Prediction of Potential Distribution of the Genus *Cricotopus* (Diptera: Chironomidae) Based on MaxEnt Model

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Abstract The prediction of suitable area is a method for predicting the potential distribution by using the maximum entropy model. This study predicted the potential suitable habitats for the genus *Cricotopus* of Chironomidae in China. The latitude and longitude information of 98 distribution sites of *Cricotopus* in China and the biological environmental factors and altitude distribution in China were collected, and suitable habitats for *Cricotopus* were predicted, obtaining the suitable ranges and areas of *Cricotopus* in China, which is consistent with the known living conditions of *Cricotopus*. The study on the diversity of *Cricotopus* and the prediction of its suitable habitats provide a theoretical basis for *Cricotopus* in water monitoring and paddy fields, as well as basic data for the study on the genus *Cricotopus*.

Key words *Cricotopus*; Diversity; Prediction of suitable area; Geographical distribution

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Cricotopus (Diptera: Chironomidae) is one of the most widely distributed invertebrates in fresh water, as well as one of the most abundant groups. The living environment of larvae is mostly inseparable from water, including running water (streams, turbulent flow, small rivers and big rivers), still water (river ditches, puddles and lakes), and even temporary puddles such as water films on rocks or trees, plant preservation water, and rock ponds by the sea. There may be water pollution in the waters where *Cricotopus* lives. Water pollution is the most important crisis to the ecosystem, which is not only harmful to human health, but also has an impact on the growth and development of organisms[1]. *Cricotopus* is a common benthic organism in running water and still water, so it can be used for water detection, and the density of its larvae and adults in and near water can be used as a detection index[2]. The larvae of *Cricotopus sylvestris* are typical herbivorous larvae in rice fields, and their feeding poses a significant threat to rice. *Cricotopus* generally feeds on organic matter such as bottom humus at the larval stage, and releases nitrogen and phosphorus substances from the organic matter in the sediment. They also eat algae, which lead to a reduction of oxygen demand, thereby reducing the probability of eutrophication in rice fields[3].

At present, there is no relevant research on the prediction of suitable areas for *Cricotopus*, but data show that there are prediction of suitable areas for Diptera, Lepidoptera, Orthoptera and other pests[4-9]. After looking up literatures, it is found that the prediction of suitable habitats for insects was mainly based on Climex dynamic simulation software from 1985 to 2004, and currently, the prediction of suitable habitats for insects is mainly based on the MaxEnt maximum entropy model. Firstly, the MaxEnt maximum entropy model combines species distribution data and environmental data for operation. Next, ArcGIS and SPSS are employed to screen major environmental factors in the first operation results, improving accuracy. Finally, the selected environmental factors are subjected to operation by the MaxEnt maximum entropy model to obtain the ranges and areas of the species' suitable habitats[10-11].

Materials and Methods

Collection and processing of distribution data The prediction of suitable habitats using the maximum entropy model required existing species' distribution data. The distribution data mainly referred to the latitude and longitude information of obtained species distribution. There were two main methods for obtaining distribution information of the genus *Cricotopus*: ① the latitude and longitude distribution information recorded by specimens collected from various regions, as shown in Appendix A, and ② the longitude and latitude information of various regions from existing literatures on *Cricotopus*. The specific distribution sites of *Cricotopus* in the various regions were obtained through literature research, and the desired information was then obtained based on Baidu Map.

The obtained longitude and latitude information was sorted into three columns in Excel according to the genus name, longitude and latitude, and saved in the csv format for future use. In this study, we mainly focused on predicting suitable habitats for *Cricotopus* throughout China, so the latitude and longitude information of *Cricotopus* in various provinces throughout the country was collected.

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The historical climate data including 10 min bioclimatic factors and 10 min altitude environmental factors from 1970 to 2000 were downloaded in the tif format in Worldclim, and the obtained data were climate factors on a global scale. In this study, we mainly focused on predicting suitable habitats for the genus *Cricotopus* nationwide, which required the extraction of 19 bioclimatic variables and altitude terrain information within China using ArcGIS combined with the Chinese map shp format. Meanwhile, the environmental information extracted by mask within China needed to be imported into ArcGIS to convert the tif format into the asc format using conversion tools, preparing for importing into MaxEnt for predicting suitable habitats.

