USE OF ECOLOGICAL NICHE MODELS OF PLANT SPECIES TO OPTIMIZE PLACEMENT OF APIARIES

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Abstract

Apiaries must be located in areas with abundant flora as they are the nutritional base for *Apis mellifera*. Asteraceae is one of the most diverse plant families in Mexico and several of its species are of interest for beekeepers. The objective of this study was to determine the best sites for the placement of apiaries with the use of ecological niche models (ENM) of some Asteraceae species important for bees in two basins of the state of Michoacán, Mexico. ENM for thirty species were obtained through records of their presence, twenty abiotic variables and one biotic variable, and a map of species richness was made to determine which sites would be environmentally appropriate for apiaries. The models were statistically evaluated using the AUC_Maxent, partial_ROC and the binomial tests and were verified in the field. The first two tests' models had values of 0.70 to 1 and the binomial test's models had values of 1. The map showed six suitable areas with the greatest richness of species. The corroboration in the field proved ENM effective by finding twenty-two of the thirty modeled species inside the predicted areas. Our results support that ENM are a good strategy to predict the ideal habitat for species important for beekeeping, and thus determine the best places to establish apiaries in the region.

Keywords: *Apis mellifera*, assemblage of species, Maxent, Mexico, Nectariferous-polliniferous flora

INTRODUCTION

Beekeeping is the agricultural activity of breeding honey bees (*Apis mellifera* L.) and installing apiaries to obtain honey and other derivatives (Bradbear, 2005; Barrios et al., 2012). In addition to honey production, bees provide important ecosystem services, especially in agriculture and pollination (FAO, 2014, Verde, 2014). According to the Mexican Agricultural and Fisheries Information Service (SIAP, 2015), approximately 1.5 million tons of honey are produced per year worldwide. China is the largest producer, exporting around 400 tons of honey per year, while Mexico is located

between the seventh and tenth place exporting around fifty tons of honey per year (FAO, 2017; Jegede, 2019). Knowledge of regional bee flora is important worldwide for beekeeping, and for good honey production strategies apiary management should be based on the availability of plant species that bees feed on (FAO, 2014; Verde, 2014; SAGARPA, 2011, 2011a, 2015, 2015a).

Mexico has approximately 22,126 flowering plant species (Villaseñor, 2016), ranking fourth in the world. According to palynological studies and bee floras of certain regions of the country, approximately 2,000 species are commonly visited by *A. mellifera* (de la Mora-González,

1988; Santana-Michel et al., 1998; Villegas-Durán et al., 1999, 2000, 2003; Bello-González, 2007; Piedras-Gutiérrez & Quiroz-García, 2007; Quiroz-García & Arreguín-Sánchez, 2008; Porter-Bolla et al., 2009; Villanueva-Gutierrez et al., 2009; Cordova-Cordova, 2009; Montoy-Koh, 2010; Ramírez-Arriaga et al., 2011; Acosta-Castellanos et al., 2011; Galarza-Mendoza et al., 2012; Ramírez-Arriaga et al., 2016; González-Sandoval et al., 2016). The state of Michoacán in western Mexico records about 6,000 species of flowering plants (Villaseñor, 2016) and at least 237 of them are considered important for beekeeping (Villegas-Durán et al., 1999; Bello-González, 2007). Although Michoacán contains abundant and diverse flora, its honey production is low compared to other states. The state occupies tenth place with almost 2,000 tons of honey per year, whereas Jalisco, its neighboring state, places third with 7,000 tons. Although both states contain similar floristic richness, there is a large difference in their honey production possibly due to inadequate placement of apiaries. Manuals on the improvement of honey production mention that apiaries should be placed near bee flora and the difficulty beekeepers have in finding the right flora. Therefore, new strategies or tools that aid in finding new apiary sites with an abundant bee flora would help to increase honey production in Michoacán as well as other regions.

