Analysis of Potential Distribution of *Spodoptera Frugiperda* In Northwest

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Abstract

Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae), a newly invaded pest that breaks out fast and severely, causes a serious threat to the national security of food production. In this study, the MaxEnt model was used to predict the potentially suitable distribution area of *S. frugiperda* in Northwest China. The potential distribution of *S. frugiperda* was predicted using meteorological factors from the correlation analysis. According to the result, a satisfactory AUC value in the MaxEnt model indicates that the prediction model has good accuracy, which is sufficient for predicting the fitness zone of *S. frugiperda* in Northwest China. The prediction results show that the potential distribution risk of *S. frugiperda* is high in western Gansu, eastern Qinghai, Shaanxi, most regions of Ningxia, and part regions of Tibetan, and it also exists in Hami, Yili, Bozhou, Urumqi, Hotan, and Aksu in Xinjiang, and more than 60% of Northwest China are suitable distribution areas for *S. frugiperda*. As China's major wheat and maize production area, Northwest China is a crucial prevention area for *S. frugiperda*. Clarifying the potential geographical distribution of *S. frugiperda* in Northwest China is essential for early warning as well as prevention and control.

Introduction

Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae), native to the tropical and subtropical regions of the Americas, is a major agricultural pest widely distributed in the American continent[1]. Since 2016, the insect has invaded more than 60 countries and regions, including Africa, Asia, and Oceania[2]. In December 2018, *S. frugiperda* adults invaded Yunnan, China, from Myanmar[3]. Moreover, on January 11, 2019, its larvae were first witnessed damaging maize in Jiangcheng County, Yunnan Province, China. After that, *S. frugiperda*, with its powerful long-distance migration ability, spread rapidly and caused damage across the country[2,4]. As of August 31, 2020, *S. frugiperda* has been found in 1,338 counties of 27 provinces nationwide. Among them, only adult insects were seen in 21 counties of Ningxia, Liaoning, Inner Mongolia, Beijing, and Tianjin. In a survey in late August, the larvae were found in 865 counties of 22 provinces, and the area where larvae occurred was 3.68 million mu[5-7]. Thus, it is essential to clarify the potential distribution of *S. frugiperda* in China for early warning as well as comprehensive prevention and control[2].

S. frugiperda has a strong flight capacity. Under suitable wind conditions, *S. frugiperda* adult can even travel 1,600 km within 30 h; in China, *S. frugiperda* is also predicted to migrate long distances[8,9]. *S. frugiperda* has a wide host range and can damage more than 300 species of plants, including rice, sorghum, millet, sugarcane, vegetable crops, and cotton. The larvae mainly feed on tender tips, drill the base of the stem, and damage the maize ears, resulting in reduced yield or even no harvest[10]. If proper control measures are not taken, *S. frugiperda* will cause severe yield losses. Based on the feeding preferences for host plants, *S. frugiperda* can be divided into two haplotypes: the maize strain, which mainly feeds on and harms maize, cotton, and sorghum; the rice strain, which mainly feeds on and harms rice and various forage grasses[11]. *S. frugiperda* that has invaded China belongs to the maize strain and damages maize mainly by feeding them in summer[7,12]. In the winter of 2019, *S. frugiperda* was found to invade in partial areas by feeding on wheat and barley[13]and in Guangxi and Yunnan by infesting sugarcane[14]. *S. frugiperda* is highly adaptable to environments and highly reproductive. Female *S. frugiperda*s can mate and spawn in a high frequency. Up to 2,300 eggs can be spawned at a time, depending on their nutritional conditions. In China, since *S. frugiperda* poses a serious long-term threat to the security of national food production, it is therefore classified as a major emergent pest on maize[8].

