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Note

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ABSTRACT Habitat quality is an important factor that can greatly affect wildlife populations. Pronghorn (*Antilocapra americana)* habitat in the Texas Panhandle, USA has been lost through growth of human settlements and agricultural lands. We determined the most pertinent environmental variables affecting habitat selection using multiple methods, including a search of peer-reviewed literature, expert opinion ranking, and habitat suitability modeling. We determined quality and extent of pronghorn habitat in the Texas Panhandle using the MAXENT modeling environment to build a presence-only habitat suitability model based on global positioning system (GPS) locations collected via aerial surveys. Our habitat suitability model indicated that woodlands, agricultural land, and summer precipitation had the greatest contributions to the overall model. Areas with greatest habitat suitability are associated with high pronghorn population densities, particularly in the northwestern corner of the Panhandle. This probabilistic model may serve as a useful tool for pronghorn conservation primarily because it provides insight into what factors are most predictive of their presence, which areas are most suitable for pronghorn, and as a simple, replicable process to identify and evaluate pronghorn habitat. © 2016 The Wildlife Society.

KEY WORDS *Antilocapra americana*, expert opinion, habitat suitability, MAXENT, pronghorn, Texas Panhandle.

The pronghorn (*Antilocapra americana*) is a North American ungulate that ranges throughout the High Plains and Trans-Pecos regions of Texas, USA (Gray 2012). Historically, pronghorn in Texas were distributed across most of the state extending as far south as the Gulf of Mexico (Leftwich 1977). During the late nineteenth and early twentieth centuries, pronghorn range decreased significantly because of increasing human populations and land developments, specifically agriculture (Leftwich 1977). Currently, most of the High Plains, and the surrounding ecoregions, have been converted from the original native rangeland into agricultural land (Gould 1969, Griffith et al. 2007). Although pronghorn are of least concern in the Texas High Plains-Panhandle wildlife district (District 2), degradation and loss of pronghorn habitat in the region poses a potential risk for pronghorn in the future (Gray 2012). Because little to no information on pronghorn habitat suitability exists in District 2, there currently is not a means to evaluate what areas represent pronghorn habitat or what variables affect habitat suitability the most.

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The Texas Parks and Wildlife Department (TPWD) currently conducts annual aerial surveys from June through August that may provide a general idea as to the probable areas of highest suitability based on density and population size of a given pronghorn herd unit, or game management area. Herd units vary in size and are delineated by natural and man-made structures (i.e., roads, escarpments, rivers, fences), and are therefore not closed populations. Pronghorn populations in District 2 are stable with an estimated population >12,000 as of August 2013 with a female to male ratio of approximately 3:1. Population size and environmental conditions vary in individual herd units. Our objective was to develop a habitat suitability model from presence-only global positioning system (GPS) data points collected from aerial surveys and relevant habitat variables, determined by the primary literature and input from pronghorn experts.

STUDY AREA

Pronghorn herd units in District 2 fall within the Rolling Sand Plains, Canadian Cimarron High Plains, and the Llano Estacado ecoregions of the High Plains (Griffith et al. 2007); the High Plains account for the southern region of the Central Great Plains (Griffith et al. 2007), which is characterized by flat to gently rolling terrain with some variation interspersed (Gould 1969). Many draws and escarpments spread throughout the region, especially along the northern border of the Llano Estacado and Canadian River Breaks (Natural Resources Conservation Service [NRCS] and U.S. Department of Agriculture [USDA] 2006). Elevation ranges from approximately 900–1,500 m with significant variation in some regions (Gould 1969, NRCS and USDA 2006, Griffith et al. 2007). Dominant vegetation in the High Plains consists of blue grama (*Bouteloua gracilis*), buffalograss (*Bouteloua dactyloides*), sideoats grama (*Bouteloua curtipendula*), and bluestem (*Andropogon* spp.) with some dominant woody species including sand havard oak (*Quercus havardii*) and sand sagebrush (*Artemesia fillifolia*; Gould 1969, NRCS and USDA 2006, Griffith et al. 2007). Dominant wildlife species include white-tailed and mule deer (*Odocoileus virginianus*, *O. hemionus*), coyote (*Canis latrans*), black-tailed jackrabbit (*Lepus californicus*), black-tailed prairie dog (*Cynomys ludovicianus*), burrowing owl (*Athene cunicularia*), and other prairie raptors such as ferruginous and swainson's hawks (*Buteo regalis* and *B. swainsoni*; Griffith et al. 2007).

