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Pronghorn (*Antilocapra americana*) Movements and Habitat Use in the Big Chino Valley, Arizona

Federal Aid in Wildlife Restoration
Project: W-78-R

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EXECUTIVE SUMMARY

Pronghorn (*Antilocapra americana*) populations in Arizona are increasingly affected by habitat fragmentation due in part to road construction, fencing, and urban growth. The Big Chino Valley (BCV), one of the largest intact expanses of pronghorn habitat in Arizona, is threatened by plans for urban and resource development and highway construction. Site specific understanding of pronghorn space use and potential barriers to movement help to assess the potential impacts of these threats within BCV. Additionally, information gathered using GPS (global positioning system) technology allows for refined estimates of habitat availability and quality to build on existing knowledge, and to help direct land management efforts to promote the long-term viability of the resident pronghorn herd. To help inform land management decisions within BCV, the AGFD Research Branch undertook a project designed to address the following objectives: 1) develop a refined predictive map of pronghorn habitat in the BCV to identify barriers to pronghorn movement and areas important to pronghorn in the valley, 2) describe current seasonal movement patterns and space use of adult pronghorn in the BCV in relation to general habitat characteristics (e.g., land ownership, roads, vegetation) and potential barriers, and 3) evaluate previously developed expert opinion-based habitat models in the BCV.

Between November 2007 and November 2008, we captured 32 (31♀, 1♂) pronghorn antelope in the BCV, located primarily in Game Management Unit 19B north of Paulden, Arizona. We fitted each animal with a GPS radio collar programmed to acquire one location fix every 13 hours and monitored collared pronghorn between November 2007 and September 2009.

We used 18,482 GPS pronghorn locations to model potential pronghorn habitat at a landscape scale using the Genetic Algorithm for Rule-set Prediction (GARP) approach. We created two separate predictive habitat models, one including vegetation type (GARPveg) and one including a soils layer (GARPsoils), each also including a suite of additional habitat attribute covariates. We tested both models quantitatively, using a subset of pronghorn GPS "test" data (n = 1,957), to determine omission and commission error of each model with Receiver Operator Curve (ROC) analysis. The GARPsoils model had higher commission error as it over-predicted suitable habitats but included large areas unused by collared pronghorn. The GARPveg model had higher precision and predicted pronghorn use without including large areas unused by collared pronghorn. When overlaid with pronghorn GPS "test" data, the GARPveg model showed that most pronghorn locations (94.3%) were located within habitat ranked as highest suitability (Class V) by the model, while areas predicted as lower suitability were used less frequently (Class IV, 1.1%; Class III, 1.6%; Class II, 0.9%; Class I, 2.1%). Location data from previous pronghorn studies in neighboring areas also substantiated predictions of habitat suitability from the GARPveg model. Our GARPveg model thus provided the best estimate of pronghorn habitat in the BCV by predicting habitat used by marked individuals as well as identifying potential areas that may support pronghorn use outside of the distribution of collared individuals.

Within the study area we identified factors that may affect whether collared pronghorn crossed major roads by evaluating habitat, fencing, and road features associated with crossing rates along the Big Chino and Williamson Valley roads. Road type (unmaintained vs. maintained gravel) had the greatest effect on collared pronghorn crossing rates; this could be related to both structural features of those roads as well as differences in vehicle traffic volume. Habitat variables that most affected road crossing rates were vegetation type and slope. Anthropogenic factors such as high building density near roads and right-of-way fencing also influenced pronghorn crossing rates. Increased road crossings by collared pronghorn in the study area were associated with unfenced and less developed roads in gently rolling, more open grassland areas.

We documented several areas where pronghorn movements in BCV were restricted by fencing, roads, or land use practices. For example, pronghorn locations arranged in linear fashion have often been attributed to animal responses to natural shifts in topography and vegetation, and in BCV, they also indicated artificial barriers to movement, such as fences, buildings, and roads. No collared pronghorn crossed Interstate 40, and other major roads in the study area restricted movements, as did some fences. Moreover, pronghorn used areas where juniper vegetation had been mechanically thinned and did not use adjacent untreated habitats composed of more dense forest vegetation. Pronghorn locations demonstrated that they appeared to avoid heavily fenced areas in the central portion of BCV where agricultural activities and vegetation predominated. Additionally, we identified several "pinch points" that suggested pronghorn movements may be constricted, for instance in the northwest corner of BCV along Williamson Valley Road and in a limited area of the central valley. In these areas and others throughout BCV, it will be really important to restore or maintain connectivity at pinch points in the future so as to enhance gene flow and maintain pronghorn abilities to move throughout their range here.

Pronghorn use of private ranch lands and public grazing allotments varied greatly and could reflect differences in range condition, habitat suitability or potential barriers to movement. Seasonal differences in use of specific ranches may be related to availability of specific cover and food resources or seasonal differences in human activity and disturbance levels. Our GARPveg predictive model pointed to ranched areas of high quality habitat where collared pronghorn use was low. These areas may have some barriers to movement where habitat or fence modifications would be most effective.

Collared pronghorn consistently preferred grassland/forbland vegetation in all seasons. In addition, pronghorn habitat use patterns documented during our study validated habitat quality ratings developed subjectively and at larger scales from expert opinions both in the BCV and statewide. While our GARPveg model predicted habitat use more precisely in the BCV than did Davis (2008[*]), it also agreed generally with, and thereby strengthened confidence in Ockenfels et al. (1996[+]) habitat quality rankings statewide for pronghorn, yet our model provides a higher resolution predictive habitat map for pronghorn in BCV than either previous model did. Our results emphasize further the value in maintaining the BCV habitat as one intact continuous block to ensure long term viability of this important pronghorn population.

[*] *Davis, L. 2008. A landscape-scale study of pronghorn habitat viability and management needs for a private lands conservation initiative in Big Chino Valley. Master's Thesis, Antioch University, Keene, New Hampshire, USA.*

[+]*Ockenfels, R.A., C.L. Ticer, A. Alexander, J.A. Wennerlund, P.A. Hurley, and J.L. Bright. 1996. Statewide evaluation of pronghorn habitat in Arizona. Arizona Game and Fish Department Federal Aid Final Report, Phoenix, Arizona, USA.*

Introduction

Pronghorn antelope (*Antilocapra americana*) have been studied in Arizona since the 1960s and continue to be a species of concern and interest to the Arizona Game and Fish Department (AGFD). Because habitat loss, modification, and fragmentation pose serious challenges to the management of this species, AGFD has investigated the movement and habitat use patterns of pronghorn across parts of central, northern, and east-central Arizona (Ockenfels et al. 1994, Ockenfels et al. 1997, Ticer et al. 1999, Ockenfels et al. 2002, Waddell et al. 2005). In addition, AGFD conducted a statewide habitat evaluation of pronghorn habitat in the mid 1990s (Ockenfels et al. 1996). While pronghorn habitat in Arizona is often naturally fragmented by unsuitable topography and dense vegetation, anthropogenic features like transportation corridors, urban development, and fences substantially add to the existing level of habitat fragmentation (Ockenfels et al. 1996).

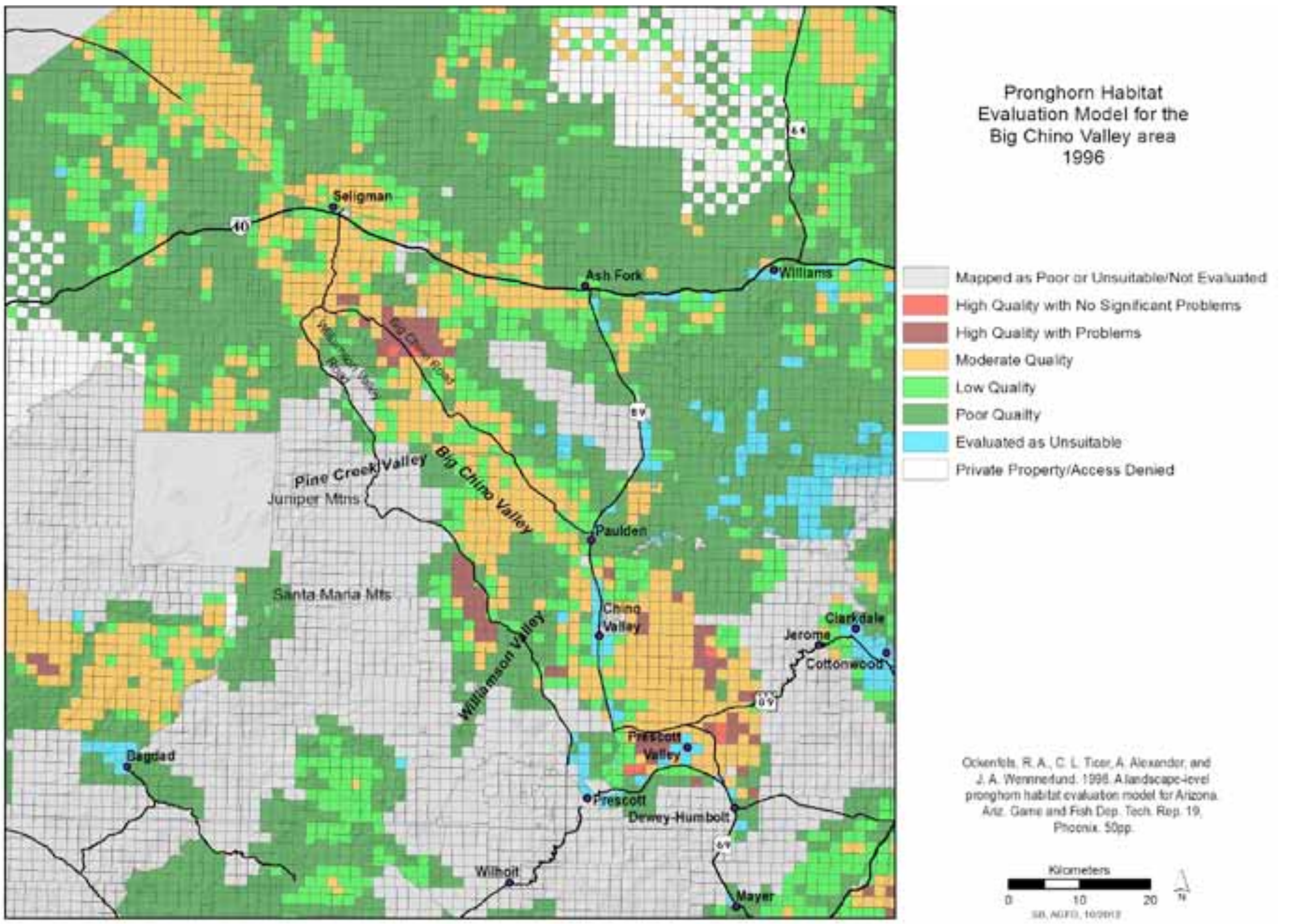

Figure 1. Habitat quality rankings developed by Ockenfels et al. (1996) in the vicinity of Big Chino Valley, Arizona.

The Big Chino Valley (BCV) north of Prescott currently represents one of the largest contiguous expanses of pronghorn habitat in Arizona. An increasing human population and rapid development of rural areas threatens the quality of this habitat with fragmentation by transportation corridors, fences, and planned alternative energy developments. Better information about pronghorn movement patterns, habitat distribution and suitability, as well as the characteristics of potential barriers, can help inform land management efforts to maintain and restore habitat quality and connectivity. To that end, a predictive habitat model was identified as a desired tool to evaluate the presence and location of barriers to pronghorn movement and to best identify those areas where habitat restoration or other management actions would provide the most effective benefits to pronghorn in the BCV. Although two habitat models had previously been developed for pronghorn in BCV, both were based on subjective expert opinion rather than on pronghorn location data. Ockenfels et al. (1996) developed a model that was used to map pronghorn habitat quality state-wide at relatively low resolution, with a minimum mapping unit of one square mile (Fig. 1). A second higher resolution map, also based on expert opinion, was developed specifically for the BCV (Davis 2008; Fig. 2). The goal of the current project was to develop a predictive habitat model for the BCV based on location data from pronghorn fitted with Global Position System

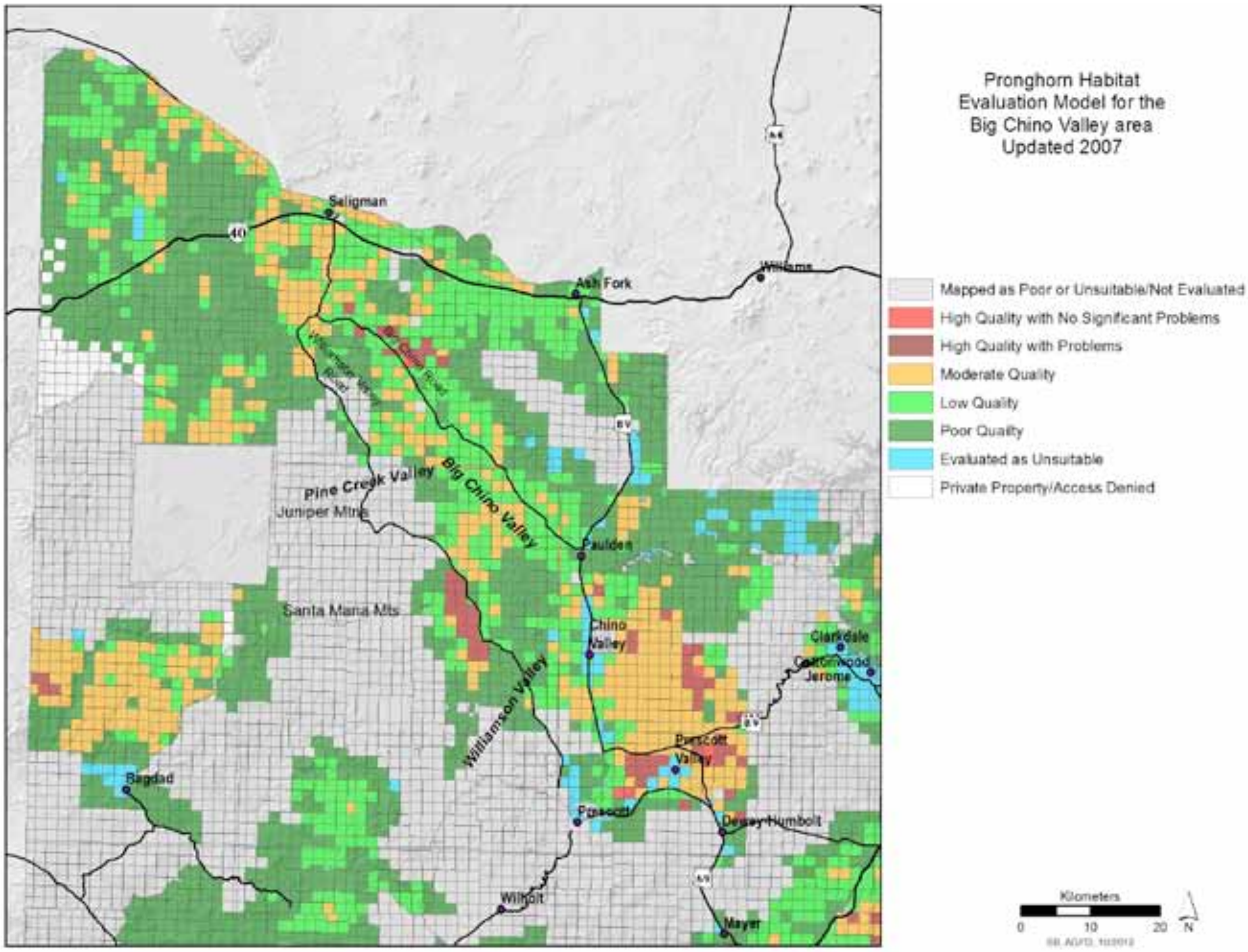

Figure 2. Habitat quality rankings developed by Davis (2008) as a modification of Ockenfels et al. (1996) in the vicnity of Big Chino Valley, Arizona.

