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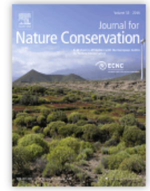

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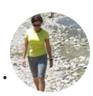

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Potential distribution of *Ursus americanus* in Mexico and its persistence: Implications for conservation

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ABSTRACT

The black bear *Ursus americanus* is an endangered species in Mexico. Its historical distribution has decreased by approximately 80% although its current distribution is not known with precision; it is only reported to be present in the mountains of Northern Mexico. This study proposes two ensemble models: Mexicoís black bear (a) potential distribution compared with Natural Protected Areas (NPAs); and, (b) persistence areas for 2024. The current distribution variables are coniferous forest, elevation and dry forest. Suitable habitat for black bear (354,047 km^2, 18.07% of the country) was found mainly in the north of the Sonoran biogeographical zone, along the Sierra Madre Occidental, the center and south of the Sierra Madre Oriental and some northern regions of the Altiplano Norte. Comparing these areas with NPAs documented that only 12.41% of potential distribution coincided with current suitable habitat. There are unprotected areas in Sierra Madre Occidental center and central and southern of Sierra Madre Oriental. The model for 2024 indicates a reduction of suitable habitat of 64.5%, mainly in the northern Sonoran zone and the center Sierra Madre Occidental. On the other hand, areas that will persist (125,673 km^2) are located along the two main mountain ranges of Mexico. Identification of these sites will allow strengthening of long-term conservation strategies.

1. Introduction

Worldwide, there are eight species of Ursidae. The Giant Panda, *Ailuropoda melanoleuca*, is the only species considered endangered, while another six are listed as vulnerable and two (*Ursus arctos* and *Ursus americanus*) are of least concern (IUCN, 2014). In Mexico *U. arctos* was declared extinct in the 20th century. The main causes for its decline were hunting and the loss of habitat (Brown 1985; AT, 2010). The black bear (*U. americanus*) is endangered in Mexico, with hunting, habitat loss the major threats. Only the population of Serranías del Burro, Coahuila, is under special protection (AP, 1999; AT 2010). Historically, black bear distribution in Mexico included the pine-oak forest and desert areas of the Sierra Madre Occidental (SMOcc) as well as forest and grasslands of the Sierra Madre Oriental (SMO, Hall 1981). However, due to human population growth and expansion, black bear distribution has been reduced up to 80% (Garshelis, Crider, & van Manen, 2008, AP, 1999). Currently, its distribution has not been defined with precision; however, it is known that there are populations in the States of Sonora, Chihuahua, Tamaulipas, Coahuila and Nuevo León (Moctezuma & Doan-Crider, 2005).

There are two studies of the historical range of black bear in Mexico (Ceballos-Gónzalez, Blanco, González, & Martínez, 2006; Delfín-Alfonso, López-González, & Equihua, 2012). Both research used historical records, which involves a temporal incompatibility between the variables used, so that the accuracy in identifying the suitable habitat is limited (Franklin 2010). Furthermore, the algorithm used, Genetic Algorithm Rule-set Prediction (GARP) has revealed deficiencies including low precision and overestimation of the areas (Stockman, Beamer, & Bond, 2006). It is necessary to implement techniques that allow accurate identification of the distribution of black bear in Mexico. One technique recently used is the application of ensemble models from multiple ecological

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niche models (Baldwin & Bender, 2008; Rodríguez-Soto et al., 2011; Podruzny, Cherry, Schwartz, & Landenburger, 2002). The ensemble models identify areas of consistency of multiple models, generating a more accurate output (Marmion, Parviainen, Luoto, Heikkinen, & Thuiller, 2008). It is also important to identify optimal habitats in areas that will remain to strengthen conservation strategies (Cuervo-Robayo & Monroy-Vilchis, 2012). This study proposes two ensemble models: (a) potential distribution of black bear in Mexico (compared whit the Natural Protected Areas NPAs); and, (b) distribution in the future (year 2024), in order to identify black bear persistence areas.

