

Black Bear Population and Connectivity in the Sky Islands of Mexico and the United States

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Abstract—The Sky Island region is a mountainous region surrounded by grasslands, deserts and intermountain valleys, located between Mexico and the United States. However, different land management and human impact can have an effect on its wildlife populations. Currently, the border wall poses an immediate threat to the survival of black bears (*Ursus americanus*), considered an endangered species in Mexico. Our aim was to determine the conservation status of black bears in the Sierra San Luis as affected by the border fence. We determined population size through camera traps and radio-telemetry, and modeled population occupancy using PRESENCE. We documented a bear population with more than 500 individuals. Surveys along the border failed to detect bears crossing it, but we identified linkages between the two countries, which shall be important for future landscape planning. Increased vehicular traffic, migration, and drug traffic have a negative effect on bear populations, exacerbated by an increase in anthropogenic activities resulting from the construction and maintenance of the border wall. We recommend modifications to the structure of the border wall, and to increase wildlife monitoring by the United States authorities in order to reduce the potential impacts that this structure has on black bears and other wildlife populations.

Introduction

The black bear is the largest carnivore and the only *Ursid* species present in Mexico (Hall 1981; Doan-Crider and Hellgren 1996). Historically, its distribution included the States of Sonora, Chihuahua, Coahuila, Tamaulipas, Durango, Zacatecas, Sinaloa, San Luis Potosí, Jalisco, Nayarit, and Aguascalientes (Leopold 1959; Baker and Greer 1962; Hall 1981; Delfín-Alfonso and others 2011). However, during the 20th century, black bears were hunted, captured, and poisoned as a means of protection, because they were perceived as a threat to livestock and crops; the bears were harvested commercially for their skins and fat (Baker 1956; Leopold 1959; Medellín and others 2005). These actions caused to loss of 80% of their range (SEMARNAP-INE 1999).

Black bears currently are classified as endangered in most of its distribution in Mexico (SEMARNAP-INE 1999; SEMARNAT 2010). Although harvesting and hunting is prohibited (CITES 2009) and there are programs for black bear conservation (PROCER; CONANP 20011), their populations are at risk because of habitat loss, fragmentation (Leopold 1959; Pelton 1982; Robins and others 2004), and other human activities (Costello and others 2001).

The populations in the Sierra Madre Oriental has increased due to protection through the implementation of Management Units for Wildlife Conservation (UMAs) and Natural Protected Areas. These populations are more abundant compared with populations in the Sierra Madre Occidental (Doan-Crider 1995a; López-González and Lara-Díaz 2010).

In the Northern part of the Sierra Madre Occidental (SMO), bears remain in a naturally fragmented habitat, the Sky Islands, (Varas 2010; Delfín-Alfonso and others, in press) in Mountain ranges as San Luis, Los Ajos, El Tigre, Sierra Azul, La Elenita, Buenos Aires, and El Gato (Gallo and Garza 2002). However, information about their population status is poor. Sierra de San Luis may be the “source population” of individuals to the rest of the Sky Islands in Mexico and one of the primary connectivity areas with the populations in United States, therefore, contributing to the recovery of black bears in Mexico (Lara-Díaz 2010; López González and Lara-Díaz 2010; Varas 2010). Additionally, in the SMO and Sky Islands, there are immediate threats that can bring negative effects from short- to long-term for black bear populations (List 2007) mainly because of the construction and operations of the border fence between Mexico and the United States (Public Law 109-367 2006), and the expansion in two additional lanes of Federal Highway No. 2 (Agua Prieta-Janos) located within 5 km south of the border.

Black bears must maintain their mobility and their ability to grow and maintain viable populations if they are to survive in a highly fragmented landscape (Meffe and Carroll 1997; Crooks 2002; Duffy 2002; List 2007). Given the uncertain status of black bears in the Sky Islands, however, it becomes necessary to establish conservation and habitat management actions, through a solid base of biological knowledge of the species, in order to give viability to their populations in the long-term (Rogers 1993; Robins and others 2004). Our

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objective was to generate information on the current status of the black bear population in Sierra de San Luis and identify key areas of connectivity between the two countries.