Nearly 80% of the land in TPWD District 2 has been converted for livestock and crop production (Griffith et al. 2007). Dominant crops are wheat, grain sorghum, corn, and soybeans (NRCS and USDA 2006, Griffith et al. 2007). Soils are primarily sandy and loamy with types consisting of mollisols, alfisols, and inceptisols (NRCS and USDA 2006, Griffith et al. 2007). Water usage in District 2 is high and withdrawn primarily from the Ogallala aquifer for agricultural use (NRCS and USDA 2006). Yearly precipitation in the District 2 area is variable but typically ranges from 36–56 cm (NRCS and USDA 2006). Average annual temperature ranges from 12–14 degrees Celsius (NRCS and USDA 2006).

METHODS

Pronghorn Locations

To develop a pronghorn habitat suitability model, we used GPS points collected from summer (Jun–Aug) 2008–2013 aerial surveys conducted by the TPWD. Pilots flew over herd units in their entirety via strip transect with a width of 402 m (2008–2010 surveys) or 805 m (2011–2013 surveys). Surveyors changed transect widths during the during the study period to test the effectiveness of different widths (Gray 2012). Observers included 2 passengers and the pilot with 1 observer verbally inputting data (GPS locations of individuals or groups of pronghorn) into CyberTracker 3.283 software (CyberTracker Conservation, Cape Town, South Africa). Aerial survey flights were conducted in a manner consistent with safety and stress mitigation for animals to reduce negative impacts of aerial sampling. Habitat data resolution was coarser than the raster version of the aerial survey data, leaving numerous overlapping points, rendering them unnecessary. To account for the overlap, and avoid pseudoreplication of locations, we entered the pronghorn location dataset into ArcMap 10.1 (Environmental Systems Research Institute, Redlands, CA, USA) and converted it to a raster dataset with a 30-m resolution, the resolution of the least coarse habitat data layer, then converted it back to a vector layout.

Ranking of Environmental Variables

We developed a list of environmental variables a priori to create the most relevant representation of those that most likely affect pronghorn habitat selection in District 2 (Table 1). We identified all relevant literature sources supporting each habitat variable, and ranked variables initially by their importance based on the primary literature. Although our list was developed from peer-reviewed literature, it represented pronghorn habitat selection generally rather than being specific to pronghorn in Texas and the surrounding states.

To provide further support for our list of variables, and to remove variables of lesser relevance to pronghorn in the Texas Panhandle, we then consulted experts (i.e., researchers with >5 yr of experience working with or researching pronghorn in the selected areas) familiar with pronghorn in

Table 1. Environmental variables selected from the primary literature based on their relative importance in pronghorn habitat selection in the Texas Panhandle, USA. We ranked variables subjectively based on their perceived significance from previous research.