2. Methods

2.1. Study area

The black bear is a Nearctic species (Moctezuma & Doan-Crider, 2005), so we considered as a study area the biogeographical zones of SMOcc, Sonoran region, SMO, Tamaulipeca, and Altiplano (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 1997). Thus, the Faja Volcánica Transmexicana was the southern limit. This area includes 1,328,664 km^2 (67.81% of Mexico, Fig. 1). The vegetation includes: (1) pine-oak forest in SMOcc and SMO; (2) the arid and semi-arid (semi-desert grassland and desert scrub) in SMOcc, North and South Altiplano (Challenger, 1998).

2.2. Presence records

Presence records were obtained in two ways: (1) review of scientific literature (Calderón 2009; Carvajal-Villareal, Maehr, Caso, & Marin, 2007; Delgadillo 2001; Doan-Crider and Hellgren, 1996; Gallo-Reynoso, Suárez-Gracia, Cabrera-Santiago, & Garza-Salazar, 2007; Juárez-Casillas, Peña-Mondragón, De la Peña-Cuellar, & Cervantes-Reza, 2007; Loaiza, 2005; Martínez-Muñoz, 2001; Moreno-Valdez 1998; Moreno, 2008; Nava 2011; Sierra, Sáyago, de C. Silva, & López, 2005; Varas-Nelson, González-López, Krausman, & Culver, 2007; Verdugo 2005; Zavala, López, & Niño, 2007); and, (2) digital data bases: CONABIO (www.conabio.gob.mx) and GBIF (www.gbif.org). We filtered the records, considering only those after 1990, due to the high rate of deforestation that occurred between 1964 and 1990 (FAO, 2001). Further, in order to reduce the spatial correlation between the records, we considered only one record per pixel (Zarco-González, Monroy-Vilchis, & Alaníz, 2013). Records of black bear located in regions where the environmental characteristics are similar in SMOcc and SMO also occur in the Altiplano region of North and South (Challenger, 1998). The data were randomly divided into two groups: 75% was used to calibrate and 25% to evaluate the models (Guisan & Zimmerman, 2000).

2.3. Environmental variables

We considered environmental and anthropogenic variables related to the presence of black bear: vegetation cover; elevation; slope; distance to water bodies and, human population density (Baldwin & Bender, 2008; Delfín-Alfonso et al., 2012; Herrera, 2003; Martínez-Muñoz, 2001; Onorato, Hellgren, Mitchell, & Skiles Jr., 2003; Rogers, 1991; Rice, Ballard, Fish, McIntyre, & Holdermenn, 2009; Sierra et al., 2005; Tankersley, 1996; Verdugo, 2005). All variables were processed to a resolution of 1 km^2 and the correlation between them was analyzed in Biomapper 4.0 software to verify that the correlation coefficients were low (<0.5, de Pando and Peña de, 2007, Merow, Smith, & Silander, 2013).

For the model of the current distribution, we used vegetation and land use types of the National Forestry Inventory Series III (INEGI, 2005). The vegetation was classified as coniferous forest, dry forest, grassland, arid and semiarid vegetation, agriculture and water bodies, and each was transformed to continuous values using a moving window of 25 km^2 (Rodríguez-Soto et al., 2011). Two