MaxEnt is a species distribution prediction model based on the maximum entropy theory and has been widely used due to its short running time, user-friendly operation, and stable running results. In recent years, using this model, global searchers have systematically studied pests such as *Drosophila melanogastes*[15], *Sirex noctilio*[3], *batocera lineolata*[16], and *S. frugiperda*. Using the MaxEnt model and ArcGIS, researchers have predicted the potentially suitable area of *S. frugiperda* in Yunnan, China[17]. Besides, Several studies have shown the potential distribution of *S. frugiperda* in Central Asia[18]. Model prediction results well simulated the potential distribution of *S. frugiperda*, which is consistent with the actual occurrence. *S. frugiperda* occurs less frequently in the irrigated areas of Northwest China (such as Xinjiang and Tibet), and the prediction shows a reduced overlap and less risk. The potential distribution of *S. frugiperda* was explored using limiting environmental factors and the collection model prediction scheme[19]. However, their prediction results lack reference value, especially for the Middle East and East Asia. The potential distribution of *S. frugiperda* in Central Asia and China have been simulated, with uncertainties in single model predictions (MaxEnt model). Regions such as Liaoning, Hebei, Beijing, Tianjin, Shanxi, Shaanxi, Inner Mongolia, Ningxia, Gansu, Qinghai, and Xinjiang are suitable distribution areas for *S. frugiperda* in spring, summer, and autumn[18,20].

China is one of the maize-producing countries, and maize is an important food crop and cash crop for China. Northwest China is a major production area of wheat and maize, so it is a crucial prevention area for *S. frugiperda*. On May 31, 2019, *S. frugiperda* was first discovered in Yang County, Shaanxi Province. After that, damagze occurred in 63 counties of this province[21]. On July 2, 2019, *S. frugiperda* larvae were investigated for the first time in summer maize fields in Duanheba Village, Liangshui Township, Wudu District, Gansu Province[22]. Although *S. frugiperda* has not caused serious damage in these regions, it is imperative to clarify the potential geographic distribution of *S. frugiperda* in Northwest China to guide early warning as well as prevention and control. This study aims to provide a theoretical basis for the further control of *S. frugiperda* in China.

Results

Prediction of potential distribution areas of *S. frugiperda*. The red parts in Figure 1 (A1, A2) show the highly suitable distribution areas of the *S. frugiperda*. As shown in Figure 1, most areas in China, such as Fujian, Jiangxi, Hunan, Guangdong, Anhui, Jiangsu, Hubei, Guangxi, Zhejiang, Shanghai, Henan, Shaanxi, Shandong, Sichuan, Chongqing, Guizhou, Tianjin, Shanxi, are highly suitable distribution areas; Ningxia, Tibet, and Gansu in Northwest China are also highly suitable distribution areas; some areas in Xinjiang are moderately suitable distribution areas; besides, other areas in Northwest China are mostly non-suitable distribution areas. According to the correlation analysis, Hami, Ili, Bortala Mongol Autonomous Prefecture, Urumqi, Hotan, Aksu in northwest China are moderately suitable distribution; eastern Tibet (Linzhi, Naqu, Ganzi, Yushu, Hercynian Mongolian autonomous region), Gansu, Qinghai, Shaanxi, Ningxia in most areas are highly suitable distribution; most of Xinjiang are non-suitable areas (Figure 1 (B2)). In China, the highly suitable, moderately suitable, low suitable, and non-suitable distribution areas of *S. frugiperda* cover 42.81%, 9.31%, 13.73%, and 34.16% of the studied area, respectively. In Northwest China, the highly suitable, moderately suitable, low suitable, and non-suitable distribution areas account for 28.03%, 13.60%, 18.77%, and 39.6% of the studied area, respectively.

Evaluation of model accuracy. The AUC value was used to evaluate the accuracy of the model prediction, and the range is [0, 1]. The larger the AUC value, the better the prediction effect, which indirectly reflects the sound prediction of the model. The ideal circumstance is that when the AUC value is 1, the distribution area predicted by the model is identical to the actual distribution area of *S. frugiperda.* The ROC curve was evaluated by the following benchmarks: when the value of AUC is between 0.5-0.6, the prediction result is failure; when the value of AUC is between 0.6-0.7, the prediction result is poor; when the value of AUC is between 0.7-0.8, the prediction result is fair; when the value of AUC is between 0.8-0.9, the prediction result is good; when the value of AUC is between 0.9-1, the prediction result is excellent. When the mean AUC value obtained by using 19 meteorological factors for the prediction analysis is 0.881 and when it is obtained by analyzing meteorological factors after filtering is 0.864, the prediction results are reasonable (Figure 2).

