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Modelling the current and future potential distribution of *Maconellicoccus hirsutus* (Green, 1908) a pest of importance for Mexico

Modelado de distribución potencial actual y futura de *Maconellicoccus hirsutus* (Green, 1908) una plaga de importancia para México

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ABSTRACT

Objective: to model the current and future potential distribution of *Maconellicoccus hirsutus* in order to identify changes in its distribution in Mexico.

Design/methodology/approach: to select a final model, 2,154 occurrence points were used and MaxEnt with the help of the Kuenm package implemented in Rstudio. It was projected throughout Mexico, using six possible climate change scenarios with a proposed threshold (0.02).

Results: a potential present surface of 1,159,335.5 km^2 was found, corresponding to 59 % of the territory, indicating a greater suitability in coastal areas including the Gulf of Mexico, the entire Pacific slope, and the Yucatan peninsula. All scenarios show an increase in the potential area of up to 1,423,890.18 km^2 in 2050 and 1,537,591.19 km^2 in 2070.

Study limitations/implications: predictions for 2050 and 2070 will depend on the climatic conditions that take place at the time, so specific studies in each region should be carried out, considering that the species may have adaptability to new climates which would imply constant monitoring. If an increase is observed in the distribution areas, the species could affect not only agricultural areas but also forest ecosystems.

Findings/conclusions: the projections made for scenarios 2050 and 2070 show an increase in the area of infestation and environmental suitability for pink cochineal, mainly in the states of the Pacific watershed, the Yucatan peninsula, and the Gulf of Mexico, with these areas being the most vulnerable.

Keywords: pests, potential distribution, MaxEnt, climate change, environmental suitability.

INTRODUCTION

Pink cochineal (*Maconellicoccus hirsutus* Green) is a pest from southern Asia and Australia; in America the infestation probably began from the low region of the California desert in autumn 1999 (Roltsch *et al*., 2006). Kairo *et al*. (2000) indicate that the pest *M. hirsutus* was reported for the first time in the Caribbean (Grenada) in 1994 as a new pest in the New World. By 2001 it had spread from Venezuela to the Bahamas and Central America, and north toward California in the United States. In Mexico, SEMARNAT (2010) reported it for the first time in 1999 in Mexicali, Baja California, and presently it is reported for Nayarit, Jalisco, Quintana Roo, Oaxaca, Guerrero, Chiapas, Colima, and Sinaloa. Because of the large number of hosts it is a pest of economic and ecological importance related to exports (Martínez, 2007). This pest affects more than 330 species (Chong *et al*., 2015), both fruit trees and forest species like lime (*Citrus aurantiifolia*) and guanacaste (*Enterolobium cyclocarpum*) (SEMARNAT, 2010). The pink cochineal represents a risk because of the reproductive and propagation speed (NAPPO, 2011).

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Geographic information systems together with statistics allow understanding the potential distribution of the species based on biological and environmental data (Guisan and Zimmermann, 2000); therefore, Species Distribution Models (SDM) provide estimations of suitable areas for pest invasion, which allow identifying potentially ideal zones in function of environmental variables (Vicente *et al*., 2016; and Cobos *et al*., 2019). One of the most robust methods to model the potential distribution is provided by MaxEnt and it does this by considering environmental variables and presence data (Elith *et al*. 2006), defining the possible distribution of a species which is subject to environmental restrictions (Phillips *et al*., 2006). Based on this, the need emerges to model the impact that climate will have on the distribution of the pink cochineal considering the risks that it can cause economically and environmentally. This study has the objective of defining the potential distribution of pink cochineal under two scenarios of climate change in Mexico (2050-2070).

MATERIALS AND METHODS

The study area covered the Mexican Republic and the data of pink cochineal presence were obtained from the National Service of Agricultural Health Innocuousness and Quality (Servicio Nacional de Sanidad Inocuidad y Calidad Agrícola, SENASICA), phytosanitary campaign 2018; the points of presence were georeferenced in ArcMap 10.3. Spatially correlated points were eliminated (two points in a pixel) with the SDMToolbox-Spatially Rarefy Occurence tool in SIG (Brown, 2014), reducing the occurrence to a single point within a distance of 1.2 km.

The environmental variables were obtained from WorldClim, with a resolution of 30 seconds (approximately 900 m at the equator), which describe current and future global climate (http://www.worldclim.org/). The variables used as scenarios of climate change correspond to those extrapolated with the model HadGEM2-ES, which is used throughout the world both for meteorological prediction and climate research. The projections that were used for 2050 and 2070 are Global Climate Models (GCM) that are adjusted in scale and were calibrated (bias was corrected) using WorldClim 1.4 as the "current" reference climate. These projections used correspond to the scenarios called Representative Concentration Pathways (RCP), RCP 4.5, RCP 6.0 and RCP 8.5; these scenarios project CO_2 concentrations, precipitation and temperature into the future (ENES, 2015) and are used globally in studies related to the climate.