Processing and screening of major environmental factors affecting the distribution of suitable habitats for *Cricotopus*

There are many environmental factors that affect the distribution of *Cricotopus*, such as humidity, precipitation, temperature, and altitude. In this experiment, 20 biological environmental factors related to precipitation, temperature and altitude were mainly selected for predicting the suitable habitats. More environmental factors lead to greater correlation, but the accuracy of models may be lower. Therefore, the prediction of suitable habitats required screening the 20 environmental factors to identify major environmental factors and improve the simulation accuracy of the maximum entropy model operation[8].

Firstly, the latitude and longitude information of known distribution sites (Table 1) needed to be imported into ArcGIS in the asc format to extract environmental factors of known locations in China using the tool of Extract Multi Values To Points. After extraction, the data were exported in the Excel format. Next, Pearson correlation analysis was conducted in SPSS to obtain a series of correlation.

Table 1 Table of predicted distribution sites of suitable habitats for the genus Cricotopus

Genus name	Longitude	Latitude	Genus name	Longitude	Latitude	Genus name	Longitude	Latitude
Cricotopus	116.091 8	31.021 3	*Cricotopus*	103.487 7	30.927 1	*Cricotopus*	83.084 5	46.653 5
	115.837 3	31.230 0		121.402 1	28.661 9		82.565 3	43.760 2
	115.818 9	31.078 4		119.673 5	29.237 1		118.134 9	26.699 0
	115.794 5	31.078 4		120.266 7	28.514 5		109.884 7	18.798 4
	115.782 0	31.168 8		120.266 7	28.514 5		108.105 4	25.318 2
	115.782 0	31.168 8		103.487 2	30.926 5		112.930 6	24.942 3
	115.782 0	31.168 8		117.671 7	34.996 8		119.793 9	41.034 9
	115.782 0	31.168 8		111.809 2	33.699 2		102.997 0	29.986 7
	115.546 9	31.230 0		108.554 1	33.553 8		107.215 8	29.134 5
	115.323 9	31.356 2		87.442 4	48.566 0		108.016 8	33.822 3
	114.937 1	30.466 0		117.505 3	40.047 1		119.448 4	30.337 6
	111.756 4	27.522 2		117.172 0	39.110 8		110.676 7	30.009 5
	111.756 4	27.522 2		119.518 3	39.853 6		111.054 9	26.403 6
	110.201 1	30.065 8		118.124 6	40.284 7		102.153 3	30.078 3
	110.176 1	30.061 7		127.606 6	45.303 4		99.959 1	26.879 2
	105.641 5	32.377 7		119.457 6	30.325 2		100.217 3	25.681 2
	105.606 0	32.497 1		119.943 0	27.356 6		89.249 6	43.005 4
	104.116 7	29.525 0		119.745 1	29.120 6		118.457 6	41.309 0
	101.163 9	21.550 6		116.850 2	26.831 0		108.888 8	40.956 9
	101.163 9	21.550 6		118.799 4	26.608 8		119.916 8	30.267 4
	100.815 6	22.010 3		116.107 6	29.457 8		119.243 5	26.088 6
	100.619 9	25.085 0		121.778 4	37.228 6		108.700 6	27.919 7
	100.619 9	25.085 0		113.788 0	23.754 0		118.863 8	32.023 5
	100.619 9	25.085 0		114.267 0	24.731 2		116.332 8	28.925 2
	100.619 9	25.085 0		111.891 2	23.441 8		109.928 4	29.995 5
	100.168 2	22.895 6		110.318 3	25.277 3		101.372 5	26.575 5
	100.155 3	23.913 5		109.871 4	25.732 0		119.198 7	27.748 1
	100.131 5	25.798 9		109.177 1	19.069 8		101.979 0	30.040 4
	100.131 5	25.798 9		106.535 1	33.916 0		103.743 9	29.598 3
	100.131 5	25.798 9		100.013 1	39.242 5		108.459 4	33.438 4
	115.762 0	30.965 5		106.304 7	35.666 6		104.044 2	35.888 0
	111.367 3	30.644 1		75.866 9	39.383 1		106.338 7	35.358 1

