# PREDICTING POTENTIAL DISTRIBUTION OF CUCURBIT LEAF BEETLES (*AULACOPHORA INDICA* AND *AULACOPHORA LEWISII*) IN CHINA USING MAXIMUM ENTROPY MODELING

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**Abstract.** *Aulacophora indica* and *Aulacophora lewisii*, two species of cucurbit leaf beetles, are significant pests that pose threats to cucurbitaceous crops. *A. indica* mainly damages cucurbitaceous crops such as cucumbers, watermelons, and pumpkins, while *A. lewisii* has a preference for loofahs. Modeling their potential distributions in China under both current and future climate scenarios is conducive to the implementation of scientific pest control measures. This study collected geographical distribution data and applied the MaxEnt model for prediction. It was found that precipitation in the warmest season was the key environmental factor affecting the distributions of both species, with contribution rates of 60% and 56% respectively. The model showed excellent predictive accuracy, with AUC values of 0.989 and 0.990 respectively. Under current climate conditions, *A. indica* is mainly distributed in the middle and lower reaches of the Yangtze River, while *A. lewisii* is distributed in the middle and lower reaches of the Yangtze River and the Pearl River Basin. Under future climate scenarios, the suitable habitat areas for both pests are expected to double and show a significant trend of northward expansion. These findings provide an important scientific basis for formulating targeted pest control strategies.
**Keywords:** *ecological niche, cucurbit leaf beetle, agricultural pests, cucurbit crops, climatic factors*

## Introduction

Melons (Cucurbitaceae) are a significant crop on a global scale, comprising over 960 species in 115 genera (Schaefer et al., 2009). This diverse family includes economically important crops such as cucumbers (*Cucumis sativus*), watermelons (*Citrullus lanatus*), pumpkins (*Cucurbita pepo*), and other cultivated varieties. The Food and Agriculture Organization of the United Nations (FAO) reported in 2019 that approximately four million hectares are dedicated to cultivating cucurbit crops worldwide. Not surprisingly, cucurbit crops are infested by a diverse array of insect pests throughout their growth cycle. These include cucurbit leaf beetle pests such as *Aulacophora indica*, *Aulacophora lewisii*, and *Diaphania indica* (Wang et al., 2020a; Debnath et al., 2023; Das et al., 2024). Notable piercing-sucking pests include *Liriomyza sativae* and *Trialeurodes vaporariorum* (Huang et al., 2009; Paschapur et al., 2023). The subterranean pest *Agrotis ypsilon* also severely affects cucurbit crops through direct feeding on leaves and roots (Hayat et al., 2021), and without effective control measures, these pests can cause substantial economic losses (Savary et al., 2019).

The leaf beetles, *A. indica* and *A. lewisii* (Chrysomelidae), are significant pest species affecting crop growth, despite their limited migratory capabilities (Nguyen, 2022). However, they exhibit notable differences in their feeding habits, where *A. indica* feeds on a variety of melon crops, including watermelon, pumpkin, cucumber,


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and squash. In contrast, *A. lewisii* has more restricted feeding habits and primarily affects Lucerne (Chen et al., 2002). Adults primarily feed on younger leaves, stems, and flowers, while larvae feed on roots or developing fruits (Liu et al., 2009). If larval damage is not promptly addressed, crop losses at the seedling stage may reach 35-75% (Kamal et al., 2014). In China, *A. lewisii* is distributed south of North China, while *A. indica* is widely distributed in Central, South, and North China and is also found throughout the Indian subcontinent and Southeast Asia. *A. lewisii* is distributed across Southeast Asia, the Mediterranean region, and Australia (Abe and Matsuda, 2005).

The distribution of agricultural pests is expanding because of climate change and human activities (Zhang et al., 2015), resulting in increased and considerable losses to agricultural production. The effective identification and prediction of pest distribution ranges are essential prerequisites for the implementation of scientific pest control and prevention strategies (Fournier et al., 2019). To this end, the MaxEnt model (Maximum Entropy Model) has gained considerable acceptance for predicting pest distributions due to its straightforward operational characteristics, the minimal impact of sample size on the prediction outcome, and increased stability (Soberón, 2007). By forecasting the distribution of significant pests such as *Spodoptera frugiperda* (Wang et al., 2020b), *Helicoverpa armigera* (Falsafi et al., 2022), and *Monochamus alternatus* (Gao et al., 2023) within their native habitats, it offered a crucial theoretical foundation for effective pest management and pest control, while facilitating the development of more precise pest management strategies to safeguard agricultural production and ecological balance.

To date, research on *Aulacophora* species has primarily focused on feeding behavior, phylogenetic relationships, and pest control (Kong et al., 2004; Baroga and Mohammad Sayed, 2006; Lee and Benen, 2015). However, systematic studies on their distribution patterns, particularly regarding habitat suitability and potential geographic ranges, remain scarce, which hinders the development of scientifically informed management strategies. Given the widespread distribution and relatively specialized feeding habits of these two cucurbit beetles, this study selected *A. indica* and *A. lewisii* as focal species to address the following questions: (1) What are their current geographic distributions? (2) How will their distributions shift under future climate change scenarios?

To address these questions, we compiled occurrence records spanning 25 provinces (each species with over 100 validated distribution points) and, for the first time, applied the MaxEnt model to predict their potential distribution ranges across China. Key environmental variables influencing their distributions were identified, and range dynamics under future climate scenarios (SSP1~2.6) were projected. The findings will provide a critical theoretical foundation for developing science-based pest management strategies. These strategies will enable stakeholders to accurately delineate high-risk areas, implement preemptive control measures, and mitigate the expansion of these pests into newly suitable regions, thereby reducing agricultural losses and economic impacts.