Before selection of the models and to avoid overadjustment, 12 environmental variables were chosen from the 19 present (Cruz-Cárdenas *et al*., 2014), BIO8, BIO9, BIO18 and BIO19 were eliminated since they have unequaled spatial artifacts (Raghavan *et al*., 2019), a correlation table was made, and a Jackknife interactive analysis was carried out in Maxent, eliminating the irrelevant and correlated variables and leaving a final set of environmental variables.

Set: mean annual temperature (BIO1), isothermality (BIO3), seasonality of the temperature (BIO4), maximum temperature of the warmest month (BIO5), range of annual temperature (BIO7), mean temperature of the warmest trimester (BIO10), precipitation of the driest month (BIO14), and seasonality of the precipitation (BIO15). Peterson *et al*. (2011) and Radosavljevic and Anderson (2013) argue that the selection of the calibration area (M) is where the species have found favorable conditions; it was defined with a buffer with a 50 km radius in the previously selected points of occurrence, representing the climates where the pest is recorded and a clip was made on them.

For the creation and evaluation of the models, Kuenm was used in R for the development of the MaxEnt models of ecological niches (Cobos *et al*., 2019), in the Rstudio platform (https://www.rstudio.com/); the algorithm MaxEnt 3.4.1 was used to generate the models (Phillips *et al*., 2017). To create the models the points of presence were separated into three sets of data selected randomly within the M selected, leaving 100 % and 70 % of the occurrences for the creation of candidate models and 30 % for independent presences (Guisan and Zimmermann, 2000).

The evaluation and selection of the candidate models were based on their importance, predictive capacity and complexity. The model's yield was evaluated according to the statistical significance of each "Partial ROC" (Peterson *et al*. 2008 and Manzanilla *et al*., 2019), the "OR" omission rates (Fielding and Bell, 1997), and the Akaike information criteria corrected for small "AICc" sample sizes (Warren and Seifert, 2011) used through Kuenm_ceval in R (Cobos *et al*., 2019).

For the final model, 10 replicas were used through Bootstrap, with a logistic exit format that projected toward all of Mexico in the present and six possible futures (RCP4.5, RCP6.0, RCP8.5 in 2050; RCP4.5, RCP6.0, RCP8.5 in 2070). Finally, a clip threshold was applied with a minimum presence value of training points (minimum training presence) that allows measuring the risk of low to high suitability and to calculate the area in km^2 (Pearson *et al*., 20007), which was obtained through the extraction of raster values; all the presence points were used and the minimum value was extracted taking as argument that a risk of invasion could happen as of this value, and after this two more thresholds were selected to visualize the data in high, medium and low environmental suitability in Mexico using ArcMap 10.3.

RESULTS AND DISCUSSION

In total, information was obtained from 19 Mexican states with presence of pink cochineal; 53,358 presence points were found from which 2,154 points were used for creation, calibration and evaluation of the models; 290 candidate models were obtained and only 20 attained the rate of omission and eight the AICc criterion. However, only one fulfilled both criteria, being statistically significant with omission rate (p=0.046), and fulfilling the AICc criteria. The model was adjusted and it was efficient in predicting the present and future potential distribution, presenting a delta AICc≤2. The model was linear and created with Set 1 of variables.

The variables with higher contribution to the model were mean annual temperature with 22.6%, mean temperature of the warmest trimester with 21.2%, and seasonality of precipitation with 17%; the ones that obtained a higher importance, which were the mean temperature of the warmest trimester with 37.9% and maximum temperature of the warmest month with 24.7% which agree with the biology of the species (Searcy and Shaffer, 2016), preferring temperatures of 20 to 27 °C (Figure 1 and 2), considering that high (35 °C) or low (15 °C) temperatures damage the species, restricting its distribution in temperate zones of the country (Chong *et al*., 2015 and García *et al*. 2014).

