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Original investigation

Potential distribution and areas for conservation of four wild felid species in Mexico: Conservation planning

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ABSTRACT

Knowing the potential distribution of species helps to focus conservation efforts more effectively, mainly when dealing with endangered species. The aim of this study was to generate potential distribution models for four species of small wild felids in Mexico (*Leopardus pardalis, Leopardus wiedii, Lynx rufus* and *Puma yagouaroundi*). The models were generated based on felids presence records, and topographic, anthropic and vegetation drivers. We used 473 records (171 for *L. pardalis*, 140 for *L. wiedii*, 86 for *L. rufus* and 76 for *P. yagouaroundi*) to build eleven models per species to then select the three with the best performance and included them in ensemble models. These were based on the formula of the weighted average, which considers the performance of the algorithms evaluated with a subsample of testing records, from which the area under the curve is calculated. In this way, in the ensemble model the consistent zones between algorithms are included, but the one with the best performance predominates. The species with the largest potential distribution area was *L. pardalis* with 34.3% of the national territory, while *L. rufus* had the smallest area (14.3%). In the four species a unique set of variables was identified that influence the probability of presence, however the altitude, the arid vegetation and the population density were important variables for three of the four species. We verified our models with recently published presence records. The results of this study reflect a robust analysis of the current and potential distribution of four species of wild felids in Mexico. In addition to being the first step to develop effective conservation strategies at national and local levels.

Introduction

The distribution of the species, especially those that are threatened, is modified by changes in the landscape. The increase in the availability of environmental information, biodiversity databases, and georeferenced records have favored the development of species distribution models (SMD) (Aubry et al., 2017). At present, these models are a fundamental tool in the planning of the management of natural resources since they relate the observations made in the field with predictive environmental variables (Guisan and Zimmermann, 2000). Currently, there are several algorithms to model potential distribution, which result in different predictions. One way to reduce the uncertainty between different algorithms is the use of ensemble models, which consider the combination of individual algorithms to obtain consistent prediction areas (Anderson et al., 2003) and robust distribution models (Hartley et al., 2006).

The destruction and fragmentation of natural ecosystems are the main causes of biodiversity loss in the world (Haddad et al., 2015), mammals are among the most threatened groups with 27% of their species in danger of extinction (Crooks et al., 2011). Fragmentation exacerbates edge effects, restricts the movement of individuals and disrupts landscape connectivity. In addition to these threats, wild cats have intrinsic characteristics (low population densities, large home ranges and slow population growth) that increase the probability of extinction (Crooks et al., 2011). Unlike the large species of wild cats such as *Panthera onca*, *Panthera leo*, *Panthera tigris*, among others, the remaining 33 species of small cats receive less attention. According to the Small Wild Cat Conservation Foundation, less than 1% of the economic resources allocated to the conservation of wild cats is invested in the 33 small species.

In Mexico, four species of small wild cats are distributed, *Leopardus pardalis* and *Leopardus wiedii* are in danger of extinction, and *Puma yagouaroundi* is threatened (SEMARNAT, 2010). There

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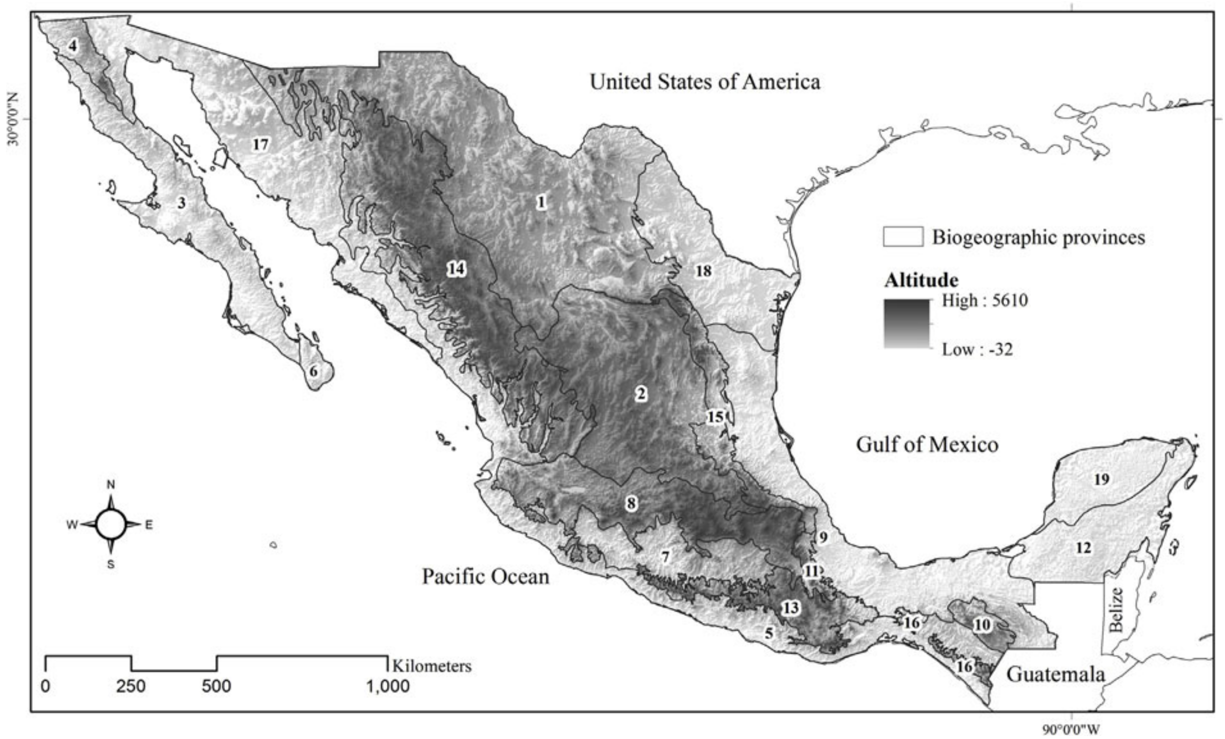

Fig. 1. Study zone, biogeographical provinces are shown (1:Altiplano Norte (Chihuahuense), 2: Altiplano Sur (Zacatecano-Potosino), 3: Baja California, 4: California, 5: Costa del Pacífico, 6: Del Cabo, 7: Depresión del Balsas, 8: Eje Volcánico, 9: Golfo de México, 10: Los Altos de Chiapas, 11: Oaxaca, 12: Petén, 13: Sierra Madre del Sur, 14: Sierra Madre Occidental, 15: Sierra Madre Oriental, 16: Soconusco, 17: Sonorense, 18: Tamaulipeca, 19: Yucatán, CONABIO 1997).

are some studies about the distribution on local-scale, mainly for *Leopardus pardalis* (Ramírez-Bravo et al., 2010; Martínez-Calderas et al., 2011). At the national level, the National Commission for the Knowledge and Use of Biodiversity (CONABIO, for its acronym in Spanish) developed in 2010 maps of historical and current distribution of several species, including *Lynx rufus* and *Puma yagouaroundi* (Ceballos et al., 2006). However, the resulting areas are overestimated, due to the algorithm used (GARP, Stockman et al., 2006; Peterson et al., 2007) and to included inaccurate historical records (Engler et al., 2004). Espinosa et al. (2017) recently conducted the distribution models for *Leopardus wiedii* and *Puma yagouaroundi* considering their original distribution in America. Nevertheless, they don't consider anthropic or landscape structure variables, in addition that the models at continental scale may have poor performance and limited predictive capacity, underestimating the predicted distribution areas. This is because the variability of environmental conditions is greater as the area for modeling increases (Ferraz et al., 2012). Therefore, it is necessary to generate models with a spatial scale congruent with the management scale (Ferraz et al., 2012). The objectives of this study were: a) to generate models of potential distribution of small wild cats in Mexico and b) identify priority areas for conservation of these species.

