Acta Botanica Brasilica, 2025, 39: e20240166
doi: https://doi.org/10.1590/1677-941X-ABB-2024-0166

Original Article

Estimating environmental suitability and potential geographic distribution of the regional endemic tree *Haematoxylum calakmulense* (Fabaceae) in the Yucatan Peninsula

Alexis Herminio Plasencia-Vázquez[1], Anay Serrano-Rodríguez[1,*], Annery Serrano-Rodríguez[2], Yarelys Ferrer-Sánchez[3]

[1] Universidad Autónoma de Campeche, Centro de Investigaciones Históricas y Sociales, Campeche, México.
[2] Universidad Autónoma de Campeche, Facultad de Ciencias Químico Biológicas, Campeche, México.
[3] Universidad Técnica Estatal de Quevedo, Facultad de Ciencias de la Ingeniería, Quevedo, Ecuador.
*Corresponding author: anayserrano1984@gmail.com.

ABSTRACT
In Mexico, species of the genus *Haematoxylum* have historically stood out for their economic value, although they have received less attention from an ecological point of view. The objective of this work was to model the ecological niche of *H. calakmulense* and characterize its potential distribution areas in southeastern Mexico. The selected distribution model included a set of eight variables: isothermality, the maximum temperature of the warmest month, the maximum temperature of the coldest month, precipitation of the driest month, soil clay content, grain density, and elevation. Considering the binary map of environmental suitability, only 4.9% of the potential range of *H. calakmulense* in Mexico is within a federally administered protected natural area. In addition, leptosol-vertisol soils are most frequently recorded in the areas where the species is most likely to occur. In general, environmental conditions are more favorable for the development of the species in the central part of the Yucatan Peninsula in Mexico. This information will serve as a basis for deepening our knowledge of the ecology of this species and will allow us to implement appropriate conservation and management projects and plans.

Keywords: *Haematoxylum calakmulense,* logwood, MaxEnt, potential distribution models, Yucatan Peninsula

Received July 02, 2024; Accepted May 27, 2025
Editor-in-Chief: Thaís Elias Almeida; Associate Editor: Vanessa Rezende

Data availability:
The datasets related to this article will be available upon request to the author.

How to cite:
Plasencia-Vázquez AH, Serrano-Rodríguez A, Rodríguez AS, Ferrer-Sánchez Y. 2025. Estimating environmental suitability and potential geographic distribution of the regional endemic tree *Haematoxylum calakmulense* (Fabaceae) in the Yucatan Peninsula. Acta Botanica Brasilica 39: e20240166. doi: 10.1590/1677-941X-ABB-2024-0166

Introduction

Many plant species are widely used for commercial purposes, but little is known about their ecology. In general, humans tend to overlook plants in relation to other living organisms, a phenomenon known as plant awareness disparity that extends even to scientists (Jose *et al.*, 2019). This phenomenon was described by Wandersee & Schussler (1999) as an inability to notice plants in the environment, recognize their importance, or appreciate their unique biological characteristics. Plant species with high use value and economic potential may be the first to be affected by overexploitation and the most likely to disappear (Chablé-Vega *et al.*, 2019; 2024). It is very important to know useful plants and even more about those species that are commercialized since their correct use depends on it (Chablé-Vega *et al.*, 2019). In this regard, it is crucial to have information on aspects such as distribution or demographic characteristics (Castañeda-Romero *et al.*, 2016). If it is possible to define the range of a species, it is possible to identify which factors determine it and how much of the existing habitat is available (López-Gallego, 2015). In this sense, ecological niche and potential distribution models have demonstrated their value and there are many studies that support this (*e.g.*, Peterson *et al.*, 2011; Wang *et al.*, 2023).

Species distribution modelling techniques have been developed and successfully applied to estimate geographic ranges of species from recorded occurrences as a function of environmental conditions encountered (Elith & Leathwick, 2009). By linking recorded occurrences to environmental conditions, ecological niches of species are inferred (Soberon & Nakamura, 2009). These niche models are then projected onto raster environmental data to provide geographic predictions of the suitability of landscapes for the species, allowing prediction of their occurrence. During the modelling process, some assumptions are made, for example, that the species is in pseudo-equilibrium with the environment (Guisan & Theurillat, 2000). The applications of species distribution models are diverse and include exploring niche segregation of different species or taxa, defining conservation areas, predicting damage in the presence of invasive species, testing hypotheses about biogeography and evolution, and assessing connectivity in landscape ecology (Guisan & Thuiller, 2005).

