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Research Article

Potential distribution of the howler monkey (*Alouatta palliata*) in cocoa agrosystems based on a niche model

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Abstract

Anthropogenic activities have caused habitat fragmentation and loss, which are the main threats to primates. Because of this, ecological niche models have become a widely used tool to determine the potential habitat of species. These models rarely include biotic factors, although vegetation variables such as height and phenology, data derived from remote sensing, were integrated into this research. We developed a model to obtain the potential distribution of the primate *A. palliata*. Therefore, records of the presence of monkeys in the field were collected, and later data were obtained on the spectral index of vegetation and the height of the canopy, derived from remote sensing, bioclimatic variables were also used. Subsequently, these variables were analyzed using the Variance Inflation Factor to discriminate those with the highest correlation. Finally, we use a Maximum Entropy algorithm included in the Maxent software, together with the presence registration data, vegetation index, height, and bioclimatic data. The predicted distribution of *A. palliata* was strongly associated with canopy height, vegetation index (RVI), and warmest quarter precipitation (Bio18). The areas with the highest probability of the presence of *A. palliata* are strongly associated with cocoa agrosystems and certain spaces of natural vegetation such as mangroves. With the integration of the variables derived from remote sensing, the potential distribution model obtained an excellent evaluation, to predict cocoa agrosystems as available habitats of the howler monkey *A. palliata*, thus identifying areas with a high probability of the presence of this species of primate, and thus offer a tool to decision-makers, to plan future studies and then establish criteria for the creation of areas for the conservation of primates in Mexico.

Keywords: Canopy height, Maxent, Remote sensing, Vegetation index

Introduction

The genus *Alouatta* is composed of at least 11 species, it is the genus with the greatest distribution in the American continent, from Mexico to Brazil and Argentina (Holzmann *et al*., 2015). One of the characteristics that define this genus is that they live in arboreal environments with very high canopies, and their ability to include a large number of young leaves (sprouts) and flowers in their diet, in addition to adapting to small fragments of habitats (Chaves & Bicca-Marques, 2017). Of the two species of the genus *Alouatta* that inhabit Mexico, the howler monkey (*A. palliata*) has the largest distribution range in the country and the American continent (Rylands *et al*., 2006).

In Mexico, this species has a potential distribution restricted to the states of Tabasco, Campeche, Quintana Roo, Yucatán, Veracruz, Oaxaca, and Chiapas (Cuarón *et al*., 2008). However, land use change and deforestation have significantly reduced the original distribution of these primates (Estrada, 2015). Due to these changes in their original habitats, this species is adapting to exploit small fragments of habitats such as coffee and cocoa agrosystems (Arroyo-Rodríguez & Días, 2010), such is the case of Tabasco. Therefore, agrosystems, such as cocoa, have the potential to be habitats for wildlife and can be a very good alternative for native fauna (Alkorta *et al*., 2003).

In Tabasco, Mexico, particularly in the municipality of Comalcalco, the howler monkey is known to have occupied anthropogenic environments such as cocoa agrosystems (Muñoz *et al*., 2006; Estrada *et al*., 2006), systems that replaced the original vegetation (Sánchez-Munguía, 2005), and with it, the natural habitat of the monkeys. This species uses the trees that provide shade to cocoa plantations, mostly large native trees (Muñoz *et al*., 2006). There are investigations where the potential of these agrosystems as a habitat for monkeys has been studied, in terms of the best environmental and vegetation conditions, for their distribution in the area they occupy in agrosystems in the municipality of Comalcalco.

In terms of anthropogenic impacts, habitat fragmentation and loss are the main threats to primates (Pyritz *et al*., 2010). Therefore, understanding the type of vegetation and the use of the tree stratum in primates is important to describe their pattern of habitat use (Li, 2007). The distribution of howler monkeys is strongly influenced by climatic and environmental factors, such as temperature, phenology, and vegetation height. Even more so, in cocoa agrosystems, since being an anthropogenic environment it has particular characteristics in its vegetation, mainly in the trees used as shade in the plantations, and in the case of howler monkeys, they have needed to use as available habitat (Muñoz *et al*., 2006).

