THE INFLUENCE OF LAND USE AND LAND COVER ON SURVIVAL AND HABITAT SELECTION OF PRONGHORN IN THE TEXAS PANHANDLE

By

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ABSTRACT

Land use and land cover (LULC) reflects how an area is being utilized from natural habitat and anthropogenic perspectives. As such, LULC can influence the ecology of wildlife. In the Texas Panhandle pronghorn (*Antilocapra Americana*) are a conspicuous member of the fauna that could be impacted by such landscape phenomena. In this study I investigate the influence of LULC on the survival and habitat selection of pronghorn in this region. To investigate the influence of LULC on survival, I obtained survival estimates for 6 different populations of pronghorn through linear regression of age structure data derived from cementum annuli of hunter harvested animals. I evaluated the importance of land use/land cover type and fragmentation statistics using a forward stepwise multilinear regression. I found that survival for pronghorn in the Texas Panhandle was 0.6146 ($r^2 = 0.9678$). The forward multilinear regression selected total available area ($t < 0.0001$, $p = 0.005$), mean patch size ($t = 0.0001$, $p = 0.007$), and mean patch edge of mixed rangeland ($t < 0.0001$, $p = 0.0406$) as having a positive influence on pronghorn survival, and total area of herbaceous rangeland ($t = -0.0662$, $p = 0.0253$) as having a negative influence on survival. To investigate the influence of LULC on habitat selection, I used pronghorn sightings obtained from aerial surveys to compare available LULC area with LULC area used by pronghorn using Compositional Analysis. Pronghorn did exhibit habitat selection within the area surveyed ($\lambda = 0.2593$, $P < 0.0001$). Comparison of habitat rankings indicated that use differed from availability for all LULC

Types, with shrub and brush rangeland being preferred over mixed rangeland, which was preferred over herbaceous rangeland, which was preferred over cropland/pasture. I concluded that LULC did have an influence on both survival and habitat selection of pronghorn, and that landscape mosaics that include shrub and brush rangeland are particularly important for pronghorn in the Texas Panhandle.

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CHAPTER I

THE INFLUENCE OF LAND USE AND LAND COVER ON SURVIVAL OF PRONGHORN IN THE TEXAS PANHANDLE

INTRODUCTION

Pronghorn (*Antilocapra americana*) are herbivorous ungulates endemic to the western United States, south central Canada, and northern Mexico, including the Texas Panhandle (Nelson 1925). Historically, millions of pronghorn ranged across the grasslands and shrub-steppes of North America, with estimates of around 35 million individuals, but by 1924 numbers fell to just 20,000 individuals because of overhunting and habitat loss (Hoover et al. 1959 as cited by Lee et al. 1994). Thanks to conservation efforts that emphasized protection of habitat, fence removal, and ethical hunting, pronghorn populations have rebounded (O'Gara and Yoakum 2004). The International Union for Conservation of Nature estimates a current population size of 700,000 individuals and considers the species to have the status of Least Concern (International Union for Conservation of Nature 2008).

Despite the recovery of the species as a whole, there are 2 populations of pronghorn listed as endangered by the United States government: the peninsular pronghorn (*Antilocapra americana peninsularis*) and the Sonoran pronghorn (*Antilocapra americana sonoriensis*; Arizona Game and Fish Department 1981). The Sonoran pronghorn population is found in southwestern Arizona and Sonora, Mexico. The population declined because of illegal hunting and competition with livestock for forage (O'Gara and Yoakum 2004). In 2002, drought brought the number of Sonoran pronghorn in the United States down to just 21 individuals, and captive breeding efforts are currently underway in Arizona to attempt to increase the population size (Wilson 2010). Peninsular pronghorn are found in Baja California Sur, and are considered the most endangered megafauna in Mexico (O'Gara and Yoakum 2004). Aerial surveys counted just 151 peninsular pronghorn in 2002 (O'Gara and Yoakum 2004). A captive breeding program has been established in Baja California Sur to enhance the wild population (Cancino 2005).

Pronghorn in the state of Texas are managed by the Texas Parks and Wildlife Department (TPWD). The Texas Panhandle is subdivided into management units called herd units. Herd unit boundaries are based on roads, fences, and other man made or natural barriers to pronghorn movement (Duncan 2015). Pronghorn are a desirable game species in Texas, both for food and as trophies (O'Gara and Yoakum 2004). The number of hunting permits allocated each year is determined by TPWD for each herd unit based on population estimates from aerial surveys (C. Richardson, Texas Parks and Wildlife Department, personal communication). Permits are then allocated to landowners based on how much suitable pronghorn habitat they own (C. Richardson, Texas Parks and Wildlife Department, personal communication).

Because of reproductive synchronicity, pronghorn in a particular population are all born within a short period of time (Gregg et al. 2001). This allows them to be placed into age classes by year. Pronghorn can be reliably aged by examining the cementum annuli of their primary incisor (McCutchen 1969). Tooth cementum is deposited in rings, a narrow dark band in the fall and winter, and a light band in the spring and summer

(Figure I.1; McCutchen 1969). This method of aging has a high degree of accuracy when applied to ungulates (Hamlin et al. 2000).

A population of pronghorn will persist or change in size depending on the survival of individuals within the population. Estimating survival allows biologists to predict future trends in population size, and gives us a way to quantify the effects of genetics, ecology, environmental conditions, and demographic variables on population size (Murray and Patterson 2006). A logical way to calculate survival would be to monitor a cohort of individuals from birth until every individual had perished. This is referred to as a horizontal construction of survival data (Ebert 1999). Applying a horizontal construction to calculating pronghorn survival would take years and be prohibitively expensive because of the species' multiyear lifespan and extensive home range.

A more time and cost effective method is to take a demographic snapshot of a population at a single moment in time, also known as a vertical construction (Ebert 1999). A vertical construction relies on the assumption that the population has a stable age distribution, that is, that each age class will always consist of the same proportion the population. (Murray and Patterson 2006). If this assumption is met, the proportions of individuals in each age class can be used to calculate survival.

Severe weather, malnutrition, and barriers to movement are major mortality factors for pronghorn (O'Gara and Yoakum 2004). Pronghorn mortality is high during severe winters, and probably has been throughout history. A Montana game warden is recorded saying that during the winter of 1893, the temperature reached -51.7°C and 80% of the pronghorn in his county starved to death because of the deep snow (Munson 1897 as cited by O'Gara and Yoakum 2004). Drought can also cause decline in pronghorn populations, such as the 2003 drought that reduced the population of Sonoran pronghorn in the US by 87% (Wilson 2010).

