Heliyon 10 (2024) e32268

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Predicting global geographical distribution and latitudinal suitability gradient for light Brown apple moth

Yu Zhang [a], Ming Yang [a], Yuhan Qi [a], Yantao Xue [a], Nianwan Yang [a,b], Gang Ma [a], Fanghao Wan [a], Xiaoqing Xian [a,**], Wanxue Liu [a,*]

[a] *State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing 100193, PR China*

[b] *Institute of Western Agriculture, The Chinese Academy of Agricultural Sciences, Changji 831100, PR China*

ARTICLE INFO

Keywords:
Epiphyas postvittana
Environment variables
MaxEnt model
Potential geographical distribution

ABSTRACT

Epiphyas postvittana, commonly known as the light brown apple moth (LBAM), is native to Australia and has a restricted global distribution. Its polyphagous nature and the recent surge in interceptions have emphasized the need for focused risk assessments to guide effective measures to curb the entry of this pest into new countries. This study aimed to perform a detailed global invasion risk assessment using an optimized MaxEnt model that incorporated 19 bioclimatic variables and elevation. The predictive outcomes underscored the significance of key variables, specifically the minimum temperature of the coldest month (bio6), precipitation of the driest month (bio14), and precipitation of the coldest quarter (bio19), in shaping the potential geographical distribution of LBAM. Regions beyond the existing range, including the southeastern United States, southern Brazil, eastern Argentina, Uruguay, southern Chile, and various Western European countries, were identified as susceptible to invasion and establishment by LBAM. An increase in suitability was observed above 45°N and 40°S under future climate scenario. With respect to climate change, LBAM would expand its potential range in Western Europe and the United States, especially under SSP5-8.5, in the 2050s. An upward trend in the latitudinal suitability gradient for LBAM in mid-high latitude areas implies that amid changing climate conditions, LBAM may find favorable habitats in these regions. For countries and regions with invasion risk, it is imperative to implement corresponding inspections and quarantine measures to thwart the introduction of LBAM, particularly in countries with established trade ties with invaded regions.

1. Introduction

Epiphyas postvittana (Walker) (Lepidoptera: Tortricidae), commonly known as the light brown apple moth (LBAM), is an important pest of a wide range of agricultural and horticultural crops. Over the centuries, the distribution of LBAM has expanded. Originating in Australia, LBAM thrives along the coasts of South Australia, Western Australia, Tasmania, New South Wales, and Victoria, with a presence in New Zealand [1]. In 1896, LBAM was first documented in Hawaii [2]. Over the next 100 years, LBAM was identified in

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[*] Corresponding author.

[**] Corresponding author.

E-mail addresses: xianxiaoqing@caas.cn (X. Xian), liuwanxue@caas.cn (W. Liu).

https://doi.org/10.1016/j.heliyon.2024.e32268
Received 14 March 2024; Received in revised form 29 May 2024; Accepted 30 May 2024

Cornwall, the United Kingdom, and Ireland [3]. LBAM first appeared in Berkeley, California, in 2006, causing significant concern and prompting widespread eradication efforts by agricultural departments [4,5]. Previous study reported the presence of LBAM in Sweden [6,7], noting presence of LBAM on imported citrus plants in a greenhouse. LBAM has been detected and intercepted in multiple countries [8–11], indicating the potential expansion of its geographical range and an increased risk of invasion. The spread of LBAM primarily occurs through the transportation of host plants [12], given its limited flying capabilities and inability to independently disperse over long distances [13,14]. Each country faces the threat of introduction of LBAM through infested host plants. Therefore, determining whether the environmental conditions of regions and countries yet to be invaded are conducive to LBAM survival is crucial for ensuring national biosecurity and formulating effective trade policies and quarantine measures.

Owing to highly polyphagous nature, LBAM is classified as an economically important agricultural pest. Inflicting damage on as many as 500 plant species within 363 genera spanning 121 families, this species poses a threat to numerous economically significant crops, including apples, grapes, strawberries, and citrus [15]. According to estimates from the United States Department of Agriculture, the average annual total crop costs from LBAM damage and control measures are approximately $104 million [16]. LBAM is also a concern because of its potential role in the transmission of plant diseases. Its larvae can carry the fungus *Botrytis cinerea*, leading to the development of gray mold disease in various plants, including grapes and strawberries [17–19]. The economic impact of disease transmission through LBAM underscores the importance of early warning and effective control measures for this pest. Unlike many insects that undergo winter diapause, LBAM overwinters in larval form and develops slowly at low temperatures. Its population is highly sensitive to environmental changes and particularly, extreme climate variations [20,21]. Therefore, during risk assessment for LBAM, global climate change has emerged as a crucial factor influencing the potential invasion risk of LBAM.

Species distribution models (SDMs) are essential tools for risk assessment and provide insights into the adaptability and spread of species under climate change and over time. Among various SDMs, MaxEnt, short for "Maximum Entropy," stands out for its effectiveness and ease of use. MaxEnt is highly suitable for modeling species distributions using presence-only data [22]. It has been extensively used to evaluate the invasion risk of exotic species [23–25] and guide conservation planning for endangered species [26]. Previous studies have used the MaxEnt model to predict the global invasion risk of LBAM [27]. However, they did not consider the impact of sampling bias and model complexity on the prediction results during model construction, which may lead to model overfitting [28,29]. Hence, in present study, we employed the optimized MaxEnt model to assess and analyze the worldwide invasion risk of LBAM based on global occurrence data. We aimed to identify the crucial environmental variables that affect LBAM, predict the potential geographical distribution (PGD) of LBAM under various climatic conditions, examine the spatial changes in the PGD of LBAM, investigate changes in suitability along latitudinal gradient in response to environmental factors, and provide a reference for early warning in the management of LBAM spread.