Ecological niche models have been widely used to determine the potential habitat of species. These models are based on the habitat characteristics (environmental variables) associated with the presence records of the target species, to define areas with similar or identical environmental conditions where the species may be present, and generate a map that represents the potential distribution of the species. The species (Calixto-Pérez *et al*., 2018). Most ecological niche models only consider abiotic factors, such as climate and topography. Currently, work is being done with vegetation index, derived from remote sensing, to integrate them into an ecological niche model. MAXENT is an ecological niche modeling software that can predict the geographic distribution of species when only occurrence data are available for analysis (Phillips & Dudík, 2008).

Therefore, in the present study, our first objective was to delimit the potential distribution area of *A. palliata* in Comalcalco, Tabasco, Mexico to describe the environmental conditions that favor high suitability for the species in cacao agrosystems in the region.

Materials and methods

Study area

The municipality of Comalcalco is located at North latitude 18°16'57" and West longitude 93°13'30. It borders to the north with the municipality of Paraíso, to the south with the municipalities of Cunduacán and Jalpa de Méndez, to the east with Jalpa de Méndez and to the west with Cárdenas (Fig. 1). The average annual temperature of 27.1°C and an average annual rainfall of 1,926.1 mm (INEGI, 2017). The original vegetation was composed of medium evergreen forest (Palma-López *et al*., 2007); Currently, cattle pastures and agricultural vegetation predominate (Ramos-Reyes *et al*., 2016).