A large portion of deaths from harsh winters and nearly all deaths during droughts are caused by malnutrition (O'Gara and Yoakum 2004). Pronghorn are ruminants, and rely on the microorganisms within their rumens to convert cellulose into volatile fatty acids. These volatile fatty acids account for 70% of a pronghorn's energy intake. During periods of starvation, rumen microorganisms die, leaving the pronghorn with no way to digest cellulose until their population of microorganisms can rebound when food is available again. The process of repopulating the rumen with microorganisms can take several days. Because of this, even after food becomes available, a pronghorn may still have to live in a negative energy balance for several days and some may die even though food is available. Malnourished pronghorn are also more susceptible to predation, disease, and parasitism, and have reduced fecundity (O'Gara and Yoakum 2004).

When present, barriers to movement can exacerbate conditions that lead to pronghorn malnutrition (O'Gara and Yoakum 2004). Historical records document pronghorn moving for hundreds of kilometers during seasonal migrations. The addition of roads and fences to the prairies, steppes, and deserts of North America have limited the ability of pronghorn to migrate or disperse as they would have historically. For example, pronghorn that spend the summer in southwestern Montana migrate 240 km south each winter to the Snake River plain in Idaho. During the winter of 1983, 200 pronghorn managed to cross the steep canyon of the Snake River and then traveled a few hundred meters south where they encountered a fenced highway. Despite being able to cross a river and rugged canyon, the pronghorn never crossed the fenced highway, and eventually returned to the other side of the river (O'Gara and Yoakum 2004). Barriers to movements increase pronghorn mortality during harsh weather. During a particularly harsh winter in the Red Desert in Wyoming, pronghorn mortality was nearly twice as high in fenced areas compared to unfenced areas (Oakley and Riddle 1974).

Habitat fragmentation, or the division of large continuous habitats into smaller, isolated fragments, has a negative effect on pronghorn and other ungulates. Fragmentation can be caused by barriers to movement such as fences, roads, and human development. Harrington and Conover (2006) documented that wire fencing caused mortality in pronghorn, elk (*Cervus canadensis*), and mule deer (*Odocoileus hemionus*) directly by entanglement and indirectly by restriction of movement. Key deer (*Odocoileus virginianus clavium*) that inhabit an island fragmented by human development have lower survival than key deer on a neighboring island lacking fragmentation (Haverson et al. 2004). Fragmentation caused by energy development causes elk to have smaller home ranges, more complex movement paths, travel longer distances, and exhibit more escape behavior than elk in nearby non-fragmented areas (Webb et al. 2011).

Pronghorn occupy a wide variety of semiarid habitats across North America (O'Gara and Yoakum 2004). Pronghorn can be found in habitats ranging from alpine meadows 3,353 m in elevation in Wyoming, to the Pacific coastal desert of Baja California Sur, Mexico, but they occur in the greatest densities in grasslands and shrub-steppes. Pronghorn are supremely adapted to ecosystems with mixtures of grasses, shrubs, and forbs where the average annual precipitation falls between 12.7 cm and 76.2

cm. Pronghorn rely primarily on their excellent vision to avoid predation, selecting habitats with vegetation less than 61 cm high, few trees, and a long range of visibility. Pronghorn are concentrate selectors, focusing on the most nutritious parts of nutritionally dense plants, primarily forbs and shrubs (O'Gara and Yoakum 2004).

The United States Geological Survey (USGS) provides GIS layers that record the land use and land cover (LULC) data for most of the United States. These data describe the type of anthropogenic use or habitat type present in a geographic area. In the Texas Panhandle the most common LULC types are rangeland and cropland. Cropland is agricultural land used for growing plants used for food or fiber (Anderson 1976). In the Texas Panhandle the most common crops are corn, wheat, sorghum, and cotton (United States Department of Agriculture 2015). Rangeland is land dominated by grasses, forbs, or shrubs, and, at least historically, influenced by herbivory (Anderson 1976). Rangeland is broken down into 3 categories: herbaceous rangeland, mixed rangeland, and shrub and brush rangeland. Herbaceous rangeland is dominated by grasses and forbs, while shrub and brush rangeland is dominated by xerophytic, woody-stemmed plants and/or cactus. If a mixture of the 2 types is present and more than one third of each type is represented, then the land is classified as mixed rangeland (Anderson 1976). Because these LULC classes expose pronghorn to different levels of fragmentation and nutrition, my hypothesis is that pronghorn survival is affected by the land use and land cover types of their habitat.

STUDY AREA

The Texas Panhandle contains 2 different ecoregions: the High Plains and the Rolling Plains (Figure 1.2; Gould 1960). The High Plains is a short grass prairie characterized by buffalo grass (*Bouteloua dactyloides*) and blue gramma (*Bouteloua gracilis*) along with scattered yucca (*Yucca spp*.), and prickly pear (*Opuntia spp*.; Correll and Johnston 1979). The soil ranges from sandy to clay (Correll and Johnston 1979). Yearly precipitation averages from 47 cm/year in the northwestern panhandle (Dallam County) to 58 cm/year the southwestern corner of the High Plains (Gray County) (National Oceanic and Atmospheric Administration [NOAA] 2016c). The majority of precipitation falls in May through August (National Oceanic and Atmospheric Administration [NOAA] 2016c). The temperature averages 13.56 °C (National Oceanic and Atmospheric Administration [NOAA] 2016b). The topography of the High Plains is primarily flat with some gently rolling hills (Correll and Johnston 1979).

The Rolling Plains meet the High Plains along the edge of the Caprock Escarpment, with the Rolling Plains towards the southeast at a lower elevation and more varying topography including many canyons and draws (Correll and Johnston 1979). The Rolling Plains are characterized by clay soils. Dominant plants include blue gramma, and little bluestem (*Schizachyrium scoparium*), as well as juniper (*Juniperus spp*.) and honey mesquite (*Prosopis glandulosa*) in disturbed areas (Correll and Johnston 1979). The average yearly precipitation is 57.5 cm/year, with most of the precipitation falling between April and October (Childress County; National Oceanic and Atmospheric Administration [NOAA] 2016a). The average temperature is 16.5 °C (National Oceanic and Atmospheric Administration [NOAA] 2016a).