Ranking	Variable	Reference
1	Precipitation	Buechner (1950), DeArment (1965), DeArment et al. (1966), Pyrah (1987), Danvir (1996), Brown et al. (2006), Canon and Bryant (2006), Simpson et al. (2007)
2	Vegetation composition	Buechner (1950), Hoover et al. (1959), Koerth et al. (1984), Pyrah (1987), Ockenfels et al. (1994), Yoakum (2004)
3	Vegetation greenness	Pettorelli et al. (2005), Mueller et al. (2008), Poor (2010), Poor et al. (2012), Ryan et al. (2012)
4	Distance to water	Einarsen (1948), Buechner (1950), DeArment et al. (1966), Sundstrom (1968), Haukos and Smith (1994), Ockenfels et al. (1994), Yoakum (2004), Morgart et al. (2005)
5	Land coverage	Buechner (1950), Bayless (1968), Amstrup (1978), Roebuck and Simpson (1982), Foster (1988), Ockenfels et al. (1994), Danvir (1996), Gray (2012)
6	Fawn Habitat	Vriend and Barrett (1978), Tucker and Garner (1983), Pyrah (1987), Canon (1993), Canon and Bryant (1997), Yoakum (2004)
7	Topography	Buechner (1950), Amstrup (1978), Kindschy et al. (1982), Ockenfels et al. (1994), Yoakum et al. (1995), Yoakum (2004)
8	Vegetation height	Einarsen (1948), Ockenfels et al. (1994)
9	Distance to roads	Howard et al. (1990), Ockenfels et al. (1994), Poor (2010), Poor et al. (2012)
10	Distance to agriculture	Einarsen (1948), Cole (1956), Hoover et al. (1959), Hoover (1966), Hepworth (1968), O'Gara and Morrison (2004), Gray (2012)
11	Distance to woodland	Buechner (1950), Pyrah (1987), Ockenfels et al. (1994)

the southwest United States and Texas to determine which of the variables selected in this step were of highest importance. Prior to consulting with pronghorn experts, we developed a list of questions that compared one variable to another based on which affected pronghorn habitat selection and ranked them based on relevance, according to the literature. We developed a questionnaire containing 24 questions that consisted of variable pairings with the highest relevance, resulting in a much shorter survey than a pairwise comparison of all relevant variables, as is typical with the analytical hierarchy process (AHP; Saaty 1980). By administering our own version of variable comparison, we were also able to offer each expert an option for immediate additional feedback to our questions and comparisons to clarify their answers, comment on the survey itself, or respond more fully or verbally to a particular comparison we included in the questionnaire. We received survey responses from 6 of the 7 experts contacted. We instructed experts to answer based on their knowledge of pronghorn habitat selection during summer, when aerial surveys took place, with input from their personal experience, rather than what they may have read in current or past literature.

We ranked responses from each of the 24 questions in a tournament format. For example, if the expert chose variable 1 over variable 2 then variable 1 went onto the next variable comparison. After we tallied all responses for the first round, we removed any variables that were not considered important by an expert from the list. We then ranked variables in each questionnaire based on the number of responses each variable received (e.g., variable 1 was chosen 4 times and variable 2 was chosen twice then variable 1 was ranked higher than variable 2). We ranked all variables in the individual questionnaires, and then averaged across the 6 questionnaires to calculate a final average ranking (Table 2). We used the variable ranking method specifically for its simplicity and economy. Although there are many other possible methods for using expert opinion (Saaty 1980, Cooke 1991, Elith and Leathwick 2009), and even though expert opinion can introduce uncertainty or bias into our pronghorn habitat analyses (Poor et al. 2012), this method was most efficient for assessment because of time constraints and numerous habitat variables.

Variables selected from the expert opinion surveys were relevant to habitat suitability in District 2 per our examination of the primary literature, but limitations in data availability restricted the creation of the following variables: fawn habitat, vegetation composition, and vegetation height. Thus, we created environmental layers only for variables that could be created from existing spatial datasets (Table 2). Vegetation greenness and precipitation data were collected from the study period with the remaining layers coming from the latest National Gap Analysis Program (GAP) dataset (2011).

Model Evaluation

We created environmental layers at 30-m resolution using ArcMap 10.1 and converted them to ASCII format. We tested the resulting ASCII files for multicollinearity using ENMTools 1.4.3 (Warren et al. 2010, Warren and Seifert 2011) to determine any linear relationship between data layers. None of the variables were highly correlated ($|r| < 0.32$). We developed a habitat suitability model using the MAXENT version 3.3 modeling environment (Phillips et al. 2006). Ecological niche modeling (ENM) exists in many different forms, but the MAXENT modeling environment is widely used (Fitzpatrick et al. 2013), and when properly informed by biologically relevant and literature-supported variables (Elith et al. 2006, Lozier et al. 2009), can provide accurate models of habitat suitability for presence-only data as well as the relative contributions of individual habitat variables (i.e., which variables have the greatest impact in improving model fit). Because little information exists concerning pronghorn habitat in District 2, creating a dependable, well-informed model is necessary for future research to build on, especially with data that is readily available and regularly collected. We ran the MAXENT model using 1,000 iterations (Razgour et al. 2011), background sampling of 10,000 pseudo-absence