Next, suitable habitats were predicted using MaxEnt. Preliminary analysis was conducted by ticking Create response curves, Make pictures of predictions and Do jackknife to measure variable importance, on 75% of the data which were randomly selected, and 25% of Random test percentage was used for verification. The operation was repeated 10 times under the condition of ticking Random seed and selecting Bootstrap as the type of reruns. The file was output in the asc format, and the output type was logistic.

Other conditions could be selected by default.

The prediction required the latitude and longitude information of the distribution sites of *Cricotopus*, as shown in Appendix A, as well as environmental factor information within China. In this experiment, 19 bioclimatic variables (bio 1-19) and elevation (elev) topographic information in China were used as environmental variables. The information table of environmental variables is shown in Table 2. These 20 environmental factors were screened, and the contribution rate of each environmental factor to the model was obtained by the jackknife method in MaxEnt, and the environmental factors with great influence were judged according to the contribution rate and the correlation value *r*. According to Table 2, the contribution rates of different environmental factors could be obtained. Combined with Pearson's correlation analysis, for environmental factors with a correlation greater than 0.8, the one with a higher contribution rate was retained. It was found according to Pearson correlation analysis that the correlation of bio 6, bio 9 and bio 11 was greater than 0.8, but the contribution rates of bio 9 and bio 11 were lower than that of bio 6. Therefore, bio 9 and bio 11 were deleted. Furthermore, based on Pearson analysis, it was found that the correlation of bio 7, bio 10, bio 13, bio 16, bio 17, bio 18 and bio 19 was greater than 0.8. After a series of screening, a total of 11 environmental factors including bio 1-bio 6, bio 8, bio 12, bio 14, bio 15 and elev were selected. Finally, based on the 11 environmental factors, the prediction of suitable habitats was carried out, and high-precision prediction results were obtained, including an AUC map, a jackknife method environmental factor importance map, contribution rates of the 11 environmental factors, suitable habitats of different grades for *Cricotopus* in China, and areas of suitable habitats of different grades.

Table 2 Initial environmental factor contribution rate

Climatic variables	Percent contribution	Permutation importance
bio 14 (Precipitation of Driest Month)	26.9	6.4
bio 6 (Min Temperature of Coldest Month)	14.3	2.3
bio 12 (Annual Precipitation)	11.8	4.3
elev (Altitude)	8.5	23.5
bio 2 (Mean Diurnal Range)	5.5	10.1
bio 16 (Precipitation of Wettest Quarter)	4.4	2.2
bio 15 (Precipitation Seasonality)	4.3	6.2
bio 17 (Precipitation of Driest Quarter)	3.5	2.9
bio 8 (Mean Temperature of Wettest Quarter)	3.5	2.5
bio 3 (Isothermality)	2.9	2.3
bio 11 (Mean Temperature of Coldest Quarter)	2.8	3.4
bio 4 (Temperature Seasonality)	1.9	2.9
bio 18 (Precipitation of Warmest Quarter)	1.6	6.7
bio 9 (Mean Temperature of Driest Quarter)	1.5	1.7
bio 10 (Mean Temperature of Warmest Quarter)	1.4	6.7
bio 19 (Precipitation of Coldest Quarter)	1.3	3.3
bio 7 (Temperature Annual Range)	1.2	1.1
bio 1 (Annual Mean Temperature)	1.1	0.6
bio 13 (Precipitation of Wettest Month)	0.8	8.2
bio 5 (Max Temperature of Warmest Month)	0.7	2.7

Sources of MaxEnt and ArcGIS software and standards for predicting suitable habitats

MaxEnt software could be obtained for free on its official homepage, and the latest version was 3.4.4. The website where it could be obtained was (https://biodiversityinformatics.amnh.org/open_source/maxent/). ArcGIS software was a geographic information system platform developed by Esri Corporation (version 10.2) for collecting, organizing, managing and analyzing information.

