Colegio de Postgraduados

Potential Distribution Models for Predicting Human-Black Bear (*Ursus americanus* var. *eremicus*) Interactions in the Sierra de Zápaliname Natural Reserve, Saltillo, Coahuila

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ABSTRACT

Objective:This research analyzed the interactions between humans and bears in the ejidos of the Sierra de Zápaliname Natural Reserve and the urban area of Saltillo, Coahuila, Mexico.

Design/Methodology/Approach: A database of approximately 481 georeferenced records of Human-Black Bear Interactions (HBI) for the year 2021 was used. Based on these records and their relationship with physiographic variables (slope, aspect, elevation, roughness) and environmental variables (normalized difference vegetation index and a humidity detection index), potential distribution models were developed using the support vector machine algorithm, which is characterized by the assumption of the Greenelian niche theory.

Results: Six potential distribution maps were generated, divided into two rainy and dry periods and three types of interaction: sightings, agricultural-livestock conflicts and captures.

Findings/Conclusions: In all models, a common pattern was found where the sites with the highest probability of IHO are places close to human settlements and areas where agriculture, livestock and landfill activities occur.

Keywords: Human-Bear Interactions, Spatial Analysis, Wildlife Management, Mapping Techniques, activity Patterns.

INTRODUCTION

The Black Bear (*Ursus americanus*) is a species with a broad ecological niche, which has allowed it to distribute across a variety of habitats, such as pine forests and deserts (Garshelis, 2022). This adaptability characterizes the Black Bear as an umbrella species (a

species that, when protected, also protects many others due to its need for large areas to thrive) in the ecosystems of the northern part of the country (Isasi-Catalá, 2011). Despite the importance of the Black Bear in Mexico, its populations are drastically declining, primarily due to land-use changes and habitat loss from fragmentation. This not only affects the Black Bear but also the distribution areas of other carnivores, such as the puma and the jaguar (Balbuena-Serrano *et al.*, 2022). According to NOM-059-SEMARNAT-2010, the Black Bear is classified as "Endangered" within the Mexican Republic and "Subject to special protection" in some populations in northern Coahuila.

Human-Black Bear interactions (HBI) are becoming increasingly frequent in areas of livestock and agricultural production, where the control of the Black Bear has primarily been through hunting (Nuñez-Torres *et al.*, 2020). The main issue with these interactions is that bears alter their behavior by consuming food from anthropogenic sources and become habituated to the presence of human settlements, which increases their interactions (Baruch-Mordo *et al.*, 2014). These HBIs intensify during the summer and fall when bears enter a state of hyperphagia and, therefore, need to maximize food intake to increase their fat reserves before hibernation (McFadden-Hiller *et al.*, 2016).

A useful tool for mapping Human-Black Bear interactions (HBI) and determining potential distribution areas are ecological niche models, which are characterized by analyzing environmental variables that, along with occurrence sites (observations of the bear and HBI), make it possible to calculate the probability of the observation occurring in another location (Escobar-Flores and Sandoval, 2022). Ecological niche models are a vital source of information for planning wildlife management strategies and have currently been applied to identify priority areas for the conservation of critically endangered species, such as the Golden-headed Lion Tamarin (*Callithrix flaviceps*) (Bataillard *et al.*, 2024), or to identify the habitat connectivity of the Black Bear in mountainous and desert valleys in northern Mexico (Lara-Díaz *et al.*, 2021).

The mere presence of the Black Bear has been a catalyst for the creation of new protected natural areas. A clear example of this is northern Coahuila, where the protection of large tracts of land, including the mountains bordering the United States, Big Bend National Park, and Black Gap in Texas, has maintained the natural biological corridor for the Black Bear (McKinney *et al.*, 2006). This research focused on the recent protected natural area of Sierra de Zápaliname, Coahuila, where over 481 records of Human-Black Bear interactions (HBI) have been documented in the last 10 years; it is also considered one of the mountains with the greatest potential habitat for the Black Bear in Mexico (Monroy-Vilchis *et al.*, 2016).

The hypothesis of this study is that potential Human-Black Bear interaction (HBI) areas will depend on the hyperphagia period (May-September), as previously reported for other areas of Black Bear distribution (Baruch-Mordo *et al.*, 2014; Nuñez-Torres *et al.*, 2020). Therefore, areas with the greatest potential habitat for the Black Bear are expected to be located in urban, agricultural, and livestock areas. It is anticipated that during the rainy season, when food is abundant in the pine forest, the potential distribution areas of HBI will shift to the forested and mountainous regions.