In Mexico, species of the genus *Haematoxylum* L. have historically stood out for their economic value, although they have received less attention from an ecological point of view (Plasencia-Vázquez *et al.*, 2017). The species *H. brasiletto* H. Karst. and *H. campechianum* L. stand out, which are mainly exploited for their dye, medicinal properties, or their wood and have been the subject of studies in some works (*e.g.*, Ávila-Calderón & Rutiaga-Quiñones, 2014; Chablé-Vega *et al.*, 2019; Plasencia-Vázquez *et al.*, 2020; García-González *et al.*, 2021). However, for the other two members, *H. sousanum* Cruz Durán & J. Jiménez Ram. and *H. calakmulense*, Cruz Durán & M. Sousa very little research has been done beyond their description as new species (Cruz Durán & Jiménez Ramírez, 2008; Cruz Durán & Sousa, 2014; Chablé-Vega *et al.*, 2019). For *H. sousanum*, ecological information and occurrence records in international databases or scientific literature are almost nil (Cruz Durán & Jiménez Ramírez, 2008, GBIF.org, 2023). In contrast, for *H. calakmulense*, although little has been studied and occurrence data are limited, a little more has been documented about the sites where it can be found (Cruz Durán & Sousa, 2014; Chablé-Vega *et al.*, 2019; GBIF.org, 2023). Although the little evidence available indicates that the species historically exploited for commercial purposes was *H. campechianum*, there are no solid elements to exclude that *H. calakmulense* was also exploited for these purposes (Dampier, 2004; Villegas & Torras, 2014; Chablé-Vega *et al.*, 2019). Since *H. calakmulense* is a species with lower representativeness in the areas where it is distributed, any harvesting activity may have a great negative impact on its populations. Considering these information gaps and the importance of deepening the knowledge of this species, the objective of this study was to model the ecological niche of *H. calakmulense* and characterize its potential distribution areas in southeastern Mexico. This information will serve as a basis for further knowledge of the natural history and ecology of this species. In addition, it will allow researchers, protected area managers, and various government organizations to implement projects, conservation plans, and appropriate management.

Materials and Methods

Study area and species occurrence records

The genus *Haematoxylum* is represented in tropical America by four species: *H. brasiletto*, *H. campechianum*, *H. sousanum,* and *H. calakmulense*. *Haematoxylum calakmulense* and *H. campechianum* are the most similar and differ in some anatomical features. *Haematoxylum calakmulense* has shorter inflorescences and leaves, with four to six pairs of shorter leaflets that are glabrous on the upper side and hairy on the underside towards the base. In contrast, *H. campechianum* has longer inflorescences and leaves and generally two to four pairs of longer and more glabrous leaflets, rarely five (Cruz Durán & Sousa, 2014). There are marked differences between *H. campechianum* and *H. brasiletto*: *H. campechianum* has actinomorphic flowers and *H. brasiletto* has zygomorphic flowers (Tucker & Kantz, 1997). *Haematoxylum sousanum* is easier to distinguish from the other species because its leaves are always paripinnate and bi-imparipinnate and the inflorescence is a terminal panicle (Cruz Durán & Jiménez Ramírez, 2008). The species of interest in this study was *H. calakmulense*, one of the lesser known species of its genus. The study area includes the ecoregions that are considered part of the Mayan rainforest (García & Secaira, 2006).

We worked across much of south-eastern Mexico, including the Yucatán Peninsula, as well as parts of the states of Tabasco and Chiapas. We also covered the northern regions of Belize and Guatemala. A total of 143 records of *H. calakmulense* were examined from data available in the Global Biodiversity Information Facility (GBIF.org, www.gib.org; revised February 2023), additional records from different herbaria, as well as information obtained during fieldwork and in the scientific literature (Niembro, 2002; Plasencia-Vázquez *et al.*, 2017; Plasencia-Vázquez *et al.*, 2020). The database was cleaned by eliminating datasets with insufficient data, duplicates, and those outside the natural distribution reported in the literature. A minimum distance of 1 km between points was established after analyzing the behavior of the Moran index for all selected variables with different intensities of database thinning (1 km, 5 km, 10 km, and 20 km), to minimize bias due to spatial autocorrelation. Database thinning was performed using R and the *spThin* package (Aiello-Lammens *et al.*, 2015). Points dated before 1970 were discarded to avoid temporal incongruence between presences and the time range described by climatic variables. Finally, models were obtained using 44 occurrences. The data were divided into three groups, 5% of the occurrences were reserved for the evaluation of the final models. Of the remaining 95% of the data, 80% was used to calibrate the models, and 20% was used to evaluate the models resulting from the calibration.

Selection of variables

Initially, 30 variables were examined that *a priori* could have a direct or indirect relationship with the occurrence of *H. calakmulense* (Table S1). The preliminary analysis included 15 climatic variables describing temperature and precipitation available in WorldClim v. 2.1 (http://worldclim.org; Fick & Hijmans, 2017), two topographic variables (elevation and slope, https://www.earthenv.org), and 13 variables characterizing the soil, such as aridity index (http://srtm.csi.cgiar.org), clay content, gray density, and cation exchange capacity in four depth ranges (0-5 cm, 5-15 cm, 15-30 cm, and 30-60 cm, https://soilgrids.org). All layers had a spatial resolution of 30" (~ 1 km^2), except for the soil layers which had a resolution of 250 m and were resampled to 1 km by calculating the average between pixels. A variable refinement process was performed according to three criteria: (1) the contribution of the variables in the maximum entropy test models, which included all 30 variables, (2) the biological importance according to the ecology of the species, based on the opinion of specialists, fieldwork and scientific literature (Cruz Durán & Sousa, 2014; Plasencia-Vázquez *et al.*, 2020), and (3) the relationship between variables, where only one variable among a pair with regression values greater than 0.8 was considered the multicollinearity and relationship (Oksanen *et al.*, 2017) was taken into account. Considering the above criteria, a set of eight or at most nine variables was selected for each analysis with different calibration ranges. In addition, the behavior of the models in each analysis was explored with two more sets of pruned variables (removing two or four variables in each set, depending on their importance value).

