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The current and future potential geographical distribution of the Italian locust, *Calliptamus italicus* (Linnaeus) (Orthoptera: Acrididae) in China

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Abstract. The Italian Locust, *Calliptamus italicus* (Linnaeus) (Orthoptera: Acrididae), is one of the most harmful species to the grasslands in Xinjiang province, China. It attacks a variety of plants in *Compositae*, *Chenopodiaceae* and *Gramineae*. We used CLIMEX and ArcGIS to determine the potential geographical distribution of *C. italicus* in China under current and future climatic scenarios. Our analysis predicted that under current climatic conditions, *C. italicus* has a wide potential distribution in areas north of the Yangtze River in China. With the climatic changes, the potential range for *C. italicus* was projected to expand, and the suitability levels of most areas would increase, especially in areas with optimal climatic conditions. We therefore suggest that surveys should be enhanced in the areas suitable for *C. italicus* to facilitate early detection and reduce potential damage.

Keywords: *Calliptamus italicus* (L.), CLIMEX, ArcGIS, potential geographical distribution, climatic change

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1 Introduction

Calliptamus italicus (Linnaeus) is one of the main insect pests of grasslands in Xin Jiang, and attacks a wide range of host plants including 45 species in 17 families. The nymphs of *C. italicus* prefer *Artemisia frigida* Willd. and *Carex onoei* Franch. et Sav., while the adults prefer not only *A. frigida* Willd., but *Salvia deserta* Schang and *Medicago falcate* Linn. [1]. The Italian locust has become the most common and damaging plant pest in Kazakhstan, regularly invading millions of hectares and causing crop damage of great economic importance [2]. In 1999, *Calliptamus italicus* was introduced to from Kazakhstan and Russia into Xinjiang province, China. It subsequently damaged approximately 2 million hectares in 2000 and 2007 in Xinjiang province [1, 3].

The distribution area of *C. italicus* stretches from Western Europe to the meadow-steppes of Central Asia in Siberia and in Kazakhstan and its neighboring countries. Its range includes countries along the northern and eastern edge of the Mediterranean Sea, Central Europe and Central Asia up to Mongolia and western Siberia [4]. These regions include the former USSR, Russia Federation, Spain, Italy, France, Ukraine, northern Africa; Siberia, Kazakhstan, Uzbekistan, Turkey, Mongolia, Iran, and Afghanistan. In China, it occurs in Xinjiang, Gansu, Qinghai, Shaanxi, and Hebei provinces [5, 6].

In this study we modeled the potential range of *C. italicus* in China based on climate suitability. Because pest ranges are likely to shift in response to changes in temperature and precipitation, we also assessed the effects of climatic change on its potential distribution.

2 Materials and Methods

2.1 Overview Of CLIMEX Model And ArcGIS

We used CLIMEX 3.0 to model the potential geographical distribution of *C. italicus* in China under current and future climate scenarios. CLIMEX model is a predictive modeling software that has been used to predict the potential geographical distribution of many pests including: *Ceratitidis capitata* (Wiedemann) [7], *Bactrocera zonata* [8], *Frankliniella occidentalis* Pergande [9], *Hyphantria cunea* [10],

Solenopsis invicta [11], *corynespora* Leaf Fall Disease [12], *Nassella neesiana* [13].

CLIMEX is a dynamic model [14] that integrates the weekly responses of a population to climate using a series of annual indices. The model combines the growth index (GI) and the stress indices (SI) into an overall ecoclimatic index (EI). EI describes the climatic suitability of a location for a species as a number between 0 and 100. In this study, we classified the EI into four categories of climatic suitability for *C. italicus*: unsuitable (EI=0), marginal (EI=0-10), suitable (EI=10-20) and optimal (EI>20) [14, 15].

To visualize the results, the CLIMEX output was 'loose-coupled' [15] to a geographical information system (ArcGIS). It can present CLIMEX results in the same map as a species distribution or other information that provides spatial context [16]. Both CLIMEX ver. 3.0 and Arc/INFO ver. 9.3 were purchased by the Plant Quarantine Lab of China Agriculture University.

