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Research article

# Zonas potenciales de *Brosimum alicastrum* Sw. y su variabilidad ante escenarios de cambio climático

# Potential areas of *Brosimum alicastrum* Sw. and its variability facing climate change scenarios

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**Abstract**

The objective of this study was to identify the regions in Mexico with the highest abundance of *Brosimum alicastrum*, as well as the edaphoclimatic and physiographic patterns that determine its current and future natural distribution. For this purpose, abundance, ecological niche, and climate change models were used, by means of geographic information system tools. This allowed the determination of the factors conditioning the natural coverage of the species in different regions of the country, and the establishment of a basis for its silvicultural management. Five regions were identified with the highest abundance of the species: *Yucatán* Peninsula, Isthmus, *Lacandona*, Western and *Huasteca*. The main factor determining the current distribution of *Brosimum alicastrum* is altitude, being more abundant in regions below 400 m. As altitude increases, its abundance decreases. The climate change scenarios were discouraging, indicating a possible total disappearance of the species' coverage in the Yucatan Peninsula region, where it is currently most abundant. Extreme variations between day and night temperatures, along with rainfall instability, will be the main factors conditioning the future natural distribution of the species in Mexico. However, new potentially suitable areas were identified for the species at altitudes above 400 m. These results can be considered as a basis for improving the forestry management of the species by region, considering the conditions that will affect its natural development in the future.

**Key words:** *Ramón* tree, maximum entropy, ecological niche, geographic information system, bioclimatic variables, WorldClim.

**Resumen**

El objetivo de este estudio fue identificar las regiones en México con mayor abundancia de *Brosimum alicastrum*, así como los patrones edafoclimáticos y fisiográficos que condicionan su distribución natural actual y futura. Para ello, se emplearon modelos de abundancia, nicho ecológico y cambio climático mediante herramientas de sistemas de información geográfica. Esto permitió determinar los factores que condicionan la cobertura natural de la especie en las regiones del país, y establecer una base para su manejo silvícola. Se diferenciaron cinco regiones con la mayor abundancia de la especie: Península de Yucatán, Istmo, Lacandona, Occidente y Huasteca. El principal factor que condiciona la distribución actual de *Brosimum alicastrum* es la altitud, pues es más abundante en regiones por debajo de los 400 m. A medida que la altitud se incrementa, sus poblaciones disminuyen. Los escenarios de cambio climático fueron desalentadores, al indicar una posible desaparición total de la cobertura de la especie en la Península de Yucatán, donde actualmente es más abundante. Las variaciones extremas entre las temperaturas diurnas y nocturnas, junto con la inestabilidad de las lluvias serán los principales factores que condicionen a futuro la distribución natural de la especie en México. No obstante, se identificaron nuevas áreas potencialmente adecuadas para desarrollo en altitudes superiores a los 400 m. Estos resultados pueden considerarse como base para mejorar el manejo silvícola de la especie por región, contemplar las condiciones que a futuro incidirán en su desarrollo natural.

**Palabras clave:** Árbol Ramón, máxima entropía, nicho ecológico, sistema de información geográfico, variables bioclimáticas, *WorldClim*.

# Introduction

*Brosimum alicastrum* Sw. is a perennial tree species belonging to the Moraceae family, and in Mexico it is known in the North of the country as *capomo*, in the Center as *ojite*, *ojuche* or *ojoche*, and in the Southeast as *nogal Maya*, *Ramón* or *oxx* (Ramírez-Sánchez et al., 2017). The tree reaches heights of 15 to 35 m, with straight stems, rough bark, ascending branches, simple leaves and a pyramidal crown; it is a monoecious species with flower heads that produce globular fruits of yellow, orange and red when ripe (López-Barrera et al., 2021).

It is naturally distributed in medium-sized subdeciduous or subevergreen forests, and in tall evergreen or subevergreen forests, in warm and tropical climates. Its altitudinal range goes from 20 to 1 600 m, with an average annual temperature >23 °C and annual rainfall between 600 and 1 500 mm. It prefers shallow, stony soils with good drainage, and a pH that varies between 6.8 and 8.2 (Peters & Pardo-

Tejeda, 1982). Due to its nutritional properties, forage quality, and availability during dry seasons, it is a tree with potential uses for animal and human food (Ramírez-Sánchez et al., 2017).

The *Ramón* tree has been investigated for its botany, nutritional properties in animal and human food, medicinal properties, forestry and plantations, and even its religious influence on Mayan culture (Espinosa-Grande et al., 2023). However, there is little research on the effects of climate change on the natural distribution of *Brosimum alicastrum* (Santillán-Fernández et al., 2021). Geographic information systems are effective tools for modelling these effects (Hijmans et al., 2005).

