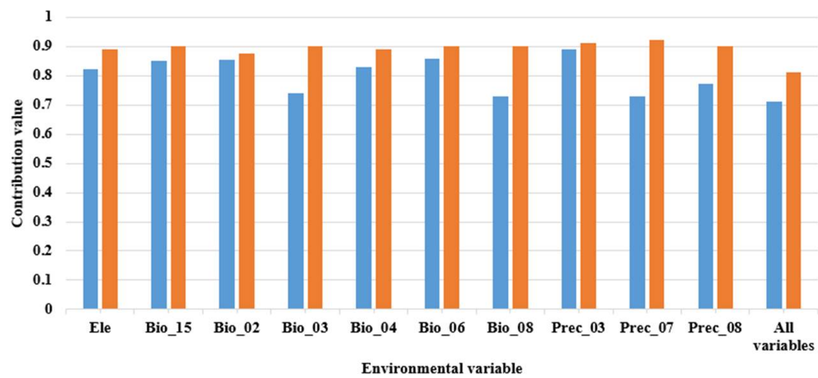

Fig.1. The contribution value of environmental factors to MaxEnt model.

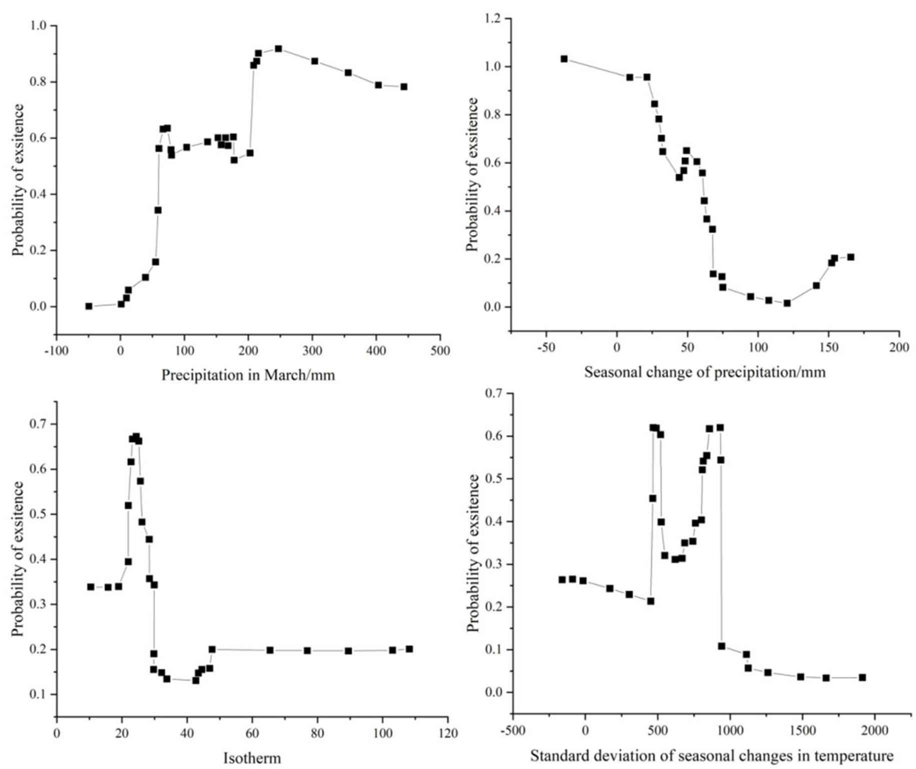

Fig. 2. Relationships between four dominant environment factors and probability of presence for *Ranunculus ternatus* Thunb.

Each of the four dominant environmental variables was used to construct single-factor models, with corresponding response curves illustrated in Fig. 2. An occurrence probability of $P < 0.50$ indicates that the environmental condition is highly unsuitable for the species' survival, whereas $P \geq 0.50$ signifies a favorable range for its habitation. The results (Fig. 2) reveal the optimal conditions for *Ranunculus ternatus* Thunb. as follows: March precipitation (Prec_03) exceeds 58.69 mm; precipitation seasonality (Bio_15) ranges from 9.74 to 60.18; isothermality

(Bio_03) lies between 22.16 and 25.76; and the standard deviation of temperature seasonality (Bio_04) is optimal within the intervals of 457.81-512.25 and 805.36-935.16.

Table 2. The contribution rate of 10 environmental variables to the distribution range of *Ranunculus ternatus* Thunb.

Environment variables	Contribution rate/%		Environment variables	Contribution rate/%
Prec_03	61.2		Bio_06	2.5
Bio_15	14.1		Bio_02	1.7
Bio_03	8.7		Prec_08	0.9
Bio_04	5.8		Bio_08	0.7
Ele	3.7		Prec_07	0.7

The present study highlights the critical role of climatic variables, particularly precipitation and temperature, in shaping the distribution of *Ranunculus ternatus* Thunb. Among the four primary environmental factors identified, March precipitation emerged as the most decisive determinant, which is consistent with the species' phenological characteristics, including rapid vegetative growth from February to April and peak flowering between early March and early April. This finding underscores the plant's preference for cool, humid, and partially shaded environments.

Temperature also exerts a profound influence on the species' distribution. Although *Ranunculus ternatus* Thunb. demonstrates strong cold tolerance, it is highly sensitive to heat stress. When ambient temperatures exceed 30 ℃, vegetative growth halts and mortality may occur, while seeds and tuberous roots enter a state of deep dormancy, rendering them incapable of germination or sprouting. These results align with the ecological responses observed in other medicinal plants, such as *Peucedanum praeruptorum* and *P. decursivum*, whose distributions are shaped by precipitation in the driest month and cold-season temperature indices; *Polygonatum cyrtonema*, which is regulated by precipitation in spring and autumn together with annual temperature range; and *Trollius chinensis*, whose growth is strongly affected by midsummer precipitation and seasonal temperature variation. Collectively, these findings highlight the general ecological principle that the interplay between temperature and precipitation serves as a fundamental determinant of the biogeographical distribution of medicinal plants in temperate and subtropical regions.

This study predicts the potential distribution of *Ranunculus ternatus* Thunb. across China, with the most suitable habitats concentrated in provinces along the Yangtze River Basin, including Jiangsu, Shanghai, Zhejiang, Anhui, southern Henan, Hubei, Jiangxi, Hunan, Guizhou, parts of Chongqing, and northern Taiwan. The total area of moderately to highly suitable habitats was estimated at approximately 913,000 km², the majority of which falls within the subtropical monsoon climate zone, with only minor extensions into temperate monsoon regions. The predicted distribution closely matches the species' known natural occurrence, and the high AUC value obtained confirms the robustness and reliability of the model. These results not only validate the predictive framework applied but also demonstrate that *Ranunculus ternatus* Thunb. possesses a broad ecological adaptability and extensive potential for cultivation. Consequently, the species holds considerable promise for large-scale agricultural promotion and sustainable utilization in traditional medicine.

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