Material and methods

Study area

The extension of Mexico is 1 959 248 km^2, 29.6% of the territory is covered by xerophilous scrub, followed by agriculture and pastureland (23.2%), deciduous forest (8.6%), coniferous forest (8.6%), oak forest (8%), among others (SEMARNAT, 2009). It presents an altitudinal range from −32 to 5610 masl., finding the highest altitudes in the province Eje Volcánico. (Fig. 1) It is divided into biogeographical provinces, which were defined from vascular plants, amphibians, reptiles, mammals and the main morphotectonic features.

Species data

Records of felids presence in Mexico were collected in three ways: a) review of digital databases like GBIF (www.gbif.org) and MANIS (www.manisnet.org), b) literature review (Mexican Mastozoological Atlas, 79 scientific papers -Appendix 1 in Supplementary material- and five books), and c) field work in six regions. The current electronic databases contain historical data from museums or private collections that may be useful in the conservation and study of the distribution of species, however they have some errors (identification of species, changes in the nomenclature, geographical accuracy) that generate inconsistencies in species distribution models (Newbold, 2010). That is why the records were depurated considering the date (1990–2013), precise coordinates (or a detailed geographical description) and a single record per square kilometer to avoid the spatial correlation of the records (Pliscoff and Fuentes-Carrillo, 2011). The records of the social science network NaturaLista (http://www.naturalista.mx/) were not included since it was launched in December 2013 (CONABIO, 2015). Data were randomly divided into two subgroups, one used for model calibration (70%) and the other for validation (30%, Araújo et al., 2005).

Environmental data

Thirteen variables that could be related to the presence of the species were considered (Table 1). We used nine environmental variables of land use and vegetation obtained from Landsat TM5 multispectral images and field verification data (INEGI, 2015). Two topographic variables were included: altitude and slope (USGS/NASA, 2007), the vector data set 1: 1 000 000 scale of

Table 1
Variables used to generate the distribution models for small felids in Mexico.

	Variable (units)	Source	Year
1	Agriculture (percentage)	INEGI	2012
2	Template forest (percentage)	INEGI	2012
3	Grassland (percentage)	INEGI	2012
4	Water bodies (percentage)	INEGI	2012
5	Deciduous forest (percentage)	INEGI	2012
6	Evergreen forest (percentage)	INEGI	2012
7	Acuatic vegetation (percentage)	INEGI	2012
8	Arid vegetation (percentage)	INEGI	2012
9	Without vegetation (percentage)	INEGI	2012
10	Elevation (meters above sea level)	USGS	2007
11	Slope (grades)	USGS	2007
12	Roads (distance to)	INEGI	2015
13	Human population (density)	Center for International Earth Science Information Network	2010

asphalted roads of two and four lanes (INEGI, 2014) and a demographic variable (population density) of the Socioeconomic Data and Applications Center (SEDAC) (http://sedac.ciesin.columbia.edu/) All variables were transformed into a raster with a resolution of 1 km^2 in the Andes version of Idrisi (Clark Labs, 2006). In BioMapper4 (Hirzel et al., 2004), the correlation of the variables was obtained and those with a value greater than 0.5 were discarded (Zarco-González et al., 2013).

Species distribution models

To estimate the potential distribution, we use OpenModeller (version 1.5.0), where different algorithms are applied simultaneously (Muñoz et al., 2009). The algorithms used were: Artificial Neural Network (Pearson et al., 2004), Environmental Distance (Hirzel and Arlettaz, 2003), GARP (version the best subsets, Stockwell and Peters, 1999) and SVM (Support Vector Machines, Drake and Bossenbroek, 2009). Maxent was obtained using Maximum Entropy Species Distribution Modeling version 3.2.19. (Phillips et al., 2006) and ENFA (Hirzel et al., 2002) in BioMapper4. With ENFA the value of marginality was obtained, this indicate the difference between the mean of the conditions used by a species and that of the global conditions. The contribution percentages of each variable to the model were obtained from Maxent. The algorithms were run for each species and the obtained models were evaluated with the Area Under the Curve (AUC) in Idrisi's Receiver Operating Characteristic (Hanley and McNeil, 1982) module (Clark Labs, 2006).

For the ensemble models we used the weighted average method, we obtained an internal AUC value (considering calibration data), and an external one (considering validation data). The external AUC was used as a pre-selection criterion for the algorithms that were included in the ensemble model, while the internal AUC was included in the weighted average formula (Marmion et al., 2009).

Table 3
Value of global marginality for each felid species, according to ENFA.

Species	Marginality
Lynx rufus	1.255
Leopardus wiedii	0.839
Puma yagouaroundi	0.602
Leopardus pardalis	0.537

L. pardalis, *L. wiedii* and *P. yagouaroundi* are sympatric throughout their distribution, therefore we made a new ensemble model to identify common zones of distribution, which we called ensemble model for tropical felids. This, as well as the potential distribution model for lynx, were reclassified (Liu et al., 2005) into two categories of habitat suitability: high (pixels with values ≥ 50) and low (<50).

To verify the models we made a revision of the recent literature (2013–2017) obtaining the coordinates where the species have been registered. Then we describe how many of the recent records coincide with the areas of high habitat suitability identified in the models.

Results

We collected 1301 records of the presence of small felids, of which 473 were retained, after depuration. The most frequent species were *L. pardalis* (171), followed by *L. wiedii* (140), *L. rufus* (86) and finally *P. yagouaroundi* (76). We made eleven models for each species (44 in total), three algorithms per species were included in the ensemble models (Table 2). Maxent had the best performance for the four species.

According to ENFA, *Lynx rufus* had the highest marginality value (1.255), suggesting that their habitat requirements are more specific than tropical wild felids (0.537, Table 3).

Table 4 shows the variables with the highest percentage of contribution to the model according to Maxent, the range within each variable in which the species is most probable to be found and if the correlation between the probability of presence and the variable is positive or negative (Table 4).