2. Material and methods

2.1. Processing of occurrence and environment data

The global occurrence data of LBAM were mainly compiled from three sources: Global Biodiversity Information Facility [30], the Barcode of Life Data System, and published literature. The occurrence data were allocated to climate data grids (5 arc-minute) in ArcGIS 10.8, with one record retained per grid to mitigate sample bias. Following collection and processing, 5340 valid data points were retained (Fig. 1). After mitigating the sampling bias, a dataset of 1340 occurrence records were employed to develop the MaxEnt model for forecasting the distribution of LBAM.

Nineteen bioclimatic variables and elevation data at 5 arc-minute spatial resolutions were acquired from WorldClim version 2 (https://worldclim.org/) and converted to the ASC format using ArcGIS 10.8. The bioclimatic variables for historical climate conditions represent the average for 1970–2000. For future climate projections (the 2030s, averages of 2021–2040; 2050s, and averages of

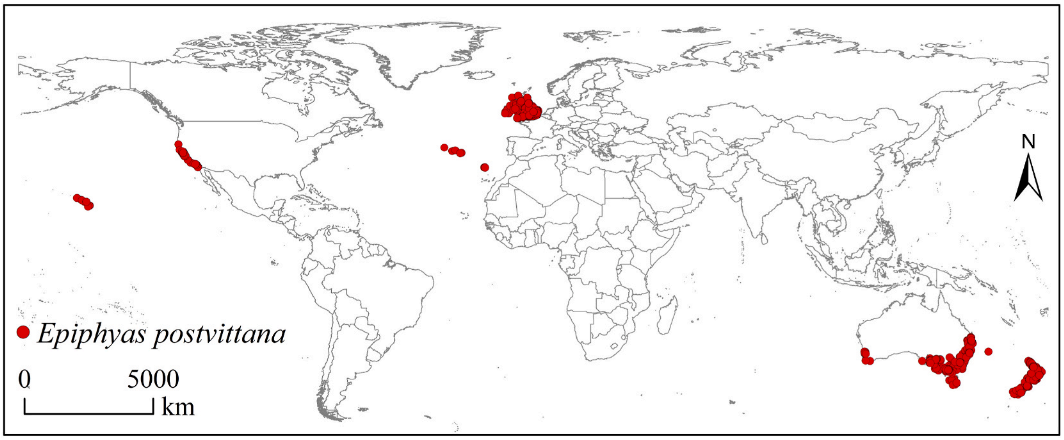

Fig. 1. Global occurrence points for *Epiphyas postvittana*.

2041–2060), three shared socioeconomic pathways (SSP1-2.6, SSP2-4.5, and SSP5-8.5) were chosen and assessed using a global climate model (GCM; BCC-CSM2-MR). Elevation was assumed to remain unchanged. To address the multicollinearity among these variables and avoid overfitting, a correlation analysis was performed (Table S1). The MaxEnt model was used to determine the contribution of each bioclimatic variable (Table S2). Variables with zero contribution were excluded. If the absolute value of the correlation coefficient was ≥0.8 between two variables, the variable with higher contribution was retained to construct the MaxEnt model. Eight bioclimatic variables and elevation were retained for model construction.

2.2. Model construction and evaluation

MaxEnt (version 3.4.1) was used to forecast the PGD of LBAM under historical and future climatic conditions. Influenced by the regularization multiplier (RM) and feature combination (FC), model complexity is crucial for accurate prediction results and model performance. The ENMeval package was used to compute the Akaike information criterion correction (AICc) value and estimate model complexity under different RM and FC combinations. Optimal parameters were selected to enhance the prediction accuracy and reliability [31]. In this study, RM varied from 0.5 to 6 in 0.5 increments, while FC encompassed H, L, LQ, LQH, and LQHP (where H = hinge, L = linear, Q = quadratic, and P = product). The parameter combination with the minimum delta.AICc value (equal to 0) was chosen for model construction [28]. In the final model, “Create response curves” and “Do jackknife to measure variable importance” were selected, with the output format set as “Logistic.” The remaining model parameters were configured based on their default values. The Receiver Operating Characteristic (ROC) curve’s Area Under the Curve (AUC) was computed to evaluate the MaxEnt model’s performance. The AUC values range from 0 to 1, where higher values signify superior performance [32].

2.3. Mapping of results

According to the minimum training presence cloglog threshold (0.03), the suitability was categorized into four levels as unsuitable <0.03, low suitability 0.03–0.28, moderate suitability 0.28–0.53, and high suitability >0.53. Spatial variations in PGD under future climate conditions were analyzed using ArcGIS tools, such as “Intersect” and “Symmetrical Difference.” The results were illustrated as unchanged, expansion, and contraction. To analyze the change in the latitudinal suitability gradient, we converted the ASC result files exported from MaxEnt to TIFF format in ArcGIS. We randomly selected one point from each grid and extracted its latitude, longitude, and suitability values. For points with the same integer part of the latitude, we calculated the average latitude and suitability and considered them as new X and Y values, respectively. Using Origin, we performed Second-order Curve Fitting while retaining a 90 % confidence interval to generate a graph of the change in suitability along the latitude gradient.

