The Potential Geographical Distribution of *Locusta migratoria tibetensis* Chen (Orthoptera: Acrididae) in Qinghai-Tibet Plateau[*]

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Abstract. *Locusta migratoria tibetensis* Chen (Orthoptera: Acrididae) is one of the most harmful species of Acrididae. It causes extensive damage to gramineous crops. The climate mapping program, CLIMEX 3.0, and the GIS software, ArcGIS 9.3, were used to model the current and future potential geographical distribution of *L. m. tibetensis*. The model predicts that, under current climatic conditions, *L. m. tibetensis* will be able to establish itself throughout much of Qinghai-Tibet Plateau in China, including Qinghai , Tibet and Sichuan province. A total of 94.23% of Qinghai-Tibet Plateau's land mass or 2.22×10^6 km^2, is climatically suitable under current climatic conditions. In this study, the potential distribution of *L. m. tibetensis* under future climate scenarios was projected and quantified climatically suitable areas. In Qinghai-Tibet Plateau, the total suitable climate land mass was increased by 0.16×10^6 km^2 or 0.70% until 2100. However, compared to 2020 and 2050, the suitable land mass was decreased by 0.47×10^6 km^2 and 0.17×10^6 km^2. The most optimal area would increase 0.16×10^6 km^2 until 2100, the most of Qinghai-Tibet Plateau would be expected to offer optimal climatic conditions for the possible spread and establishment of the pest. The analysis of this information indicated a high degree of accuracy for the CLIMEX model. The significant increases in the potential distribution of *L. m. tibetensis* projected under the climate change scenarios considered in this study suggest that biosecurity authorities should consider the effects of climate change when undertaking pest risk assessments.

Keywords: *Locusta migratoria tibetensis* Chen, CLIMEX, potential geographic distribution, ArcGIS, climate change.

1   Introduction

Locusta migratoria tibetensis Chen is one of the most harmful pests and causes large amounts of damage to gramineous crops. Since 1990s, the occurrence of *L. m. tibetensis* has showed a rising trend. Especially in 2003 to 2006, there were 1000 to 3000 individuals per m^2 along the valley areas of Jinsha River, Yarlung Zangbo River and Yalong River, which had threaten the production of highland barley and grass [1-2].

The distribution area of *L. m. tibetensis* is only in China at present, including northern of Qinghai, Tibet and west of Sichuan province[3]. Studies showed that there was a significant correlation between increasing of potential distribution area and global warming. The annual surface temperature increased at the speed of 0.0301℃, while the potential distribution area increased 504.38 km^2 per year. This result indicated that a little increment in temperature would bring a great extension in distribution of *L. m. tibetensis*[2].

The CLIMEX model has been used to describe the potential distribution of some pests, such as *Ceratitis capitata* (Wiedemann)[4-5], *Bactrocera tryoni*(Froggatt) [6-7], *Carpomya vesuviana* Costa[8], *B. tsuneonis*(Miyake)[9], *B. scutellata* (Hendel)[10], *Toxotrypana curvicauda* Gerstaecker[11], *B. zonata*(Saunders)[12], *Melanoplus sanguinipes* (Fabricius) [13]. This model has also previously been used to predict the effects of climate change on species' potential distributions using either a regional global climate model [14] or synthetic climates[15-16]. Species examined using this approach include *B. dorsalis* (Handel)[17], *Melaleuca quinquenervia*[18] and *Melanoplus sanguinipes* (Fabricius)[13]. To know the potential distribution of the *L. m. tibetensis* under climate change assumptions due to potential climate change impact, the CLIMEX 3.0 model was used to assess the response of *L. m. tibetensis* to climate and to make predictions for the 2100s.

2   Materials and Methods

2.1   Overview of the CLIMEX Model

CLIMEX is a dynamic model[19] that integrates the weekly responses of a population to climate using a series of annual indices. The growth and stress indices are calculated weekly and then combined into an overall annual index of climatic suitability, the Ecoclimatic Index (EI). This index is expressed on a scale of 0 to 100. Some suggested guidelines are provided[20-21] based on the EI. An EI of 0.00 indicates that the climate is unsuitable for the species and that the species cannot persist in an area under average environmental conditions. An EI of 0.01–9.99 indicates marginal conditions, an EI of 10.00–19.99 indicates suitable conditions, and an EI of 20+ indicates optimal conditions. An EI of 100 indicates that conditions are perfect throughout the year. However, few environments are sufficiently stable to provide perfect habitat all year[17].