Analysis of dominant environmental variables influencing the potential distribution area of *S. frugiperda.* The Jackknife of the MaxEnt model was used to obtain the relative importance of different environmental variables on prediction. As shown in Figure 3, according to the fitness analysis of *S. frugiperda* using 19 environmental variables, Bio19, Bio1, Bio11, and Bio18 have a greater influence on the potential distribution of *S. frugiperda*.

Discussion

Since the invasion of *S. frugiperda* in Africa, it has caused annual losses of \$2.481 billion to \$6.187 billion[20]. For thousands of years, the planting industry has been dominant in China, and the significance of agriculture cannot be neglected. However, *S. frugiperda* poses a considerable threat to maize, wheat, and other main food crops in China. As of April 2020, the occurrence acreage of *S. frugiperda* reached 111.33 hm^2 in Yangdong District, Yangjiang City, Guangdong Province, including a heavy occurrence acreage of 13.33 hm^2 [23]. Based on the meteorological data after conducting correlation analysis, the results reveal that 65% of areas of China are the potential distribution areas of *S. frugiperda*. In addition, over 60% of the areas in Northwest China are suitable distribution areas (28.03% in the highly suitable distribution areas, 13.60% in the moderately suitable distribution areas, and 39.6% in the low suitable distribution areas). Among those areas, Linzhi and part areas of Shannan in Tibet, western areas of Gansu, Shaanxi, and most areas of Ningxia are highly suitable distribution areas; sporadic areas of Hami, Yili, Bozhou, Urumqi, Hotan, and Aksu in Xinjiang are moderately suitable distribution areas. There are also potential distribution areas in other parts of Northwest China.

In this study, the MaxEnt model was used to predict the suitable distribution. After correlation analysis, the model results show that most areas in China, such as Fujian, Jiangxi, Hunan, Guangdong, Anhui, Henan, Guizhou, and Yunnan provinces, are highly suitable distribution areas. The above results are generally consistent with those in previous studies[20]. However, the study of the potential distribution areas in Northwest China differed somewhat from the previous studies[20]. It is concluded that Shaanxi, Gansu, Ningxia, and parts of Qinghai in Northwest China are low suitable distribution areas; most parts of Xinjiang and Tibet are non-suitable distribution areas but also have high fitness zones. In contrast, in this study, most areas of Shaanxi, Qinghai, Gansu, Ningxia, and part of Tibet are considered highly suitable distribution areas; some parts of Xinjiang are moderately suitable distribution areas for the *S. frugiperda.* This classification may be led by the different sample sites. In this study, distribution data from CABI (www. cabi.org /ISC /datasheet /29810) were used to construct the model. CABI maps the approximate distribution of invasive species at a macroscopic scale, with a focus on national or provincial administrative centers. These administrative centers only represent the area where the species is found, which are significantly different from the specific distribution points. Therefore, they cannot reflect the actual distribution of the species in detail[24].

In this study, the distribution areas in the world of *S. frugiperda* were involved in the model analysis. The suitable distribution areas in Northwest China covered a relatively high proportion. Both this study and previous studies[20] reveal that *S. frugiperda* has strong migration ability in the suitable distribution areas in Northwest China. Northwest China, as an important maize production area, may still be a potentially suitable distribution area for *S. frugiperda*. Therefore, this insect should be closely monitored and controlled.

Four environmental variables that exerted a strong influence on the distribution points of *S. frugiperda* were obtained by correlation analysis, namely Bio19 (Precipitation of the coldest quarter), Bio18 (Precipitation of the warmest quarter), Bio4 (Temperature seasonality), and Bio12 (Average annual precipitation). Besides, among the 19 environmental variables models, the environmental variables that had a greater impact on the distribution area were Bio19(Precipitation of coldest quarter), Bio1 (annual mean temperature), Bio11 (Mean temperature of the coldest quarter), and Bio18 (Precipitation of the warmest quarter). This result shows that temperature and precipitation are the main factors affecting the distribution of *S. frugiperda*. A relatively low temperature with a large temperature difference helps prohibit the spread and establishment of the insect[17]. In addition, precipitation impacts the migration and dispersal of *S. frugiperda*.

