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Current and potential distribution of *Xyleborus ferrugineus* and *Xyleborus volvulus* (Coleoptera: Curculionidae) in Mexico

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ABSTRACT

Species distribution models are a useful tool to project their potential dispersion. The objective of this study was to define the current distribution and model the possible expansion of *Xyleborus ferrugineus* and *Xyleborus volvulus* in Mexico. The models were performed in the Maxent algorithm, 242 and 152 presence records for each species were used, and the WorldClim bioclimatic variables were used. The models were evaluated using the area under the receiver operating characteristic curve; to evaluate the risks of extrapolation of the models, the Multivariate Environmental Similarity Surface was used. The variables that made up the final models of both species were: Bio 13, Bio 3, Bio 2, Bio 14 and Bio 5. No areas of climatic suitability for *Xyleborus ferrugineus* were found in the states of Aguascalientes, Guanajuato and Zacatecas, on the contrary, the states with the largest surface area with climatic suitability were Chiapas, Tamaulipas and Veracruz (60,202.4, 65,970.6, 67,397.4 km^2). Regarding *Xyleborus volvulus* Baja California, Baja California Sur, Coahuila, Nuevo León have 0 km^2 of climatic suitability and the states with the largest surface area with climatic suitability were Jalisco, Chiapas and Veracruz (60,566.0, 64,154.9, 67,774.8 km^2). This study showed that Mexico has extensive areas of climatic suitability for both insect species to establish themselves in areas where they are not currently present.

KEYWORDS: climatic suitability, Maxent, WorldClim, MESS, ecological niche.

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INTRODUCTION

Agricultural pests have a negative impact on crops; however, due to changes in weather patterns, their risk of spreading will increase (United Nations, 2021). This poses a considerable danger to different crops, since the appearance and expansion of pests may cause severe damage to crops, decreasing productivity and increasing management costs (Zepeda Jazo, 2018).

In 2022, the world produced 8,978,275.2 tons of avocado, of which 28.17% was produced in Mexico (2,529,581.41 tons) (FAOSTAT, 2024). According to the statistical yearbook of agricultural production of the Agrifood and Fisheries Information Service (SIAP), national production is greater than that reported by FAO since this agency reports 2,973,344.42 tons. The states with the highest production are Michoacán with 2,252,783.06 tons (75.76%), Jalisco with 323,228.37 tons (10.87%) and Estado de México with 132,478.25 (4.45%) (SIAP, 2024).

The above-mentioned quantities indicate the importance of generating information on the current and potential distribution of *Xyleborus ferrugineus* and *X. volvulus*, two pest species that can cause considerable damage to avocado.

Mapping and analyzing the distribution of these species will allow farmers and plant health authorities to develop more effective management strategies, anticipate pest outbreaks, and protect avocado crops. The main objective of the study was to map their current distribution and model the potential dispersal of *Xyleborus ferrugineus* and *X. volvulus* in Mexico.

MATERIALS AND METHODS

Study area and known records. Ecosystem diversity and climatic conditions in Mexico (Figure 1A), to model the potential distribution of both species (*Xyleborus ferrugineus* and *X. volvulus*), all documented records of their distribution were used.
We downloaded the records from data sources such as GBIF (GBIF,2024), snib and scientific literature and validated them using the distribution reported on the "Bark and Ambrosia Beetles of the Americas" page, the European and Mediterranean Plant Protection Organization (EPPO) page and the Centre for Agriculture and Biosciences International (CABI) page (Figure 1B and 1C).