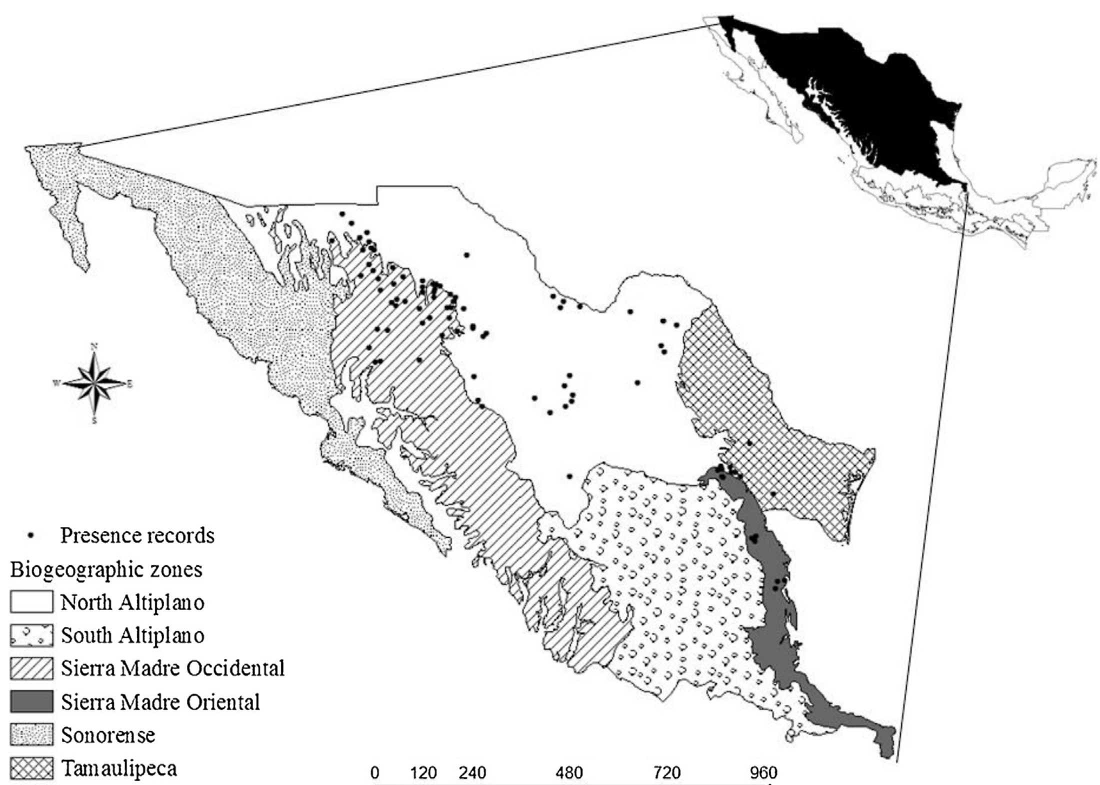

Fig. 1. Study zone and records of *U. americanus* in Mexican regions.

Table 1
Variables to model the potential distribution of black bear.

	Variable	Source
1	Coniferous forest	National Forestry Inventory Series III (INEGI, 2005)
2	Dry forest	National Forestry Inventory Series III (INEGI, 2005)
3	Arid vegetation	National Forestry Inventory Series III (INEGI, 2005)
4	Grassland	National Forestry Inventory Series III (INEGI, 2005)
5	Agriculture	National Forestry Inventory Series III (INEGI, 2005)
6	Distance to water sources	National Forestry Inventory Series III (INEGI, 2005)
7	Elevation	Digital elevation model (USGS, 2007)
8	Slope	Digital elevation model (USGS, 2007)
9	Human population density	Center for International Earth Science Information Network (2005)

topographic variables were included: elevation and slope; and, the human population density in 2010 (Table 1).

The scene (coniferous forest, dry forest and elevation) for the year 2024 was held in the Land Change Modeler module of Idrisi. This was in two phases: (a) the coverage of the two variables coniferous forest and dry forest was obtained for the years 1976 and 2000 (Velázquez et al., 2000), (b) the percentage change was estimated for this period (24 years) and, the coverage of both variables for 2024 was calculated using this percentage (Cuervo-Robayo & Monroy-Vilchis, 2012).

2.4. Current distribution model

We generated potential distribution models with algorithms of OpenModeller (de Souza et al., 2009): Euclidean Distance (ED), Mahalanobis Distance (MD), Environmental Distance (ED), Genetic Algorithm for Rule-set Production (GARP), Artificial Neural Networks (ANN) and Support Vector Machines (SVM). Independently, we used the algorithm Maximum Entropy (Maxent) to identify the contribution of each of the variables (Phillips, Anderson, & Schapire, 2005) and the algorithm ENFA (Ecological Niche Factor Analysis) was applied to obtain the global value of marginality and tolerance (Hirzel, Hausser, Chessel, & Perrin, 2002). All algorithms were classified in two families (Franklin 2010; Rangel & Loyola, 2012); and, were evaluated with the area under the curve (AUC) in Idrisi Taiga (Pearce & Ferrier, 2000; Roura-Pascual, Brotons, Peterson, & Thuiller, 2008). Thus, we obtained two evaluations: internal (with the calibration data) and external (with the evaluation data). We chose the family of algorithms with the highest value to include in the ensemble model (Araújo and New, 2007), which was generated using the weighted average formula (Marmion et al., 2008). The ensemble model also was evaluated with AUC and from this was obtained the suitable habitat for the presence of this species, considering the median as threshold of suitability (Liu, Berry, Dawson, & Pearson, 2005). The final model was overlaid with Natural Protected Areas of Mexico, to determine the percentage of suitable habitat that is currently protected by them.