## Materials and methods

### *Modelling method*

The MaxEnt model employs environmental variables and species distribution data to forecast the prospective geographical range of a given species across a defined study area. The accuracy of the model was evaluated by comparing predicted outcomes with the actual observations. The MaxEnt model can identify the most probable distribution of


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entropy given incomplete information, thereby generating predictions that align as closely as possible with actual outcomes. In the construction of ecological niche models, the MaxEnt model can handle multivariate data while accounting for the interactions between different environmental variables. A substantial body of evidence exists demonstrating that the MaxEnt model outperforms other ecological niche models in terms of predictive accuracy and model stability. Moreover, it has been demonstrated to exhibit superior predictive capability for species distributions (Yang et al., 2013; Urbani et al., 2015). This conclusion is supported by the findings of Phillips et al. (2006) and West et al. (2016).

### *Occurrence data*

In the summer months of 2019 and 2023, comprehensive fieldwork was conducted in China to gather data on the geographic distribution (longitude and latitude) of two species of *Aulacophora*. The research yielded a total of 152 geographic distribution sites for *A. indica* and 102 for *A. lewisii*, with 44 and 47 actual surveyed distribution sites, respectively. The remaining distribution points were obtained from the Global Biodiversity Database (https://www.gbif.org/) and domestically published literature and reports. In the absence of specific geographic coordinates, the corresponding latitude and longitude information was obtained by geographically pinpointing the name of the area. The accuracy of the model would be adversely affected by spatial autocorrelation if the sample sites were in close proximity; therefore, we imported the data into ArcGIS v10.8 for an analysis of spatial correlation (Brown et al., 2017). Finally, 128 valid distribution sites for *A. indica* and 100 sites for *A. lewisii* were selected for model construction (*Fig. 1*).

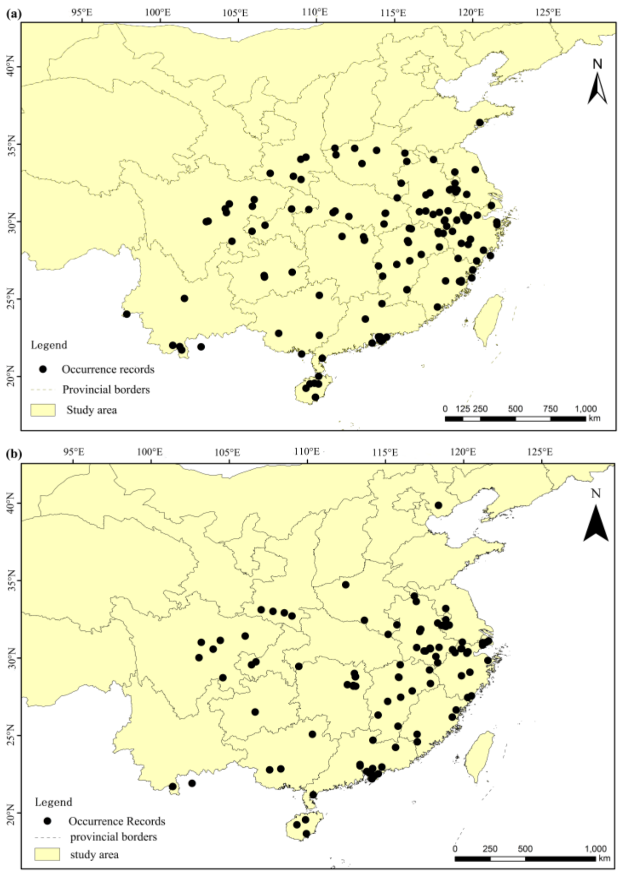


***Figure 1.*** *Distribution point data of two pests A. indica (a) and A. lewisii (b)*


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### *Environmental variables and processes*

Environmental data were obtained from the WorldClim v2.1 database (https://www.worldclim.org/), including current conditions (19 bioclimatic variables, Bio1~Bio19, at 2.5 arcmin resolution, ≈5 km) with 11 temperature-related and 8 precipitation-related parameters (*Table 1*), and future projections (2021~2040) under the SSP1~2.6 scenario representing a low radiative forcing pathway that limits global warming to 1.5~2°C by 2100.

In consideration of the potential for an expanded range of environmental variables to increase the complexity of the model, introduce random error, and reduce the precision of the forecast outcomes, we employed ENMtools v1.1.2 software to perform a Pearson correlation analysis (Graham, 2003) on the 19 environmental variables. Variables with a correlation coefficient of $|r| < 0.8$ were excluded from the model, while variables with a coefficient of ≥ 0.8, indicating a greater contribution rate, were selected for subsequent model predictions.

***Table 1.*** *Environment variables and the relative information*

| Code | Environmental factor | Unit |
|---|---|---|
| bio1 | Annual mean temperature | ℃ |
| bio2 | Mean diurnal range | ℃ |
| bio3 | Isothermality | / |
| bio4 | Temperature seasonality | / |
| bio5 | Max temperature of warmest month | ℃ |
| bio6 | Min temperature of coldest month | ℃ |
| bio7 | Temperature annual range | ℃ |
| bio8 | Mean temperature of wettest quarter | ℃ |
| bio9 | Mean temperature of driest quarter | ℃ |
| bio10 | Mean temperature of warmest quarter | ℃ |
| bio11 | Mean temperature of coldest quarter | ℃ |
| bio12 | Annual precipitation | mm |
| bio13 | Precipitation of wettest month | mm |
| bio14 | Precipitation of driest month | mm |
| bio15 | Precipitation seasonality | mm |
| bio16 | Precipitation of wettest quarter | mm |
| bio17 | Precipitation of driest quarter | mm |
| bio18 | Precipitation of warmest quarter | mm |
| bio19 | Precipitation of coldest quarter | mm |

### *Model optimization*

The optimal model was constructed by optimizing the model settings instead of utilizing the default settings, thereby ensuring greater accuracy. Prior studies have demonstrated that the environmental characteristic parameters (FC) and regularization coefficients (RM) in MaxEnt models exert a significant influence on the stability of the model (Swets, 1988; Wei et al., 2018). To identify the optimal parameters of the model, a series of parameter combinations were established and subsequently evaluated using the ENMTools program. This entailed calculating the Akaike Information Criterion (AIC), the


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corrected Akaike Information Criterion (AICc), and the Bayesian Information Criterion (BIC) scoring values for each parameter combination. AICc is a statistical method used to select the optimal model among multiple candidate models, with the primary aim of preventing model overfitting. BIC is a statistical approach for model selection that achieves optimal balance between model goodness-of-fit and complexity. Both the BIC and AICc values were used as a measure of model optimization and a combination of the minimum BIC and AICc values was selected as the optimal parameters of the maxent model (Cobos et al., 2019). In addition, it was also necessary to combine the response curves obtained under each set of parameters to identify the optimal parameters.

