Final Report
New Mexico Wildlife Habitat Linkage Assessment – Pronghorn

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PROJECT OVERVIEW

In this project, we completed a state-wide connectivity analysis for pronghorn (*Antilocapra americana*) across New Mexico. This project is funded by Resources Legacy Fund and The Wilderness Society, and is an expansion of an ongoing project funded by New Mexico Game and Fish for assessing wildlife connectivity and linkages across the state of New Mexico. In our previous assessments, we evaluated core movement habitats and corridors for four species of major ecological and management values, including elk (*Cervus canadensis*), bighorn sheep (*Ovis canadensis*), black bear (*Ursus americanus*), and lesser prairie-chicken (*Tympanuchus pallidicinctus*), using a state-of-the-art connectivity simulation tool (UNICOR) and statistical models (Wan et al. 2018). In this expanded study, we used the same methods and same study extent to evaluate core movement areas and corridors for pronghorn. In addition to the written report, we produced spatially-explicit GIS products that illustrate predicted core areas and corridors for the study species. Our products are designed to be incorporated into the New Mexico Crucial Habitat Assessment Tool (NM CHAT) and Biota Information System of New Mexico (BISON-M) to support species management at the landscape level.
INTRODUCTION

Given increasing human development and fragmentation of natural habitats, wildlife populations are becoming ever more isolated (Cushman 2006). Maintaining landscape connectivity between key population core areas can mitigate this isolation by maintaining the exchange of individuals and their genes between populations (Crooks and Sanjayan 2006, Cushman et al. 2013). However, it is often unfeasible to maintain all habitats and linkages due to limited resources on any given project. In this sense, identifying key habitats and linkages that provide the most benefits for target species is useful prioritizing wildlife habitat management efforts.

The New Mexico State Wildlife Action Plan (SWAP) lists a number of threats to wildlife populations in the state of New Mexico, including residential and commercial development, agriculture, energy production and mining, transportation and utility corridors, human intrusions and disturbance, natural system modification, invasive and problematic species, pollution, and climate change (New Mexico Department of Game and Fish 2016). All of these threats can potentially affect habitat quality and disrupt connectivity between wildlife populations. In order to more effectively manage wildlife habitats, it is critical to understand the potential impacts of these threats.

As a collaboration with the New Mexico Department of Game and Fish, we previously conducted a wildlife linkage assessment that evaluated and ranked the importance of core habitats and corridors for four native wildlife species, including elk (*Cervus canadensis*), bighorn sheep (*Ovis canadensis*), black bear (*Ursus americanus*), and lesser prairie-chicken (*Tympanuchus pallidicinctus*), across the full extent of New Mexico (Wan et al. 2018). These assessments utilized established resource selection models and state-of-the-art simulation tool UNICOR to quantify the effects of landscape features on species population connectivity. Our assessment produced spatially-explicit maps estimating connectivity strength, which provided important information for understanding connectivity patterns and movement behaviors of study species. Based on these connectivity models, we identified habitats and corridors that showed the greatest potential to provide the most benefits for each study species. Products from our assessment were designed to be integrated into The Western Association of Fish and Wildlife Agencies Crucial Habitat Assessment Tool (CHAT), which was developed to establish a common framework to store data on the interactions between development and wildlife and provide an interactive tool to facilitate understanding and discussion. Our assessment provided practical recommendations to guide and prioritize wildlife management and conservation efforts.

As an expansion of the New Mexico wildlife linkage assessment, we received funding support from Resources Legacy Fund and The Wilderness Society to conduct the same analyses for pronghorn (*Antilocapra americana*). The goal of this project was to complete a wildlife habitat linkage assessment across the full extent of New Mexico that evaluates core habitats and corridors for pronghorn. This project produced predictions of the importance of core areas and corridors for pronghorn and inform future efforts to improve landscape connectivity in the state, including efforts to improve animal movement across roads and connectivity of protected lands.
METHODS

Study area and focal species
The study area of this assessment encompassed the full extent of the state of New Mexico. Pronghorn was selected as the focal species in this assessment because of its significant scientific, ecological, educational, and recreational values. It is the sole native endemic ungulate species in North America (White et al. 2007) and serves as an important prey species for many predators, such as bobcats (*Lynx rufus*), coyotes (*Canis latrans*), golden eagles (*Aquila chrysaetos*), mountain lions (*Puma concolor*), and wolves (*Canis Lupus*) (Ockenfels 1994, Berger et al. 2008). It is of considerable interest to the public as a staple game species (New Mexico Department of Game and Fish 2018) and as an aesthetically appealing wildlife heritage.