(GPS) collars and to examine model predictions in relation to known animal locations, movement patterns, and occupied areas to identify potential movement barriers and areas key to maintaining connectivity for pronghorn across the BCV. In addition to facilitating an evaluation of existing expert-based models, results of this study are intended to inform future land management activities (e.g., habitat treatments or barrier alterations) implemented to maintain and restore habitat quality and connectivity for pronghorn in the BCV. This study is also intended to inform future land use, transportation and energy development plans.

Objectives

Our objectives were to use GPS location data on pronghorn to:

- Develop a refined predictive map of pronghorn habitat in the BCV to identify a) areas important to pronghorn movements in the valley, and b) potential movement barriers.
- Describe current seasonal movement patterns and space use of adult pronghorn in the BCV in relation to general habitat characteristics (e.g., vegetation, roads, land ownership) and potential barriers.
- Evaluate previously developed expert opinion-based habitat models in the BCV.

We used findings of our study to offer recommendations for land management on both private and public lands within BCV that promote the long-term viability of this pronghorn population.

STUDY AREA

The study area encompassed about 3,000 km^2 in central Yavapai County, Arizona, north of the city of Prescott and west of the town of Paulden (Fig. 3). Topography consisted of the broad Big Chino and Williamson valleys broken by rolling hills and small mountains. During the study, annual precipitation averaged 28.8 cm and annual average low and high temperatures ranged from 4.8°C to 21.9°C (Western Regional Climate Center 2009). Vegetation included desert scrub at the lower elevations (about 1300 m) and montane coniferous forests above 2200 m. The central portions of the study area (about 1400 m) comprised plains grassland transitioning into conifer woodland (juniper-savanna woodlands) in the foothills (Brown 1994). Other habitat types occurring as minor community components included Mohave desert scrub and interior chaparral (Brown 1994). Other ungulate species in the study area included mule deer (*Odocoileus hemionus*) and javelina (*Pecari tajacu*), with elk (*Cervus elaphus*) occurring at higher elevations in more complex topography. Coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*) and mountain lion (*Puma concolor*) were common predators in the study area.

In 2007, the pronghorn population of the BCV was estimated at 300–775 individuals located primarily within Game Management Unit (GMU) 19B and portions of GMUs 17A and 17B (AGFD unpublished data; Fig. 3). Pronghorn in surrounding GMUs also likely interact with pronghorn in BCV. For instance, pronghorn in GMU 18A (n = 300–400 individuals, AGFD unpublished data, 2009) to the west of BCV may be connected through the north end of Williamson Valley. However, pronghorn in GMU 10 (n = 300–800 individuals, AGFD unpublished data, 2007) were likely isolated from pronghorn in BCV by Interstate 40 (I-40). Similarly, pronghorn to the east in GMUs 19A and 8 (n = 300–800 individuals, AGFD unpublished data, 2007) were likely isolated from those in BCV by State Route (SR) 89.

With the exception of the towns of Prescott, Paulden, Seligman, Ash Fork, and Chino Valley, where private lands predominate, land ownership consisted primarily of a checker-board distribution of private and Arizona State Trust Land sections leased for livestock grazing. A vast majority of these lands were managed by large privately-owned cattle ranches including: Campbell Ranch, CV and CF Ranches (presented separately here but currently managed as one unit, the CV-CF Ranch), Coury Ranch, T2 Ranch, K4 Ranch, Kieckhefer Foundation Ranch (JWK Foundation), Lobo Ranch, Yavapai Ranch, Las Vegas Ranch, Bar Triangle Ranch, and the area referred to as the Big Chino Water Ranch (Fig. 4). Adjacent foothills and mountains to the east and west were public lands managed by the Prescott National Forest. Juniper (*Juniperus spp.*) thinning was a common form of habitat restoration in the shrub-encroached grasslands of BCV and over 10,000 hectares had been treated within the study area in the past 10 years. These treatments were implemented on public and private lands to improve both livestock grazing and pronghorn habitat.

For the purposes of capturing and collaring pronghorn, the northern boundary of the study area was I-40, a major east-west transportation corridor in northern Arizona. The eastern boundary was SR 89, from its junction with I-40 at Ash Fork south to the city of Prescott. The western boundary was represented by the Juniper and Santa Maria mountains, a set of ridges west of Williamson Valley Road, an improved gravel road that runs north-south from I-40 to the city of Prescott (Fig. 3). While these boundaries represent the area where pronghorn were captured, the boundaries of the predictive habitat model were defined by the movement patterns of the collared pronghorn (see methods on pg. 7).

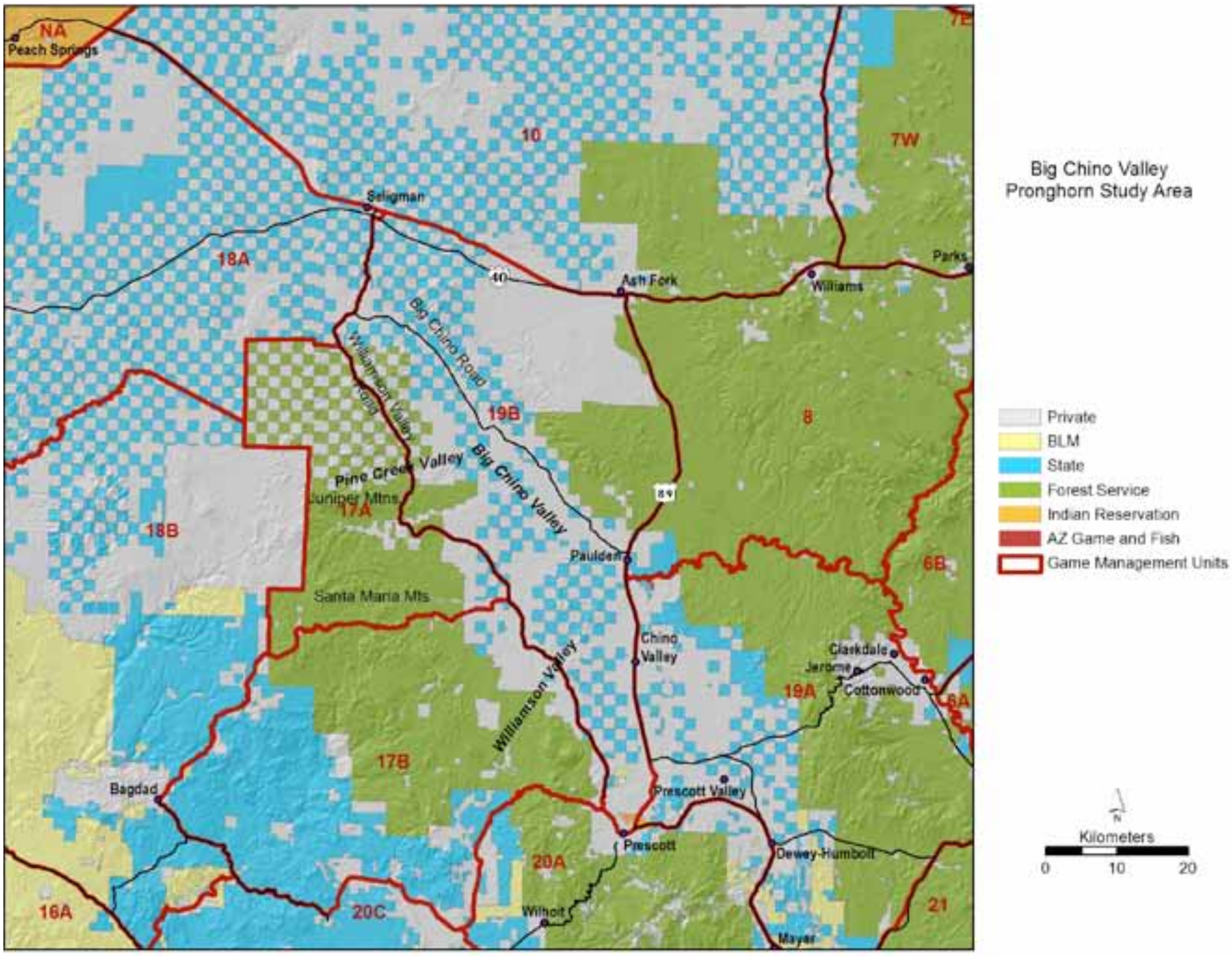

Figure 3. Land ownership, Game Management units, roads and highways within the Big Chino Valley, Arizona, study of pronghorn movement and habitat use, 2007–2009.

METHODS

Between November 2007 and November 2008, we captured pronghorn via helicopter with a net gun (Barrett et al. 1982, Firchow 1986) or dart rifle. Each pronghorn was fitted with either a spread-spectrum or store-on-board Global Positioning System (GPS) collar equipped with a pre-programmed time release mechanism (TGW-3490, Telonics, Inc., Mesa, AZ). Collars were programmed to acquire a location fix every 13 hours. Monthly aerial telemetry flights were conducted to monitor the status of collared pronghorn and to upload data from the store-on-board collars. All collars were recovered at mortality sites or after the scheduled collar-release (drop off) in fall 2009.

Development and Evaluation of a Predictive Habitat Model

We used GPS data collected between November 2007 and September 2009 to build and evaluate a predictive habitat model. To ensure that all animals were represented equally and that the model was not skewed by data from a particular season, we only included animals for which we had data representing each season of the year, and we randomly removed data points from individual animal datasets so that all animals were represented by the same number of data points. Because GPS collars attempted a location

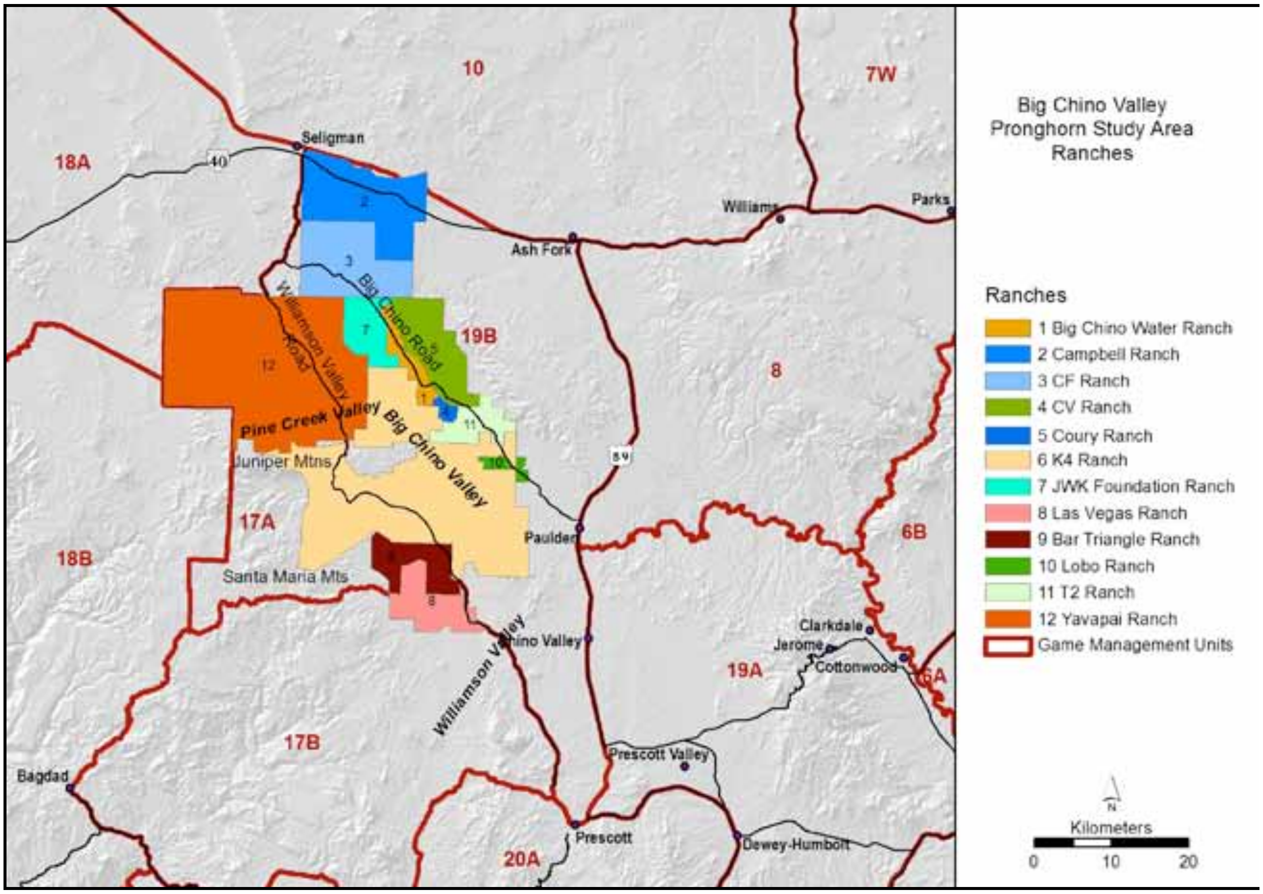

Figure 4. Boundaries of livestock ranches in the vicinity of the Big Chino Valley, Arizona. Note that the CV and CF ranches are now managed as one ranching operation.

fix once every 13 hours, the dataset included both daytime and nighttime locations. We assumed that consecutive locations were independent because pronghorn are believed to be able to move distances the length of our study area during a 13-hour period. We then randomly selected 80% of each animal's locations for use in model development and combined data from animals into one input file and retained the remaining 20% of data as "test data" for model evaluation.