SPSS software used IBM SPSS Statistics 26.0, which could be obtained on the official website.

Basic map information: For the map of the People's Republic of China, the JSON file of the map could be found in Datev aliyun (http://datav.aliyun.com/tools/atlas/index.html). Next, the obtained JSON file was converted into an shp file through online conversion.

Java software: version Java.8 was sourced from (https://www.java.com/en/download/).

When using MaxEnt for prediction, all we needed to do was importing the longitude and latitude information of the distribution sites and environmental factors of *Cricotopus* that had already been obtained into the Sample column and the Environment layer column, respectively, and then setting prediction conditions (the prediction conditions were the same as the preliminary prediction conditions).

This study mainly relied on the area value under the receiver operating characteristic (ROC) curve, *i.e.*, the AUC value, to determine the simulation results of the model. The ROC curve, also known as the sensitivity curve, was plotted using different binary classification methods, with false positive rate and true positive rate as the x-axis and y-axis, and the area under the curve was the AUC value. The range of AUC values was [0, 1], and the closer the value to 1, the greater the correlation between the environmental variables and the model constructed from the distributed sites, and the higher the accuracy and credibility of the prediction results[17]. The evaluation criteria are shown in Table 3.

Table 3 AUC evaluation criteria table

Range of AUC	Range of criterion
$0.5 \leq AUC < 0.6$	Failed
$0.6 \leq AUC < 0.7$	Poor
$0.7 \leq AUC < 0.8$	Ordinary
$0.8 \leq AUC < 0.9$	Good
$0.9 \leq AUC < 1$	Excellent

Classification criteria for suitable habitats of the genus *Cricotopus*

The "asc" format files in the predicted results were converted into raster files using the "Conversion tools ASCII to Raster" tool in ArcGIS 10.2 software. Next, the current suitable habitats of the genus *Cricotopus* were classified by the Natural breaks (Jenks) method into following grades: unsuitable habitats: $0 \leq$ existence probability < 0.12, lowly suitable habitat: $0.12 \leq$ existence probability < 0.31, moderately suitable habitat: 0.31 ≤ existence probability < 0.50, and highly suitable habitat: 0.50 ≤ existence probability < 0.80.

Results and Analysis

Judgment on the accuracy of the prediction model

Based on the 11 selected environmental factors, the ROC curve in Fig. 1 and the AUC curve in Fig. 2 were obtained for predicting suitable habitats. It was found that the average training AUC for reruns was 0.901. With the AUC value, the area under the curve as the measurement standard for model prediction, the prediction effect was excellent. The ROC curve was used to verify the prediction accuracy of the model in this study. The ROC curve is currently widely used in the evaluation of species potential distribution prediction models. The mean omission rate on training data and predicted omission rates of the test samples were obtained, and it was found that there was no significant deviation between the mean omission rate and the predicted omission rates of the samples, proving that the model was successfully constructed. The above two results proved that the prediction model could be used for predicting suitable habitats of the genus *Cricotopus*.

Analysis of major environmental factors

The relation between various environmental variables and the potential geographic distribution of the genus *Cricotopus* was studied using the contribution rate and permutation importance obtained from running the MaxEnt model and the jackknife method. From the perspective of contribution rate, it could be concluded that the first four variables having the highest contribution rates ranked as precipitation of driest month (bio 14) > minmum temperature of coldest month (bio 6) > precipitation (bio 12) > elev (Altitude), as shown in Table 4. The cumulative contribution rate also reached 77, which was significantly higher than other environmental factors, so these four were the main environmental factors affecting the prediction of suitable habitats.