Species distribution models based on geographic information systems facilitate the identification of areas with a greater probability of development, both under current and future conditions (Elith et al., 2011). The generation of these models only requires soil and climate variables corresponding to the points of presence of plant species (Hijmans et al., 2005). Among the models to estimate ecological niche (potential zones) and project the effects of climate change on plant taxa, the maximum entropy model (MaxEnt) has demonstrated superior performance compared to other models (Navarro-Cerrillo et al., 2011).

The maximum entropy principle attempts to find the most widespread probability distribution, or the closest to uniform, given certain edaphoclimatic restrictions of the *in situ* presence points of the analyzed species (Elith et al., 2011). However, it should be considered that the scenarios estimated by these algorithms do not contemplate that plant varieties can be cultivated in an environment outside their natural distribution thanks to the introduction of additional resources such as water for irrigation, nutrients for fertilization, and pest and disease management (van Zonneveld et al., 2009).

The use of the maximum entropy algorithm to predict the effects of climate change on the natural cover of plant taxa has shown reliable results in tropical forest tree species such as *Lysiloma latisiliquum* (L.) Benth. (Garza-López et al., 2018), *Pinus patula*

Schltdl. & Cham., *Pinus tecunumanii* F. Schwerdtf. *ex* Eguiluz & J. P. Perry (van Zonneveld et al., 2009), and *Swietenia macrophylla* King (Garza-López et al., 2016). These results allowed decisions to be made regarding the conservation or use of tree varieties, by determining the climatic variables that most influence their development.

Based on the above, the objective of this research was to identify the regions of Mexico with the greatest abundance of *Brosimum alicastrum*, as well as to analyze the edaphoclimatic and physiographic patterns that influence its current and future natural distribution. This was done through the use of abundance, ecological niche and climate change models, supported by geographic information system tools, in order to determine the patterns that condition the natural cover of the species in the different regions of the country, and eventually its silvicultural management.

# Materials and Methods

## Study area

The georeferenced point distribution of *Brosimum alicastrum* in Mexico, recorded in the 2014 National Forest and Soil Inventory (Comisión Nacional Forestal [Conafor], 2016), was considered. The areas where the species develops in the wild in the country are predominantly in the evergreen and semi-deciduous forests of the western and eastern coasts of the national territory, with special abundance in the southeast (Vega et al., 2003).

## *Brosimum alicastrum* abundance zones

An abundance analysis was used to delimit the regions in Mexico with the highest concentration of *Brosimum alicastrum* specimens. Georeferenced data of the point distribution of the species were used, which were analyzed with the DivaGis v7.5 software based on the methodology described by Hijmans et al. (2012). A pixel size of 2.5 minutes was used with a circular neighborhood of one degree, which is equivalent to an area of 5 $km^2$ (Hijmans et al., 2005). In each pixel, the number of trees recorded per georeferenced point was counted.

## Potential *Brosimum alicastrum* areas

To identify regions in Mexico with similar characteristics to the areas where *Brosimum alicastrum* currently develops, the georeferenced data of its punctual distribution were associated with 19 bioclimatic variables available in the global database WorldClim (Fick & Hijmans, 2017), in addition to 16 edaphoclimatic variables: Annual evaporation (*evapo_anual*), Mean annual temperature in humid climates (*t_humid*), Organic matter present in the soil (*MO*), Altitude (*dem*), Organic carbon present in the soil (*CO*), Annual evaporation in dry climates (*evapo_dry*), Annual evaporation in humid climates (*evapo_humid*), Annual precipitation in dry climates (*pp_dry*), Annual precipitation in humid climates (*pp_humid*), Electrical conductivity in the soil (*CE*), soil pH, nutrients in the soil (K, Na, Mg and Ca), and the proportion of sodium absorption by the soil (*RAS*).

The resolution of the 35 variables used was 30 s, equivalent to a pixel size of one $km^2$. It is worth mentioning that, since their permutations were analyzed, and according to Hijmans et al. (2005), it is desirable to have the maximum number of variables since minimal variations in the gradients of some variable can cause significant changes in the gradients of other associated variables; no correlation test was performed between the 35 variables. The georeferenced points of presence of the species were linked to the 35 edaphoclimatic variables using the ecological niche methodology of Hijmans et al. (2005) in the software MaxEnt v3.4.1 (Philips et al., 2018) and DivaGis v7.5 (Hijmans et al., 2012); both climatic and geographic extremes were considered, because these extremes often represent new ecological niches (Philips et al., 2018). This approach determined the probability that *Brosimum alicastrum* will develop adequately in other regions of Mexico, where it is not currently distributed naturally. In addition, the analysis also identified the most determining soil and climate variables for the development of the species in the new potential areas.