To visualize the results, the CLIMEX output was 'loose-coupled'[16] to a geographical information system (ArcGIS). This system was purchased from ESRI to create thematic maps. ArcGIS was also used to make projections of the land areas that would have a suitable climate for the pest species.

2.2 Meteorological Databases and Climate Change

Two climate databases were used in this modeling exercise. By default, CLIMEX uses 30-year averages of climate data to estimate climatic suitability. The CLIMEX standard meteorological dataset was first used to create an initial fit. This dataset accompanied CLIMEX version 3.0 and consists of 30-year averages from 1961 to 1990 for an irregularly spaced set of 2500 climate stations. Subsequently, a regular girded 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)[22] was used to fine-tune the parameter fit. The dataset consisted of 67,420 points spaced on a 0.5° latitude×0.5° longitude regular grid for significant land areas worldwide.

The future average annual temperature will increase 1.3-2.1℃, 2.3-3.3℃, 3.9-6℃ until 2020, 2050, 2100 respectively. While the future annual mean precipitation will increase 2-3%, 5-7%, 11-17% until 2020, 2050, 2100 respectively in China[17,23]. In this study, we use the average data of temperature and annual mean precipitation for the potential geographical distribution analysis in the future.

2.3 Fitting CLIMEX Parameters

To fit the CLIMEX model for *L. m. tibetensis*, 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. Parameters used in the CLIMEX model are presented in table 1.

Temperature Index

In this paper, the minimum temperature for development (DV0) was set at 14.6°C (Li *et al.*, 2007). The lower and upper optimum temperatures for *L. m. tibetensis* populations were set at 15–28°C[24]. So the lower and upper temperature optima (DV1 and DV2) were set at 15 and 28°C, respectively[24-25]. As a result of the species is established in Tibet, and the day average temperature is no more than 32°C (http://cdc.cma.gov.cn/), so the upper threshold temperature (DV3) was set at 32°C.

Moisture index

In commonly, Locust like desiccated environment for embryonic development stage. They survive well when the soil moisture in May at 0.03-0.3[26]. However, we have found that the soil moisture can be reach to 0.40 in October, this would be related with there was a long snow-covered time in Qinghai-Tibet Plateau. So in this paper, the

lower soil moisture limit for development (SM0) was set to 0.02, the lower and upper limits for optimal growth (SM1 and SM2) were set to 0.03 and 0.5 respectively[25,27]. According to one year soil moisture changes of Tibet, the upper soil moisture limit for development, SM3, was set to 0.7 (http://cdc.cma.gov.cn/).

Table 1. Parameters used in the CLIMEX model for the *L. m. tibetensis*

Parameter	Value
DV0 Lower threshold temperature	14.60
DV1 Lower optimum temperature	15.00
DV2 Upper optimum temperature	28.00
DV3 Upper threshold temperature	32.00
SM0 Lower threshold of soil moisture	0.02
SM1 Lower limit of optimum soil moisture	0.03
SM2 Upper limit of optimum soil moisture	0.50
SM3 Upper threshold of soil moisture	0.70
DPD0 Diapause induction day length	11
DPT0 Diapause induction temperature (average weekly minimum)	11.0
DPD1 Diapause termination temperature (average weekly minimum)	3.0
DPD Diapause development days	120
DPSW Summer or winter diapause ('0' for winter diapause, '1'for summer diapause)	0
TTCS Cold stress temperature threshold	-17.00
THCS Cold stress accumulation rate	-0.0003
TTHS Heat stress temperature threshold	33.00
THHS Heat stress accumulation rate	0.005
SMDS Dry stress soil moisture threshold	0.002
HDS Dry stress accumulation rate	-0.003
SMWS Wet stress soil moisture threshold	0.70
HWS Wet stress accumulation rate	0.001

Diapause Parameter

Diapause is an important biology characteristic for locust to endure bad environment. In this paper, we take *Melanoplus sanguinipes* (Fabricius) for setting diapause parameter of *L. m. tibetensis*[13]. Compared to *Melanoplus sanguinipes*, the diapause day length and development days of *L. m. tibetensis* are very close to *Melanoplus sanguinipes* (http://cdc.cma.gov.cn/), also *L. m. tibetensis* is winter diapauses[26].