3. Results

3.1. Model performance and significant variables

The optimization results of the MaxEnt model using various combinations of RM and FC are depicted in Fig. 2. According to the delta.AICc value (0), the most favorable combination was identified as LQHP (linear, quadratic, hinge features, and product) with RM set at 0.5 (Fig. 2A). This configuration yielded the highest AUC value (Fig. 2B). The ROC curve, averaged across replicate runs, is presented in Fig. 2C. The average AUC value for the optimized MaxEnt model was 0.955 over 10 replicates, demonstrating the effective predictive performance of the MaxEnt model established in this study for LBAM’s potential geographical distribution.

Jackknife analysis showed that the most significant variables influencing the PGD of the LBAM were bio6 (minimum temperature of the coldest month), bio14 (precipitation of the driest month), and bio19 (precipitation of the coldest quarter) (Fig. 3A). bio6 had the highest gain and provided the most useful information. The response curves illustrated how the climatic habitat suitability of the LBAM changed with respect to various bioclimatic variables. The LBAM incidence probability increased with bio6 until approximately 2 °C. It then decreased and approached 0 at approximately 15 °C (Fig. 3B). For bio14, the LBAM incidence probability was positively correlated with bio14 until approximately 40 mm. It then gradually decreased and approached 0 at approximately 300 mm (Fig. 3C).

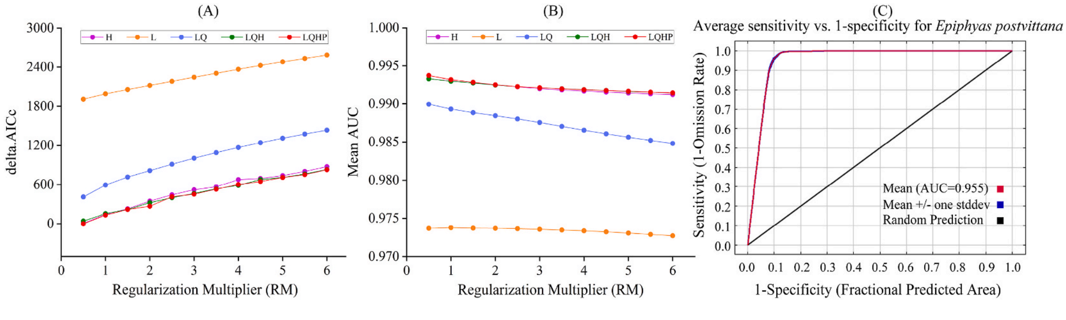

Fig. 2. MaxEnt model optimization and performance results. (A): delta. AICc value under different combinations of RM and FC; (B) the Mean AUC value under different combinations of RM and FC; (C) the performance of the MaxEnt model.

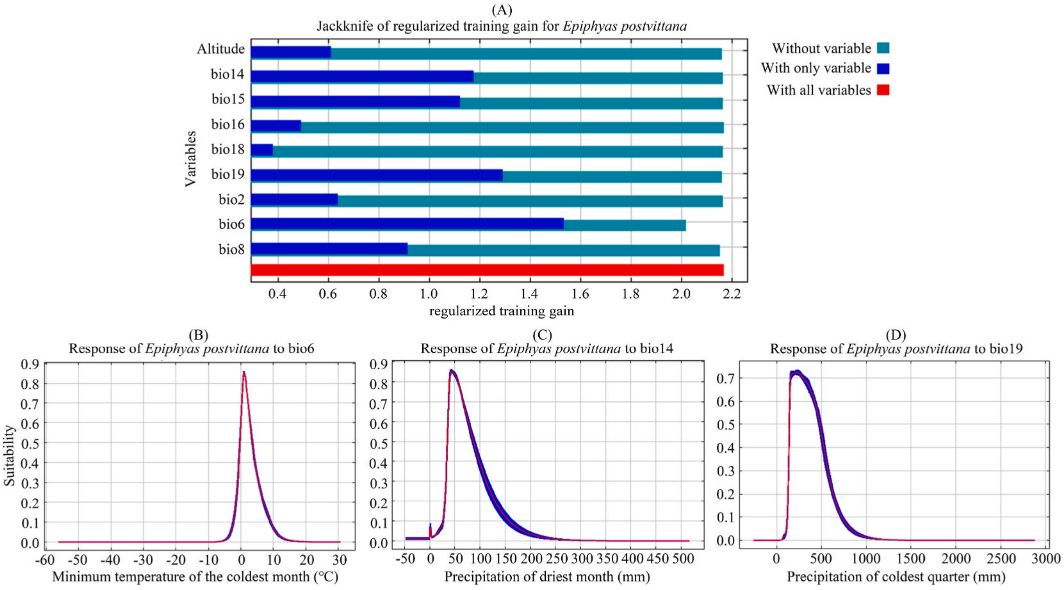

Fig. 3. Importance of environmental variables to LBAM according to the Jackknife and response curves of three significant bioclimatic variables. (A): the Jackknife result of variables; (B): the response curve of bio6; (C) the response curve of bio14; (D) the response curve of bio19.