METHODS

Biologists from TPWD collected the primary incisors from pronghorn at hunter check stations in the Texas Panhandle from 2012-2015 during the hunting season. These teeth were then sent to Matson's lab, Milltown, Montana, for cementum annuli analysis. I used the age frequency data provided by Matson's lab to calculate annual survival. Animals under the age of 3 were underrepresented, so I excluded them from the analysis. To calculate survival I regressed the ln (frequency) on age for ages 3-12 with linear regression. The inverse log of the slope of this line represents the average annual survival for animals between ages 3-12 (Hellgren et al. 2000). I repeated this process for each herd unit that had at least 20 individuals aged 3-12. I then excluded any herd unit where $r^2 < 0.6$, leaving 6 herd units for analysis (Figure 1.2).

I used GIS to investigate the relationship between land use and land cover type with pronghorn survival in each of the 6 remaining herd units. I began with the pronghorn herd unit layer developed by TPWD. I intersected this with the USGS land use land cover layer (Texas Natural Resources Information System, Austin, TX) in Arc View 3.3 (Environmental Systems Research Institute, Inc., Redlands, CA). Then I assigned areas to the polygons within the layer to calculate the total amount of area of each land use/land cover type in each herd unit. Then I used the spatial statistics function within the Patch Analyst extension (Ontario Ministry of Natural Resources, Thunder Bay, Canada) to calculate the fragmentation statistics within each herd unit.

Fragmentation statistics quantify how LULC areas are distributed on the landscape. For each herd unit I evaluated Shannon's evenness index of patch size, which measures how evenly distributed the proportions of different LULC types are, and Shannon's diversity index, which measures evenness weighted by abundance of patch types. I also measured the total area, total edge, edge density, mean patch edge, mean patch size, patch size coefficient of variance, and number of patches for each herd unit as well as for the land use land cover areas classified as agricultural land, cropland and pasture, herbaceous rangeland, and mixed rangeland within each herd unit. I then performed a forward multilinear regression to compare these 43 variables to herd unit specific survival in SAS at $\alpha = 0.05$. (SAS Institute, Inc., Cary, NC).

RESULTS

The majority of the pronghorn harvested for this study came from the High Plains ecoregion. The teeth were collected from 523 hunter harvested animals, including 9 females and 514 males. The age distribution of pronghorn across all herd units ranged 1-13 years (Figure I.3). Across all herd units, the survival of pronghorn ages 3 through 12 was 0.6146 ($r^2 = 0.9678$). Across the 6 herd units used in the analysis, annual survival of pronghorn ages 3 through 12 ranged 54.2-79.5% (Table I.1).

The forward multilinear regression selected total herd unit area ($t < 0.0001$, $p = 0.005$), mean patch size ($t = 0.0001$, $p = 0.007$), and mean patch edge of mixed rangeland ($t < 0.0001$, $p = 0.0406$) as having a positive influence on pronghorn survival, and total area of herbaceous rangeland ($t = -0.0662$, $p = 0.0253$) as having a negative influence on survival. All remaining landscape variables were not significant at $\alpha = 0.05$.

DISCUSSION

Survival has been estimated in several pronghorn herds across the United States. In North Dakota, seasonal survival estimates for adult pronghorn were > 90% except for in the fall, when male survival was reduced by half due to hunting (Kolar et al. 2012). In southwestern Arizona, male Sonoran pronghorn had a survival rate of 92% and females had a survival rate of 96% (deVos and Miller 2005). In South Dakota survival estimates of adult female pronghorn ranged from 82-100% (Jacques et al. 2007). While these estimates are higher than the ones I calculated in this analysis, comparisons cannot be made without also knowing recruitment, and do not necessarily raise concern for the population health of pronghorn in the Texas Panhandle.

Herd units boundaries are delineated by roads and other barriers to pronghorn movement. The majority of the boundaries of the herd units used in my analysis are comprised of paved, fenced roads and highways. Ockenfels et al. (1997) found that paved, fenced roads are a significant limiter of pronghorn movement. None of the 37 radio-collared pronghorn in their study ever crossed a paved, fenced road for the 2-year duration of their study. Barriers to movement, such as paved or fenced roads, that restrict populations of pronghorn to smaller areas may hinder pronghorn from accessing areas with higher food availability during harsh winters or droughts (O'Gara and Yoakum 2004). While there are roads that run through the interior all of the herd units, most of the interior roads are unpaved or have sections that lack fencing (personal observation). Herd units with large total areas possibly allow pronghorn more area to search for potentially scarce resources. Similarly, large patches of a particular LULC type represent areas that are free of barriers such as roads that might hinder pronghorn movement. The positive effect of the herd unit total area and mean patch size on pronghorn survival supports the hypothesis that fragmentation by major roadways and other barriers to movement hurt pronghorn survival.

The positive effect of the mean patch edge of mixed rangeland is probably tied to the nutritional needs of pronghorn. Pronghorn are concentrate selectors, meaning that the majority of their diet is comprised of energy dense forbs and the most energy dense parts of shrubs (Yoakum 1967, O'Gara and Yoakum 2004). Many forbs are disturbance adapted and are more common in edge communities. Mixed rangeland also includes several shrub and cacti species that are used by pronghorn, such as sand sagebrush (*Artemisia filifolia*). The only pronghorn diet study conducted in the Texas Panhandle suggested that sand sagebrush was the most abundant plant in pronghorn winter diets in the High Plains, comprising 19% of their diet (Roebuck 1982). It is logical to conclude that access to this important winter food item, along with increased availability of forbs, explains the positive effect of the mean patch edge of mixed rangeland.

I speculate that the negative impact of the total area of herbaceous rangeland is because of 2 factors. First, herbaceous rangeland is classified as rangeland dominated by grasses and lacking shrubs and cacti (Anderson 1976). Shrubs and cacti are both important parts of pronghorn diets in the High Plains, especially in times of limited availability such as winter (Roebuck 1982). The time period that data were being collected for this analysis fell during a historic drought in the Texas Panhandle (Figure I.4), which potentially increased pronghorns' reliance on these important forage types. Second, land used in the Conservation Reserve Program (CRP) is classified as herbaceous rangeland (Anderson 1976). Conservation Reserve Program land is land that was formerly used as cropland that has been reseeded with grasses. In Texas, much of CRP land was not planted with native species and is often a monoculture of exotic species such as weeping lovegrass (*Eragrostis curvula*; Carrol et al. 1993). Because grass is only a small proportion of pronghorn diet in the Texas Panhandle (Roebuck 1982), a monoculture of exotic grass would be poor pronghorn habitat. If a herd unit contains a large amount of CRP land it is essentially wasted space that pronghorn have to spend energy navigating through or around in order to access more suitable habitats. It would be interesting to further investigate if CRP land specifically is tied to pronghorn survival. Overall, my results support the hypothesis that pronghorn survival is impacted by habitat composition.

