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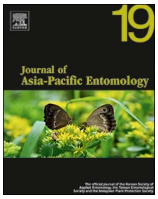

Species distribution modeling for wildlife management: Ornamental butterflies in México

Jazmin Jacinto-Padilla[a], Jose Lopez-Collado[a,*], Catalino Jorge Lopez-Collado[a], Carlos Gilberto García-García[b]

[a] Colegio de Postgraduados, Campus Veracruz, Carretera federal Xalapa-Veracruz km 88.5, 91690, Veracruz, Mexico
[b] Colegio de Postgraduados, Campus Córdoba, Carretera federal Córdoba-Veracruz km 348, 94946, Veracruz, Mexico

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ABSTRACT

Butterflies are biotic natural resources that have an economic value in different countries because of their aesthetic features. The objective of this paper was to estimate the geographic distribution of 17 species considered of ornamental importance in México. Presence data was compiled from specialized sources and public databases. Distribution maps were generated for each species with MaxEnt, using predictor variables related to temperature and precipitation. A spatial similarity and species diversity analysis was applied to group the species based on their geographic distribution. The distribution models were considered appropriate based on the Area Under the Curve, which ranged from 0.75 to 0.94 computed with independent data. Three geographic groups were identified; the first group had the largest coverage (% of national area) and comprised the species *Pyrisitia proterpia* (59%), *Danaus gilippus* (70%) and *Zerene cesonia* (72%). The second group ranged in coverage from 23% (*Archaeoprepona demophon*) to 50% (*Anteos maerula*), while the third group had the smallest coverage, ranging from 17% to 40%. Overall, the species diversity presents a latitudinal gradient, increasing from the north to the southern, Neotropical part of México. States with the highest species potential are Veracruz, Tabasco, Colima, Michoacán, Guerrero, Chiapas, Oaxaca, and most of the Yucatan peninsula. The application of these results to use butterflies to make souvenirs and as components of ecotourism is discussed.

Introduction

Insects are the largest living group on earth; nearly one million of species have been described (Gaston, 2005). As related to humans, their impact can be positive or harmful. Insects cause damage as direct pests or as disease vectors. Beneficial insects provide pollination services, biological control of pests, food, or aesthetic value. Using insects for recreational purposes involves the establishment of insectariums and butterfly gardens, sale of specimens to collectors, release in social events like weddings, and to create handicrafts (Boppré and Vane-Wright, 2012). Butterflies are probably the most important aesthetic insect group; they possess a diverse coloration and wing patterns to camouflage, to attract other individuals with mating purposes and for thermoregulation (Kingsolver, 1987; Caro, 2017); also, they display aposematic colors to warn and confuse potential predators (Joron, 2009). These features have evolved to adapt and respond to the changing environment (Nijhout, 2001) and to people, they are key components in their attractiveness. Color and body shape elicit a positive attitude in children (Breuer et al., 2015), eye-spots tend to increase likeness and positive reactions to conservation (Manesi et al., 2015) and color and shape are the main factors tourists associate with likeness or rejection of some Neotropical butterflies to make souvenirs (Lopez-Collado et al., 2016).

The order Lepidoptera includes near 160,000 species described worldwide (Kristensen et al., 2007). Inventories have been constructed for Nymphalidae, Papilionidae and Pieridae in the Neotropical region (Lamas, 2000); in México, there are about 14,507 species, from which 1825 belong to the superfamily Papilionoidea, one of the most studied group (Llorente-Bousquets et al., 2014). Despite distribution maps for some species have been constructed, most of these maps are pinpoint location records (Luis-Martinez et al., 2003; Hernández-Mejia et al., 2008; Oñate-Ocaña and Llorente-Bousquets, 2010); few have been generated using quantitative models (Hawkins, 2010; Salinas Gutierrez, 2010; Legal et al., 2015; León-Cortés et al., 2015). On the other hand, there are some species in these families which have a commercial value in the international butterfly sales market (Boppré and Vane-Wright, 2012), for example: *Danaus gilippus* (Cramer), *Dryadula phaetusa* (L.), *Glutophrissa* (= *Appias*) *drusilla* (Cramer), *Hama-*

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[*] Corresponding author.
E-mail address: jlopez@colpos.mx (J. Lopez-Collado).

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dryas feronia (Fruhstorfer), *Heliconius charitonia* (L.), *Heraclides* (= *Papilio*) *anchisiades* (F.), *Papilio cresphontes* Cramer, *Heliconius erato* (L.), *Papilio* (= *Heraclides*) *thoas* L., *Lycorea halia* (Hübner), *Morpho helenor* (Cramer), *Pyrisitia* (= *Eurema*) *proterpia* (F.), *Siproeta stelenes* (L.), and *Zerene cesonia* (Stoll) (Cruz-Salas, 2011). In México, the most known species is probably the Monarch butterfly *Danaus plexippus* (L.), which is confined to temperate forests in the states of Michoacán and México during the winter season (Vidal et al., 2014) while *Morpho* sp. is recognized in the Yucatan peninsula (México Desconocido, 2017a). Other species of aesthetic importance are the beetle "Maquech" *Zopherus chilensis* Gray (Romero-Kantún and Sánchez-Galván, 2014), and the firefly *Macrolampsis palaciosi* (Zaragoza-Caballero, 2012; México Desconocido, 2017b).