Then, the collected data were randomly grouped using 25% for the test set and 75% for the training set, according to the model description. Jackknife is a resampling technique used to evaluate the stability of statistical estimators and assess variable importance. The Jackknifing method was used to evaluate the contribution rate of the environmental factors, and the number of repetitions was 10. The maximum entropy (MaxEnt) model generates receiver operating characteristic (ROC) curves, with the area under the curve (AUC) serving as the primary metric for evaluating model predictive accuracy. The AUC value was employed to assess the outcomes of the model predictions and if the AUC value falls within the range of 0.9 to 1, it is indicative of excellent prediction results. If the AUC value falls between 0.8 and 0.9, it is indicative of good prediction results, while an AUC value between 0.7 and 0.8 indicates a fair prediction result. A value between 0.6 and 0.7 indicates a poor prediction result, while a value between 0.5 and 0.6 indicates a failed prediction result (Chetan et al., 2014).

MaxEnt is utilized to calculate the contribution of each environmental factor and to analyze their corresponding response curves. The distribution maps of *A. indica* and *A. lewisii* were generated through the application of the MaxEnt modelling approach, while the fitness zones for these two species were evaluated using the natural discontinuity method. The distribution map of the Chinese region was overlaid with four defined suitability zones, where the suitability zones were defined as follows: 0~0.2 (unsuitable habitat), 0.2~0.4 (poor suitability habitat), 0.4~0.6 (medium suitability habitat), and 0.6~1 (high suitability habitat). Subsequently, the area encompassed by each suitability zone was quantified.

## Results

### *MaxEnt model calibration and validation*

The optimal model parameters for *A. indica* were identified as LQHP (Linear, Quadratic, Hinge, and Product features) with a regularization multiplier of 1. For *A. lewisii*, the optimal parameters were LQH (Linear, Quadratic, and Hinge features) and a regularization multiplier of 1. These selections were based on calculated AICc and BIC scores, as well as the smoothness of the fitted response curves. In the MaxEnt model's ROC curve analysis, the mean AUC values for *A. indica* and *A. lewisii* were 0.989 and 0.990, respectively, with standard deviations (SD) of 0.0017 and 0.0019 (*Fig. 2*). These results indicate high accuracy and reliability of the model's predictions.

### *Contribution of environmental variables with univariate analysis*

Pearson correlation and contribution analyses revealed that the environmental variables most strongly correlated with *A. indica* were bio4, bio6, bio13, bio14, and


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bio18. Similarly, for *A. lewisii*, the environmental variables most strongly correlated with this species were bio4, bio10, bio13, bio14, and bio18. Of the five selected environmental variables, warmest season precipitation (bio18) was identified as the most influential factor for both *A. indica* and *A. lewisii*, contributing 60% and 56%, respectively (*Fig. 3*). The results of the Jackknife test also indicated that the environmental variable with the highest gain, when used in isolation, was bio18 (*Fig. 4*). This finding is consistent with the results of the contribution rate analysis, which showed that bio18 represents the primary factor influencing the distribution of the two species of *Aulacophora*.

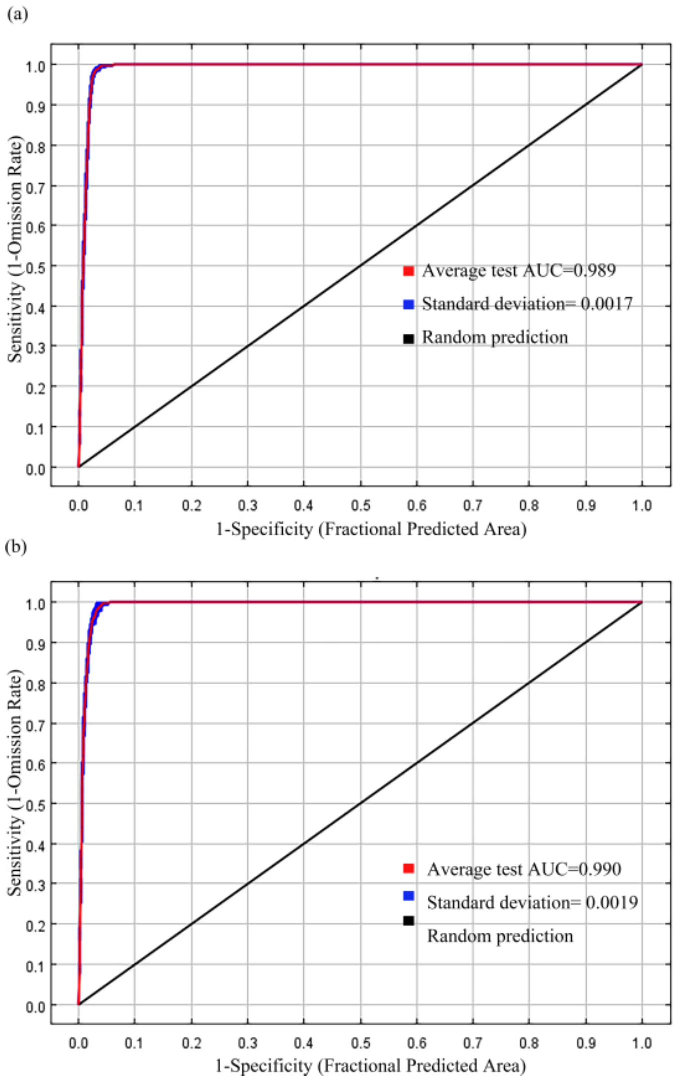


***Figure 2.*** *Statistical plots of MaxEnt analysis A. indica (a) and A. lewisii (b). The receiver operating characteristic (ROC) curves and the average test area under curve (AUC) values for the accuracy analysis of the MaxEnt predicted habitats for the two Aulacophora species*

When the potential distribution probability is greater than 0.5, the corresponding range of ecological factor values is more conducive to the survival of *A. indica* and *A. lewisii*. The blue portion of the graph represents the range of 10 calculations, while the red portion depicts the average (*Fig. 5*).


