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Maximum entropy niche-based modeling (Maxent) of potential geographical distribution of *Coreura albicosta* (Lepidoptera: Erebidae: Ctenuchina) in Mexico

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Abstract

There are many butterfly and moth species in Mexico whose possible areas of distribution are still largely unknown. Some are endemic and rare but are not yet protected by the Norma Oficial Mexicana NOM-059-SEMARNAT-2010 (Environmental protection—Native species of flora and fauna from Mexico). An example is the moth *Coreura albicosta* Draudt (Lepidoptera: Erebidae: Ctenuchina), a rare and apparently endemic species known from southern Mexican cloud forest habitats. To document the distribution of this species, ArcView was used to map its known distribution in Mexico. Maxent models were used to predict *C. albicosta*'s potential distribution. Results indicate that *C. albicosta* is distributed exclusively in high altitudes along mountainous cloud forests of the Sierra Madre Oriental and the mountains of Chiapas. The Maxent model proved to be highly reliable (AUC = 0.984), and the ability to predict the excluded grid in every model was high (88.9%). Environmental variables with a large contribution to the model were vegetation type and mean annual precipitation. Only 1.0% of the species' known distribution and 6.8% of the potentially favorable grids coincided with the existing network of spaces protected in Mexico. Results emphasize the need to promote the conservation of this endemic cloud forest species and support the proposed inclusion of *C. albicosta* in the Mexican legislation for species protection with the purpose of conservation.

Key Words: ArcView; endemic species; biodiversity; biological conservation

Resumen

Existen numerosas especies de mariposas y polillas cuyas posibles áreas de distribución en México son totalmente desconocidas. Algunas de estas especies son endémicas o raras, sin embargo ninguna está protegida en la Norma Oficial Mexicana 059-SEMARNAT-2010 (Protección ambiental-Especies nativas de México de flora y fauna silvestres). Un claro ejemplo de este problema es la polilla *Coreura albicosta* Draudt (Leipdoptera: Erebidae: Ctenuchina), una especie rara y aparentemente endémica conocida solo de los bosques nublados del sur de México. A objeto de aumentar el conocimiento sobre la distribución de esta especie se utilizaron los programas Arcview, para ubicar puntos de distribución conocida de México y Maxent, para establecer modelos de predicción de su distribución potencial. Los resultados obtenidos indican que *C. albicosta* se encuentra exclusivamente en bosques nublados en la Sierra Madre Oriental y las montañas de Chiapas. El modelo Maxent fue altamente confiable (AUC = 0.984) y su capacidad para predecir la cuadrícula excluida en cada modelo fue elevada (88.9%). Las variables ambientales de mayor contribución al modelo fueron el tipo de vegetación y la precipitación media anual. Sólo 1.0% de los datos de distribución conocidos de esta especie y 6.8% de cuadrículas potencialmente favorables predichas coincide con la red de áreas protegidas de México. Estos resultados enfatizan la necesidad de promover la conservación de esta especie endémica de bosques nublados y proponer la inclusión de *C. albicosta* en la legislación mexicana de protección de especies para estimular su conservación.

Palabras Clave: ArcView; especie endémica; biodiversidad; conservación biológica

The knowledge of the distribution of numerous species, especially when they are part of a group as diverse as the arthropods, is scarce and frequently imprecise mainly because surveys are incomplete most of the time (Jiménez-Valverde & Hortal 2003), sampling efforts are frequently inadequate (Romo & García-Barros 2005), and sampling methods used are not necessarily standardized (Jiménez-Valverde & Lobo 2004). To determine the conservation status of any organism, a clear knowledge of their biology, population fluctuation, and distribution is needed (New 2014). However, the inability to register all species during any particular sampling survey is a serious methodological problem for biodiversity studies (Gotelli & Colwell 2001). One of the strategies used to address such problems is based on the development of predic-

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tive models of the potential distribution of the species, which can also be used for effective strategies of species conservation (Peterson et al. 2000; Barbosa et al. 2003; Loiselle et al. 2003; Anderson & Martínez-Meyer 2004; Romo et al. 2014). Among the well-established methods, maximum entropy (Maxent) is one of the most reliable (Phillips et al. 2004, 2006; Elith et al. 2006; Benito de Pando & Peñas de Giles 2007; Wisz et al. 2008).