Calibration, evaluation, and selection of the distribution model

The effect of the area considered in the calibration of the model was analyzed by studying two buffers, 40 and 60 km around the occurrence points, and compared with the model trained on the whole study area (ecoregion). Although information on the mode of seed dispersal is scarce, the calibration areas used were considered reasonable due to their characteristics (Cruz Durán & Sousa, 2014). The process of calibration, obtaining the final model, and evaluation was carried out using the *kuenm* package in R (Cobos *et al.*, 2019). The maximum entropy machine learning algorithm (MaxEnt), recommended for presence-only data, was used to obtain potential distribution maps. A simple MaxEnt configuration was selected for model calibration, which included five variable response types: linear (l), quadratic (q), product (p), and a combination of these (lq, lp, lqp). In addition, the performance of the models was tested with 16 multiple regularization values: 0.1-1.0, 1.5, 2.0, 2.0, 2.5, 3.0, 3.5, 4.0. The performance of the candidate models was evaluated by considering the statistical significance of the prediction (partial ROC), the omission rate of the models (considering an omission error of 5%), and the model fit and complexity according to the Akaike information criterion (AICc; Warren & Seifert, 2011). A categorical map was created from the continuous fitness values by establishing four criteria: Unsuitable (≤0.10), Low (0.11-0.30), Moderate (0.31-0.70), and High (≥0.71) (Abdelaal *et al.*, 2019). A binary map, useful for future management decisions, was also obtained by analyzing the different thresholds that determined the outcome (Fielding & Bell, 1997). Finally, 'equal training sensitivity and specificity' (0.27) was defined as a threshold criterion, an intermediate value between 'maximum training sensitivity plus specificity' (0.34), which tends to underestimate potentially suitable areas, and '10th percentile training presence' (0.20), which tends to overestimate them.

Characterization of the niche in the environmental space

To characterize the environment occupied by the species and to explore the environmental conditions available in the accessible area, a Principal Component Analysis (PCA) was performed. The density of occurrence of *H. calakmulense* in the environmental space was plotted with the first two components on a 100 x 100 grid (Broennimann *et al.*, 2012). This plot allows visualization of the extent and location of the niche in relation to the environmental conditions available in the study area. The R package *ecospat* was used for this purpose (Broennimann *et al.*, 2012; Petitpierre *et al.*, 2012).

Management implications

The representativeness of the environmental suitability of *H. calakmulense* in the protected areas of Mexico (CONANP, 2023) was evaluated to analyze the degree of protection of the species in the country. In addition, the area and percentage of suitability in the different categories of land use and vegetation type were calculated according to the map of the National Institute of Statistics and Geography of Mexico, Series VII (INEGI, 2021) and soil type (García & Secaira, 2006).

Results

Calibration, evaluation, and selection of the distribution model

Among the proposed calibration areas, a 40 km buffer around the points was selected because it had the lowest number of parameters and higher model significance (Tab. 1). The best model selected included the set of eight unpruned variables: isothermality (bio3), maximum temperature of the warmest month (bio5), maximum temperature of the coldest month (bio6), precipitation of the driest month (bio17), soil clay content (5-15 cm), grain density (0-5 cm) and elevation. The model was performed with a regularization multiple of 0.6 and a response function of the 'lq' type variables. The model selected performed well with an AUC value of 0.90±0.02 for the training data. The partial ROC curve analysis yielded an average AUC of 1.82 and a 5% omission rate of 0 was obtained.

Potential distribution pattern of *H. calakmulense*

Environmental conditions are most favourable for the development of the species in the central portion of the Yucatan Peninsula in Mexico (Fig. 1a). The highest percentages of suitable areas for the species are found in the states of Campeche (46.3%), Quintana Roo (41.2%) and Yucatan (8.9%). Outside its known range, some areas with favorable conditions for *H. calakmulense* were found in the extreme northwestern part of the state of Veracruz (3.4%), mostly associated with coastal areas, and in Oaxaca (0.2%) (Fig. 1a). Outside of Mexico, the species occurs in a small part of northern Guatemala and Belize (Fig. 1a). An analysis of the map by category shows that the highly suitable areas in Mexico are distributed in the states of Quintana Roo (51.7%) and Campeche (49.3%), the latter mainly in the municipality of Calakmul (Fig. 1b). The moderately suitable areas are in Campeche (46.2%), Quintana Roo (35.5%), Yucatan (13.3%) and Veracruz (5.0%).

Clay content at a depth of 30-60 cm was the variable with the greatest contribution to the model (Tab. 2), with a maximum optimum value of 700 g/kg (Fig. 2). However, isothermality was the largest contributor in terms of importance in the permutation and the third largest in terms of percentage contribution (Tab. 2). Precipitation in the driest quarter was the second most important variable, with a percentage very close to that of isothermality (Tab. 2), in a range between 0 and 190 mm approximately (Fig. 2).

Environmental Niche Characterization

In general, the environmental niche of *H. calakmulense* appears to be narrower than the environmental conditions available in the study area and represents a relatively marginal location (Fig. 3, Fig. S1). The first two components of the PCA explained 64.5% of the total variability of the data, with mean annual precipitation (bio12), precipitation of the driest quarter (bio17), and clay content being the main contributing variables (Fig. 3).

Implications for conservation management in Mexico

Considering the binary map of environmental suitability (Fig. 1a), only 4.9% of the potential range of *H. calakmulense* in Mexico is within a federally administered protected natural area (Fig. 1c). The largest percentage (4.3%) is shared between the Mexican Caribbean Biosphere Reserve and Calakmul (Fig. 1c). However, 21.7% of the suitable area for the species is located in a natural protected area (ANP) under some other form of management (state, municipal, ejido, community, or private) (Fig. 1c). Among the latter, the management categories where suitable areas for the species are best represented are: Zone subject to ecological conservation (11.2%), State Reserves (10.2%) and to a lesser extent State Ecological Parks (5.1%) (Fig. 1c, Table S2).