The decrease in precipitation influences positively the highest averages of pink cochineal which is why marked droughts could benefit the species (García *et al*., 2014). This relationship suggests that the classification of the importance of the MaxEnt variables interprets biologically the factors that rule the distribution of the

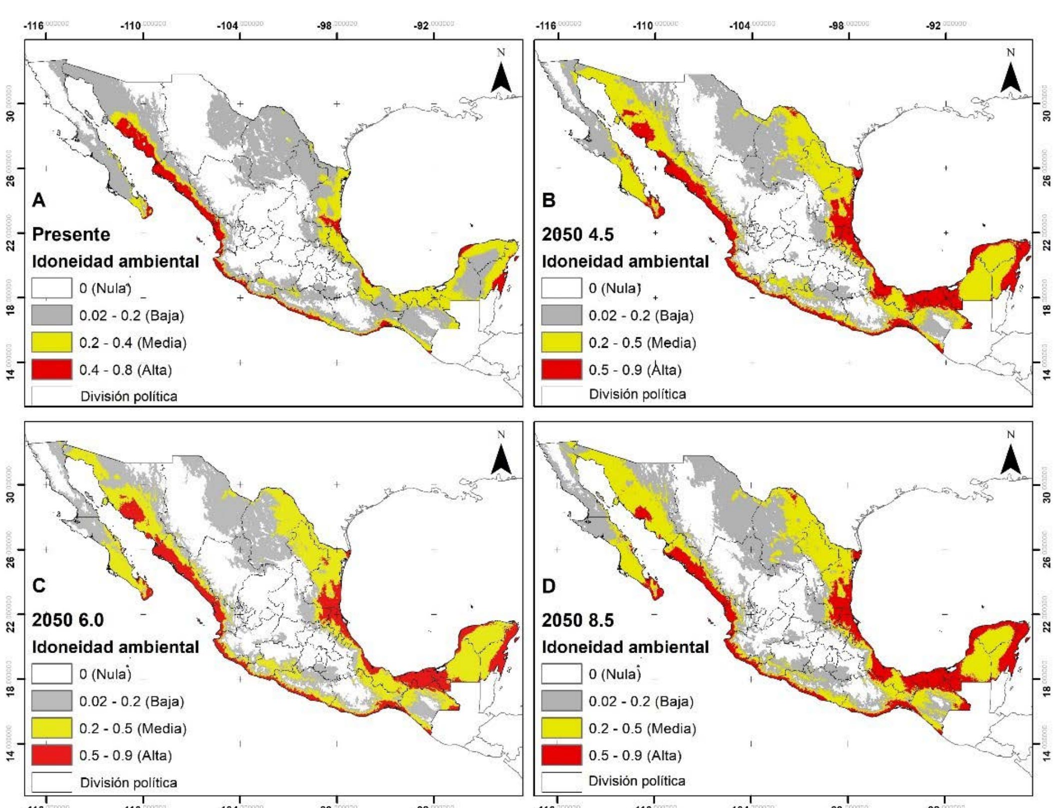

Figure 1. Scenarios until 2050 of *M. hirsutus*, A) present, B) RCP 4.5 scenario, C) RCP 6.0 scenario, D) RCP 8.5 scenario. Source: authors' elaboration.