Lepidoptera are among the few insect groups so far studied using predictive distribution modeling (Hill et al. 2003; Romo et al. 2006; Jiménez-Valverde et al. 2008; Newbold et al. 2009; Lozier & Mills 2011; Gutierrez et al. 2012; Lv et al. 2012; Romo et al. 2013). In Mexico, only one study related to monarch butterflies *Danaus plexippus* L. (Lepidoptera: Nymphalidae) have used this sort of modeling analysis (Oberhauser & Peterson 2003). However, none has used Maxent specifically.

As a first approach, we have compiled information of a rare but very likely endemic species of the cloud forests of the Sierra Madre Oriental in Mexico, *Coreura albicosta* Draudt (Lepidoptera: Erebidae: Ctenuchina). The currently known distribution has been established mainly based on collections and records published between 1916 and 2010*.* Its habitat is restricted and as far as we know is limited to the mountainous cloud forest of the Sierra Madre Oriental and the cloud forests of Chiapas and Oaxaca. Mountainous species such as *C. albicosta* are expected to suffer from climate changes in the future (Beniston et al. 1997; Hill et al. 2002; Wilson et al. 2007). This species is also demographically rare, and only 38 registered specimens have been reported from 10 Mexican localities. Besides this scarcity of collected specimens, *C. albicosta* is, at the same time, ecologically rare and only flies at dawn and at dusk in environments of limited access with high relative humidity and precipitation. As most of the mountainous cloud forests in Mexico are under-sampled, knowing the potential distribution of this species, as well as similar species, could be valuable and provide information to improve future surveys. These reasons led us to consider that the species may be a good candidate for studying distribution and conservation status. Thus, the aim of this work was to study the potential distribution of *C. albicosta* in Mexico.

Materials and Methods

The study area included the entirety of Mexico (1,964,375 km^2) which contains both Nearctic and Neotropical elements primarily defined by the Sierra Madre mountains (up to 3,700 m elevation along a 1,350 km range). The target insect *C. albicosta* is a rare moth species found in mountainous cloud forests of the Sierra Madre Oriental. Locality data for the species were obtained from Hernández-Baz (1992) and Hernández-Baz et al. (2012), which include updated curatorial information. Additionally, the database “polilla” (SEMARNAT/CITES/CP-0026-VER/05; SEMARNAT 2010) and registers of the group for the Americas from 1758 to 2013 were consulted. Only 38 records for 10 localities were found for *C. albicosta* in these databases.

The geographical coordinates of all collection sites obtained from curatorial information for *C. albicosta* were corroborated based on Selander & Vaurie (1962), as well as the INEGI catalog of names and the topographic chart of Mexico (1:250,000) developed by the National Statistics, Geography and Informatics Institute (INEGI 1991). All data were verified using http//www.googleearth.com and the ArcView 2.0 program (ESRI 1998). The geographic coordinates of every collection site were converted into decimal degrees (Trujano & Rodríguez 2008) to be later included in a geographic information system through the ArcView 2.0 program. For this process, 2 coverages or levels of information were used: the first one referred to the national limits of Mexico within the continental context and the second one to the state limits inside Mexico. A Robinson projection with a 1:50,000 scale was used. The decimal grades in the map show the distance in kilometers. A map to demarcate the geographic distribution of *C. albicosta* in Mexico was generated.

VARIABLES USED, DISTRIBUTION MODELING, MODELING PARAMETERS, AND DECISION THRESHOLDS

The environmental information on 11 variables taken from the National Commission for the Knowledge and Use of Mexican Biodiversity (CONABIO) database (http://www.conabio.gob.mx/) was investigated using a resolution of 30 Arc seconds. The variables used were evapotranspiration, elevation, slope gradient, average annual precipitation, mean annual temperature, average of maximum annual temperature, average of minimum annual temperature, absolute minimum temperature (minimum temperature registered in the coldest month), absolute maximum temperature (maximum temperature of the warmest month), and human population density (data from 2010). Additionally, we included vegetation type in Mexico, obtained also from CONABIO. To avoid auto-correlation of the variables while doing the models, a Pearson correlation analysis was performed. When the correlation coefficient was higher than 0.75, we chose either the variable more significant to the biological level for the species or the one easier to interpret (Rissler et al. 2006; Rissler & Apodaca 2007). Therefore, the variables used to develop the final models were 1) evapotranspiration (Evapo), 2) mean annual precipitation (AnPrec), 3) height (elevation) (DTM: Digital Terrain Model), 4) human population density (Popul), and 5) potential vegetation (PotVeg).