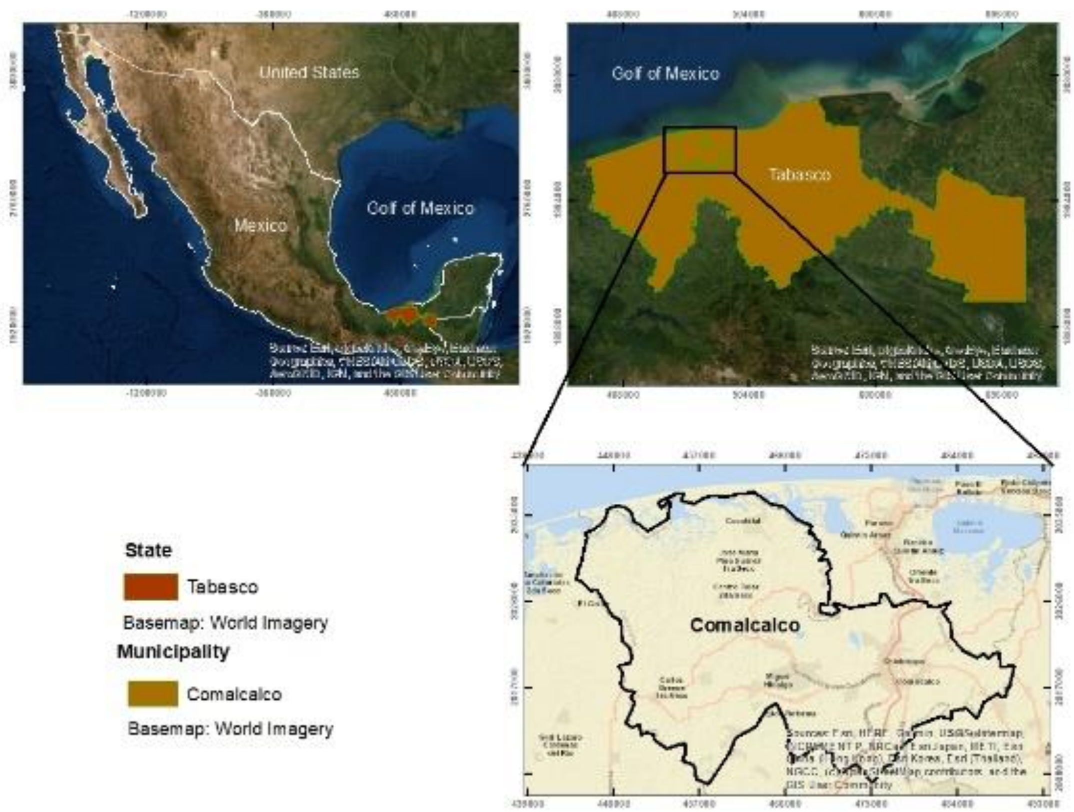

Figure 1. Map of the study área

Collection and processing of presence data

The records were obtained through field data through direct observation, surveys, and interviews. The records obtained in the field were refined to avoid spatial correlation of the data and reduce sampling bias; since they are not eliminated, the model would tend to be underestimated (Luoto *et al*., 2005, Peterson *et al*., 2011; Halvorsen *et al*., 2016). For this, the records were systematically selected in a subsample distributed in geographic space (Merckx *et al*., 2011; Fourcade *et al*., 2014). They were first projected as geo-referenced points in ArcGis 9.3, then a grid with 100 x 100 m quadrants was built throughout the study area using Hawth's Analysis tool. In each grid quadrant, a record was selected, eliminating those with more than one point per quadrant (Boria *et al*., 2014; Fourcade *et al*., 2014).

Pre-processing of satellite images

Sentinel satellite images were used, which were obtained from the portal: https://scihub.copernicus.eu/dhus/#/home. To which the geometric and radiometric correction was applied through the ArcGIS v 9.2 software and the atmospheric correction through the QGIS v 2.18.10 software.

Vegetation Spectral Index

Nine vegetation indexes were calculated: Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI), Soil-Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI), Second Modified Soil Adjusted Vegetation Index (MSAVI2), Transformed Vegetation Index (TVI), Perpendicular Vegetation Index (PVI), Modified Soil Adjusted Vegetation Index (MSAVI1) and Ashburn Vegetation Index (AVI). The index was selected based on literature reports that associate them with the characterization of the vegetation.

Canopy height of shade trees

Height data were obtained by interpolating the Canopy Height Model (CHM) throughout the study area, using different extensions of the ArcGis v 9.2 software.

Bio-climatic variables

17 bioclimatic variables were analyzed, related to temperature and precipitation data in raster format (Ordoñez-Sierra, 2014) (Table 1).

Table 1. Description of the bioclimatic variables

Variable	Description of the variable
Bio1	Average annual temperature (°C)
Bio4	Temperature seasonality (standard deviation * 100)
Bio5	Maximum temperature of the warmest month (°C)
Bio6	Minimum temperature of the coldest month (°C)
Bio7	Annual temperature range (°C)(Bio5Bio6)
Bio8	Average temperature of the rainiest quarter (°C)
Bio9	Average temperature of the driest quarter (°C)
Bio10	Average temperature of the warmest quarter (°C)
Bio11	Average temperature of the coldest quarter (°C)

Bio12	Annual rainfall (mm)
Bio13	Precipitation of the wettest month (mm)
Bio14	Precipitation of the driest month (mm)
Bio15	Precipitation seasonality (coefficient of variation)
Bio16	Precipitation of the wettest quarter (mm)
Bio17	Precipitation of the driest quarter (mm)
Bio18	Precipitation of the warmest quarter (mm)
Bio19	Precipitation of the coldest quarter (mm)

Variance Inflation Factor (VIF)

The VIF was calculated of bioclimatic variables and spectral indices. To analyze the multicollinearity between variables. These analysis results can help to avoid the over-fitting phenomenon of the model.

Potential distribution modeling

To carry out the potential distribution model, the MAXENT program was used based on an ecological niche for the howler monkey (*A. palliata*) in cocoa agrosystems. MAXENT is based on a maximum entropy algorithm, spreading probabilities as uniformly as possible, subject to the constraints of observed values (ie known occurrences).

Model evaluation

To evaluate the performance of the final model, the ROC analysis within MAXENT will be used, and thus, obtain the values of the area under the AUC curve (Phillips *et al*., 2006; Phillips & Dudik, 2008). To evaluate the performance of the model, what was established by Sweets (1988) was considered: AUC 1-0.9 = excellent; 0.9-0.8 = good; 0.8-0.7 = acceptable; 0.7-0.6 = poor; 0.6-0.5 = not suitable. This analysis provides sensitivity and specificity values, the average percentage contribution of each variable to the model, and the analysis of the contribution of each variable to the model (Phillips *et al*., 2006). The MAXENT analysis was run using 75% of the records as training data to build the model and the remaining 25% to test the model. This approach is conservative in estimating ecological niches since it eliminates extreme values that can result from misidentifications or georeferencing.