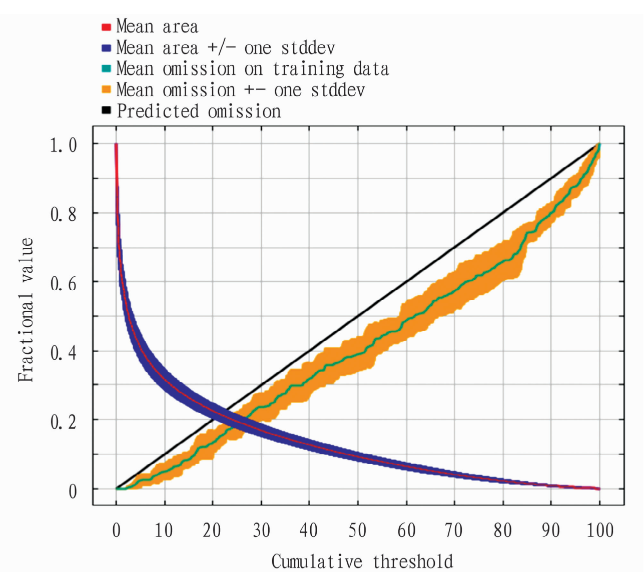

Fig. 1 Predicted omission rate and predicted omission rate curve for suitable habitats of the genus *Cricotopus*

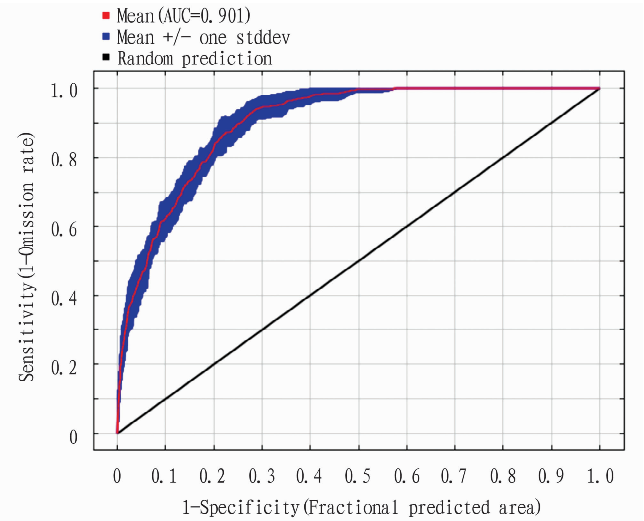

Fig. 2 Prediction of the AUC curve for suitable habitats of the genus *Cricotopus*

Table 4 Contribution rates of major environmental factors

Climatic variables	Percent contribution	Permutation importance
bio 14 (Precipitation of Driest Month)	34.4	10.9
bio 6 (Min Temperature of Coldest Month)	26.8	25
bio 12 (Annual Precipitation)	9.3	4.2
elev (Altitude)	6.8	20.8

The chart obtained by the jackknife method could display the influences of various environmental factors on the prediction model. In specific, the length of the blue strip represented the degree of influence of corresponding environmental factor on the prediction of the distribution of the genus *Cricotopus*. A longer blue strip indicated greater impact, and the environmental factor was thus more important. A green strip represented that the environmental factor had variables that other environmental factors did not have, and it also had great influence on the distribution prediction of species. According to the obtained Fig. 3, it can be known that environmental factor bio 6 (min temperature of coldest month) had a great influence on the prediction of suitable habitats of *Cricotopus*, while bio 2 (mean diurnal range), bio 12 (annual precipitation) and bio 14 (precipitation of driest month) had less obvious influence than bio 6, but they were also very important.

It could be concluded from the importance analysis of environmental factors combined with the response curves that when the existence probability of *Cricotopus* was greater than 0.5, the habitat was more beneficial to the life of *Cricotopus*. It could be known through analysis on single factor response curves as shown in Fig. 4, that the suitable living environment for *Cricotopus* consisted of following most suitable environmental factors: annual precipitation of 500 – 2 000 mm, precipitation of driest month in the range of 2 – 85 mm, min temperature of coldest month greater than 5 ℃, and altitude of 0 – 1 500 km.

