Postprint: MaxEnt-Based Prediction of Suitable Habitats for Locusta migratoria tibetensis in China

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Abstract

The Tibetan migratory locust is an endemic species of the Qinghai-Tibet Plateau and a significant pest of highland barley and forage grasses, with its damage range exhibiting an expanding trend in recent years. Investigating and delineating the suitable habitat areas for the Tibetan migratory locust in China is of paramount importance for formulating early monitoring, warning, and control measures for this insect pest. Maximum entropy theory has been extensively applied in species distribution modeling in recent years. Based on distribution data and environmental variables of the Tibetan migratory locust, we utilized the MaxEnt ecological niche model and ArcGIS to predict its potential distribution areas in China, employed ROC curves to evaluate model accuracy, and applied the jackknife test to identify dominant environmental variables and their suitable ranges. The AUC values from two simulations were 0.996 and 0.993, respectively, indicating a high degree of concordance between predicted and actual distributions. The highly suitable habitats for the Tibetan migratory locust in China are primarily located in Garzê Prefecture of Sichuan Province, and Qamdo Prefecture, Nyingchi Prefecture, Shannan Prefecture, and Lhasa City of the Tibet Autonomous Region. The moderately suitable habitats radiate outward from the highly suitable areas as centers, concentrating in the eastern Qinghai-Tibet Plateau region. Altitude, average rainfall in August, average rainfall in January, isothermality, and average temperature from December to February constitute the primary environmental variables influencing the potential distribution of the Tibetan migratory locust.

Full Text

Preamble

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Predicting Potential Ecological Distribution of *Locusta migratoria tibetensis* in China Using MaxEnt Ecological Niche Modeling

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Abstract

The Tibetan migratory locust (*Locusta migratoria tibetensis* Chen) is an endemic subspecies of the Tibetan Plateau and a destructive pest of highland barley and forage grasses. In recent years, its damage range has shown an expanding and spreading trend. Investigating and identifying the suitable habitat areas for this pest in China is of great significance for developing early monitoring, warning, and control measures. The maximum entropy theory has been widely applied in species suitability research in recent years. Based on distribution information and environmental variables for the Tibetan migratory locust, the MaxEnt ecological niche modeling software (maximum entropy model) combined with ArcGIS (Geographic Information System) was applied to predict its potential geographic distribution in China. Dominant bioclimatic factors and their appropriate value ranges were also investigated. The results showed that the training data AUC values were 0.996 and 0.993 in the two simulations, indicating excellent predictive performance. The highly suitable area for *L. migratoria tibetensis* was located in Ganzi Prefecture of Sichuan Province, and Changdu, Linzhi, Shannan, and Lhasa of the Tibet Autonomous Region, whereas the moderately suitable area was in western Sichuan, eastern Tibet, and northern Yunnan. The important environmental factors affecting the distribution of *L. migratoria tibetensis* were altitude, average precipitation in August, average precipitation in January, isothermality, average mean temperature in January, average mean temperature in December, and average mean temperature in February.

Keywords: *Locusta migratoria tibetensis*; MaxEnt; suitability analysis; environmental factors

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Introduction

There are approximately 10,000 species of locusts worldwide, distributed across all continents except Antarctica. *Locusta migratoria* is a globally distributed pest species, with *Locusta migratoria tibetensis* being the highest-altitude subspecies endemic to the Tibetan Plateau. It is distributed across Tibet, Sichuan, and Qinghai provinces, feeding primarily on highland barley, forage grasses, and weeds. Historical records indicate that the Tibetan migratory locust has caused numerous disasters on the Tibetan Plateau, destroying crops completely. In Sichuan' s Ganzi and Aba prefectures, and in Qinghai' s Yushu and Tibet' s Ali regions, the locust has erupted over large areas. In particular, the Yarlung Zangbo River, Yalong River, and Jinsha River valleys in the Hengduan Mountains have experienced severe outbreaks, causing tremendous damage to local agricultural and pastoral production and resulting in incalculable economic losses.

Predicting species' suitable distributions is an important research area in ecology. Species Distribution Models (SDMs) have become an important tool for studying species suitability. These models use known species occurrence data combined with corresponding environmental variables and mathematical theory to calculate species distribution probabilities in target areas, quantifying relationships between environmental variables and species distribution, as well as identifying limiting factors and habitat preferences. SDMs are commonly applied to predict potential distribution areas, assess suitability for endangered and valuable species, and conduct paleobiogeographic research, yielding good results.