The Maxent program version 3.3.3k (http://www.cs.princeton.edu/~schapire/maxent/) was used to develop the models. This program uses data on presence of species, together with the environmental variables selected to build the models. Moreover, it works well when there are relatively few presence data (Phillips et al. 2006; Hernández et al. 2006*;* Pearson et al. 2007; Wisz et al. 2008) (only 10 localities are known in our case). The default values of the program were used. The logistic output was selected because it is easiest to understand (Phillips & Dudik 2008). The estimated importance of the environmental variables was calculated with the Jackknife tests offered by the program.

Although it is true that 38 records of the species is a problematic bottleneck in such a large area, it is possible to use potential distribution models in conservation studies when the species has limited distribution and restricted ecological characteristics (de Castro Pena et al. 2014) in order to try to overcome those obstacles. Because the presence data were less than 25 localities, we used the Jackknife (leave-one-out) procedure implemented by Pearson et al. (2007). In order to do that, we built a model for each data point (10), and a presence point was eliminated from each data group, and then each subsequent model was constructed using the remaining $n - 1$ localities. An average final model is represented (Fig. 1). The predictive capacity of the final model chosen was evaluated by comparing it with the models that were capable of predicting the excluded presence point.

It is necessary to select a threshold that will enable distinguishing between grids that are either adequate or unfavorable for the species. Opinions differ about which threshold should be chosen (Liu et al. 2005), and we selected 2 thresholds: 1) an Equal Training Sensitivity and Specificity Logistic Threshold (ETSSLT), which was highlighted by Liu et al. (2005) as one of the best 5 decision thresholds, indicating that it selects a model that has the same probability of predicting real presences as real absences; and 2) a slightly more restrictive arbitrary threshold in which most of the information of presence is gathered but without overestimating the potential predicted area, because