Having ages from more females would allow for comparison of gender based survival. Because nearly all of the individuals in this study were obtained by hunter harvest, the sampling bias was strongly skewed towards males. Allowing the harvest of more females would help rectify this disparity. It would also be interesting to obtain a better representation of younger age classes so that they could be included in the survival estimate.

When managing pronghorn, biologists should take into account that smaller herd units are more likely to have lower survival. While it is not possible to remove barriers such as roads to enlarge herd units, biologists should select harvest quotas that reflect the lower survival in small herd units. Biologists and landowners managing for pronghorn should consider encouraging a mosaic of LULC types that includes many patches of shrub and brush rangeland while minimizing the amount of herbaceous rangeland. I would also recommend that TPWD continue to collect age data from harvested animals, especially in herd units that had too few animals to include in the study. Adding additional herd units to this type of analysis has the potential to further clarify factors that influence pronghorn survival.

Table I.1: Sample size, annual survival, and r^2 derived from age-structured regression of pronghorn in 6 herd units in the Texas Panhandle, 2012-2015.

Herd unit	***n***	**survival**	**r^2**
4	43	0.6831	0.8285
7	21	0.6826	0.8349
8	157	0.5778	0.8023
9	27	0.7952	0.6434
17	105	0.5416	0.9207
25	75	0.6431	0.9573

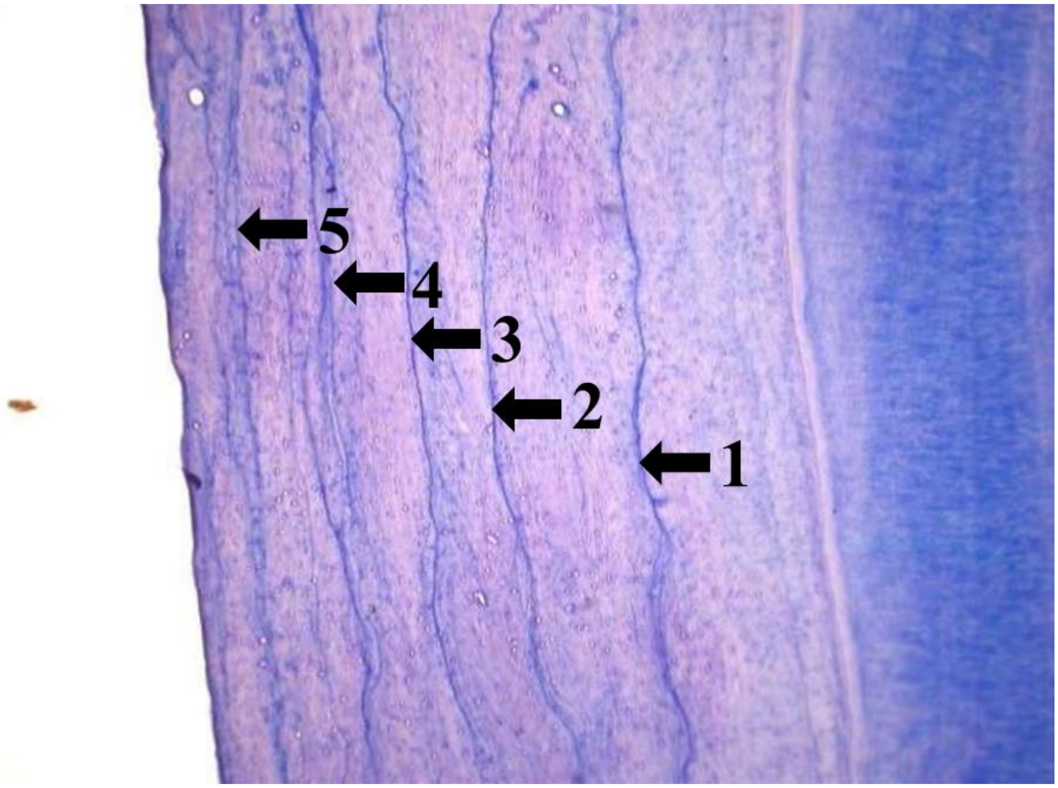

Figure I.1: An example of cementum annuli in an ungulate tooth that has been prepared by Matson's lab for cementum analysis. Note the alternating bands of dark and light tissue. Numbered bands represent the beginning of a new year's growth.