Results

Presence data collection

A total of 65 records of the presence of howler monkeys (*A. palliata*) in cocoa agrosystems were obtained.

Multicollinearity between variables

The bioclimatic variables and vegetation index least collinearity were: RVI, Bio18, and Height (Fig. 2). Therefore, for the potential distribution model, the variable Precipitation of the Warmest Quarter (Bio18), Ratio Vegetation Index (RVI) and Vegetation Height (Altura) was used, since they were the variables that contributed the most in a model applied in cocoa agrosystems, to predict the presence of the howler monkey (*A. palliata*).

variable	altura	bio1	bio4	bio5	bio6	bio7	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19	avi	evi	msavi1	msavi2	ndvi	pvi	rvi	savi	tvi
altura		0.756	1.075	0.749	0.817	1.113	0.845	0.779	0.869	0.849	0.911	1.048	0.845	0.917	0.904	0.876	1.512	1.550	1.580	1.575	1.605	1.513	0.760	1.567	1.551
bio1			0.865	4.744	2.018	0.822	2.747	4.028	1.000	1.006	0.950	0.999	1.022	0.984	0.937	1.154	0.768	0.769	0.765	0.765	0.787	0.767	1.324	0.766	0.792
bio4				1.496	0.533	**51.89**	2.495	0.575	0.774	**22.13**	1.209	0.771	**26.34**	1.167	0.960	0.579	0.970	0.953	1.204	0.967	0.933	0.971	1.091	0.961	0.929
bio5					1.157	1.285	4.448	1.590	1.263	1.091	1.578	0.724	1.183	1.572	1.338	0.851	0.822	0.813	0.932	0.810	0.795	0.821	1.288	0.809	0.803
bio6						0.517	0.764	**18.15**	2.013	**19.59**	1.118	1.018	2.707	1.162	1.386	2.598	0.983	0.995	7.362	0.976	0.994	0.981	0.973	0.982	1.007
bio7							2.380	0.556	0.704	0.540	1.027	0.867	0.639	0.992	0.844	0.600	0.944	0.929	9.844	0.944	0.921	0.944	1.119	0.938	0.914
bio10								0.988	0.698	6.610	0.871	1.048	0.678	0.858	0.748	0.777	0.749	0.743	8.959	0.749	0.761	0.749	1.454	0.745	0.760
bio11									1.575	**28.43**	1.038	1.030	1.879	1.087	1.202	2.114	0.887	0.895	9.066	0.882	0.904	0.886	1.078	0.886	0.915
bio12										1.533	7.748	0.580	0.688	8.223	0.601	1.101	1.371	1.355	1.312	1.319	1.177	1.369	0.838	1.332	1.203
bio13											0.979	1.384	2.303	0.927	0.886	**10.90**	0.971	0.978	0.965	0.966	0.962	0.970	1.015	0.966	0.971
bio14												0.520	3.832	**84.39**	2.521	0.778	1.396	1.362	1.330	1.337	1.154	1.395	0.855	1.346	1.174
bio15													0.655	0.513	0.610	1.775	0.778	0.789	0.798	0.796	0.871	0.779	1.218	0.792	0.861
bio16														3.710	0.722	1.464	1.279	1.271	1.233	1.238	1.133	1.277	0.861	1.248	1.157
bio17															1.848	0.755	1.414	1.381	1.348	1.355	1.177	1.413	0.843	1.366	1.198
bio18																0.833	1.427	1.401	1.362	1.370	0.968	1.425	0.828	1.383	1.228
bio19																	0.908	0.918	0.910	0.910	0.809	7.240	1.064	**12.06**	**87.72**
avi																		**102.49**	**105.708**	**79.217**	0.974	**105.31**	0.553	**107.31**	6.546
evi																			**101.332**	**100.577**	0.946	**86.84**	0.543	**101.57**	8.452
msavi1																				**108.401**	0.750	**100.18**	0.548	**80.63**	7.626
msavi2																					0.881	**80.78**	0.547	**100.91**	7.732
ndvi																						0.907	0.506	0.91	0.936
pvi																							0.555	**101.39**	6.407
rvi																								0.536	0.502
savi																									**10.236**
tvi																									