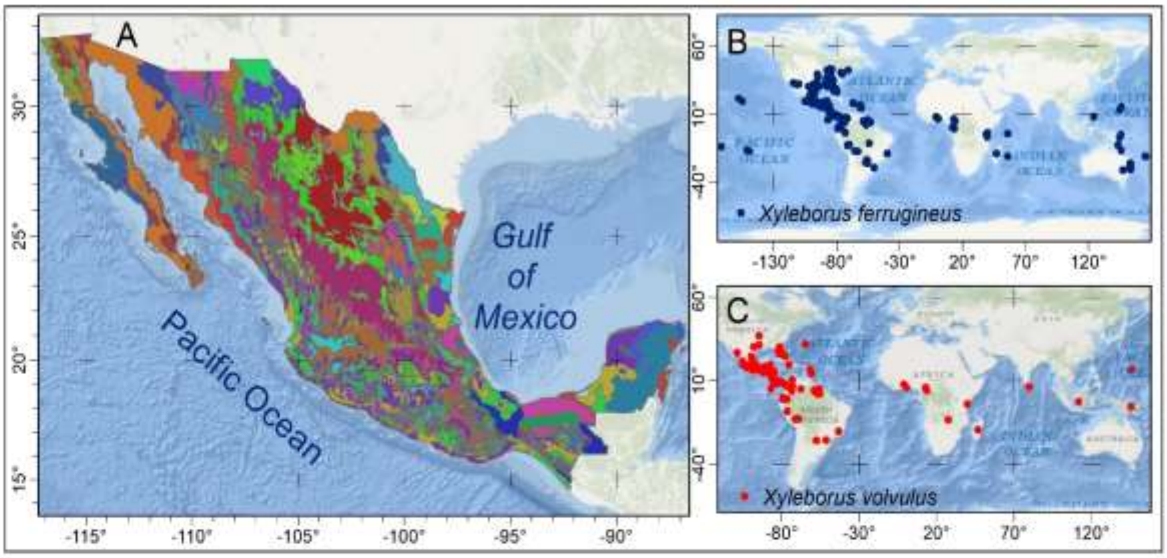

Figure 1. Geographical representation of the study area and presence records of the studied species.

Bioclimatic variables, selection and calibration area. We used the bioclimatic variables from WorldClim, eliminating variables 8, 9, 18, and 19 due to discontinuities in pixel values in regions of South America and the southeastern United States of America. To select the final variables, we applied a variance inflation factor analysis with a threshold of 3; those with the lowest correlation were included in the modeling (Table 1). The calibration area of the models (M according to the BAM diagram) was delimited from the ecoregions of the world (Figure 2B and 2C).

Table 1. Bioclimatic variables used to model the potential distribution of *Xyleborus ferrugineus* (X. f.) y *X. volvulus* (X. v.).

Variable	Description	X. f.	X. v.
BIO1	Annual Mean Temperature		
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	X	X
BIO3	Isothermality (BIO2/BIO7) (×100)	X	X
BIO4	Temperature Seasonality (standard deviation ×100)		
BIO5	Max Temperature of Warmest Month		X
BIO6	Min Temperature of Coldest Month		
BIO7	Temperature Annual Range (BIO5-BIO6)		
BIO10	Mean Temperature of Warmest Quarter	X	
BIO11	Mean Temperature of Coldest Quarter		
BIO12	Annual Precipitation		
BIO13	Precipitation of Wettest Month	X	X
BIO14	Precipitation of Driest Month	X	X
BIO15	Precipitation Seasonality (Coefficient of Variation)		
BIO16	Precipitation of Wettest Quarter		
BIO17	Precipitation of Driest Quarter		

Construction, transfer and evaluation of model. We developed the models in Maxent 3.4.4 with the following settings: logistic output format, deactivating the automatic features and the extrapolation and clamping options. We transferred the models to Mexico and performed the extrapolation risk analysis (MESS multivariate environmental similarity surface). We evaluated the model through cross-validation with 10 repetitions.