Ecological niche models (ENM) can be a useful tool to address the problem of apiary location. ENM considers the combination of biotic and abiotic ecological conditions that a species can tolerate in a multidimensional space (Soberón, 2007, 2010; Peterson et al., 2011). Maximum entropy used by Maxent software is one of the best-performing mathematical algorithms used to generate ENM (Elith et al., 2006; Elith & Leathwick 2009; Phillips et al., 2006; Navarro-Cerrillo et al., 2011). Theoretically, ENM could help to locate the ideal conditions for plant species important for beekeeping and therefore improve the location of apiaries. ENM have been used for estimating floristic richness patterns (Villaseñor et al., 2013; Alvarado-Cárdenas et al., 2017), designing sampling methods for

rare or little-known species (Gil & Lobo, 2012), evaluating the impact of land use changes on threatened species and proposed conservation sites (Sánchez-Cordero et al., 2005; Peterson et al., 2006; Yáñez-Arenas et al., 2012), predicting species' potential future distribution under climate change scenarios (Lane & Jarvis, 2007; Feria-Arroyo et al., 2013; Cruz-Cárdenas et al., 2016; Estrada et al., 2016) and delimiting the potential distribution of invasive species (Palma-Ordaz & Delgadillo-Rodríguez, 2014). In relation to beekeeping, ENM have been used to estimate the distribution of bees in growing areas (Polce et al., 2013). The question addressed in this work is whether ENM can help determine suitable sites for the location of apiaries based on the plant species that *A. mellifera* feeds on. We considered the Asteraceae species to be one of the plant families visited most frequently by *Apis mellifera*. In Mexico at least 147 Asteraceae species have reported important for beekeeping (Piedras-Gutiérrez & Quiroz-García, 2007; Quiroz-García & Arreguín-Sánchez, 2008; Castellanos-Potenciano et al., 2012; Nates-Parra et al., 2013).

The assumption that underlies this research is that because Asteraceae species are among the most visited by *A. mellifera*, we can determine sites of species richness by modeling the ecological niches of Asteraceae species important for beekeeping and thereby pinpointing locations environmentally suitable for the establishment of apiaries. In order to evaluate our assumption, we selected the Asteraceae species most important for beekeeping in the study area, generated abiotic and biotic variables, elaborated ENM for the selected species, identified the contribution of the abiotic and biotic variables in the ENM species of the family, validated the models statistically and in the field, and determined which areas were environmentally suitable to find most of these species in the field.

MATERIAL AND METHODS

Area of study and selection of plant species

The study area consists of two hydrologi-

cal basins in the western Mexican state of Michoacán: Lake Chapala and the Duero River Basin (Fig. 1). Both basins belong to one of the most important hydrographic regions in Mexico, the Lerma-Santiago region, which begins in central Mexico (State of Mexico) and runs west to Michoacán and Jalisco. The Lake Chapala basin covers about 4,715 km² and is delimited by the coordinates 20°22' North, 19°50' South, 102°21' East and 103°34' West. On the other hand, the Duero River basin has an approximate area of 2,661 km², delimited by the coordinates 19°40' North, 20°15' South, 101°45' East and 102°45' West. The two basins together include fifty-three municipalities (Appendix 1).

The Asteraceae species were selected according to whether the species are distributed in the study area (Chapala-Duero basins), they are reported in the bee flora of Michoacán (Villegas-Durán et al., 1999), honey bee pollen inventories or related floras and there are at least five records (Phillips et al., 2006) to generate the ENM. The search for specimens documenting the species was conducted in the National Herbarium of Mexico (MEXU) in Mexico City, Herbarium of the Interdisciplinary Research

Center for Regional Integral Development (CIMI) in Jiquilpan, Michoacán and Herbarium of the Institute of Ecology (IEB) in Pátzcuaro, Michoacán.

Processing of presence records

With the data obtained of the selected species, a database of thirty species was constructed with a total of 286 records for the study area. Each species had 5 to 40 records (Tab. 1). Only species with at least five records, the minimum number recommended to construct ENM (van Proosdij et al., 2006) were included in the study.

Generation of abiotic variables

Data for monthly minimum and maximum temperatures and precipitation between 1961 and 2016 were obtained from ninety-eight climatological stations of the Mexican National Meteorological Service (<http://smn.cna.gob.mx/es/climatologia/informacion-climatologica>) generated by the Mexican National Water Commission. In addition, 195 geographical data were used with such soil properties (INEGI, 2006; Cruz-Cárdenas et al., 2014b) as electrical conductivity, pH and organic matter. A geostatistical analysis

Fig. 1. Delimitation of the study area (Chapala and Duero River Basin). The red line divides the municipalities corresponding to each basin.

Table 1.