2.2 Meteorological Databases And Climatic Change

Two climate databases were used in our model. We first used the CLIMEX standard meteorological dataset, based on 30 year averages from 1961 to 1990, to create an initial model output. This dataset contains information for 2500 weather stations worldwide. Secondly, we used a regular gridded dataset of the normal climate for the same period, TYN SC 2.0 (http://www.cru.uea.ac.uk/~timm/grid/TYN_SC_2_0.html) [17] to fine-tune the model output. The dataset consisted of 67,420 weather stations spaced on a 0.5° latitude×0.5° longitude regular grid for significant land areas worldwide.

For the climate change scenario, we modeled an average annual temperature increase of 2.3-3.3°C and, an annual mean precipitation increase of 5-7% by 2050 in China [18].

2.3 Geographic Data Sets

For geographic background datasets, we downloaded the electronic map of China national boundary, province boundary and national grassland distribution from <http://nfgis.nsd.gov.cn/> at a scale of 1:4,000,000.

2.4 Comparing Current And Climatic Change Scenarios

In order to visualize the differences in the potential geographical distribution for *C. italicus* under current and future climate conditions, the respective suitable land and grassland areas for each EI category were calculated in ArcGIS for each scenario.

2.5 Fitting CLIMEX Parameters

To fit the CLIMEX model for *C. italicus*, the parameters were manually and iteratively adjusted until the simulated geographical distribution, as estimated by the EI values, coincided with the species' known native distribution and the reported description of its range. Due to the lack of the data we used the information for the related species *Melanoplus sanguinipes* (Fabricius) [19] to fit the initial values. Parameters used in the CLIMEX model are presented in table 1.

Temperature Index

The lower developmental threshold of *C. italicus* was 15.5°C [20]. In this paper, the minimum temperature for development (DV0) was set at 15.50°C. The lower optimum temperatures for *C. italicus*'s populations were set at 17°C to correspond to its distribution in northern Africa. Because this species is now established in Xinjiang province, so we set the upper threshold temperature to 35°C [21].

Moisture Index

To fit the known *C. italicus*'s distribution in Xinjiang province, the lower soil moisture limit for development (SM0) was set to 0.01. We used this value because locusts normally require a desiccated environment for embryonic development. They survive well when the soil moisture in May is between 0.03-0.3 [22]. So in this paper, the lower and upper limits for optimal soil moisture (SM1 and SM2) were set to 0.03 and 0.3 respectively. Based on the *C. italicus*'s distribution in the central Europe, the upper soil moisture limit for development (SM3) was set to 0.6.

Table 1. Parameters used in the CLIMEX model for the *C. italicus*

Parameter	Initial value	Final value
DV0 Lower threshold temperature	10.0°C	15.5°C
DV1 Lower optimum temperature	16.0°C	17.0°C
DV2 Upper optimum temperature	28.0°C	28.0°C
DV3 Upper threshold temperature	32.0°C	35.0°C
SM0 Lower threshold of soil moisture	0.02	0.01
SM1 Lower limit of optimum soil moisture	0.05	0.03
SM2 Upper limit of optimum soil moisture	0.30	0.30
SM3 Upper threshold of soil moisture	0.70	0.60
DPD0 Diapause induction day length	11h	10h
DPT0 Diapause induction temperature (average weekly minimum)	11.0°C	11.0°C
DPD1 Diapause termination temperature (average weekly minimum)	3.0°C	6.0°C
DPD Diapause development days	120	90
DPSW Summer or winter diapause (‘0’ for winter diapause, ‘1’ for summer diapause)	0	0
TTCS Cold stress temperature threshold	-18.0°C	-18.0°C
THCS Cold stress accumulation rate	-0.0004	-0.0008
TTHS Heat stress temperature threshold	35.0°C	35.0°C
THHS Heat stress accumulation rate	0.008	0.0005
SMDS Dry stress soil moisture threshold	0.020	0.010
HDS Dry stress accumulation rate	-0.003	-0.003
SMWS Wet stress soil moisture threshold	0.7	0.6
SMDS Dry stress soil moisture threshold	0.001	0.003

Diapauses Index

Diapause is an important biological characteristic that allows locust to survive harsh environmental conditions. *Calliptamus italicus* overwinters below ground in the egg stage[23]. Based on its distribution in Iran, Afghanistan [4], Tibet and Sichuan province, we set the diapause induction day length to 10. We adjusted the diapauses

parameters to identify suitable in areas in Xinjiang province based on *C. italicus*'s distribution, north of the Mediterranean Sea, and north of Africa, based on that distribution, we set the diapause termination temperature and the diapause development days to 6 and 90.