## Climate change scenarios for *Brosimum alicastrum*

The vulnerability of the regions where *Brosimum alicastrum* currently develops to future climate variations was estimated with the MIROC6 climate change model, under an ssp585 scenario for the period 2061-2080, with a resolution of 30 s. This model, recommended by Ruiz et al. (2022) for Mexico, contemplates a gradual increase in greenhouse gas emissions, as well as a socioeconomic component of population growth and consumption (Tatebe et al., 2019). The data were obtained from WorldClim (2024) global database.

With the specific distribution of the species and the climate change models, scenarios were generated on the impact of climate change on the natural distribution of Brosimum alicastrum in Mexico for the 2061 to 2080 period, based on the methodology proposed by Hijmans et al. (2005) and the software MaxEnt v3.4.1 (Philips et al., 2018) and DivaGis v7.5 (Hijmans et al., 2012). This analysis also allowed us to identify the temperature and precipitation variables that will influence the development of the species in the future.

## Results and Discussion

According to data from the National Forest and Soil Inventory (Conafor, 2016), the presence of *Brosimum alicastrum* was recorded in 19 of the 32 federal entities of Mexico (Table 1). However, 82.15 % of the trees (12 306) were concentrated in four states in the South of the country: *Quintana Roo* (35.63 %), *Campeche* (28.11 %), *Oaxaca* (10.21 %) and *Chiapas* (8.20 %). The natural distribution of the species was predominantly recorded (87.47 %) in the ecosystems of primary medium sub-evergreen forest (58.30 %, 8 735 trees), primary high evergreen forest (19.55 %, 2 929), and primary medium sub-deciduous forest (9.62 %, 1 442).

**Table 1.** State coverage of sampling sites, number of trees and dominant vegetation where *Brosimum alicastrum* Sw. develops in Mexico according to the National Forest and Soil Inventory 2014.

| States | Sites | | Trees | | Dominant vegetation | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Trees | |
| | Number | % | Number | % | Type * | Number | % |
| *Quintana Roo* | 1 957 | 41.42 | 5 338 | 35.63 | SMQ | 5 050 | 94.60 |
| *Campeche* | 1 242 | 26.29 | 4 211 | 28.11 | SMQ | 3 361 | 79.81 |
| *Oaxaca* | 413 | 8.74 | 1 529 | 10.21 | SAP | 1 340 | 87.64 |
| *Chiapas* | 370 | 7.83 | 1 228 | 8.20 | SAP | 1 049 | 85.42 |
| *Nayarit* | 126 | 2.67 | 580 | 3.87 | SMS | 507 | 87.41 |
| *Veracruz* | 162 | 3.43 | 455 | 3.04 | SAP | 333 | 73.19 |
| *Jalisco* | 125 | 2.65 | 369 | 2.46 | SMS | 309 | 83.74 |
| *Tamaulipas* | 49 | 1.04 | 335 | 2.24 | SBC | 237 | 70.75 |
| *San Luis Potosí* | 54 | 1.14 | 200 | 1.33 | SMQ | 115 | 57.50 |
| *Michoacán* | 56 | 1.19 | 170 | 1.13 | SMS | 115 | 67.65 |
| *Sinaloa* | 20 | 0.42 | 134 | 0.89 | SMS | 79 | 58.96 |
| *Yucatán* | 61 | 1.29 | 124 | 0.83 | SMS | 104 | 83.87 |
| *Hidalgo* | 15 | 0.32 | 111 | 0.74 | SAP | 109 | 98.20 |
| *Guerrero* | 25 | 0.53 | 65 | 0.43 | SBC | 23 | 35.38 |
| *Tabasco* | 25 | 0.53 | 64 | 0.43 | SAP | 31 | 48.44 |
| *Colima* | 9 | 0.19 | 31 | 0.21 | SMS | 30 | 96.77 |
| *Durango* | 10 | 0.21 | 29 | 0.19 | BQ | 14 | 48.28 |
| *Puebla* | 3 | 0.06 | 5 | 0.03 | SAP | 3 | 60.00 |
| *Querétaro* | 3 | 0.06 | 4 | 0.03 | BQP | 3 | 75.00 |
| Total | 4 725 | 100.00 | 14 982 | 100.00 | | | |

BQ = Primary oak forest; BQP = Primary pine-oak forest; SAP = High primary evergreen forest; SBC = Low primary deciduous forest; SMQ = Medium primary sub-evergreen forest; SMS = Medium primary sub-deciduous forest.