Entomotourism involves a diverse array of activities aimed to collect, preserve, and interact with insects for aesthetic reasons (Lemelin, 2015). Components of the butterfly rearing and trading activities include about 250 insectariums, pavilions, pollinator parks and museums worldwide (Lemelin, 2015), near a hundred festivals are organized every year in North America (Hvenegaard, 2016) and in Japan about 900 events related to insects occur annually (Hosaka et al., 2016). In particular, the economic value of butterflies has been estimated around US$ 100 million (Boppré and Vane-Wright, 2012; Lemelin, 2015) while the market value of insects as pets and festivals range between US$ 38 million and 44 million in Korea (Kim et al., 2008). Central and South American countries account for 30% to 40% of the butterfly world trade, Costa Rica exports near 400,000 pupae per year (Ickis et al., 2006; Rich et al., 2014). Objective data of the importance of entomotourism in México is scarce; it has been estimated that 250,000 persons visit the Monarch butterfly sanctuaries (Lemelin, 2013); total travel expenditures ranged from US$ 44.2 million to 88.5 million per year and the willingness to pay for conservation fluctuated from US$ 16 to 38 per person (Romo-Lozano, 1998). A raw estimate of the souvenir and handicraft market value for year 2015, based on the number of tourists, expenditures by tourists and the proportion of these expenditures on handicrafts gives US$ 261.3 million per year for national and US$ 652.3 million for international tourists (SECTUR, 2013; INEGI, 2016). In addition, a non-exhaustive search on the internet indicates there are some butterfly houses and insectariums and several businesses provide live butterflies. People buy and release these insects in social events such as weddings, baptisms, *quinceañera*, and graduation parties and butterflies are also used to make handicrafts and accessories (DS Montes Azules SA CV, 2015). On the other hand, the potential of Neotropical butterflies as a source to make handicrafts has been explored in Veracruz, México; near 76% of the visitors were willing to buy butterfly-based handicrafts, and 82% considered color as the main selection factor (Lopez-Collado et al., 2016). Therefore, México has emerged in using butterflies as an additional ecotourism element in states such as Campeche, Distrito Federal, Morelos, Yucatán, and Quintana Roo (Zoológico de Chapultepec, 2015).

Species distribution modeling is an important technique that has been applied to develop wildlife management strategies, like proposing conservation policies for the jaguar, *Panthera onca* (L.), a threatened species (Rodríguez-Soto et al., 2011) and to assist in locating potential areas for the sustainable use of natural resources (Centeno and Arriaga, 2010; González-Bocanegra et al., 2011). Previous studies on butterfly species distribution in México have addressed issues on taxonomy, ethology, conservation, biogeography and biological diversity (Luis et al., 2000; Pozo et al., 2014). Other countries like Colombia, Costa Rica, Ecuador, and Peru have inventoried butterflies aimed to support bio commerce activities (Fagua et al., 2002; Monge-Nájera and Gómez, 2003; Martínez, 2005; Mulanovich, 2007; Sivinta, 2011). Lack of wildlife management planning regarding spatial aspects of distribution have lead people to use tropical butterflies around and within recreation parks, causing some concerns in conservation management and proposing regulation practices to preserve species diversity (Mancera Rodríguez and Reyes García, 2008; Putri, 2016). Therefore, to better plan for a sustainable use of these natural resources, it is important to know where these species can be found, thus, the purpose of this research was to quantitatively estimate the potential geographic distribution in México of some butterfly species of aesthetic importance.

Table 1
Family, species, and code of ornamental butterflies, and number of presence records.

Family	Species	Records
Nymphalidae	*Adelpha basiloides* (Bates)	106
Nymphalidae	*Archaeoprepona demophon* (Fruhstorfer)	86
Nymphalidae	*Danaus gilippus* (Cramer)	377
Nymphalidae	*Dryadula phaetusa* (L.)	80
Nymphalidae	*Hamadryas feronia* (L.)	70
Nymphalidae	*Heliconius charithonia* (L.)	236
Nymphalidae	*Heliconius erato* (L.)	129
Nymphalidae	*Lycorea halia* (Hübner)	144
Nymphalidae	*Morpho helenor* (Cramer)	117
Nymphalidae	*Myscelia ethusa* (Doyère)	143
Nymphalidae	*Siproeta stelenes* (Fruhstorfer)	254
Papilionidae	*Heraclides anchisiades* (F.)	131
Papilionidae	*Papilio thoas* (Rothschild & Jordan)	173
Pieridae	*Anteos maerula* (F.)	257
Pieridae	*Glutophrissa drusilla* (Lamas)	201
Pieridae	*Pyrisitia proterpia* (F.)	433
Pieridae	*Zerene cesonia* (Stoll)	482

Material and methods

Species selection and data collection

We select 17 butterfly species ranked with high potential for making souvenirs in Veracruz, México (Cruz-Salas, 2011) (Table 1). Records of presence data were compiled from different databases: Unidad de Información para la Biodiversidad (UNIBIO, 2015), LIFEMAPPER (2015), GBIF (2015), CONABIO (2015) and other specialized information sources (Durán et al., 2010; León, 2010; Cruz-Salas, 2011). The location points were visually screened to eliminate duplicate records and those wrongly geo-referenced.

Bioclimatic variable selection

The distribution models of ornamental butterflies in México were estimated with Maxent v3.3.3k (Phillips et al., 2006), using bioclimatic variables selected after 19 predictor layers from the Climate Atlas of México digital database (Fernández-Eguiarte et al., 2010) and records of species occurrence. To minimize information redundancy and get the least number of predictor variables with an acceptable predictive power, a heuristic selection process was applied in two stages. In the first stage we got a preliminary estimate of the number of acceptable layers by evaluating groups of 4, 8, 9, 12, 16 and 19 variables obtained from a random selection without replacement with five replicates each except the last. The Area Under the Curve (AUC) was used to measure the goodness of fit of the models and the default configuration of MaxEnt was used. To guide the selection of the predictor variables, Pearson correlation indices r were computed using the values of the predictor variables extracted from the observation points, then, the indices were binarized to 0 if $r < 0.7$ and to 1 if $r \geq 0.7$. A frequency correlation matrix was constructed, where the cells contained the sum of the binarized indices to identify the pairs of variables having the highest correlation frequency. Variables having the highest frequency were discarded and only remained those related to the biology of butterflies, which is influenced by temperature and precipitation (Moyers-Arévalo and Cano-Santana, 2009). In this step a base group of seven variables was selected and in the second step, subsequent random layers were added to assess its effect on the predictive power of the models; from these runs, one additional variable was selected to estimate the final models.