Asteraceae species of beekeeping interest selected for the study area. The number of records upon which ecological niche models (ENM) were based are shown, with the number of new records collected during fieldwork indicated in parentheses. Values from statistical evaluation of each ENM are also given

Species	Number of records	AUC Maxent	Average AUC of partial Roc
<i>Acmella repens</i> (Walter) Rich.	9 (1)	0.93	1
<i>Ageratina mairiana</i> (DC.) R.M. King & H. Rob. var. <i>mairiana</i>	6	0.7	1
<i>Ageratum corymbosum</i> Zuccagni	13 (2)	0.87	0.98
<i>Aldama dentata</i> La Llave	11 (8)	0.93	1
<i>Ambrosia peruviana</i> Willd.	11 (3)	0.83	0.99
<i>Astranthium orthopodum</i> (B.L. Rob. & Fernald) Larsen	8	0.86	1
<i>Baccharis heterophylla</i> Kunth	9 (1)	0.89	1
<i>Baccharis salicifolia</i> (Ruiz & Pav.) Pers. subsp. <i>salicifolia</i>	8 (5)	0.92	1
<i>Barkleyanthus salicifolius</i> (Kunth) H. Rob. & Brettell	21 (4)	0.77	0.99
<i>Bidens aequisquama</i> (Fernald) Sherff var. <i>aequisquama</i>	12 (4)	0.74	1
<i>Bidens aurea</i> (Aiton) Sherff	5	0.76	1
<i>Bidens odorata</i> Cav. var. <i>odorata</i>	5 (1)	0.86	1
<i>Cosmos bipinnatus</i> Cav.	5 (4)	0.9	1
<i>Cosmos sulphureus</i> Cav.	5 (2)	0.83	1
<i>Dahlia coccinea</i> Cav.	12 (2)	0.89	1.01
<i>Erigeron longipes</i> DC.	7 (1)	0.82	1
<i>Galinsoga parviflora</i> Cav.	9 (12)	0.85	1
<i>Guardiola mexicana</i> Humb. & Bonpl. var. <i>mexicana</i>	5	0.70	1
<i>Melampodium divaricatum</i> (Rich.) DC.	40 (12)	0.87	0.98
<i>Melampodium perfoliatum</i> (Cav.) Kunth	10 (8)	0.95	1
<i>Parthenium hysterophorus</i> L.	5 (1)	0.91	1
<i>Pittocaulon velatum</i> (Greenm.) H. Rob. & Brettell var. <i>velatum</i>	5	0.95	1
<i>Pluchea carolinensis</i> (Jacq.) G. Don	6	0.65	1.01
<i>Pluchea salicifolia</i> (Mill.) S.F. Blake	6 (1)	0.78	1
<i>Tagetes erecta</i> L.	10 (5)	0.84	1
<i>Tagetes filifolia</i> Lag.	7 (3)	0.86	1
<i>Tithonia tubiformis</i> (Jacq.) Cass.	8 (12)	0.79	1
<i>Verbesina sphaerocephala</i> A. Gray	15 (8)	0.87	1
<i>Vernonia alamanii</i> DC.	7 (3)	0.84	1.03
<i>Viguiera dentata</i> (Cav.) Spreng.	5	0.84	1.15

(Goovaerts, 1999) of the climate and soil data was applied, and its first step consisted of data exploration and transformation with the use of the natural logarithm to adjust the data to a normal distribution. A structural analysis was then carried out and experimental variograms were elaborated for calculating the semi-variance (γ) of the data with the following formula (1):

$$(1) \gamma(h) = \frac{1}{2} n \sum_{i=1}^n [Z(x_i+h) - Z(x_i)]^2$$

The semi-variance of all the samples is within a particular space, separated by a distance (h); n is the total number of sample pairs; $Z(x_i)$ are the sampled locality climatic and soil values; and $Z(x_i+h)$ are the sampled locality values to the h interval distance. The experimental variogram was adjusted to a linear model that recorded

the minimum sum of squares error (SSE) for each dependent variable (Gallardo, 2006). Then, the spatial prediction after the adjustment of the experimental variogram was inferred using universal Kriging, as indicated by the cross-validation test, for climate and soil data. On the other hand, the climate variables were imported to DIVA-GIS 7.5 (DIVA-GIS, 2016) to generate five bioclimatic variables. In addition, four climatic seasonality variables and three evapotranspiration variables were produced. To generate the evapotranspiration variables, Turc's model was applied (Turc, 1954) as explained in Cruz-Cárdenas et al. (2014a). The continuous Mexican elevation model of INEGI (2017) was used to generate three topographic variables. In addition, remote sensing data were downloaded from the Landsat L8 satellite OLI / TIRS C1 Level -1 (Earth Explorer) over a period of one year (July 2016 to July 2017) using the scenes path 28, row 46 and path 29, row 46. Twelve mosaics of bands 4 (red) and 5 (infrared) were used to generate standard vegetation indexes for each mosaic applying the formula proposed by Manrique (1999), where *NIR* = near infrared band and *RED* = red band. Subsequently, the Normalized Vegetation Index (NDVI) for each mosaic was generated using this formula (2) proposed by Manrique (1999):