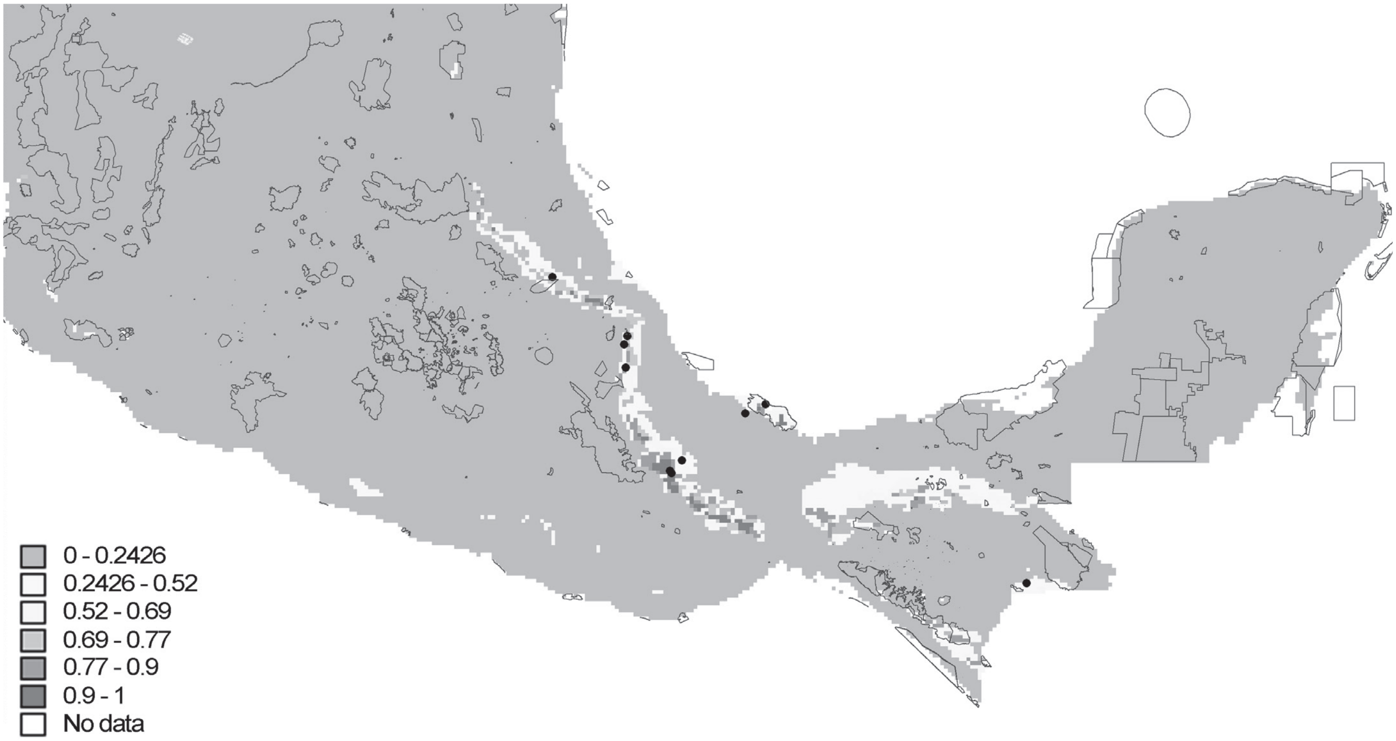

Fig. 1. Model of potential distribution of *Coreura albicosta* with enhancement of the favorable climatic regions for this species, and superposition with the network of protected areas of México. Gray: lower probability of appropriate environmental conditions for distribution of the species. Light gray sections represent the decision threshold (0.2426) in which the grids are favorable for the distribution of the species. Darker sections inside light gray: areas with high probability of presence of the species. Black dots indicate the known distribution of the species. The protected areas are represented with a black line.

wide thresholds are not the ones preferred for conservation purposes (Pearce & Ferrier 2000; Loiselle et al. 2003). The thresholds of decision were obtained from the model evaluated with all the localities.

EVALUATION OF THE MODELS

The AUC (area under a receiver operating characteristic curve) value provided by Maxent was used to measure the discriminative capacity of the generated models (Pearce & Ferrier 2000), because this is a measurement independent from the chosen threshold (Swets 1988; Fielding & Bell 1997). The AUC can assume values between 0 and 1. Values between 0.7 and 0.9 correspond to a model of average useful application, and values above 0.9 indicate the highest accuracy of the model (Pearce & Ferrier 2000; Newbold et al. 2009; Lv et al. 2012). The statistical significance of the prediction was calculated additionally by using 11 binomial tests of omission provided by Maxent (Phillips et al. 2006). An admissible prediction requires significant *P* values. Also, the leave-one-out process was evaluated using the *P* values and the percentage of success obtained with the pValueCompute.exe program (Pearson et al. 2007).

COMPARISON WITHIN THE NETWORK OF PROTECTED AREAS

Coreura albicosta is a rare and endemic species that is not currently protected by the Mexican Norm NOM-059-ECOL. Thus, it was desirable to determine the status of the species within the network of state, municipal, and federal protected areas administered by the National Commission of Protected Natural Areas [Comisión Nacional de Áreas Naturales Protegidas (CONANP)] according to CONABIO (http://www.conabio.gob.mx/). Grids were considered protected when at least 15% of their surface was included in the Mexican network of protected areas.

Results

The number of favorable grids, according to the environmental characteristics they share with the grids where the species is found was very high (1,566; Table 1) when considering the ETSSLT threshold (value of 0.2426). However, for a species with only 10 known locality records, a more restrictive arbitrary threshold was preferred. The threshold value chosen was 0.9 and led us to select 69 grids (Table 1).

The known distribution of this moth species includes the states of Veracruz, Chiapas, Oaxaca, and Puebla (Fig. 1, black dots). The distribution model also suggested as potential favorable areas the wet mountainous forests of Tamaulipas and San Luis Potosí, because they share similar environmental characteristics. Favorable distribution areas were shown only for 2.2% of the national territory (Fig. 1). These areas were restricted to the mountainous cloud forests of the Sierra Madre Oriental and adjacent areas.

The relevant variables that helped to create the potential distribution models, according to the Jackknife trial, were the vegetation type (51.9%), the mean annual precipitation (41.8%), and evapotranspiration (6.3%). The AUC value (test data AUC = 0.984, training data AUC = 0.992) suggested that the model was highly accurate and viable and of higher precision than any other model obtained randomly. The binomial tests were significant ($P < 0.05$), thus showing the reliability of

Table 1. Number of predicted grids that were environmentally favorable to *Coreura albicosta* predicted by the final model under the thresholds adopted and presented in Fig. 1. ETSSLT threshold: 0.2426. Arbitrary threshold with the most favorable grids: 0.9. A gradation between them is also displayed.