Species distribution map generation

To produce the species distribution models, georeferenced presence records were separated into two groups: 70% to generate the model, and 30% for validation. The models were produced with MaxEnt and the selected bioclimatic variables. Additionally, to improve the estimation, 10 runs were made with the bootstrap option to generate maps with average values; the output format was logistic. For easier viewing and interpretation, distribution maps were binarized to presence-absence using a cut-off value of 0.2.

Species diversity analysis

The potential species richness was analyzed by summing the binary distribution maps of the 17 species and grouped into four categories. The classification was based on the number of species with the following classes: zero (0), low (1–4), medium (5–11) and high (12–17). To explore the interaction between latitude and species diversity, a two-dimensional kernel density distribution was estimated using both factors.

Spatial similarity of species

A hierarchical cluster analysis was applied to the 17 species to estimate their spatial similarity, based on 1-abs(r) as a measure of distance. In this case, a preliminary analysis was performed with sample sizes of 50, 100, 500, 1000, 2500, 5000 and 10,000 points extracted from the distribution maps to select an optimal sample size. The selected sample size was based on the visual inspection of the correlation coefficients for which a stable response was achieved. The values to compute the correlation indices were taken by random sampling of the final distribution maps for each sample size, and the correlation between each pair of species was calculated. With the final sample size, the tree similarity was built; cluster stability was measured by bootstrap using the Jaccard index (Henning, 2007). The analysis was performed with R v3.2.1 (R Core Team, 2015) and Mathematica v8.01 (Wolfram Research, 2011), the maps were made with Quantum GIS v2.10.1 (QGIS Development Team, 2009).

Results

Selection of predictor variables

The distribution of the ornamental butterfly species was computed with eight bioclimatic variables. Of the eight selected variables (Table 2), two were annual averages, thought to reflect conditions throughout the year, these were temperature and precipitation. The other variables are related to the season of the year; they can occur in summer and winter as warm and cold quarters or periods of rain and drought. These layers can be related to key biological phases, for example, during winter some species may go to hibernation or enter in diapause; on the contrary, hot, summer conditions are favorable for the development of populations (Fleming et al., 2005).

Table 2
Selected bioclimatic variables to generate the distribution models of ornamental butterflies in México.

Bioclimatic variable	Name	Base group[a]
BIO 01	Annual mean temperature	+
BIO 10	Mean temperature of warmest quarter	+
BIO 11	Mean temperature of coldest quarter	+ +
BIO 12	Annual precipitation	+
BIO 16	Precipitation of wettest quarter	+
BIO 17	Precipitation of driest quarter	+
BIO 18	Precipitation of warmest quarter	+
BIO 19	Precipitation of coldest quarter	+

[a] The + symbol correspond to the selected base group, + + is an additional variable to improve model performance.

Potential species distribution

Distribution maps are presented in three groups according to the similarity cluster analysis. The first group (Fig. 1A) corresponds to three species with the largest potential coverage varying from 59 to 72% (Fig. 2). The species with the largest area was: *Z. cesonia*, the Southern Dogface butterfly, followed by the *D. gilippus*, the Queen butterfly, and *P. proterpia*, the Tailed Orange butterfly; all of them are known to have a wide distribution in the Americas and reach the northern parts of the country, including parts of the Baja California Peninsula. The second group comprised species with an intermediate coverage, ranging from 23 to 50%, the species with the lesser coverage in this group were L. *halia* and *A. demophon* (Fig. 1B). Most of the species in this group were distributed in the southern coastal parts of the Gulf of México, the Pacific Ocean and the Yucatan Peninsula. The only species tending to occupy the Pacific coast and part of the Yucatan Peninsula was *A. demophon*.

The third group of species had the smallest coverage, between 17 and 40% (Figs. 2, 3). Most of these species tend to distribute more toward the south-eastern regions. The more restricted species was *H. erato*, the Crimson-patched Longwing, its distribution agrees with a previous qualitative map that shows this species covering the Yucatan peninsula and southern parts of México (Brown, 1979).

Two remarking aspects of these species are that, first, their distribution corresponds to the Neotropical region of México; essentially covering the southern part of the country, and second, that the estimated distribution is conservative because of the elimination of low suitability values when the models were binarized. On average, the potential distribution of these ornamental species is estimated as 38.9%.

Spatial similarity analysis

As mentioned before, the spatial similarity analysis divided the species into three main groups (Fig. 4); the stability of the groups, as measured by the Jaccard similarity index was: 0.81, 0.75 and 0.88, pointing to stable clusters. In the first group, the species *P. proterpia*, *Z. cesonia* and *D. gilippus* had the widest, common spatial distribution (Fig. 1A). The second group contained the largest number of species; these species had a relatively similar, homogeneous coverage, for example, the *H. anchisiades-L. halia*, *A. maerula-S. stelenes* and *A. basiloides-P. thoas* pairs share a similarity arrangement. The only species separated from this group is *A. demophon*, distributed more to the west (Fig. 1B). The third group had a small coverage, but *M. ethusa* reached 40% of coverage (Figs. 2, 3C). In this group, *M. ethusa* is near to *H. erato*, while *M. helenor* is closer to *D. phaetusa* and *H. feronia*.

Species diversity

The species diversity distribution is presented in Fig. 5; the zero class covers 23% of the country, the low 29%, medium 18% and high 30%. Also, the species composition clearly shows that the Neotropical region of México, that is, the states of the Yucatan peninsula and the southern part of the country, are those containing the greatest species diversity. The middle and upper classes covered almost half of the country area (48%), while in the northern part there is a significant decrease in the number of species. In this region, the Baja California peninsula on its southern region had less species diversity than states at the same latitude but located on the Pacific coast or the Gulf of México probably because is isolated by the sea.