We delineated the area from which models were developed by using all available animal locations to develop a collective 95% fixed kernel home range and then buffered the collective home range by the mean maximum distance moved by individual collared animals (Worton 1989). We assumed that this buffer provided the model with a range of habitat types both used and unused by pronghorn within colonization distance of known pronghorn locations in the BCV.

Pronghorn are a wide-ranging species with large home ranges, and only a subset of the population in BCV was monitored with GPS collars. Our ability to make inferences about non use of specific areas was limited by the number of radio collared animals. Because false absences can cause considerable bias in models designed to evaluate or predict habitat use (Gu and Swihart 2004, Keating and Cherry 2004), we chose to use a modeling method that does not make strict assumptions about absences.

We developed our predictive habitat model using Genetic Algorithm for Rule-set Prediction (GARP) implemented in the program Desktop GARP (Stockwell and Nobel 1992, Stockwell and Peters 1999). This approach, which has previously been used to predict distribution of a wide range of species in diverse habitats (e.g., Illoldi-Rangel et al. 2004, Adjemian et al. 2006, Kostelnick et al. 2007), is based on the ecological niche theory (Hutchison 1957) and recognizes that a species' presence is influenced by a multidimensional set of environmental conditions. GARP is a machine-learning approach that uses known species' localities against a backdrop matrix of environmental features to evaluate the probability of a species being present in a given area. The background matrix often contains environmental or ecogeographic variables (e.g., climatic elements, elevation, topography, vegetation), but may also include anthropogenic variables, like roads, structures, fences or even population densities. The program uses an iterative algorithm to evaluate a series of decision rules (e.g., envelope, atomic, or logit rules) to generate the best set of criteria that explain how locations are distributed on the landscape (Hirzel et al. 2002). For example, while atomic rules assign a single value to a variable, envelope rules use fixed percentiles of values for each parameter such that they may state that if annual temperature falls between 25-30°C and elevation is between 400 and 1000m, a species would be predicted present on the landscape (Stockwell and Peters 1999). In essence, the program iteratively holds back a subset of the presence data and uses these data subsets to test the rules, then modify, incorporate, or reject them through multiple iterations until the best set of variable conditions is determined that most accurately predicts the species' distribution. These rules are then used to map the geographic distribution of the species using a Geographic Information System (GIS; Peterson and Vieglais 2001). Additional detailed descriptions of GARP methods are presented in Stockwell and Peters (1999) and Payne and Stockwell (http://biodi.sdsc.edu/Doc/GARP/Manual/manual.html).

We generated GIS layers for 21 available ecogeographical variables believed to have a potential influence on the distribution of pronghorn (Table 1). We used ArcGIS 10.0 and a 30-m^2 cell resolution to determine slope and elevation for each cell of the modeling area. For each 30-m^2 cell, we generated an index of solar radiation (i.e., a continuous measure of energy [watt hours/m^2]) influenced by aspect and slope, using the annual mean value (Rich et al. 1994, McCune and Keon 2002). We calculated an index of ruggedness for a 150 X 150 m (5 X 5 cells) area centered on each cell (Sappington et al. 2007). This index ranges from zero to one, with a value of one indicating the highest ruggedness (Sappington et al. 2007). For each cell of the modeling area, we estimated the distance to the nearest major road, highway, and railroad (2008 Tiger data, U.S. Census Bureau), and the distance to each of seven major vegetation types (Table 2) compiled from the Southwestern Regional GAP Analysis Project digital landcover dataset (fws-mcfwru.nmsu.edu/swregap; USGS 2004). We used soil data available in the Arizona General Soils map (nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo; NRCS 2008) to estimate the shortest distance to each of six major soil groups from each cell in the modeling area. Finally, we generated an estimate of the percentage of developed land for each 30-m^2 cell by digitizing buildings from aerial photographs to determine the percent of developed land within a circle with radius of 1 km, centered on each cell.

Although GARP is not believed to be highly sensitive to correlation among variables (Stockwell and Peters 1999), we used Pearson correlation coefficients to identify ecogeographic variables that were strongly correlated (i.e., where Pearson correlation coefficients > 0.70). In addition, because we assumed that vegetation could be highly influenced by soils, we generated one model using vegetation and one model using soils (each along with all other ecogeographic variables).

For development of the two models, we allowed the GARP algorithm to consider all ecogeographic variables and rule types (e.g., atomic, range, or negated range rules; logistic regression; Payne and Stockwell [http://biodi.sdsc.edu/Doc/GARP/Manual/manual.html]). We ran 1000 iterations (or until the model converged) 200 different times in GARP using 15 rule combinations to produce 3,000 models. Because of the stochastic nature of GARP algorithms, every model generated by GARP is unique, even when the same training data and variables are used. To maximize accuracy, each model compromises between commission error (instances in which areas are predicted as habitat but are not used by collared pronghorn) and omission error (instances in which areas are not identified as habitat but are actually used by collared pronghorn). Using guidelines developed by Anderson et al. (2003), we selected a best subset of 20 models by first choosing all models with intrinsic and extrinsic omission error of < 5%, and then choosing from those the 20 models with commission error closest to the median commission error. We then combined this best subset of 20 models to create one best predictive model by assigning each cell in the modeled area a relative "likelihood of use" (LOU) score of 1 to 20, based on the number of models predicting pronghorn presence in each cell (Anderson et al. 2003, Drake and Bossenbroek 2004). We assumed that higher LOU scores indicated higher habitat suitability for pronghorn.

We evaluated the two resulting predictive habitat models (one including vegetation and one including soils) with two approaches by placing the 20% animal locations held back as test data over each resulting map. First, we assigned five habitat classes based on the relative LOU scores (in ascending likelihood of use and suitability: 1-4 = Class I, 5-8 = Class II, 9-12 = Class III, 13-16 = Class IV, and 17-20 = Class V). We then compared the Bonferroni 90% simultaneous confidence interval of the percentage of locations in each habitat class to the expected frequency distribution based on percent availability of each class. We then calculated Jacob's D values (ranging -1.0 to 1.0) to examine the extent of selection or avoidance by pronghorn (Jacob 1974, Byers et al. 1984). Second, we used receiver-operator characteristic (ROC) analysis (Hanley and McNeil 1982, Chen et al. 2007), implemented in a web-based calculator to evaluate the two models (J. Eng, Johns Hopkins University, http://www.jrocfit.org., accessed 31 August 2011). ROC analysis is used to test the sensitivity (absence of omission error or a false negative) and specificity (absence of commission error or a false positive) of the predicted habitat models, in relation to their ability to successfully predict presence of test data (Wiley et al. 2003, Iguchi et al. 2004, Chen et al. 2007). ROC scores vary between 0 and 1 and are maximized (at 1) when test data fall into areas predicted as habitat by all models, whereas a score of 0.5 signals that test locations are as likely to fall into predicted habitat as non-predicted habitat (i.e., no better than random). We compared the predictive abilities of the model constructed with vegetation variables to the model created with soil variables to select the one final model that had the highest predictive value for modeling suitable pronghorn habitat.

We used GPS-collected data to build and quantitatively test our GARP models, but then also overlaid all other known pronghorn locations in the vicinity of BCV, including data from animals fitted with VHF or GPS collars in previous studies, on the final predictive map to qualitatively examine their agreement to GARP-predicted suitable habitat.

Seasonal Movement Patterns and Space Use

To describe the general seasonal habitat use and movement patterns of pronghorn, we divided their location data into 3 seasons: "Spring", encompassing late gestation, fawning and fawn rearing (April–June), "Fall", encompassing the pre-rut and rut (July–September), and "Winter", encompassing the post-rut and early gestation period (October–March). To describe movement patterns, we mapped and visually examined seasonal GPS locations for individual pronghorn. In addition, we also examined individual movements in relation to model results to identify areas currently known to maintain landscape connectivity in the BCV. We only included animals for which we had collected a total of ≥100

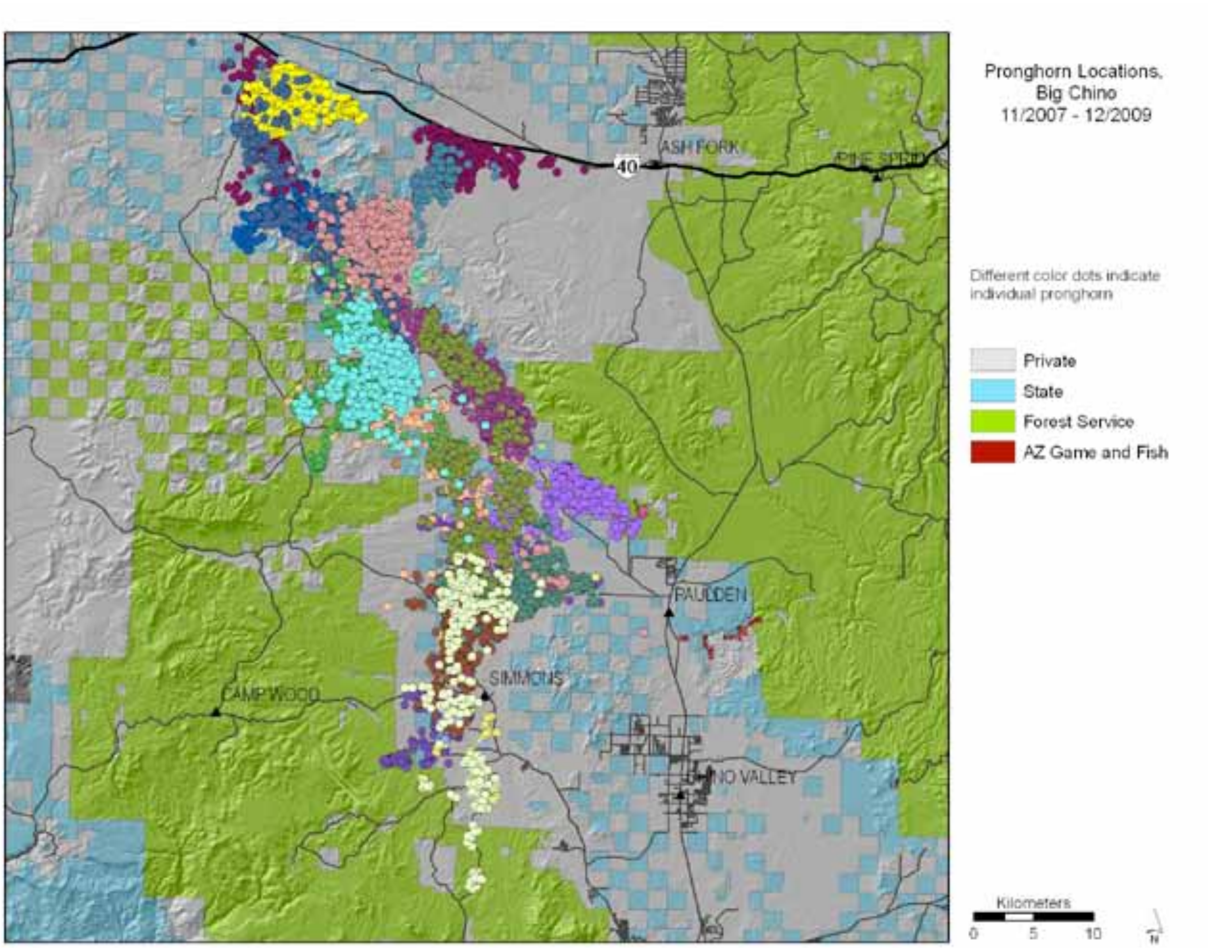

Figure 5. Plotted locations for collared female pronghorn (n = 31) in study of movement and habitat use patterns in the Big Chino Valley, Arizona, 2007–2009.

locations. We examined seasonal habitat use by vegetation type and land ownership to provide a general description of pronghorn habitat use during each season. We compared the Bonferroni 90% simultaneous confidence interval of the percentage of locations in each vegetation type to the expected frequency distribution based on percent availability of each class, then calculated Jacob's D values (Jacob 1974, Byers et al. 1984), which range from -1.0 to 1.0, to examine the extent of avoidance or selection of vegetation types. To examine seasonal use of individual ranches, we overlaid pronghorn locations on a ranch boundary GIS cover provided by TNC's Verde River Program, Prescott, Arizona (Fig. 4). We compared the Bonferroni 90% simultaneous confidence interval of the percentage of locations on each ranch to the expected frequency distribution based on percent availability of each ranch in the study area (Byers et al. 1984). To provide potential explanation of ranch use patterns by collared pronghorn, we reported availability of preferred vegetation types and LOU scores as determined by our predictive model on each ranch and combined this with an evaluation of potential movement barriers.