Stress Parameter

We adjusted the stress parameters to account for *C. italicus*' global distribution. This was done to reduce the likelihood that our prediction maps for climatic suitability would not include areas where *C. italicus* cannot survive.

3 Results

3.1 Potential Geographical Distribution Under Current Climate

The CLIMEX parameter values were calibrated until the predicted geographical distribution agreed with the observed global distribution for *C. italicus*. With the current climate scenario our model predicted that North America, southern South America, most of the Europe, the edge of the Mediterranean Sea, isolated parts of north and south Africa, Central Asia, West Asia, East Asia and southern Australia were potentially suitable for *C. italicus* establishment (Figure 1). Known regions of occurrence, such as Italy, Spain, and Central Europe, with EIs between 0 and 20 were considered to have marginally suitable to suitable climates for establishment. Locations such as Kazakhstan, western Siberia, and Xinjiang where high population levels occur had EIs > 20, and were considered optimally suitable for *C. italicus*.

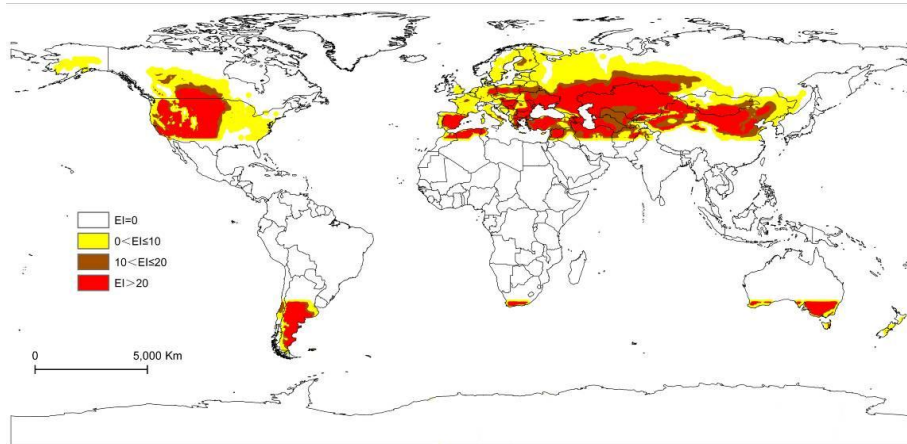


Fig. 1 The global Ecoclimatic Index (EI) values for *C. italicus* under the current climate scenario (1961-1990 averages) (□, unsuitable (0.00); ■, marginal (0.01–10); ■, suitable (10–20); ■, optimal (20.00+).)

Our model predicted that, under current climatic conditions, *C. italicus* could establish north of the Yangtze River in approximately 29% of China (Figure 2a). Optimal climate conditions occurred in most of Beijing, Tianjin, Xinjiang, Inner Mongolia, Gansu, Ningxia, Shaanxi, Shanxi, Hebei and small parts of Qinghai, Jilin, Shandong, and Henan. Climate conditions are projected to be marginal in parts of Heilongjiang, Jilin, Liaoning, Inner Mongolia, Gansu, Xinjiang, Qinghai, Shaanxi, Henan, Shandong, Anhui, Jiangsu, Sichuan and Hubei. The remaining areas south of the Yangtze River were unsuitable for the establishment of *C. italicus*. The grassland GIS layer further refined the model and estimated that (insert at-risk provinces here) were at risk for establishment based on climate and host presence (Figure 2b).

3.2 Potential Geographical Distribution Under Future Climate

The climate change scenario indicated that China is likely to become hotter and wetter by 2050. As a result, the potential range for *C. italicus* is projected to expand. Under the climate change scenario, the percentage of China's land area and grassland area at risk for *C. italicus* establishment increased from 29% to 31% and 96% to 98%, respectively. ,