The comprehensive contribution rate and jackknife method test showed that annual precipitation, min temperature of coldest month, precipitation of driest month and altitude were main factors affecting the distribution of *Cricotopus*. Although altitude had a small impact on the jackknife method, it contributed significantly to the contribution rate. Therefore, considering all factors comprehensively, altitude was also a main factor affecting *Cricotopus*.

Distribution range of suitable habitats for the genus *Cricotopus* in China

Based on 11 major environmental factors and 98 known distribution sites of *Cricotopus*, a highly reliable prediction model for their suitable habitats was constructed, and suitable habitat ranges and areas of *Cricotopus* were obtained, including the ranges and areas of unsuitable, lowly suitable, moderately suitable and highly suitable habitats for *Cricotopus* in China. It could be seen that although the suitable habitats of *Cricotopus* were distributed throughout the country, few were located in Xinjiang, Tibet, Qinghai, Inner Mongolia, Heilongjiang and Jilin provinces, where although there were suitable habitats, most of them were lowly suitable habitats.

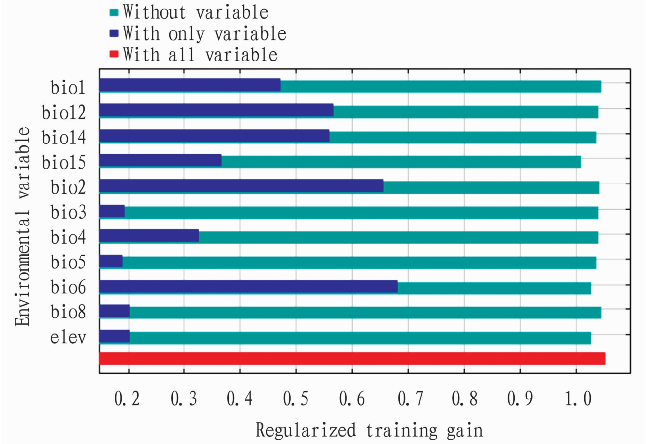

Fig. 3 Importance map of environmental factors using the jackknife method for the genus *Cricotopus*