To examine road characteristics that influenced collared pronghorn movements along two major roads in the BCV, we identified individuals that crossed the Williamson Valley Road (WV Road) and Big Chino Road (BC Road). We plotted lines connecting consecutive locations of individual pronghorn to discover approximate locations of road crossings, but found that the elapsed

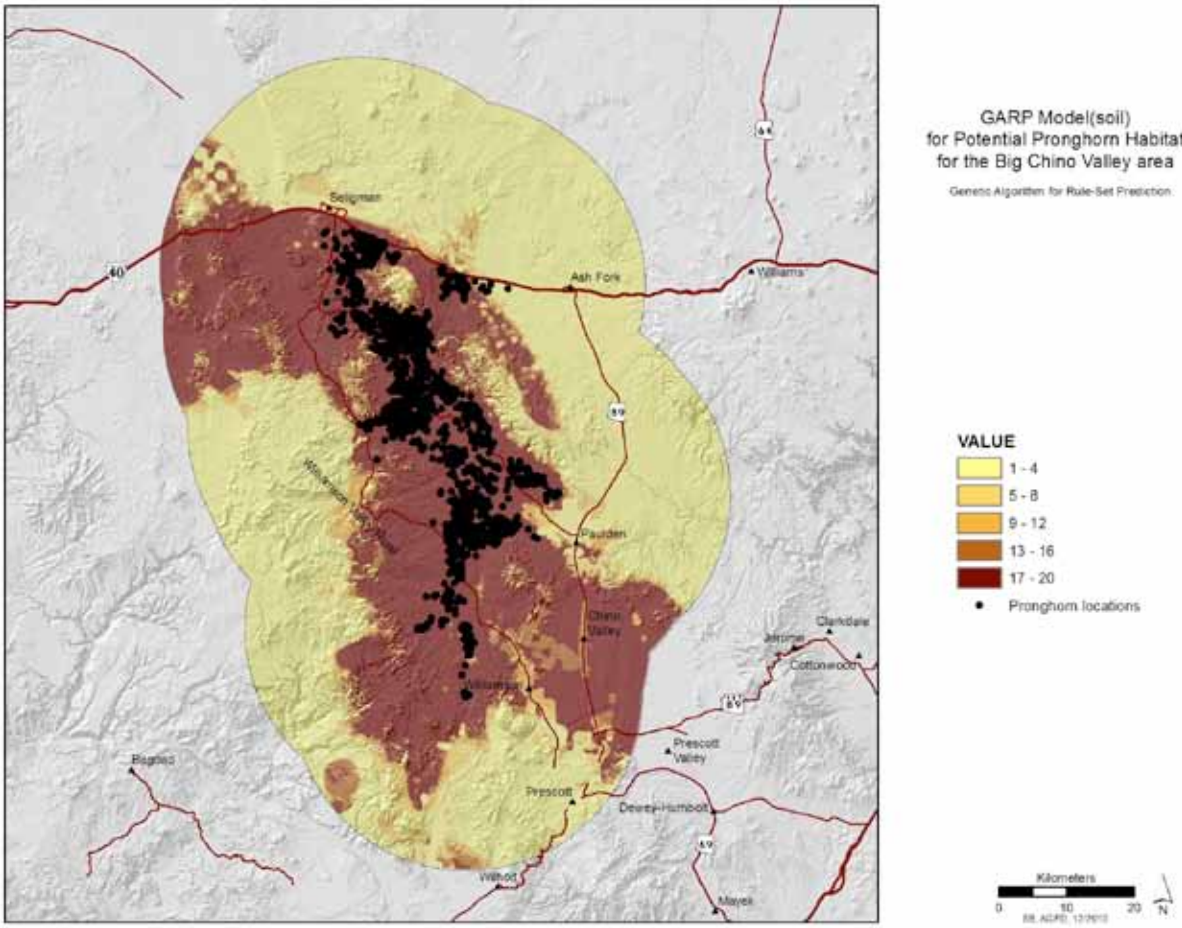

Figure 6. Predictive pronghorn habitat use model, GARPsoil, including soil type (excluding vegetation) covariate, developed with Genetic Algorithm for Rule-set Prediction (GARP), and overlaid with test locations (n = 1957) from collared pronghorn in the Big Chino Valley, Arizona, 2007–2009. Values (1–20) represent increasing habitat suitability as modeled for pronghorn.

time between fixes (13 hours) precluded any identification of specific points of road crossing. So we divided roads into 1.6 km (1 mile) segments and used classification and regression tree (CART) analysis to examine possible relationships between the number of pronghorn crossings per section of road and fence and habitat characteristics associated with each section of road (Table 3; Breiman et al. 1984). We used CART analysis as an exploratory approach to determine the hierarchical order of importance of each variable relative to pronghorn crossing rate. Each branch of the CART tree represents a split in the data based on G^2 statistics separated by examining the sum of squares due to mean differences in crossing rate.

We also examined individual animal locations visually for linear or disjointed patterns indicating potential existence of movement barriers to both individuals and the population at large. To determine the potential features restricting pronghorn movements, we overlaid linear-trending locality data from individual animals on GIS covers for roads, vegetation type, and topography. For those sites where mapping information was insufficient to ascertain a cause for the observed patterns, we conducted site visits to verify, identify, and record characteristics of potential movement barriers in BCV. We then used individual and

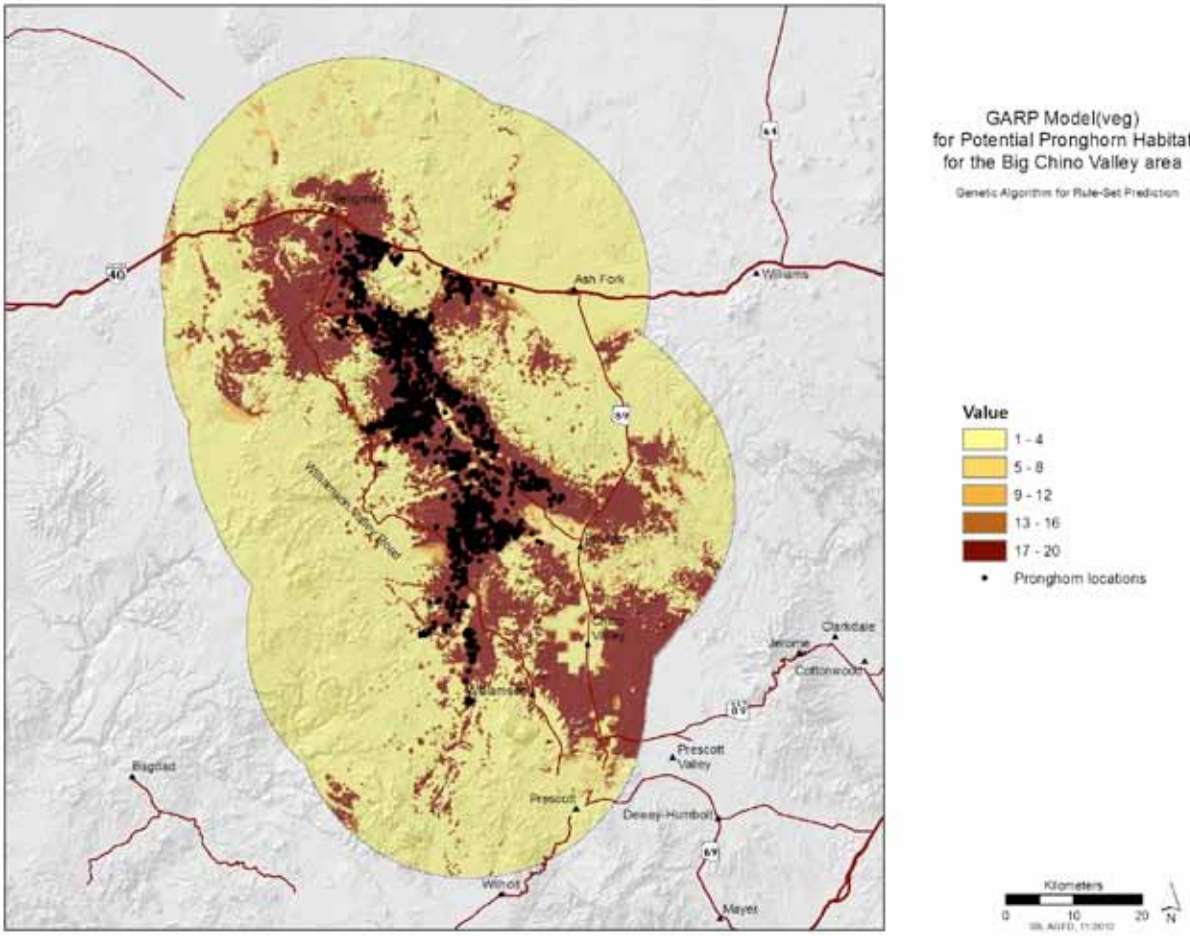

Figure 7. Predictive pronghorn habitat use model, GARPveg, including vegetation class (excluding soil) covariate, developed with Genetic Algorithm for Rule-set Prediction (GARP), and overlaid with test locations (n = 1957) from collared pronghorn in the Big Chino Valley, Arizona, 2007–2009. Values (1–20) represent increasing habitat suitability as modeled for pronghorn.

collective pronghorn locality data, along with results of our predictive habitat model, to identify connection points or routes that appear to be critical for maintaining pronghorn movement and population connectivity across the Big Chino Valley.

Evaluation of Previously Developed Expert-Based Habitat Models

We overlaid our pronghorn test data on habitat quality maps created by Ockenfels et al. (1996) and Davis (2008) to determine if these subjective expert models of habitat suitability fit selection patterns of collared pronghorn. We compared the Bonferroni 90% simultaneous confidence interval from the percentage of test locations in each habitat class to the expected frequency distribution based on percent availability of each class, and then calculated Jacob's D values to examine the extent of pronghorn habitat avoidance or selection. We then plotted 500 random points throughout the study area and recorded the habitat quality ratings from the Ockenfels et al. (1996) and Davis (2008) models as well as the LOU score from our final predictive GARP model. To determine the level of agreement among the three models, we calculated the average LOU scores for each of the five habitat quality classes (i.e., GARP model classes I-V) and contrasted those to values for five habitat quality classes (e.g., "unsuitable, low, high") from Ockenfels et al. (1996) and Davis (2008).

RESULTS

Evaluation of Predictive Habitat Model

Between November 2007 and September 2009, we obtained 18,482 GPS locations from 31 female pronghorn, with a mean of 596 locations per animal (Fig. 5). No ecogeographic variables were highly correlated to any other, so all variables were included in creating the GARP models. The two GARP models, one including soils as a covariate (GARPsoils; Fig. 6) and one including vegetation as a covariate (GARPveg; Fig. 7) were each developed with 9,785 pronghorn locations and tested with 1,957 locations. The ROC value for the GARPveg model was slightly higher and indicated a better fit to the test data than the GARPsoils model (Table 4). Although the GARPveg model's lower sensitivity value suggested a higher omission error rate, this difference was slight (Table 4). Moreover, the GARPsoils model exhibited a greater commission error by including as highly suitable habitat large areas with dense human development (e.g., around the town of Chino Valley) or outside the distribution of the test data (Fig. 6). In contrast, the GARPveg model's substantially higher specificity value (Table 4) suggested it fit the test data more precisely (Fig. 7). We therefore selected the GARPveg model as the more representative and better fitting predictive habitat model. Visual evaluation also indicated that the GARPveg model performed well at predicting habitat use by pronghorn when compared with location data from other independent pronghorn research projects that overlapped the study area (Fig. 8). For instance, much of the habitat east of the towns of Chino Valley and Paulden, AZ, where we had no location information from our study animals, was identified as suitable habitat in the GARPveg model and visually corroborated with location data from other research done on pronghorn (Fig. 8).

Seasonal Movement Patterns and Space Use

We plotted seasonal distributions for collared pronghorn ($n = 23$) for which we had collected a total ≥ 100 locations during the course of the study. Location data of some collared pronghorn ($n = 5$) showed seasonal aggregations of locations, thereby suggesting seasonal movements, while most ($n = 18$) were more indicative of consistent year-round habitat use (Fig. 9). Pronghorn used grassland-forbland vegetation types most frequently, although woodland types were used roughly 25% of the time; this pattern of habitat use was consistent among all three seasons. Annual use of grassland-forbland vegetation (73%) by collared pronghorn was greater than the availability of that habitat (18.5%) across the study area, suggesting strong selection (Table 5). Conversely, annual use of all other vegetation types was less than their availability, suggesting avoidance (Table 5). Likewise, pronghorn test locations suggested they avoided habitats ranked as low LOU by both GARP models and selected for habitats having high LOU in both models (Table 6).

Collared pronghorn use on each of 12 major ranches in the BCV study area varied spatially and temporally. Based on location data, pronghorn use was consistently highest on the K4, Campbell, CV and CF, and JWK Foundation ranches across most seasons (Table 7). Although the K4 Ranch contained the largest proportion of the study area and encompassed a large area covered by grassland-forbland, the other four ranches also experienced high use by collared pronghorn despite the smaller proportion of the study area encompassed by each. Conversely, pronghorn use of the Yavapai and Bar Triangle ranches was lower than expected based on the availability of land within the study area but consistent with the minimal amount of grassland-forbland vegetation present on each ranch. Some ranches had pronghorn use that was consistently lower (Yavapai) or higher (CF and JWK Foundation) year-round than expected, while others (Las Vegas and T2) showed seasonal variation in relative pronghorn use. However, some ranches such as the Coury or Big Chino Water ranches had high mean LOU scores but low relative use by collared pronghorn (Table 7). The lack of congruity between LOU scores and collared pronghorn use on some ranches suggested that other environmental or anthropogenic factors may inhibit or discourage pronghorn from using the individual ranches.

The CART model separated fence and habitat characteristics along BC Road and WV Road into 8 nodes based on the frequency of pronghorn crossings at each 1.6 km (1 mile) section (Figs. 10, 11). Road type was the first differentiating variable, representing the most important factor predicting the number of pronghorn crossings/1.6 km section. Average crossings/1.6 km section of road was higher for BC Road than for WV Road (Figs. 10 and 11). For BC Road, the number of sides of the road that were fenced was the second most important variable affecting pronghorn crossings. Average number of pronghorn crossings/1.6 km section was higher for road sections with no fence or fence on only one side of the road (Fig. 10). The third most important variable affecting the number of pronghorn crossings along BC Road was building density, which split the CART branches into three more nodes. As building density decreased, the average number of pronghorn crossings/1.6 km sections increased. A final split occurred at the third level node with lower building density, but this time, a higher average number of pronghorn crossings/1.6 km section was associated with greater building densities (Fig. 10).

For WV Road, average slope was the most important variable affecting pronghorn crossings/1.6 km section. Sections of road that were along open areas with gentle slopes rather than flat topography had higher average number of pronghorn crossings (Fig. 11). Vegetation type was the next most important variable affecting pronghorn crossings. Road sections with a preponderance of grassland vegetation had higher average number of pronghorn crossings/1.6 km than those made up of mostly shrubby or woodland vegetation types (Fig. 11). Finally, whether or not the roadside was fenced divided the final node, with fenced sections having a slightly higher average number of pronghorn crossings/1.6 km sections (Fig. 11).