In relation to the different categories of land use and vegetation in the Mexican territory, the best represented within the potential distribution area of the species is the secondary tree vegetation (34.5%), which is also the most important within the areas with the highest probability of distribution (47.2%) (Fig. 4a, Table S3). Leptosol-vertisol soils are most frequently recorded in the areas where the species is most likely to occur (Fig. 4, Table S4).

Table 1. Final ecological niche models for *H. calakmulense* considering different calibration areas (40 km buffer, 60 km around the presence points and ecoregions). The final selected model is highlighted in bold. Composition of variable sets: Set1 (bio3, bio4, bio6, bio17, Clay30_60, Bulk5_15, cec0_5, elevation); Set3 (bio6, bio16, Bulk5_15, elevation).

Calibration area	Variables	Mean AUC ratio	Response	Regularization multiplier	Partial ROC	Omission rate at 5%	AICc	Delta AICc	W AICc	N parameters
buffer_40 km	**Set1**	**1.903**	**lq**	**0.6**	**0**	**0**	**947.1**	**0**	**0.15**	**9**
	Set1	1.902	lq	0.7	0	0	947.5	0.4	0.10	9
	Set1	1.722	lq	0.8	0	0	948.0	0.9	0.10	9
	Set1	1.721	lq	0.9	0	0	948.5	1.4	0.10	9
	Set1	1.723	lq	1	0	0	949.1	2.0	0.10	9
buffer_60 km	Set1	1.694	lp	1	0	0	946.9	0	0.90	7
Ecorregions	Set3	1.750	lp	0.1	0	0	944.8	0	1.00	7

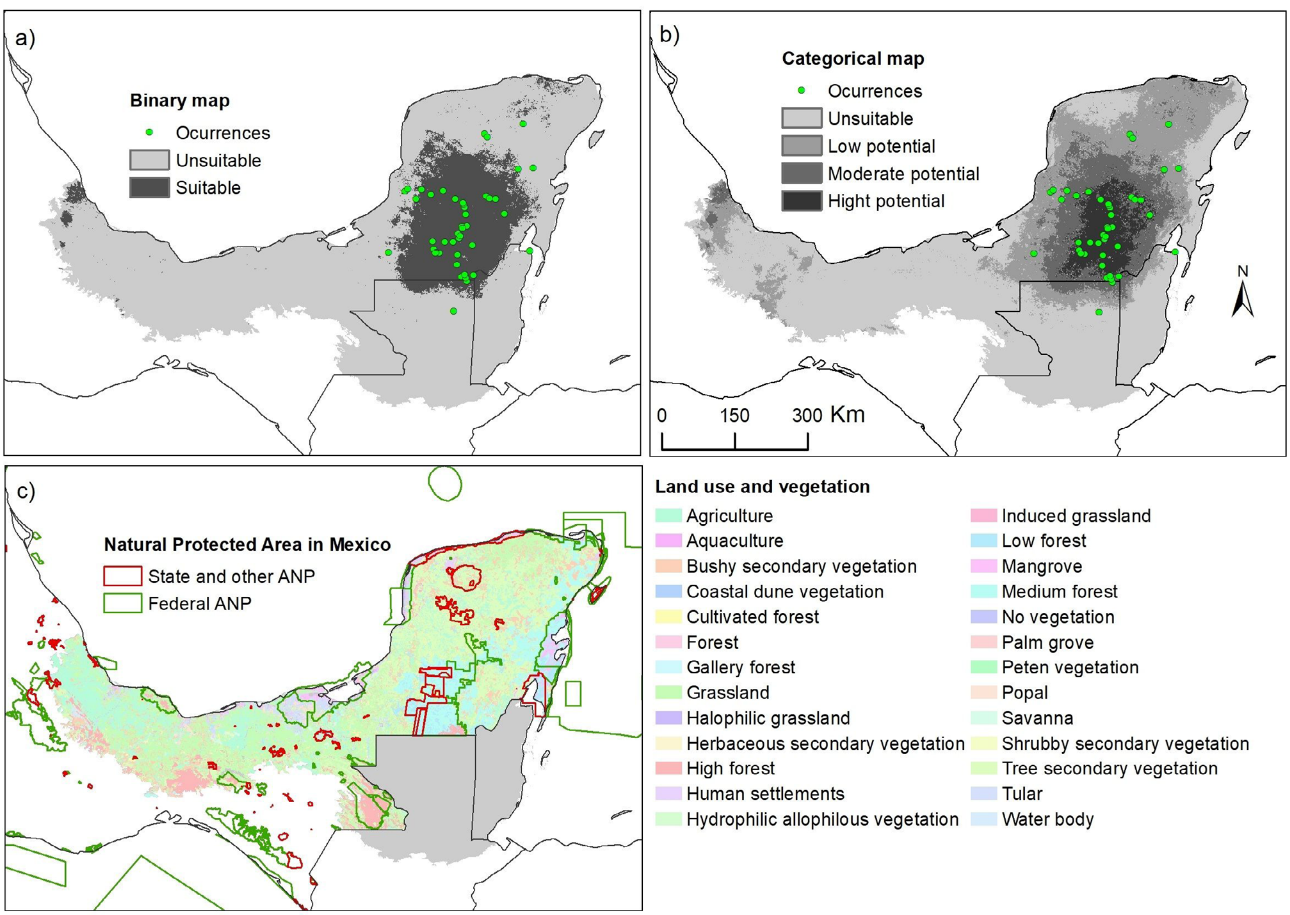

Figure 1. Models of environmental suitability for *H. calakmulense*: a) binary model, b) categorical model of suitability, and c) representation of federal natural protected areas (ANP) and state, municipal, *ejido* (local form of social organization in rural areas), community and private protected areas (marked in red) on a map of land use and vegetation of Mexico (INEGI, 2021).