MATERIALS AND METHODS

The research was conducted in the protected natural area of the Sierra de Zápaliname State Natural Reserve (Figure 1), established on October 15, 1996, due to its hydrological importance, as it provides more than 30% of the drinking water consumed by the city of Saltillo. The mountain range is located at the following coordinates: latitude 25° 15' 00"-25° 25' 58.35" and longitude 100° 47' 14.5"-101° 05' 3.8", covering an area of 25,768.68 hectares. The Sierra de Zápaliname is part of the Gran Sierra Plegada subprovince, characterized by valleys, plains, and folded elevations. At elevations above 2600 m, forests predominate, while at lower elevations, there are oak-pine forests, oak forests, and chaparral vegetation (Encina-Domínguez *et al.*, 2008).

Human-Black Bear Interaction Records

The records and databases used in this study were obtained from the following sources and correspond to the year 2021: 1) database obtained from the Wildlife Division of the Secretary of Environment (SMA) of the Government of the State of Coahuila, 2) database from the Wildlife Management area of the Mexican Wildlife Protection Association (PROFAUNA), and 3) fieldwork in collaboration with the Secretary of Environment of the State of Coahuila. The data will be divided into three categories of Human-Black Bear interactions (HBI): The first category is called sightings, with 143 records; captures of bears, with 37 records; and agricultural conflicts, with 301 records.

Physiographic Variables

Digital Elevation Models (DEMs) were downloaded from the U.S. Geological Survey (USGS) Global Visualization Viewer (http://glovis.usgs.gov) with a spatial resolution of 30

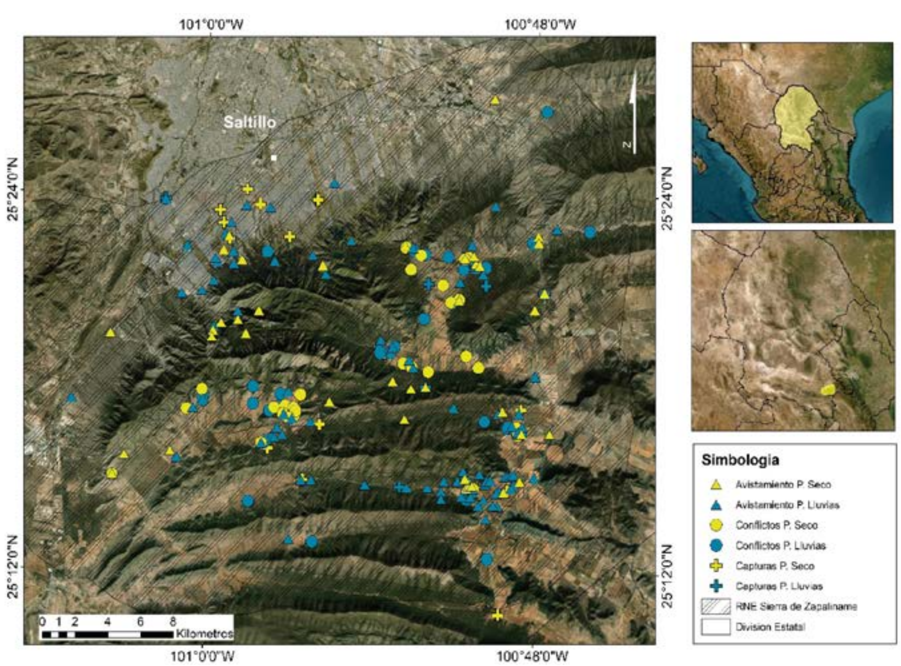

Figure 1. Location of the Sierra de Zápaliname State Natural Reserve and the records of Human-Black Bear interactions (HBI).

m. From the DEMs, four topographic variables were generated using the spatial analysis tools available in ArcGIS 10.8 as follows: (1) elevation above sea level (m); (2) slope (0-90°); (3) vector ruggedness measure (VRM), a measure of terrain roughness, with values ranging from 0 for flat areas to 1 for canyons and ravines (Sappington *et al.* 2007); (4) terrain curvature.