Threshold	0.2426	0.52	0.69	0.77	0.9
No. of grids	1,566	757	321	214	69

the model. The success rate to predict the excluded grid in each model was also high (88.9%) and statistically significant for the considered thresholds ($P < 0.05$).

When we considered the network of protected areas, 1 of the 10 grids of the known distribution of the species presented more than 15% of its surface under protection. Few of the potential predicted grids were within the network of protected areas in the country (Fig. 1). Specifically, 172 predicted grids (6.8%) (above the threshold 0.2426) showed over 15% of their surface within the network of protected areas. Using the most restrictive threshold, 5 grids out of the 69 most favorable were also within this web.

Discussion

The distribution of *C. albicosta* was modeled after climatic, vegetation, and human impact data. The mean annual precipitation variable best correlated with the distribution known for the species. This variable and the potential vegetation (especially the mountainous cloud forest and the wet tropical forest) were the most influential variables to build the models. This result was predictable because the main known habitat of the species is characterized by high precipitation. Moreover, both the mean annual precipitation and the real evapotranspiration as measurement of water–energy balance are well-known and influential variables in the distribution of butterflies (Hawkins & Porter 2003; Stefanescu et al. 2004). The vegetation cover is also an important factor for the distribution of butterflies according to Kerr (2001) and Kerr et al. (2001). In this case, the potential areas are distributed to a great extent along cloud forests.

The anthropic factor was not considered to build the models because it did not add any information relative to the distribution of *C. albicosta*, although it is an influential variable in butterfly distributions (Stefanescu et al. 2004). This could be because each known distribution area of *C. albicosta* presented a different population density. Also, it is interesting that the elevation was not necessarily the most important variable in this mountainous moth species, and the altitude at which the moth can be found varied in different areas of Mexico. We have studied specimens of *C. albicosta* found between 161 m (around the San Martin volcano in the tropical region of "Los Tuxtlas," Veracruz) and 1,538 m (Hernández-Baz et al. 2012). Therefore, having only 10 localities and such variation in altitude among them, the elevation variable was not considered significant to build our models.

McPherson & Jetz (2007) found that endemic species were modeled with higher precision than those that were not endemic. This is due to the fact that their distribution tends to be restricted and the known data precision is frequently more reliable. Such reasoning led us to work with *C. albicosta*. Although the relatively low number of known presence records of the species could potentially impede model development, the contrary was true here, and several authors confirmed that in such conditions the predictive capacity of the models is always good (Pearson et al. 2007; Kumar & Stohlgren 2009). There is no apparent methodological problem in the use of only 10 localities in order to propose conservational measures for this scarce species (de Castro Pena et al. 2014), and thus a reasonable amount of information about the geographical distribution of *C. albicosta* was used. Moreover, our success when evaluating the models was quite high (88.9%). Nevertheless, there are still regions of Mexican territory that have not been well surveyed, especially regions with mountainous cloud forests. New information from very isolated regions of Mexico will help to increase the precision of the Maxent models. Moreover, it seems that the potential distribution of *C. albicosta* could not be restricted to Mexico, because the prediction extends to the bordering Guatemala. There is a gene flow beyond the border that should be considered for its conservation status, but we do not have enough information to predict potential areas in Guatemala, if indeed they occur there. In the absence of such data, a preventive measure of conservation in Mexico becomes increasingly necessary.

When the known distribution of this rare and endemic species was characterized in relation to the network of protected areas in Mexico, it became clear that *C. albicosta* is unprotected from the legal point of view, as only 1 site within a protected area was found inside the network. This may not bode well for the survival of the species, because without protection its habitat could be more fragile and susceptible to alteration or degradation. In general, the loss and degradation of the habitat is one of the main threats to Lepidoptera (Hill et al. 2001; Warren et al. 2001; New 2014).

Because the distribution of any species depends on variables related to climate, it is likely that the species could rapidly respond to climatic change (Luoto et al. 2006). However, *C. albicosta* is a species that inhabits mountainous forests; thus, its vulnerability to increasing temperature along with the loss of favorable habitats due to global warming is likely high (Beniston et al. 1997). Therefore, ultimately a good knowledge of the biological and ecological characteristics of the species is required (Lv et al. 2012).

In conclusion, the model revealed a fragmented distribution with few potential distribution areas favorable for this moth species, barely coinciding with the network of protected areas in Mexico. Moreover, it indicated fragile habitats for *C. albicosta* because these mountain cloud forests may be very disturbed due to the effects of climate change.

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