Study Area

The Sierra de San Luis (SSL; fig. 1) is located at the NE of Sonora (31° 11' N, 108° 56' W) within the Sky Islands region, which consists of mountains that are isolated from one another by large extensions of desert and grasslands (Onorato et al. 2003; The Wildlands Project 2000). The area is also under the influence of the SMO, the Rocky Mountains, and the Chihuahuan and Sonoran deserts (Ponce-Guevara and others 2005).

The SSL is characterized by a dry temperature with summer rains. The average temperature in the summer is between 18 °C and 7 °C in winter (INEGI 1973). The average annual precipitation ranges from 450 mm (~1500 m) to 700 mm (~2500 m; Íñiguez et al. 2005). July receives the highest rainfall (86 to 106 mm) and the lowest precipitation occurs in May (2.7 to 3.2 mm; INEGI, 1973). The elevation of the locations ranges from 1,500 to 1800 m (Rodríguez-Martínez and others 2008). The hydrogeology is characterized by the presence of the Cajon Bonito River and several artificial water bodies and puddles (Rodríguez-Martínez and others 2008).

The dominant vegetation consists of grasslands and scrub. The representative species are the palmilla (*Nolina microcarpa*), Engelmann's nopal (*Opuntia pheacantha*), maguey (*Agave palmeri*) and sotol (*Dasylirion wheeleri*). There are also areas with gallery forests

dominated by aspen (*Populus* sp.) and in some areas juniper-oak or huizachal-oak associations can be found (Rodríguez-Martínez and others 2008).

Methods

Population Size

To estimate the black bear population size in SSL, we placed camera traps (WildView5®) in two sites from July to August 2010—23 camera traps in El Pinito Ranch and 29 camera traps in Los Ojos Ranch. The camera traps were placed on roads identified as fauna passages and were separated about 1 km. They were placed with S-N orientation. As bait, we placed in front of each camera a combination of sardines in tomato sauce, a mixture of oat-corn, and finally a vanilla extract sprayed with an atomizer into the above mixture. The camera traps were programmed to record the date and time (military format) and to take three successive photographic events every minute if they were activated.

Black bears in the photographic records were identified at the individual level through a comparative analysis of opinions where five observers discriminated individuals between the images obtained independently. Unusable photographs to distinguish individuals were eliminated, producing a consensus by which was established the average number of individuals; this approach has been used successfully in other studies (Kelly and others 2008). With these results, we constructed a capture-recapture history for each individual generating