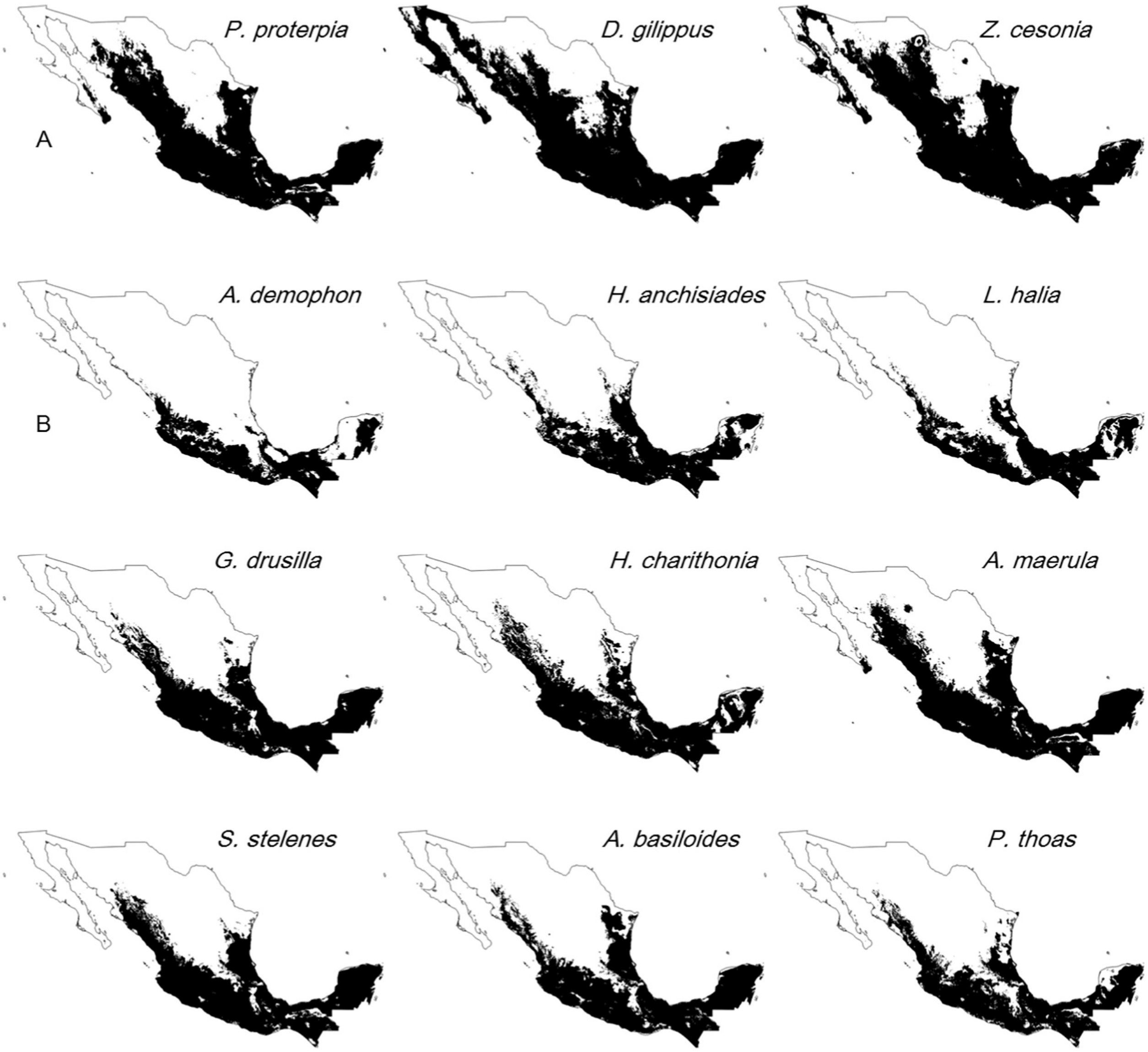

Fig. 1. Potential geographic distributions of groups A and B of ornamental butterfly species based on their spatial similarity.

The Mexican states that had the highest diversity are in the Gulf of México: Tamaulipas, Veracruz and Tabasco; in the Yucatan Peninsula: Campeche, Yucatan and Quintana Roo; the Pacific coastal area: Nayarit, Jalisco, Colima, Michoacan, Guerrero, Oaxaca and Chiapas; in the central part: state of México, Morelos, Puebla, and Hidalgo, and in the north, San Luis Potosi. States with a medium diversity comprised those contiguous to the previous states, including Sinaloa, Durango, Guanajuato and Tamaulipas. These results are consistent with the location of some butterfly gardens used in recreational tourism in these areas, for example the Xcaret ecological park is located in the Yucatan peninsula (Parque Ecologico Xcaret, 2016).

The relationship between latitude and species diversity is presented as a two-dimensional kernel density (Fig. 6); it clearly separates the country in two zones; the northern region is less diverse, with the least diversity peak around 30°N. A transition zone, with the lowest density, occurs by 21°N, near the Tropic of Cancer. The southern region is the more diverse, with the highest diversity peak located around 16°N.

Model validation

The AUC values as a function of the number of layers showed an asymptotic response (Fig. 7), with four layers the performance is relatively low but the predictive power of the models seems to stabilize with eight layers, additional layers increase the AUC but at a lower rate. With eight layers the AUC values ranged between 0.85 and 0.98, similar to 12 layers, but in the latter case there was a replicate with an AUC = 0.84 (*A. maerula*). In general, it appears that eight layers were sufficient to build models with high predictability, that is, 75% or more of the runs had AUC values equal or higher than 0.90.

As mentioned before, seven layers were chosen as the base group due to their biological relevance to the species ecology. We constructed the models with these layers and one additional; after examining the AUC values it was decided to include the variable BIO 11 (Table 2) to generate the final distribution models. The predictive power of the final distribution models, as measured by the AUC is presented in Table 3. For training, the AUC values varied from 0.78 to 0.94 and those for testing, that is, using independent records, varied between 0.75 and 0.94. Further, the AUC achieved with bootstrap sampling to generate the final maps ranged from 0.74 to 0.92, being also relatively high. The median value across these computation methods was 0.87; therefore, we considered the generated models as reliable to predict the geographical distribution of these species.