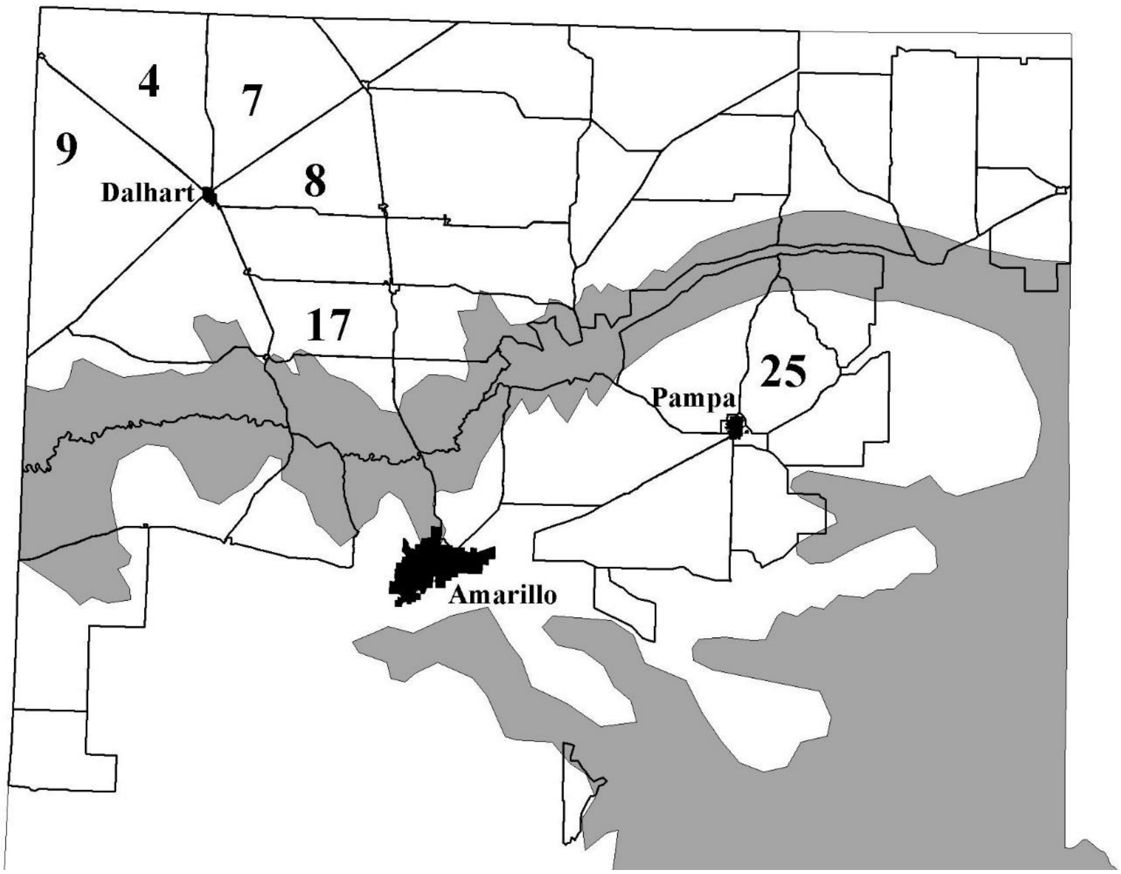

Figure I.2: The Texas Panhandle with herd units are outlined in black, and the herd units included in my analysis are labeled with their number. Major population centers are denoted in black. The High Plains ecoregion is filled in white, and the Rolling Plains ecoregion is filled in gray as defined by Gould et al. (1960).

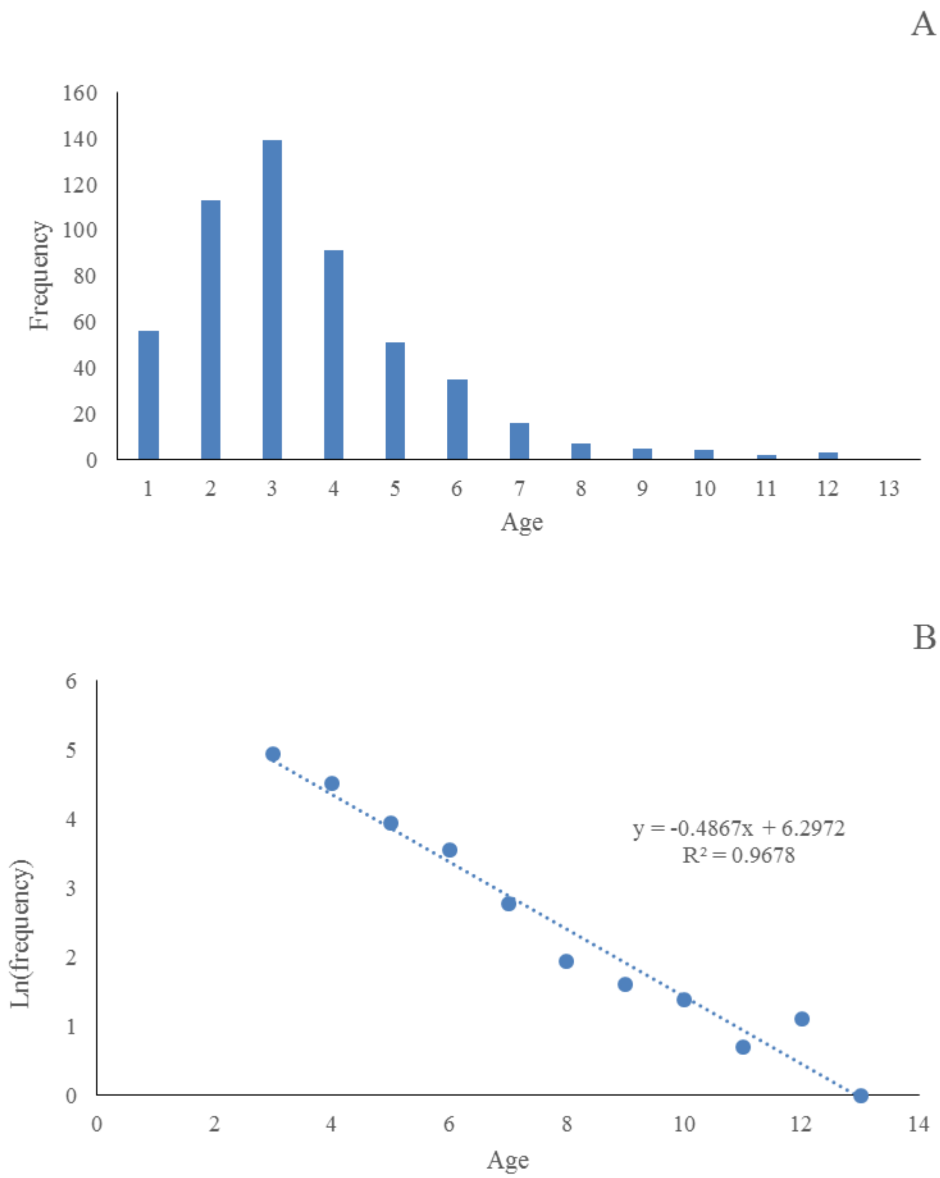

Figure I.3: Age distribution (A) and age structured regression (B) derived from cementum annuli analysis of pronghorn (n= 523) from the Texas Panhandle, 2012-2015.