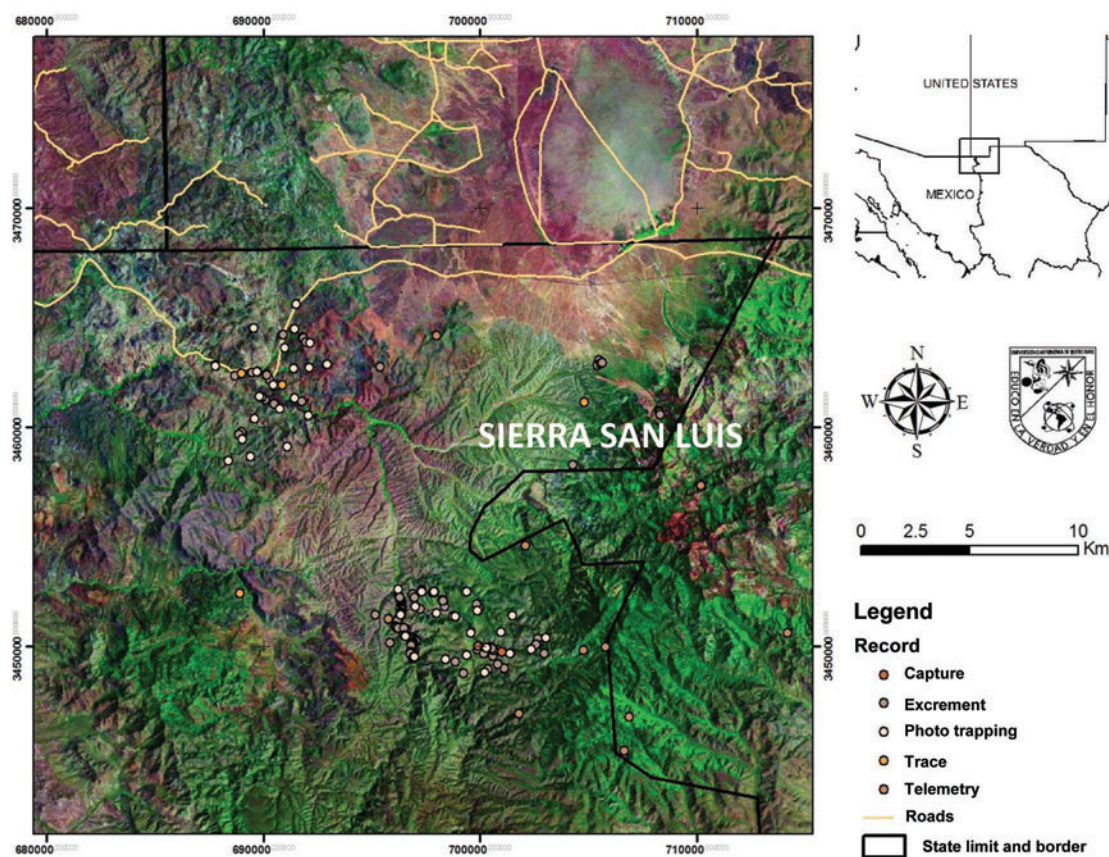


Figure 1—Study area and records of Black Bear in Sierra de San Luis, Sonora, México.

a database of presence (1) or absence (0) according to the sampling days.

The abundance was estimated with the MARK 6.0 program (White 2008), using the Capture tool, considering the assumptions of a closed population through the appropriate model of capture probability. We calculated the effective sample area generating a buffer surrounding each camera, using the average home range for black bear in SSL (32.33 km²; López-González and Lara-Díaz 2010), in the ArcMap ver. 9.3 program (ESRI 2008), with the “buffer” tool, and avoiding overlapping areas. The final area was calculated using the extension Xtools Pro (ver. 5.3) for ArcMap. For black bear density, the abundance parameter was divided by the effective sampling area, being reported as number of individuals per km². Finally, the density data (individuals/km²) was extrapolated to the SSL area.

Occupancy and Connectivity

Black bear records obtained during the study (including photographs, feces, capture, telemetry, traces) were used to generate the occupancy probability of the species in the study area, using the PRESENCE ver. 3.0 program (Hines 2006) and following the protocol established by Donovan and Hines (2007), which considers a single species, in a season of sampling, with covariates associated to the sites.

We considered an area of 26,307 km² (fig. 2) for calculating the occupancy probability. With the help to GIS, we divided the area into

a grid with sampling units of 1 km each. Each sampling unit visited, where we placed a camera trap or searched for traces, was associated to black bear presence or absence. Sampling units that were not visited during the monitoring events were listed with a dash (-) because it was unknown if the species was present or not. Thus, the detection history of the species was generated. Additionally, we generated a matrix of covariates associated with each sample unit: elevation (USGS 1993), Normalized Difference Vegetation Index (NDVI; Earth Observatory 2010), roughness (USGS 2001) and slope (USGS 2001), all of them important variables for black bear presence (Moreno 2008).

To associate the covariates of elevation, roughness, and slope to sample units, we used the ArcView 3.2 program (ESRI 1999) where each covariate is represented by a raster layer, and they were clipped to the study area through the Spatial Analyst extension (ver. 1.1). The information of each layer was added to the grid of the study area through the Get Grid Value extension 2 (Davies 2000). Moreover, the NDVI values for each of the sample units was generated by a LANDSAT satellite image using Image Analysis extension (Pinedo and Pinedo 2006) for Arcview 3.2 program (ESRI 1999). The covariates were normalized to be introduced to the program (Mackenzie and others 2003).

Based on the black bear detection matrix and the covariates matrix, we generated probability models with the PRESENCE program (Hines 2006). Each model considered the occupancy probability and detection probability associated with one or more covariates, also considering