Figure 2. Table showing values of Variance Inflation Factor (VIF) of bioclimatic variables and vegetation index. Values of more than 10 are indicated in red and bold.

Potential distribution modeling

Areas with a potential distribution of *A. palliata* are shown in red, gradually decreasing to low probability in blue (Fig. 3).

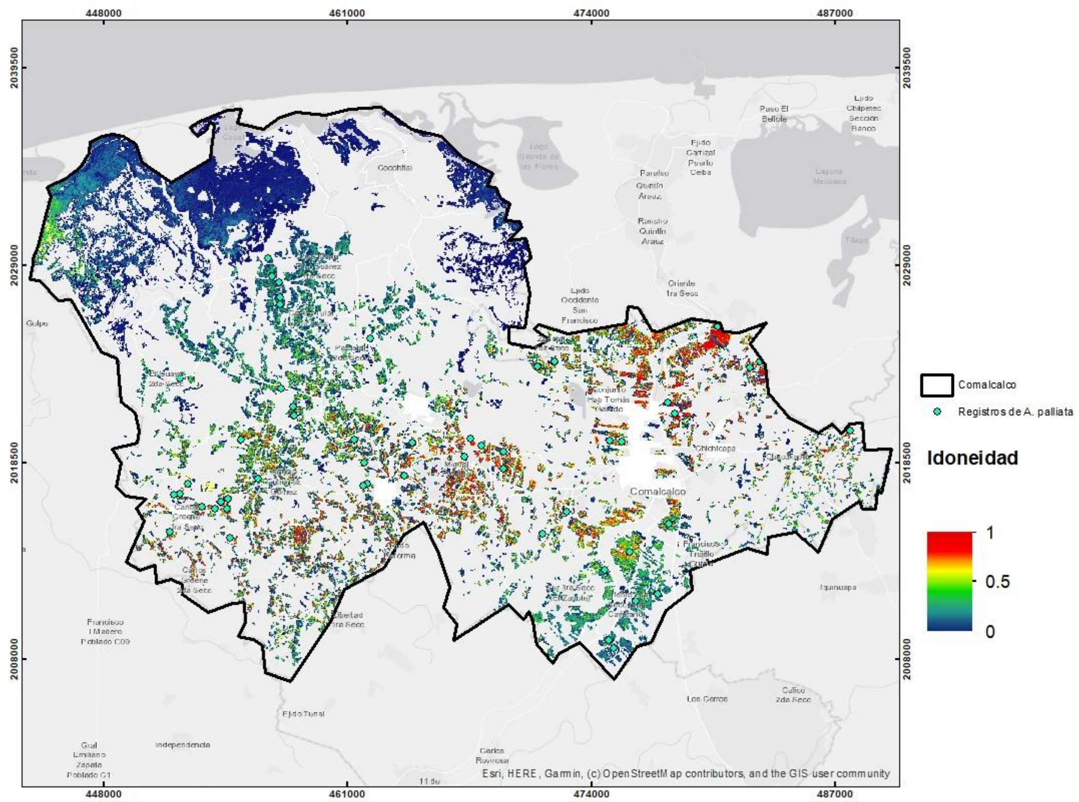

Figure 3. Potential distribution of *A. palliata* in cocoa agrosystems

Model evaluation

The MAXENT model for *A. palliata* achieved an excellent score with mean ROC curve values having an AUC of 0.935 for training data and 0.940 for test data, and a minimal presence of training of 0.095 (Fig. 4).