For bio19, the LBAM incidence probability was positively correlated with bio19 until approximately 250 mm, then gradually decreased and approached zero at approximately 1250 mm (Fig. 3D).

3.2. PGD of LBAM under different climate scenarios

The PGD of LBAM under historical and future climate scenarios mainly covered western Europe, southern South America, southeastern Asia, southern Oceania, and southern North America (Figs. 4 and 5). Comparisons between historical and future climate scenario projections indicated an expansion trend in the range of PGD under SSP1-2.6, SSP2-4.5, and SSP5-8.5 in the 2030s and 2050s.

Under the historical climate conditions (Fig. 4), the PGD area of LBAM was approximately 1401.14 × 10^4 km^2. The PGD area of LBAM on each continent in descending order was Europe (314.17 × 10^4 km^2), South America (300.47 × 10^4 km^2), Asia (220.74 × 10^4 km^2), Oceania (213.16 × 10^4 km^2), North America (208.83 × 10^4 km^2), and Africa (143.78 × 10^4 km^2) (Fig. 6B, Table S3). The area of highly suitable habitats for LBAM was predicted at approximately 164.60 × 10^4 km^2 and mainly covered Australia and New Zealand in Oceania; Ireland, the United Kingdom, France, Belgium, the Netherlands, Italy, Spain, and Portugal in Europe; Chile, Uruguay, and southern Brazil in South America; and the southeastern and western United States in North America. Moderately suitable habitats for LBAM were found in parts of Australia, France, Germany, Italy, the United States, Argentina, and Brazil, accounting for 250.62 × 10^4 km^2. The area of low-suitability habitats was estimated to be 985.93 × 10^4 km^2 and was mostly detected in parts of China and Japan in Asia; Australia and New Zealand in Oceania; most countries in the EU Union; Morocco, Algeria, Ethiopia, Uganda, and South Africa in

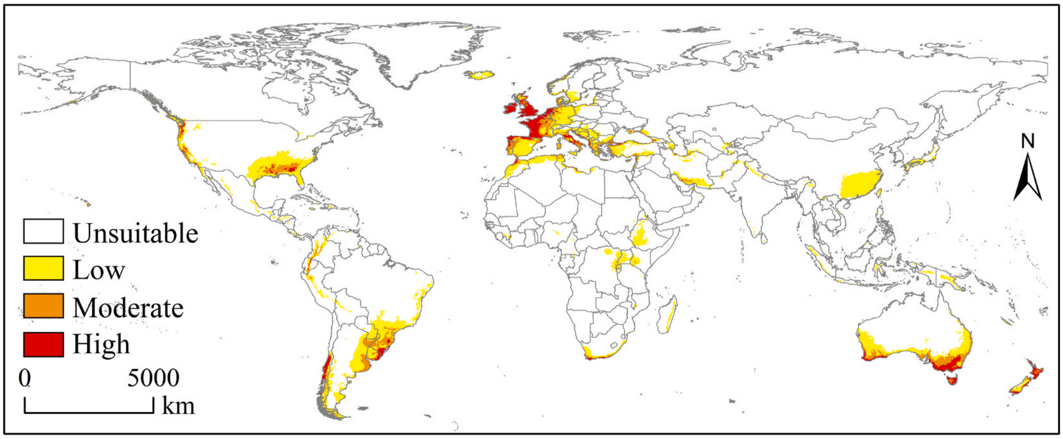

Fig. 4. Potential geographical distribution of *Epiphyas postvittana* under historical climate conditions.