Then we obtained the ensemble model for tropical felids (Fig. 2) and an individual one for each species (Fig. 3 for *L. pardalis*, Fig. 4 for *L. wiedii*, Fig. 5 for *P. yagouaroundi*) and one ensemble model for *L. rufus* (Fig. 6). The table shown below contains the area identified in the consensus models, the percentage of these areas with respect to the surface of the country and the provinces in which it is located (Table 5).

As for the verification of the models, we found 28 scientific articles from which 47 recent presence records were extracted (15 for

Table 2
Performance of algorithms included in the ensemble models of potential distribution for small felids in Mexico.

Species	Algorithm	AUC Internal	AUC External
	GARP with Best Subsets (new open Modeller implementation)	0.748	0.766
Leopardus pardalis	Maxent	0.887	0.857
	SVM (Support Vector Machines)	0.772	0.805
	ENFA	0.783	0.807
Leopardus wiedii	Maxent	0.937	0.885
	SVM (Support Vector Machines)	0.874	0.835
	ENFA	0.729	0.729
Puma yagouaroundi	Maxent	0.882	0.821
	SVM (Support Vector Machines)	0.849	0.772
	GARP with Best Subsets (Desktop GARP implementation)	0.751	0.803
Lynx rufus	Maxent	0.859	0.855
	SVM (Support Vector Machines)	0.830	0.852

Table 4
Variables with higher percentage of contribution and range in which the probability of presence of the felid species was greater than 50%, according to Maxent. The correlation refers to the effect of the variable on the probability of presence.

Species	Variable	Contribution percentage (%)	Range	Correlation
	Altitude	17	0–1700 masl	Positive
Leopardus pardalis	Arid vegetation	16.6	<65%	Negative
	Evergreen forest	14.1	<20%	Positive
	Arid vegetation	33.8	0%	Negative
Leopardus wiedii	Population density	16.3	<2300	Negative
	Altitude	9.1	0–1800 masl	Negative
	Arid vegetation	25	<35%	Negative
Puma yagouaroundi	Population density	21.8	<2500	Negative
	Evergreen forest	12.9	>30%	Positive
	Altitude	66.7	2500–4.500 masl	Positive
Lynx rufus	Population density	23.5	>1000	Positive
	Deciduous forest	4.1	>98%	Negative

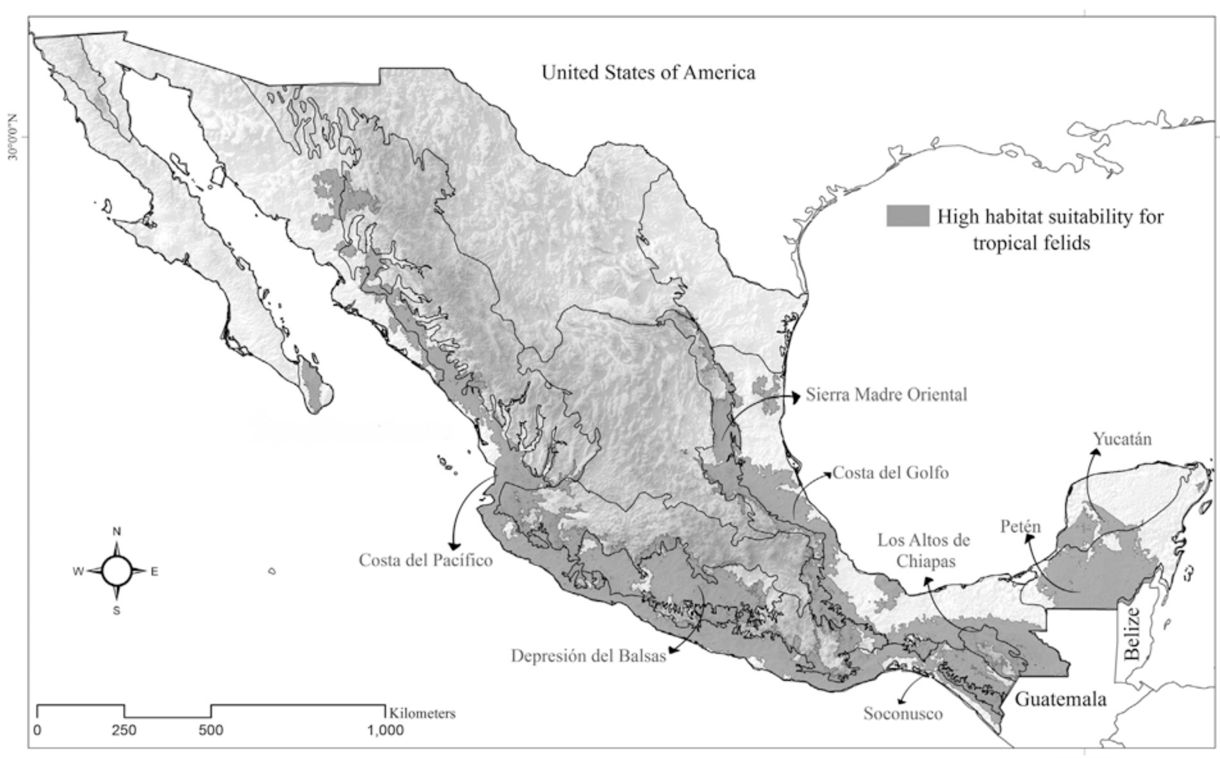

Fig. 2. Ensemble model of potential distribution of three tropical felid species in Mexico.

L. pardalis, 15 for *L. rufus*, 9 for *L. wiedii* and 8 for *P. yagouaroundi*, Appendix 1.2 in Supplementary material).

By superimposing the recent records of the species on the polygons identified in ensemble models, we found a 60% match for *L. rufus* and 71.87% for tropical felids (Appendix 1.1 in Supplementary material, fig. A and B).

Discussion

Information about habitat use of species is important for planning conservation actions (Hodge, 2014). The distribution models for *L. pardalis* and *L. wiedii* are the first for Mexico, despite being two of the ten most endangered carnivores in the country (Valenzuela and Vázquez, 2007). The conservation of these regions identified as important in ensemble models increases the protection not only of small mexican wildcats but also of other threatened vertebrates such as birds (Ortega-Huerta and Vega-Rivera, 2017), amphibians and reptiles (Domíguez-Vega et al., 2012)

Leopardus pardalis

Although the historical altitudinal range reported for the species is 1200 masl, recently, Valdez-Jiménez et al. (2013), recorded an ocelot at 1898 masl in the Calvillo, Aguascalientes locality. The second most important variable related to the presence of the ocelot was the arid vegetation, with negative correlation; however, one of the most recent records locates the species in submontane scrubland (Velazco-Macías and Peña-Mondragón, 2015). Therefore the possibility that this species begins to use areas with this type of vegetation and at altitudes outside the common range is not ruled out. The evergreen forest had a positive influence on the probability of ocelot presence, in this type of vegetation is where it is found more frequently, so it is fundamental for the conservation of this felid to maintain the remnants of evergreen forest, since at the national level more than 95% of tropical humid forests (including evergreen forests and cloud forests, INE, 2007) have been lost.