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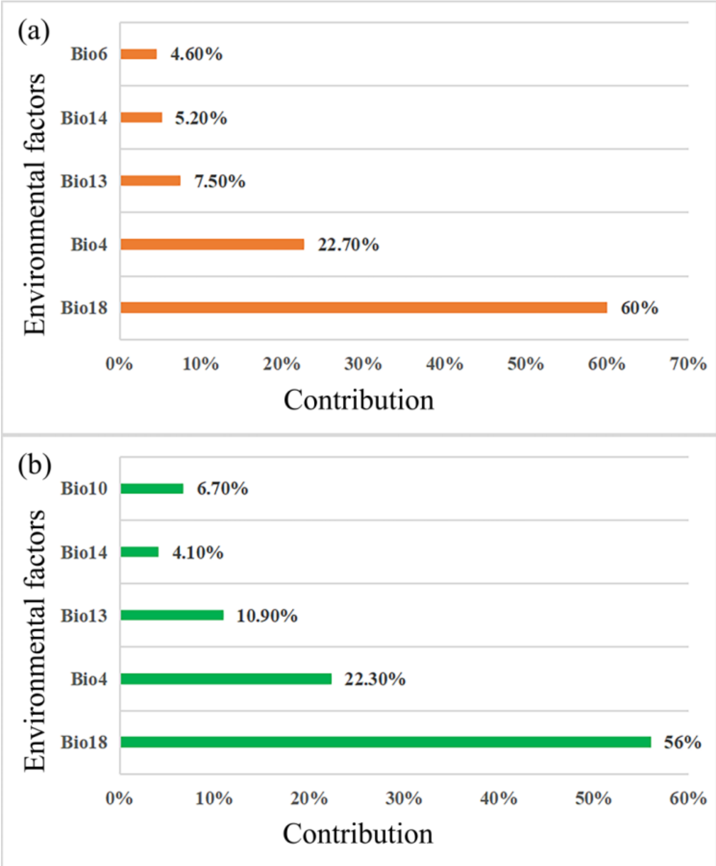


***Figure 3.** Analysis of the contribution of environmental variables in the MaxEnt model for A. indica (a) and A. lewisii (b)*

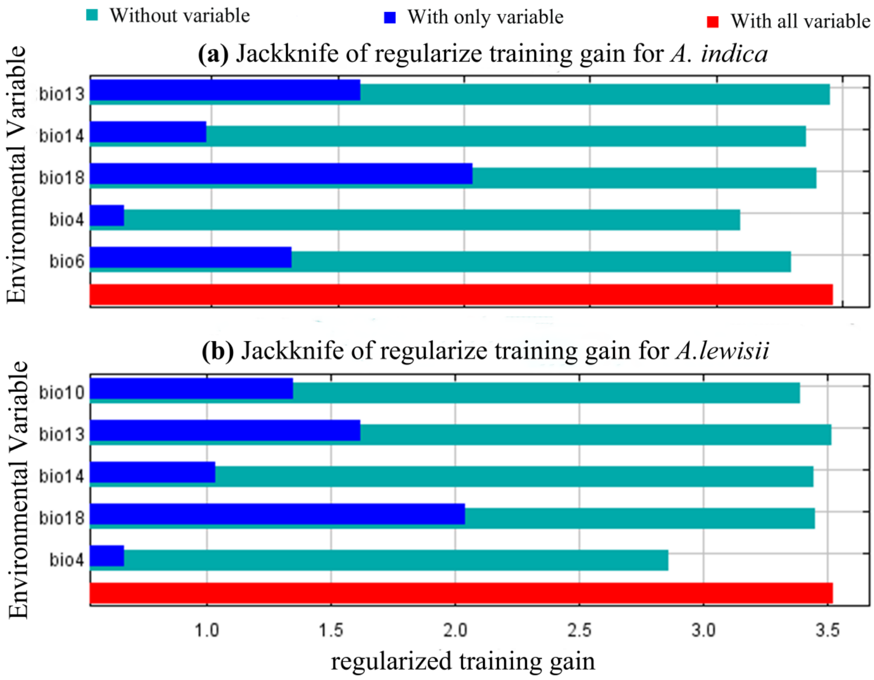


***Figure 4.** Importance of environmental variables included in the MaxEnt model for A. indica (a) and A. lewisii (b), according to the jackknife test*


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For *A. indica*, the optimal precipitation range in the wettest month was 185~292 mm, in the driest month 22~54 mm, in the warmest season 431~863 mm, and in the coldest month 6~7°C. The optimal coefficient of variation for seasonal temperature variation was 641~936 (*Fig. 5*).

