SUITABLE HABITATS FOR COUGARS (*PUMA CONCOLOR*) IN TEXAS AND NORTHERN MEXICO

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Abstract—We predicted current and potential distribution of cougars (*Puma concolor*) in Texas and bordering states in Mexico (Chihuahua, Coahuila, Nuevo León, and Tamaulipas) by creating a model of suitable habitats. We used MaxEnt to create our model using radiotelemetric data from southern and western Texas, as well as a suite of environmental variables. Our values for area under the receiver-operator curve (>0.85 for both training and test data) suggested that our model was a good predictor of habitat and distribution. Our map can aid in identifying areas where further research is needed to detect presence, status of populations, connectivity of corridors, and other demographic characteristics that are necessary for conservation and management of cougars.

Resumen—Predecimos la distribución actual y potencial de pumas (*Puma concolor*) en Texas y sus estados fronterizos en México (Chihuahua, Coahuila, Nuevo León, y Tamaulipas) creando un modelo de adecuación de hábitat. Usamos MaxEnt para crear nuestro modelo utilizando datos radiotelemétricos del sur y oeste de Texas, al igual que un juego de variables ambientales. Nuestros valores para el área bajo la curva receptor-operador (>0.85 para datos tanto de entrenamiento y de prueba) sugieren que nuestro modelo es bueno para predecir hábitat y distribución. Nuestro mapa puede ayudar a identificar áreas donde más investigaciones son necesarias para detectar presencia, estado poblacional, conectividad de corredores, y otras características demográficas que son necesarias para la conservación y el manejo de pumas.

Prior to European settlement, cougars (*Puma concolor*) occupied all habitats in North and South America, from tropical rainforests to arid deserts (Cunningham et al., 2001; Currier, 1983; Logan and Sweanor, 2000). Overharvesting and other anthropogenic activities, including overexploitation of prey and degradation of habitats from fragmentation and loss, have reduced cougars to <50% of their historic range (Logan and Sweanor, 2000), which now is mostly in remote areas (Currier, 1983; Dickson and Beier, 2002; Luna-Soria and López-González, 2005; Schmidly, 2004). Nevertheless, with establishment of regulated harvests in about 1965 (Logan and Sweanor, 2000) populations have increased because of decreased harvest, their high resilience and adaptability, and their opportunistic nature. As a result, the cougar is listed as a species of least concern by the International Union for Conservation of Nature and Natural Resources (www.iucnredlist.org). Regardless, they are protected in most countries of South and Central America and their harvest is regulated in North America, including the United States and Mexico (López-González and González-Romero, 1998). In Texas, harvesting is not regulated (Schmidly, 2004). Thus, few data exist on mortalities in Texas because reporting of harvests is voluntary. Moreover, adequate information does not exist for cougars in Mexico (Lopez-Gonzalez and Gonzalez-Romero, 1998). Although there is considerable information on population demographics and distribution in temperate North America, other than Texas, there are only a few studies in Mexico, Central America, and South America, where even the distribution has not been documented fully (López-González and González-Romero, 1998). Current threats include high mortalities attributed to control of predators, accidents associated with humans (Currier, 1983), loss of habitat, declining populations of prey (Harveson et al., 1999), and poaching (Rosas-Rosas et al., 2003).

One step toward understanding population dynamics and distribution of cougars is to create maps of suitable habitats that reflect potential distribution through a gradient of probability of occurrence associated with quality of habitat. Modeling of ecological niche is one technique for predicting geographic distribution of a species based on past occurrence (Illoldi-Rangel et al., 2004; Hernandez et al., 2008). This modeling attempts to predict the realized niche by relating occurrence and environmental variables that shape such distribution using biotic and abiotic factors (Illoldi-Rangel et al., 2004; Phillips et al., 2006; Hernandez et al., 2008; Phillips and Dudik, 2008). Predictive maps aid in identifying areas where further research is needed to verify presence, determine status of populations, and assess other ecological characteristics that are necessary for management of a species. This especially is important in areas where differing management strategies exist, such as along the Texas–Mexico border. Thus, our objective was to develop a predictive map of suitable habitats for cougars in Texas and bordering states in Mexico (e.g., Chihuahua, Coahuila, Nuevo León, and Tamaulipas).