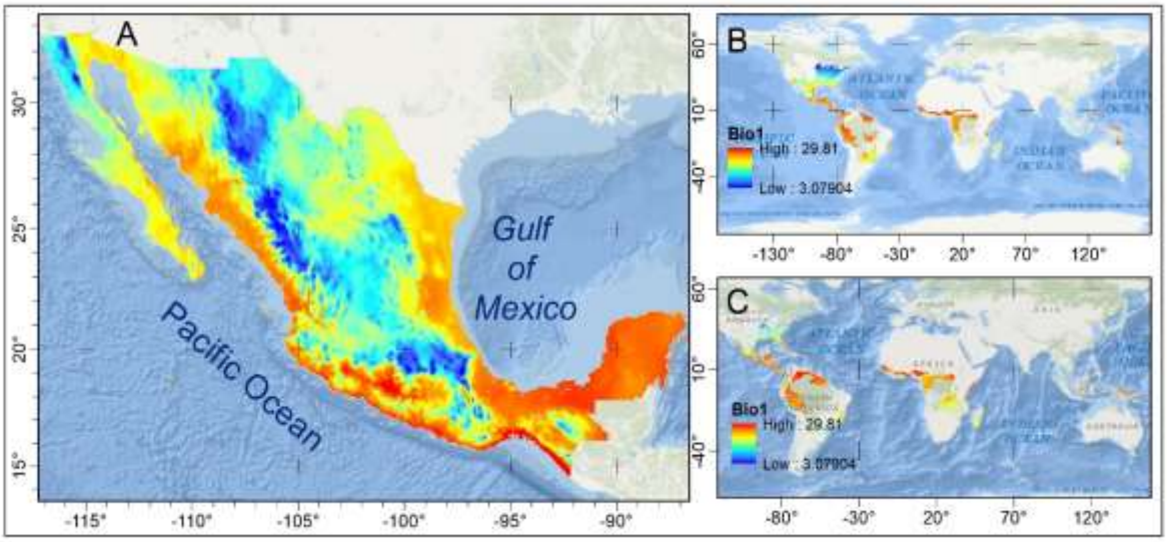

Figure 2. Transfer area (A) and calibration area of *Xyleborus ferrugineus* (B) y *X. volvulus* (C).

Current and potential distribution. The current distribution of *Xyleborus ferrugineus* and *X. volvulus* is delimited from the geographic coordinates where the species have been reported and the potential distribution is determined with the binarized logistic output models using the cut-off threshold of the 10th percentile of training presences. We calculate the surface area by state to determine the climatic suitability of each of the species.

RESULTS

Records of presence and selection of climatic variables. Of the 1,404 and 624 presence records collected for *Xyleborus ferrugineus* and X. *volvulus* (used in the modeling), only 242 and 152, respectively, were considered. The environmental variables that made up the *Xyleborus ferrugineus* model were: Bio 2 (Mean diurnal range) with 42.5 % contribution, Bio 13 (Precipitation of Wettest Month) with 17.4 % contribution, Bio 3 (Isothermality) with 15.6 % contribution, Bio 14 (Precipitation of driest month) with 14.3 % contribution and Bio 10 (Mean temperature of warmest quarter) with 10.3 % contribution.

The variables that were included in the final model of *Xyleborus volvulus* were: Bio 13, Bio 3, Bio 2, Bio 14 and Bio 5 with their respective percentage of contribution to the model (37.9, 31.9, 15.8, 8.6, 5.7).

Construction, transfer and evaluation of model. By transferring the *Xyleborus ferrugineus* model to the regions of Mexico, new areas of suitability are predicted for those currently reported. Of the 32 states of the Mexican Republic, only Aguascalientes, Guanajuato and Zacatecas have 0 km^2 of climatic suitability for *Xyleborus ferrugineus*. For this same species, Tlaxcala, Morelos, Mexico City, Querétaro and Baja California obtained areas smaller than 1,000 km^2. Colima, Baja California Sur, Mexico, Hidalgo, Michoacán, Chihuahua, Durango, Puebla, San Luis Potosí, Coahuila, Yucatán, Jalisco and Nayarit were states that obtained areas between 1,016.6 and 19222.5. Finally, the states with the largest area with climatic suitability were Chiapas, Tamaulipas and Veracruz (60,202.4, 65,970.6, 67,397.4) (Table 2).

Regarding *Xyleborus volvulus*, Baja California, Baja California Sur, Coahuila and Nuevo Leon have 0 km^2 of climatic suitability. Tlaxcala, Aguascalientes, Mexico City, Queretaro, Colima, Morelos, Guanajuato, Hidalgo, San Luis Potosi, Zacatecas and Yucatan obtained surfaces between 100 and 10,000 km^2 (Table 2).

Puebla, Quintana Roo, Mexico, Tamaulipas, Tabasco, Nayarit, Sinaloa, Michoacán and Campeche were states that obtained areas between 11,604 and 38,521.0 km^2, Durango, Sonora, Oaxaca, Guerrero and Chihuahua obtained between 41,664.9 and 52,703.0 km^2. Finally, the states with the largest area with climatic suitability were Jalisco, Chiapas and Veracruz (60,566.0, 64,154.9, 67,774.8) (Table 2).

Evaluation of the models through cross-validation with 10 replicates showed that the *Xyleborus ferrugineus* model obtained an AUC value = 0.71. The *Xyleborus volvulus* model obtained an AUC value = 0.72.

Table 2. Climatic suitability surface of *Xyleborus ferrugineus* (X. f.) and *X. volvulus* (X. v.) approximate for each state of Mexico.