Environmental Variables

The land cover layer for the study area was obtained with a spatial resolution of 10 meters for the year 2021 from the website https://livingatlas.arcgis.com/landcover/. The classification was performed by Karra *et al.* (2021), who used six bands from the Sentinel-2 satellite (red, green, blue, NIR, SWIR1, SWIR2) of surface reflectance-corrected images. These authors propose nine land cover classes, which are presented in the following Table 1.

Two other environmental variables were also obtained: the Normalized Difference Vegetation Index (NDVI) proposed by Rouse *et al.* (1974) and the Normalized Water Index proposed by McFeeters (1996).

To calculate these indices, two Sentinel-2 satellite images with a resolution of 10 meters were first obtained and processed from the United States Geological Survey portal (www.glovis.usgs.gov). The dataset was acquired on November 3, 2021, representing the end of the rainy season, and on May 2, 2021, representing the end of the dry season. These two seasons were chosen to compare the effect of seasonality on the photosynthetic activity of vegetation and moisture.

The NDVI uses the proportions of absorption in the red region (R) and the reflectance of vegetation cover in the near-infrared region (NIR). The NDVI was calculated with the following equation:

$$NDVI = (NIR - R)/(NIR + R)$$

NDVI values ranged from −1.0 to 1.0. On the other hand, the NDWI maximizes the reflectance of water bodies in the green band and minimizes the reflectance of water in the

Table 1. Land cover classes proposed by Karra *et al.* (2021).

ID	Clasification
1	Water
2	Forest
4	aquatic vegetation
5	Crops
7	Urban
8	Bare ground
9	Snow
10	Clouds
11	grasslands

NIR band. The NDWI was calculated using bands three and eight of the Sentinel 2A-MSI sensor. NDWI values >0.10 indicated a probable water body (Escobar-Flores *et al.*, 2019).

Modeling the Potential Distribution of Human-Bear Interactions (HBI)

Based on the georeferenced records of HBI, three groups of presence data were generated for modeling: 1) sightings, 2) captures, and 3) Human-Bear conflicts. The input layers prior to modeling included the four physiographic variables and the three environmental variables, and a common spatial resolution of 30 meters per pixel was defined. The modeling was performed using the open-source program OpenModeller, utilizing the Support Vector Machine (SVM) algorithm. This algorithm is based on Hutchinson's ecological niche theory (Takola and Schielzeth, 2022) and is grounded in statistical learning theory, producing good classification results from complex and noisy data. It separates classes with a decision surface that maximizes the margin between them. This surface can be referred to as the optimal hyperplane, and the data points closest to this hyperplane are called support vectors. The pre-modeling parameters included a gamma type function with a polynomial kernel. The polynomial degree was set to 3, meaning that at least three lines are generated before calculating the potential distribution (Drake *et al.* 2006).

For each model, the area under the receiver operating characteristic curve (AUC) was calculated. AUC values greater than 0.70 were considered to distinguish between observed locations and potentially unsampled ones (Ferson *et al.*, 2000). The model is represented in a map of suitable habitat probability with values ranging from 0 to 1.

RESULTS AND DISCUSSION

The potential distribution models obtained from the different Human-Bear Interactions (IHO) were effective, with AUC values ranging from 0.80 to 0.88 for rainy seasons and from 0.92 to 0.96 for dry seasons. These AUC values indicate that the study area has a high probability of suitable habitat for the Black Bear. These results are consistent with those reported by Monroy-Vilchis *et al.* (2016; Figure 2) in their research on the potential habitat for the Black Bear in Mexico. There was also agreement with Lara-Díaz *et al.* (2020) and Balbuena-Serrano *et al.* (2022; Figure 1), which describe the main ecological corridors for the Black Bear in Mexico, where Sierra Zapaliname is part of the corridor in the Sierra Madre Oriental.

In the model corresponding to the rainy season, it is observed that the urban area in the south of Saltillo has probability values close to 0.80 (Figure 2), indicating a greater likelihood of bear sightings during the hyperphagia period (Nuñez-Torres *et al.*, 2020). This suggests that the high availability of food may be encouraging bears in this region to extend their hyperphagia period possibly until December.

The increase in bear sightings in the urban periphery may raise the incidence of bear-vehicle collisions on roads, as reported by Zarco-González *et al.* (2023), where they identify that roads such as ring roads and intersections where cars travel at higher speeds have a greater probability of collisions. This concern is evident in the study area because there is a ring road that borders the Sierra de Zapaliname and the city of Saltillo.