The highest abundance of *Brosimum alicastrum* in Southern Mexico has been documented by López-Barrera et al. (2021) who pointed out that this region contains the greatest diversity of morphotypes of the species. However, Santillán-Fernández et al. (2021) analyzed that the decrease in rainfall, combined with the increase in temperatures in the South of the country, will reduce the forest cover of *Brosimum alicastrum*. Therefore, knowing the edaphoclimatic patterns that influence its natural distribution could be key to improving conservation strategies (Vega et al., 2003).

## ***Brosimum alicastrum*** **abundance zones**

The spatial distribution of the *Brosimum alicastrum* abundance zones identified five areas with the highest presence of the species (Figure 1). The regions of greatest abundance were located in the South of the country: the *Yucatan* Peninsula, the Isthmus and *Lacandona*, areas previously described by López-Barrera et al. (2021) as having the greatest richness. These areas, with a strong influence on the diet of the Mayan culture, are where the species is known as “the corn of the Mayans”, “the Mayan nut”, “the *Ramón* tree”, or “*Óox*” (in the Mayan language).

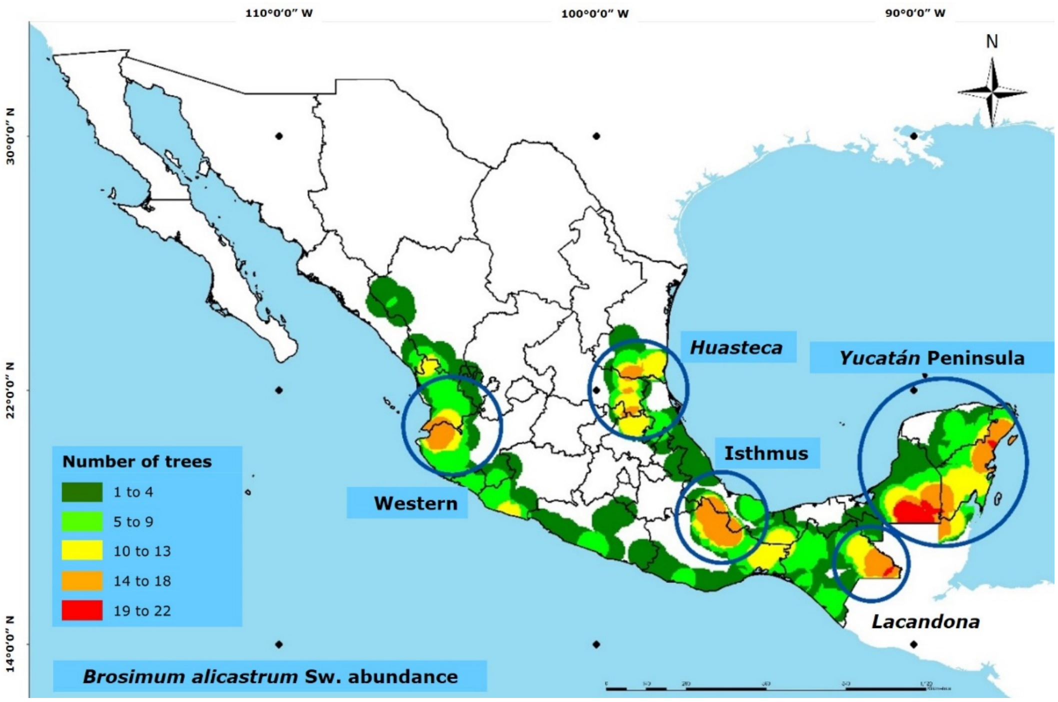
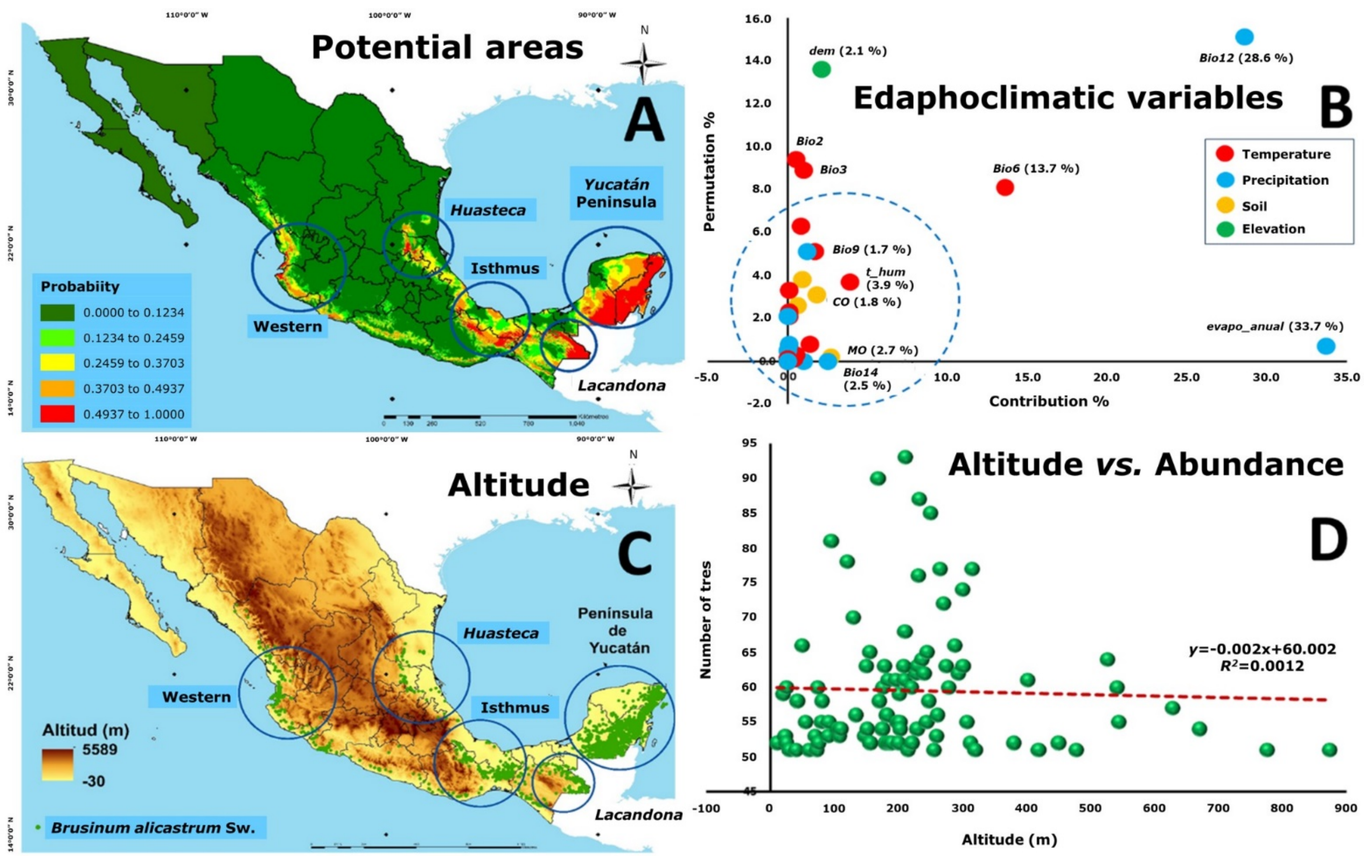