Finally, in relation to the preliminary analysis to select the sample size and build the similarity tree, Fig. 8 shows the values of the

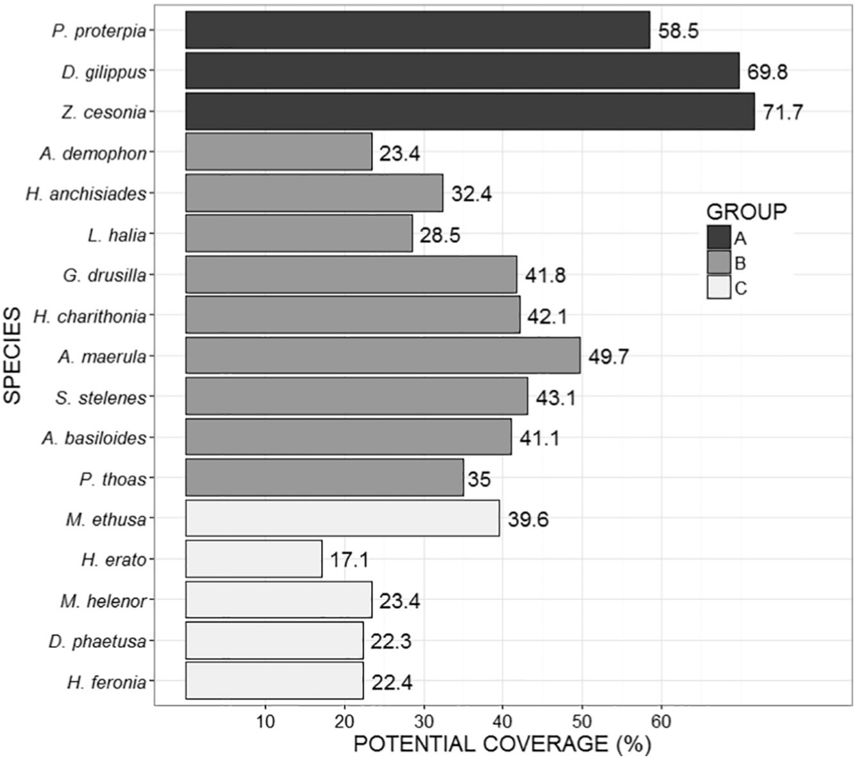

Fig. 2. Potential area coverage (%) by some ornamental species of butterflies in México. Species are grouped based on their spatial similarity.

correlation coefficients between some pairs of species as a function of the sample size. It is noted that, in general, with a sample size of 500 points, the r values are similar to those obtained with larger sample sizes. However, to increase the reliability for this analysis, 5000 points were taken randomly.

Discussion

National and international biological scientific collections serve to investigate various aspects through the free exchange of information (Henao, 2006; Giovenardi et al., 2013). With this type of information sources, we compiled the data necessary to estimate the distribution of some ornamental butterflies in México. The results indicated an average distribution of 38% of the national area, especially in the southern states, reflecting the high diversity of Papilionoidea in the country, which has 10% of the world total (Llorente-Bousquets et al., 2014). The expected distribution in the Neotropical, southern part of the country is mainly due to two factors: first, the Mexican Transition Zone is an area of tectonic convergence of the Nearctic and Neotropical regions, the latter being the richest of all the biogeographic regions (Koleff et al., 2008). The second factor is that the gradient from extratropical to the intertropical regions presents many orographic formations, with the southern parts and the coastal regions being the richest, especially in the evergreen, deciduous and tropical moist mountain forests (Luis et al., 2000). Furthermore, in these places the diversity of host plants, natural vegetation within shade coffee systems and disturbed ecosystems stimulate the presence of butterflies (Muriel et al., 2011). In addition, agricultural areas with multi-layered vegetation hedges,

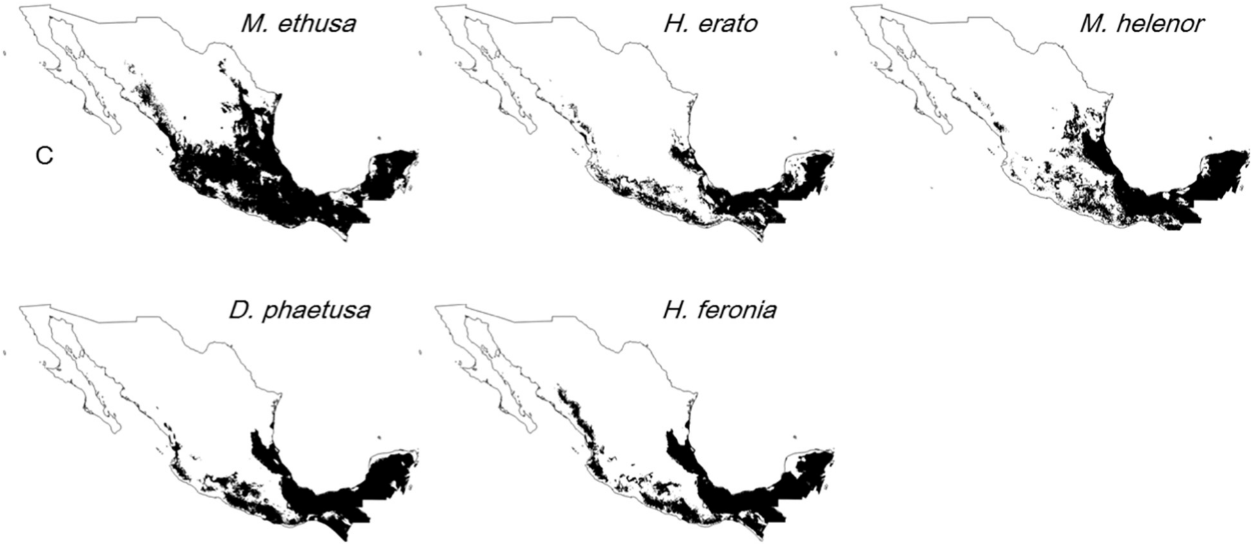

Fig. 3. Third group of butterfly species with similar spatial distribution patterns in México.