However, there was no related report about diapause induction and termination temperatures.

Stress Parameter

All stress parameters were adjusted by the real distributions in China, to ensure that the predictions of areas suitable for the insect were consistent with the insect's current absence.

2.4   Estimating the Size of Land Areas of Suitable Climate Projected by the CLIMEX Model

The land areas projected to have a climate suitable under current and future conditions for *L. m. tibetensis* (EI>0) were quantified for Qinghai-Tibet Plateau (table 2).

Table 2. Projected area that is climatically suitable (EI>0) for *L. m. tibetensis* under the current climate, expressed as an area (10^6km^2) and as a percentage of the total land of Qinghai-Tibet Plateau, and the percentage changes in Qinghai-Tibet Plateau for 2020, 2050 and 2100 in comparison with those obtained under the current climate. The climate model was run for the future climate changes in China[23].

	Area with EI>0 under current climate	Mean changes in areas with EI>0 under future climate in comparison with those obtained under current climate		
		2020	2050	2100
Total area (10^6km^2)	2.22	-0.47	-0.17	0.16
% total land area	94.23	-1.99	-0.72	0.70

3   Results

3.1   The Potential Distribution of L. m. Tibetensis under Current Climatic Conditions

The projections using the model suggest that under current climatic conditions, *L. m. tibetensis* can potentially establish itself to the Qinghai-Tibet Plateau (fig. 1, a). The results of the analysis indicate that Qinghai-Tibet Plateau would be expected to offer optimal climatic conditions for the possible spread and establishment of the pest. After CLIMEX modeling, the extent of the land area that is climatically suitable for *L. m. tibetensis* under the current climate is quantified by ArcGIS in table 2. A total of 94.23% of Qinghai-Tibet Plateau's land mass or 2.22×10^6 km^2, is climatically suitable.

3.2   The Potential Distribution of L. m. Tibetensis under Future Climate Scenarios

In this study, the potential distribution of *L. m. tibetensis* under future climate scenarios was projected and quantified climatically suitable areas. In Qinghai-Tibet Plateau, the total suitable climate land mass was increased by 0.16×10^6 km^2 or 0.70% until 2100 (table 2). However, compared to 2020 (fig.1, b) and 2050 (fig.1, c), the suitable land mass was decreased by 0.47×10^6 km^2 and 0.17×10^6 km^2 (table 2). The most optimal distribution area (EI: 20.00+) would increase 0.16×10^6 km^2 until 2100 (fig.1, d).
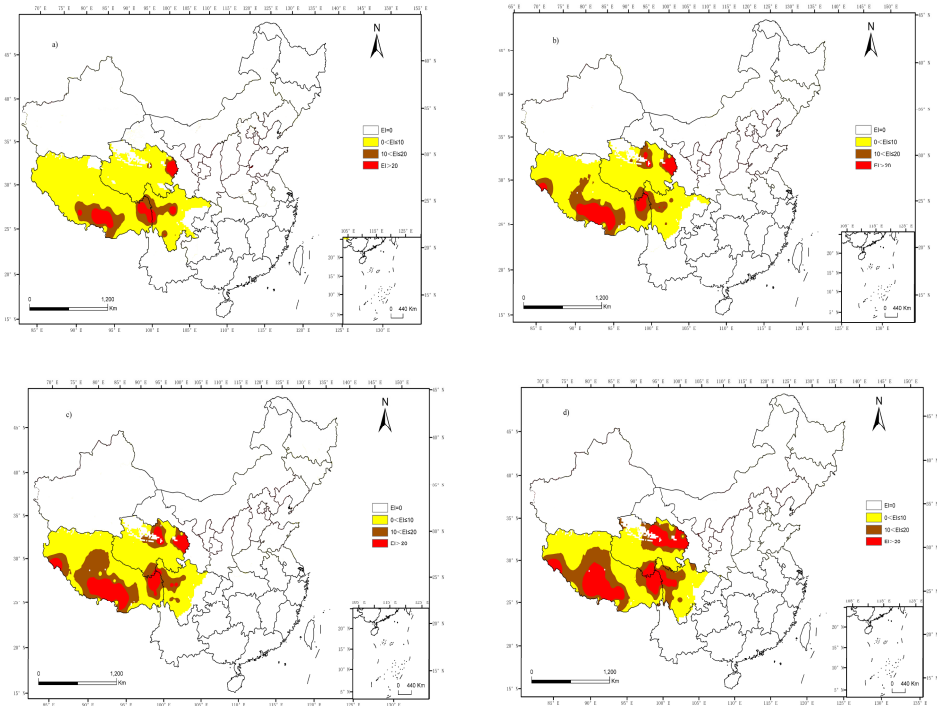