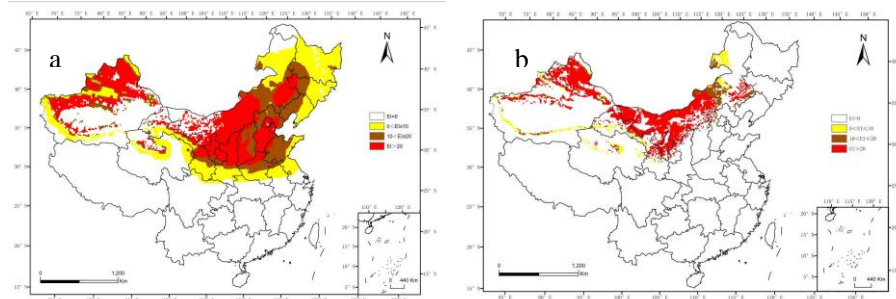


Fig. 2 The Ecoclimatic Index (EI) values for *C. italicus* in China under the current climate scenario (1961-1990 averages) with vegetation distribution (□, unsuitable (0.00); ■, marginal (0.01–10); ■, suitable (10–20); ■, optimal (20.00+).) (a) for land area, b) for grassland area)

Also, the overall climate suitability of China's land area is projected to increase with climate change, especially in those areas with optimal climatic conditions (Figures 3). Our model predicted that by 2050, the proportion of the marginal areas will decrease from 9% to 7%, suitable areas will decrease from 8% to 6%, and optimal areas will increase 11% to 17%. Therefore, the overall suitable area will increase by 2% by 2050. For grassland, the proportion of the marginal areas will decrease from 10% to 4%, suitable areas will decrease from 14% to 7%, and the optimal areas will increase from 71% to 86%, so the overall suitable area will increase by 2% by 2050 (Figure 4).

4 Discussion

In this study, we combined Climex EI values with grassland host presence to increase the precision of the predictive maps. However, the model predictions discussed above surely have some limitations.

Additional factors like dispersal, host density, competition, and the effects of natural enemies [24], soil type, geographical barriers and human activities could be incorporated to generate more robust predictions. Also, the use of model evaluation techniques like the ROC curve [25] could be used to determine which modeling approaches, e.g. Maxent, GARP, DIVA-GIS and CLIMEX, are most appropriate for predicting the establishment potential of pests like *C. italicus* in a particular area.

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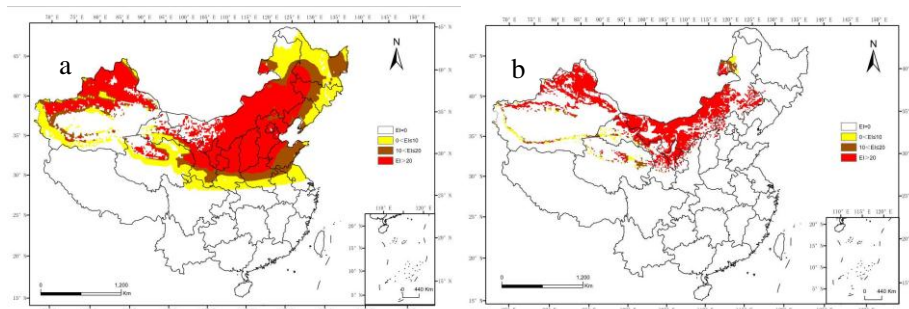


Fig. 3 The Ecoclimatic Index (EI) values for *C. italicus* in China in 2050 with vegetation distribution (□, unsuitable (0.00); ■, marginal (0.01–10); ■, suitable (10–20); ■, optimal (20.00+).) (a) for land area, b) for grassland area)

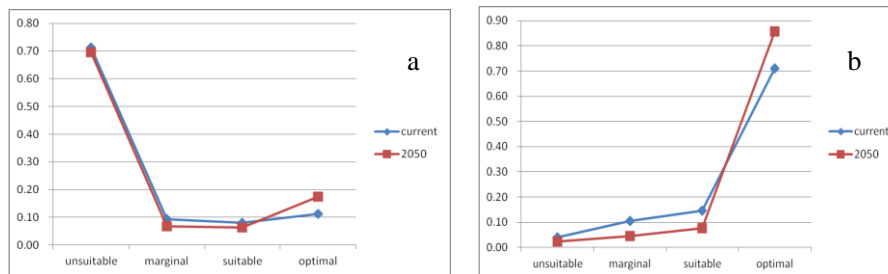


Fig. 4 Changes in area by EI category for total land area and grassland area under current and climate change scenarios (a) for land area, b) for grassland area)

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