Estado	surface X. f. (km^2)	Estado	surface X. v. (km^2)
Aguascalientes	0.0	Baja California	0.0
Guanajuato	0.0	Baja California sur	0.0
Zacatecas	0.0	Coahuila	0.0
Tlaxcala	0.5	Nuevo León	0.0
Morelos	107.0	Tlaxcala	113.6
Ciudad de México	144.6	Aguascalientes	248.7
Querétaro	507.5	Ciudad de México	586.5
Baja California	901.4	Querétaro	821.0
Colima	1,016.6	Colima	2,533.6
Baja California Sur	1,735.5	Morelos	4,176.3
México	2,430.5	Guanajuato	4,554.8
Hidalgo	4,727.7	Hidalgo	5,539.6
Michoacán	4,826.1	San Luis Potosí	9,318.9
Chihuahua	4,968.8	Zacatecas	9,397.1
Durango	5,737.7	Yucatán	9,861.1
Puebla	6,701.8	Puebla	11,604.5
San Luis Potosí	11,590.9	Quintana Roo	12,626.5
Coahuila	12,952.7	México	12,705.7
Yucatán	13,226.6	Tamaulipas	14,725.2
Jalisco	13,350.2	Tabasco	23,864.8
Nayarit	19,222.5	Nayarit	27,436.6
Tabasco	23,864.8	Sinaloa	35,059.8
Quintana Roo	28,600.3	Michoacán	37,675.9
Sonora	29,580.3	Campeche	38,521.0
Nuevo León	35,666.8	Durango	41,664.9
Guerrero	36,947.1	Sonora	46,723.1
Sinaloa	39,321.1	Oaxaca	50,912.8
Campeche	44,694.8	Guerrero	50,975.0
Oaxaca	48,277.8	Chihuahua	52,703.0
Chiapas	60,202.4	Jalisco	60,566.0
Tamaulipas	65,970.6	Chiapas	64,154.9
Veracruz	67,397.4	Veracruz	67,774.8

Current and potential distribution. The current distribution of both species is similar, the projection of the potential distribution model of *Xyleborus ferrugineus* showed that this species tends to prefer distribution areas with warm climates (Figure 3). The potential distribution model of *Xyleborus volvulus* elucidated that this species has a wider range of temperature tolerance, that is, it tolerates warm and temperate climates compared to X. *ferrugineus* (Figure 4).

The extrapolation risk analysis performed for the *Xyleborus ferrugineus* model showed that the predictions made in Sonora should be interpreted with caution since it has a considerable area of non-analog climates (Figure 3). The MESS analysis for the *Xyleborus volvulus* model showed that Nuevo León, San Luis Potosí, Guanajuato, Jalisco, Zacatecas and Sonora are states that presented non-analog climates, so the predictions for these areas should be interpreted with caution (Figure 4).