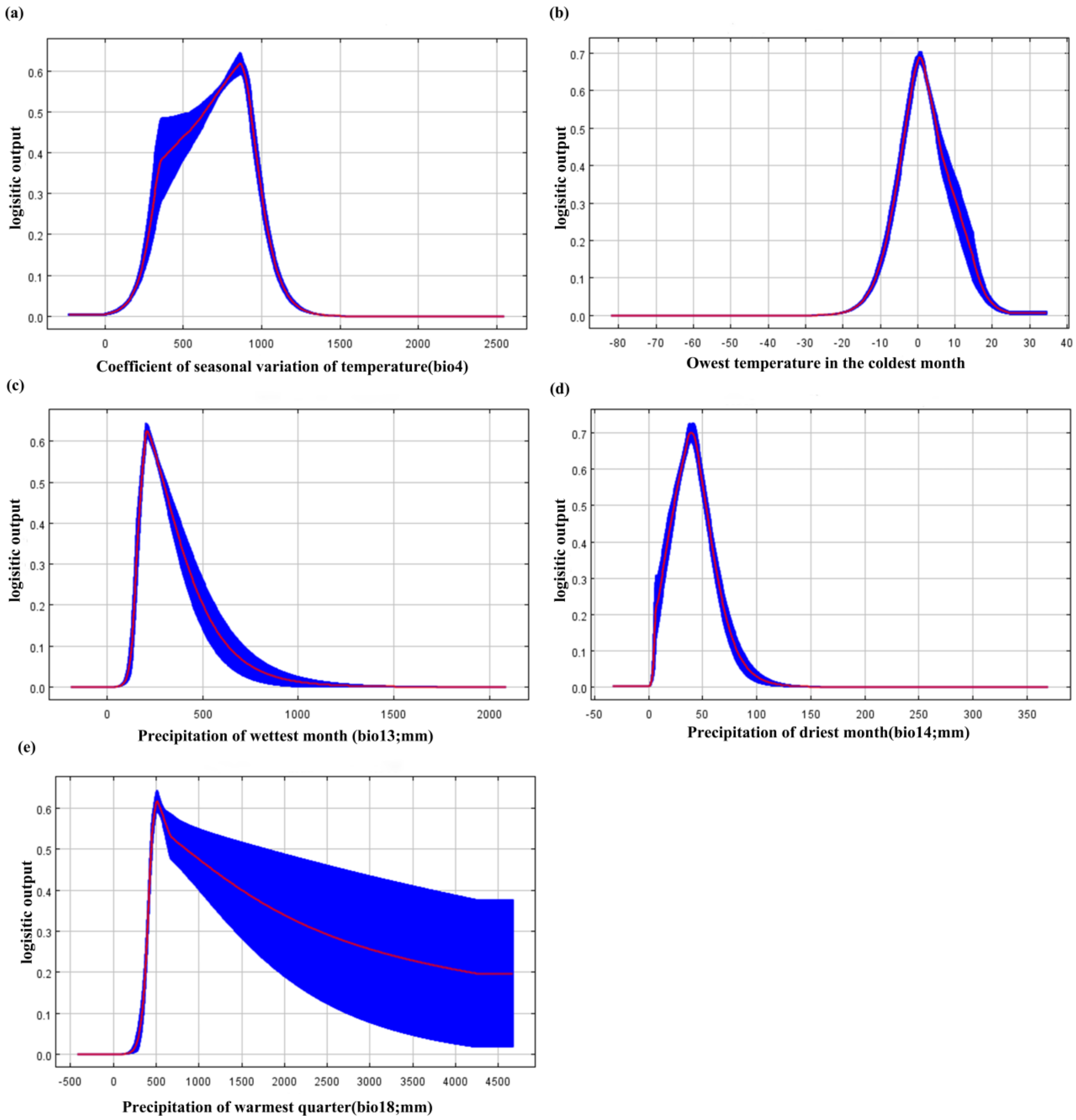


***Figure 5.*** *Response curves of environmental variables evaluated with the MaxEnt model for A. indica: (a) Temperature seasonality, (b) Min temperature of coldest month (°C), (c) Precipitation of wettest month (mm), (d) Precipitation of driest month (mm) and (e) Precipitation of warmest quarter (mm)*

For *A. lewisii*, the optimal temperature range for the warmest season was 25.8~28.7°C, while the optimal precipitation range for the wettest month was 180~291 mm, and the optimal precipitation range for the driest month was 24~55 mm. Additionally, the optimal precipitation range for the warmest season was 428~1000 mm. Finally, the optimal range of the coefficient of variation of the seasonal variation of temperature was 631~934 (*Fig. 6*).


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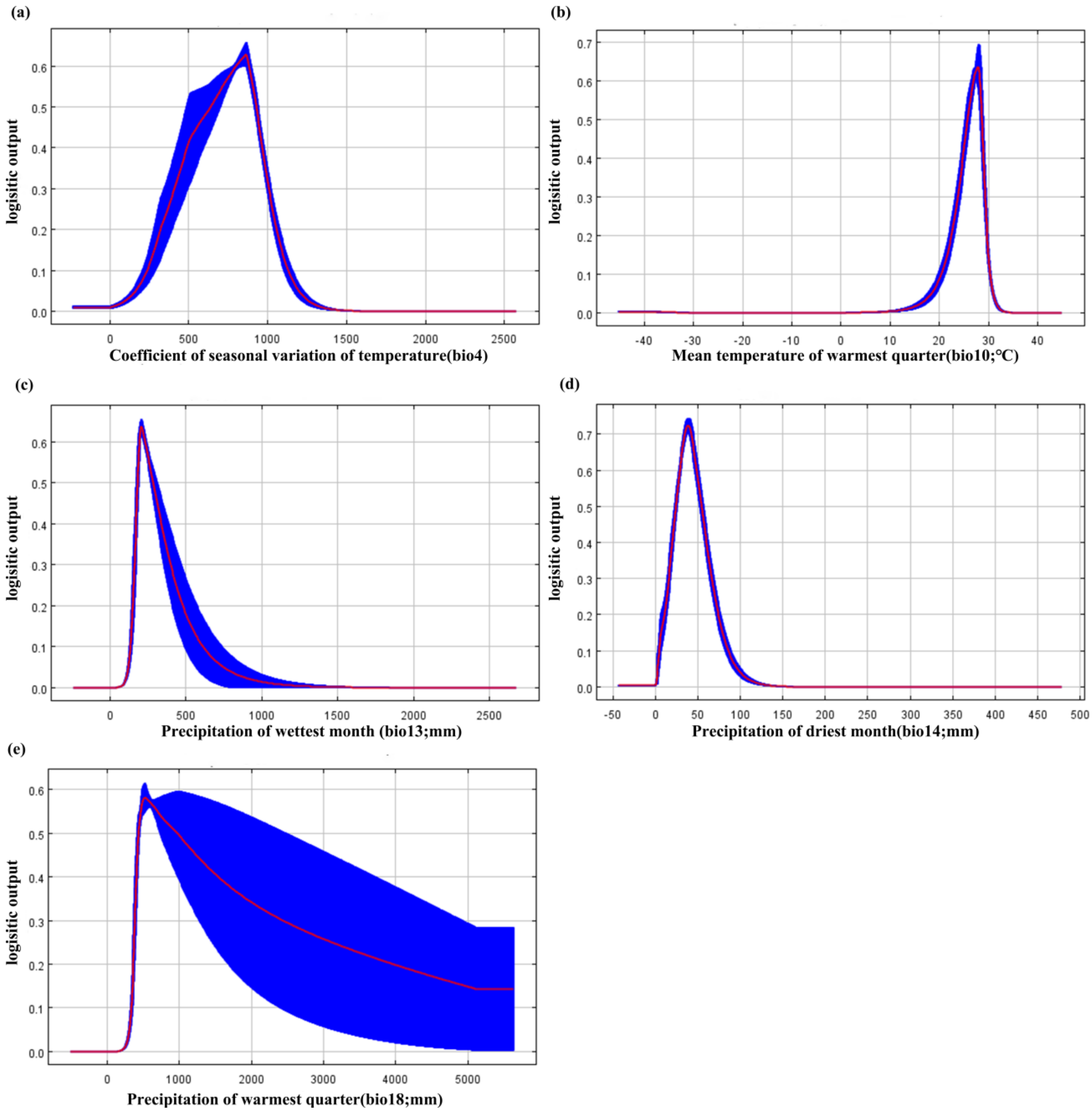