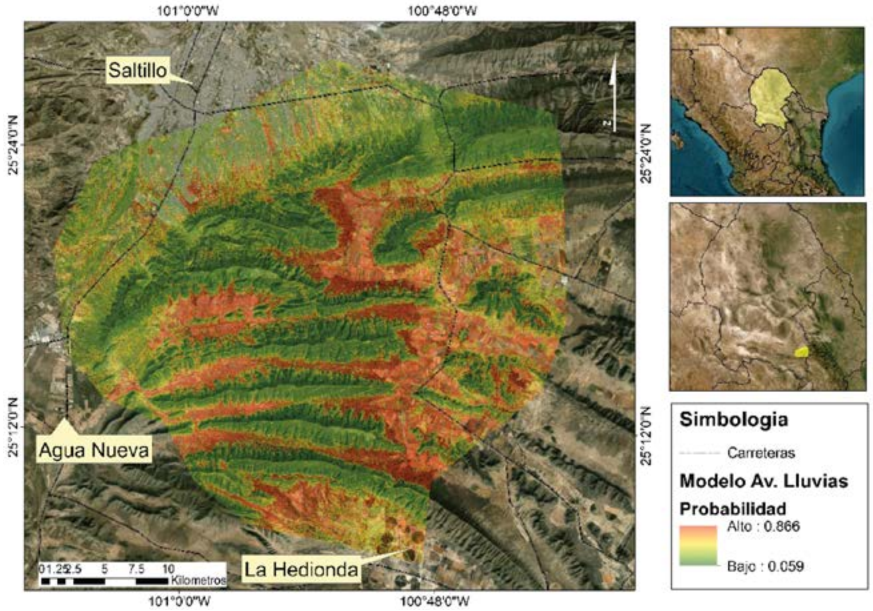

Figure 2. Potential distribution model of Black Bear sightings during the rainy season.

In the dry period (May), the probability of bear sightings in urban areas drastically decreased compared to the rainy season. Habitat suitability values were very low, below 0.1, while values greater than 0.8 were found entirely in the forested region of Sierra de Zapaliname, where bears may be in the hibernation or pre-hyperphagia stage (Johnson *et al*., 2015) (Figure 3).

Regarding the capture model during the rainy season, the model shows a distribution similar to that of sightings, where sites with higher probabilities (>0.8) are common in

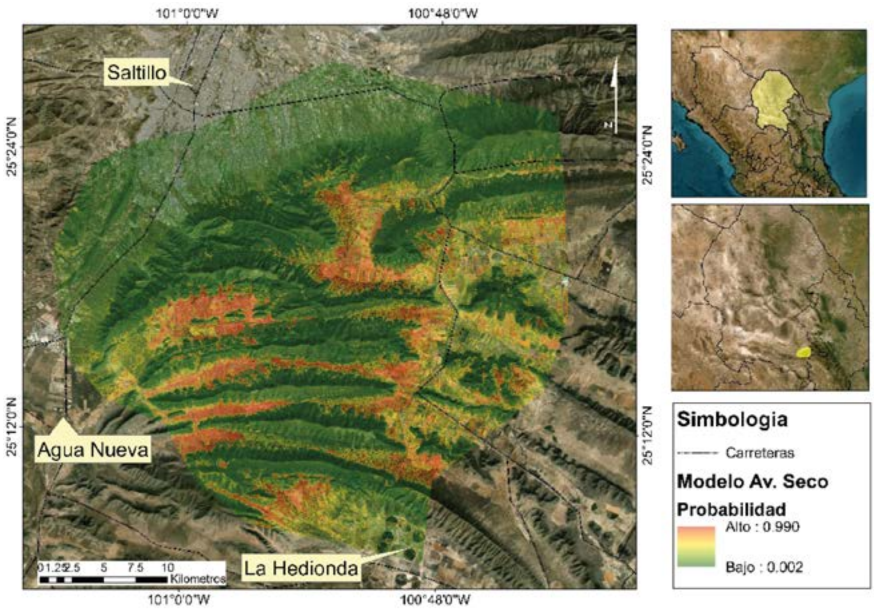

Figure 3. Potential distribution model of Black Bear sightings during the dry season.

urban areas, a result that is similar to that reported by Lackey *et al.* (2018) in various studies from the United States (Figures 4 and 5). In the dry season, the conflict models show a potential distribution focused on the pine-oak forest (Figure 5), which possibly indicates a lower Human-Bear Interaction (HBI) in urban areas (Valdez and Ortega, 2014).