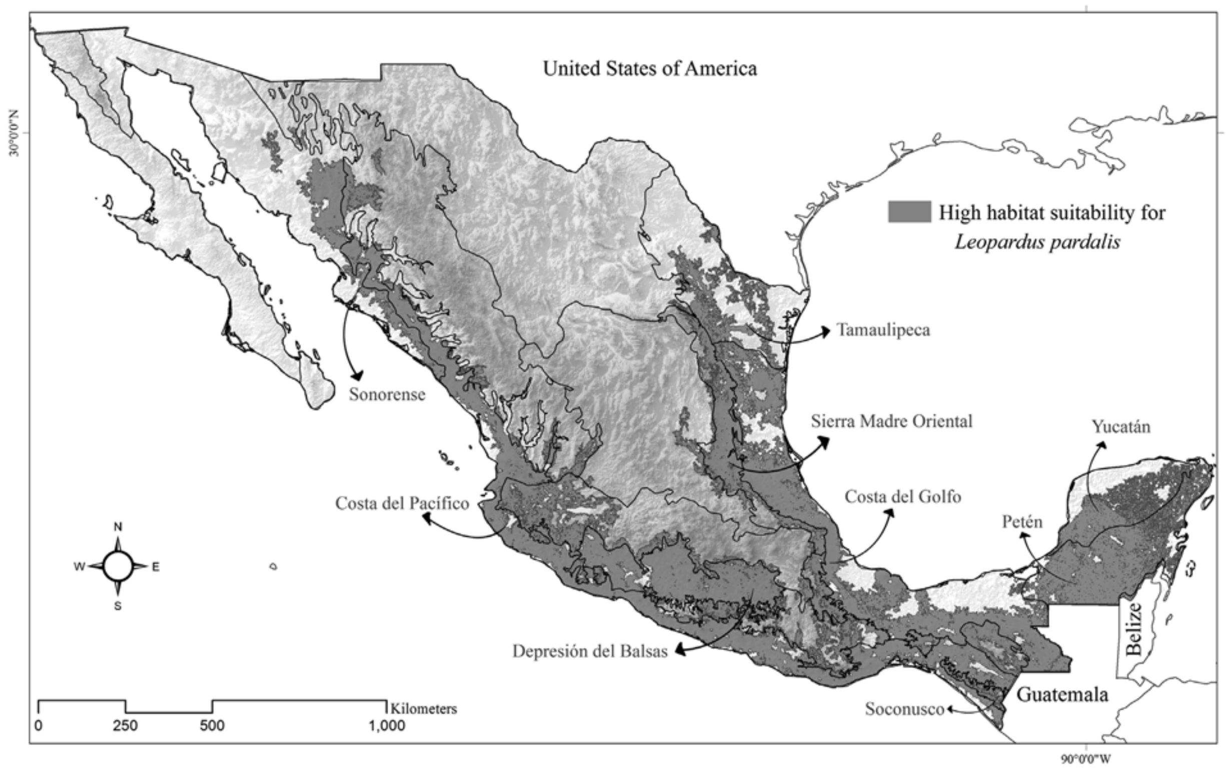

Fig. 3. Ensemble model of *Leopardus pardalis* (AUC = 0.868).

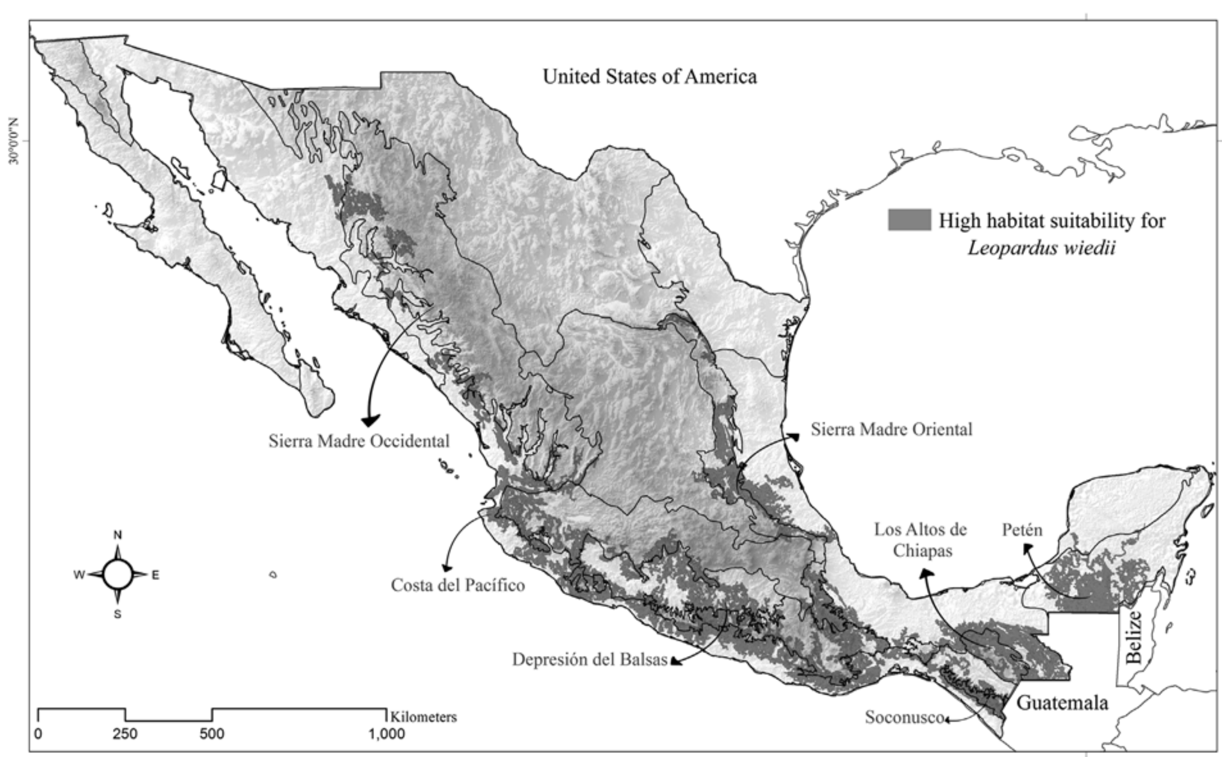

Fig. 4. Ensemble model of *Leopardus wiedii* (AUC = 0.883).

Unlike the distribution models of the other three species, human population density was not important in the model of *L. pardalis*, since it is considered one of the most tolerant felids to human presence. According to Pérez-Irineo and Santos-Moreno (2014) the ocelot can use sites close to human settlements or live-stock grazing areas, only if the surrounding vegetation cover is dense.