The MaxEnt (maximum entropy) model demonstrates higher simulation accuracy than other models and has gained widespread recognition in the field for its short runtime, stable results, and small sample size requirements. It has been applied to simulate and predict the suitability of various diseases and pests, such as citrus huanglongbing (*Candidatus Liberibacter asiaticus*), leaf scorch disease (*Xylella fastidiosa*), and the rice water weevil (*Lissorhoptrus oryzophilus*). Previous research on the Tibetan migratory locust has focused primarily on biological characteristics, quantitative traits, and genetic features, with no reports on ecological niche prediction. This study uses MaxEnt to investigate the relationship between locust distribution and environmental variables, aiming to predict its potential distribution in China and provide important references for developing reasonable prevention and control measures.

1. Distribution Data and Processing for *Locusta migratoria tibetensis*

1.1 Species Distribution Data

The MaxEnt model requires species distribution data and environmental data. Distribution data consist of latitude and longitude coordinates of occurrence points. Tibetan migratory locust distribution data were obtained through: (1) Field surveys in Sichuan, primarily in high-incidence areas of Ganzi and Aba prefectures; (2) Database queries including the Global Biodiversity Information Facility (GBIF, http://www.gbif.org/), the International Center for Agricultural and Biosciences (CABI, http://www.cabi.org/), the Southwest China Animal Resources Database (http://www.swanimal.csdb.cn), and the Teaching Specimen Resource Sharing Platform (http://mnh.scu.edu.cn/); (3) Review of published literature on Tibetan migratory locusts. When nymphs or adults were found, GPS coordinates were recorded.

To avoid overfitting caused by high spatial autocorrelation, a buffer analysis was applied. Given the environmental variable spatial resolution of 2.5 arc-minutes (approximately 4.5 km), only one point was retained when distribution points were within 1.5 km of each other, yielding 170 distribution points total. Since locusts inhabit high-altitude areas with poor transportation and harsh climates, making complete coverage difficult, a buffer radius was set. MaxEnt performs better than other models with small sample sizes, showing higher accuracy.

Coordinates were entered into Excel and saved as *.CSV format with fields for species name, longitude, and latitude according to the MaxEnt software manual.

1.2 Environmental Variable Data Sources

All environmental variables used in this study were derived from the WorldClim database (http://www.worldclim.org), which provides global climate raster data generated through interpolation of meteorological records. The database includes 19 bioclimatic variables with strong biological significance that reflect temperature and precipitation characteristics and seasonal variations. Altitude data were also included as a topographic factor. Data were extracted for the study area (Sichuan, Yunnan, Guizhou, and Qinghai) at 2.5 arc-minute resolution (4.5 km). Monthly mean precipitation and temperature data were also selected.

shows the climatic variables used for predicting the potential geographic distribution of *Locusta migratoria tibetensis*.

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2. Screening Key Environmental Variables Affecting Potential Distribution

2.1 Variable Selection and Screening

Various environmental factors affect species distribution, including climatic, topographic, and vegetation factors. This study initially selected 24 environmental variables. The jackknife test in MaxEnt software was used to determine each variable' s contribution to model prediction, eliminating variables with small contributions and retaining key limiting factors to improve simulation accuracy. Spearman correlation analysis was used to calculate correlations among environmental factors to eliminate multicollinearity effects on model building and interpretation. Variables with correlation coefficients >0.8 were considered highly correlated.

MaxEnt software (version 3.3.3k, freely available at http://www.cs.princeton.edu/~schapire/maxent/) was used to predict suitable distribution areas. Model accuracy was evaluated using the Area Under Curve (AUC) of the Receiver Operating Characteristic (ROC) curve, which provides performance assessment across all threshold ranges and is considered the best evaluation metric for ecological niche models. AUC ranges from 0 to 1, with values closer to 1 indicating higher model accuracy.

2.2 Habitat Suitability Classification

MaxEnt outputs presence probabilities worldwide. Using ArcGIS conversion tools, these were transformed into raster format for mapping locust presence probability in China. MaxEnt output values range from 0 to 1, where higher values indicate higher probability of species presence. Based on locust ecology and previous reports, suitability was classified into four levels: non-suitable (<0.05), low suitability (0.05–0.33), moderate suitability (0.33–0.66), and high suitability ($ $0.66), displayed with different colors.

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3. Results

3.1 Screening Dominant Environmental Variables

Not all environmental variables are essential for predicting species potential distribution. Following methods by Lei et al., variables with small contributions were eliminated using MaxEnt' s built-in jackknife module. The cumulative contribution rate of different environmental variables to locust potential distribution showed altitude as the primary limiting factor, with a single-factor contribution rate of 42.6%. The cumulative contribution of average precipitation in January, average precipitation in August, average temperature in January, average temperature in December, and average temperature in February reached 85.0%.

Spearman correlation analysis of the seven selected environmental variables showed no pairwise correlation coefficients exceeding 0.8, indicating they could be used as dominant variables for model reconstruction.

shows the percent contribution and cumulative contribution of environmental variables affecting *L. migratoria tibetensis* distribution. shows the pairwise Spearman correlation coefficients among environmental variables.