In the capture models, it was found that slopes less than 10 degrees accounted for 100% of captures, regardless of the dry or rainy season. Despite the discrepancy with publications and reports from other areas of bear distribution in Mexico, which indicate that bear

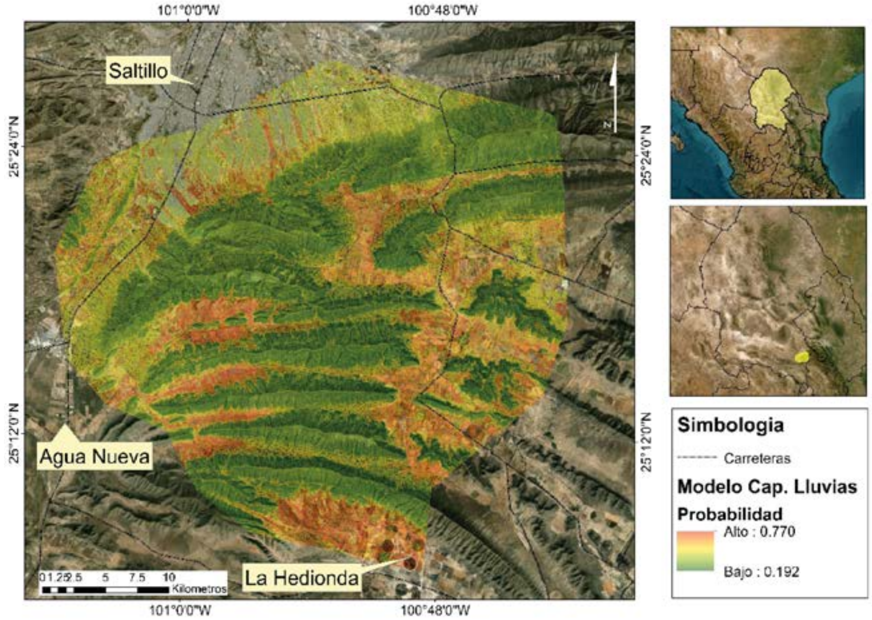

Figure 4. Potential distribution model of Black Bear captures during the rainy season.

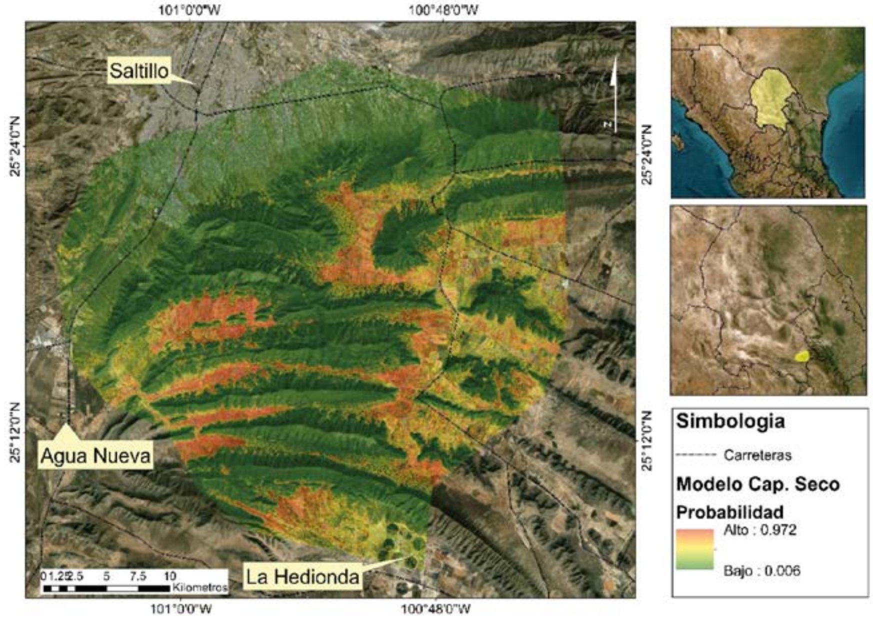

Figure 5. Potential distribution model of Black Bear captures during the dry season.

habitat is associated with steep slopes (Sollmann *et al.*, 2016), the models obtained in this study (Figures 4 and 5) indicate the influence of urban areas and human activities on the increase in bear captures.