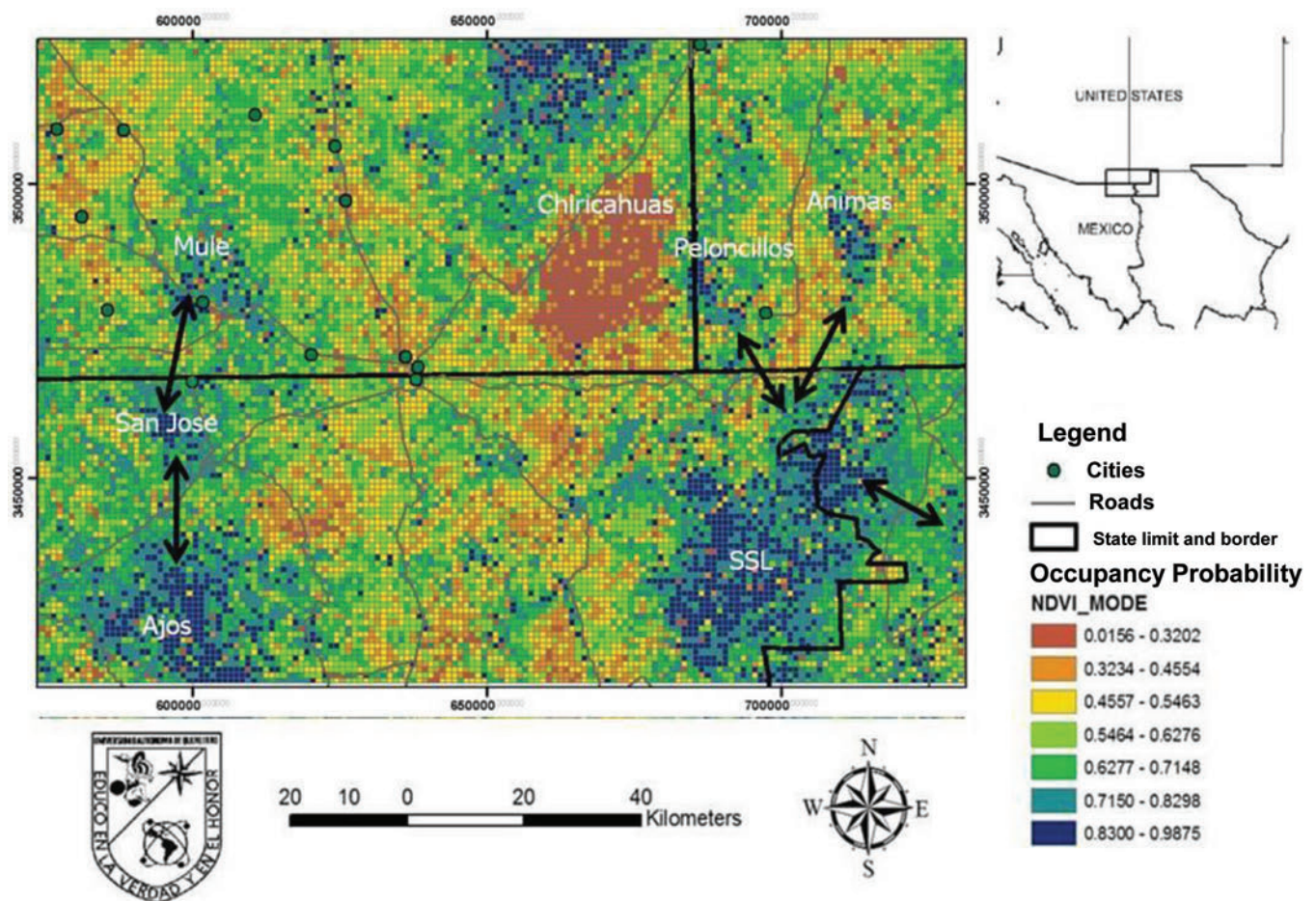


Figure 2—Occupancy probability of black bear (*Ursus americanus*) in the border region of Sonora and Chihuahua, México.

a constant covariate and a time-dependent covariate (Donovan and Hines 2007). Thus, we generated 1,056 models, given by the possible combinations among covariates. The best model to explain the occupancy and detection probabilities was selected through the lower Akaike Information Criteria (AIC) (King and others 2007).

Once we obtained the best model and given the occupancy probabilities per sample unit of 1 km² (obtained by the program), these probabilities were associated with a space-map to get a representative image of the occupancy probability distribution of black bears in the study area. This was achieved by using the ArcMap 9.3 program (ESRI, 2008) considering areas with the highest occupancy probability and greater coverage, which are the more likely for having connectivity between areas.