Table 2. Environmental variables used for the habitat suitability model ranked based on the number of times the variable was selected in a questionnaire given to 6 pronghorn researchers. We adjusted results for bias by dividing the number of responses for the variable by the number of questions containing that variable. Variables are ordered based on ranking by expert opinion and each variable has a description for how it was created and its contribution to the overall habitat suitability model.

Variable	Source	Average expert ranking	Resolution	Variable contribution (%)
Land coverage	U.S. Geological Survey National Gap Analysis Program (GAP)	1	30 m	3.7
Precipitation	Parameter-elevation on Independent Slopes Model (PRISM)	2	4 km	20.1
Vegetation composition	Data unavailable	3		
Vegetation greenness	Normalized Difference Vegetation Index (NDVI) data from Moderate Resolution Imaging Spectroradiometer (MODIS)	4	250 m	3.2
Vegetation height	Data unavailable	5		
Distance to agriculture	GAP	6	30 m	20.1
Fawn habitat	Data unavailable	7		
Distance to woodland	GAP	8	30 m	48.0
Distance to water	GAP	9	30 m	4.9

points, and hinge features because the robustness using both categorical and continuous variables as well as the output of smooth functions (Phillips and Dudik 2008, Elith et al. 2011). We used 20% of the points for testing and the remaining 80% for training. To achieve the best model fit and to avoid overfitting, we varied the regularization parameter using odd values from 1–19 (Warren and Seifert 2011). We resampled each model using a 20-fold cross-validation to ensure variance was reduced (Phillips and Dudik 2008, Elith et al. 2011). We set all other MAXENT settings at program defaults.

RESULTS

Observers collected 5,175 points during the 2008–2013 aerial surveys. Upon resampling, the final vector layer contained 5,126 points, which constituted the dataset used in the habitat suitability analysis. Variables determined to have the highest significance in pronghorn habitat selection based on expert opinion were land coverage, precipitation, vegetation composition, vegetation greenness, vegetation height, distance to agriculture, fawn habitat (i.e., preferred habitat for fawning; presence of shrubs, large rocks, variable topography), distance to woodland, and distance to water (Table 2), which was similar to the literature review (Table 1). Lack of spatial data prevented our use of some habitat variables, specifically vegetation composition, vegetation height, and fawn habitat variables (Table 1). Thus, variables included in the analysis were land coverage, summer (Jun–Aug) precipitation, summer vegetation greenness, distance to agriculture, distance to woodland, and distance to water (Tables 1 and 2).

The final pronghorn habitat suitability model, using the environmental variables ranked via expert opinion, had a regularization parameter of 1 with a test area under the curve (AUC) of 0.715 and training AUC of 0.717, which indicated that a presence point chosen at random would receive a higher ranking than a randomly chosen pseudo-absence point (Phillips and Dudik 2008). The top 3 contributing variables to the overall model, or the variables that had the greatest percentage contribution to model fit, were distance to woodland, precipitation, and distance to agriculture (Table 2). Ranking of variables within MAXENT differed from that suggested by expert opinion, especially variables experts ranked as most important such as land cover and vegetation greenness (Table 2). The habitat suitability index (HSI), or the logistic output from MAXENT for each pixel, increased with increasing distance from woodland areas (e.g., a pixel with a distance of 21,177.24 m from any woodland had an HSI of 0.72, whereas a pixel with a distance of 655.22 m had an HSI of 0.13). Areas with low precipitation were associated with a low overall HSI, whereas areas with moderate to high precipitation were associated with greater habitat suitability (e.g., a pixel with 18.69 cm of precipitation had an HSI of 0.58, whereas a pixel with 13.02 cm of precipitation had an HSI of 0.09). Habitat suitability also increased with increasing distance from agricultural land (e.g., a pixel with a distance of 20,201.97 m from agricultural land had an HSI of 0.68, whereas a pixel located within agricultural land had an HSI of 0.26). There are exceptions to each of these examples in the model, but these exceptions can be explained by the influence of other variables (e.g., an area with high precipitation has a low HSI but is in close proximity to woodlands or agriculture).