The conflict models during the rainy season coincide with the sighting and capture models, where the urban areas of Saltillo show suitable habitat probability values greater than 0.80 (Figures 6 and 7). This result is very similar to that of Núñez-Torres *et al.* (2020; Figure 2), where their Human-Bear Interaction (IHO) model for northern Mexico shows

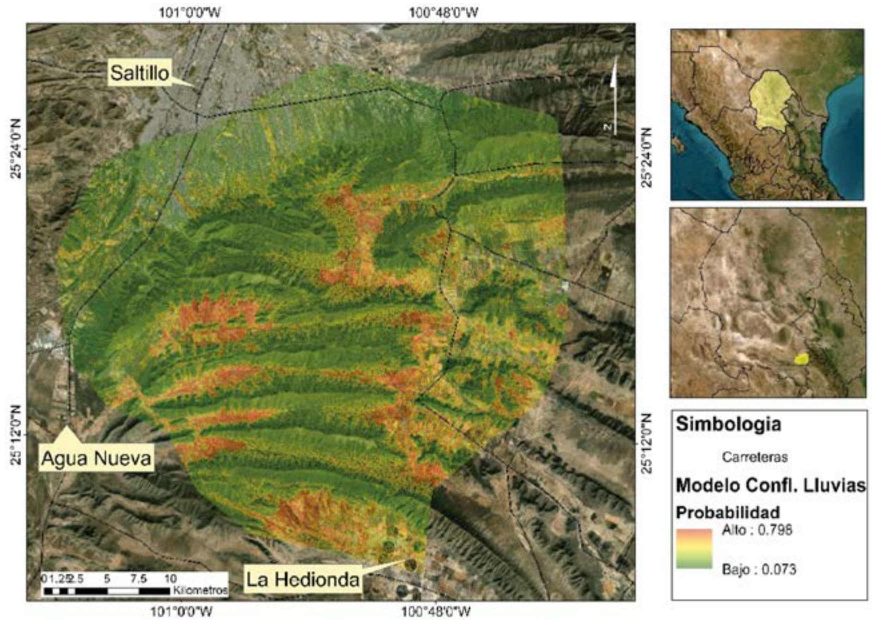

Figure 6. Potential distribution model of conflicts involving the Black Bear during the rainy season.

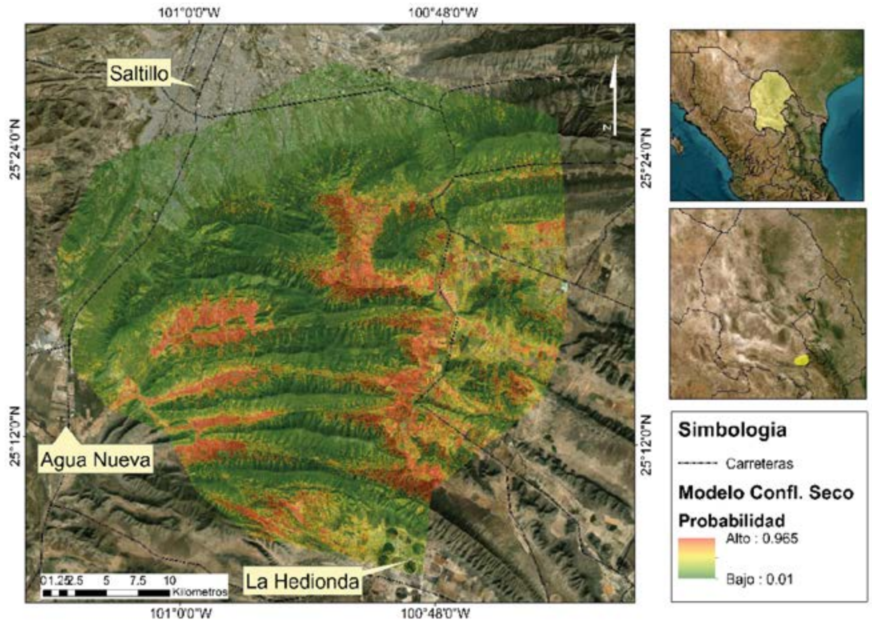

Figure 7. Potential distribution model of conflicts involving the Black Bear during the dry season.

probability values greater than 0.75. The variables with the highest contribution to human-bear interactions are distance to urban areas, distance to forest, and the presence of free-grazing livestock.