***Figure 6.*** *Response curves of environmental variables evaluated with the MaxEnt model for A. lewisii: (a) Coefficient of seasonal variation of temperature, (b) Mean temperature of warmest quarter (°C), (c) Precipitation of wettest month (mm), (d) Precipitation of driest month (mm) and (e) Precipitation of warmest quarter (mm)*

### *Distribution in China under current climatic conditions*

The MaxEnt model showed that the suitable distribution areas of *A. indica* and *A. lewisii* were largely congruent; however, there were notable discrepancies in the extent of high, medium, and poor suitability across these areas. The area of High suitability Habitat (HSH) for *A. indica* was approximately equivalent to that of *A. lewisii*, while the area of Medium suitability Habitat (MSH) was markedly larger, and the area of Poor suitability Habitat (PSH) was comparatively smaller (*Table 2*). For *A. indica*, HSH areas were concentrated in the middle and lower reaches of the Yangtze River. MSH areas were dispersed around these HSH regions, while PSH areas were distributed along the periphery of the overall distribution area (*Fig. 7a*).


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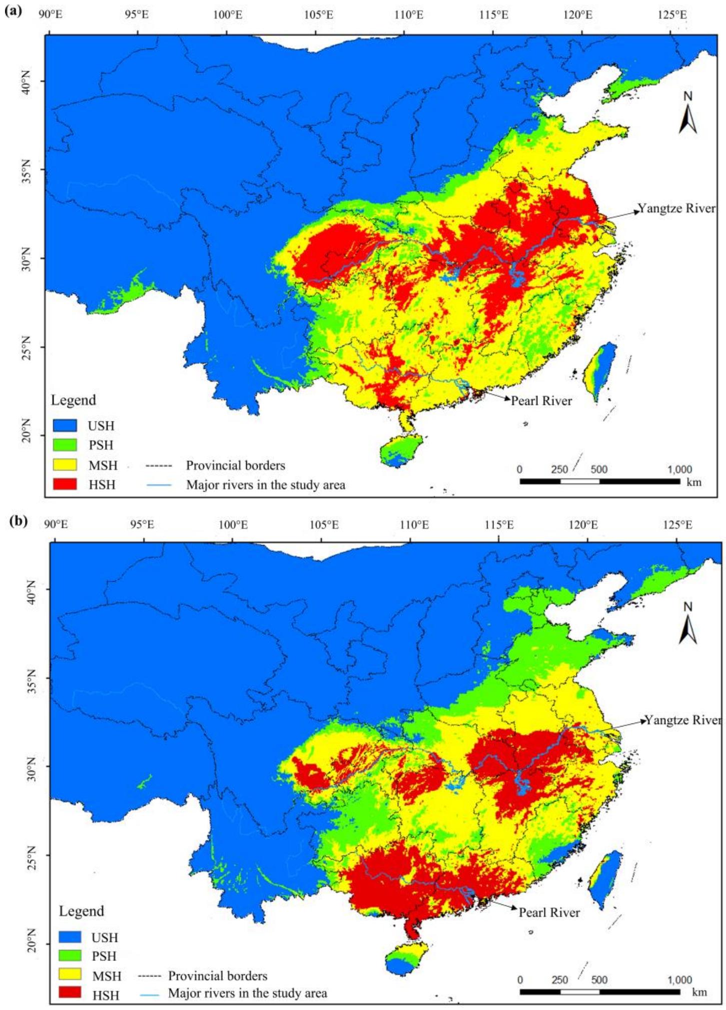


***Figure 7.*** *MaxEnt model-predicted suitable habitats for A. indica (a) and A. lewisii (b) across the Chinese region under the current climate scenario. USH refers to unsuitable habitat, PSH refers to habitat with poor suitability, MSH to habitat with medium suitability, and HSH to habitat with high suitability*

***Table 2.*** *MaxEnt modelled habitat composition for A. indica and A. lewisii in China under current climate conditions. USH refers to unsuitable habitat, PSH refers to habitat with poor suitability, MSH to habitat with medium suitability, and HSH to habitat with high suitability*

| **Scenarios** | **Habitat index** | ***A. indica*** | | ***A. lewisii*** | |
|---|---|---|---|---|---|
| | | **Area ($10^7$ hm$^2$)** | **Percentage** | **Area ($10^7$ hm$^2$)** | **Percentage** |
| Current | HSH | 5.717 | 6.06 | 5.566 | 5.90 |
| | MSH | 11.434 | 12.11 | 8.78 | 9.31 |
| | PSH | 3.611 | 3.83 | 5.546 | 5.86 |
| | USH | 70.3638 | 78.00 | 74.508 | 78.93 |
| | Total | 94.4 | | 94.4 | |

The distribution of HSH for *A. lewisii* was concentrated in the lower Pearl River Basin and the middle and lower Yangtze River Basin. The MSH areas were situated in


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proximity to the highly suitable areas in the middle and lower Yangtze River Basin, while the PSH areas were distributed in discontinuous patches at the periphery of the distribution area (*Fig. 7b*).