Table 2. Contribution of variables to the distribution model in MaxEnt for *H. calakmulense*.

Variable	Abbreviation	Percent contribution	Permutation importance
Clay content 30-60 cm	clay30_60	41.3	5.9
Driest trimester precipitation	bio17	17.3	17.5
Isothermality (Bio2/Bio7) (×100)	bio3	16.8	38.7
Elevation	elev	11.6	8.7
Seasonal temperature (standard deviation * 100)	bio4	5.0	17.5
Coldest month maximum temperature	bio6	3.3	2.9
Cation exchange capacity 0-5 cm (at ph 7)	cec0_5	2.6	3.3
Bulk density 5-15 cm (cg/cm3)	bulk5_15	2.1	5.7

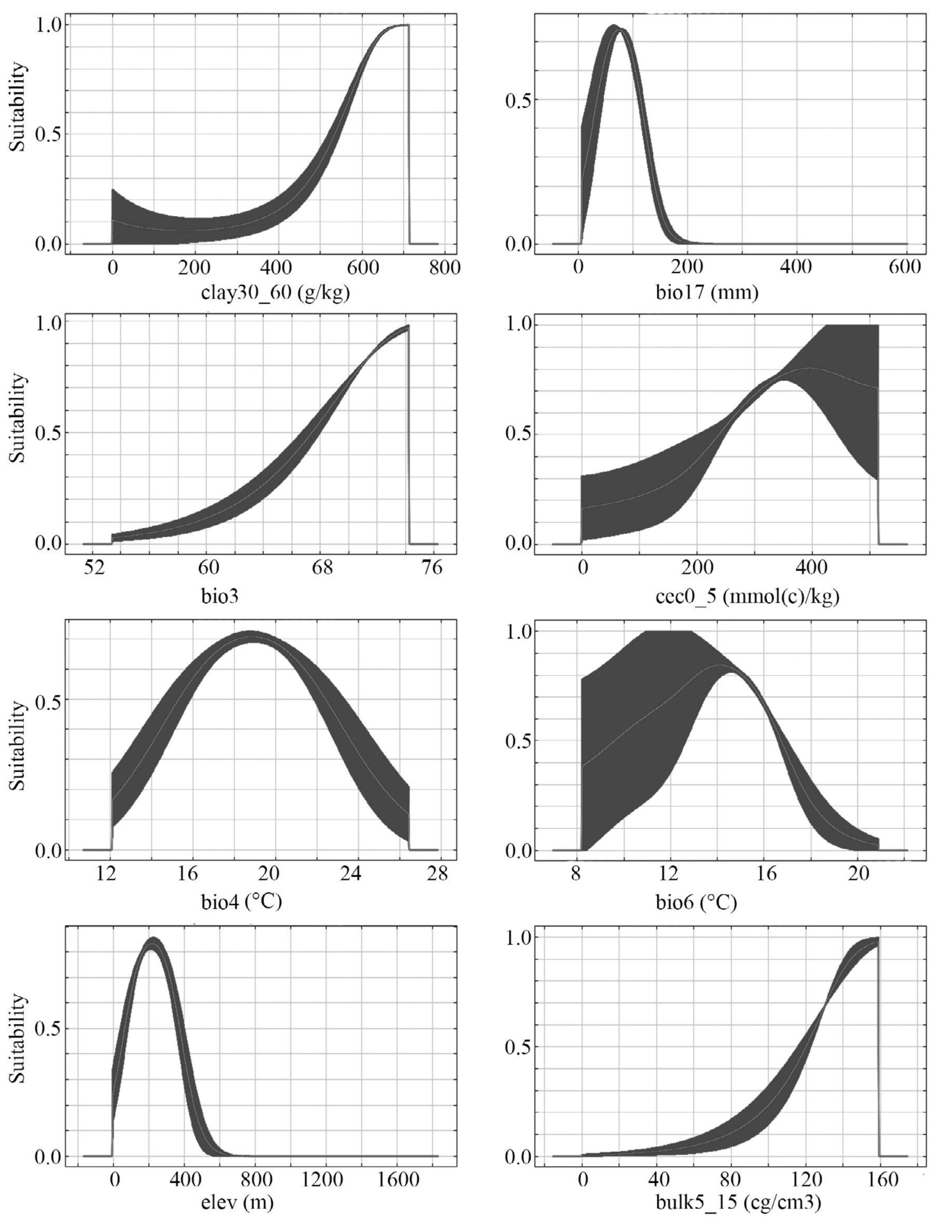

Figure 2. Response curves of the environmental variables included in the potential distribution models of *H. calakmulense*, obtained with the MaxEnt algorithm. The figure shows the behavior of environmental suitability with respect to the environmental variations of each climatic variable.