3.2 Model Accuracy Testing

The AUC values for model accuracy testing were 0.996 and 0.993, indicating excellent predictive accuracy and showing that the results can be used for habitat zoning of the Tibetan migratory locust. [Figure 1: see original paper] shows the AUC values for model applicability testing.

3.3 Geographic Distribution Prediction in China

Based on the seven dominant environmental variables and locust distribution data, the MaxEnt model predicted the potential distribution under current climate conditions. The suitable range was 88.79°–113.57°E, 21.52°–38.33°N. High suitability areas were mainly in Sichuan and Tibet, including Ganzi Prefecture in Sichuan and Changdu, Linzhi, Shannan, and Lhasa in Tibet. Moderate suitability areas radiated outward from high-suitability areas, concentrated in the eastern Tibetan Plateau, including western Sichuan and northern Yunnan.

The total suitable area was 170.55$\times10^{4}$ km^2, accounting for 17.77% of China' s territory. High, moderate, and low suitability areas covered 22.51$\times10^{4}$ km^2 (13.2%), 63.04$\times10^{4}$ km^2 (36.96%), and 85.01$\times10^{4}$ km^2 (49.84%) of the total suitable area, respectively. [Figure 2: see original paper] shows the predicted suitable distribution map.

3.4 Jackknife Test Results

The jackknife test reflects each variable' s contribution to distribution gain. When a variable is used alone for training and yields high scores, it indicates high predictive value. When excluding a variable significantly reduces training scores, it contains unique information important for distribution. Jackknife analysis showed altitude as the key factor affecting locust distribution, with training gain >1.2. Isothermality (Bio3), average temperature in January (Tmean1), and average temperature in February (Tmean2) also showed training scores >1. [Figure 3: see original paper] shows the importance of environmental variables.

3.5 Environmental Variable Response Curves

The response curves between dominant variables and distribution probability were plotted using MaxEnt. The suitable altitude range was 2870–5188 m, with optimal height at 3941 m. Probability increased with altitude up to 3941 m, then decreased. Isothermality suitability was 38.5–47.2, with probability decreasing as isothermality increased. The response trends for precipitation and temperature variables were similar, differing only in magnitude and range. [Figure 4: see original paper] shows the response curves, and summarizes the suitable ranges for each dominant variable.

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4. Discussion

Environmental variable selection affects ecological niche model predictions. Many studies use WorldClim' s 19 bioclimatic variables, which are derived from temperature and precipitation data and thus have inevitable autocorrelation and multicollinearity issues. Highly correlated variables introduce redundant information affecting predictions. This study used correlation analysis and contribution rates to effectively eliminate low-contribution variables, reducing redundancy and improving accuracy.

AUC is the most widely used method for model accuracy evaluation, providing performance assessment across all thresholds. This study' s AUC values of 0.993 and 0.996 indicate high accuracy, showing good agreement between predicted and actual distributions. Using ArcGIS for post-processing of MaxEnt raster files reduced systematic errors.

The predicted suitable range of 88.79°–113.57°E, 21.52°–38.33°N includes high-suitability areas in Sichuan and Tibet, and moderate-suitability areas in the eastern Tibetan Plateau. Previous studies found locusts lay most egg pods in grassland environments, which are highly suitable habitats. The predicted high-suitability areas include major grasslands like Ruoergai, Longdeng, and Maoya, as well as the Yarlung Zangbo and Yalong River valleys, where locusts pose extremely high risk.

Among the seven dominant variables, isothermality was most important, indicating locust distribution is constrained by both altitude range and local temperature variability. The suitable altitude range of 2870–5188 m aligns with the known restriction of this species to the Tibetan Plateau. Studies show locusts can survive at 560 m but with high mortality, and no low-altitude distributions have been found.

Winter low temperature critically affects egg overwintering and hatching success. The locust' s supercooling point is -22.02°C for eggs and -6.46°C for 4th-instar nymphs. This study found locust presence probability correlates with January mean temperature, but excessive cold reduces viability. Precipitation in January and August also significantly affects distribution, as locusts inhabit relatively dry grassland areas and require appropriate humidity for mating and reproduction starting in July.

However, MaxEnt has limitations: (1) It represents fundamental niche under ideal conditions without interspecies competition, predicting a potentially wider niche than actual; (2) It cannot fully express biotic interactions, soil salinity, or dispersal capacity, which also affect distribution; (3) The WorldClim data (1950-2000) lack recent climate data, and ongoing global warming will affect species distribution patterns. Future work should incorporate updated climate data and consider biotic factors to improve predictions.

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