S. frugiperda can be divided into two haploid genotypes, including the maize strain and the rice strain. The former feeds mainly on maize, cotton, and sorghum, while the latter feeds more on rice and various forages. Both have caused significant damage not only to the economy of China but also the world[25]. In this paper, only 19 meteorological factors were used to analyze and predict the prediction model merely in an ideal and objective situation. However, the actual distribution of *S. frugiperda* was not only related to climatic factors, but anthropogenic activities, food, and natural enemies could impact its distribution. In future studies, a broad viewpoint is needed to achieve more accurate predictions[26].

Materials And Methods

Distribution data and treatment of *Spodoptera frugiperda.* The distribution data of *S. frugiperda* in this study were divided into two parts: (1) valid data for *S. frugiperda* were downloaded from the Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/) database and the species distribution data of the model were recorded. (2) Recorded data of China's reports. A total of 3,085 sample points were exported into a table after importing distribution point data using ArcGIS10.2 software(Figure 4). The table was saved as a CSV file in the order of species name, the longitude and latitude of distribution points, and sample points were acted as the species distribution data of the model.

Selection of environmental variables. (1) Using 19 environmental variables in the global prediction model:

Data on environmental variables for global prediction models: Nineteen bioclimatological variables with a spatial resolution of 2.5' were originated from WORLDCLIM (http//www.worldclim.org/) version 1.4.

(2) Correlation analysis: During the operation of MaxEnt, if there is a strong correlation between the environmental variables, the model will be excessively fitted. Therefore, ArcGIS software was used to extract the values of 19 variables. Pearson correlation coefficient was used to calculate the correlation between variables whose correlation coefficient is higher than 0.9 were eliminated.

(3) Nineteen environmental variables were run in the MaxEnt model (except for the number of runs, the other settings were consistent with the operation of this experimental model), and then variables were screened according to the contribution rate and correlation analysis results of each variable in the initial model. After the above procedures, four variables (BIO19, BIO18, BIO12, bio4) were finally reserved for establishing the final model[27].

Software and map data. The software MaxEnt (version 3.3.3.) used in this paper was downloaded from the MaxEnt homepage (http: //www.cs.princeton.edu~schapire/MaxEnt). ArcGIS 10.2, developed by Environmental Systems Research Institute, Inc., was also used. The vector map scale of China is 1:4 million, which was downloaded from the National Geomatics Center of China (http://nfgis.nsdi.gov.cn/) for free.

Methods. The distribution points and environmental variables of *S. frugiperda* were imported in MaxEnt; 75% of the distribution points were randomly selected as training data, and 25% as test data. Other parameters in the Jackknife model were selected as default parameters, and the results predicted in this model were continuous raster data with values between 0 and 1. The output file format of MaxEnt was ASCII, which would be imported into ArcGIS to be converted to raster format. The Natural Breaks was used to classify the fitness level of *S. frugiperda* into four categories according to the fitness index (P) with Jenks' natural breaks method[28]: non-suitable distribution areas (P < 0.08), low suitable distribution areas (0.08 ≤ P < 0.25), moderately suitable distribution areas (0.25 ≤ P < 0.47), and highly suitable distribution areas (P ≥ 0.47). The vector maps of Shaanxi, Gansu, Ningxia, Xinjiang, and Tibet were used as the base map to conduct extraction by mask in ArcGIS**.** The Natural Breaks was used for classification again. Finally, the potential distribution areas of *S. frugiperda* in Northwest China were identified.