### *Distribution in China under future climate conditions (SSP1~2.6)*

The MaxEnt model projections showed that the total suitable habitat areas for *A. indica* and *A. lewisii* expanded by 2.673 × $10^7$ hm² (12.87%) and 4.038 × $10^7$ hm² (20.30%), respectively, relative to current distribution data. Notably, the northward expansion of suitable habitats significantly enlarged the extent of HSH for both species. MSH and PSH underwent substantial transitions towards HSH, with increases of 162.11% and 179.19%, respectively (*Table 3*). Spatially, the suitable habitats of *A. indica* and *A. lewisii* overlapped in three major regions: the North China plains, the lower Pearl River reaches, and the plains of the middle and lower Yangtze River (*Fig. 8*). These findings underscore the need for coordinated pest management strategies across these shared habitats.

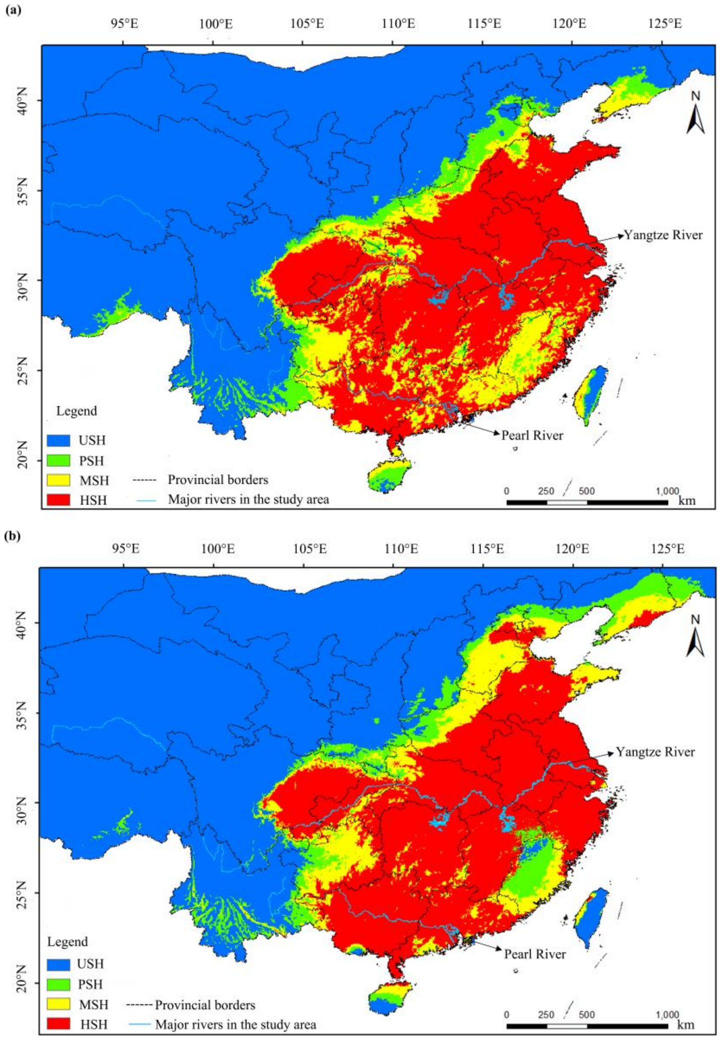


***Figure 8.*** *MaxEnt model projections of suitable habitats for A. indica (a) and A. lewisii (b) across China under future climate conditions. USH refers to unsuitable habitat, PSH refers to habitat with poor suitability, MSH to habitat with medium suitability, and HSH to habitat with high suitability*


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***Table 3.*** *MaxEnt modelled habitat composition for A. indica and A. lewisii in China under future climate conditions. USH refers to unsuitable habitat, PSH refers to habitat with poor suitability, MSH to habitat with medium suitability, and HSH to habitat with high suitability*

| **Scenarios** | **Habitat index** | ***A. indica*** | | ***A. lewisii*** | |
|---|---|---|---|---|---|
| | | **Area ($10^7$ hm$^2$)** | **Percentage** | **Area ($10^7$ hm$^2$)** | **Percentage** |
| Future | HSH | 14.985 | 15.88 | 15.540 | 16.46 |
| | MSH | 5.375 | 5.69 | 4.741 | 5.02 |
| | PSH | 3.075 | 3.26 | 3.650 | 3.87 |
| | USH | 70.965 | 75.17 | 70.469 | 74.65 |
| | Total | 94.4 | | 94.4 | |

## Discussion

In this study, an ecological niche model was employed to predict current and future suitable habitats for *A. indica* and *A. lewisii*. The AUC values of the constructed models were all greater than 0.9, indicating that the predictions were highly accurate. Results also showed that environmental factors associated with precipitation and temperature exert a significant influence on the occurrence and distribution of *A. indica* and *A. lewisii*. Moreover, fluctuations in these factors were closely correlated to the potential spatial distribution of these pests (Chang et al., 2008). The warmest season precipitation (bio18) was identified as the most significant environmental predictor, with optimal intervals of 431~863 mm and 428~1000 mm. This is likely because elevated temperatures and humidity levels are conducive to egg incubation and larval infestation (Lu et al., 2024), where the summer months in China (June~August) represent a period of elevated infestation rates for both species' larvae. Additionally, the lowest temperatures of the coldest season also affect the distribution of *A. indica*. *A. indica* has one or two generations per year, overwintering as an adult, where its survival during this period is contingent upon the ability to withstand temperature extremes. Results also showed a correlation between the mean temperature of the warmest season and the occurrence of *A. lewisii*, suggesting that these larvae are susceptible to elevated temperatures and that ambient temperature has a considerable influence on their growth and development.