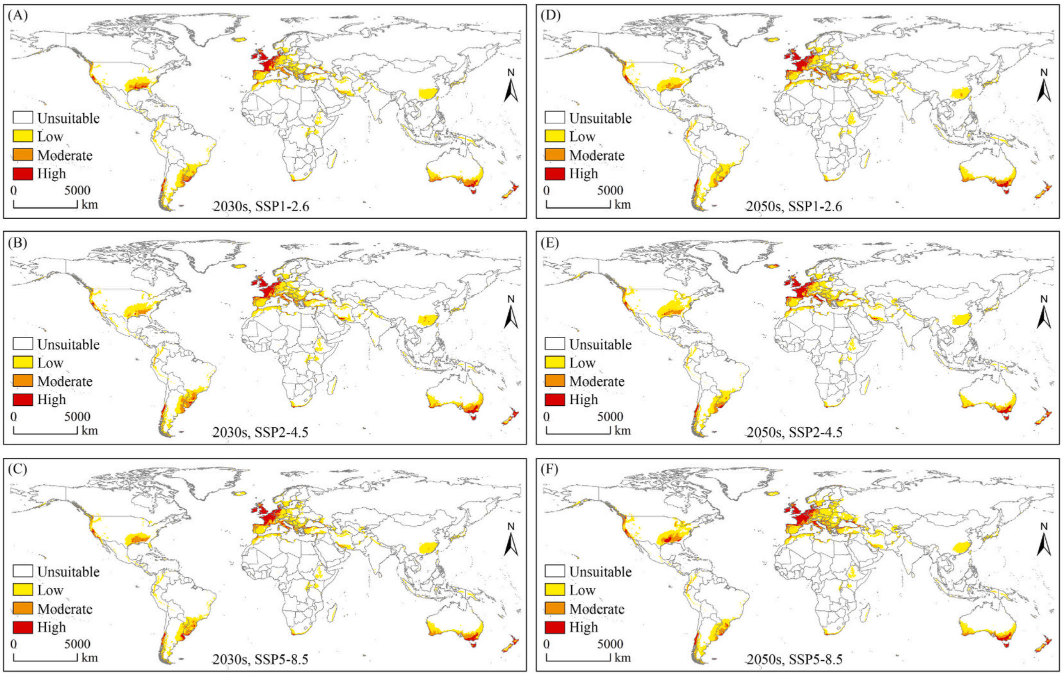

Fig. 5. Potential distribution of *Epiphyas postvittana* under future climate conditions. (A): Potential distribution of *Epiphyas postvittana* under SSP1-2.6 (2030s); (B): Potential distribution of *Epiphyas postvittana* under SSP2-4.5 (2030s); (C): Potential distribution of *Epiphyas postvittana* under SSP5-8.5 (2030s); (D): Potential distribution of *Epiphyas postvittana* under SSP1-2.6 (2050s); (E): Potential distribution of *Epiphyas postvittana* under SSP2-4.5 (2050s); (F): Potential distribution of *Epiphyas postvittana* under SSP5-8.5 (2050s).

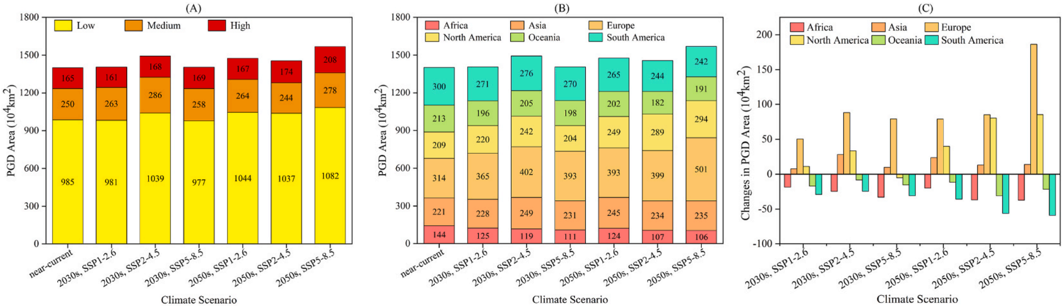

Fig. 6. Potential geographical distribution areas and changes of *Epiphyas postvittana* under different climate scenarios. (A): potential geographical distribution area of different suitable levels; (B): potential geographical distribution area in each continent; (C) the changes in potential geographical distribution area in each continent.

Africa; the United States in North America; and Argentina, Uruguay, and Brazil in South America.

Under future climate conditions (Fig. 5A–F), the PGD area of LBAM showed an upward trend and was largest at approximately 1568.74 × 10^4 km^2 under the SSP5-8.5 scenario in the 2050s (Fig. 6A and B, Table S3). LBAM had the largest PGD area in Europe and the smallest in Africa, which was similar to the results under historical climate conditions. Under the driving force of future climate change, the PGD area of LBAM on each continent changed differently. LBAM would gain a wider suitable habitat range in Asia, Europe, and North America than in Africa, South America, and Oceania (Fig. 6C–Table S4). The high suitability PGD area was projected to increase, except under the SSP1-2.6 scenario in the 2030s. The moderate-suitability PGD area showed a similar trend, except under the SSP2-4.5 scenario in the 2050s. The low-suitability PGD area would increase in the 2050s but slightly decrease under the SSP1-2.6 and SSP5-8.5 in the 2030s (Fig. 6A).

3.3. Spatial variation of PGD under future climate

In the context of climate change, the spatial variations in the PGD for LBAM were depicted as “unchanged” “expansion,” and “contraction” (Fig. 7A–F, Table S5). Climate change was expected to benefit LBAM by expanding its suitable habitats, particularly under the SSP5-8.5 scenario in the 2050s; in this case, the PGD expansion area was the largest (Fig. 7F), covering approximately 409.27 × 10^4 km^2. This expansion primarily occurred in Iran, the Republic of Uzbekistan, eastern Europe (Poland, the Czech Republic, Austria, and Slovakia), the eastern United States, and southern Argentina. The largest habitat loss area was projected to occur under the SSP5-8.5 scenario in the 2050s (Fig. 7F), accounting for approximately 241.68 × 10^4 km^2. This was primarily concentrated in the coastal regions of the southeastern United States, South America (southeastern Brazil, Paraguay, and eastern Argentina), Africa (the Democratic Republic of the Congo, Uganda, Kenya, Ethiopia, and Madagascar), Asia (southern China, Myanmar, and Iran), and Oceania (Australia). Under the SSP5-8.5 scenario in the 2050s, the spatial variations of PGD for LBAM were most pronounced, with "expansion," "contraction," and "unchanged" areas covering 409.27 × 10^4 km^2, 241.68 × 10^4 km^2, and 1160.17 × 10^4 km^2, respectively.