**Figure 1.** Abundance distribution regions of *Brosimum alicastrum* Sw. in Mexico.

Zones of abundance were also identified in Western Mexico, where the species is known as "*capomo*" and its fruit is used as flour and coffee substitutes (De Luna-Vega et al., 2017). Another important area was the *Huasteca* region; there it is called "*ojite*" and is largely used as fodder (López et al., 2015). Vega et al. (2003) indicated that the natural distribution of the species is mainly located in semi-evergreen medium forest ecosystems in Western and Eastern Mexico, and is more abundant in the South of the country, where soil and climate conditions are more favorable for it.

## Potential zones for *Brosimum alicastrum*

The potential zones for *Brosimum alicastrum*, determined from soil, climate and physiographic patterns, were based on the point record of 4 725 sampling sites with a total of 14 982 trees, a sufficient sample to guarantee reliable predictions in MaxEnt (Elith et al., 2011). The results were significant with a Coefficient of adjustment of 92.1 % (*AUC*=Area under the curve). Figure 2A shows that Southern Mexico offers the best soil, climate and physiographic characteristics for the optimal development of the species.




A = Delimitation of potential zones of *Brosimum alicastrum* in Mexico obtained through soil and climate factors; B = Estimated contribution and importance of the permutation of soil and climate variables to the maximum entropy model that predicts potential zones for *B. alicastrum*, the percentage of contribution to the model is indicated in parentheses; C = Spatial relationship of altitude with the natural distribution of *B. alicastrum*; D = Simple linear regression model that determined that the higher the altitude (m), the lower the abundance of *B. alicastrum*.

**Figure 2.** Potential zones, soil and climate variables and the relationship of altitude with the natural distribution of *Brosimum alicastrum* Sw. in Mexico.

Santillán-Fernández et al. (2021) analyzed that the regions of Southern Mexico, where *Brosimum alicastrum* naturally grows, have rainfall greater than 500 mm per year, an average annual temperature greater than 26 °C, and altitudes less than 400 m. However, De Luna-Vega et al. (2017) for the Western region, and López et al. (2015) for the *Huasteca*, documented the natural presence of the species at altitudes above 1 000 m. Therefore, altitude may be a factor that influences the width of the potential areas for *Brosimum alicastrum* in the Western and *Huasteca* regions (Vega et al., 2003).