Variables with the least overall contribution were distance to water, land coverage, and vegetation greenness (Table 2). The HSI was greatest with some distance (<10,000 m) from water sources; however, HSI decreased as the distance increased suggesting that pronghorns do not require constant access to water but still rely on water sources in their range (e.g., a pixel 417.42 m from a water source had an HSI of 0.38, which increased to an HSI of 0.63 at 10,156.28 m and then declined to an HSI of 0.32 at 14,542.18 m). The land coverage type with the highest suitability was introduced and semi-natural vegetation ($HSI = 0.62 \pm 0.0023$ SD). The land coverage types with the lowest suitability were agricultural vegetation ($HSI = 0.51 \pm 0.0021$ SD) and developed and other human use ($HSI = 0.56 \pm 0.0035$ SD). All other land coverage types, forest and woodland, semi-desert, shrubland and grassland, nonvascular and sparse vascular rock vegetation, open water, and recently disturbed or modified vegetation types, had the same suitability index value ($HSI = 0.60 \pm 0.0017$ SD). Habitat suitability in response to vegetation greenness varied, especially in areas with high densities of agriculture (e.g., an area with a higher HSI of 0.76 had an NDVI value of 0.29, but an agricultural area had an HSI of 0.45 and an NDVI value of 0.79). Even though the overall trend showed a positive relationship between NDVI and habitat suitability, agricultural vegetation had higher vegetation greenness than the surrounding native and introduced vegetation.

The most suitable areas of pronghorn habitat were found in the northwest corner of District 2, specifically in Dallam, Hartley, Moore, and Potter counties, and represented areas with relatively high pronghorn population density (Fig. 1). The areas with the greatest HSI were within, or near, herd units that primarily fell within the High Plains ecoregion. The least suitable areas for pronghorn habitat in District 2 were found in the eastern portion of the district, within the Southwestern Tablelands ecoregion and the southern-most portion of the High Plains.

DISCUSSION

According to the experts surveyed for this study, the primary variables responsible for lack of pronghorn habitat in District 2 were land coverage, precipitation, and vegetation composition (Table 2). However, the results of the model determined a somewhat different ranking, with distance to woodland, precipitation (correctly predicted by the experts), and distance to agriculture being the most influential on pronghorn habitat suitability (Table 2). When comparing the expert-ranked variables with the MAXENT-ranked variables, the order appears reversed, except for precipitation. Although the lists appear disparate, there is some consistency between the basic components of each of the highest-ranked variables. Generally, land coverage had a minimal effect, but specific land cover types, such as woodlands and agriculture,