The southeast and some sites in the north of the Sonorense province are important for distribution of the ocelot. These sites could be the only corridor between populations of *L. pardalis*

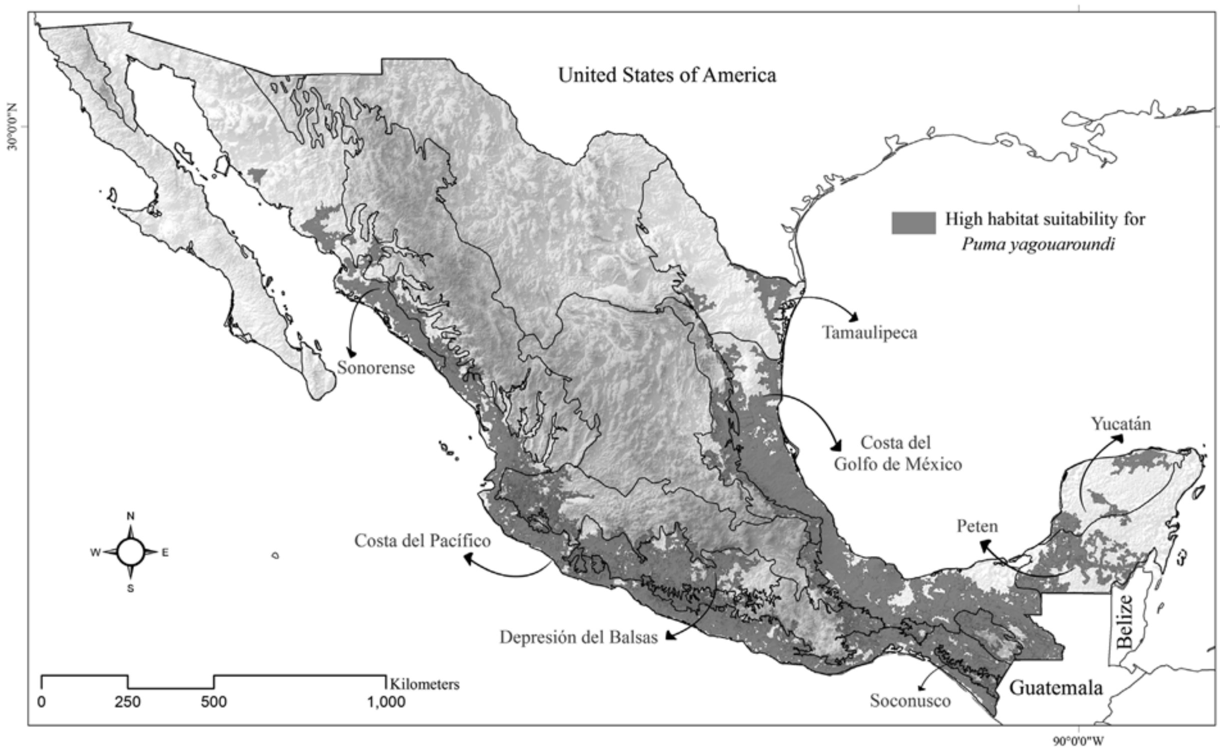

Fig. 5. Ensemble model of *Puma yagouaroundi* (AUC = 0.810).

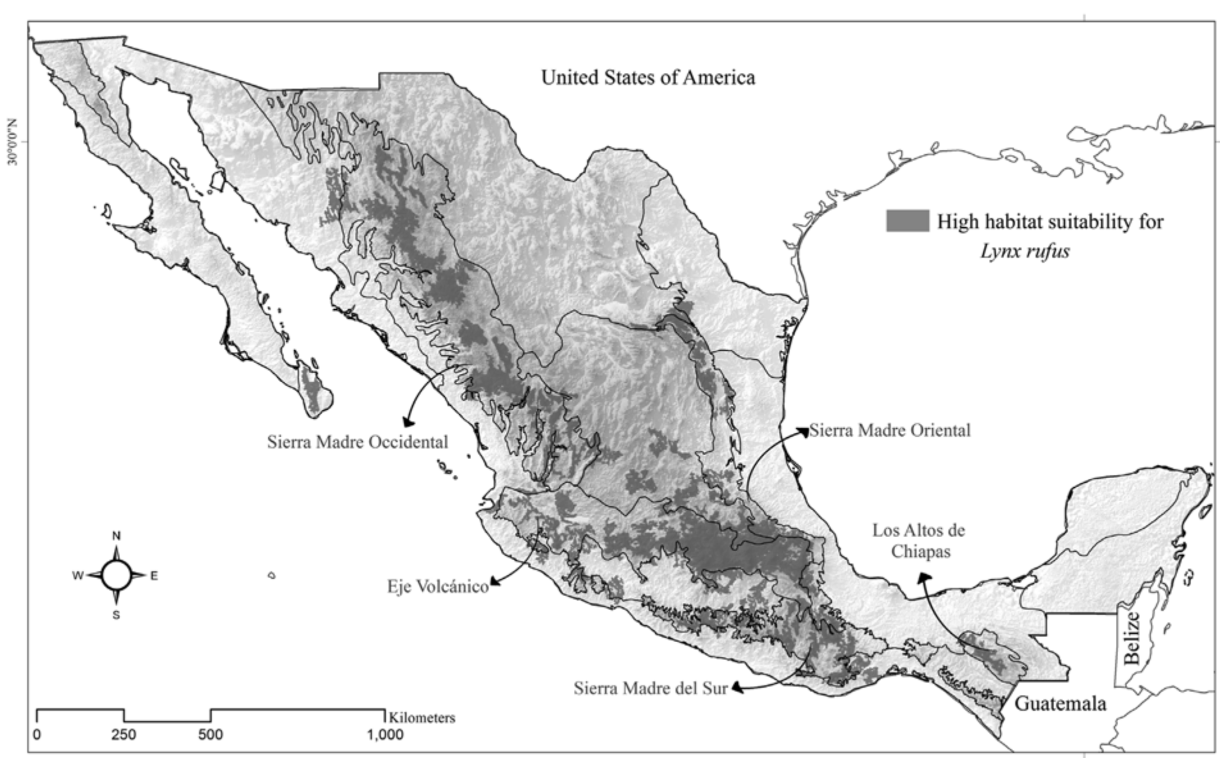

Fig. 6. Ensemble model of *Lynx rufus* (AUC = 0.847).

in the north of the country and of southern Arizona (Ávila-Villegas and Lamberton-Moreno, 2013). Coinciding with the study by Grigione et al. (2009), the northeast of the Sierra Madre Oriental was identified as an important area in the conservation of *L. pardalis* and as a possible corridor. This region, in addition to potentially connecting the populations of northern Mexico with those of southern Texas, can also connect populations from the northeast of the Sierra Madre Oriental to the south of Tamaulipeca province. The human population growth in South Texas leads to an increase in communication routes and, there-

Table 5
Area of suitable habitat delimited from the ensemble models for each species.