CONCLUSIONS

The influence of physiographic variables was decisive in the models of Human-Bear Interactions (IHO). It was observed that records of the bear show a constant relationship with slopes of less than 10 degrees in areas close to urban and rural communities, while in the mountainous region, both proximity to water bodies and sites with high ruggedness (indicating canyons and mountains) are habitat elements that bears may be using as escape routes and access to their food (Carter *et al.*, 2010; Baruch-Mordo *et al.*, 2014).

This research demonstrates that the probability of sightings and captures of black bears varies between the rainy and dry seasons. During the rainy season, an increase in the likelihood of interactions was observed in urban areas, possibly due to greater food availability, while in the dry season, interactions concentrated in forested areas, particularly in pine-oak forests. This indicates that seasonality influences the behavior of the black bear, which should be considered in the management and conservation strategies for the species. Based on the maps generated in this study, landowners and authorities can work together to create Wildlife Management Units (UMAs) that focus on an innovative type of utilization: photographic safaris featuring the charismatic black bear. This activity would be non-extractive according to the General Wildlife Law, which facilitates its implementation in the short term ($<$2 years). In this way, what is currently a human-bear conflict could transform into an economic opportunity for the landholders. A limitation of using the Support Vector Machine algorithm is that it only models the Grinnellian niche, meaning the relationship between environmental variables and the occurrence records of the bear. It does not consider other factors such as predation, the presence of prey, and population dynamics —factors that are relevant for improving predictions not only for the bear but also for the species that share its habitat.

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REFERENCES

Balbuena-Serrano, Á., Zarco-González, M. M., Carreón-Arroyo, G., Carrera-Treviño, R., Amador-Alcalá, S., Monroy-Vilchis, O. 2022. Connectivity of priority areas for the conservation of large carnivores in northern Mexico. *Journal for Nature Conservation*, 65, 126116. https://doi.org/10.1016/j.jnc.2021.126116

Baruch-Mordo, S., Wilson, K. R., Lewis, D. L., Broderick, J., Mao, J. S., Breck, S. W. 2014. Stochasticity in natural forage production affects use of urban areas by black bears: implications to management of human-bear conflicts. *PloS one* 9, e85122. https://doi.org/10.1371/journal.pone.0085122

Bataillard, L., Eriksen, A., de Melo, F. R., Milagres, A. P., Devineau, O., Vital, O. V. 2024. Using ecological niche modelling to prioritise areas for conservation of the critically endangered Buffy-Headed marmoset (*Callithrix flaviceps*). *Ecology and Evolution* 14, e11203. https://doi.org/10.1002/ece3.11203

Carter, N. H., Brown, D. G., Etter, D. R., Visser, L. G. 2010. American black bear habitat selection in northern Lower Peninsula, Michigan, USA, using discrete-choice modeling. *Ursus* 21, 57-71.

Drake, J. M., Randin, C., Guisan, A. 2006. Modelling ecological niches with support vector machines. *Journal of applied ecology* 43, 424-432. https://doi.org/10.1111/j.1365-2664.2006.01141.x

Elith J. 2000. Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. Quantitative methods for conservation biology. Springer

Encina-Domínguez, Juan A., Encina-Domínguez, Francisco J., Mata-Rocha, Efrén, Valdes-Reyna, J. 2008. Aspectos estructurales, composición florística y caracterización ecológica del bosque de oyamel de la Sierra de Zapalinamé, Coahuila, México. *Boletín de la Sociedad Botánica de México* 83, 13-24.

Escobar-Flores J.G, Sandoval, S., Valdez, R., Shahriary, E., Torres, J., Alvarez-Cardenas, S., Gallina-Tessaro, P. 2019. Waterhole detection using a vegetation index in desert bighorn sheep (*Ovis canadensis cremnobates*) habitat. *PLoS ONE 14*(1): e0211202. https://doi.org/10.1371/journal.pone.0211202

Escobar Flores J.G., Sandoval, S. 2022. Artificial intelligence to model the potential distribution of Agave durangensis. International Geoscience and Remote Sensing Symposium, Kuala Lumpur, Malaysia. 5828-5831. https://doi.org.10.1109/IGARSS46834.2022.9883767.

Ferson, S., Burgman, M., Elith, J. 2000. Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. *Quantitative methods for conservation biology*, 39-58.