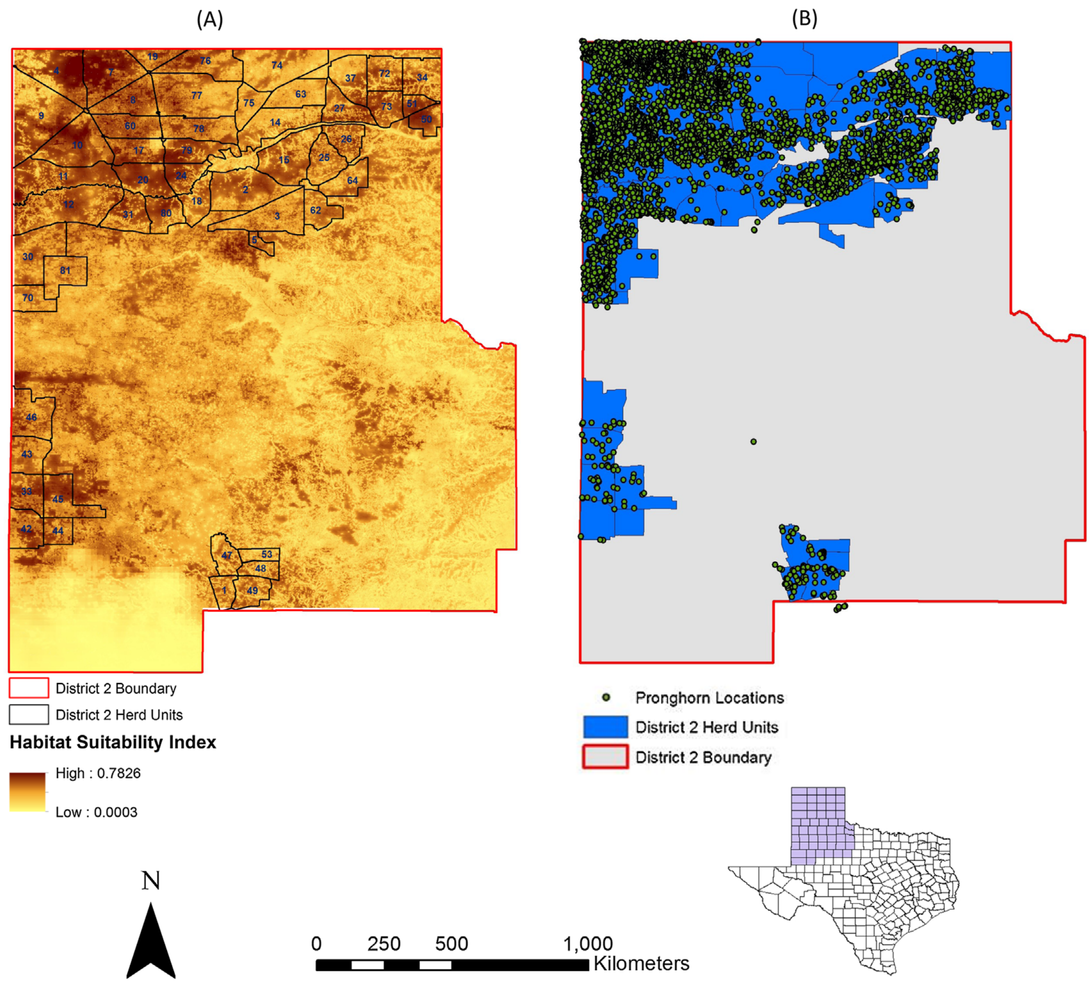

Figure 1. (A) MAXENT output for pronghorn habitat suitability in the Texas Panhandle and High Plains wildlife district (District 2) in northern Texas, USA. The lighter areas represent low habitat suitability and darker areas represent high habitat suitability. Pronghorn herd units are outlined in black. (B) Layer of pronghorn locations (green) collected during aerial surveys and used as the input for the habitat suitability model. Each pronghorn herd unit (blue) in District 2 (red) was sampled via strip transect during the 2008–2013 aerial surveys.

had the highest influence. Woodlands represented unsuitable areas because pronghorn prefer unhindered visibility and an overall open terrain (Yoakum 2004). Agriculture may sometimes present a more beneficial alternative to pronghorn than woodlands because of available forage (Cole 1956, Hoover et al. 1959, Bayless 1968, O'Gara and Morrison 2004, Gray 2012) but represents a loss of natural pronghorn habitat (Yoakum 2004). Vegetation composition, which was ranked third by experts, was also present in the MAXENT analysis through the distance to agriculture and distance to woodland variables. Pronghorn prefer areas with low vegetation profiles (Buechner 1950, Pyrah 1987, Ockenfels et al. 1994) and diverse species of native shrubs, grasses, and forbs (Einarsen 1948, Buechner 1950, Hailey 1979, McDonald 2005).

Some differences between the expert and MAXENT rankings had more to do with data availability (i.e., vegetation composition, vegetation height, and fawn habitat) than variable importance. Some of the variables we deemed as important through the primary literature could not be effectively included in the model because of limited data availability. Thus, it is difficult to say whether our results would have been different had all ranked variables been included or even if variable ranking would have changed significantly. Even though we were unable to incorporate all the variables determined to be of importance, the data we used were the best data available to meet our needs.