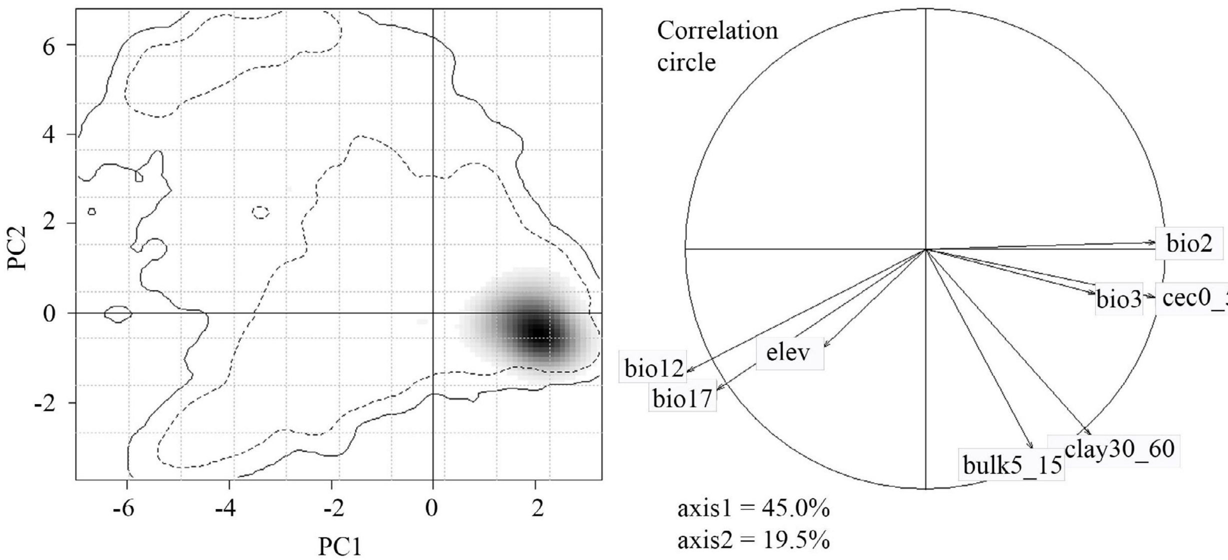

Figure. 3. Niche representation by density of occurrence in environmental space (left panel) of *H. calakmulense* and principal component analysis (right panel).

Discussion

In 2014, *H. calakmulense* was defined as a Mesoamerican species (Cruz Durán & Sousa, 2014). With the existing information coming only from herbarium specimens, these authors described that it occurs in the center and south of the Yucatan Peninsula (states of Campeche, Yucatan, and Quintana Roo), Guatemala and Belize (Cruz Durán & Sousa, 2014). This information from herbaria is highly valued because it provides a historical reference of the locations where this species is currently found (Plasencia-Vázquez *et al.*, 2017). In addition, these data are the historical reference to understand under which natural conditions the species has evolved over time, depending on the different changes that have occurred in the region due to anthropogenic activities. However, it should be considered that herbarium data only give us an approximation of the distribution of the species, as they are often not representative and collections are usually made in the most accessible areas, such as roadsides (Pérez & Duno, 2015).

The model obtained for this species is generally consistent with this description by Cruz Durán & Sousa (2014), although it shows that environmental conditions exist in other areas within the states of Veracruz and Oaxaca, but in a very low percentage, which can have several interpretations. The models indicate environmental suitability and depend on the variables used to obtain them (Drake & Richards, 2018), which does not mean that *H. calakmulense* inhabits these areas, either because of dispersal problems or because it has never done so historically. In addition, it should be noted that virtually nothing is known about its natural history and ecology, so information about new occurrences can still be obtained. In the future, efforts should be made to visit these areas where this species could potentially develop to confirm if it is present.

In the areas where *H. calakmulense* was found, vegetation was represented by lowland savanna forest, lowland subdeciduous flooded forest, medium subdeciduous forest, medium subdeciduous altered forest, and lowland subdeciduous forest (Cruz Durán & Sousa, 2014). Plasencia-Vázquez *et al.* (2017) also used information from herbarium specimens to characterize the ranges of *H. calakmulense* in the Yucatán Peninsula. These authors confirmed that most individuals of the species collected in this region were found in sites with high and medium subperennial rainforests, although a significant percentage were recorded in cultivated pastures. The pattern is generally consistent with what has been described previously, as the highest percentage of favorable habitat is found in areas currently occupied by secondary arboreal vegetation, followed by grassland, intermediate rainforest, and agricultural land. The Mexican Southeast is one of the regions of the country that has lost the most vegetation cover in recent years (Bonilla-Mohenoa & Aideb, 2020), so there are large areas of secondary vegetation and areas dedicated to agricultural or livestock activities. As explained above, the model predicts environmental suitability and many of the suitable areas were formerly occupied by forests that have been lost due to human activities and land use change.

Currently, it has been shown that *H. calakmulense* is maintained in sites where it was collected years ago, some of them in livestock matrices (Chablé-Vega *et al.*, 2019). *Haematoxylum calakmulense* has a more restricted distribution in the center and south of the Yucatan Peninsula and in the interior of Guatemala and Belize (Cruz Durán & Sousa, 2014; Plasencia-Vázquez *et al.*, 2017).