Fig. 1. Climatic suitability (EI) for the locust in the current and future climate scenarios projected using CLIMEX™. a)Qinghai-Tibet Plateau, current climate; b)Qinghai-Tibet Plateau, 2020; c)Qinghai-Tibet Plateau, 2050; d)Qinghai-Tibet Plateau, 2100. □, unsuitable (0.00); ▨, marginal (0.01–10); ▨ , suitable (10–20); ▨, optimal (20.00+).

4   Discussion

L. m. tibetensis as the independent subspecies which has been nominated by Chen[3]. The taxonomy of *L. m. tibetensis* has been studied recently; Zhang *et al.*[28-29] had illustrated the potential importance of phylogeographical history in shaping the divergence and distribution patterns of *L. m. tibetensis* and other subspecies, he thought

that *L. m. tibetensis* had independent genetic evidence for strong population substructure, as a result of geographical blocking for there was no gene flow between the inner and outside of Qinghai-Tibet Plateau. This is the reason for the current distribution of *L. m. tibetensis*, and we only predicted the potential distribution in Qinghai-Tibet Plateau in this paper.

The results of this study indicate that *L. m. tibetensis* is expected to be able to establish itself under temperate zones. Such conditions are to be found in most of Qinghai-Tibet Plateau. Moreover, the results suggested that as climate changes, the potential distribution of *L. m. tibetensis* would expand into cold regions, as it would expand into northward of the Plateau.

We have known that *L. m. tibetensis* is only in Qinghai-Tibet Plateau at present[3]. Studies showed that a little increment in temperature would bring great extension in distribution of *L. m. tibetensis*[2]. This study presented an example of influence of global warming on plateau ecology. So how climatic changes influence the potential distribution of insect in Qinghai-Tibet Plateau will need more attentions[30-31].

Potential distributions cannot be predicted based on climate alone. There is also a need to consider dispersal and species interactions, such as host availability. For example, mangoes, *Mangifera indica* Linn, are distributed in over 70 countries, more than 90% are grown in Asia (India, Pakistan, Bangladesh, Myanmar, Malaysia, China, Thailand, etc.), while Tanzania, Zaire, Brazil, Mexico, the United States, etc., also cultivate mangoes[32]. Competition and the effects of natural enemies[33] should also be considerations. Moreover, the limiting factors considered to affect the geographical distributions of pests should include soil type, geographical features, natural and geographical barriers and human activities. For example, the host plant *B. tsuneonis* limited citrus[9], so the prediction of the potential distribution of *B. tsuneonis* in China considered the factor of host distribution. Additionally, the irrigation and land use map were also taken into consideration for *Carpomya vesuviana*[8] and *Rhagoletis pomonella*[34]. The land use map removed the desert, river and lake, and urban land use type, etc. Therefore, the predictions based on the model and the results discussed above surely have some limitations; these additional factors should also be considered, and more detailed risk assessments should be useful for obtaining more scientific predictions.

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