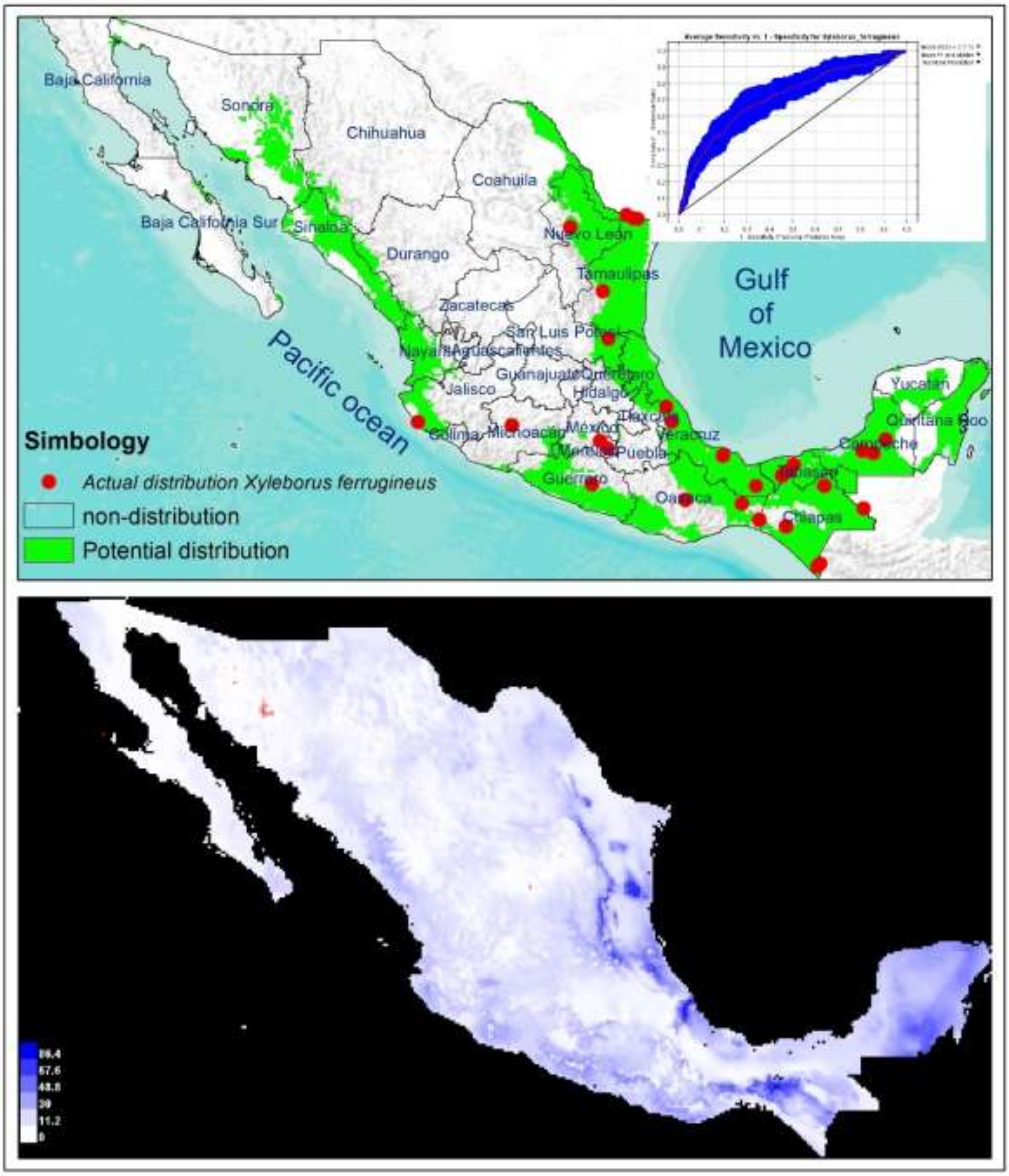

Figure 3. Current distribution models, potential distribution and extrapolation risk analysis (MESS) for *Xyleborus ferrugineus* in Mexico.