Materials and Methods—Ecosystems of the world have been subdivided into classes of similar type, quantity, and quality of natural resources (Griffith et al., 2004). These classes have been designated as ecoregions and allow resource managers to define conservation priorities on local and global scales (Cantu et al., 2007). Moreover, each ecoregion has levels of specificity, with level I being the coarsest and level IV being the finest. Here, we developed a predictive model that describes suitable habitats for cougars in Texas and bordering states in Mexico using level-III ecoregions in this region as presented by the Commission for Environmental Cooperation (http://www.cec.org).

We used very-high-frequency data from radiotelemetry from two areas in Texas. In southern Texas, the study was conducted on ranches in and around the intersection of McMullen, Webb, Duval, and La Salle counties during 1994–1997, and included 1,374 locations collected from 10 cougars (6 males, 4 females; Harveson, 1997). In western Texas, studies were conducted in Big Bend National Park (J. M. Packard et al., in litt.) and Big Bend Ranch State Park (M. T. Pittman et al., in litt.) in southernmost Brewster and Presidio counties during 1984–1997, and included 2,762 locations collected from 16 cougars (9 males, 7 females). We pooled these datasets for a total of 4,136 radiotelemetric locations from 26 individual cougars.

We obtained spatial and environmental data for Texas and bordering states in Mexico. We downloaded Normalized Difference Vegetation Indexes and Vegetation Continuous Fields from the Global Land Cover Facility (http://www.landcover.org/data/) derived from satellite images taken during 2000 and 2001; resulting in layers Normalized Difference Vegetation Index-00, Normalized Difference Vegetation Index-01, Vegetation Continuous Field-00, and Vegetation Continuous Field-01. We acquired compressed Orthorectified Landsat ETM+ images from the National Aeronautics and Space Administration (http://zulu.ssc.nasa.gov/mrsid/mrsid.pl). We separated the three bands in each image into individual layers (band 7 = Zulu1, band 4 = Zulu2, and band 2 = Zulu3). We downloaded digital-elevation models for Texas from the Texas Natural Resource Information System (http://www.tnris.state.tx.us/datadownload/download.jsp) and for states in Mexico from Instituto Nacional de Estadistica, Geografia, e Informatica (http://www.inegi.org.mx/inegi/default.aspx?s=geo). We reprojected layers in Mexico to match our projection for Texas and merged them in ArcGIS (version 9.0, Environmental Systems Research Institute, Redlands, California) to create an elevation layer (Elevation). We used Elevation to calculate slope, hillshade, and aspect. We used spatial analysis in ArcGIS to reclassify aspect according to directional characteristics (1 = flat, 2 = north, 3 = northeast, 4 = east, 5 = southeast, 6 = south, 7 = southwest, 8 = west, or 9 = northwest) to create the layer Aspectr. We used Elevation to calculate the Vector-ruggedness-measure using a script developed by Sappington et al. (2007) with a 3-by-3 and 5-by-5 neighbor rule to create the layers Vector-ruggedness-measure-3 and Vector-ruggedness-measure-5, respectively.

We also downloaded vector layers for roads, rivers, soils, vegetation, and borders of Mexico from Instituto Nacional de Estadistica, Geografia, e Informatica. For Texas, we obtained roads and rivers from General Land Office (http://www.glo.state.tx.us/gisdata/gisdata.html), soils and borders from Texas View Consortium of Institutions of Higher Learning (http://www.texasview.org/), and vegetation from Texas Parks and Wildlife Department (http://www.tpwd.state.tx.us/landwater/land/maps/gis/data_downloads/). Vector layers downloaded for Mexico had to be adjusted spatially to match layers acquired for Texas, while layers in Texas had to be broadened to match coarser spatial resolution and classification of vegetation and soils for Mexico. The classification system for soils in both countries was different; thus, we created a unified soil layer using names corresponding to order using the World Reference Base for Soil Resources (International Union of Soil Sciences Working Group World Reference Base for Soil Resources, 2007). Using spatial analysis in ArcGIS, we calculated density for rivers and roads creating the layers Deriver and Deroglo, and converted soils and vegetation to rasters creating the layers World-reference-base-for-soil-resources-NO and Vegtyno.