In the context of prevailing climatic conditions, the distribution of HSH of *A. indica* and *A. lewisii* showed similarities, with notable differences observed in their respective distribution areas. The HSH of *A. indica* were situated in the plains of the middle and lower reaches of the Yangtze River and the Sichuan Basin. In contrast, the HSH of *A. lewisii* were located in the lower reaches of the Pearl River Basin and the plains of the middle and lower reaches of the Yangtze River. Furthermore, the distribution area of *A. indica* was larger than that of *A. lewisii* in the MSH, indicating that *A. indica* currently exhibits superior environmental adaptability compared to *A. lewisii*. The identified HSH for both pest species warrant immediate establishment of enhanced monitoring networks by plant protection agencies to detect population fluctuations and formulate preparedness strategies against large-scale infestation events.

In the context of future climate change, while *A. indica* and *A. lewisii* exhibit a similar pattern of range expansion, there are notable differences in the magnitude of this expansion and in the regional distribution of the species. The expansion of the HSH of *A. lewisii* was more pronounced, increasing from 5.90% to 16.46%. This is likely


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attributable to its enhanced adaptability to climate change. The newly identified distribution areas of *A. indica* were primarily concentrated in the northern and northeastern regions of the country, possibly due to its preference for humid or semi-humid environments. Visualization of the predicted changes in suitable distribution areas under future climate scenarios for both *Aulacophora* species, as indicated by the MaxEnt model, shows a tendency for these areas to migrate towards higher latitudes and altitudes. Prior research has documented an expansion of the range of *Ostrinia nubilalis* into higher latitudes (Porter, 1995) and an extension of the season of occurrence (Trnka et al., 2007). Furthermore, the range of *Helicoverpa armigera* has expanded to high latitudes and high altitudes (Zhu et al., 2011), while its occurrence period during the first and second generations increased significantly (Huang, 2021). This is accompanied by an increase in the number of eggs laid and the number of generations (Ge et al., 2005). Furthermore, the range of *Liromyza sativa* is also expanding into higher latitudes and altitudes (Chen and Kang, 2002). Thus, this study lends support to previous findings, signifying the impact of climate change on the geographical distribution of species as pervasive. In the context of global warming, expanded ranges confer the capacity to adapt to a more diverse range of environmental conditions, thereby enhancing the probability of survival and reproduction in ecosystems. Unfortunately, this simultaneously increases the challenges of pest control and management.

Consequently, in anticipation of the future distribution patterns of these pests, it is imperative to expeditiously recalibrate agricultural planting strategies and devise adaptable pest prevention and control measures. In suitable areas such as North China and Northeast China, the relevant departments should initially implement monitoring points at the forefront of potential propagation. These points can serve to prevent the abrupt spread of the pest, averting untimely prevention and control measures that might lead to substantial economic losses within the agricultural sector. Concurrently, the promotion of the film cover planting method or the application of grass ash near the seedlings is encouraged to mitigate the damage caused by larvae in the soil. In the early stages of pest outbreaks, priority should be given to the implementation of physical prevention and control methods, such as the establishment of insecticide nets (Meng et al., 2014), which has been shown to effectively reduce the incidence of crop leaf damage. In instances where pest damage is extensive, it is imperative to employ rational strategies that involve the judicious utilization of chemical pesticides that are characterized by efficiency, minimal toxicity, and a low propensity to leave residual traces.

It is noteworthy that the two *Aulacophora* species are not only endemic to China but also occur in the Indian subcontinent and Southeast Asia, where *A. lewisii* has been documented in Southeast Asia, the Mediterranean region, and Australia. However, distribution records of these two *Aulacophora* species remain scarce outside China. In contrast, their documented range in China spans exceptionally diverse ecosystems, including tropical, subtropical, temperate and arid regions. This comprehensive environmental gradient (18°N~36°N, 97°E~121°E) encompasses all potential habitat types suitable for these pests.

Our systematic sampling across this gradient, covering 18 latitudinal degrees and 24 longitudinal degrees, establishes China as a representative study area. The derived management strategies should prove valuable for controlling these pests in other regions with similar ecological conditions.


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To enhance the generalizability and international relevance of our findings, future studies should incorporate distribution data from other geographic ranges. Such expansion would provide a more complete understanding of both current and potential future global distributions of these *Aulacophora* species.

## Conclusions

In conclusion, the MaxEnt model was effective in predicting the distribution of the two *Aulacophora* species in their potential habitats. The model analysis indicated that precipitation during the warmest season was the most critical factor influencing the distribution pattern. The model predicted that the total area of MSH and HSH of *A. indica* ($17.151 \times 10^7$ $hm^2$) would be significantly larger than that of *A. lewisii* ($14.346 \times 10^7$ $hm^2$) under current climatic conditions, suggesting that *A. indica* may possess a stronger environmental adaptive capacity. The model predictions indicated that the potential distribution areas of both pests exhibited a tendency to expand to higher latitudes in the future, with the northward expansion of *A. lewisii* ($4.038 \times 10^7$ $hm^2$) being more significant than that of *A. indica* ($2.673 \times 10^7$ $hm^2$). This shift in distribution patterns may lead to an increase in new agricultural risk zones in North and Northeast China, resulting in a substantial rise in agricultural damages. It is therefore recommended to prioritize the strengthening of monitoring and early warning systems for these new risk zones, as well as the development of customized prevention and control programs for the dispersal characteristics of the two pests. These measures are crucial in order to mitigate the potential economic losses that may arise from this change.

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