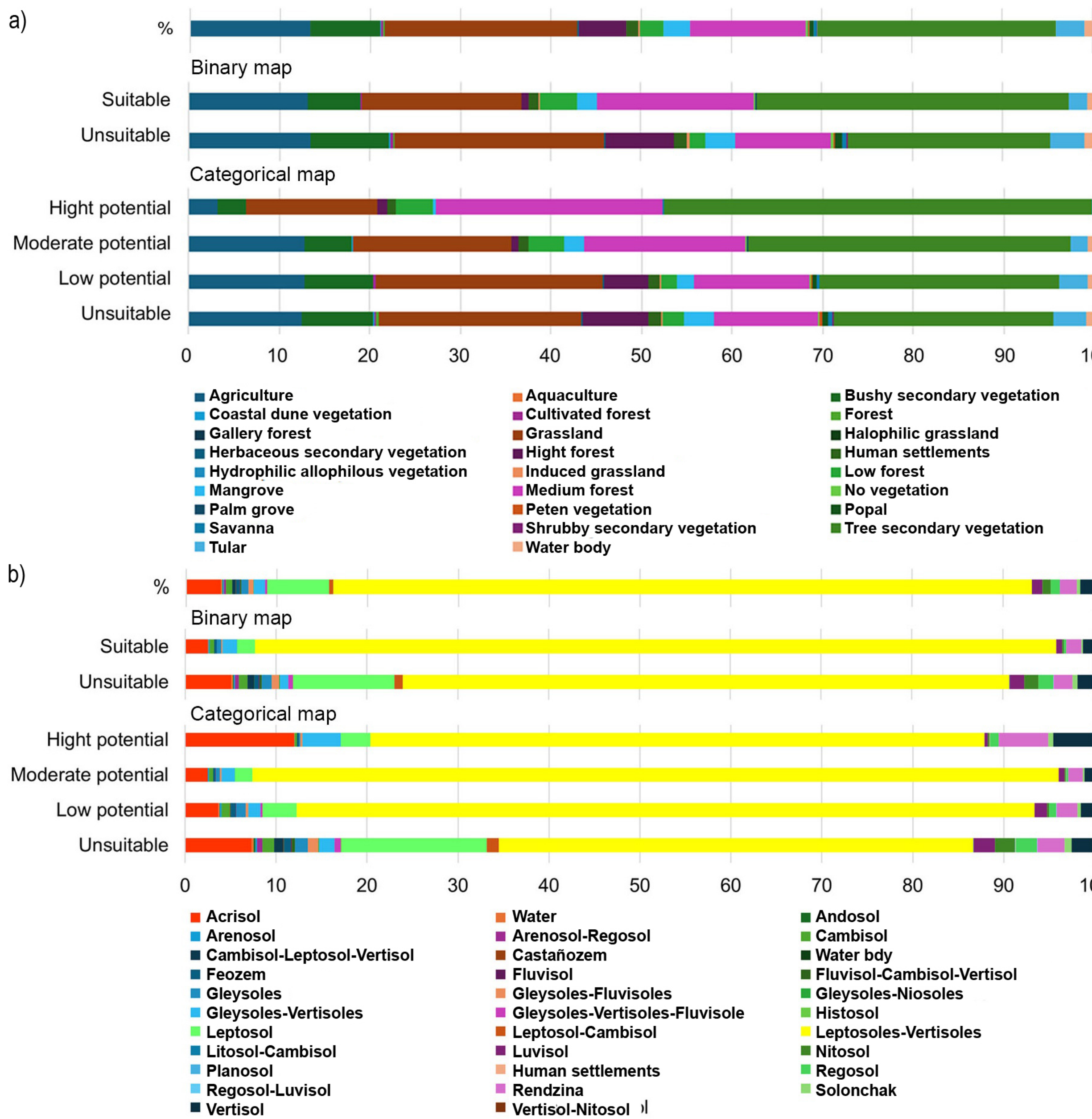

Figure 4. Representativeness of environmental suitability for *H. calakmulense* (%), in a) land use categories and vegetation types in Mexico (second section) and b) type of soil.

This species is found in the vegetation of savanna lowland rainforest, flooded semi-deciduous lowland rainforest, medium semi-deciduous rainforest, altered medium semi-deciduous rainforest, and low semi-deciduous rainforest, as well as in pastures and *acahuales*, but never grouped to form *tintales* (Cruz Durán & Sousa, 2014; Plasencia-Vázquez *et al.*, 2017; Chablé-Vega *et al.*, 2019). The "*acahuales*" are part of the ecological succession of a traditional agricultural system in the region and are formed by the establishment of woody species after the crops have been abandoned (Ochoa-Gaona *et al.*, 2007). The "*tintales*" are congregations of individuals of the same species of *Haematoxylum*, particularly *H. campechianum* (Cruz Durán & Sousa, 2014). The Calakmul region is where the largest number of individuals of the species has been reported historically (Cruz Durán & Sousa, 2014; Plasencia-Vázquez *et al.*, 2017). In the Calakmul Biosphere Reserve and the Zoh-Laguna region of Campeche, both species coexist in sympatry (Cruz Durán & Sousa, 2014; Plasencia-Vázquez *et al.*, 2017; Chablé-Vega *et al.*, 2019).