All layers were matched in projection, resolution (1 km), and extent. We used two extents; Predicted and Actual. Predicted is the largest extent available, which is slightly smaller than the actual area of Texas, Chihuahua, Coahuila, Nuevo León, and Tamaulipas. Predicted served as the modeling-projection extent, while Actual represented the modeling-development extent. To create Actual extent, we made one polygon for southern Texas and another for western Texas, which included all telemetry locations of the area in the smallest size possible, we merged both polygons into a single file, and we clipped all coverage layers to this extent.

We used MaxEnt (version 3.3.1; http://www.cs.princeton.edu/~schapire/maxent/; Phillips et al., 2006) to generate models of ecological niche using presence-only data and to identify which environmental variables, or combinations of them, better predicted occurrence, resulting in a habitat-suitability model for cougars. We used all layers clipped to Actual extent to build the model, using 70% of available locations as training data and the remaining 30% as testing data with 1,000 iterations using random seed and 5,000 background points. We removed duplicate records, calculated jackknife values as measures of importance of variables, and output was in logistic format. We also used the area under the receiver-operator curve to assess accuracy of models. Ranges in values of area under the receiver-operator curve were 0 (low predictability) to 1 (high predictability). This model was extrapolated to the Predicted area, which also generated a clamping map that indicated areas where projection of the model was stretched beyond its capabilities (Clamp).

We used the jackknife procedure in MaxEnt to evaluate the contribution of each variable in the model. We removed all variables with jackknife values <0.05 and continued to rerun and remove other variables until all layers contained values >0.05. To avoid poor predictions, we used raster calculator in ArcGIS to delete areas with high Clamp values from our final Predicted model. To do this, we reclassified the Clamp map into three classes. Values of zero were reclassified as 100, values >0 and ≤ 0.5 were reclassified as 50, and values >0.5 were reclassified to zero. Then, using raster calculator, we multiplied the suitability value (range, 0–1) of the Predicted model by the reclassified Clamp map. This resulted in a model that kept its original predictive values (now with values of 0–100), except where predictions were believed to be poor. Low-Clamp areas (<0.5) were shrunk to one-half of their original suitability value, while high-Clamp regions received predictive values of zero. High-Clamp values do not necessarily mean poor suitability, but rather that the model is predicting over an area that is outside the range of values of the training data.

RESULTS—Our final predictive map (hereafter, habitat-suitability map) for cougars achieved area-under-the-receiver-operator-curve values of 0.852 for the training dataset and 0.838 for the testing dataset. Variables that we retained for our model included (in order of importance) Elevation, Zulu2, Vegtyno, Deriver, Vegetation Continuous Field-00, Vector-ruggedness-measure-5, Zulu1, Deroglo, Zulu3, World-reference-base-for-soil-resources-NO, Slope, Normalized-difference-vegetation-index-01, and Hill. The Clamp map represents areas where predictability of the habitat-suitability map is stretched beyond its capability; thus, it corresponds to areas where prediction of the model was poor. To avoid compromising the integrity of our model, we devalued those poorly predicated areas by multiplying the reclassified Clamp map by the habitat-suitability model. The potential distribution map in Fig. 1 is the result of removing poorly predicted areas from the habitat-suitability model created by MaxEnt.

DISCUSSION—Our values for area-under-the-receiver-operator curves (>0.83 for both training and testing data) suggest good discrimination by the model (Boyce et al., 2002). Moreover, most areas with high-Clamp values coincided with anthropogenic features such as

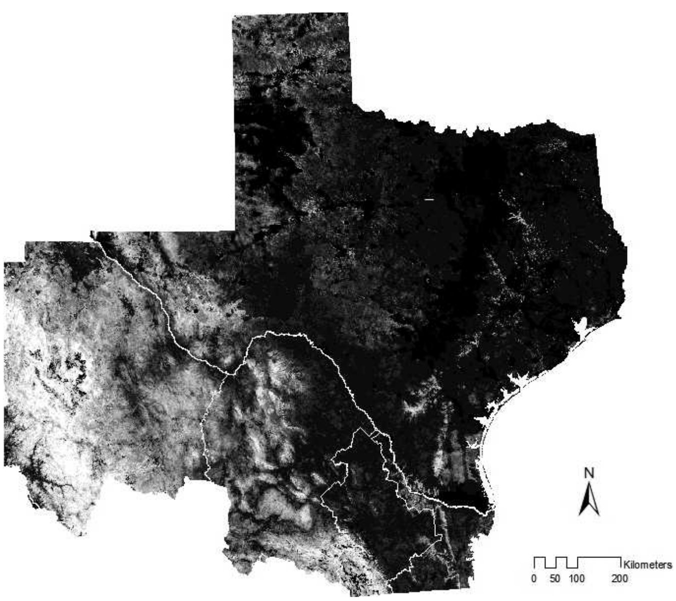

FIG. 1—Habitat-suitability map for cougars (*Puma concolor*) in Texas and northern Mexico. Paler areas have a greater probability of supporting populations of cougars.