We identified multiple areas where pronghorn locations were distributed in a linear fashion or otherwise suggested the presence of a movement barrier. When overlaid on GIS layers, most linear movements paralleled dense juniper-dominated vegetation (n = 3), changes in topography (n = 4), or roads (n = 6). For instance, at two sites, pronghorn locations were distributed linearly along borders between juniper thinning treatments and untreated areas, while other linear movements followed contour lines of increasing elevation (Fig. 12). Moreover, Interstate 40 at the northwest end of the study area essentially blocked all pronghorn movements to suitable habitats north of the freeway, and paved sections of WV Road may have served as a similar barrier south of I-40 (Fig. 13). Further, when we examined sequential location data for individual pronghorn, we identified additional areas in the BCV where pronghorn movements suggested barriers and helped highlight areas of potential concern where efforts to preserve connectivity should be focused (Fig. 13). Our site visits to the BCV further illustrated that the potential impairments to pronghorn movement were most often imposed by sharp changes in vegetation or topography or found along pronghorn-unfriendly fences that were either too low to the ground and/or surrounded by dense tumbleweed skeletons.

Evaluation of Previously Developed Expert-Based Habitat Models

Based on test location data, collared pronghorn showed strong avoidance of areas ranked in both expert-based models as unsuitable or poor habitat and exhibited increased selection for low, moderate, and high quality habitats (Table 8). Both GARP models indicated avoidance of all habitat classes except those with the highest LOU scores (Table 6). Still, mean LOU scores within habitat classes displayed considerable agreement between the GARPveg model and both expert-based habitat models (Table 9). Moreover, when

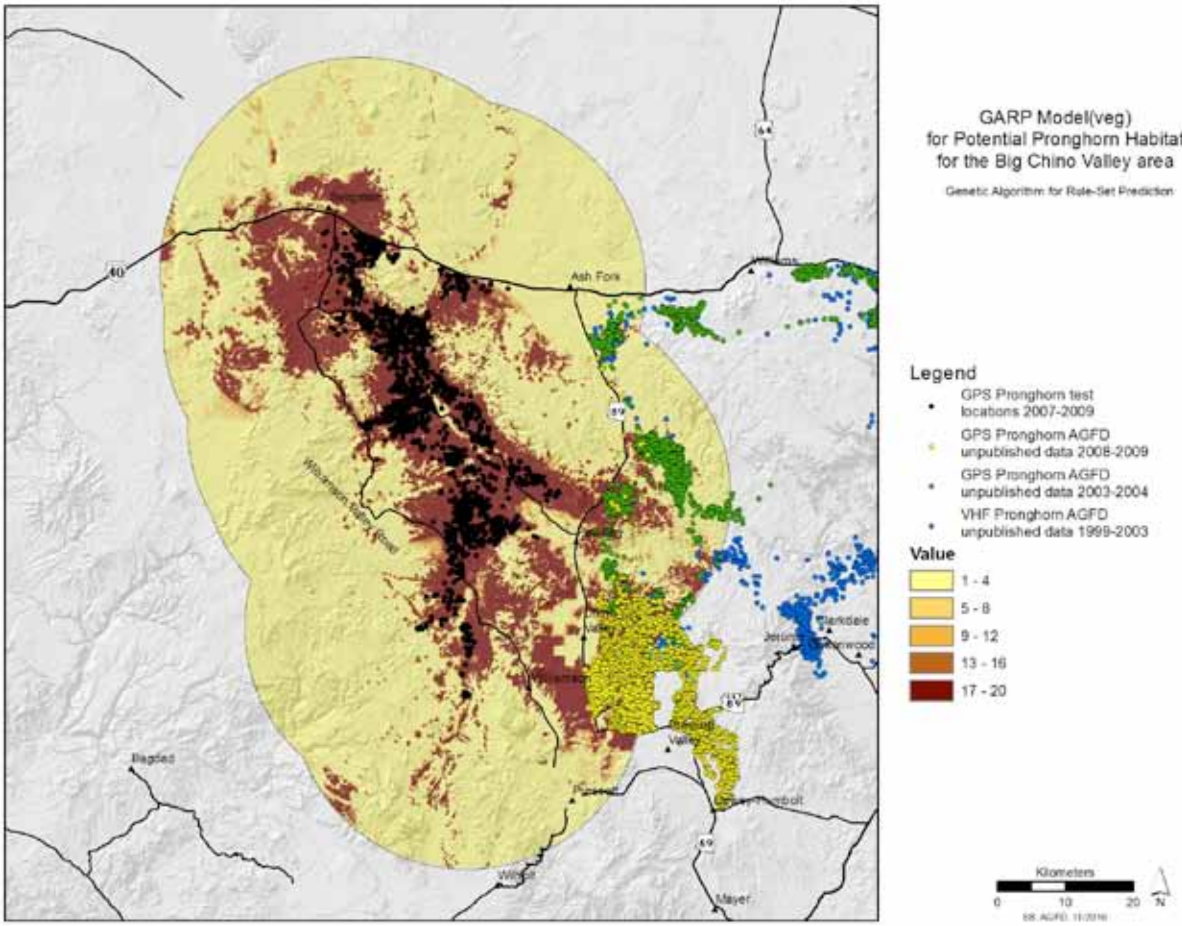

Figure 8. Predictive pronghorn habitat use model, GARPveg, developed with Genetic Algorithm for Rule-set Prediction (GARP) using vegetation type and overlaid with locations obtained from previous pronghorn studies in the area and test locations (n = 1957) from collared pronghorn in the Big Chino Valley, Arizona, 2007–2009. Values (1–20) represent increasing habitat suitability as modeled for pronghorn.

we overlaid location data from previous pronghorn research conducted in habitats east of the towns of Chino Valley and Paulden, AZ, all three models predicted high quality habitats in areas where pronghorn had previously been identified (Figs. 1, 2, 8 and 14).

DISCUSSION

As one of the premier pronghorn habitat areas in the state, the Big Chino Valley has the potential to provide an extensive contiguous landscape for pronghorn. Our GARPveg habitat model suggests that as of September 2009, there was contiguous pronghorn habitat from one end of BCV to the other. Habitats with the highest LOU (i.e., levels IV, V in Table 6), and therefore the highest suitability for pronghorn, are concentrated within the central part of the study area, and animal locality data confirm that these areas are extensively used. Conversely, the models also highlight areas of BCV that have high predicted LOU but did not receive much use by collared pronghorn. For example, collared pronghorn did not use large areas at the northwest end of BCV or strips of land in the southern portion of the valley that had high LOU values (Fig. 13). Multiple factors may influence the likelihood of use and habitat suitability for pronghorn in such areas. Certainly while grassland

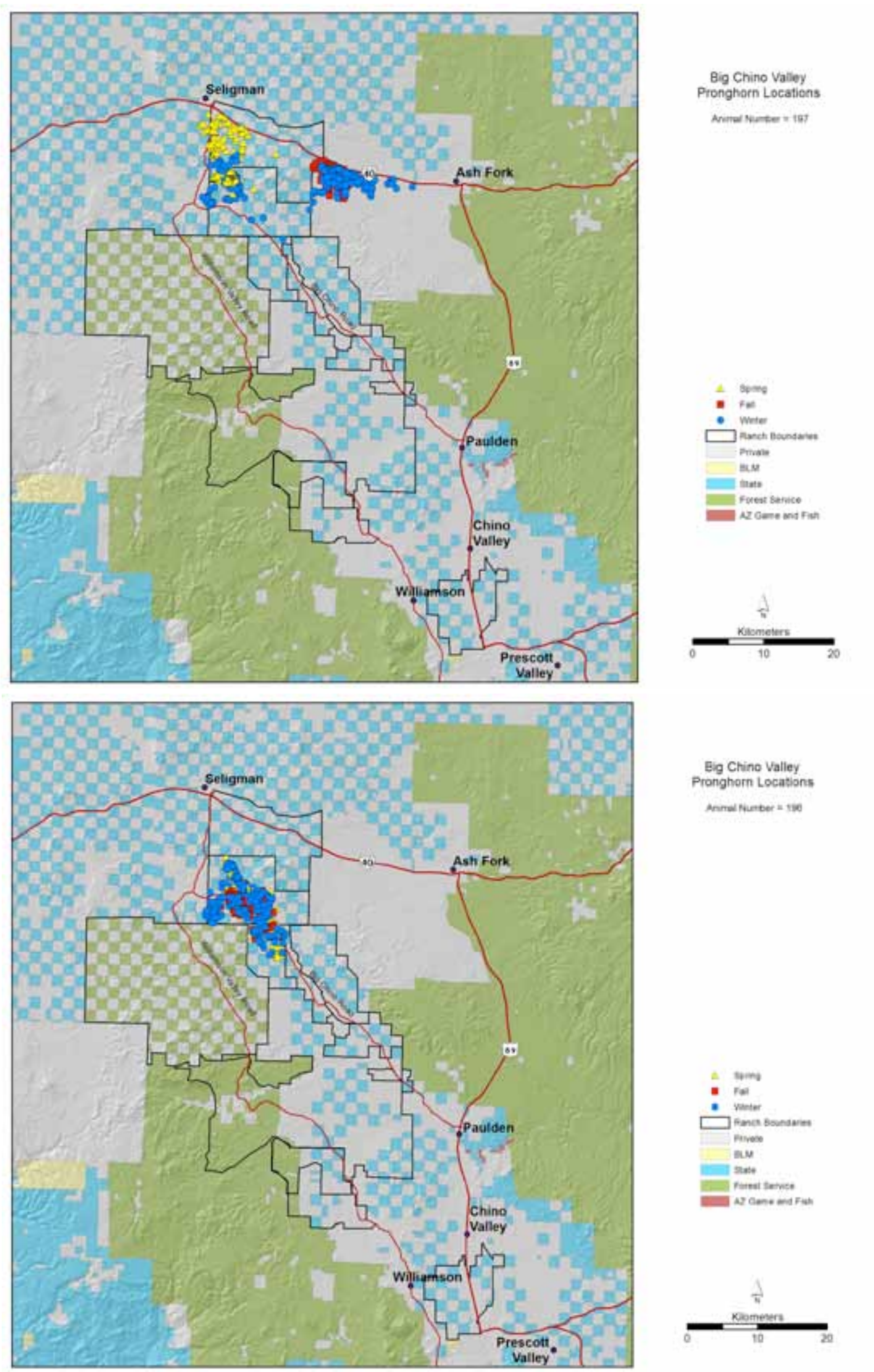

Figure 9. Plotted locations for two collared female pronghorn (197 and 196) showing seasonal space use patterns in the Big Chino Valley, Arizona, 2007–2009.

vegetation and gentle terrain enhance habitat suitability, our models suggest that both natural and artificial features in the landscape may be affecting pronghorn movements in the BCV. For example, natural features like steeper terrain on the valley sides or juniper-dominated woodlands can funnel pronghorn movements and act as barriers. The GARPveg model also indicated that artificial structures, like large roads, fencing, houses and agricultural activities (Fig. 13), may also create areas that are largely impassable for pronghorn (Alexander and Ockenfels 1994, Ockenfels et al. 1996).

The impacts of roads and highways

Roads and highways fragment pronghorn habitat use in Arizona and the BCV (Ockenfels et al. 2000). Collared pronghorn in our study did not cross Interstate 40 on the north end of BCV (Figs. 5, 13), and other major roads in the study area, such as Highway 89 along the eastern edge of BCV, likely impair their movements (Fig. 8). Moreover, pronghorn in the BCV rarely crossed WV road along most of its course through Williamson and Pine Creek Valleys, yet they did occasionally cross WV road along the southern end of the study area (Fig. 13). Thus, a lack of observed pronghorn locations in areas with high LOU scores may be due to roads obstructing animal movements; however, an absence of pronghorn locations in the northwest corner may also have resulted from fewer collared animals in that area as our capture efforts were focused more in the central portions of BCV.

Collared pronghorn crossed both roads (WV and BC) traversing the study area, although crossing rates/1.6 km section were affected by many variables. Our CART analysis identified road type (unmaintained vs. maintained gravel) as the factor that had the greatest effect on collared pronghorn crossing rates in BCV. This could be related to structural features of those roads as well as differences in vehicle traffic volume, but may also correspond to habitat suitability or the number of collared individuals present in those areas. Although we did not directly measure vehicle traffic, the less developed BC Road likely experienced reduced traffic. Greater vehicle traffic is usually associated with increased wildlife-vehicle collisions and decreased road permeability for wildlife (Clevenger and Waltho 2000, Dodd et al. 2007).

The influence of land use and habitats

Fencing and human activities may restrict pronghorn movements (Buechner 1950, Hailey et al. 1966, Martinka 1967, Ockenfels et al. 1994). In the BCV, high LOU scores on ranches that received low use by collared pronghorn (Table 7) suggested that barriers on the landscape may prevent animal access to suitable habitats or that other factors such as human activities may cause them to avoid these areas. For instance, our site visits to the BCV revealed that the lack of pronghorn use on areas with high LOU scores (e.g., on the Coury and Big Chino Water Ranches; see Fig. 13 and Table 7) may result from extensive fencing and/or mechanical farming activity in cultivated areas. Likewise, linear edge patterns in pronghorn movements were often associated with fences, and our site visits revealed that even barbed wire fences with the appropriate configuration to allow pronghorn passage may have become barricades when obstructed by dense accumulations of tumbleweeds. Moreover, urban and agricultural development or recreational activity may affect wildlife movements across landscapes (Ruediger 2001). Pronghorn respond negatively to significant agricultural and urban development (Yoakum 2004), and we found that anthropogenic factors, such as proximate building density and agricultural developments affected pronghorn road crossing rates over BC Road. We documented fewer pronghorn locations where building density was high and developed areas appeared to have lower model suitability (Fig. 10) and/or where farmed vegetation or fallow fields predominated (Table 5; Figs. 5, 7), a pattern of avoidance consistent with habitat use in other parts of their range (Hoskinson and Tester 1980). However, some researchers have indicated that pronghorn elsewhere use and seasonally prefer some agricultural areas planted with herbaceous forage species, especially legumes like alfalfa (*Medicago sativa*) and early growing grasses (Yoakum 1980, Gamo 1997).