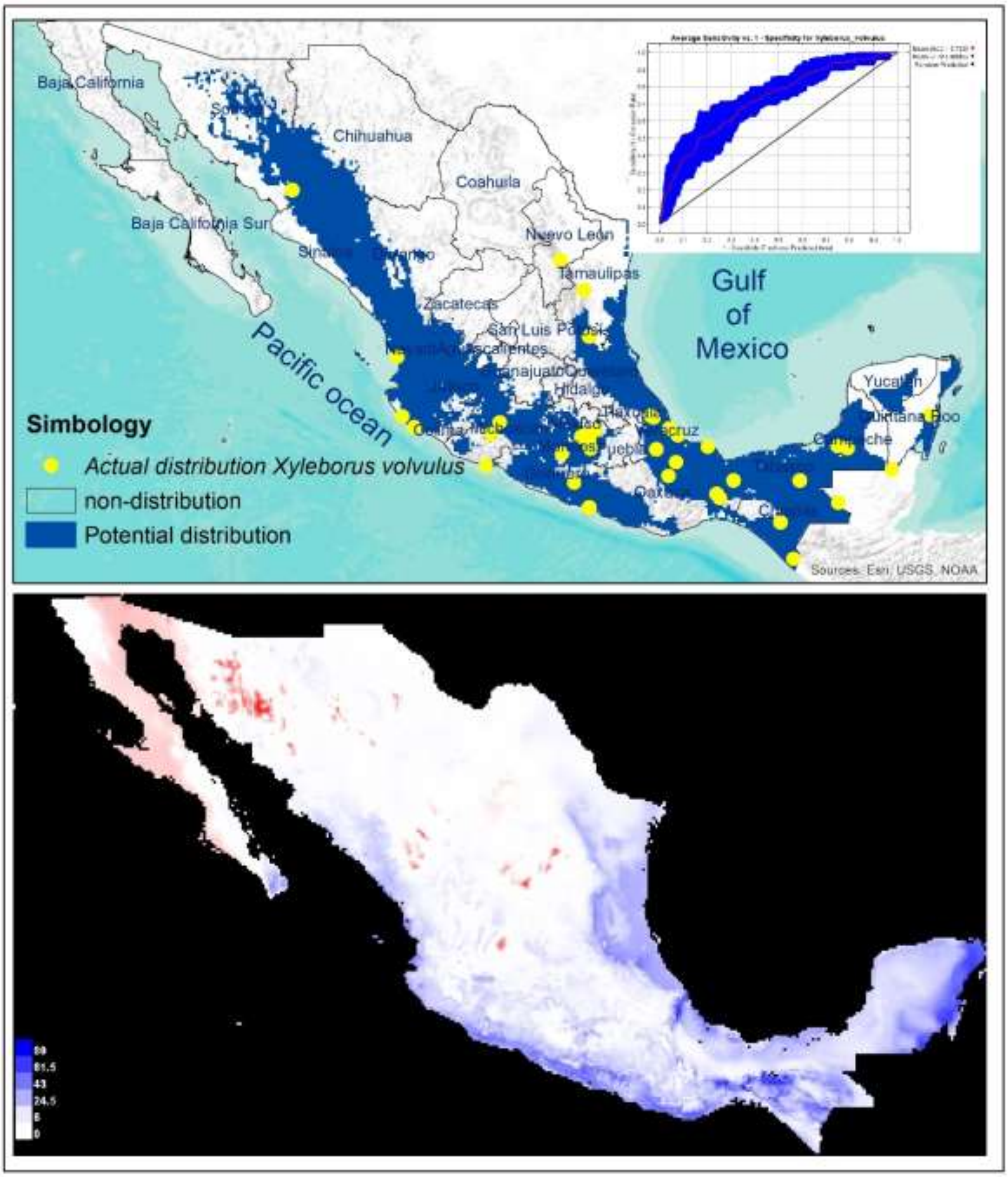

Figure 4. Current distribution models, potential distribution and extrapolation risk analysis (MESS) for *Xyleborus volvulus* in Mexico.

DISCUSSION

Selection of climatic variables. The selection of environmental variables in the modeling of agricultural pests is important, since this depends on the characterization of the climatic niche of the species, which is projected to the geographic space and determines the potential distribution of the species. According to Yoon & Lee (2021), the set of variables used in the modeling may differ depending on the target species, since the species have different distribution patterns. Reducing the multicollinearity of the variables and selecting those that best contribute to the model can help optimize the delimitation of the distribution areas of agricultural pests (Yoon & Lee, 2021).

Construction, transfer and evaluation of the model. The models of both species were made in Maxent, this algorithm has demonstrated efficiency in modeling distribution areas of pest species of economic importance, due to the impact they have on crops (Lira-Noriega et al., 2018). According to Rivera Martínez et al. (2022), carrying out spatial analysis of pest insects is of great importance, since it allows knowing the distribution and population fluctuation of organisms within crops. The analysis of the

Multivariate Environmental Similarity Surface showed that there was extrapolation when the models of both species were transferred to Mexico; however, it is common when the models are transferred to other geographic spaces (Radomski et al., 2022). Regarding the work of Yoon & Lee (2021), the evaluation of the models revealed that they had a low performance.

Distribution actual y potential. Projecting the potential distribution of the main agricultural pest species is important, since from the detected geographic areas, the efforts of integrated management programs of the studied pest can be directed and the different control measures, whether biological, cultural, physical and chemical, can be directed towards specific infestation areas (Rivera Martínez et al., 2022). Modeling the potential distribution of pest insects is crucial for decision-making in their management and control, especially those of quarantine importance. Lira-Noriega et al. (2018) recognize the importance of modeling the distribution of the genus *Xyleborus*, since they are a group of insects that includes some of quarantine importance and their monitoring is essential.

CONCLUSIONS

This study has allowed us to map the current and potential distribution of *Xyleborus ferrugineus* and *Xyleborus volvulus* in Mexico, showing that Mexico has extensive areas of climatic suitability for the establishment of both insect species, meaning that these species could expand into areas where they are not currently present, which poses important challenges for the protection of agricultural crops and forest areas.

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