Declarations

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Figures

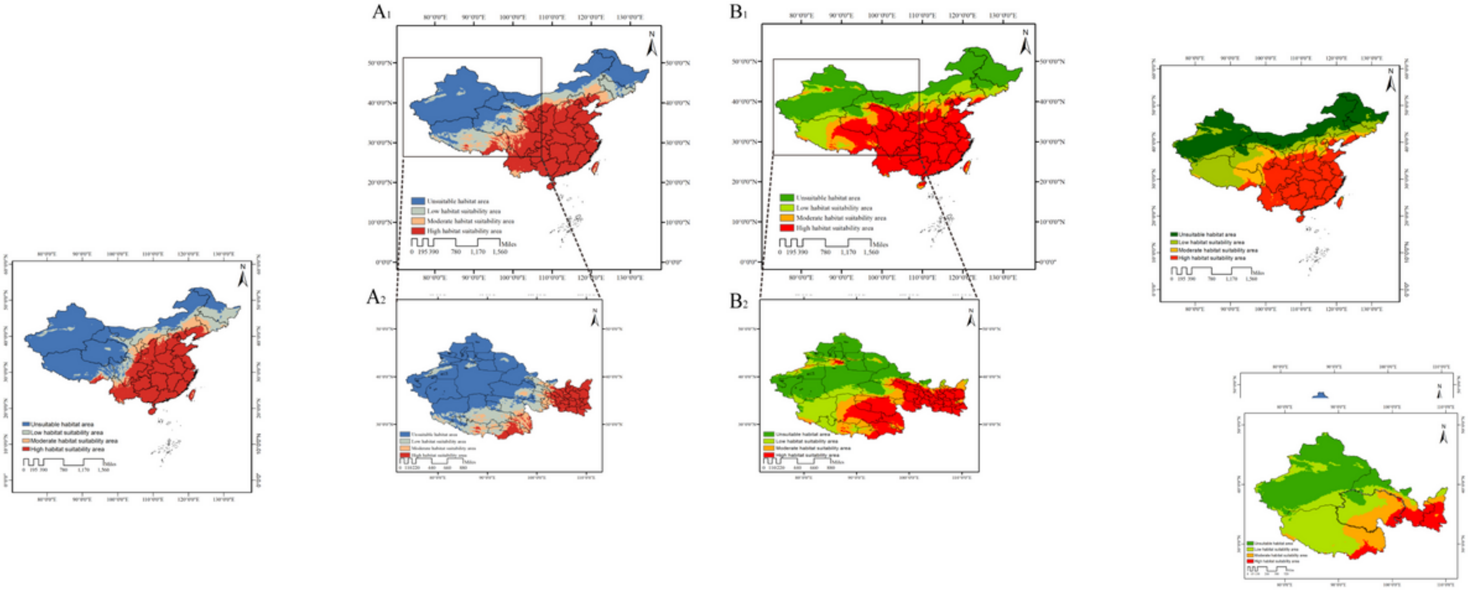

Figure 1

Predicted potential distribution of Spodoptera frugiperda (A: Global model; B: correlation analysis model)