Ensemble model	Area (km^2)/percentage with respect to the country	Provinces
Tropical felids	450,840 km^2 (23.01%)	Costa del Pacífico, Costa del Golfo, Sierra Madre Oriental, Oaxaca, Petén and Yucatán
Leopardus pardalis	672,611 km^2 (34.33%)	Sonorense, Costa del Pacífico, Depresión del Balsas, Soconusco, Yucatán and Petén,
Leopardus wiedii	314,531 km^2 (16.05%)	Sierra Madre Occidental, Costa del Pacífico, Depresión del Balsas, Sierra Madre Oriental, Oaxaca, Petén, Soconusco and Costa del Golfo.
Puma yagouaroundi	441,518 km^2 (22.53%)	Sonorense, Costa del Pacífico, Depresión del Balsas, Soconusco, Yucatán, Petén, Costa del Golfo and Tamaulipeca
Lynx rufus	281,348 km^2 (14.35%)	Sierra Madre Occidental, Eje Volcánico, Sierra Madre del Sur, Los Altos de Chiapas and Sierra Madre Oriental

fore, mortality of ocelot individuals due to run over (Haines et al., 2005).

Leopardus wiedii

Exist a few information about the distribution and ecological requirements of *L. wiedii*. It is susceptible to human disturbance, land-use change and deforestation (Rocha-Mendes and Bianconi, 2009). The variables with the greatest contribution to their potential distribution were arid vegetation, human population density and altitude, all with a negative correlation. *Leopardus wiedii*, like *L. pardalis* and *P. yagouaroundi* are considered as neotropical species (Grigione et al., 2009), associated mainly to evergreen forest, this explains the negative influence of arid vegetation. Regarding the altitude, the majority of the populations are reported in sites less than 1000 masl; however, Aranda and Valenzuela-Galván (2015) reported the species in cloud forest at 2750 masl. Although, agriculture was not an important variable in this study, according to Hodge (2014), *L. wiedii* may be using the edges between the forests and agriculture fields for rodent predation.

Potential distribution areas are more fragmented in the Sierra Madre Occidental and in the northern Costa del Pacífico. Its distribution continues until the south of the Costa del Pacífico in Chiapas and is interrupted in Tabasco, therefore the area of the province of Petén is isolated. The discontinuity found in Tabasco may be a consequence of the high deforestation rates in this region in previous years, since between 1940 and 1980 almost the whole forest area was lost (Céspedes- Flores and Moreno- Sánchez, 2010).

Puma yagouaroundi

This species is generally associated with low population densities; however, there are records of its presence within 500 m to human settlements (Coronado-Quibrera, 2011). The potential distribution obtained for this species is more continuous than obtained for *L. wiedii,* probably due to its capacity to inhabit edges between forests and open areas such as pastures (Aranda, 2005).

When comparing the ensemble model obtained for *P. yagouaroundi* with distribution reported by CONABIO (Ceballos et al., 2006), there are some differences, mainly in the predicted area, since the mentioned study reported 821,911.6 km^2 as potential distribution area, i.e. 41.8% of the total country; in addition to consider areas on the California peninsula where the species has not been registered.

The northern region of the Tamaulipeca province represents an important area to maintain the genetic diversity of southern Texas felids populations, in this area Holbrook et al. (2013) evaluated the genetic diversity of *P. yagouaroundi* in free living and reported low diversity values.

In general the Tamaulipeca province the results coincide with Grigione et al. (2009), is indeed an important area for the distribution of three tropical felids. The difference is that the area identified in this study reaches north of Tamaulipas, just on the border with Texas. This region is important since the presence of *L. pardalis* and *L. wiedii* has been documented, represents the northern limit of the distribution of both species and in recent years had been affected for change of land use to cropland (vegetables, citrus, sugarcane, cotton, among others, Campbell, 2003).

Lynx rufus

Lynx is commonly found from sea level up to 3600 masl (Romero, 2005). However, in the distribution model there is a trend towards the regions of the main mountain systems of the country, such as the Sierra Madre Occidental and the Eje Volcánico, in which the altitude values surpass 4000 masl.

Due to the wide altitudinal range in which *L. rufus* is found, it inhabits a great variety of environments (Romero, 2005). It is mainly associated to areas with dense vegetation cover, but unlike tropical species, *L. rufus* uses cover not only to hide, but also to withstand extreme temperatures (Sunquist and Sunquist, 2002). In Mexico it is more abundant in the center of the country in pine, pine-oak, oak and fir tree forest (Romero, 2005).

This model also predicts areas in which the species has not been reported as Altos de Chiapas, this means that environmental conditions exist for allow its presence, so it is necessary to conduct a new investigation in order to verify or rule out the presence of the species in this area.

As for the distribution presented by CONABIO (Ceballos et al., 2006), some differences are also observed. The area previously proposed was 1,706,921 km^2 (87.1% of the total of the country). Similarly, Roberts and Crimmins (2010) conducted a study in which they evaluated the spatial distribution and population trends of *L. rufus* in North America. They report that in Mexico the suitable habitat for *L. rufus* covers 1,702,545 km^2, i.e. 86.9% of the national territory, whereas in this study we estimated 281,348 km^2 (14.3% of the total area of the country). It is important to mention that the models generated by CONABIO, at least for *L. pardalis* and *P. yagouaroundi* have been modified repeatedly. The data used to generate the models and the depuration of these they seem to be a black box, so the results are quite questionable.

The verification of the maps of potential distribution, from recent presence records, is a way of demonstrating the usefulness of the spatial distribution models. For species with large home range it is important to consider and know not only the distribution, but also the connectivity between patches of habitat, so this study sets the stage for future research on this subject. Finally, the information generated from the models of potential distribution is a starting point for the identification of areas towards which to direct conservation efforts. They are also the foundations for the design and subsequent proposal of specific and effective strategies based on the characteristics of the areas identified for the conservation of species and ecosystems in the long term.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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References

Anderson, R.P., Lew, D., Peterson, A.T., 2003. Evaluating predictive models of species distributions: criteria for selecting optimal models. Ecol. Modell. 162, 211–232, http://dx.doi.org/10.1016/S0304-3800(02)00349-6.

Aranda, M., 2005. Puma yagouaroundi. In: Ceballos, G., Oliva, G. (Eds.), Los mamíferos silvestres de México. CONABIO – UNAM – Fondo de Cultura Económica, México D.F, pp. 358–369.

Aranda, M., Valenzuela-Galván, D., 2015. Registro notable de margay (*Leopardus wiedii*) en el bosque mesófilo de montaña de Morelos, México. Rev. Mex. Biodivers. 86, 1110–1112, http://dx.doi.org/10.1016/j.rmb.2015.09.015.

Araújo, M., Pearson, R., Thuiller, W., Erhard, M., 2005. Validation of species climate impact models under climate change. Glob. Chang. Biol. 11, 1504–1513, http://dx.doi.org/10.1111/j.1365-2486.2005.01000.x.