3.4. Change in suitability along latitudinal gradient under climate change

Climate change will have a considerable impact on the spatial distribution of exotic species, particularly by altering the suitability of habitats for invasive and noninvasive species, thus leading to new distribution patterns. This study simulated changes in suitability along latitudinal gradient of the LBAM resulting from climate change. There was an upward trend in suitability for future climate conditions at the mid-high latitudes (Fig. 8). This indicated that climate change will increase the risk of LBAM invasion in these regions.

In the Northern Hemisphere, the suitability along latitudinal gradient of LBAM under future climate scenarios resembled that under historical climate conditions between approximately 0° to 45°N. However, a substantial increase in suitability was observed above 45°N (Fig. 8A, C, and 8E). The potential habitats with medium (0.28–0.53) or high (above 0.53) suitability were primarily concentrated between 45°N and 60°N.

In the Southern Hemisphere, the suitability along latitudinal gradient for LBAM also showed an upward trend in the mid-latitudes above 40°S under the SSP1-2.6 scenario and above 47°S under the SSP2-4.5- and SSP5-8.5-scenarios. However, this increase in suitability along latitudinal gradient was observed only in the 2050s (Fig. 8B, D, and 8F). Below 40°S, it was lower under the SSP1-2.6 and SSP5-8.5 scenarios than under historical climate conditions. In contrast, under SSP2-4.5, it resembles the historical climate. Potential habitats with medium or high suitability were primarily distributed within the 30–50°S range.

4. Discussion

In this study, we performed a comprehensive global invasion risk assessment of LBAM using an optimized MaxEnt model to offer insights for early warning systems and effective control measures against LBAM. LBAM invasion in California and the substantial

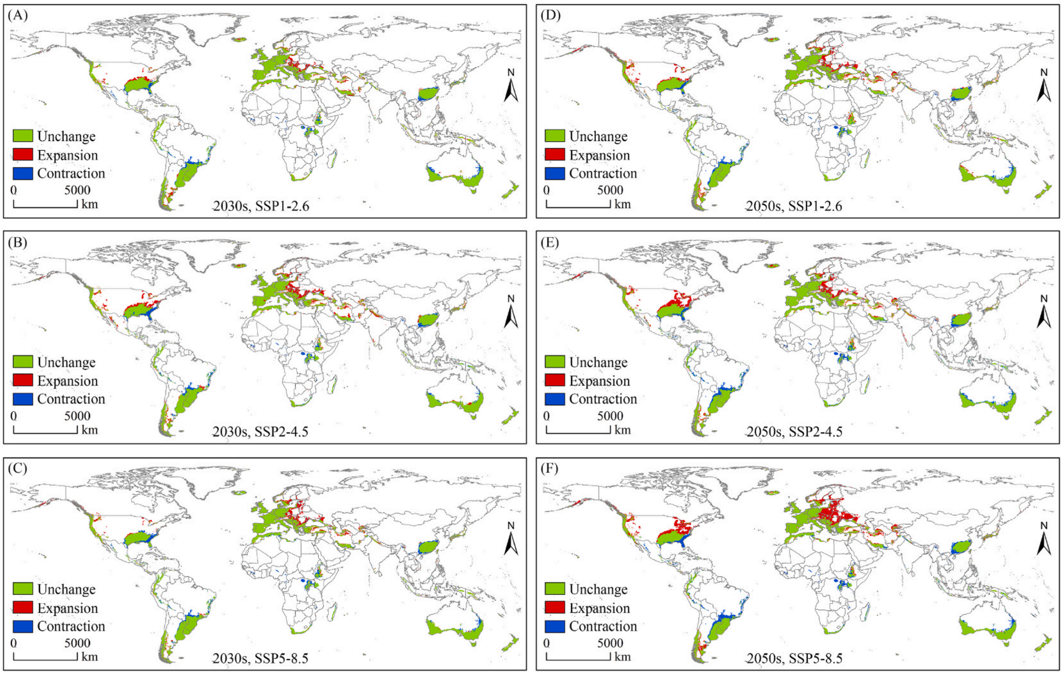

Fig. 7. Spatial variation of potential distribution of *Epiphyas postvittana* under future climate scenarios. (A): spatial variation of potential distribution under SSP1-2.6 (2030s); (B): spatial variation of potential distribution of under SSP2-4.5 (2030s); (C): spatial variation of potential distribution of under SSP5-8.5 (2030s); (D): spatial variation of potential distribution of under SSP1-2.6 (2050s); (E): spatial variation of potential distribution of under SSP2-4.5 (2050s); (F): spatial variation of potential distribution of under SSP5-8.5 (2050s).