Perhaps not all artificial structures present significant barriers to pronghorn. As suggested by the final distinct nodes of the CART analysis for both BC and WV roads (Figs. 10, 11), pronghorn may cross roads more frequently in areas associated with higher building density. Although this may appear to be counter-intuitive, it should be noted that in the BCV, livestock fences and ranch houses/outbuildings are often located in more open grassland habitats. Thus while it is possible that roadside features like fencing and building density can reduce permeability for wildlife (Ruediger 2001), these features may also be associated with important habitat variables, such as a desired vegetation type, gentle slope, a degree of openness (e.g., lack of canopy or dense brush), or even lower predator densities (i.e., fewer coyotes to prey on fawns) that would allow for increased permeability. Such structures may also occupy areas along traditional migratory routes or movement corridors across the landscape.

Previous studies have also reported an association between increased road permeability and wildlife habitat suitability (Putnam 1997, Clevenger and Waltho 2000). While we did not directly analyze the relationship between habitat suitability and road crossing rates of pronghorn, we note that along the more undeveloped Williamson Valley Road, our CART analysis suggested that the habitat variables that most affected pronghorn road crossing rates were slope and vegetation type (Fig. 11). Consequently, visual inspection of areas where animal locations suggested higher animal crossings confirmed that pronghorn crossed roads more frequently in open grassland areas with gentle slopes, even though such areas comprised only 18.5% of the vegetation in our study area (Table 5). Moreover, our model results corroborate with others (Alexander and Ockenfels 1994) and strongly suggest that pronghorn avoid dense juniper woodlands, like those that comprise two-thirds of the BCV study area, but will travel through stands that have been mechanically thinned (Fig. 12).

Our GPS data suggested that collared pronghorn preferred grassland-forbland habitats consistently across all seasons (Table 5), although other environmental factors may also dictate their use of open habitats. While fences or human activities may exclude pronghorn from using an area, pronghorn may avoid places that they can access if range conditions are substandard or have been reduced by land use practices. Our model results may be useful in suggesting areas where basic habitat characteristics (e.g., slope, vegetation, elevation, distance to roads) make a site highly suitable, but in reality, the forage conditions may need some restoration to improve forage quality. Diet quality and production of forbs may be key factors influencing pronghorn use of an area (Schwartz et al. 1977, Brown et al. 2002, Hosack et al. 2002). Forbs provide a major food source for pronghorn, and general habitat characteristics in the places they grow, such as low visual obstruction and open terrain, suit the pronghorn's ability to avoid predators (Stephenson et al. 1985, Ockenfels 1994, and Lee et al. 1998). Soil properties also often correlate with pronghorn habitat use and productivity (Ellis 1970, Stoszek et al. 1980, Bristow et al. 2006). Efforts to improve range condition via juniper removal, evaluation of cattle grazing practices, and restoration of native grassland communities may increase pronghorn use of these areas.

Pronghorn use of BCV ranches

Pronghorn use of private ranch lands and grazing allotments on public lands varied widely. For example, the K4 ranch accounted for the largest proportion of grassland-forbland vegetation in BCV and also consistently had the highest seasonal pronghorn use (Table 7). Likewise, the CF (managed currently as a portion of the larger

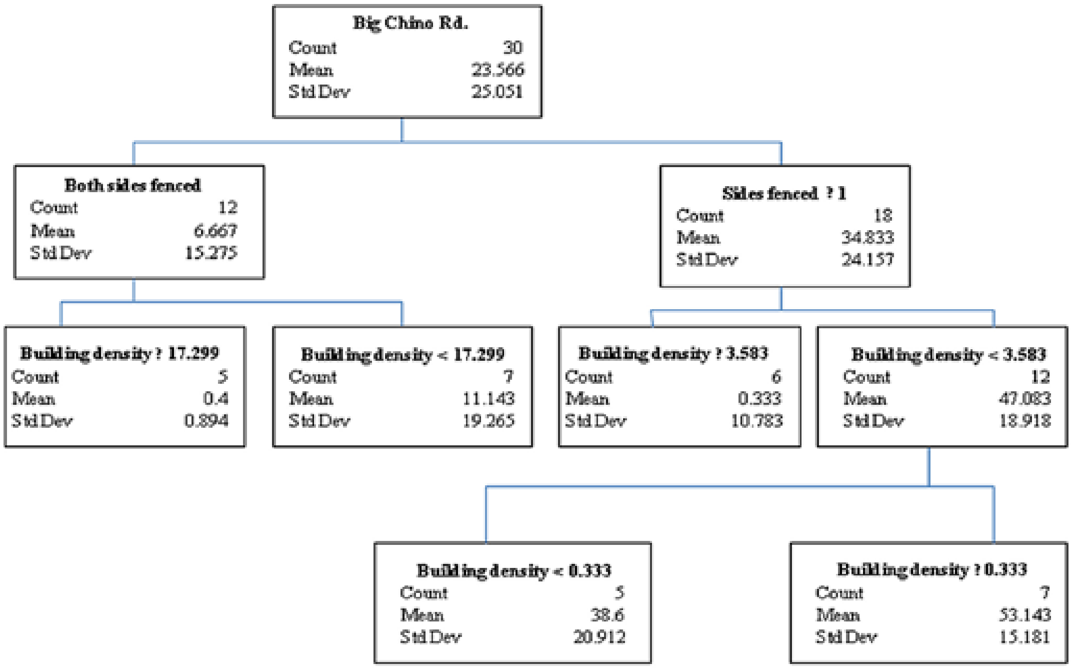

Figure 10. Classification and Regression Tree (CART) modeled decision tree for roadside fencing and building density (for buildings within 1.6 km of road) variables associated with crossing rate of collared pronghorn along sections of Big Chino Road, Arizona, 2007–2009.

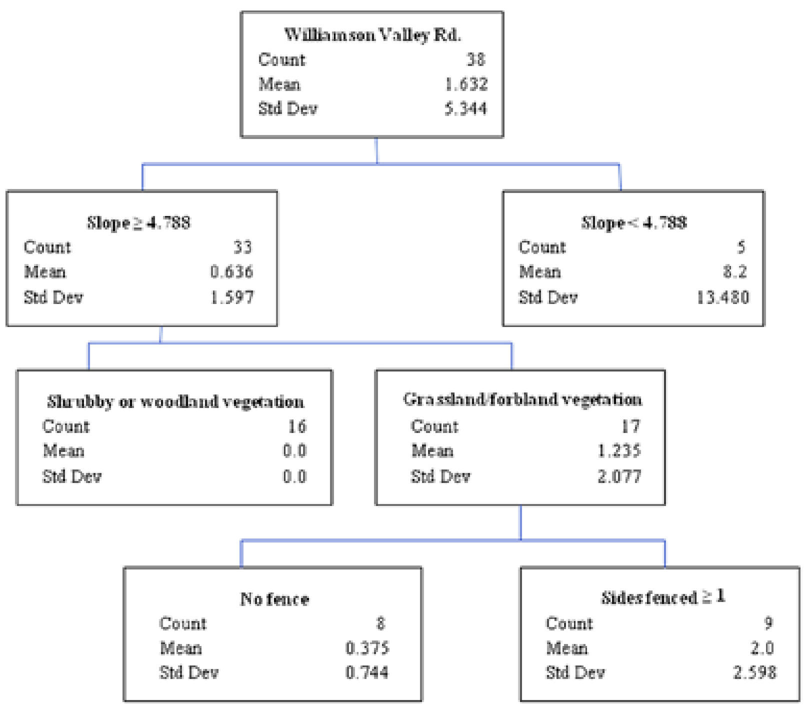

Figure 11. Classification and Regression Tree (CART) modeled decision tree for variables (average slope/5.12 km^2, vegetation type, and roadside fencing) associated with crossing rate of collared pronghorn along sections of Williamson Valley Road, Arizona, 2007–2009.

CV-CF Ranch) and JWK Foundation ranches, though much smaller in land area, consistently attracted high relative use by pronghorn during all seasons. Our GARPveg model indicated that these ranches contained high quality habitat that likely attracted pronghorn. Moreover, all three ranches occupy prime areas used by collared pronghorn moving up and down the BCV (Fig. 13B) and may thus show high pronghorn activity simply because animals are moving through the length of the valley. In contrast, other ranches, such as the Bar Triangle and Yavapai Ranches, showed significantly lower seasonal use than expected by collared pronghorn. While low observed use may be an artifact arising from our centralized capture efforts and the subsequent distribution of collared animals, lower pronghorn use of these ranches likely reflects not only the decreased suitability of more extensive juniper woodlands present, particularly on the Yavapai Ranch, but also the effects of being farther removed from migratory corridors, increased vehicle traffic, higher residential development and fencing where the bottom strand is less than 45cm off the ground along stretches of road in the southern end of BCV.

Differences in seasonal use of specific ranches may also correspond to seasonal variation in human activities (e.g., hunting, farming), pronghorn biology (e.g., fawning, breeding or overwinter feeding) and/or the availability of resources such as forage or cover. While our study was not designed to examine habitats critical to distinct phases of pronghorn life history, one reasonable assumption may be that those ranches that saw significantly higher activity in spring may be of greater value to pregnant does and their fawns, whereas ranches with higher pronghorn occupation in the fall or winter seasons may be important refugia areas from hunting during the breeding season or overwintering, respectively. Moreover, changes in availability of forage almost certainly affect seasonal use of different ranches in BCV by pronghorn. For instance, pronghorn shift their diets to include more shrub species as forbs become less available in the winter (Yoakum 1990). Our data showed that pronghorn increased use of woody or forested habitats in winter (Table 5), where perhaps they exploited small shrubby vegetation or sought a more sheltered environment than on open grasslands. This shift in habitats may be reflected in increased winter use of ranches like the T2 and Big Chino Water Ranch (Table 7). As well, we observed other contributing factors to low pronghorn use of these and neighboring ranches; these factors included high human agricultural activity in the summer and fall months and/or extensive fencing on Big Chino Water, Coury, and T2 ranches. While our pronghorn location data demonstrate that pronghorn move freely over fences on the T2 Ranch, the near absence of collared animals on the neighboring Coury Ranch suggests that fences may present a significant barrier to pronghorn, whereas both fences and agricultural activities may reduce use of the Big Chino Water Ranch.

Also of interest is the contrast between model results and observed pronghorn use of the two smallest ranches in BCV. The Lobo and Coury Ranches both account for only a fraction of the total ranched area in the valley, with the Coury Ranch situated in the core of our study area near the majority of observed pronghorn locations and the Lobo Ranch on the southeastern edge of the BCV. Whereas pronghorn moving through the central valley should have created traffic moving across the Coury Ranch, our GPS data indicated that pronghorn avoided it completely, despite the ranch's high model LOU score (Table 7, Fig. 13). Conversely, the Lobo Ranch is located on the eastern fringe of the valley away from central passageways, yet pronghorn used the Lobo Ranch significantly more than expected in two of the three seasons (Table 7). As 90% or more of the area on each ranch was predicted to be suitable pronghorn habitat, and ranch location does not seem to be the limiting variable, the difference in actual use in each season may demonstrate instead that extensive or impassable fencing, high levels of agricultural activity, or differences in range condition may significantly influence pronghorn use of ranchlands.

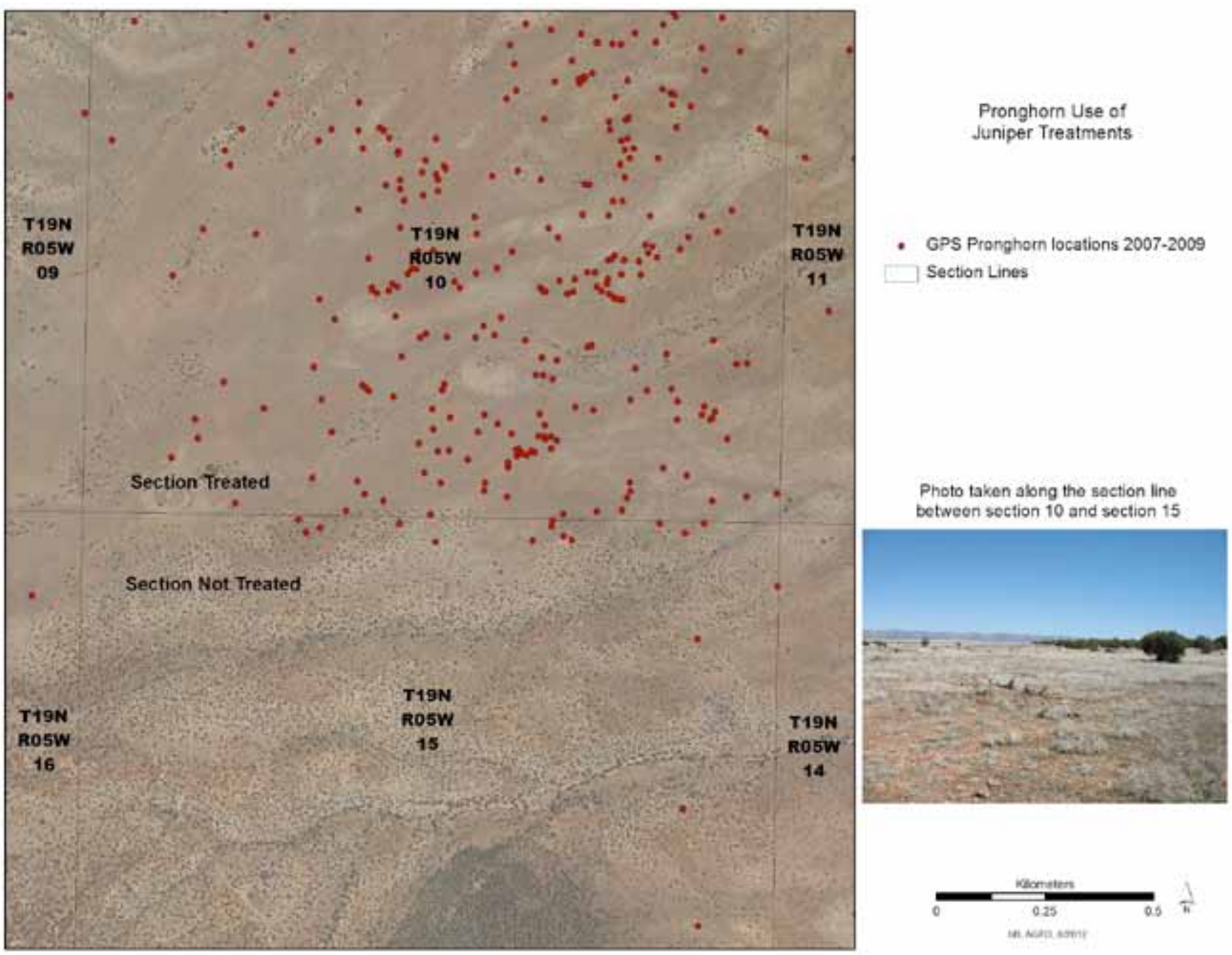

Figure 12. Collared pronghorn used habitat within areas that had been mechanically treated to reduce juniper densities. Linear-trending collared pronghorn locations were found at the boundary of treated and untreated habitat in the Big Chino Valley, Arizona 2007–2009.