Pronghorn typically occurs in open grassland, shrubsteppes, and semidesert grassland habitats (Yoakum 1980; Yoakum et al. 1996, 2014). Human development is the major cause of pronghorn habitat loss and fragmentation. For example, construction of railroad tracks, roads, and highways, oil and natural gas wells, pipelines, transmission lines, and wind and solar power structures pose threats to pronghorn as they form barriers to dispersal movement and migration pathways and isolate populations (Sawyer et al. 2002, 2013; Hebblewhite 2008; Beckmann et al. 2012). Additionally, increasing human transportation on railroads and highways are leading to increasing mortality of pronghorn from wildlife-vehicle collisions (O’Gara 2004, Maffly 2007).

Pronghorn migratory pathway selection model
As a first step in the assessment, we applied a previously developed pronghorn migratory pathway selection model (Jakes 2015) to our current study area. Briefly, this model was developed to predict the probability of pronghorn use at the second-order selection scale (Johnson 1980) during Fall seasons using generalized linear mixed models (GLMMs) with GPS telemetry collar movement data collected from the North American Sagebrush Steppe region in 2004-2010. Predictor variables in the model represented factors that were tested to be important to habitat selection of the pronghorn. There were four categories of variables – landcover, topography, hydrography, and human development (Fig. 1-4). Landcover variables included open water, barren ground, developed area, shrubland, riparian wetland, grassland, pasture and perennial cropland, coniferous forest, and deciduous forest (Fig. 1). Topographic variables included vector ruggedness measure, slope, and aspect (Fig. 2). Hydrography was represented by the density of hydrological features (Fig. 3). Variables for human development included paved roads density, all roads density, and oil and gas wells density (Fig. 4).

All landcover variables were derived from the land cover GIS layer obtained from the 2011 National Land Cover Database (Homer et al. 2015). Topographic variables were calculated using the ASTER Global Digital Elevation Model (GDEM) v2 data (ASTER 2013). Hydrography density was calculated with the National Hydrography Dataset for New Mexico (National Geospatial Program 2018). The paved roads and all roads densities were calculated the Topologically Integrated Geographic Encoding and Referencing (TIGER) road dataset (U.S. Department of Commerce 2013).
Census Bureau 2017). The density of oil and gas wells was calculated with an oil and gas wells map produced by the New Mexico Oil Conservation Division (2018). All densities were calculated using a 1000 m search radius. After preparing each variable in the form of GIS layer, we applied the same variable coefficients of Jake’s (2015) model to produce a probability map of pronghorn use for New Mexico state. The probability map has a value ranging from 0 to 1 at any given location, indicating probability of habitat use during Fall seasons. Values near 0 represent low probability of habitat use, and values near 1 represent high probability of habitat use. All GIS layers used in the modeling had a 30 m x 30 m resolution.

**Landscape resistance model**

We created a landscape resistance model for predicting the relative permeability of landscape features to pronghorn movement. This was done by using an inverse function to convert the habitat selection probability map described above into a resistance surface. The resulting resistance surface had a value between 1 (when habitat suitability = 1) and 100 (when habitat suitability = 0). Resistance values on the surface represent the movement cost for pronghorn. Low resistance values indicate areas easier and more likely for a species to traverse. Conversely, high resistance values indicate areas unfavorable and more unlikely for species movement. The resistance surface was used in a later step as the input raster for our connectivity simulations.

**Species distribution**

In order to conduct our connectivity simulations, we also need information about the relative distribution of the pronghorn. This information was used to help create initial individuals’ locations in our connectivity simulations. We obtained statewide population estimates of pronghorn from the New Mexico Department of Game and Fish. Population was estimated for each Game Management Units (GMUs) based on surveys conducted during 2015-2017. We obtained GMUs shapefiles from the New Mexico Department of Game and Fish, and created random points within each GMU with the number of points matching the pronghorn population estimates. The collection of points showed the approximate relative abundance of each study species across the study area. However, because the points were restricted by the boundaries of the GMUs, they resembled segregated and geometric blocks of points on the map (Fig. 5a). To recreate a more natural species distribution, we followed the method of Wan et al. (2018) and generated a smooth continuous surface by calculating the kernel density of points using the Kernel Density tool in ArcGIS (Fig. 5b). We then used the continuous surface as the inclusion probability raster to populate the study area with unique spatial points (Fig. 5c) equal to the approximate state-wide total pronghorn population ($n = 45,000$) as estimated by the New Mexico Department of Game and Fish (2015). Finally, because of the large number of points, we randomly sampled a subset of points ($n = 5,000$) for our analyses (Fig. 5d).
**Connectivity corridor simulation**