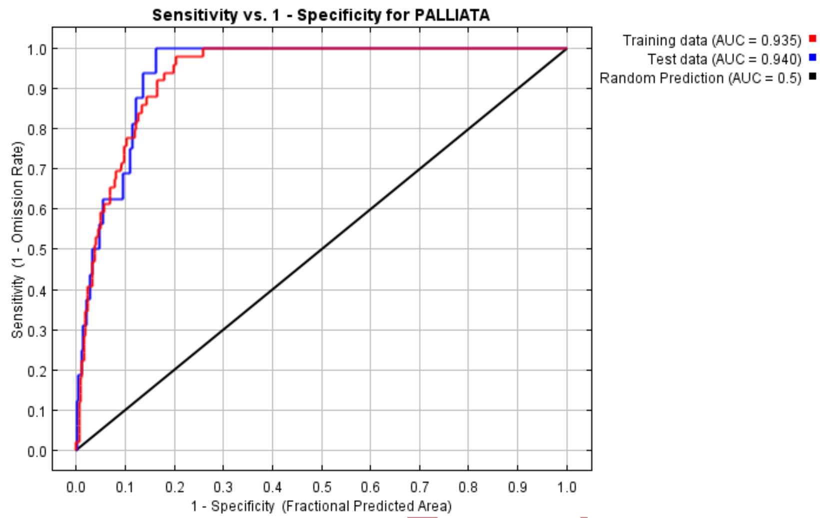

Figure 4. ROC curve derived from the potential distribution model of *A. palliata*

In the Jackknife test, height was the variable with the highest gain when it was run in isolation, and since it was not included in the model, the gain decreased, so it seems to have the greatest amount of useful information for the model than the other variables (Fig. 5).

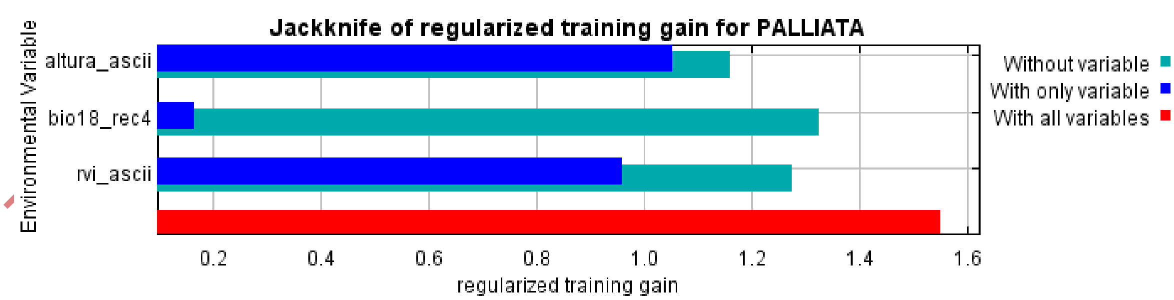

Figure 5. Jackknife test of the distribution model for *A. palliata*

Discussion

The main difference between niche and distribution models is that distribution models are a cartographic representation of the suitability of space for the presence of a species based on the variables used to generate said representation (Maciel-Mata *et al*., 2015; Mateo *et al*., 2011). While the ecological niche model is the combination of ecological conditions in which a species can survive and reproduce (Maciel-Mata *et al*., 2015; Pablos *et al*., 2010). The concept of niche is central to ecology. It is widely used to describe both the range of conditions necessary for the persistence of the species and its ecological role in the ecosystem (Polechová & Storch, 2008), and variables such as structure and phenology can be integrated through ecological niche models of vegetation.

In this study, the potential distribution model was developed with the MaxEnt software, to describe the probability of the distribution of *A. palliata* in cocoa agrosystems, using vegetation characteristics as in other niche models. For example, to analyze the vertical structure of certain reptile communities, data derived from LiDAR (Sillero & Goncalves-Seco, 2014) and spectral index such as NDVI were used to estimate the distribution of Bithynia siamensis goniomphalos (Pratumchart *et al*., 2019), these models used data derived from remote sensing. However, previous models to predict available habitats for howler monkeys (*A. palliata*) have only used bioclimatic data, (Calixto-Pérez *et al*., 2018), and no vegetation features are associated with the presence of these primates. In this sense, the data derived from remote sensing, particularly LiDAR, are opening up new knowledge in the ecology of species (Sillero *et al*., 2009; Sillero *et al*., 2012).