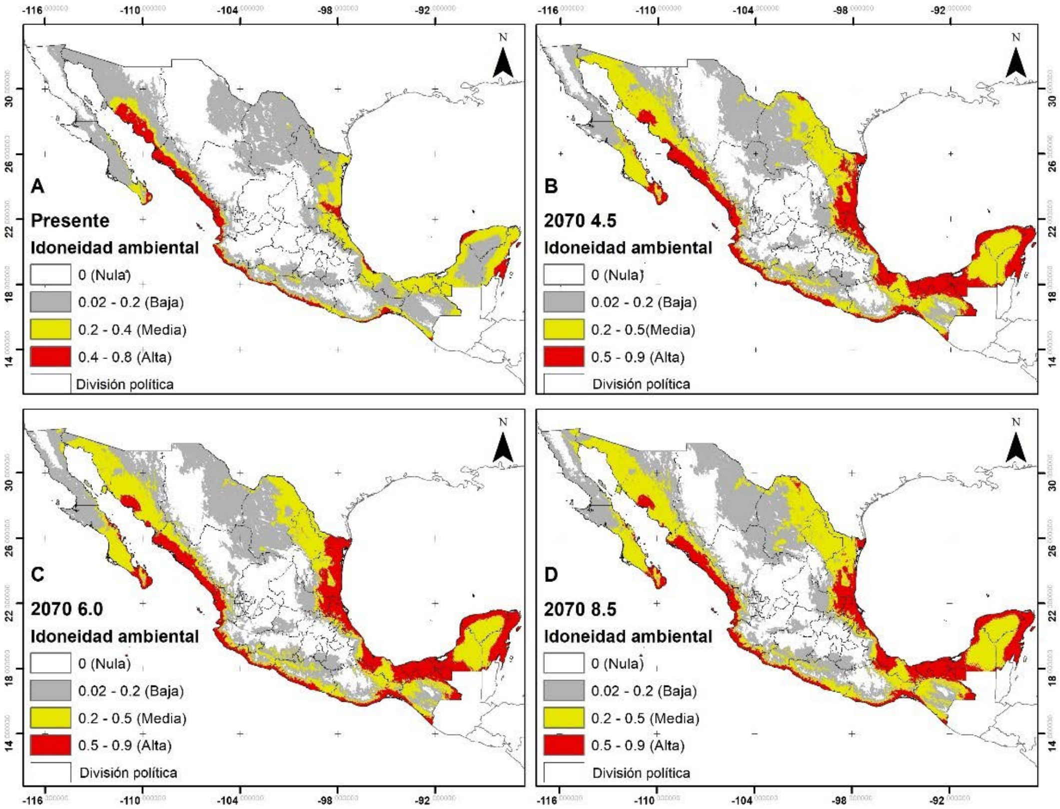

Figure 2. Scenarios to 2070 of *M. hirsutus*, A) present, B) RCP 4.5 C) RCP 6.0, D) RCP 8.5. Source: self made.

species (Searcy and Shaffer, 2016). According to the threshold suggested (0.02), there is a distribution surface present of the species of 1,159,335.50 km^2 (59% of the territorial surface) that is distributed on the entire Pacific watershed, from Baja California to Chiapas (Table 1); a high suitability is observed from southern Tamaulipas to the Yucatan Peninsula (Figura 1D). These results agree with those reported by García *et al*., 2014: the states of high environmental suitability for the species are Sonora, Sinaloa, Nayarit, Colima, Chiapas, Tabasco and Nayarit.

The RCP 4.5, 6.0 and 8.5 scenarios to 2050 show an increase in the environmental suitability and in the surface compared to the present (Figure 2); the surfaces of medium irrigation, 0.3 to 0.5, and high risk from 0.5 to 0.9, are in the Yucatan Peninsula, Gulf of Mexico and Sinaloa, while in Morelos and Puebla this suitability is low, of 0.02 to 0.3 (Figure 2D). In all the scenarios to 2050 (4.5, 6 and 8.5) an increase is observed in the percentage of the surface projected (68, 67 and 73%) compared to the surface present (59%) (Table 1). In the projections to 2070 an increase is observed in the surface in all the scenarios compared to the surface present (Table 1), predicting a low risk of invasion for interior zones of Mexico, and medium to high for coastal zones. The high temperatures reflected in the RCP 8.5 indicate an increase in the area of medium and high suitability in the Yucatan Peninsula (Figure 2 D).

Table 1. Areas (km^2) and suitability of *M. hirsutus* in scenarios 2050 and 2070.

Suitability	Present area (km^2)	2050			2070		
		4.5	6	8.5	4.5	6	8.5
Low	786,873.77	731,868.09	736,945.34	794,727.16	741,889.95	761,901.18	841,100.26
Half	270,206.14	348,956.57	346,917.45	365,791.97	351,207.79	357,294.84	377,939.60
High	102,255.59	258,825.94	222,494.28	263,371.05	285,047.52	309,333.81	318,551.33
Total	1,159,335.50	1,339,650.60	1,306,357.07	1,423,890.18	1,378,145.26	1,428,529.83	1,537,591.19

Areas in the two scenarios and RCP compared to the total national surface.

An evolution of the surfaces is observed in the two scenarios in all the RCPs, the surface present projected in low suitability ranges from 786,873.77 km^2 to 841,100.26 km^2 in the extreme scenario 2070 RCP 8.5; on the other hand, the surface projected in medium suitability ranges from 270,206.14 to 377,939.60 km^2 in the scenario 2070 RCP 8.5, and the present surface projected of high suitability ranges from 102,255.59 to 318,551.33 km^2, with increments found in the surfaces projected (Table 1). Laboratory studies show the relation of the pest with temperature and dry periods indicating that the species could invade areas within the thresholds of lower 14.5 °C and higher 35 °C temperature, and the optimal temperature for development of 29 °C (Chong *et al*., 2015), so the suitability of the species and the change in climate would generate growths in zones of presence of pink cochineal.

CONCLUSIONS

The high reproductive rates of the species, the broad number of hosts, global warming and droughts constitute indisputable arguments to beware of, in face of the possible changes in the distribution of this pest (Martínez, 2007). It should be considered that the climate conditions projected could vary from one region to another, which is why specific studies must be performed with the conditions of each place. Based on the RCP of the two scenarios, the increase in temperature and the decrease in precipitation provide an increase in the surface projected and in the environmental suitability of pink cochineal in Mexico. In the scenarios (2050 and 2070) an increase is observed in the surface projected and environmental suitability for *M. hirsutus*, primarily in the states of the Pacific watershed, the Yucatan Peninsula and the Gulf of Mexico, with the latter zones being the most vulnerable, while the northern states and Mexican high plateau present low suitability.

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