We used UNICOR (Landguth et al. 2012), an individual-based species connectivity and corridor identification simulation tool, to predict and map connectivity corridors for pronghorn. UNICOR applies Dijkstra’s shortest path algorithm to analyze movement cost around any number of individual’s locations on a resistance surface. The resulting output is a raster surface of expected density of dispersing individuals. We used the landscape resistance model and spatial points samples described in previous steps as input resistance surfaces and individuals’ source locations in the UNICOR simulations, and mapped two types of connectivity corridors for pronghorn: (1) kernel density estimation on least cost paths, and (2) cumulative resistant kernel.

**Kernel density estimation on factorial least cost paths**

Factorial least cost path analysis is commonly used for analyzing connectivity patterns. It quantifies pairwise optimal paths between all individuals on a landscape. However, it is unrealistic to assume that only a single path is being used between any given two individuals. To more realistically represent the behavior of organisms, we incorporated a kernel density estimation by buffering all least cost paths with a 1-km Gaussian smoothing kernel. This approach produces density surfaces that predict the most probable movement routes connecting species populations, which provides managers with visual guidance on identifying corridors for maintaining connectivity.

**Cumulative resistant kernel**

Similar to the kernel density estimation on least cost paths approach, a cumulative resistant kernel connectivity analysis does not assume a single path between two individuals. The cumulative resistant kernel approach considers the dispersal ability of a species, and estimates omnidirectional least-cost dispersal kernel around each individual location, given a dispersal threshold, after which all kernels are added together to produce a density map predicting connectivity strength at each location on the landscape (Compton et al. 2007). Dispersal threshold was parameterized to 50 km, representing our conservative estimates of the average dispersal distance of pronghorn based on the literature (Jacques et al. 2009, Kolar et al. 2011, Jake 2015). This approach produces density surfaces that predict core habitat areas for species movement.

**Core movement habitat and corridor**

To analyze the spatial characteristics of core habitat and corridors, we classified each connectivity map generated from UNICOR simulations (i.e., the kernel density smoothed factorial least cost paths and the cumulative resistant kernel density surfaces) into a binary map. We defined habitat patches classified from the cumulative resistant kernel as core habitats, and the factorial least cost paths habitat patches as corridors. For core habitats, this was done by using 20% of maximum value of the resistant kernel connectivity map as a threshold, i.e., areas above this threshold value were classified as habitat, whereas areas below the threshold value
were classified as non-habitat. Because the estimated number of pronghorn was much higher and more concentrated in northeastern New Mexico than the rest of the state (Fig. 1), the analysis resulted in only a single large core habitat patch in that area. In order to identify potential core habitats in other parts of New Mexico, we conducted a posthoc analysis. We normalized the cumulative resistant kernel connectivity across the entire map, and then used 20% of the new maximum value as a threshold to reclassify core habitats. We considered any islands of habitats that were not connected to the main habitat patch identified the first time as additional potential core habitats. Then, we refill these islands of habitats with the original connectivity values. For corridors, we used 10% of the maximum value of the factorial least cost paths connectivity map as the threshold.

**Prioritizing core habitat patches**

To evaluate the relative importance of core habitat patches to connectivity, we ranked each core habitat patch based on its (1) total area, (2) per area connectivity strength, and (3) connectivity contribution. Connectivity contribution of each patch was calculated by dividing its total connectivity strength by the cumulative connectivity of all patches. Habitat patches with larger extent, higher connectivity strength, and greater contribution were ranked higher. The ranks of each patch in the three criteria were added together, providing a collective rank score for each habitat patch. Habitat patches with a low score (i.e., high collective rankings) indicated high relative importance to connectivity among populations.

We calculated the mean and the standard deviation of collective rank scores, and classified each patch into a high, medium, or low priority patch using the collective score. Collective scores less than the mean minus 1 standard deviation were classified as high priority, scores between the mean minus 1 standard deviation and the mean were classified as medium priority, scores above the mean were classified as low priority.