large urban areas (i.e., Austin–San Antonio area, Houston, Dallas, and Lubbock) and interstate highways (i.e., I-20, I-10, and I-35), which represent unsuitable habitat for cougars. Clamp values generally were low for the Mexican portion of the model. If we consider that the highest Clamp values in Texas were associated with anthropogenic features, the lack of Clamp in Mexico could be explained because northern Mexico contains more natural areas, fewer urban areas, and lower density of roads. Regardless, we believe that the final model (Fig. 1) represents a robust habitat-suitability model for cougars in Texas and northern Mexico.

In 2005, the GAP-Analysis Program published a potential distribution map for cougars in the western United States (http://gapmap.nbii.gov/generatemap.php?species=Puma%20concolor). That map predicted suitable habitat in areas of western and central Texas and identified isolated suitable patches in eastern and northern Texas. However, this map does not include portions of southern Texas where we are certain that cougars occur, as indicated by data used to create the model (Harveson, 1997).

Another attempt to predict distribution of cougars in Texas using ecological-niche modeling came from Young (2008). His map was created using a genetic algorithm for rule-set production with data on locations and environmental variables from across the United States, but removing anthropogenic areas such as roads, cities, and other land-cover-land-use attributes. His model is similar to ours but is more fragmented. This fragmentation can be explained by removal of roads, cities, and some land-cover-land-use attributes; however, other ecological-niche models created using a genetic algorithm for rule-set production are fragmented, while models developed using MaxEnt tend to be more continuous (Phillips et al., 2006). When comparing methods of MaxEnt and a genetic algorithm for rule-set production, Phillips et al. (2006) noted that MaxEnt usually performs better than a genetic algorithm for rule-set production, especially when combining continuous and categorical data. Although we did not remove roads and cities from our predictive map like Young (2008), we did remove high-Clamping areas that coincided with such anthropogenic features.

Like the model of Young (2008), our model predicted highly suitable areas where presence has not been confirmed, such as the Gulf Coast Plains. Rather than being an over-prediction of the model, this is likely the result of the diminished range of cougars due to past overexploitation. Geographic barriers (Peterson and Vieglais, 2001), whether natural or anthropogenic, may explain why individuals from abundant populations have not dispersed and reoccupied these areas. Thus, predicted areas that are not occupied, may not imply an over-prediction of the model but rather may represent past occurrence and potential distribution where recolonization could occur. Such recolonization could be natural, as has been documented in the Dakotas (Thompson et al., 2009), or aided through reintroduction efforts, such as cougars from Texas released into Florida (Comiskey et al., 2004). Moreover, these currently vacant areas could help identify reintroduction sites or identify translocation sites for problematic cougars. To address these potential management scenarios, a study of connectivity is needed to evaluate the role of relatively isolated patches to the long-term persistence of cougars in Texas and northern Mexico.

Geographic distribution of a species is one of the most fundamental pieces of information a biologist must have to make appropriate management decisions. Even well-studied species, such as cougars, have inadequate distribution maps. Because it is impossible to document every occurrence of species throughout the world, researchers rely on indirect methods to locate or model habitats and basic environmental needs of species. This is especially important in areas that are largely privately owned, like Texas and bordering states in Mexico where access can be limited. Consequently, ecological-niche models, such as the habitat-suitability map presented here, have become a key tool helping researchers assess suitability of an area for a species. Nevertheless, performance of the model is limited by accuracy and availability of biotic and abiotic variables that are used.

The potential distribution map presented here is the first habitat-suitability map created for cougars in Mexico. Although it is not the first map created for Texas, we believe that it represents a better delineation of current and potential distribution in Texas. Many areas identified as highly suitable already contain cougars; while those that do not are important as they represent patches where cougars potentially could reoccupy given that these patches have adequate connectivity and protection.

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