Pronghorn habitat appears to be in limited supply because of anthropogenic and environmental influences (Fig. 1). According to the model, much of the pronghorn habitat in District 2 is found within designated herd units with most of the habitat representing areas that are non-wooded with moderate precipitation and variable levels of agriculture. Dependence of pronghorn on open areas has been documented in previous studies (Buechner 1950, Yoakum 1972, Pyrah 1987, Ockenfels et al. 1994, Yoakum et al. 1995). Much of the forage preferred by pronghorn is found in grassland and shrubland communities (Einarsen 1948, Buechner 1950, Wentland 1968, Amstrup 1978, Pyrah 1987) with little tall shrub and tree encroachment (Buechner 1950, Pyrah 1987, Ockenfels et al. 1994, Bright and van Riper 1996). Our habitat model shows a higher HSI in areas with the least amount of woodland and greatest amounts of non-woody vegetation, whether introduced or native. The overall lack of pronghorn habitat near woodlands is supported by previous studies on pronghorn habitat preference, primarily their avoidance of wooded areas (Wydeven and Dahlgren 1985, Pyrah 1987, Ockenfels et al. 1994, Bright and van Riper 1996). Pronghorn preference of shrublands and grasslands during summer (Bayless 1968, Danvir 1996), that also tend to have lower vegetation profiles, is also supported by the model (Fig. 1). Areas with the highest HSI are located in the northern portion of District 2 within the Rolling Sand Plains, Canadian-Cimarron High Plains, Llano Estacado, and Shinnery Sands ecoregions. Much of the High Plains regions in District 2 are dominated by grasslands with some shrub and forb cover (Griffith et al. 2007). Forests and woodlands in the High Plains are found within riparian or riverine zones or in mesquite encroachments (Griffith et al. 2007) with the adjacent Southwestern Tablelands having greater densities of woodlands (Griffith et al. 2007). Our model indicates that these areas tend to have a lower HSI, which is consistent with previous research concerning pronghorn selection of grasslands and shrublands over woodlands (Yoakum et al. 1995).

Precipitation has a direct relationship to water and forage availability (Buechner 1950, Pyrah 1987, Brown et al. 2006), which, in turn, affects habitat suitability. According to the pronghorn habitat suitability model, importance of precipitation is somewhat varied. Some areas with the highest HSI are located within herd units that do not exhibit the greatest levels of precipitation, but areas with greater precipitation levels are also suitable. According to our results, pronghorn habitat can be found in areas with a wide range of precipitation levels during summer, but pronghorn tend to avoid areas with the least precipitation. Even with the importance of precipitation, however, vegetation greenness had the least impact on pronghorn habitat suitability according to the model. The lack of importance of vegetation greenness is in contrast to a similar pronghorn habitat suitability measure using MAXENT (Poor 2010, Poor et al. 2012). Distance to water also displayed little impact on habitat suitability, which contrasts with Poor (2010) and Poor et al. (2012). Lack of significance of distance to water in our study may be due to presence of smaller water sources, such as stock tanks or smaller playa, that were not detected when creating the GAP dataset. Pronghorn have been observed using man-made water sources, such as stock ponds and tanks (Sundstrom 1968, Autenreith et al. 2006), and water from irrigation, which is prevalent throughout District 2. Playa wetlands in the High Plains are also a significant source of water for pronghorn, especially because of the abundance of playas (Haukos and Smith 1994). Because of the widespread availability of water via playas and other water sources in District 2, water availability may not be a limiting factor for pronghorn; it may, however, be a limiting factor for pronghorn in other parts of their range.