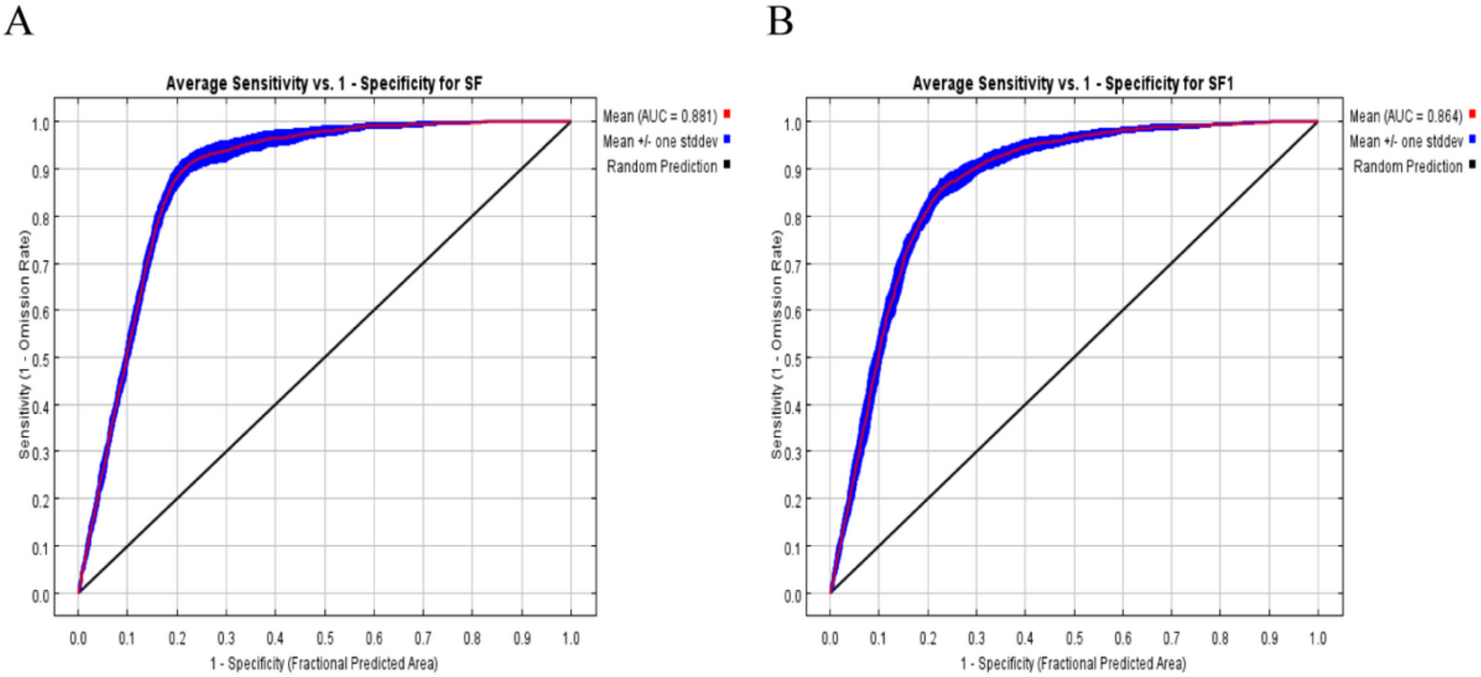

Figure 2

ROC curve verification of the predicted potential habitat for S. frugiperda by MaxEnt model(A: Global model; B: correlation analysis model)