2.5. Distribution model for year 2024

The variables that contribute in 75% of the current distribution (coniferous forest, elevation and dry forest; Table 2), and the family of algorithms with the best performance were used for modelling potential distribution in year 2024. The ensemble model was performed using the weighted average formula and considering internal AUC values. This last model was also evaluated with the external AUC (Marmion et al., 2008). The two ensemble models were converted to Boolean and multiplied in order to identify persistence areas for 2024.

Table 2
Percent of contribution of each variable according to Maxent.

Variable	Percent of contribution (Maxent)
Coniferous forest	40.6
Altitude	21.4
Dry forest	13.5
Arid vegetation	11.0
Human population density	4.7
Distance to water bodies	4.0
Agriculture	4.0
Grassland	0.7
Slope	0.3

Table 3
Value of area under the curve (AUC) of the algorithms used to model potential distribution of black bear. * Algorithms included in the ensamble model.

Algorithm	AUC value of models for present	AUC value of models for year 2024
ANN*	0.780	0.853
GARP*	0.874	0.822
Maxent*	0.860	0.845
SVM*	0.857	0.740
CSM	0.810	
ED	0.795	
ENFA	0.835	
EM	0.859	0.835

3. Results

Three hundred forty one records of the presence of *U. americanus* were obtained in Mexico between the years 1896–2013. With filtration, we retained 90 records. They are located mainly in north of SMOcc and SMO, and in the northern region of Altiplano (Fig. 1). ENFA indicated high marginality (0.702), suggesting that the requirements for the black bear presence are specific. It is also a relatively intolerant species (overall tolerance = 0.46) to environmental variations on the variables that allow their presence, which are coniferous forest, elevation and dry forest, as reported by Maxent (Table 2).

The artificial intelligence algorithms family performed best: ANN; GARP; Maxent; and, SVM (Table 3). These were used to generate the ensemble model of the current distribution (Fig. 2), that identified 354,047 km^2 of black bear suitable habitat, found mainly in the north of the Sonoran region along the SMOcc, the center and south of the SMO and some northern regions of the Altiplano. Mexican NPAs safeguard only 43,940 km^2 (12.41% of current suitable habitat) and there are unprotected areas in SMOcc center and central and southern SMO (Fig. 2).

The model of potential distribution for year 2024 indicates a reduction in suitable habitat of 228,374 km^2 (64.54%) in the northern Sonoran region and the center SMOcc. In addition, areas of northwestern to North Altiplano and areas that are located along the SMO and southeastern of South Altiplano zone (Fig. 3) will decline. Persistence areas (125,673 km^2) are located along the two main mountain ranges of Mexico (Fig. 3).