Results

Population Size

We obtained a total 30 different individuals in El Pinito Ranch and 18 different individuals in Los Ojos Ranch with a sampling effort of 4,413 camera-days. The abundance was estimated at 34 and 24 individuals, respectively. El Pinito Ranch had a higher density (0.322 individual/km²) compared to Los Ojos Ranch (0.161 individual/km²; table 1).

The SSL has an approximate area of 2,300 km² including 50 km south of the international border. Extrapolating the estimated average density obtained through our study, we believe there may be a black bear population of about 550 individuals; however, this population estimate may be reduced depending on management and predator control being carried out by different ranches in the area.

Occupancy and Connectivity

In the period from June 23 to November 3, 2010, we obtained a total of 209 records that documented the black bear presence. These records included 149 feces, six sets of traces, 41 camera-trap stations, four captures and 10 telemetry locations (fig. 1).

The best occupancy probability model (AIC = 390.37) was the one associated with the occupancy probability (*psi*) to NDVI, and the detection probability (*p*) to time. According to this model, the most likely area where black bears can be found is SSL, whose connectivity to the United States occurs in two main points from Puerto de San Luis (Mexico) to Animas Mountains (United States) and from the west of the SSL to Peloncillo Mountains (United States), eventually connecting to the Chiricahua Mountains (fig. 2). The region of the Sierra de Enmedio, in the Chihuahua State, hardly connects to the north with appropriate areas for the black bear, making it likely that individuals migrate north along the Sierra de San Luis. The other connectivity passage to the United States for black bear populations in the Sky Islands is the north part of the Sierra de Ajos (Mexico) through the Sierra San José (Mexico) and connecting with Mule Mountains (United States; fig. 2).

Discussion and Conclusions

The black bear population in Sierra de San Luis seems to be the largest in Sonora and Chihuahua. The abundance and density data obtained, as well as indirect records, have been higher compared with mountain ranges as Ajos, El Tigre and La Madera in México, where the densities have been estimated to be less than 0.05 individuals/km² (Lara-Díaz 2010).

The monitoring carried out during the study period shows a potential increase in black bear population in SSL relative to previous years (Sierra Corona and others 2005; Rodríguez and others 2008). This increase allows this population to be a source of individuals to other populations in the region. This result may be the outcome of multiple management strategies in the region, with areas dedicated to conservation with no hunting and a limited predator control. However, we must consider that some ranches still continue to implement measures against predators, and, therefore, the habitat for the black bears may be less suitable. Consequently the population size in SSL may be smaller.

In terms of connectivity, black bears should not have restrictions to continue crossing the border on the existing vehicle barriers. We believe that asking for modifications to the construction structure and the placing of it would be unrealistic. However, we can recommend to remove or modify the barbed wire that makes up the lower portion of the barrier and to raise the final strand; these simple actions can facilitate transition of young or juvenile black bears. Adults seem to have no problem crossing because they can easily climb the vehicle barriers.

It is important to reduce people and vehicular traffic in the areas identified as priority for possible connectivity of black bear populations from the two countries. If possible, increasing remote monitoring techniques (cameras and unmanned aerial vehicles) by the border agents would help the bears to continue crossing in these priority areas. Likewise, implementation of crossing points for wildlife with the expansion of Federal Highway No. 2 should reduce the number of collisions and, thus, would increase the probability that a black bear makes it to the border and across it. If black bear populations are to survive in the Sky Islands of the Northwest of Mexico, it is essential to maintain the connectivity sites from SSL and Sierra de Ajos to the United States.

Although the black bear population in SSL is reproducing and has recently increased, individuals of this population are not sufficient to reevaluate the endangered category in the region. Black bears are still widely pursued under the belief that they seriously affect production activities in the area. Finally, continuous monitoring of black bears populations in the Sky Islands is essential to assess the species status in the medium and long-term, and it is also essential to develop strategies for conservation and appropriate management.

Table 1—Abundance and density of black bear (*Ursus americanus*) at two study sites in the Sierra de San Luis, Sonora, México.

Site	Abundance (individuals)	S. E.	Interval (95% confidence)	Effective Sampling area (km ²)	Density (Ind./km ²)	Density S. E.t
El Pinito	34	3.98	31 a 50 individuals	105.600	0.322	0.387
Los Ojos	24	4.51	20 a 40 individuals	149.340	0.161	0.369

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