Aubry, K.B., Raley, C.M., McKelvey, K.S., 2017. The importance of data quality for generating reliable distribution models for rare, elusive, and cryptic species. PLoS One 12 (6), e0179152, http://dx.doi.org/10.1371/journal.pone.0179152.

Ávila-Villegas, S., Lamberton-Moreno, J., 2013. Wildlife survey and monitoring in the sky Island region with an emphasis on neotropical felids. In: Gottfried, Gerald J., Ffolliott, Peter F., Gebow, Brooke S., Eskew, Lane G., Collins, Loa C. (Eds.), Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelago III and 7th Conference on Research and Resource Management in the Southwestern Deserts; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 441–447.

Campbell, L., 2003. Jaguarundi. In: Endangered and Threatened Animals of Texas Their Life History and Management. Wildlife Division. 4200 Smith School Road Austin, Texas 78744.

Ceballos, G., Blanco, S., González, C., Martínez, E., 2006. 'Lynx rufus. Distribución potencial'. Extraído del proyecto DS006' Modelado de la distribución de las especies de mamíferos de México para un análisis GAP.

Center for International Earth Science Information Network-CESIN-Columbia University and Centro Internacional de Agricultura Tropical –CIAT-, 2010. Gridded Population of the World, Versión 3 (GPWv3): Population Density Grid, Future Estimates. NASA Socioeconomic Data and Aplications Center SEDAC, Palisades, NY (Accessed 15.05.2016).

Céspedes-Flores, S., Moreno- Sánchez, E., 2010. Estimación del valor de la pérdida de recurso forestal y su relación con la reforestación en las entidades federativas de México. Investigación ambiental 2, 5–13.

Clark Labs, 2006. Idrisi 15: the Andes edition. Clark Photo Labs, Worcester, Massachusetts, MA, USA.

CONABIO, 2015. NATURALISTA Plataforma de Ciencia (Accessed: 20-05-2015) https://www.gob.mx/conabio/prensa/naturalista?idiom=es).

Coronado-Quibrera, W., 2011. Distribución geográfica y ecológica del jaguarundi (*Puma yaguaroundi*) en el estado de San Luis Potosí, México. Master thesis. Colegio de Postgraduados. Montecillo, Texcoco, Edo. de México.

Crooks, K., Burdett, C., Theobald1, D., Rondinini, C., Boitani, L., 2011. Global patterns of fragmentation and connectivity of mammalian carnivore habitat. Philos. Trans. R. Soc. Lond. B Biol. Sci. 366, 2642–2651, doi: [10.1098/rstb.2011.0120].

Domíguez-Vega, H., Monroy-Vilchis, O., Balderas-Valdivia, C., Gienger, C.M., Ariano-Sánchez, D., 2012. Predicting the potential distribution of the beaded lizard and identification of priority areas for conservation. J. Nat. Conserv. 20 (4), 247–4253, http://dx.doi.org/10.1016/j.jnc.2012.04.003.

Drake, J.M., Bossenbroek, J.M., 2009. Profiling ecosystem vulnerability to invasion by zebra mussels with support vector machines. Theor. Ecol. 4, 189–198, http://dx.doi.org/10.1007/s12080-009-0050-8.

Engler, R., Guisan, A., Rechsteiner, L., 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. J. Appl. Ecol. 41, 263–274, http://dx.doi.org/10.1111/j.0021-8901.2004.00881.x.

Espinosa, C., Trigo, T., Tirelli, F., Gonçalves da Silva, L., Eizirik, E., Queirolo, D., Mazim, D., Peters, F., Favarini, M., de Freitas, T., 2017. Geographic distribution modeling of the margay (*Leopardus wiedii*) and jaguarundi (*Puma yagouaroundi*): a comparative assessment. J. Mammal. 1, 252–262, http://dx.doi.org/10.1093/jmammal/gyx152.

Ferraz, K., Ferraz, S., Cunha de Paula, R., Beisiegel, B., Breitenmoser, C., 2012. Species distribution modeling for conservation purposes. Natureza Conservaçao 10 (2), 214–220.

Grigione, M., Menke, K., López-González, C., List, R., Banda, A., Carrera, J., Carrera, J., Giordano, A., Morrison, J., Sterrnberg, M., Thomas, R., Van, B., 2009. Identifying potential conservation areas for felids in the USA and Mexico: integrating reliable knowledge across an international border. Oryx 43, 78–86, http://dx.doi.org/10.1017/S0030605308002019.

Guisan, A., Zimmermann, N., 2000. Predictive habitat distribution models in ecology. Ecol. Modell. 135, 147–186, http://dx.doi.org/10.1016/S0304-3800(00)00354-9.

Haddad, N., Brudving, L., Clobert, J., et al., 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Sci. Adv. 1 (2), e1500052, http://dx.doi.org/10.1126/sciadv.1500052.

Haines, A., Tewes, M., Laack, L., 2005. Survival and sources of mortality in ocelots. J. Wildl. Manag. 69, 255–263.

Hanley, J., McNeil, B., 1982. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology 143, 29–36, http://dx.doi.org/10.1148/radiology.143.1.7063747.

Hartley, S., Harris, R., Lester, P., 2006. Quantifying uncertainty in the potential distribution of an invasive species: climate and the Argentine ant. Ecol. Lett. 9, 068–1079, http://dx.doi.org/10.1111/j.1461-0248.2006.00954.x.

Hirzel, A.H., Hausser, J., Chessel, D., Perrin, N., 2002. Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? Ecology 83 (7), 2027–2036.

Hirzel, A., Arlettaz, R., 2003. Modelling habitat suitability for complex species distribucions by environmental-distance geometric mean. J. Environ. Manage. 32, 614–623, http://dx.doi.org/10.1007/s00267-003-0040-3.

Hirzel, A., Hausser, J., Perrin, N., URL: 2004. Biomapper 4.0. Lab. of Conservation Biology, Department of Ecology and Evolution. University of Lausanne http://www.unil.ch/biomapper.

Hodge, A., 2014. Habitat selection of the margay (*Leopardus wiedii*) in the eastern Andean foothills of Ecuador. Mammalia 78, 351–358, http://dx.doi.org/10.1515/mammalia-2013-0070.

Holbrook, J., Caso, A., De Young, R., Tewes, M., 2013. Population genetics of jaguarundis in Mexico: implications for future research and conservation. Wildl. Soc. Bull. 37, 336–341, http://dx.doi.org/10.1002/wsb.246.

INE (Instituto Nacional de Ecología), 2007. Transformación de los Sistemas Naturales de México (Accessed: 20.05.2016) http://www2.ine.gob.mx/publicaciones/libros/43/dos.html#top.

INEGI (Instituto Nacional de Estadística y Geografía), Escala 1:250 000. Serie VI 2015. Conjunto de datos vectoriales de Uso del suelo y vegetación. http://www.beta.inegi.org.mx/temas/mapas/usosuelo/.