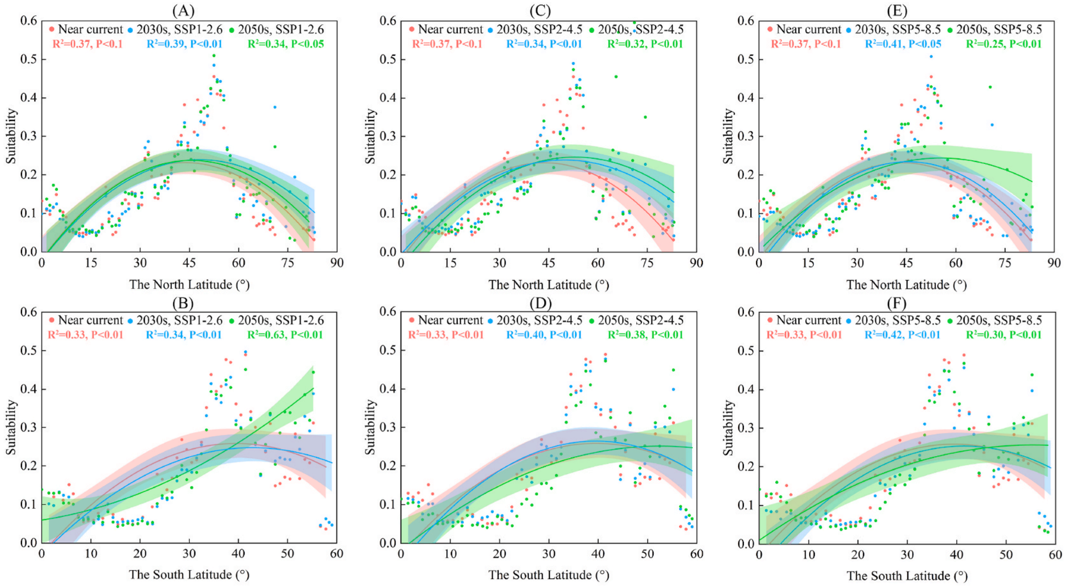

Fig. 8. Changes in latitudinal suitability gradient for *Epiphyas postvittana*. (A): Changes in latitudinal suitability gradient for *Epiphyas postvittana* in the Northern Hemisphere under SSP1-2.6; (B): Changes in latitudinal suitability gradient for *Epiphyas postvittana* in the Southern Hemisphere under SSP1-2.6; (C): Changes in latitudinal suitability gradient for *Epiphyas postvittana* in the Northern Hemisphere under SSP2-4.5; (D): Changes in latitudinal suitability gradient for *Epiphyas postvittana* in the Southern Hemisphere under SSP2-4.5; (E): Changes in latitudinal suitability gradient for *Epiphyas postvittana* in the Northern Hemisphere under SSP5-8.5; (F): Changes in latitudinal suitability gradient for *Epiphyas postvittana* in the Southern Hemisphere under SSP5-8.5.

investment by the United States in eradication efforts have received considerable attention, leading to extensive research on LBAM, particularly focusing on assessing invasion risk [21,27,33,34].

Most studies used the CLIMEX model for predictions, except for one study that used MaxEnt [27]. Disparities between prior studies and our study findings emerged within the geographical realms of African countries, Mexico in North America, and Brazil and Argentina in South America. Previous study outcomes indicated extensive habitats that are highly suitable for LBAM. Our predictive results suggested limited and predominantly low-suitability habitats in these areas. The main reasons for the differing results between the two studies are as follows: first, the occurrence data used to construct the predictive models were different. In this study, we addressed sampling bias in the occurrence data. Intercepted data and specific trapping records were also excluded from the analysis. Second, the environmental variables used to construct the predictive models were different. When selecting environmental variables, we used correlation analysis and variable contribution rates to choose the factors that most significantly impact LBAM distribution, whereas the previous study did not consider variable contribution rates. And we incorporated altitude as a factor into the model construction, which helped us avoid the overprediction of Lozier and Mills' results [27], making the predictive results more reasonable. Third, the impact of MaxEnt model complexity on prediction results was accounted for in this study. We considered the influence of model complexity on predictive outcomes and used ENMeval package to select the optimal model parameters to reduce the impact. Despite variations in the predictive results between the two models, both outcomes emphasized the potential threat of LBAM extending beyond its current distribution range. When evaluating model performance, metrics, such as the AUC and True Skill Statistic, are commonly used to assess the efficacy of the MaxEnt model in predicting PGD. These metrics are based on the specificity and sensitivity illustrated by the ROC curve as highlighted by previous study [35]. In this study, a focused computation of the AUC value was performed, with a commendable performance of the developed model.

The PGD of LBAM under historical climatic conditions was mainly distributed in southern Australia, New Zealand, the United States (Hawaii, California, and southeastern United States), and some Western European countries. This is consistent with the current LBAM distribution pattern, suggesting that these regions should focus on management and control. The expansion trend in the range of PGD and upward trend in suitability along latitudinal gradient under future climate change scenarios suggested that future environmental conditions may become suitable for LBAM population development, especially in areas at high latitudes, including the northeastern and western United States, Poland, and the Czech Republic, and these areas should invest in early warning, prevention, and monitoring of this species.

The invasive potential of an organism depends on its ability to withstand adverse environmental conditions, including extreme temperatures and precipitation [36–40]. This ensures the acquisition of a suitable energy budget to complete its life cycle, especially for invaders lacking winter diapause. Temperature tolerance has regained attention, particularly in invasive species that encounter extreme temperatures as barriers to invasion and range expansion. Owing to the absence of winter diapause, LBAM is constrained in its potential distribution expansion by cold tolerance [20]. The minimum temperature of the coldest month is a significant environmental variable affecting LBAM PGD. When the temperature drops below −6 °C, LBAM's suitability tended toward zero, which was consistent with previous findings that at −6.5 °C, the LT_{50} of LBAM larvae was approximately 40 h [41]. The absence of winter diapause and moderate cold tolerance observed in LBAM were likely to constrain its dispersal and establishment in the northern regions [21]. At 35 °C, egg development ceases, and larval mortality can reach 100 % [42]; the optimum temperature for its development is approximately 20 °C [43]. The low heat tolerance of LBAM likely plays an important role in restricting its PGD in some tropical regions.