Such may also be the case for the two ranches with the lowest average LOU scores. The Yavapai Ranch, which encompasses the second largest ranch area in BCV and contains the second largest percent of the total grassland vegetation (among all ranches, Table 7), shows very little pronghorn use in any season. Yet the Campbell ranch, which is the third largest ranch in the BCV but with less than half the area or total grassland of the Yavapai Ranch, shows significantly higher pronghorn use in two seasons than is expected by its availability. The discrepancy in use between the two ranches may well depict differences in accessibility or range condition. Even though the Yavapai Ranch has extensive grassland cover and our GARP models predicted higher habitat suitability on the north end and far east side, pronghorn likely avoid using most of the central area and western half of the ranch because of its' hilly topography (Fig. 13). In contrast, as the Campbell Ranch connects to additional areas of high habitat suitability on almost all sides (Fig. 13), pronghorn use on this ranch is likely indicative of a vital passageway for animals moving to good habitats north, south and west of the ranch border. Thus, the critical pinch point found on the Campbell Ranch, as well as others like that on the east side of the neighboring CF Ranch (Fig. 13C), is important to protect in efforts to maintain contiguous habitat for pronghorn moving across BCV. Moreover, if WV Road and the presence of I-40 form significant movement barriers to pronghorn, animals may also be

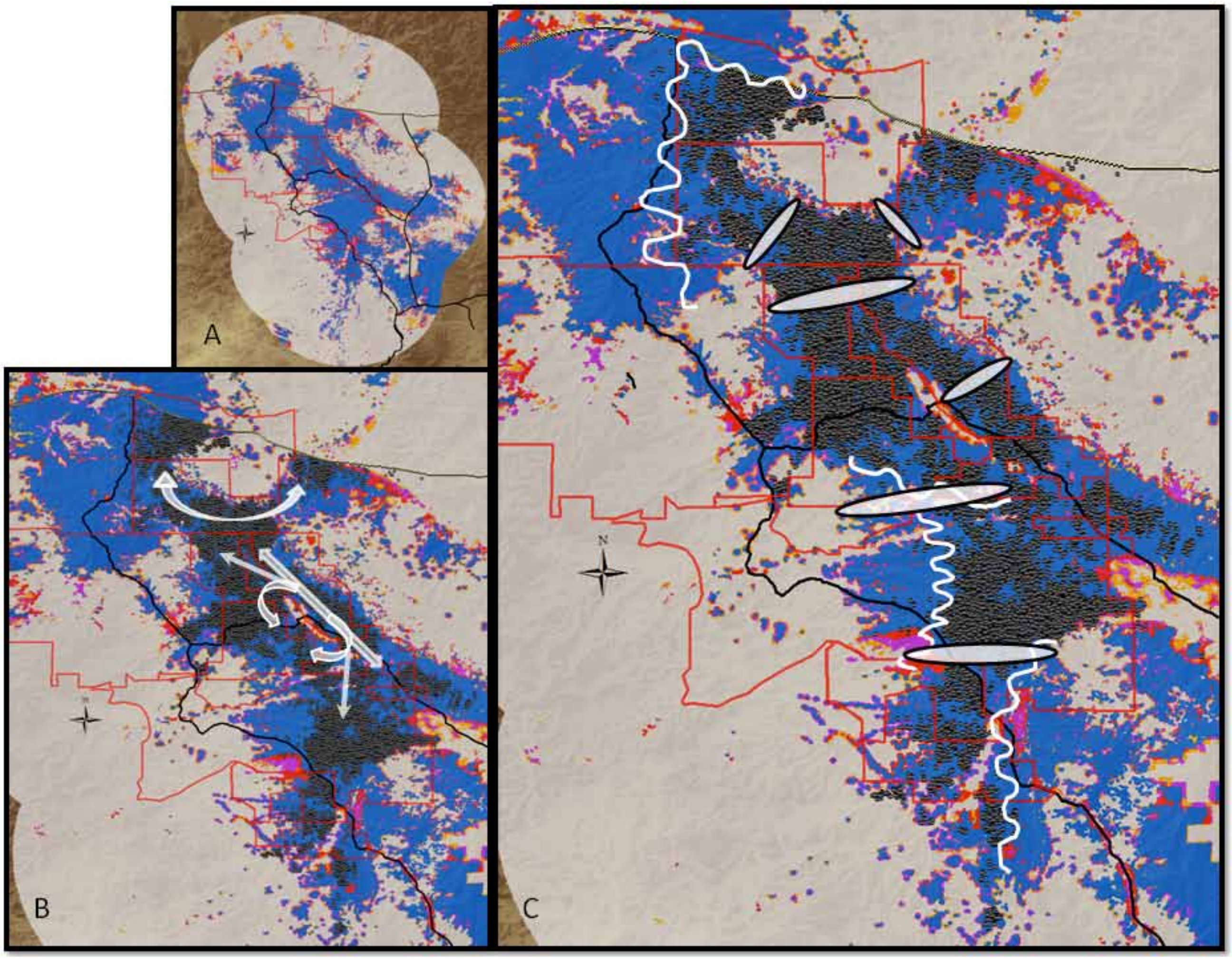

Figure 13. A) GARPveg suitability model (as in Fig. 6) as of September 2009 for pronghorn in Big Chino Valley (BCV), AZ. Blue, pink, orange, and cream shades represent model areas of highest to lowest predicted suitability, respectively. Red lines outline private ranch boundaries, and major roads are drawn in black. B) Collared pronghorn locations (gray circles) overlaid on GARPveg suitability model. White arrows indicate travel routes frequently taken by collared individuals and suggest areas where connectivity is important. C) Areas of concern for pronghorn movement in BCV. White lines depict areas where movements may already be impaired, while white circled areas are drawn perpendicular to direction of pronghorn movements to indicate likely pinch points where efforts to maintain connectivity should be focused because land alterations may heavily impact landscape connectivity and hinder pronghorn movements.

congregating on the Campbell Ranch and seeking ways to cross I-40 or WV Road to access high quality habitats on the other side.

Management implications

Our GARPveg model provides a detailed model of habitat suitability in the BCV. Although the model's immediate use may be limited to the BCV, it presents a high resolution map of pronghorn habitat and lends support to the Ockenfels et al. (1996) model (Tables 8, 9), which in turn, provides suitability ratings for the entire state. Consequently, the Ockenfels et al. (1996) habitat quality rankings are likely adequate to inform land management decisions statewide, while our GARPveg model provides a higher resolution habitat model, and represents a better tool for guiding management decisions at a local scale such as in the BCV.

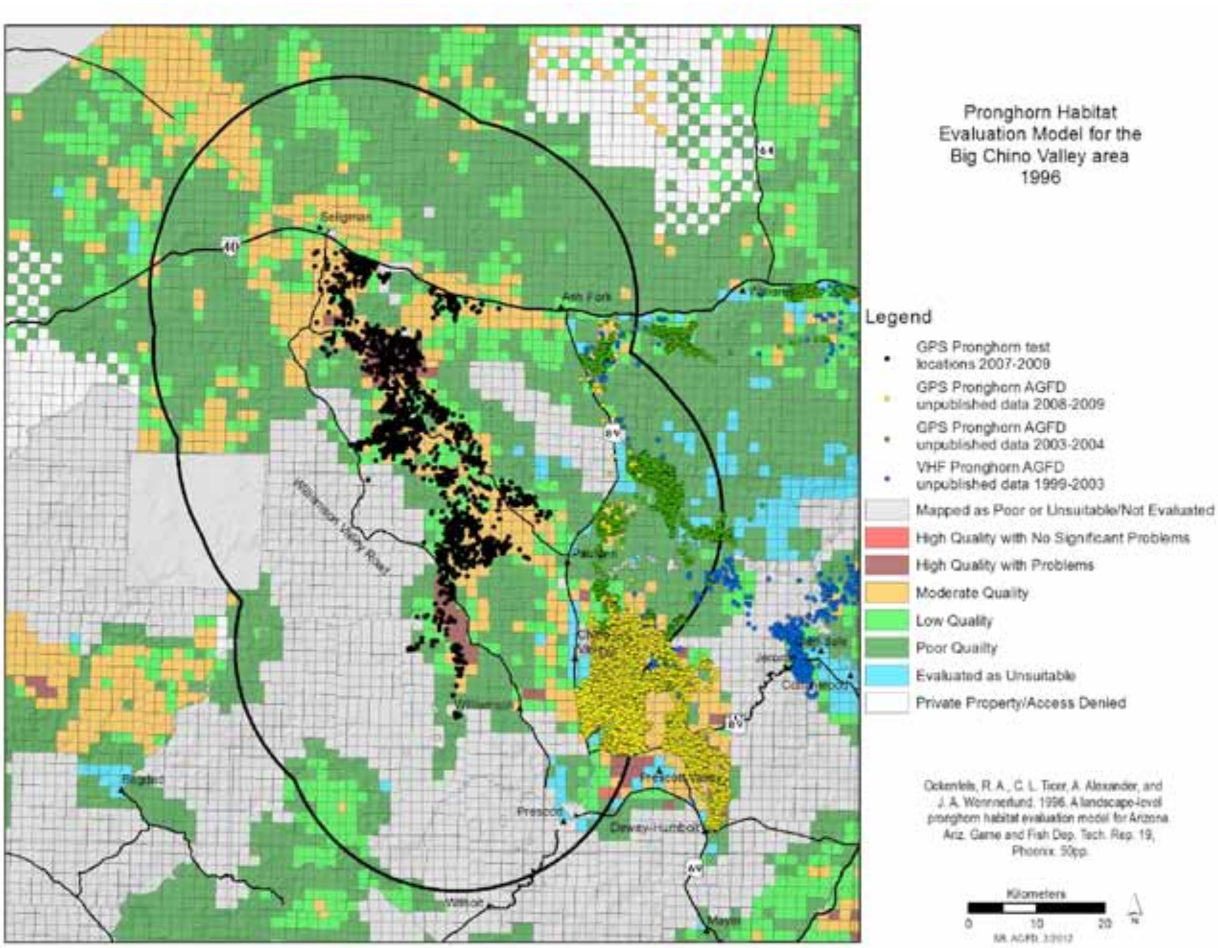

Figure 14. Pronghorn Habitat Evaluation Model map (Ockenfels et al. 1996) overlaid with locations obtained from previous pronghorn movement studies in the area (1999–2009) and test locations (n = 1957) from collared pronghorn in the Big Chino Valley, Arizona, 2007–2009.

Our results provide further support for the need to maintain habitat in BCV as a large intact continuous block to sustain local pronghorn populations. As depicted in Figure 13B, pronghorn move north, south and across the valley, but our data suggest that there are currently natural and artificial barriers that impede animal movements in BCV. Freedom of movement is critical because it not only provides opportunities for connectivity and gene flow within the population, but also allows for movements that aid animals in responding to ecological and/or spatial challenges, such as short- and long-term changes in forage, cover, or disturbance. We propose that the following observations can inform management to maintain and improve habitat conditions and enhance habitat connectivity for pronghorn in BCV:

- The use of test data indicated that the GARPveg model had high predictive power, and that it is therefore able to predict where suitable habitats for pronghorn may be located in BCV. In this way, landscape models of this nature help us to identify areas having potentially high value to animals, but also point to natural or artificial barriers to movement and suggest areas to consider for habitat or fence line modifications that are most likely to benefit pronghorn. For example, our model suggests a large block of highly suitable habitat in the northwest corner of BCV remained unused by any collared pronghorn during our study (Fig. 13). Although uncollared animals may be present in this area, a lack of collared pronghorn movement into this highly suitable habitat begs the question of accessibility and barriers to movement. We have proposed efforts that could improve permeability along the northern end of the WV road, such as modifying roadside habitats or altering fence lines. Permeability across I-40 would likely require construction of an over- or under-pass. At the southern end of BCV, we observed multiple pronghorn-unfriendly fence lines along roadways, so connectivity for pronghorn may be increased through simple alterations designed to increase permeability of existing fence lines with the installation of goat bars (Lee et al. 1998) or raising bottom strands more than 18 inches off the ground. Seasonal accumulation of vegetation, such as dried tumbleweeds, along fence lines may also present a barrier to pronghorn movements along otherwise permeable fences, and efforts to improve permeability should be focused on control or removal of build-up.