When analyzing the temperature, precipitation, soil, and elevation variables that condition the potential natural distribution of *Brosimum alicastrum*, it turned out that three of the 35 variables included in the ecological niche model (Hijmans et al., 2005) contributed with 75.9 % of the predictions: *Evapo_anual* (Annual evaporation, 33.7 %), *Bio12* (Annual precipitation, 28.6 %), and *Bio6* (Minimum temperature of the coldest month, 13.6 %). It seems that the variables associated with micro and macro nutrient patterns in the soil do not condition the development of the species in a natural way (Figure 2B).

The influence of annual evaporation on the natural distribution of *Brosimum alicastrum* has been described by Santillán-Fernández et al. (2021) in regions of the *Yucatán* Peninsula, where 85 % of the precipitation evaporates. Regarding annual precipitation (*Bio12*) and minimum temperature in the coldest month (*Bio6*), Vega et al. (2003) described the ecological zones in which the species grows on the Mexican Pacific coast, and identified that *Brosimum alicastrum* grows best in regions with mean annual precipitation of 800 to 1 200 mm, and with minimum temperatures above 20 °C.

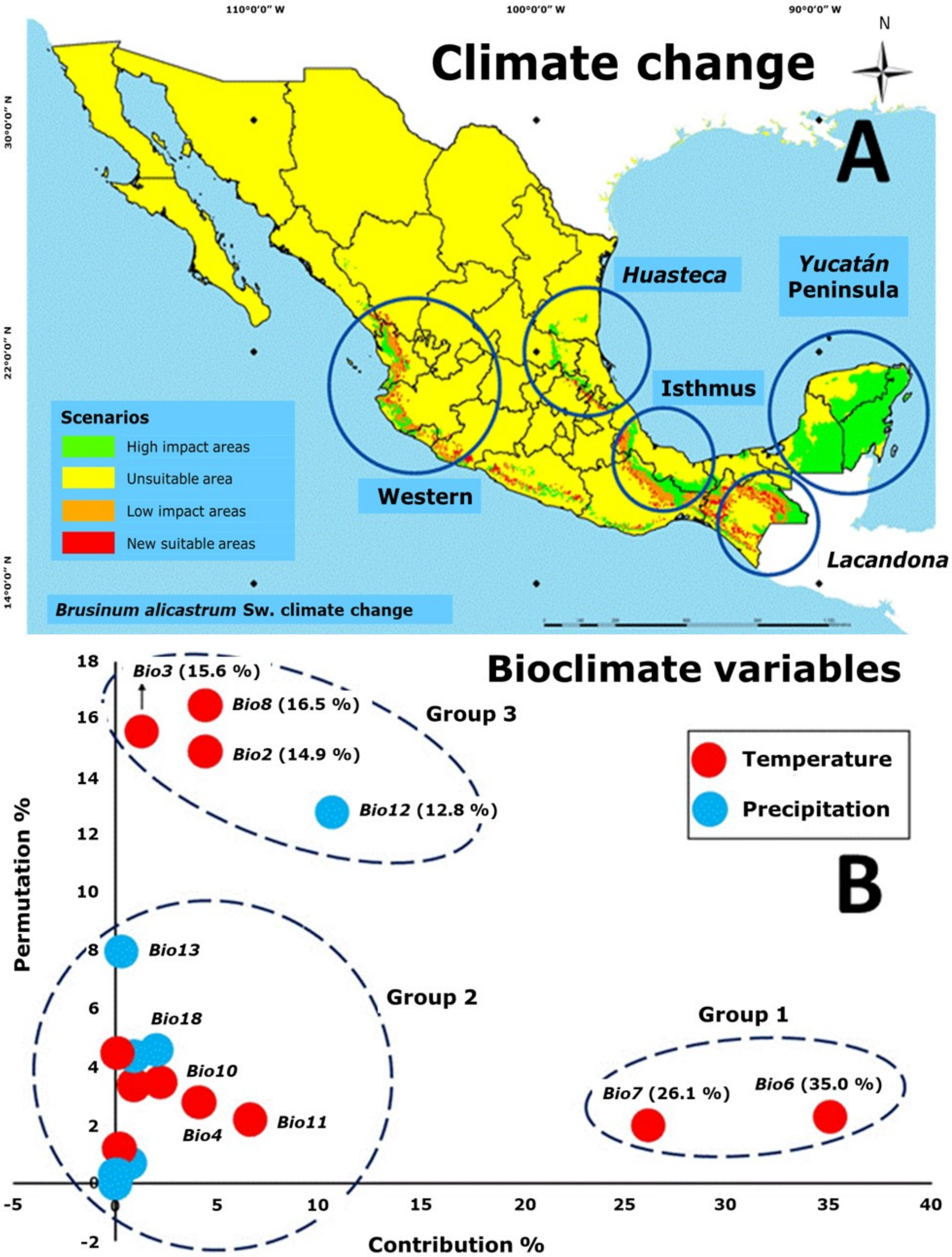
However, variables with high percentages in permutation are important to take into account in the prediction of ecological niche modeling (potential zones), since minimal variations in their gradients can cause significant changes in the gradients of other associated variables (Hijmans et al., 2005). The variables with the highest permutations were: *Bio12* (Annual precipitation, 15.1 %), and *dem* (Altitude in m, 13.6 %). Vega et al. (2003) documented that the ecological niche of *B. alicastrum* is more likely in areas with altitudes below 200 m, mean annual temperature above 28 °C, and annual precipitation of 800 to 1 200 mm.