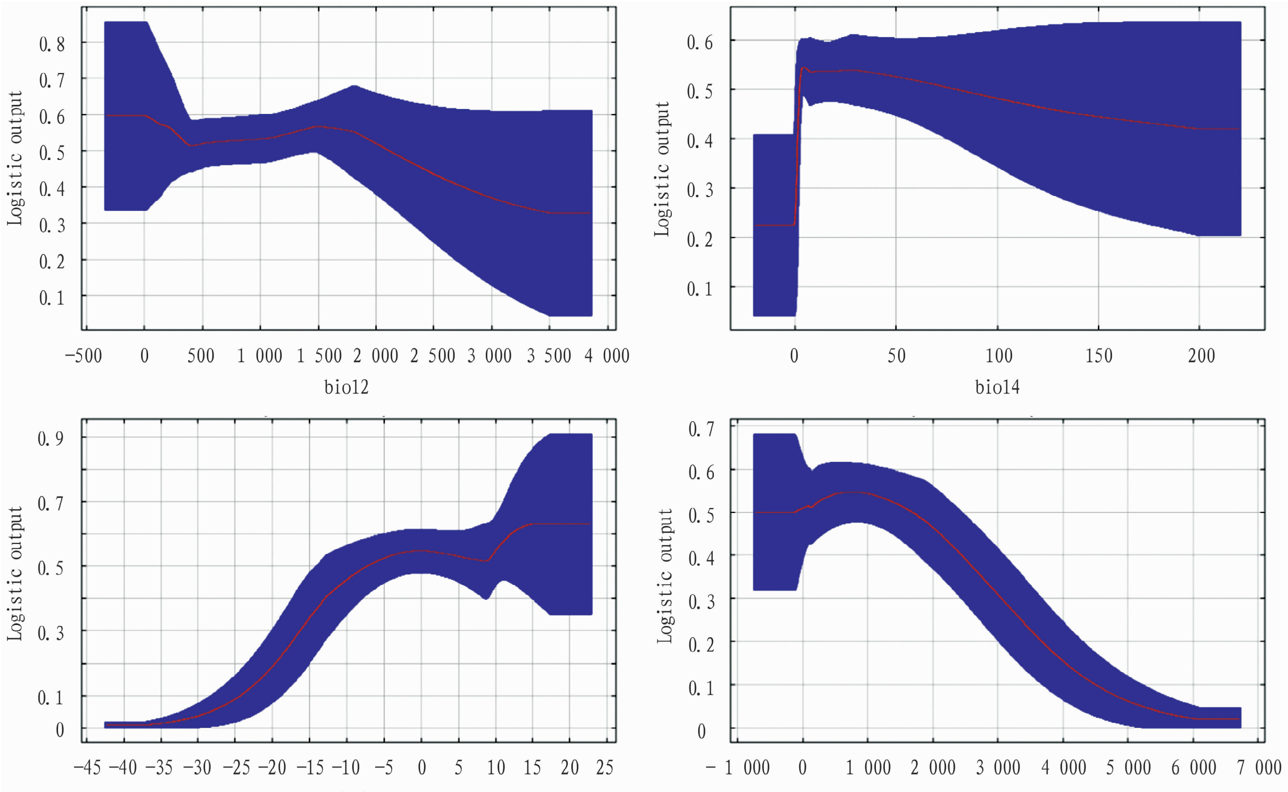

Fig. 4 Response curve of the main environmental variables of the genus *Cricotopus*

Starting from the area south of the Yellow River, the ranges of suitable habitats for the genus *Cricotopus* began to expand, with most of the suitable habitats being at highly or moderately suitable levels[12]. The ranges of highly suitable habitats were mainly concentrated in the areas south of the Yellow River and north of the Yangtze River in China, because the Qinling Mountains are distributed between the Yangtze River and Yellow River. There is a significant difference in climate between the north and south slopes of the Qinling Mountains. To the south of the Qinling Mountains, there is more solar radiation, higher temperatures, more precipitation and a humid climate, while the opposite is true north of the Qinling Mountains. In specific, more than 90% of Guizhou was highly suitable[13], mainly because Guizhou belongs to the humid monsoon climate zone in the eastern part of the middle subtropical zone, where the climate is warm and humid all year round and suitable for plant growth. There is no cold weather, abundant rainfall, more cloudy and rainy days and less sunshine in winter, and the climate differences are significant. In Hunan, where Hengshan

Mountain is located, Hengshan Xuanzhou Wetland Park has an average annual temperature between 16 and 18 ℃, the highest temperature in the range of 26 – 30 ℃, and an average annual precipitation of 1 423 mm, and there are multiple months of the year suitable for the growth of *Cricotopus*[14]. Sichuan is located in a basin and near the middle and lower reaches of the Yangtze River, with abundant water sources, humid climate, and suitable temperature. Mount Taishan is distributed in the east of Shandong, and has a suitable climate. The Dabie Mountains are located at the border of Hubei, Anhui, and Henan provinces, with a humid climate and abundant water[15]. Zhejiang is close to Mount Wuyi, and has an annual average temperature of 17.0 – 18.4 ℃ and an annual precipitation of 1 800 mm. Hainan Island, Taiwan Island and other regions also have a large distribution of highly suitable habitats, mainly due to the warm climate throughout the year, small daily range changes and close proximity to the sea[16]. The environment of the predicted distribution ranges of highly and moderately suitable habitats matched with several important environmental factors (bio 2, bio 6, bio 12, bio 14) that affected the predicted ranges of suitable habitats for *Cricotopus*. Therefore, the predicted suitable habitats are consistent with the actual situation.