Garshelis, D.L. 2022. Understanding Species–Habitat Associations: A Case Study with the World's Bears. *Land* 11, 180. https://doi.org/10.3390/ land11020180

Isasi-Catalá, E. 2011. Los conceptos de especies indicadoras, paraguas, banderas y claves: su uso y abuso en ecología de la conservación. *Interciencia* 36, 31-38. http://www.redalyc.org/articulo.oa?id=33917727005

Johnson, H. E., Breck, S. W., Baruch-Mordo, S., Lewis, D. L., Lackey, C. W., Wilson, K. R., Broderick, J., Mao, J. S., Beckmann, J. P. 2015. Shifting perceptions of risk and reward: Dynamic selection for human development by black bears in the western United States. *Biological Conservation* 187, 164-172. https://doi.org/10.1016/j.biocon.2015.04.014

Karra, C. Kontgis, Z. Statman-Weil, J. C. Mazzariello, M. Mathis, Brumby S. P. 2021. Global land use / land cover with Sentinel 2 and deep learning. IEEE International Geoscience and Remote Sensing Symposium IGARSS, Brussels, Belgium. 4704-4707. http.//doi.org/ 10.1109/IGARSS47720.2021.955349

Lackey, C. W., S. W. Breck, B. F. Wakeling, White, B. 2018. Human-Black Bear Conflicts: A review of common management practices. *Human-Widlife Interactions Monograph* 2:1-68.

Lara-Díaz, N. E., Coronel-Arellano, H., Delfín-Alfonso, C. A., Espinosa-Flores, M. E., Peña-Mondragón, J. L., López-González, C. A. 2021. Connecting mountains and desert valleys for black bears in northern Mexico. *Landscape Ecology* 36, 2811-2830. https://doi.org/10.1007/s10980-021-01293-9

McFadden-Hiller, J. E., Beyer, D. E., Jr., Belant, J. L. 2016. Spatial distribution of black bear incident reports in Michigan. *PloS One* 11, e0154474. https://doi.org/10.1371/journal.pone. 0154474

McFeeters, S. K. 1996. The Use of the Normalized Difference Water Index (NDWI) in the Delineation of Open Water Features. *International Journal of Remote Sensing* 17,1425-1432.

Mckinney, B. R., and Villalobos, J. A. D. 2006. Preliminary Report on Maderas del Carmen Black Bear Study, Coahuila, México. Frederic (Rick) S. Winslow and Larisa L. Harding, 23.

Monroy-Vilchis, O., Castillo-Huitrón, N. M., Zarco-González, M. M., Rodríguez-Soto, C. 2016. Potential distribution of *Ursus americanus* in Mexico and its persistence: implications for conservation. *Journal for Nature Conservation,* 29, 62-68. https://doi.org/10.1016/j.jnc.2015.11.003

Nuñez-Torres, M. M. Zarco-González, O. Monroy-Vilchis, Carrera-Treviño R. 2020. Human–black bear interactions in Northern Mexico, Human Dimensions of Wildlife 25:5, 438-451. http://doi.org. 10.1080/10871209.2020.1752419

Rouse J.W., Hass R. H., Schell J. A, Deering D.W. 1974. Monitoring vegetation systems in The Great Plainswith ERTS. Proceedings of the Third Earth Resources Technology Satellite-1 Symposium, Washington, DC, 301-3017.

Sappington J., M, Longshore K., M, Thompson D. B. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. *Journal of Wildlife Management* 71, 1419-1426. doi:10.2193/2005-723.

Sollmann, R., Gardner, B., Belant, J. L., Wilton, C. M., Beringer, J. 2016. Habitat associations in a recolonizing, low-density black bear population. *Ecosphere* 7, e01406. https://doi.org/10.1002/ecs2.1406

Takola, E., Schielzeth, H. 2022. Hutchinson's ecological niche for individuals. *Biology & Philosophy* 37, 25. https://doi.org/10.1007/s10539-022-09849-y

Valdez, R., Ortega-S, J. A. 2014. Ecología y manejo de fauna silvestre en México. Editorial del Colegio de Postgraduados.

Zarco-González, Z., Carrera-Treviño, R., Monroy-Vilchis, O. 2023. Conservation of black bear (*Ursus americanus*) in Mexico through GPS tracking: crossing and roadkill sites. *Wildlife Research* 51, WR22121 https://doi.org/10.1071/WR22121