- The GARPveg model and pronghorn locations reveal patterns of movement north, south and across the BCV and identify critical 'pinch points' where habitat connectivity may be compromised or vulnerable (Fig. 13). The model also indicates areas of highly suitable habitat in BCV, yet devoid of collared animals. These areas suggest that animal movements may be impaired, as by fences, vegetation changes, or residential development. The model also helps to identify key areas where, if resources are limited, efforts should be focused to maintain connectivity, for example, between the two primary areas on the CV-CF Ranch or between the K4 and Las Vegas ranches, as indicated by arrows and circled areas in Fig. 13B and C, respectively. Any significant land alterations that impede pronghorn movements at circled pinch points may be particularly detrimental to sustaining pronghorn populations in BCV.
- Although pronghorn prefer open, flat grassland-forbland habitats, areas of apparent high suitability on some of the ranches were under used (Table 7). Our GARPveg model, as depicted in Fig. 13, indicates several areas across BCV where highly suitable pronghorn habitat was unexploited by collared animals. Fences, roads and traffic, intense agricultural or human activity, thick overgrown vegetation and/or topographical changes across the landscape may deter pronghorn from accessing suitable habitats. Assuming that pronghorn have access to these areas (i.e., no barriers), efforts to improve connectivity between and use of these areas may be enhanced by improving rangeland conditions, via juniper thinning, evaluating cattle grazing practices, or restoring native grassland communities. Collared pronghorn in the BCV used areas where juniper thinning treatments had created open habitats. Juniper thinning and removal serve to restore open spaces, improve grassland habitat availability, and may provide corridors that allow for increased pronghorn movements and population connectivity; this may be especially true within areas of otherwise suitable habitat.
- Our GARPveg model corroborates the more coarse (1 mi^2 resolution) habitat quality map developed by Ockenfels et al. (1996) and therefore lends support for continued use of this tool to inform pronghorn habitat management across Arizona.

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Table 1. Ecogeographic variables included in development of a predictive habitat model for pronghorn in the Big Chino Valley, Arizona, 2007-2009.

Ecogeographic variable	Description
Slope	Slope (%) of individual 30-m^2 pixel.
Elevation	Elevation (m) of individual 30-m^2 pixel.
Solar Radiation	Watt hours/square meter, calculated for each individual 30-m^2 pixel, and based on the annual value.
Ruggedness	Index of ruggedness over a 150 m x 150 m area (22,500 m^2) centered on each 30-m^2 pixel.
Distance to major roads	Shortest distance (m) from each 30-m^2 pixel to a major road (interstate, highway, access ramp, or arterial).
Distance to paved streets	Shortest distance (m) from each 30-m^2 pixel to a paved street (excluding major roads, jeep trails, dirt roads, trails).
Distance to railroad	Shortest distance (m) from each 30-m^2 pixel to a railroad.
Distance to woodland/forest vegetation type	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP woodland or forest vegetation type.
Distance to medium or high shrub/scrub vegetation type	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP medium to high height/density shrub or scrub vegetation type (Table 2).
Distance to low height/density shrub/scrub vegetation type	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP low height/density shrub or scrub vegetation type.
Distance to grassland or forbland vegetation type	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP grassland or forbland vegetation type.
Distance to agriculture	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP agriculture vegetation type.
Distance to savanna vegetation type	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP savanna vegetation type.
Distance to other vegetation type	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as ReGAP water, developed, barren, etc)
Distance to soil group 1	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as Roundtop-Boysag, Cabezon-Thunderbird-Springerville, Rudd-Bandera-Cabezon, Lithic Haplustolls-Lithic Argiustolls-Rock Outcrop, or Tortugas-Purner-Jacks.
Distance to soil group 2	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as Lithic Torriorthents-Lithic Haplargids-Rock Outcrop, Winona-Boysag-Rock Outcrop, or Lithic Torriorthents-Lithic Haplustolls-Rock Outcrop.
Distance to soil group 3	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as Bonita-Graham-Rimrock.
Distance to soil group 4	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as Mirabal-Dandrea-Brolliar.
Distance to soil group 5	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as Lonti-Balon-Lynx, Palma-Clovis-Trail, of Continental-Latene-Pinaleno.
Distance to soil group 6	Shortest distance (m) from each 30-m^2 pixel to a pixel classified as Pastura-Abra-Lynx or Pastura-Poley-Partri.
Percent developed land	The percent of developed land within a circle with radius of 1 km, centered on each 30-m^2 pixel.

Table 2. Vegetation associations within vegetation types (in bold) used to examine pronghorn habitat use by collared pronghorn in the Big Chino Valley, Arizona, 2007-2009, and to develop a predictive habitat map.

Vegetation associations-vegetation types	Percent of study area
Woodland, forest types	
Madrean pine-oak forest and woodland	2.8
Rocky mountain ponderosa pine woodland	4.7
Colorado plateau pinyon-juniper woodland	36.6
Madrean pinyon-juniper woodland	22.1
North American warm desert lower montane riparian woodland and shrubland	0.1
Med-height-density shrub types	
Mogollon chaparral	10.7
Inter-mountain basins big sagebrush shrubland	0.3
Apacherian-chihuahuan Mesquite upland scrub	0.6
Low-height-density shrub/scrub types	
Inter-mountain basins semi-desert shrub steppe	0.3
Chihuahuan creosotebush, mixed desert and thorn scrub	0.1
Grassland-forbland types	
Inter-mountain basins semi desert grassland	1.1
Apacherian-chihuahuan piedmont semi-desert grassland and steppe	17.4
Agriculture	
Agriculture	0.5
Savanna	
Madrean juniper savanna	0.3
Inter-mountain basins juniper savanna	0.1
Other	2.3

Table 3. Covariates included in analysis of road crossings by pronghorn in the Big Chino Valley, Arizona, 2007-2009.

Covariate	Description
Fence Type[a]	Categorical: none, barbed wire, net mesh
Sides of road fenced	Categorical: one, two
Type of bottom strand[a]	Categorical: goat bar, smooth, barbed
Height of bottom strand[a]	Categorical: < 17 inches, ≥ 17 inches
Vegetation type	Categorical: predominant vegetation type within 1.6 km of the road section (seven classes shown in Table 2)
Building density	Continuous: Percent developed (buildings) land within 1.6 km of road section
Percent slope	Continuous: Average slope (%) of individual 30-m^2 pixels within 1.6 km of road section
Ruggedness index	Continuous: Index of ruggedness within 1.6 km of road section

[a] When both sides of the road were fenced with different types of fences, we recorded characteristics from the side subjectively judged to be more restrictive to pronghorn movements.

Table 4. Receiver-operator characteristic (ROC) area, sensitivity, and specificity values of Genetic Algorithm for Rule-set Prediction (GARP) habitat use models, generated using soil type covariate (GARPsoils) and vegetation type covariate (GARPveg) for pronghorn in the Big Chino Valley, Arizona, 2007-2009.

Model	ROC area	Sensitivity	Specificity
GARPsoils	0.843	99.4%	57.5%
GARPveg	0.882	96.1%	71.2%

Table 5. Percent use (by collared pronghorn locations, n = 9804), number of pronghorn locations by season, and availability of different habitats in Big Chino Valley, Arizona, 2007-2009. (Blank where sample size too small to calculate measure)

Vegetation type	% of study area	% of total pronghorn locations	No. pronghorn locations Spring	Fall	Winter	Bonferroni 90% CI	Jacob's *D*[a]
Woodland, forest	66.3	25.3	688	646	1149	24.3–26.5	-0.70
Med-height/density shrub	11.6	1.4	34	72	25	0.9–1.5	-0.83
Low-height/density shrub/scrub	0.4	< 1.0	0	0	1		
Grassland/forbland	18.5	72.4	1874	1939	3284	70.7–72.9	+0.84
Agriculture	0.5	< 1.0	1	1	6		
Savanna	0.4	< 1.0	0	1	1		
Other	2.3	< 1.0	26	35	21	1.3–1.9	-0.18

[a] Ratio of use to availability: avoidance < 0 < selection.

Table 6. Distribution of pronghorn test data relative to five habitat classes (I-V, low to high), developed with Genetic Algorithm for Rule-set Prediction (GARP), using soil (GARPsoils) and vegetation type (GARPveg) covariates in the Big Chino Valley, Arizona, 2007-2009.

GARPsoils

Habitat Class	No. of locations	% of locations	Bonferroni 90%CI	km^2 available	% of area	No. of locations expected	Jacobs' *D*[a]
I	4	0.20	0.03 - 0.44	3733.77	51.60	1009.81	-0.99
II	4	0.20	0.03 - 0.44	293.20	4.05	79.26	-0.99
III	4	0.20	0.03 - 0.44	246.43	3.41	66.73	-0.89
IV	5	0.26	0.01 - 0.59	304.30	4.21	82.39	-0.99
V	1940	99.14	98.65 - 99.63	2657.16	36.73	718.81	0.99
	1957	100.00		7234.86	100.00	1957.00	

GARPveg

Habitat Class	No. of locations	% of locations	Bonferroni 90%CI	km^2 available	% of area	No. of locations expected	Jacobs' *D*[a]
I	40	2.1	1.35 - 2.86	4748.36	65.62	1284.18	-0.98
II	17	0.9	0.40 - 1.40	292.72	4.05	79.26	-0.65
III	32	1.6	0.94 - 2.26	229.05	3.17	62.04	-0.34
IV	22	1.1	0.55 - 1.65	182.69	2.53	49.51	-0.40
V	1846	94.3	93.08 - 95.52	1782.04	24.63	482.01	0.96
	1957	100.00		7234.86	100.00	1957.00	

[a] Ratio of use to availability: avoidance < 0 < selection.

Table 7. Ranch area (km^2), percent grassland-forbland by ranch, mean likelihood of use (LOU) scores (1-20) modeled in GARP, rank order of ranch suitability as predicted by LOU scores and percent grassland found on each ranch, and seasonal percent use of ranches by collared pronghorn in the Big Chino Valley, Arizona, 2007-2009.

Ranch	**Area of ranch**[a]	**% grassland on ranch**[b]	**Model LOU**	**Rank order of ranch suitability to pronghorn**		**Seasonal percent of pronghorn locations**[c]		
				Model LOU	% grass on ranch	Spring	Fall	Winter
Big Chino Water	26.35 (1.77)	67.74 (3.51)	17.31	4	3	3.4	2.4	**5.0**
Campbell	139.18 (9.33)	22.46 (6.15)	9.95	11	11	**15.2**	**14.4**	9.7
CF[d]	117.23 (7.86)	40.06 (9.23)	15.87	7	8	**12.1**	**17.7**	**16.0**
Coury	6.40 (0.43)	56.47 (0.71)	16.13	6	4	0.0	0.0	0.0
CV[d]	83.22 (5.58)	49.96 (8.17)	16.61	5	5	**8.5**	**14.1**	6.3
K4	468.46 (31.40)	40.18 (37.01)	12.47	9	7	32.5	<u>24.5</u>	**44.9**
JWK Foundation	46.41 (3.11)	83.74 (7.64)	18.89	2	1	**9.9**	**16.7**	**4.2**
Las Vegas	60.11 (4.03)	34.52 (4.08)	15.31	8	9	<u>5.4</u>	<u>2.4</u>	<u>3.6</u>
Bar Triangle	53.20 (3.57)	32.39 (3.39)	10.87	10	10	3.4	1.8	1.9
Lobo	10.50 (0.70)	81.41 (1.68)	19.65	1	2	**1.8**	**1.8**	<u>0.3</u>
T2	39.76 (2.67)	44.15 (3.45)	18.18	3	6	3.0	0.1	**6.0**
Yavapai	441.03 (29.56)	17.27 (14.98)	7.54	12	12	<u>4.8</u>	<u>4.1</u>	<u>2.1</u>

[a] Percent of individual ranch areas represented within the total ranched land of the study area in parentheses.
[b] Percent of area on individual ranches that is composed of grassland-forbland vegetation (percent of total ranched grasslands of each ranch in parentheses).
[c] Bold indicates use (based on 90% Bonferroni confidence interval) is significantly higher than availability (based on percent of available ranched land), underline indicates use is significantly lower than availability.
[d] The CF and CV Ranches are presented here as two separate entities, but they are currently managed as a single ranching operation.

Table 8. Pronghorn use of habitat classes as calculated with previously developed expert opinion-based habitat models in the Big Chino Valley, Arizona (animal locations taken 2007-2009).

Ockenfels et al. 1996

Habitat Class	No. of locations	% of locations	Bonferroni 90%CI	km^2 available	% of area	No. of locations expected	Jacobs' D [a]
Unsuitable	52	2.66	1.81 - 3.51	2192.88	30.23	591.60	-0.88
Poor	56	2.86	1.98 - 3.74	2824.50	38.93	761.86	-0.91
Low	328	16.76	14.79 - 18.72	955.27	13.17	257.74	0.14
Moderate	1175	60.04	57.46 - 62.62	1145.41	15.79	309.01	0.78
High	346	17.68	15.67 - 19.69	136.37	1.88	36.79	0.84
	1957	100.00		7254.44	100.00	1957.00	

Davis 2008

Habitat Class	No. of locations	% of locations	Bonferroni 90%CI	km^2 available	% of area	No. of locations expected	Jacobs' D [a]
Unsuitable	52	2.66	1.81 - 3.51	2169.67	36.59	716.10	-0.91
Poor	56	2.86	1.98 - 3.74	1831.78	30.89	604.60	-0.88
Low	1009	51.56	48.93 - 54.19	1136.41	19.17	375.20	0.64
Moderate	637	32.55	30.08 - 35.02	695.65	11.73	229.60	0.57
High	203	10.37	8.76 - 11.98	95.56	1.61	31.50	0.75
	1957	100.00		5929.07	100.00	1957.00	

[a] Ratio of use to availability: avoidance < 0 < selection.

Table 9. Mean and Standard Deviation (SD) of likelihood of use scores developed with Genetic Algorithm for Rule-set Prediction (GARP) for random (n = 500) points within habitat classes calculated with previously developed expert-based habitat models and the GARPveg predictive habitat model in the Big Chino Valley, Arizona, using pronghorn GPS localities from 2007–2009.

Ockenfels et al. 1996				**GARPveg**			
Habitat Class	**Mean**	***n***	**SD**	**Habitat Class**	**Mean**	***n***	**SD**
Unsuitable	1.00	9	0.00	I	1.22	199	0.66
Poor	7.77	234	8.33	II	6.77	26	1.21
Low	11.42	100	8.67	III	10.40	15	1.12
Moderate	16.24	140	6.56	IV	14.32	22	1.25
High	19.88	17	0.49	V	19.72	238	0.69
		500				500	

Davis 2008				**GARPveg**			
Habitat Class	**Mean**	***n***	**SD**	**Habitat Class**	**Mean**	***n***	**SD**
Unsuitable	1.00	9	0.00	I	1.22	199	0.66
Poor	7.77	234	8.33	II	6.77	26	1.21
Low	13.04	141	8.38	III	10.40	15	1.12
Moderate	16.10	103	6.66	IV	14.32	22	1.25
High	19.85	13	0.56	V	19.72	238	0.69
		500				500	