According to Segura-Castruita and Ortiz-Solorio (2017), as altitude increases, temperature tends to decrease, which explains why in mountainous regions of Mexico (Figure 2C), *Brosimum alicastrum* is unlikely to be distributed naturally, as it does not tolerate environments with temperatures below 20 °C (Vega et al., 2003). Therefore, altitude seems to condition the natural distribution of the species, and although it did not directly contribute to the prediction of its ecological niche, it was a variable with a high percentage of permutation. Matovelle et al. (2021) documented that altitude tends to directly influence regional precipitation and temperature, which explains why as altitude increases, the abundance of *Brosimum alicastrum* decreases (Figure 2D).

## Climate change scenarios for *Brosimum alicastrum*

The future habitat of *Brosimum alicastrum* in Mexico, projected using the MaxEnt algorithm, with a MIROC6 climate change model and an ssp585 scenario for the period 2061-2080 with a 30 s resolution, was significant with an adjustment coefficient (*AUC*) of 0.911, obtained after 500 iterations. According to Fielding and Bell (1997), the *AUC* takes values close to one when there is a good fit with the assessment data.

The climate change model identified four scenarios (Figure 3A): (1) Low impact areas (areas where *Brosimum alicastrum* potentially occurs at present and in the future); (2) High impact areas (areas where the species potentially occurs at present but is not suitable in the future); (3) New suitable areas (areas where the species potentially occurs in the future which are not suitable for natural occurrence under current conditions); and (4) Area not suitable, either under current conditions or predicted under future conditions (outside the realized niche) (Hijmans et al., 2005).




A = Effects of future climate from 1961 to 2080 on the current natural distribution of *Brosimum alicastrum* in Mexico; B = Estimated contribution and importance of the permutation of bioclimatic variables to the maximum entropy model that predicts the effect of future climate from 2061 to 2080 on the current natural distribution of *Brosimum alicastrum*, the percentage contribution to the model is indicated in parentheses.

**Figure 3.** Climate change scenarios for *Brosimum alicastrum* Sw. in Mexico and the bioclimatic variables that contribute to the delimitation of these scenarios.

Figure 3A shows that the regions most vulnerable to the effects of future climate on the natural development of *Brosimum alicastrum* were located in the South of the country, especially in the *Yucatán* Peninsula. The adverse effect on the presence of the species in the *Yucatán* Peninsula due to future climate variations has been previously described by Santillán-Fernández et al. (2021), who predicted a reduction in distribution areas with a concentration in the center of the region.

However, unlike the model by Santillán-Fernández et al. (2021), a total reduction of the species in the *Yucatán* Peninsula was estimated; the difference in the results may be due to the fact that the climate change model used by these authors was projected up to 2050, and although they considered a gradual increase in greenhouse gas emissions, they did not include the socioeconomic component of population growth and consumption patterns based on fossil fuels until 2080 (ssp585) (Tatebe et al., 2019). However, both models agreed that the increase in temperature (*Bio6* and *Bio7*) and the instability of precipitation (*Bio12*) would condition the natural distribution of the species.

Another relevant aspect of the present study was that the low-impact areas and new suitable areas were concentrated on the high parts of the *Sierra Madre Oriental* (in the *Huasteca*, Isthmus and *Lacandona* zones), and the *Sierra Madre Occidental* (for the Western zone). Sánchez et al. (2011) detected that some tropical forest species migrate to higher altitude areas as a mechanism of adaptation to climate change; therefore, silvicultural management of *Brosimum alicastrum* in coastal areas may be a viable option for its conservation (Hernández-González et al., 2015).