$$(2) NDVI = (NIR - RED) / (NIR + RED)$$

For the generated variables, a pixel size of 1 km² was taken at a resolution of 0.008333 calculated with the following formula (3) proposed by Hengl (2006):

$$(3) \text{Resolution and adequate pixel size} = \leq 0.05 \sqrt{A/N},$$

where *A* is the area in km² (the size of the area is 57,948 km²) and *N* is the sample size. For climatic data, *N* was the total climatic stations (98), and for the soil properties data *N* was the total sampling points (195).

Finally, a principal components analysis (PCA) was applied to the climate, seasonality climatic, soil, topography, and normalized vegetation

index variables (Tab. 2), in order to reduce the correlation and the dimension of the variables. The components that cumulatively explained 95% of the variance of the original variables (Tab. 3) (Cruz-Cárdenas et al., 2014) were selected for further analysis.

Generation of the biotic variable

Seven records of field observations of the presence of *Apis mellifera* in the study region were documented and analyzed in Maxent 3.3.3k (Phillips & Dudick, 2008) to elaborate its ENM, and the main components generated in the previous point were used as environmental variables. In the modeling, the parameters established by default for Maxent were followed, except the commands "Extrapolate" and "Do clamping" were deactivated which are recommended only when making niche transfer models (Owens et al., 2013). The final map was exported as a logistic model without any clipping and used as the biotic variable to be used in the modeling of the species of Asteraceae (Fig. 2).

Niche modeling and statistical validation of plant species

To reduce collection bias and avoid spatial autocorrelation among records (Soberón et al., 2000), a pattern analysis was performed with each species as proposed by Cruz-Cárdenas et al. (2014). Of the thirty total species, this procedure was only executed for the ten species that had the ten or more required records. The set of uncorrelated presence data was then used to generate the model, one part for training and the other part to validate the model (testing). To construct the niche models of the thirty selected species, the parameters established by default in Maxent 3.3.3k (Phillips & Dudick, 2008) were used, except for the deactivated "Extrapolate" and "Do clamping" options. The logistic models, were transformed to a boolean layer (presence-absence) using a species-specific cut-off threshold through the minimization of the number of omission errors using Maxent's Threshold table (Anderson et al., 2003; Phillips et al., 2006; Phillips & Dudik, 2008).

The statistical validation of the models consisted

Table 2.

Abiotic (environmental) variables used to construct the ecological niche models

Climatic variables
BIO1= Annual Mean Temperature
BIO12= Annual Precipitation
BIO15= Precipitation Seasonality (Coefficient of Variation)
BIO3= Isothermality (BIO2/BIO7) (* 100)
BIO4= Temperature Seasonality (standard deviation *100)
Seasonality climatic variables
PPH= Precipitation of the humid months
PPS= Precipitation of the dry months
TH= Mean temperature of humid months
TS= Temperature of the dry months
ETTRA= Real annual evapotranspiration
ETRAS= Real evapotranspiration of the dry months (november to abril)
ETRAH= Real evapotranspiration of the humid months (may to october)
Soil properties
CE= Electric conductivity
MO= Organic material
pH= Hydrogen potential
Topographic attributes
ORIENT= Aspect
ALT= Elevation
PEND= Slope
Normalized vegetation indices 2016-2017
NDVIH= Humid months of year normalized index
NDVIS= Dry months of year normalized index

Table 3.

Results of principal components analysis based on the twenty environmental variables

Component	Standard deviation	Proportion of variance	Cumulative Proportion
1	3.35348	0.56229	0.56229
2	1.42728	0.10186	0.66415
3	1.29146	0.08339	0.74754
4	1.09974	0.06047	0.80801
5	1.00487	0.05049	0.8585
6	0.95576	0.04567	0.90417
7	0.71744	0.02574	0.94825

Fig. 2. Ecological niche modeling of *Apis mellifera*.

in three tests. First, we used the Maxent-calculated AUC value (Phillips et al., 2006) (Tab. 1). Second, the partial-ROC of each model was calculated (Peterson et al., 2008) with the use of the Partial-ROC program (Narayani, 2008) following the established parameters of 50% of the validation points resampled in 1000 replicas for bootstrap under an error of omission of

less than 5% (Tab. 1), and finally a binomial test (Anderson & González, 2011; Cruz-Cárdenas et al., 2014a), which evaluates whether a particular model is better than a randomly generated model ($p < 0.5$). The binomial test only was done for those species with ten or more records (Tab. 4).