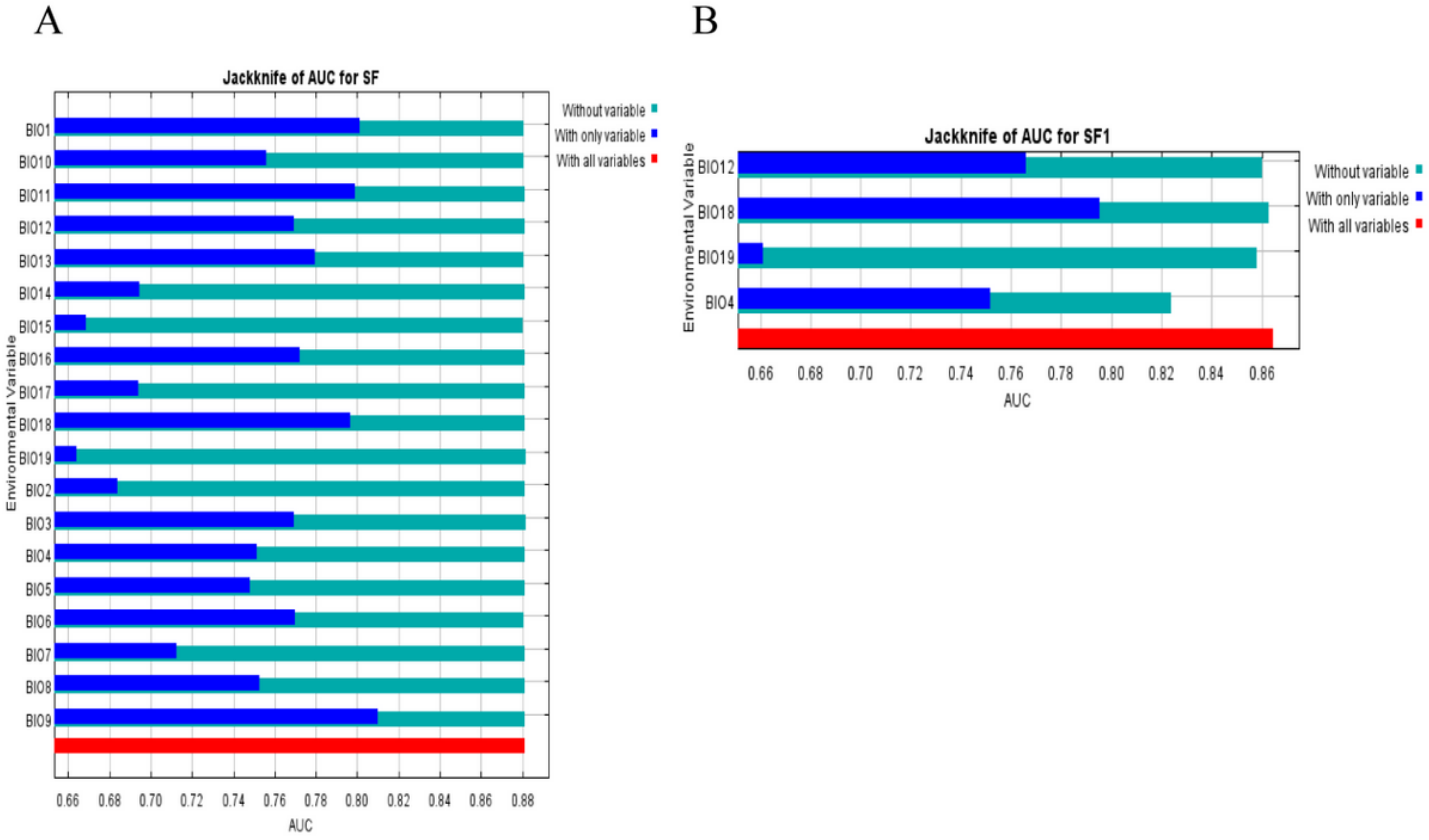

Figure 3

The influence of environmental variables for *S. frugiperda* distribution prediction

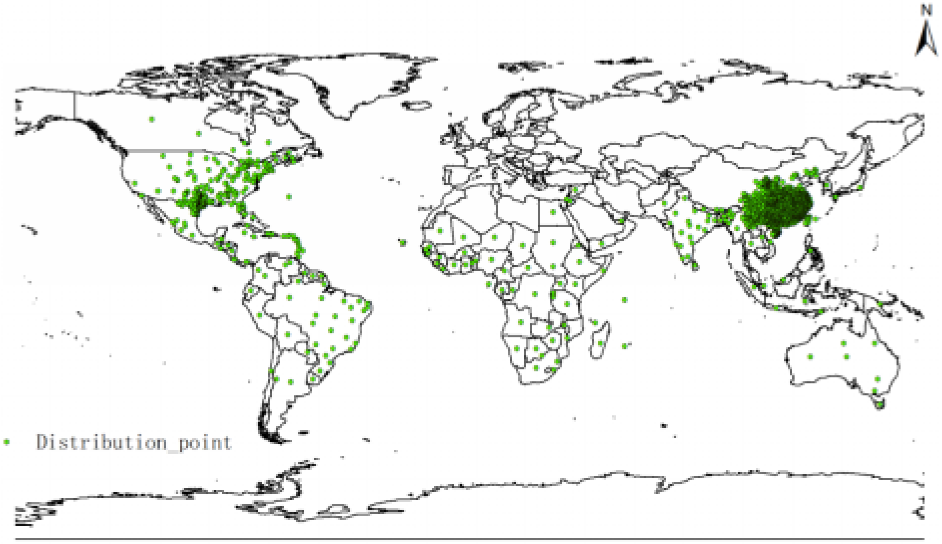

Figure 4

Distribution map of *Spodoptera frugiperda*