When analyzing the contribution and permutation of the bioclimatic variables used in the estimation model of the effect of future climate on the natural distribution of *Brosimum alicastrum*, three groups of variables were distinguished (Figure 3B). The variables of Group 1 explained 61.1 % of the model predictions: *Bio6* (Minimum temperature in the coldest month), 35.0 %, and *Bio7* (Annual temperature range), 26.1 %.

The variables of Group 2 did not present significant contributions. However, in Group 3 the variables with the highest percentage of permutation were: *Bio8* (Average temperature of the wettest quarter), with 16.5 %, *Bio3* (Isothermality), with 15.6 %, *Bio2* (Average diurnal range), with 14.9 %, and *Bio12* (Annual precipitation), with 12.8 %. The analysis of these variables is important because minimal variations in their gradients can cause significant changes in the gradients of other associated variables (Hijmans et al., 2005).

It seems that the variations in the minimum temperature (*Bio3*, Isothermality) of the coldest month (*Bio6*), that of the Annual range (*Bio7*), that of the wettest quarter (*Bio8*) and the heterogeneity of these between day and night (*Bio2*), as well as the instability of rainfall (Annual precipitation, *Bio12*), conditioned the natural distribution of *Brosimum alicastrum* in Mexico. Martínez-Austria and Patiño-Gómez (2012) defined that one effect of climate change will be the intensity and instability of dry periods, as a consequence of a gradual increase in temperature patterns, which will alter the physiological cycles of cultivated and non-cultivated plants (Yepes & Silveira, 2011).

The effect that temperature variations will have on the natural distribution of *Brosimum alicastrum* in climate change scenarios projected to horizons of 2050 has been documented as a determining factor, even ahead of instability in rainfall (Santillán-Fernández et al., 2021); this is due, according to Vega et al. (2003), to the fact that the species tolerates prolonged dry periods, but is very sensitive to temperature variations.

Thus, one measure to ensure its conservation and potential use is to migrate to forestry schemes that simulate the ideal environmental conditions for its development (Hernández-González et al., 2015), both in the regions where it is currently distributed, as well as in potential distribution areas in the future. Although it is documented that the species has great social importance for family production, with cultural management for several centuries; it is currently a local resource with limited forestry management (Espinosa-Grande et al., 2023).

# Conclusions

Five regions in Mexico were identified with the highest presence of *Brosimum alicastrum*: (1) *Yucatán* Peninsula (located between the borders of the states of *Campeche*, *Quintana Roo* and *Yucatán*); (2) Isthmus (North of *Oaxaca* and South of *Veracruz* states); (3) *Lacandona* (North of the state of *Chiapas*); (4) West (West of *Jalisco* state and South of *Nayarit* state); and (5) *Huasteca* (South of the states of *Tamaulipas* and *San Luis Potosí*, and North of *Hidalgo* and *Querétaro*). It was also identified that the factor that determines the potential areas where the species develops best in its natural form is altitude, which directly influences temperature. *Brosimum alicastrum* is distributed with greater abundance in regions with altitudes less than 400 m, and as altitude increases its abundance decreases, because it adapts better to warm regions with temperatures above 26 °C.

Future climate scenarios showed discouraging results, with a total reduction in the coverage of *B. alicastrum* in the *Yucatán* Peninsula region, where it is currently most abundant. However, it should be noted that the climate change model analyzed considered population growth variables and consumption patterns based on the use of fossil fuels until 2080, but left out of its analysis algorithm the cultural management of the species.

Extreme variations in the minimum temperature (*Bio3*, Isothermality) of the coldest month (*Bio6*), that of the Annual range (*Bio7*), that of the wettest quarter (*Bio8*) and the heterogeneity of these between day and night (*Bio2*), as well as the instability of rainfall (Annual precipitation, *Bio12*) were the factors that, apparently, will condition the natural distribution of *B. alicastrum* in the future. The climate change model also identified new areas suitable for the species at altitudes above 400 m, so it seems that the species will have to migrate to new ecological niches for its survival.

Finally, these findings acquire special relevance if we consider that, to date, the species has limited silvicultural management and a high potential as animal and human food, so this regionalization can be taken as a basis for a differentiated forestry management, and to improve the conditions that will affect its natural development at local, regional and national levels in the future.

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### Conflict of interest

The authors declare that they have no conflict of interest.

### Contribution by author

Alberto Santillán Fernández: conceptualization and design of the study, statistical analysis and writing of the final manuscript; José Eduardo López Frías: analysis of the information and writing of the original manuscript; Alfredo Esteban Tadeo Noble: preparation of cartographic maps using GIS and data review; Homar Barba Costeño: analysis of the information and writing of the original manuscript; Leonardo Velasco Casarez: data review and writing of the final document; Javier Enrique Vera López: review, monitoring of results and writing of the final manuscript.

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