Table 4.
Binomial test for the ten Asteraceae species with enough records to carry out the test

Species	Total records/ Records predicted by model	* Binomial test (probability of success)	P value ($p \leq 0.05$)
1.- <i>Ageratum corymbosum</i>	5/5	1	0.03125
2.- <i>Aldama dentata</i>	5/5	1	0.03125
3.- <i>Ambrosia peruviana</i>	2/2	1	0.25
4.- <i>Barkleyanthus salicifolius</i>	13/13	0.84	0.01123
5.- <i>Bidens aequisquama</i> var. <i>aequisquama</i>	5/5	1	0.03125
6.- <i>Dahlia coccinea</i>	6/4	0.66	0.3437
7.- <i>Melampodium divaricatum</i>	21/19	0.90	0.0001106
8.- <i>Melampodium perfoliatum</i>	3/3	1	0.125
9.- <i>Tagetes erecta</i>	4/4	1	0.0625
10.- <i>Verbesina sphaerocephala</i>	6/5	0.83	0.1094

* Null hypothesis = the probability of success is less than 0.5; Alternative hypothesis = probability of success is greater 0.5. Probability value to reject the null hypothesis, $p \leq 0.05$.

Fig. 3. Map of potential richness of Asteraceae species of beekeeping importance for the study area and environmentally suitable sites to situate apiaries.

Field validation of the ENM

To validate the ENM of the selected species in the field, first the flowering season (phenology) of the species was considered and second the visits to the majority of the municipalities according to the information provided by the ENM and the richness map obtained. The locations used to generate the model were avoided whenever possible. We made sixteen trips to the field from July to December 2017 and January to March 2018.

Determination of the ideal sites for the establishment of apiaries

Each of the models was taken in its logistic format without cutoff thresholds, including all the probability values, and a sum of all them was generated (Cianfrani et al., 2010). To choose the number of classes and intervals in the resulting map, we used the mean of the values of species richness, provided by the probability values and multiplied by the number of models (Law et al., 2009). As a result, a map of potential richness of Asteraceae species of beekeeping importance was obtained for the study area (Fig. 3), and the uppermost two classes were taken to determine

the environmentally suitable sites to situate apiaries.

Software used

For the spatial analysis we used the raster and SCP plugins (Structured Conservation Planning) from the QGIS program (QGIS Development Team, 2018). For statistical analyses, we used the R statistical software gstat and sp packages (R Core Team, 2017).

RESULTS

Almost 6,000 vascular plant species are recorded in the state of Michoacán (Villaseñor, 2016), including Asteraceae 837 species (Villaseñor, 2016). A floristic inventory of the bee flora of the state records Asteraceae as the most important family, recording 43 out of 837 species. However, literature review of bee floras for other areas of Mexico revealed nineteen additional species, totaling sixty-two species of beekeeping importance that occur in the study area.

The consulted databases provided at least five records to construct ENM for thirty species

Table 5.

Loading values of the twenty environmental variables from the principal component analysis. The five variables selected for each component due to their high loading value are indicated in bold

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5	Comp.6	Comp.7
ALT	0.262	0.173					
BIO1	0.226	0.418	0.120	0.135			
BIO12	0.233	0.314	0.142	0.287			
BIO15	0.226	0.418	0.120	0.135			
BIO3	0.224	0.369		0.231	0.128	0.118	
BIO4		0.219	0.148	0.310	0.406	0.719	
CE			0.485	0.418	0.410	0.192	
ETRA_AN	0.280	0.167					
ETRAH	0.278	0.160					
ETRAS	0.255	0.220	0.146	0.109		0.101	
MO	0.238	0.125		0.106			0.130
NDVIHUM	0.139	0.184	0.451	0.447	0.146		
NDVISEC	0.142	0.168	0.491	0.397	0.112		0.187
ORIENT		0.171		0.191	0.718	0.556	0.289
PEND	0.192		0.198	0.116	0.228	0.186	0.898
PH	0.272	0.144	0.173	0.137			
PPH	0.278	0.160					
PPS	0.255	0.220	0.146	0.109		0.101	
TH	0.253		0.245	0.267		0.182	
TS	0.260	0.157	0.222	0.122			