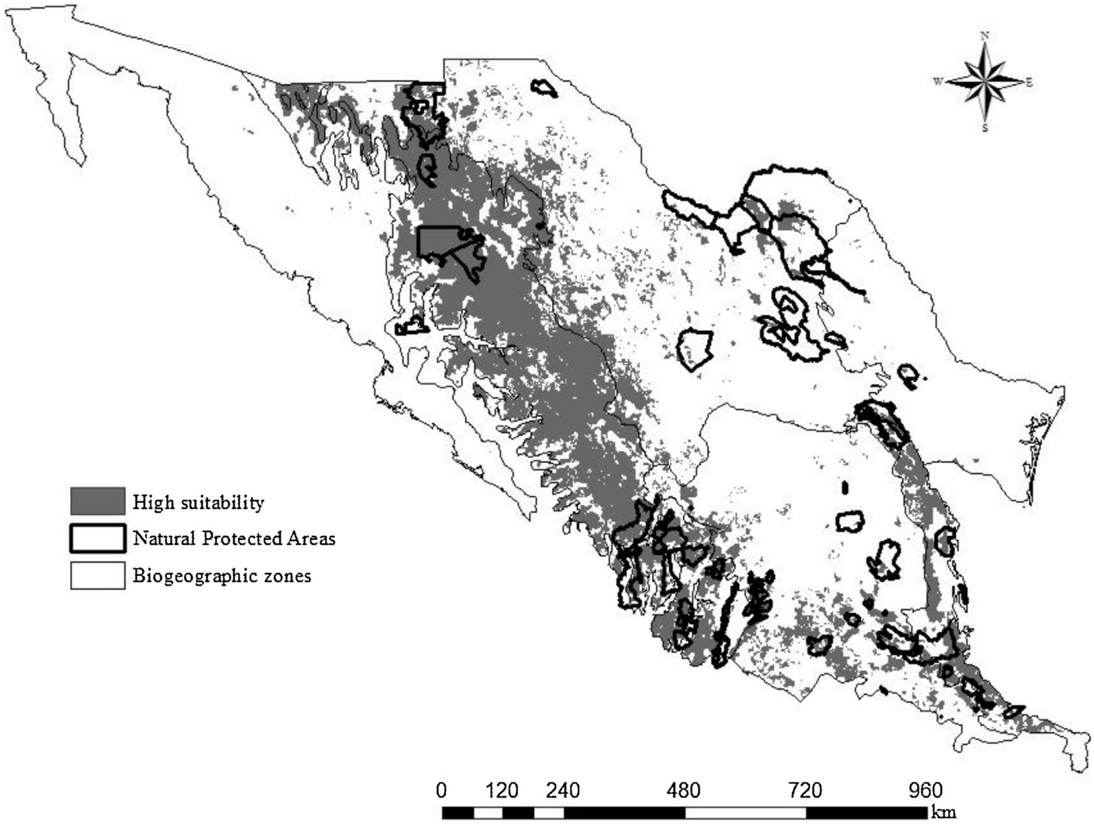

Fig. 2. Potential habitat for black bear in Mexico and natural protected areas.