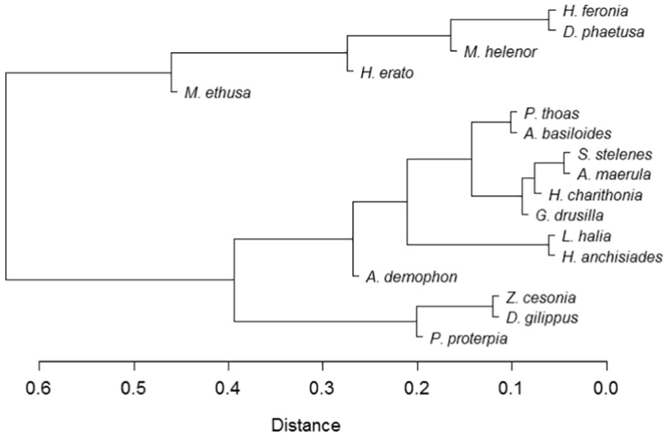

Fig. 4. Spatial similarity tree of 17 ornamental butterfly species, distance is measured as 1-abs(r).

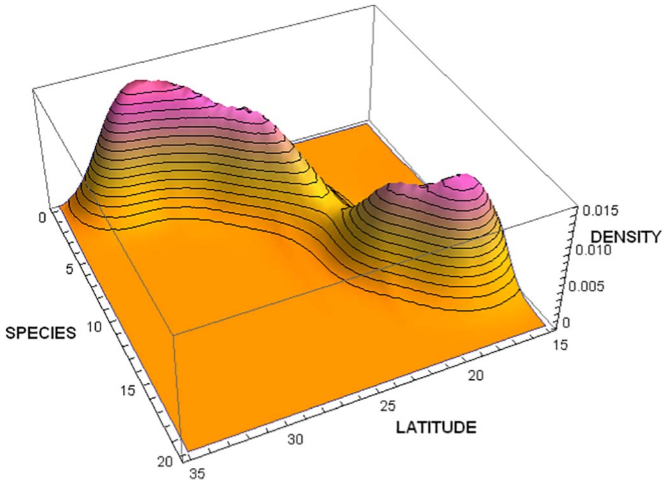

Fig. 6. Two-dimensional kernel density as a function of butterfly species diversity and latitude.

scattered trees in pastures, grazing and agroforestry systems containing tree species, such as *Bursera simaruba* L., *Tabebuia rosea* (Bertol.) and *Cordia allidora* (Ruiz & Pav.) help the conservation, abundance and distribution of common butterflies (Tobar and Ibrahim, 2010); for example, *Anartia fatima* (F.), *Hamadryas februa ferentina* (Godart) and *S. stelenes*. These landscapes allow some species to integrate into the primary vegetation and into the urban areas, forming biological corridors (Orozco et al., 2009). Based on the estimated distributions and the species ecology, the presence regions may include disturbed areas, for example cultivated areas and secondary vegetation (Bonebrake and Sorto, 2009).

The first group showed the widest distribution (Fig. 1A). The Queen butterfly is known to have a wide distribution in the Americas, from Argentina to the southern U.S. (Moranz and Brower, 1998), while *P. proterpia* and *C. cesonia* are also expected to have a wide distribution due to their ability to occupy disturbed habitats (Bonebrake and Sorto, 2009). Species of the second group have a broad relationship between habitat and their distributions; for example, the zebra butterfly (*H. charithonia*) inhabits secondary forests, agricultural and perturbed areas from which the adults feed on nectar of flowers (Henao, 2006; Orozco et al., 2009). In this case, the distribution depends on the availability of feeding resources for the larvae, which nurture from *Passiflora adenopoda* DC. and *P. rubra* L. (Millán et al., 2010). The capacity of this species to occupy different habitats translates to a wide distribution. On the contrary, though *H. erato* belongs to the same genus as the previous species, the adult inhabits more restricted habitats, like the mountain wet forests and tropical rainforests (Jiggins and Davies, 1998); and the larvae feed on some species of *Passiflora* as well. Because the areas of these biomes have been reduced, its distribution has been reduced as well.

On the other hand, *A. basiloides* has an intermediate distribution, it covers both coastal parts of the country but is absent in the central and northern parts probably because of two reasons: the first is the orographic barriers formed by the mountains of the Sierra Madre Oriental and Sierra Madre Occidental and the second reason is because these regions are relatively dry. According to Glassberg (2007), this