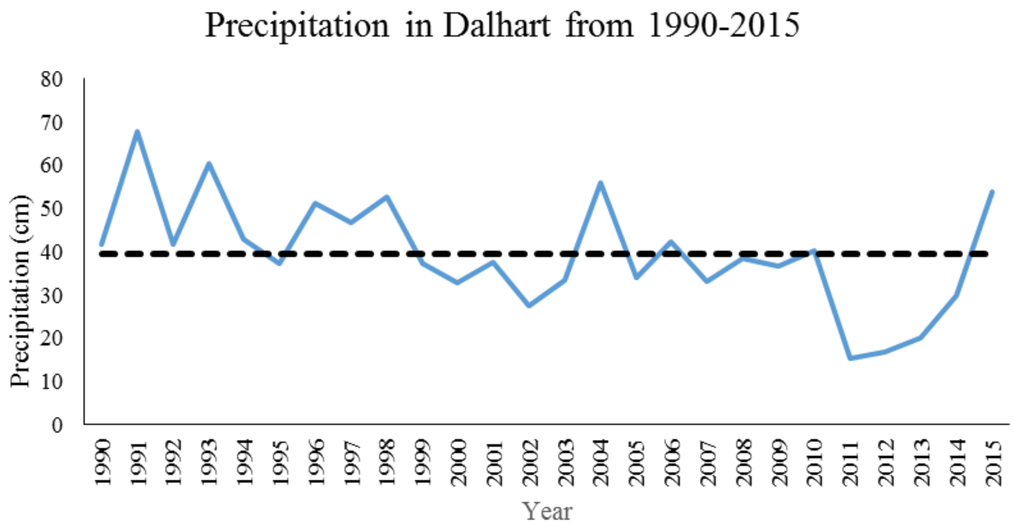

Figure I.4: Yearly total precipitation in Dalhart, Texas from 1990-2015. Yearly precipitation is indicated by the solid line, and the 25 year average is represented by the dashed line. Note the severe drought from 2011 through 2014.

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CHAPTER II

THE INFLUENCE OF LAND USE AND LAND COVER ON HABITAT SELECTION OF PRONGHORN IN THE TEXAS PANHANDLE

INTRODUCTION

Animals select the habitat in which they live based on a variety of variables such as resource availability, interspecific and conspecific competition, and their life history strategies (Morris 2003). Habitat selection studies typically compare the amount of available habitat of different types to the amount of use each of those types actually receive by the species in question (Aebischer et al. 1993). If a habitat type is used more than it is available, it is said to be preferred by the animal in question, and if it is used less than it is available, then it is said to be avoided. Understanding and detecting habitat selection allows biologists to better understand phenomena such as population regulation, predator-prey interaction, assemblages of ecological communities, and even complex issues such as speciation and maintenance of biodiversity (Morris 2003). Determining habitat selection is also an essential tool for conservation planning, allowing conservationists to determine critical habitat types or assemblages to set aside or modify for conservation or restoration (Jones 2001).

Habitat selection studies are typically conducted by tracking individual animals using radio telemetry or GPS technology (Aebischer et al. 1993, Sawyer et al. 2006, Pierce et al. 2004). One way of calculating habitat selection is Compositional Analysis, which evaluates selection of multiple habitats by comparing proportional habitat use (Aebischer et al. 1993). Compositional Analysis offers statistical power and the ability to rank multiple habitats, but the user needs to be aware that it can be mathematically biased by rare habitat types and zero values. In Compositional Analysis, the marked animal is usually used as the experimental unit, and locations of the animal are the subsamples for that unit. By comparing the habitat use of multiple animals to the habitat available, it is possible to rank habitat types from most preferred to most avoided (Aebischer et al. 1993). However, purchasing, deploying, and relocating radio collars and other similar tracking devices can be expensive, and many animals need to be monitored in order to achieve statistical integrity, further adding to momentary and logistical cost (Aebischer et al. 1993, Fuller and Snow 1988).

Pronghorn (*Antilocapra americana*) are herbivorous ungulates endemic to south central Canada, the western United States, and northern Mexico, including the Texas Panhandle (Nelson 1925). In the 1800s there were an estimated 35 million pronghorn in North America (Hoover et al. 1959 as cited by Lee et al. 1994). By 1924 numbers had fallen to just 20,000 individuals because of overhunting and habitat loss (Hoover et al. 1959 as cited by Lee et al. 1994). Thanks to conservation efforts, pronghorn populations have recovered to the current population size of 700,000 individuals, and the International Union for Conservation of Nature gives them the status of Least Concern (International Union for Conservation of Nature 2008).

Pronghorn in the United States occupy arid to semi-arid rangelands. They have a highly diverse diet that fluctuates depending on the plant communities available to them. Historically, pronghorn shared the range with bison (*Bison bison*), elk (*Cervus canadensis*), and mule deer (*Odocoileus hemionus*; Meagher 1986, O'Gara 1978). Because of this competition for forage, pronghorn evolved to be concentrate selectors, preferentially selecting high quality forage that was passed over by the larger, less selective grass/roughage feeders. In shortgrass prairies, such as the Texas Panhandle, pronghorn diet primarily consists of a wide variety of forbs, occasionally shrubs and cacti, and rarely some grasses (Yoakum 1967, Roebuck 1982).

Pronghorn use their excellent eyesight and ability to run at high speeds for long distances to avoid predators such as coyotes (*Canis latrans*) and bald eagles (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*; O'Gara and Yoakum 2004). Because of this, they prefer habitats with high visibility and flat to undulating topography (Buechner 1950). Pronghorn are adapted for semi-arid environments, with most pronghorn occupying areas that receive between 12.7 cm – 76.2 cm of precipitation annually (O'Gara and Yoakum 2004). Pronghorn typically select for areas where vegetation does not exceed 63.5 cm in height (O'Gara and Yoakum 2004). Yoakum (1972) estimated that 68% of pronghorn occupy grasslands, 32% occupy shrub-steppes, and <1% occupy deserts.

Pronghorn in Texas have lost habitat over the last 2 centuries because of conversion of native rangeland into cropland and other agricultural land cover types (Leftwich 1977, Griffith et al. 2007). In the Texas Panhandle, the most common crops are corn, sorghum, wheat, and cotton (United States Department of Agriculture 2015). Pronghorn will consume winter wheat during certain times of the year, but most of the year these crops offer little to no forage for pronghorn (Roebuck 1982). Overgrazing by domestic cattle also poses a threat to pronghorn habitat. High intensity grazing can suppress forbs that pronghorn depend on, degrading rangeland that might have otherwise been prime pronghorn habitat (O'Gara and Yoakum 2004).

Pronghorn in the state of Texas are managed by Texas Parks and Wildlife Department (TPWD). Pronghorn are a desirable game species in Texas, and hunter harvest limits are determined by estimating population sizes within management areas called herd units. Population estimates for each herd unit are obtained by flying transect aerial surveys. Surveys are typically conducted for each herd unit every 2 years, usually in the months of June and July (Texas Parks and Wildlife Department).

My objective is to use preexisting aerial survey data to assess pronghorn habitat selection. I will use compositional analysis to determine if pronghorn select for or against different land use and land cover types in the Texas Panhandle.