The habitat suitability model indicated that agricultural land located in District 2 provided mixed levels of suitability for pronghorn. In some areas agricultural land has a high HSI, whereas much of the agricultural land was either moderately or minimally suitable (Fig. 1). Some agricultural land is selected by pronghorn as satisfactory forage during summer (Einarsen 1948, O'Gara and Morrison 2004), which can affect their seasonal distribution. According to Gray (2012), agricultural land can potentially increase forage opportunities for pronghorn in District 2. Agricultural land represents a loss of pronghorn habitat simply because of land conversion, which negatively affects pronghorn (Yoakum 2004). However, agricultural land provides nutritional support for pronghorn populations (Buechner 1950, Hoover 1966, Hepworth 1968), albeit at the expense of farmers (Einarsen 1948).

The pronghorn habitat suitability model exhibited a better than random predictive performance ($AUC = 0.715$; $SD = 0.017$) across all replications. Although the model showed good performance in discriminating between presence and absence points, there are a number of factors to consider. Expert opinion can bias variable selection because of beliefs and experiences of different people (Hurley et al. 2009, Poor 2010, Poor et al. 2012), which may have led to improper selection, or removal, of variables. Our literature review, and accompanying expert opinion survey, also involved general habitat characteristics that were not always specific to District 2. Broad habitat categories (e.g., vegetation composition, land coverage) encompass a range of characteristics that can be broken down into more specific categories (e.g., plant species diversity, forb biomass). Variables used in our analysis may be representative of the habitat characteristics that affect pronghorn habitat selection the most, but the variables themselves may be too coarse to create the best fitting habitat suitability model. Borders of the herd units themselves are meant to represent a barrier to pronghorn movement (e.g., highways, fences, topographic features), and may have also affected the overall fit of the model simply because of their influence on where the pronghorn were located. However, the effectiveness of barriers that represent the borders of herd units in restricting pronghorn movement is debatable and little scientific data has been collected to assess their efficiency. Anecdotal evidence from managers, biologists, and land owners in District 2 suggest that standard barbwire fencing, often used to indicate highway right-of-ways and borders of land ownership, is often ineffective in restricting pronghorn movement. Because of the availability of more concise spatial data, in addition to data collection issues (i.e., strip transects can cause data stratification, and differential sampling of herd units across years), evidence of pronghorn movement patterns, and overall project time constraints on data collection may have affected the overall inference we can achieve from our model.

The variables used to create the model are relevant to pronghorn habitat suitability in Texas, which provides support for the overall performance of our model. No other habitat suitability model exists for the Texas Panhandle, which means the results of this study are an important first step in enhancing habitat management efforts in the region. The environmental layers we used were also produced from the highest resolution data available for District 2 from datasets with an extensive burden of proof to their accuracy. Although the fit of the model attests to the relevancy of the final product, consideration of habitat characteristics specific to pronghorn in District 2 on a smaller scale will more accurately represent pronghorn habitat in the region (Elith and Leathwick 2009). In future studies, newer modeling environments, such as the currently understudied environment of MAXLIKE, which assess occurrence probability rather than habitat suitability alone (Fitzpatrick et al. 2013), may be pertinent for further assessments of pronghorn habitat use.

MANAGEMENT IMPLICATIONS

According to the model, pronghorn habitat is greatly affected by anthropogenic expansion and invasion of woody species. Human developments and expanding woodlands need to be evaluated (i.e., monitored to determine pronghorn avoidance) for their negative impacts on local and migratory pronghorn populations. To more accurately assess the risk of habitat loss, however, further research on the factors affecting pronghorn habitat selection is needed in District 2 to fully understand the additional variables needed to increase the fit of the overall model.

Although the model used coarse environmental data and presence-only locations, the methodology for creating such a model makes it accessible to wildlife managers regardless of the species-of-interest or environment. Researchers and wildlife managers alike often use coarse data to analyze population dynamics and habitat suitability in large areas. The MAXENT modeling environment provides a highly flexible, forgiving analysis that, when used properly, can provide a dependable output. The methodology was also cost-effective because of our use of datasets created independently of our project. Because the model is exploratory, it creates a framework for future habitat studies and monitoring that can easily serve as a basis for future research exploration for pronghorn as well as provide a method for researchers to generate habitat models for other species in different parts of the world.

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