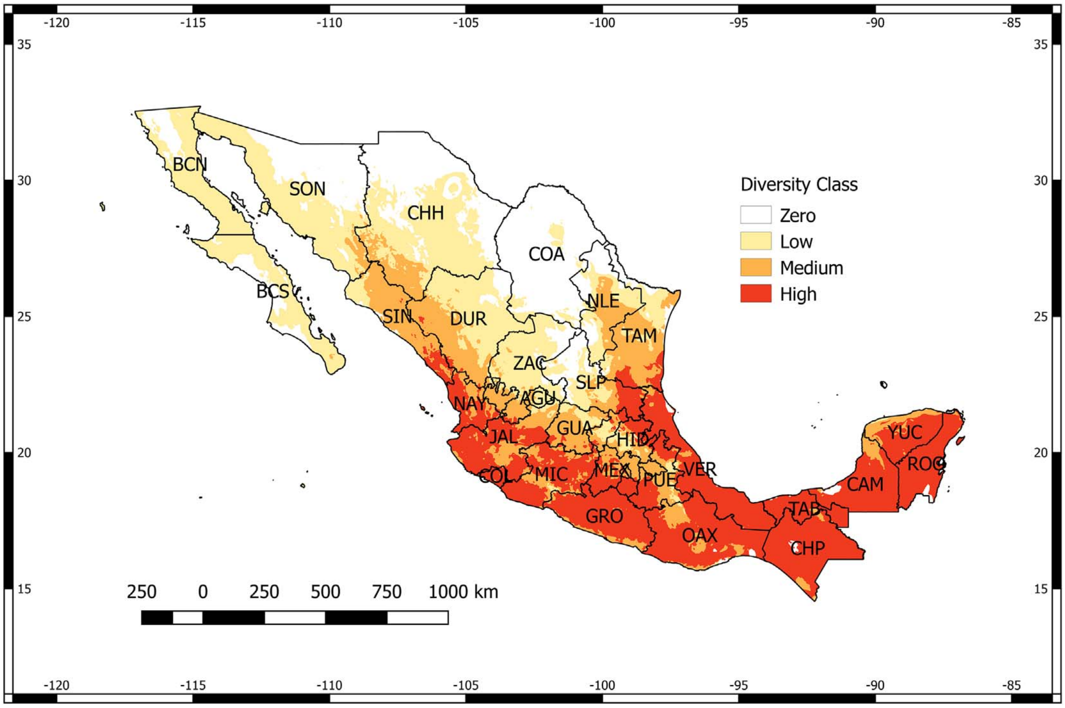

Fig. 5. Species diversity distribution of 17 ornamental butterflies in México. The color gradient represents the potential species diversity.

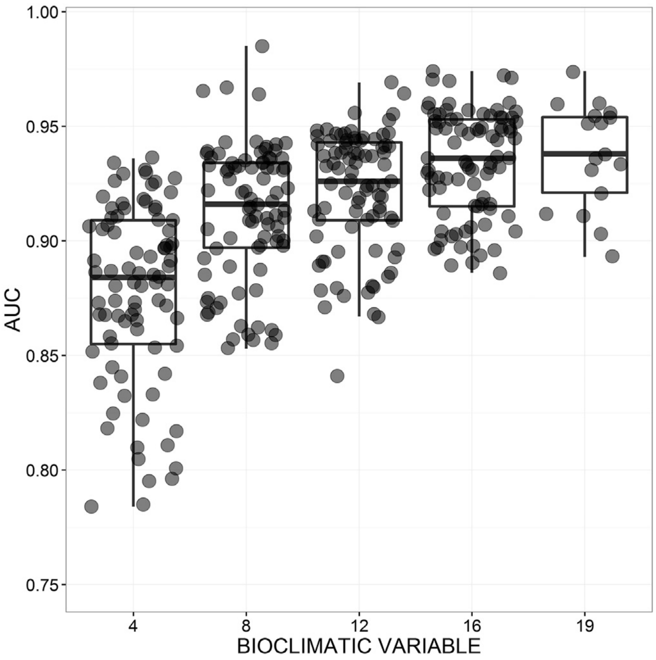

Fig. 7. Boxplots with the 25, 50 and 75 quartile of the Area Under the Curve (AUC) of 17 butterfly species in relation to the number of bioclimatic predictor layers. Points are single AUC replicates for each species.

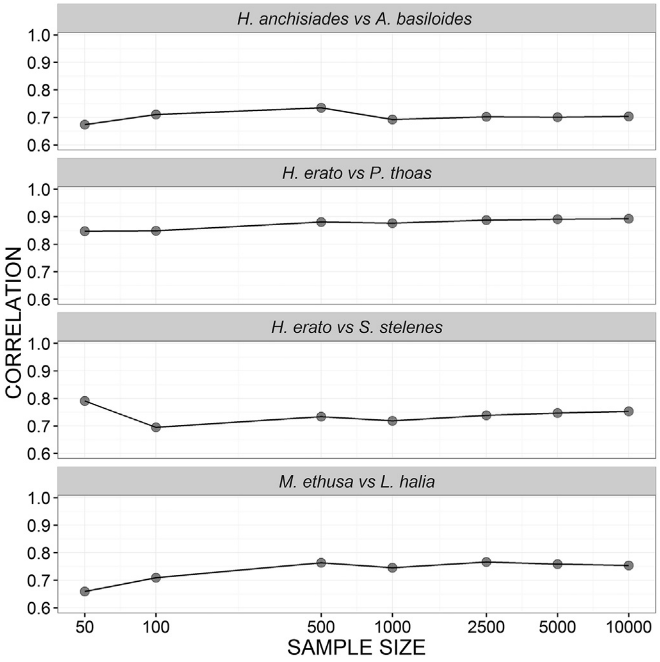

Fig. 8. Correlation values between some pairs of ornamental butterfly species depending on the sample size, note the log scale for the sample size axis.

Table 3
Area Under the Curve values (AUC) relative to the distribution models of 17 ornamental butterflies.

Species	AUC for standard model estimation		AUC for boostrap
	Training data	Test data	Average (n = 10)
A. basiloides	0.876	0.833	0.821
A. demophon	0.932	0.887	0.902
D. gilippus	0.804	0.754	0.751
D. phaetusa	0.926	0.903	0.896
H. feronia	0.892	0.938	0.893
H. charithonia	0.884	0.843	0.843
H. erato	0.944	0.938	0.915
L. halia	0.908	0.922	0.882
M. helenor	0.927	0.893	0.888
M. ethusa	0.906	0.828	0.845
S. stelenes	0.894	0.833	0.845
H. anchisiades	0.917	0.868	0.865
P. thoas	0.903	0.873	0.862
A. maerula	0.854	0.814	0.792
G. drusilla	0.894	0.829	0.845
P. proterpia	0.831	0.761	0.788
Z. cesonia	0.786	0.760	0.741

species has a distribution covering the central and southern parts of the country, the slight discrepancy may be due to the different methodologies used to predict the distribution. In the case of *A. maerula*, it is distributed from the United States to Peru and throughout México (Díaz and Llorente, 2011). The current estimate covers some northern, central and southern parts of México, and in the north it distributes close to the Sierra Madre Oriental and Sierra Madre Occidental. This result suggests that the ranges are somewhat conservative and the species has a slightly wider distribution.