STUDY AREA

The Texas Panhandle contains 2 different ecoregions, the High Plains and the Rolling Plains (Figure II.1) (Gould 1960). The High Plains plant community is a short grass prairie characterized by buffalo grass (*Bouteloua dactyloides*) and blue gramma (*Bouteloua gracilis*) along with scattered yucca (*Yucca spp*.) and prickly pear (*Opuntia spp*.; Correll and Johnston 1979). The soil in the High Plains ranges from clay to loamy fine sand, and is deep, well drained and calcareous (Pringle 1980). Yearly precipitation averages from 47 cm per year in the northwestern Panhandle (Dallam County) to 58 cm per year in the southwestern corner of the High Plains (Gray County; National Oceanic and Atmospheric Administration [NOAA] 2016c). The majority of precipitation falls from May through August. The temperature averages 13.56 °C (National Oceanic and Atmospheric Administration [NOAA] 2016b). The topography of the High Plains is primarily flat with some gently rolling hills (Correll and Johnston 1979).

The Rolling Plains are at a lower elevation than the High Plains, meeting along the edge of the Caprock Escarpment (Correll and Johnston 1979). The Rolling Plains are characterized by clay soils and moderately rough topography. Tall to mid grasses are dominant, including blue gramma and big bluestem (*Andropogon gerardi*). Woody plants such as juniper (*Juniperus spp*.) and honey mesquite (*Prosopis glandulosa*) are common invaders in disturbed areas (Correll and Johnston 1979). The average yearly precipitation is 57.5 cm per year, with most of the precipitation falling between April and October (Childress County; National Oceanic and Atmospheric Administration [NOAA] 2016a).The average temperature is 16.5 °C (National Oceanic and Atmospheric Administration [NOAA] 2016a).

The Texas Panhandle is subdivided into management units called herd units. Herd unit boundaries are based on roads, fences, and other man-made or natural barriers to pronghorn movement. There are currently 52 herd units managed by TPWD in the Texas Panhandle.

METHODS

All of the aerial surveys used in this study were conducted by TPWD in the Texas Panhandle (Figure II.1). TPWD provided me with transect aerial survey data for 2009 and 2015. These data included the GPS coordinates of survey flight paths as well as GPS locations of pronghorn sightings. Surveys were flown in a zig-zagging pattern meant to cover as much area of a herd unit as possible (Figure II.2). I imported the locations of pronghorn sightings and survey flight paths into Arc View 3.3 (Environmental Systems Research Institute, Inc., Redlands, CA). I buffered the flight paths by 400 m because that was considered the maximum range of visibility by TPWD personnel conducting the surveys (Figure II.3). I intersected the buffered flight path layer with the land use land cover layer produced by the United States Geological Survey (Texas Natural Resource Information System, Austin, Texas, USA; Figure II.4). I then calculated the amount of each habitat type available on each transect. I overlaid this layer with the GPS locations of pronghorn sightings (Figure II.5), and calculated the proportion of pronghorn that utilized each habitat type for each transect.

I then assessed habitat selection using compositional analysis. Compositional analysis evaluates selection of multiple habitats by comparing log-ratios of use and availability (Aebischer et al. 1993, Kazmaier et al. 2001). This technique is usually applied in radio telemetry studies, using individual animals as replicates (Aebischer et al. 1993). For my analysis I used individual transects as my replicates, and locations of pronghorn sighted on those transects in lieu of radiolocations. The proportion of each habitat type in the buffer around the flight path was considered the pronghorn's available habitat, and proportion of pronghorn sightings in each habitat along that transect was considered the pronghorn's used habitat. I calculated the proportion of pronghorn found in each habitat type, and compared this proportion of used habitat with the proportion of each habitat available along each transect using Compositional Analysis. If no pronghorn were sighted in a habitat type, the zero value was replaced with 0.001, as per Aebischer et al. (1993).

I deemed that transects that contained fewer than 10 pronghorn sightings did not have enough data to give a good representation of proportional habitat use and would therefore bias the results, so they were excluded from analysis. Any LULC type constituting less than 3% of the total area was also excluded from analysis to avoid rarity biasing the results (Aebischer et al. 1993).

Compositional Analysis was performed in Resource Selection Analysis Software for Windows (Leban 1999). Resource Selection Analysis calculated the difference of log ratios of available and used habitats, and performed a MANOVA to compare the usages between habitats, following Aebischer et al. (1993). When use differed from availability, preference was said to occur when use was greater than availability, and avoidance when use was less than availability. I set $\alpha = 0.05$ for this analysis.

RESULTS

I received data from 113 transects from TPWD. Transects from 2009 covered 9,591 km^2, and transects from 2015 covered 13,913 km^2. After transects with <10 animals has been removed, 64 transects remained for analysis. These 64 transects contained 5,346 pronghorn sightings. Fourteen LULC types were identified along the transects (Figure II.4), but 10 of the types constituted less than 3% of the total area so they were removed from the analysis, leaving cropland/pasture, herbaceous rangeland, shrub and brush rangeland, and mixed rangeland for analysis.

Comparison of the pooled data from 2009 and 2015 indicated that pronghorn did exhibit habitat selection within the area surveyed ($\lambda = 0.2593$, $P < 0.0001$). Comparison of habitat rankings indicated that use differed from availability for all habitat types, with shrub and brush rangeland > mixed rangeland > herbaceous rangeland > cropland/pasture. Shrub and brush rangeland was preferred more than mixed rangeland was, and herbaceous rangeland and cropland/pasture were both avoided.

DISCUSSION

Compositional analysis suggested that pronghorn preferred rangeland that included large proportions of brush, favoring both shrub and brush rangeland and mixed rangeland. This goes against the conventional wisdom that pronghorn should select habitat that has the highest density of forbs and the greatest visibility (O'Gara and Yoakum 2004). My analysis suggested that pronghorn in the Texas Panhandle avoided herbaceous rangeland, which should have the most forbs and greatest visibility.

I hypothesize that the pronghorn's selection for brush was because of the lack of precipitation in the years the surveys were conducted. The first year of survey data was conducted in 2009 when the yearly precipitation of 36.67 cm of precipitation was slightly below the 25 year average of 39.51 cm (Figure II.6). Low precipitation levels likely reduced the abundance of available forbs, leading to a greater reliance on shrubs such as sand sagebrush (*Artemisia filifolia*). The second year included in this analysis, 2015, was at the end of a severe 4 year drought (Figure II.6). Roebuck (1982) found that sand sagebrush was the most abundant species in Texas High Plains pronghorn winter diets, comprising 19% of total forage. A study of pronghorn diet in the Texas High Plains, conducted before the end of the drought in 2014 and 2015, also suggested heavy utilization of sand sagebrush, including one composite sample where 82% of the total forage consumed was sand sagebrush (R. T. Kazmaier, West Texas A&M University, unpublished data).