**RESULTS**

Our landscape resistance model for pronghorn showed that low resistance areas spanned across northeastern to central eastern New Mexico and mostly located in grassland habitats and flat terrain (Fig. 6). These low resistance areas also overlapped with areas with high pronghorn populations (Fig. 5). Conversely, forested habitats, roads, and areas with steep slopes showed high resistance and create barriers to pronghorn movement (Fig. 6).

The factorial least cost paths with kernel estimation analysis revealed multiple major movement pathways that extended from northeastern New Mexico to western and southeastern New Mexico (Fig. 7a). The cumulative resistant kernel analysis showed that core habitats of pronghorn was highly concentrated in northeastern New Mexico. Our posthoc normalization of the cumulative
resistant kernel surface revealed a few small islands of potential core habitats at the southwestern and southern sides of New Mexico, but their connectivity strength was very weak because of substantially lower pronghorn population compared with the pronghorn populations in northeastern New Mexico (Fig. 7b).

The core habitat patches were mostly located at low resistance areas. Core areas P1 was clearly the most important core habitat patch, ranking top in every category we examined (Table 1, Fig. 8). Core areas P2 and P2 ranked next, but they were by far much smaller and had much lower connectivity strength compared with core area P1. The other two core areas, P3 and P5, were even smaller and ranked at the bottom. Our prioritization analysis ranked corridor 2 as the most important (Table 1, Fig. 8). It was the major pathway that connected core area P1 with P2. Corridor 3 ranked second and connected core area P1 with P4. Other corridors, 1 and 4, extended from the main core area P1, but did not connect to other identified core areas (Fig. 8).

**DISCUSSION**

In addition to what we have discussed in our previous assessment (Wan et al. 2018), we advocate conservation and wildlife management strategies to transition away from fine-scale single-species focus to a landscape-scale holistic and comprehensive multi-species approach (Noon et al. 2009). We see an opportunity to use the findings from this and our previous wildlife linkage assessment to design multi-species conservation strategy involving intersection and prioritization of core areas and corridors for bear, elk, bighorn sheep, lesser prairie-chicken, and pronghorn. Such connectivity analysis will aid conservation planning and management in terms of identifying areas that are important for multiple species and designing optimal set solutions that protect sufficient core areas and corridors for all species with minimum area.

Our results from this project indicate that, other than in the northeastern part of New Mexico, there is an overall lack of linkages among pronghorn habitats. Particularly, pronghorn populations near southern New Mexico appears to be isolated from the main pronghorn populations in the north. Even though there are large habitat patches with low landscape resistance between the northern and southern pronghorn populations in New Mexico, human structures, especially the city of Roswell and surrounding highways, are acting as major barriers that block pronghorn dispersal (Fig. 6 and 7). Thus, movement of pronghorn populations between the north and the south is unlikely without habitat conservation efforts such as constructions of wildlife crossings on highways. Our corridor analysis suggests potential locations (Fig. 8: corridor 3 and 4) for building these wildlife crossings that are more likely to be effective.

Finally, continual increase of human activities and development, including agriculture, and the construction of roads, and oil and gas wells, many natural habitats will become more fragmented and isolated. Adding these to the impact of climate change, many wildlife species will likely
experience a gradual range shift to compensate for habitat loss and fragmentation (Kelly and Goulden 2008). In this context, our findings are useful in at least two ways. First, our findings provide a yardstick to measure how current and future human development might affect the connectivity of a species. Second, our models help to identify areas mostly likely be used by a species to disperse during range shift. And thus, land managers can prioritize their current management efforts to start protecting and conserving these important areas.

REFERENCES


Table 1. Prioritizing core habitat area and corridor by relative importance of connectivity to pronghorn. Identifiers of core habitat (P1-P5) and corridor (1-5) correspond with those in Fig. 8.

<table>
<thead>
<tr>
<th>Core</th>
<th>Total area (km²)</th>
<th>Total connectivity</th>
<th>Connectivity contribution</th>
<th>Connectivity per km²</th>
<th>Area rank</th>
<th>Per area connectivity rank</th>
<th>Contribution rank</th>
<th>Collective rank score</th>
<th>Priority</th>
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<th>Connectivity per km²</th>
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<td>Medium</td>
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</tbody>
</table>
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