In the third group (Fig. 3), all the species show a similar, restricted distribution pattern, leaning toward the east, Golf of México coastal states and southern parts, that is, they have a more Neotropical distribution (León-Cortés et al., 2015). The exception is *M. ethusa* which extends in both coastal parts and more toward the northern parts, a similar, regional pattern were obtained by León-Cortés et al. (2015) for this species in the Yucatan peninsula. Conversely, *H. feronia* is usually located in undisturbed tropical dry and rain forests, it gathers where the tree density is high as perches on the basal area for camouflage; the adult feeds on fermented fruits of different species, e.g. *Spondias mombin* L. (Vargas-Zapata et al., 2015).

The latitudinal gradient of the species diversity agrees with other studies, for example, for swallowtail butterflies (Condamine et al., 2012) and woody angioperm plants (Kerkhoff et al., 2014). Different hypotheses have been proposed, for example, ancestral climate affinities (Romdal et al., 2013) and multi-factor processes (Lamanna et al., 2014). For those species occupying northern regions, it is hypothesized that cold tolerance and migratory habits influence the occurrence in these regions (Hawkins and DeVries, 2009). The Queen butterfly is a close relative to the Monarch butterfly which is known to have migratory habits (Urquhart and Urquhart, 1976); on the other hand, *P. proterpia* and *Z. cesonia* are within a group considered extratropical (Hawkins and DeVries, 2009).

Although distribution models indicate only the potential occurrence and not abundance, it has been reported that from January to April, the abundance of butterflies is relatively constant, between May and August it raises, in September and October the greatest diversity of species is observed and in the months of November and December the number of individuals decreases gradually (Hernández, 1993; Hernández-Mejia et al., 2008; Moyers-Arévalo and Cano-Santana, 2009). Moreover, Martínez-Noble et al. (2015) found the highest species richness between May and August and the lowest in September–October. That is, the population dynamics is affected in different ways, which reflects in changes in the species distribution. One interesting case is *M. helenor*, which is considered to have expanded its distribution to northern Tamaulipas, probably because of the climate change (Galvez et al., 2013) and is a favorite butterfly for making souvenirs (Cruz-Salas, 2011). This background information suggests that some of these species may be present throughout the year, that they may adapt to environment disturbances, and can coexist with human populations in agricultural landscapes, inhabiting shrubs and trees landscapes, shade coffee farms, backyard gardens, agroforestry, rural and peri-urban gardens, among others (Orozco et al., 2009; Tobar and Ibrahim, 2010; Muriel et al., 2011). In areas where farming is practiced with a moderate use of chemicals; these types of agroecosystems can promote the richness and abundance of butterflies, therefore, strengthening the sustainable production in agricultural and wilderness areas, and allowing a moderate use of these resources in natural environments (Romeu, 2000). In a sense, the butterflies inhabiting different forest types can be seen as a non-timber product that can be used as raw material to make handicrafts and help increase the income of rural residents (López, 2008; Tapia-Tapia and Reyes-Chilpa, 2008; FAO, 2014).

To our knowledge, this is a first attempt to quantitatively estimate the potential distribution of some Papilionoidea that have an aesthetic value in México. Our results agree with previous work on the biogeography of this group (Luis-Martinez et al., 2003; León-Cortés et al., 2015); we expect to provide a guide to where these species can be extracted to make souvenirs or for wildlife management. For example, regarding the potential use of these species for leisure or entertainment, some distribution areas coincide with colonial cities of high national tourist influx such as Morelos, Guerrero, Veracruz, Michoacan, Oaxaca, Chiapas and Yucatan, as well as with some beach and coastal tourism centers in Sinaloa, Jalisco, Guerrero, Oaxaca and Quintana Roo (Propin and Sánchez, 2007; SECTUR, 2013). A further use of these results is to combine the diversity layer with other information sources to delimit the areas that can be managed near tourist sites, either to extract specimens for handicrafts, for trading or to establish entomotourism places (Hamdin et al., 2015). For example, Jacinto-Padilla (2016) applied an analytic hierarchy process to combine species diversity, roads, access to raw material, exclusion of federal protected areas, tourism destinations, tourist and local population in the state of Veracruz, México to delimit zones where these species can be extracted to produce souvenirs; it was found that only 11% of the state area could be managed for such activities. In contrast, we would expect a smaller suitable zone to manage butterflies in the tourist attractions of the Baja California Peninsula because it has low species diversity. Therefore, the boundaries of these suitable areas are further restricted by socio-economic constraints.

It should be noticed that the analyzed species are not regulated in México; that is, they are not classified as threatened or in risk of extinction, for example, the Monarch butterfly (*Danaus plexippus* L.) and *Papilio esperanza* Beutelspacher are regulated species (SEMARNAT, 2010) and they were not considered in this study. Moreover, federal regulations are required to establish ecotourism zones (SEMARNAT, 2006). Therefore, we consider that using scientific techniques may help for a better planning on using natural resources. To take advantage of the ornamental butterflies in their native environment and considering the importance of México as a tourism destination country, more research is needed to address the different ways butterflies can be managed. For example, to establish wildlife conservation units as a tourist alternative for visitors, that is, to diversify services offered in ecotourism activities; local communities can be empowered by organizing around such activities (Jouault and Pulido-Marariaga, 2014). Another challenge is to consider the effect of climate change; it is known that global warming and land change use affects the elevation distribution of Neotropical butterflies; to address this subject, it is important to consider the interactions among butterflies and their plant hosts as well, which are also affected by climate change (Romo et al., 2014; Molina-Martinez et al., 2016). Currently, when the species habitat is enhanced to increase the populations, it implies preserving it within and across agro-ecosystems and natural landscapes. Moreover, it is worth mentioning that México has protected areas that prevent the unrestricted use of these species (Halffter, 2011). Using these species to make souvenirs and accessories or to establish butterfly farms and gardens would also require further strategic planning to balance the protection of these species and their extraction, this research provides with quantitative information to guide in these processes.

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