This potential distribution model was generated using data derived from remote sensing, so to determine the importance of the variables, the Jackknife test was applied, through which it was determined that the main variables related to the potential distribution of *A. palliata* in cocoa agrosystems, in order of importance were: the height of the vegetation obtained through LiDAR technology, the spectral vegetation index RVI and the bioclimatic variable bio18. However, there are previous studies of niche models for primates, although not in cocoa agrosystems and using only bioclimatic variables, where the variables with the highest gain were: bio5 for *Alouatta pigra*, bio19 for *A. palliata* and bio9 for Ateles geoffroyi. Therefore, the variables that both models have detected as important are obtained using new habitat mapping tools, such as LiDAR; this provides an improvement in the reliability of habitat mapping in anthropogenic landscapes as a case study (Valle *et al*., 2011).

To evaluate the predictive accuracy of the model, the ROC curve was used, in which the AUC values of training and testing of the model were excellent at 0.93 and 0.94, respectively. All these results can be used to define favorable areas for monkeys and implement conservation programs (Barbosa *et al*., 2003).

The Maxent model indicated cocoa agrosystems and mangroves for *A. palliata* as available habitats. In other countries, there are mangrove-dwelling monkeys, such as the proboscis monkey (Nasalis larvatus), an endangered primate endemic to the island of Borneo in Indonesia, which inhabits mangroves, peatlands, and riparian forests (Bernard *et al*., 2011). Capuchin monkeys (Sapajus flavius and Cebus capucinus), occupy the mangroves in Malaysia, for rest, shelter, and food (Medeiros *et al*., 2019), which demonstrates the adaptability of these animals. These species, like many, are affected by the loss of their habitat, due to both human activities and natural disasters (Harding, 2015). The importance of mangroves in the study area is due to the trend in changing land use, of cocoa agrosystems. Therefore, the behavioral adaptability of these monkeys and their ability to exploit a variety of food sources have played a key role in their survival, since despite being considered arboreal, they also use the ground to search for vegetables, invertebrates, and small vertebrates as food (Medeiros *et al*., 2019).

Niche models can describe demographic, birth, and death rates of individuals, and this translate into population dynamics, for species threatened by local extinction (Schurr *et al*., 2012), this type of model can measure the degree of spatial connectivity between populations based on environmental suitability (Soley-Guardia *et al*., 2016). Some studies describe habitat connectivity as having important effects on metapopulation dynamics since it determines regional persistence and the genetic diversity of species in fragmented landscapes (San Vicente & Valencia, 2012; Schooley & Branch, 2011). ; Mühlner *et al*., 2010), as could be the case of howler monkeys in cocoa agrosystems. However, few studies in Mexico have addressed the conservation of the primate population from a metapopulation perspective, such as the one carried out by Escobedo-Morales & Mandujano (2007) for *A. palliata*, in Los Tuxtlas, Mexico, where those populations Occupying patch-like habitats, connected by establishing corridors of vegetation, significantly enhance metapopulation persistence.

Conclusion

Spatial modeling based on data derived from remote sensing, to obtain certain vegetation characteristics such as height and phenology, is considered a powerful tool, mainly through the use of new technologies such as LiDAR for mapping the structure of the habitat of the species. With the integration of these types of variables, in the present study, the potential distribution was estimated, and an excellent evaluation was obtained, to predict the available habitats of the howler monkey *A. palliata* in cocoa agrosystems, since the integration of the three variables height, vegetation index and bioclimatic, turned out to be an acceptable approach. Although the study was carried out in cocoa agrosystems, information on suitability was also obtained on certain spaces of natural vegetation such as mangroves, these spaces could be of great ecological importance for howler monkeys due to their behavioral adaptability since in other countries certain species of tree monkeys have used them as a refuge. Therefore, this type of potential distribution model is an important tool for decision-makers in the evaluation of certain valuable spaces for the conservation of species threatened by local extinction.

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