INEGI (Instituto Nacional de Estadística y Geografía), 2014. INEGI (Instituto Nacional de Estadística y Geografía) (Accessed: 20.05.2016) http://www.inegi.org.mx/geo/contenidos/topografia/topografia_1m.aspx.

Liu, C., Berry, P., Dawson, T., Pearson, R., 2005. Selecting thresholds of occurrence in the prediction of species distribution. Ecography 28, 385–393, http://dx.doi.org/10.1111/j.0906-7590.2005.03957.x.

Marmion, M., Parviaenen, M., Luoto, M., Heikkinen, R., Thuiller, W., 2009. Evaluation of consensus methods in predictive species distribution modelling. Divers. Distrib. 15, 59–69, http://dx.doi.org/10.1111/j.1472-4642.2008.00491.x.

Martínez-Calderas, J., Rosas-Rosas, O., Martínez-Montoya, J., Tarango-Arámbula, L., Clemente-Sánchez, F., Crosby-Galván, M., Sánchez-Hermosillo, M., 2011. Distribución del ocelote (*Leopardus pardalis*) en San Luis Potosí, México. Rev. Mex. Biodivers. 82, 997–1004, http://dx.doi.org/10.22201/ib.20078706e.2011.3.

Muñoz, M., Giovanni, R., Siqueira, M., Sutton, T., Brewer, P., Pereira, R., Canhos, D., Canhos, V., 2009. openModeller: a generic approach to species' potential distribution modelling. GeoInformatica 15, 111–135, http://dx.doi.org/10.1007/s10707-009-0090-7.

Newbold, T., 2010. Applications and limitations of museum data for conservation and ecology, with particular attention to species distribution models. Prog. Phys. Geogr.: Earth Environ. 34 (1), 3–22, http://dx.doi.org/10.1177/0309133309355630.

Ortega-Huerta, M., Vega-Rivera, J., 2017. Validating distribution models for twelve endemic bird species of tropical dry forest in western Mexico. Ecol. Evol. 19, 7672–7686, https://doi: 10.1002/ece3.3160.

Pearson, R., Dawson, T., Liu, C., 2004. Modelling species distributions in Britain: a hierarchical integration of climate and land-cover data. Ecography 27, 285–298, http://dx.doi.org/10.1111/j.0906-7590.2004.03740.x.

Pérez-Irineo, G., Santos-Moreno, A., 2014. Density, distribution, and activity of the ocelot *Leopardus pardalis* (Carnivora: felidae) in Southeast Mexican rainforests. Rev. Biol. Trop. 62, 1421–1432, http://dx.doi.org/10.15517/RBT.V62I4.12941.

Peterson, A., Papes, M., Eaton, M., 2007. Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. Ecography 30, 550–560, http://dx.doi.org/10.1111/j.0906-7590.2007.05102.x.

Phillips, S., Anderson, R., Schapire, R., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Modell. 190, 231–259, http://dx.doi.org/10.1016/j.ecolmodel.2005.03.026.

Pliscoff, P., Fuentes-Carrillo, T., 2011. Modelación de la distribución de especies y ecosistemas en el tiempo y en el espacio: una revisión de las nuevas herramientas y enfoques disponibles. Rev. Geogr. Norte Gd. 48, 61–79, http://dx.doi.org/10.4067/S0718-34022011000100005.

Ramírez-Bravo, O., Bravo-Carrete, E., Hernández-Santín, C., Schinkel-Brault, S., Kinnear, C., 2010. Ocelot (*Leopardus pardalis*) distribution in the state of Puebla, Central Mexico. Therya 1, 111–120, http://dx.doi.org/10.12933/therya-10-12.

Roberts, N., Crimmins, S., 2010. Bobcat population status and management in North America: evidence of large-scale population increase. J. Fish Wildl. Manag. 1, 169–174, http://dx.doi.org/10.3996/122009-JFWM-026.

Rocha-Mendes, F., Bianconi, G., 2009. Opportunistic predatory behavior of margay, *Leopardus wiedii* (Schinz, 1821) in Brazil. Mammalia 73, 151–152, http://dx.doi.org/10.1515/MAMM.2009.017.

Romero, R., 2005. Lynx rufus. In: Ceballos, G., Oliva, G. (Eds.), Los mamíferos silvestres de México: 362–364. CONABIO – UNAM – Fondo de Cultura Económica, México D.F.

SEMARNAT (Secretaría del Medio Ambiente y Recursos Naturales), 2009. Inventario Nacional Forestal y de Suelos México 2004-2009. Una herramienta que da certeza a la planeación, evaluación y el desarrollo forestal de México. Press, Zapopan, Jalisco, México.

Stockman, A., Beamer, D., Bond, J., 2006. An evaluation of a GARP model as an approach to predicting the spatial distribution of non-vagile invertebrate species. Divers. Distrib. 12, 81–89, http://dx.doi.org/10.1111/j.1366-9516.2006.00225.x.

Stockwell, D., Peters, D., 1999. The GARP modelling system: problems and solutions to automated spatial prediction. Int. J. Geogr. Inf. Sci. 13, 143–158.

Sunquist, M., Sunquist, F., 2002. Wild Cats of the World. University of Chicago Press, Chicago.

USGS (United States Geological Survey), 2007. Shuttle Radar Topography Mision (SRTM) 3-arc Second ARTM Format Documentation. USGS/NASA http://www.edc.usgs.gov/products/elevation/srtmbil.html.

Valdez-Jiménez, D., García-Balderas, M., Quintero-Díaz, G., 2013. Presencia del ocelote (*Leopardus pardalis*) en la “Sierra del laurel”, municipio de Calvillo, Aguascalientes, México. Nota científica. Acta Zoológica Mexicana (n.s.) 29, 688–692.

Valenzuela, D., Vázquez, L., 2007. Consideraciones para priorizar la conservación de carnívoros mexicanos. Pp. 197-214 in Tópicos en sistemática, biogeografía, ecología y conservación de mamíferos. Universidad Autónoma del Estado de Hidalgo, Pachuca, México.

Velazco-Macías, C., Peña-Mondragón, J., 2015. Nuevo registro de ocelote (*Leopardus pardalis*) en el estado de Nuevo León, México. Acta Zoológica Mexicana (n.s.) 31, 470–472.

Zarco-González, M., Monroy-Vilchis, O., Alaníz, J., 2013. Spatial model of livestock predation by jaguar and puma in Mexico: conservation planning. Biol. Conserv. 159, 80–87, http://dx.doi.org/10.1016/j.biocon.2012.11.007.

SEMARNAT (Secretaría del Medio Ambiente y Recursos Naturales), 2010. PROYECTO de Modificación del Anexo Normativo III, Lista de especies en riesgo de la Norma Oficial Mexicana NOM 059 SEMARNAT 2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo, publicada el 30 de diciembre de 2010.