In contrast, *H. campechianum* has a wider distribution than *H. calakmulense* (Plasencia-Vázquez *et al.*, 2017) and occurs naturally in Guatemala, Belize, and the Yucatán Peninsula, Mexico (Niembro, 2002). *Haematoxylum campechianum* has been recorded mainly in association with coastal areas, although it is also common in inland areas (Cruz Durán & Sousa, 2014; Plasencia-Vázquez *et al.*, 2017; Chablé-Vega *et al.*, 2019). In general, it is a taxon of great ecological plasticity that manages to adapt to different environments and grows associated with numerous plant formations in the Yucatan Peninsula (Pennington & Sarukhán, 1998; Niembro, 2002; Plasencia-Vázquez *et al.*, 2017; Chablé-Vega *et al.*, 2019). It has been found as isolated individuals in different vegetation formations, such as lowland rainforests, medium-sized rainforests, mangroves, *acahuales*, or forming *tintales* (Pennington & Sarukhán, 1998; Plasencia-Vázquez *et al.*, 2017; Chablé-Vega *et al.*, 2019). In Campeche, Mexico, *H. campechianum* is well represented in Palizada, in the southwestern part of the Yucatan Peninsula, and in the Los Petenes Biosphere Reserve (Plasencia-Vázquez *et al.*, 2017).

The areas where *H. calakmulense* has been described are characterized by high humidity in clayey, moist, black soils at elevations between 0 and 300 m (Cruz Durán & Sousa, 2014). The highest percentage of *H. calakmulense* records in the Yucatán Peninsula were located in areas where a combination of leptosol-vertisol type soils predominated, and more frequently between 200 and 300 m elevation (Plasencia-Vázquez *et al.*, 2017). The model also fits this description, since the most suitable areas for the species are located at 300 m altitude (in a range of 0-400 m), mostly on leptosol-vertisol soils. This type of soil tends to have a high clay content and low permeability when wet, which is why it tends to retain water during the rainy season (Reyes, 2014). It is important to highlight that the variable that contributed most to the model was the clay content at 30-60 cm, which confirms the great importance of the soil type for this species.

Regarding the climate of the sites where *H. calakmulense* was collected, Plasencia-Vázquez *et al.* (2017) indicate that the predominant climate was warm subhumid [Aw1(x')]. This type of climate is characterized by the presence of rain in the summer and a high percentage of rain in the winter season, with little thermal oscillation and higher temperatures before the summer solstice (Orellana Lanza *et al.*, 2010). When analyzing the climatic variables that contributed most to the model (precipitation during the driest quarter and isothermality), they reaffirmed that *H. calakmulense* develops best in areas where there is not much variability in temperature throughout the year and precipitation between 0-200 mm during the driest quarter.

Both the model obtained and that described in the literature (Plasencia-Vázquez *et al.*, 2017) indicate that *H. calakmulense* populations are found in low percentages in areas under a conservation program in Mexico. This is a worrying situation for a species that is poorly known, and the scarce information on the status of its populations indicates that it is not very abundant due to its low densities. The survival of species with a more restricted distribution is often more critical in the face of anthropogenic disturbances (such as deforestation, habitat loss, and fragmentation due to land-use change) or natural disasters such as hurricanes (Hernández-Oria *et al.*, 2007; IUCN, 2008). Therefore, the extent of distribution is one of the criteria for classifying species into different threat categories (Semarnat, 2010; IUCN, 2012). On the other hand, *H. calakmulense* may be more of a habitat specialist. The dispersal mechanisms of the species are not known, nor are the interaction networks it is part of, which would be a useful aspect to assess in the future. However, it is possible that *H. calakmulense* is important in its area, at least for meliponiculture, similar to *H. campechianum*, which is listed as a melliferous species (Cetzal-Ix *et al.*, 2019). The inflorescences and the petals of *H. calakmulense* are smaller (Cruz Durán & Sousa, 2014), which could mean that its pollinators are different from those of *H. campehianum* (possibly smaller), or perhaps that it receives fewer visits from pollinators. However, it is necessary to continue studying this important species, especially at the ecological level.

Supplementary material

The following online material is available for this article:
Table S1. Set of initial variables for modelling the potential distribution of *H. calakmulense* in south-eastern Mexico and northern Guatemala and Belize.
Table S2. Representativeness of environmental suitability for *H. calakmulense* in protected natural areas with different administrations and management categories.
Table S3. Representativeness of environmental suitability for *H. calakmulense* in areas with different vegetation types and land uses.
Table S4. Representativeness of environmental suitability for *H. calakmulense* in areas with different soil types.
Figure S1. Summary of variables included in the selected models for both available environments (background) and *H. calakmulense* occurrence points.

Acknowledgments

To the editors and anonymous reviewers of the manuscript for their recommendations to improve the quality of the presentation of the study. We thank CONAHCYT (Consejo Nacional de Humanidades, Ciencia y Tecnologías de México) for the postdoctoral fellowship granted to Anay Serrano-Rodríguez (CVU 594692) in CIHS (Centro de Investigaciones

Históricas y Sociales, Universidad Autónoma de Campeche, México).

Author Contributions

Conceptualization: A.H.P.V. and A.S.-R.; Data curation: A.H.P.V. and A.S.-R.; formal analysis: A.S.-R. and A.H.P.V.; funding acquisition: A.S.-R. and A.H.P.V.; investigation: A.S.-R., A.H.P.V., A.S.R. and Y.F.-S.; methodology: A.S.-R., A.H.P.V., A.S.R. and Y.F.-S.; writing–original draft: A.H.P.V. and A.S.-R.; writing–review & editing: A.S.-R., A.H.P.V., A.S.R. and Y.F.-S.

Conflicts of Interest

The authors declare no conflict of interest.

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