(Tab. 1). Among the most common species found in the area, *Aldama dentata* La Llave, *Baccharis salicifolia* (Ruiz & Pav.) Pers., *Melampodium divaricatum* (Rich.) DC., and *Verbesina sphaerocephala* A. Gray are widely recognized for their frequent bee visits. The other thirty-two species documented in the bee flora of the region did not have enough records for ENM models, but their occurrence information was used to improve the richness map (Appendix 2). According to the load values of the principal components, fourteen out of twenty environmental variables were important for the species modeling (Tab. 5) and were used to generate the ENM. The statistical validation of the models with the AUC-Maxent and AUC tests of the partial ROC categorize the models as bad if they have a value lower than 0.60, regular

with a value between 0.60 and 0.70 and good with values between 0.80 and 1. Based on this classification, the AUC-Maxent test considered all models from regular to good with values ranging from 0.70 the lowest to 0.95 the highest (Tab. 1). For the partial ROC test, all models were considered good with values from 0.98 to 1. Among the species in which the binomial test was conducted, all models had values of 1 or close to 1 (Tab. 4) and were better than a randomly generated model.

In the field, twenty-three of the thirty modeled species were found. Of those, five were found only one additional time, while the other eighteen species yielded between two and twelve new records within the study area during our fieldwork (Tab. 1).

The map summing the thirty ENM revealed

richness values ranging from one to thirty species. Using the uppermost classes of potential richness (13-30 species), six important areas with species of beekeeping importance were determined (Fig. 3). These six areas represent the most environmentally suitable sites for the placement of apiaries, which were located in twenty-five municipalities of the study area (Appendix 1).

DISCUSSION

Austin (2002) mentioned that environmental variables influence directly or indirectly ENM. Such direct variables as temperature and precipitation variables affect the physiology of organisms and can be a determinant for their survival, and indirect variables as topographic variables, latitude or altitude do not drastically impact the physiology of organisms but affect their geographical distribution. Considering Austin's assumptions and the results obtained in the PCA (Tab. 5) for twenty of the studied species, at least three important variables, annual evapotranspiration (ETRA-A), evapotranspiration of the wet months (ETRA-H) and pH may directly affect their occurrence, and altitude (ALT) may influence them indirectly (Tab. 5). For the ten remaining species, annual precipitation (BIO12), temperature seasonality (BIO4), temperature of the humid months (TH), temperature of the dry months (TS), standardized vegetation indexes (NDVIH, NDVIS), electrical conductivity (CE) and organic matter (OM) are variables possibly influencing occurrence directly, while orientation (ORIENT) and slope (PEND) indirectly (Tab. 5).

The ENM of the modeled species echoed the environmental suitability of each species within the study area. In all the models, the suitability was observed to be geographically broader than the spatial distribution of known occurrences (Appendix 3). The maximum entropy algorithm uses each training records to maximize the occurrence of the object (species), seeking a uniform distribution throughout the study area (Phillips et al., 2006; Phillips & Dudik, 2008; Elith & Leathwick, 2009; Fithian & Hastie, 2012). In addition, the models were made with the

default configuration; when such configurations as regularization parameters β are changed in Maxent, non-overadjusted and more restricted models can be obtained (Anderson & González, 2011). For this reason, in many works related to niche modeling, statistical parameters are used to evaluate the models, e.g. Maxent's AUC, partial ROC and binomial test (Peterson et al., 2008; Anderson & González, 2011; Cruz-Cárdenas et al., 2014; Martínez-Méndez et al., 2016). Whether the models are made with the default configuration or modified parameters of the configuration, the purpose of the evaluation is to reflect the statistical robustness of the models. For the thirty MNE elaborated, the statistical parameters indicated they were statistically robust models.

The values of AUC-Maxent partial ROC (Peterson & Soberón, 2008; Baldwin, 2008; Peterson et al., 2011; Martínez-Méndez et al., 2016), indicate the models are regular to good, with a minimum values of 0.70 and maximum of 1 (Tab. 1). Similarly, the binomial test showed values of success of 1 or close to 1, and the models are better than a randomly generated model (Tab. 4). The statistical robustness of the models resulted in an 80% ENM success rate, considering that twenty-three of the thirty species of beekeeping importance were actually found during field trips. Peterson et al. (2011) mentioned that ENM can be used to find new populations of species in places that had not been previously explored.