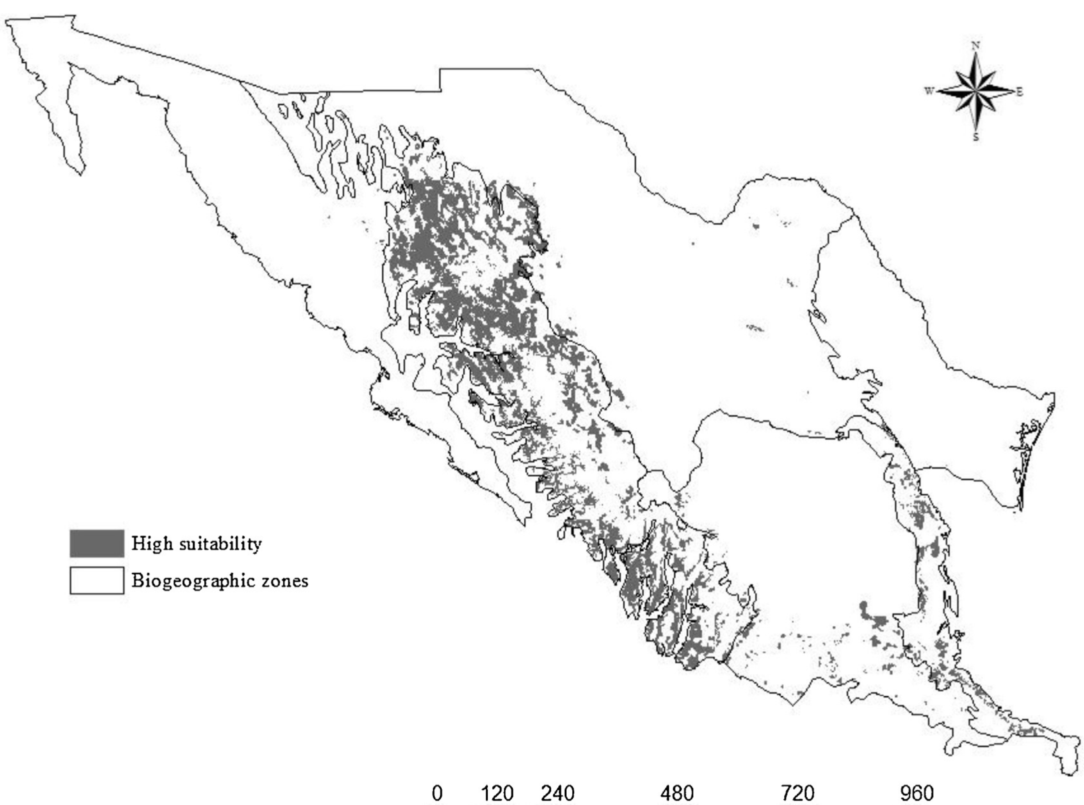

Fig. 3. Potential habitat for black bear in Mexico in 2024 as defined by the ensamble model.

4. Discussion

Large mammals are important for planning biodiversity conservation strategies, because they are considered umbrella species (Ray 2010), so it is necessary to identify the distribution of these species and on this basis to propose long-term conservation areas.

The records of black bear distribution were mainly in northern SMOcc, SMO and Northern Altiplano. However, the environmental characteristics in each of these areas are similar (Challenger, 1998). Furthermore, the distribution of the records need not be random if the geographic space presents homogeneous technical characteristics (Merow et al., 2013).

Suitable habitat for black bear is currently 18.07% of the country, located north of the Sonora zone, northeastern and north of Altiplano zone and along the SMOcc and SMO (Fig. 2). However, the model of potential distribution of black bear for year 2024 predicts a loss of 64.54% of current habitat (Fig. 3). The loss is predicted to be in northern Sonora and throughout the SMOcc, and areas of the Northern Altiplano zone, particularly in the northeast of Coahuila and the zone of SMO. This habitat loss is alarming, considering the lack of recent records in the southern region of the SMOcc, SMO and North Altiplano; this may be evidence of local extinctions or low population densities.

Suitable habitat for black bear proposed in this study differs from that reported by Ceballos-Gónzalez et al. (2006), because the latter does not include 130,704 km^2 found in areas along the west SMOcc region and the southern region of the SMO. These areas are important because it is the southernmost range of the species and their presence was reported recently (Rojas-Martínez & Juárez-Casillas, 2013). This area may be the connection between the populations of the SMO and the Biosphere Reserve Sierra Gorda, Querétaro. Another important difference is that Ceballos-Gónzalez et al. (2006) mentioned that most of the Northern and Southern of Altiplano zone is suitable habitat, although foraging conditions for black bear are not present.

The current distribution model identifies important areas for this species such as the Sierra de San Luis Sonora, which could facilitate gene flow among the Mexican populations and those present in Sky Island, Arizona (Atwood et al., 2011). In addition, the region of Serranías del Burro, Coahuila, México is identified as suitable. In this region, Doan-Crider and Hellgren (1996) reported the highest population density in Mexico, which has served as a reservoir for the reproduction of the black bear as well as for dispersion and recolonization into Texas (Onorato, Hellgren, & Doan-Crider, 2004; Rice et al., 2009). Likewise it has been reported the migration and dispersal of individuals towards areas of the State of Chihuahua (Hellgren, Onorato, & Skiles, 2005).

However, considering that the model of potential distribution for 2024 predicted a loss of 64.54% of suitable habitat, it is important to generate studies and management actions to prevent this. In this respect, it has been proven that the border wall between Mexico and the United States has had negative impacts on the migration of black bear (Varas, 2007). This study helps to identify steps that promote wildlife habitat continuity and allow genetic exchange between the two populations.

The model of the current distribution shows that suitable habitat is concentrated mainly in the mountainous regions of the SMOcc, which may be due to the high percentage of vegetal cover. However, we also identified suitable habitat in the southern part of this region where the distribution model for the 2024 shows persistence areas over this mountainous system (Fig. 3). Therefore, we consider it important to conduct studies to determine the presence of the species there.