The highly suitable habitats were mainly distributed in Hainan, Guizhou, Hunan, Zhejiang, Anhui, Chongqing, Hubei and Taiwan, China; the main distribution provinces of the moderately suitable habitats included Beijing, Tianjin, Yunnan, Guizhou, Hunan, Jiangxi, Zhejiang, Jiangsu, Anhui, Hubei, Chongqing, southern Shaanxi, southern Gansu, and southeastern Sichuan; and the lowly suitable habitats were mainly distributed in Hebei, Liaoning, Beijing, Tianjin, Shandong, Henan, Shaanxi, Shanxi, southern Gansu, southeastern Sichuan, Chongqing, Yunnan, Guizhou, Hubei, Hunan, Anhui, Jiangsu, Shanghai, Jiangxi, Zhejiang, Guangxi, Guangdong, Fujian and other southern regions. Other regions were all within the scope of unsuitable habitats, which were mainly located in northern China where there is a lack of water sources, and the climate environment is relatively harsh. The lack of water sources is not conducive to the reproduction and survival of *Cricotopus*, so these regions are not conducive to their survival.

Predicted areas of suitable habitats for the genus *Cricotopus* in China

According to MaxEnt, the predicted ranges of suitable habitats for *Cricotopus* were obtained. After importing the obtained data back to ArcGIS, the distribution areas of different suitable habitats are shown in Table 5. From Table 5, it can be seen that the area of unsuitable areas in China was 5 704 167 square kilometers; the area of lowly suitable habitats in China was 1.47 million square kilometers; the area of moderately suitable habitats in China was 1 566 945 square kilometers; and the highly suitable habitats covered an area of 900 833.4 square kilometers throughout China. The unsuitable habitats accounted for 59.41% of the total area of the country; the lowly suitable habitats accounted for 15.31%; the moderately suitable habitats accounted for 16.322%; and the highly suitable habitats accounted for 9.383%.

Table 5 Suitable habitat grades and distribution areas

Suitable grade of suitable habitat	Area of suitable habitat
Unsuitable habitat	570.416 7
Lowly suitable habitat	147
Moderately suitable habitat	156.694 5
Highly suitable habitat	90.083 34

Conclusions and Discussion

Based on the MaxEnt model combined with GIS technology, the potential distribution areas of the genus *Cricotopus* were predicted, and the spatial distribution pattern and suitability of *Cricotopus* in China were intuitively obtained. The AUC value of the model was as high as 0.901, which proved the high accuracy of the prediction results and could accurately reflect the potential geographical distribution of the genus *Cricotopus* in China. Through the prediction of suitable habitats, it was found that the ranges of suitable habitats for the genus *Cricotopus* in China were mainly 17.705° N – 41.53° N, 97.564° E – 123.256° E, starting from Hainan Island in southern China and reaching the southeastern part of Shaanxi along the Yellow River in northern China, Southern Beijing, Tianjin, southern Liaoning and other places. The overall range could reach Yunnan in the west and Shandong, Jiangsu, Shanghai, Zhejiang, Fujian and the eastern coastal areas of Guangdong in the east. In this range, the suitable habitats of *Cricotopus* are the most concentrated, and most of them were moderately and highly suitable. For other places, only a few of them were distributed in Tibet, Inner Mongolia, Xinjiang, Heilongjiang, Jilin and northern Gansu. Environmental variables were analyzed by combining contribution rate, permutation importance value and jackknife test. The main environmental factors affecting the geographical distribution of *Cricotopus* were annual precipitation, precipitation of driest month, min temperature of coldest month, and altitude.

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play a role similar to energy metabolism in electron transfer during photosynthesis and respiration[14]. The mechanism of Se increasing chlorophyll and carotenoid contents in plant leaves under low temperature stress is that Se can stimulate respiratory rate and electron flow in respiratory chain and protect chloroplast enzymes. Meanwhile, Se can regulate chlorophyll synthesis through the interaction of 5-aminoaevulinic acid dehydratase (ALAD) with -SH and porphobilinogen deaminase (PBGD)[15].

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