Seven species were not observed during field work: *Ageratina maireriana* var. *maireriana*, *Astranthium orthopodum*, *Bidens aurea*, *Guardiola mexicana* var. *mexicana*, *Pittocaulon velatum* var. *velatum*, *Pluchea carolinensis*, and *Viguiera dentata*. Several arguments can be proposed to explain their lack of new populations, and perhaps the most important is habitat transformation. An important portion of the study area is now occupied by agricultural fields, where such agricultural techniques as herbicides or quilts (weed cloth) are commonly used to eliminate weeds, may influence their absence in the landscape. Cousens and Mortimer (1995) argue these agricultural practices modify popu-

lations' densities and seedbank composition and result in changes in floristic composition.

The six environmentally suitable zones concentrating the largest richness of Asteraceae modeled, show a high coincidence with the ENM of *Apis mellifera* (Fig. 2 and 3). These areas therefore combine the two key conditions for apiary placement: high probability of occurrence of bees and a broad spectrum of bee-important plant species. Data on honey production in the study region (SIAP, 2015) record the highest honey production in the municipalities of Jamay in the state of Jalisco and Zamora in the state of Michoacán, about 861 and 81 tons per year, respectively. The ideal apiary areas identified as zones 5 and 3 in our maps are located in these municipalities. In total the six high-richness sites represent an area of 2,488 km², 34% of the total 7,376 km² study area. Thus, the search for ideal sites for apiaries settlement can be significantly narrowed down through the use of ENMs. The thirty species with ENM out of sixty-two occurring in the study area plus fourteen out of twenty environmental variables considered important in model generation, allowed us to identify six important areas where conditions would favor beekeeping activities. These areas were confirmed as important once fieldwork validated the occurrence of the twenty-three out of thirty bee-important plant species in localities where they had not been previously searched for. It is well known that the larger the number of bee important species in a region, the better the honey production. The healthy condition of the honeycomb depends on the quality of the pollen collected (floral resources). Therefore, if a large number of species that bees feed on are present around the hive, the survival of the colony is more likely and the quality of honey produced will increase.

The Asteraceae species analyzed in this study are among the most important and frequently cited in beekeeping studies. Thus, the areas identified as important in this paper will play an important role in the improvement of local honey production. We hope that such governmental institutions as SAGARPA and SEMARNAT in Mexico will apply our information in the near

future to find the most environmentally suitable sites and assist beekeepers in the search for apiary locations.

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Appendix 1.

Municipalities of the state of Michoacán that are in the Chapala and Duero River basins. The selected area corresponds to the main zone identified as a priority area for apiary placement (Figure 3)

Basin	Municipality	Selected Area
Chapala	Acatlán de Juárez	
Chapala	Atotonilco el Alto	
Chapala	Ayotlán	1
Chapala/Duero	Briseñas	
Chapala	Cojumatlán de Regules	
Chapala	Concepción de Buenos Aires	4
Chapala	Cotija	
Chapala	Chapala	
Duero	Charapan	6
Duero	Chavinda	5
Duero	Cherán	6
Duero	Chilchota	6
Duero	Churintzio	
Duero	Ecuandureo	
Chapala	Ixtlahuacán de los Membrillo	1
Duero	Ixtlán	
Duero	Jacona	
Chapala	Jamay	3
Chapala	Jiquilpan	
Chapala	Jocotepec	1
Chapala	La Barca	3
Chapala	La Manzanilla de la Paz	4
Duero	Los Reyes	6
Chapala	Marcos Castellanos	
Chapala	Mazamitla	4
Duero	Nahuatzen	
Chapala	Ocotlán	3
Chapala/Duero	Pajacuarán	5
Duero	Paracho	6
Duero	Penjamillo	
Chapala	Poncitlán	2
Duero	Purépero	6
Chapala	Quitupan	
Chapala	Sahuayo	
Chapala/Duero	Tangamandapio	5
Duero	Tangancícuaro	6
Duero	Tanhuato	

Chapala	Teocuitlan de Corona	
Chapala	Tinguindin	
Chapala	Tizapán el Alto	
Chapala	Tlajocomulco de Zuñiga	
Duero	Tlazazalca	6
Chapala	Tocumbo	
Chapala	Tototlan	
Chapala	Tuxcueca	
Chapala	Valle de Juarez	
Chapala/Duero	Venustiano Carranza	5
Chapala/Duero	Villamar	5
Duero	Vista Hermosa	
Duero	Zacapu	6
Chapala	Zacoalco de Torres	
Duero	Zamora	5
Chapala	Zapotlán de Rey	

Appendix 2.