Suitable habitat for black bear was identified at elevations between 1500 and 3500 m and coincides with that previously reported (Moctezuma 1997). Slopes between 20 and 80% are important, as they provide refuge sites that are inaccessible to humans (Verdugo 2005). The North and South of Altiplano zone are identified as areas with little probability of occurrence of the species; this region has predominantly arid and semi-arid vegetation with extreme weather. This biogeographic zone can be considered as a geographical barrier between the subspecies *U. a. machetes* and *U. a. eremicus*.

The suitable habitat for black bear is scarce in the zone Tamaulipeca, there are small areas of coniferous forest, which offer food resources required by the bear, and however, the isolation between populations could generate metapopulations (Hewitt & Doan-Crider, 2007). We recommend studies to analyze potential corridors that allow the genetic exchange in this zone.

Our results indicate that black bear is a highly marginal species that prefers sites with coniferous forest vegetation cover, which is consistent with previous studies (Baldwin & Bender 2008; Delfín-Alfonso et al., 2012; Herrera, 2003; Martínez-Muñoz, 2001; Onorato et al., 2003; Rogers, 1991; Rice et al., 2009; Sierra et al., 2005; Tankersley, 1996; Verdugo, 2005). The importance of the coniferous forest is related to the availability and quality of food. Due to their omnivorous diet (Larivière, 2001), food resources have a direct influence on the rate of growth, reproduction and survival of cubs (Costello et al., 2003). In Mexico, it has been documented that their diet mainly consists of vegetal material, predominating species as *Quercus* spp., *Juniperus deppeana*, *Juniperus flaccida*, *Pyrus communis*, *Pinus cembroide*, *Pinus remota*, *Arctostaphylos pungens*, *Conopholis mexicana*, *Desmodium psilophyllum* (Delgadillo, 2001; Doan-Crider, 1995; Juárez-Casillas & Varas, 2013; Martínez, Delgadillo, Herrera, & González, 2014; Nava, 2011). Some species like grasses, *Opuntia* spp., *Dasylirion* spp. and *Yucca* spp., are also eaten by the bear, but less frequently, as reported in previous studies (Martínez, 2014; Nava, 2011; Sierra et al., 2005). Therefore, if the rate of deforestation conifer forest and dry forest continues to increase, as from 1976 to 2000 (Velázquez et al., 2002) by 2024, black bears will be vulnerable to local extinction. Likewise, we identified that arid and semi-arid vegetation contributes little to the presence of the black bear in Mexico.

As the variables of vegetal cover allow the presence of the black bear, the loss and fragmentation of their habitat because of the growth and expansion of the human populations, as well as anthropogenic activities, promote dispersal of individuals in search of alternative foods (Noyce & Garshelis, 2011). This makes them vulnerable to road kill (Hellgren et al., 2005). On the other hand, the black bear is relatively tolerant to human presence, so in some cases it is likely to associate human settlements as sources of food (Spencer, Beausoleil, & Martorello, 2007). This association can result in individuals causing damage to infrastructure, crops and livestock predation. The latter situation is one of the causes of increased persecution and negative attitudes towards bear conservation (Don Carlos, Bright, Teel, & Vaske, 2009; Garshelis et al., 2008; Hewitt & Doan-Crider, 2007; Onorato et al., 2003). Therefore, it is necessary to develop strategies to maintain adequate management of the areas where suitable habitat remains and to reduce the threats facing the species. Otherwise, it is likely that the loss and fragmentation of its habitat and hunting lead to extinction, as happened with *U. arctos* (Brown 1985; AT 2010).

This study suggests the need to establish new areas for the conservation of black bear in the central and southern regions of the SMOcc, which will persist at least until 2024 (Fig. 3). It is also important to analyze biological corridors to allow dispersal and gene flow between populations. Currently there is no information about corridors in any NPAs. This lack of suitable habitat protection within NPAs has also been reported for the jaguar (Rodríguez-Soto et al., 2011) and other threatened vertebrates (Domínguez-Vega, Monroy-Vilchis, Balderas-Valdvia, Gienger, &

Ariano-Sánchez, 2012), which demonstrates the lack of biological data supporting national conservation strategies.

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