Precipitation directly through soil moisture and flight thresholds and indirectly through food plants and natural enemies influences the spread and population establishment of invasive crop pests [36,44]. For LBAM, a holometabolic insect, precipitation can influence pupal survival and adult emergence through population development [45]. The precipitation of the driest month and precipitation of the coldest quarter were key variables affecting the PGD of LBAM. LBAM suitability approached zero when the precipitation of the driest month fell below 0 mm or when the precipitation of the coldest quarter was less than 100 mm. Previous study observed a negative correlation between LBAM flight activity and rainfall, with flights absent when daily precipitation exceeded 32.5 mm and not anticipated when precipitation surpassed 39 mm [44]. Therefore, precipitation plays a highly intricate role in the population development and dispersion of LBAM. The loss of suitable habitats in coastal areas may be attributed to extreme precipitation events. In tropical regions, unsuitable habitats and the contraction of suitable habitats may result from drought, with extremely high temperatures contributing to this phenomenon. Global warming may increase the risk of LBAM invasion in high latitude regions by alleviating the adverse effects of low-temperature stress. The dual effects of widespread temperature rise and reduced precipitation may potentially reduce the risk of LBAM invasion in certain tropical regions.

Factors, such as host plant distribution [21], the presence of natural enemies [46], and the trade network [47], constitute additional crucial elements that are not directly integrated into the current model but may impact the potential invasion of this species. Population genetic variation is a crucial aspect that should be considered in risk assessments, which can be used to assess the invasiveness of invasive species [48]. Although genetic variation may be less critical in the short term compared to factors influencing population persistence, it can become a decisive factor in enabling a population to endure and adapt over the long term to changing environments [49,50]. Integrating molecular biology information allows for a detailed risk assessment, facilitating the tailored development of quarantine policies and management measures based on local conditions.

With the increasing mobility of people and goods propelled by globalization, natural biogeographic barriers are gradually receding, enabling plants, animals, and pathogens to “hitchhike” and spread over extensive distances [51]. Previous study posited that LBAM invasion is not an unavoidable consequence of geographical proximity [52]. LBAM has exhibited limited long-distance dispersal capabilities and can cover a maximum distance of 600 m [13,14]. LBAM flight patterns are influenced by temperature and precipitation conditions during flight [44,53]. The invasion and genetic tracing analysis of California’s LBAM population has shown its Australian origin and not Hawaiian; this has emphasized that trade exerts more influence than geographical and political boundaries in facilitating LBAM invasion [52]. Interception data from diverse countries, including the identification of this species on imported citrus plants in a greenhouse in Sweden and on grapes imported from Australia at Chinese ports [6–8,54], reinforce this assertion. Therefore, implementing rigorous inspections and quarantine measures for goods traded from epidemic-affected countries can effectively prevent LBAM entry. Regular monitoring plays a vital role in averting a potential LBAM outbreak. Human activities, like irrigation, can alter moisture conditions, creating a favorable environment for LBAM in field crops. Facility agriculture, encompassing greenhouse production of vegetables and ornamental plants, serves as a refuge for LBAM, offering protection against cold and heat stress and facilitating its establishment in specific areas. In LBAM management, a combination of various control measures, including the implementation of the sterile insect technique [55], such as the application of parasitoids and predators [56–58], can be implemented to reduce pest populations and achieve optimal control efficacy.

5. Conclusion

Our study used an optimized MaxEnt model to predict the potential global distribution of the LBAM under both historical and future climate scenarios. Our prediction results highlighted the significance of key variables, such as the minimum temperature of the coldest month, precipitation of the driest month, and precipitation of the coldest quarter, in shaping the potential distribution of LBAM. Future climate conditions are likely to create a favorable environment for LBAM, leading to the expansion of its PGD. The suitability along latitudinal gradient was expected to increase, particularly in high latitude areas. Our findings have provided insights for the management and control of this pest, with a focus on regions, such as the southeastern United States, southern Brazil, eastern Argentina, Uruguay, southern Chile, and various Western European countries, highly suitable for LBAM. To effectively mitigate the spread of this species and prevent the introduction and establishment of LBAM in new regions, we recommend implementing strict inspection and quarantine measures for trade vectors.

Funding

This study was funded by the National Key R&D Program of China (grant No. 2023YFC2605200), National Key R&D Program of China (grant no. 2021YFC2600400), and Technology Innovation Program of Chinese Academy of Agricultural Sciences (grant no. caascx-2022-2025-IAS).

Declaration of interest’s statement

The authors declare no conflict of interest.

Data availability statement

Data included in article/supplementary material/referenced in the article.

CRediT authorship contribution statement

Yu Zhang: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Ming Yang:** Methodology, Formal analysis, Data curation. **Yuhan Qi:** Methodology, Formal analysis, Data curation, Conceptualization. **Yantao Xue:** Formal analysis, Data curation, Conceptualization. **Nianwan Yang:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Gang Ma:** Writing – review & editing, Supervision. **Fanghao Wan:** Writing – review & editing, Supervision. **Xiaoqing Xian:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Wanxue Liu:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32268.

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