Species of Asteraceae of bee importance occurring in the study area and their distribution among the Mexican states. (**Cam**= Campeche, **Chis**= Chiapas, **Col**= Colima, **Cdmx**= Ciudad de México, **Dgo**= Durango, **Gro**= Guerrero, **Jal**= Jalisco, **Mich**= Michoacán, **Mor**= Morelos, **Oax**= Oaxaca, **Tab**= Tabasco, **Tams**= Tamaulipas, **Ver**= Veracruz, **Yuc**= Yucatán)

Species	Cam	Chis	Col	CdMx	Dgo	Gro	Jal	Mich	Mor	Oax	Tab	Tams	Ver	Yuc
<i>Achillea millefolium</i>													x	
<i>Acmella repens</i>								x						
<i>Ageratina maireriana</i> var. <i>maireriana</i>								x					x	
<i>Ageratum</i> <i>corymbosum</i>			x											
<i>Aldama dentata</i>						x					x		x	
<i>Aldama linearis</i>							x							
<i>Aldama pachycephala</i>							x							
<i>Ambrosia peruviana</i>													x	
<i>Astranthium</i> <i>orthopodum</i>								x						
<i>Baccharis</i> <i>heterophylla</i>			x					x						
<i>Baccharis salicifolia</i>			x		x		x					x		x
<i>Barkleyanthus</i> <i>salicifolius</i>								x				x	x	
<i>Bidens aequisquama</i>								x						
<i>Bidens aurea</i>		x				x								
<i>Bidens bigelovii</i>									x					
<i>Bidens chiapensis</i>		x												
<i>Bidens laevis</i>								x						
<i>Bidens odorata</i>				x		x				x		x		
<i>Calea ternifolia</i>			x											
<i>Calea urticifolia</i>		x	x				x							
<i>Calyptracarpus vialis</i>					x									
<i>Cosmos bipinnatus</i>							x	x						
<i>Cosmos sulphureus</i>		x	x			x	x							
<i>Chromolaena collina</i>			x											
<i>Chromolaena odorata</i>												x	x	
<i>Dahlia coccinea</i>			x				x							
<i>Dyssodia papposa</i>						x								
<i>Erigeron longipes</i>								x						
<i>Galinsoga parviflora</i>								x						
<i>Guardiola mexicana</i>								x						
<i>Lasianthaea</i> <i>ceanothifolia</i>			x											
<i>Lasianthaea fruticosa</i>		x												

<i>Melampodium divaricatum</i>					x		x	x		x
<i>Melampodium perfoliatum</i>					x					
<i>Montanoa bipinnatifida</i>				x						
<i>Montanoa karwinskii</i>					x					
<i>Montanoa leucantha</i> subsp. <i>arborescens</i>	x		x							
<i>Montanoa tomentosa</i> subsp. <i>xanthiifolia</i>	x									
<i>Otopappus tequilanus</i>			x							
<i>Parthenium hysterophorus</i>									x	x
<i>Pittocaulon velatum</i> var. <i>velatum</i>						x				
<i>Pluchea carolinensis</i>	x		x			x			x	x
<i>Pluchea salicifolia</i>			x						x	
<i>Porophyllum punctatum</i>						x	x			
<i>Roldana albonervia</i>							x			
<i>Roldana angulifolia</i>										x
<i>Roldana barba-johannis</i>						x				
<i>Rumfordia floribunda</i>										x
<i>Simsia amplexicaulis</i>			x				x			x
<i>Simsia lagasciformis</i>			x							x
<i>Smallanthus maculatus</i>							x			
<i>Tagetes erecta</i>						x			x	
<i>Tagetes filifolia</i>						x				
<i>Tithonia rotundifolia</i>	x		x				x			
<i>Tithonia tubiformis</i>	x		x			x	x	x	x	x
<i>Verbesina angustifolia</i>	x									
<i>Verbesina sphaerocephala</i>			x			x	x			
<i>Vernonia alamanii</i>							x		x	
<i>Viguiera dentata</i>	x		x	x						x
<i>Xanthium strumarium</i>						x				
<i>Zinnia angustifolia</i>							x			
<i>Zinnia elegans</i>							x			

Appendix 3.

Ecological niche of 30 species of bee importance in the Lake Chapala and Duero river basins in Michoacán. The green area represents the potential distribution, the red points are the training records and the black points are the testing records. Yellow stars are new records found during field validation of models.