I speculate that pronghorn in the High Plains shift their diets during periods of low forb availability to consume greater percentages of shrubby vegetation, such as sand sagebrush, one of the most common brush species found in the High Plains (Correll and

Johnston 1979). This would explain the selection of habitat with high percentages of brush. It is important for managers to consider this when managing for pronghorn. While forbs constitute the majority of pronghorn's diets during years of normal precipitation (Yoakum 1967, Roebuck 1982), shrubby vegetation, particularly sand sagebrush, is apparently an important hardship food source in the High Plains of Texas. To test this hypothesis, it would be beneficial to repeat this study once the High Plains have adequately recovered from the drought, to see if selection changes with precipitation. Conventional management practices for pronghorn in grassland biomes focus on increasing forb abundance (O'Gara and Yoakum 2004, Wilson et al. 2010). While forbs usually comprise the majority of pronghorn diets in grasslands, my results support also managing for shrubs and brush to be used as a hardship food source for when forbs are scarce

Compositional analysis is usually a technique used in radio telemetry studies (Thomas and Taylor 2006). I was encouraged by its utility and ease of application to aerial survey data. Management agencies should consider using preexisting aerial survey data to investigate habitat selection for pronghorn in other areas. In Texas this could be particularly useful in the Trans Pecos where pronghorn populations have declined. The utility of this technique is not limited to pronghorn, and could easily be applied to other species monitored by aerial surveys, such as deer (*Odocoileus* spp.) or bighorn sheep (*Ovis Canadensis*). Once the GIS layers have been created, compositional analysis is very quick to complete and could provide valuable information about habitat selection for management of these species. It is also more cost effective to use aerial surveys that are already planned rather than purchasing and deploying radio collars on multiple individuals.

Further research needs to be done to compare results of compositional analysis done using radio telemetry data to aerial survey data. Radio telemetry studies that utilize Compositional Analysis usually use an animal's home range as available habitat, whereas my study used the somewhat arbitrary polygon of buffered flight paths. Also, radio telemetry studies usually use the individual as the experimental unit, where I used transects. It would be beneficial to compare the same population using both of these techniques and compare the results to see if the different methods yield similar results.

In this study it is possible that some areas that were flown were not truly available to pronghorn because of barriers such topography or non-porous fence lines. This would be especially important to consider if this technique was employed in the Trans Pecos where net wire fencing is wide spread, limiting pronghorn movement (O'Gara and Yoakum 2004). This problem is not exclusive to aerial survey based studies however, as not all of an animal's home range in a radio telemetry study may actually be accessible to the animal either.

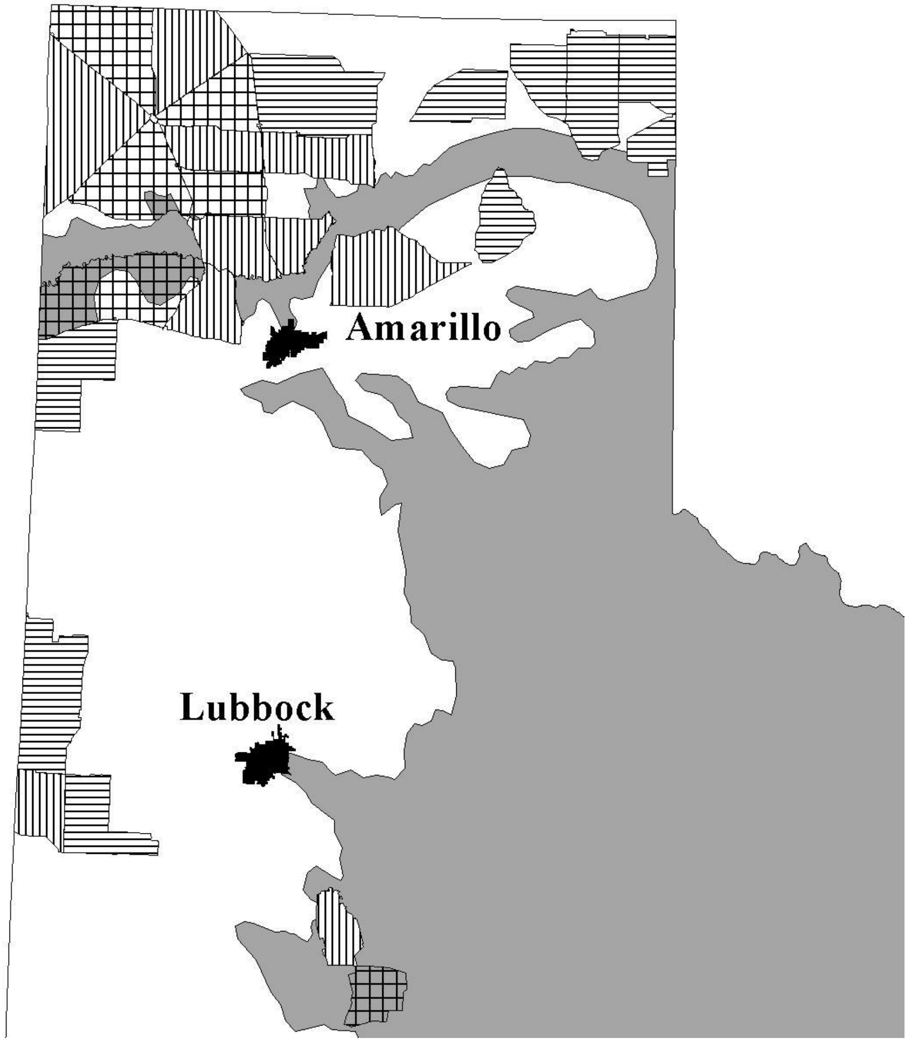

Figure II.1: Texas Parks and Wildlife Department pronghorn herd units in the Texas Panhandle. Herd units filled with vertical lines were surveyed in 2009, herd units filled with horizontal line where surveyed in 2015, and herd units cross-hatched were surveyed in both 2009 and 2015. Major cities are shown in black. The High Plains ecoregion is filled in white, and the Rolling Plains ecoregion is filled in gray as defined by Gould et al. (1960).

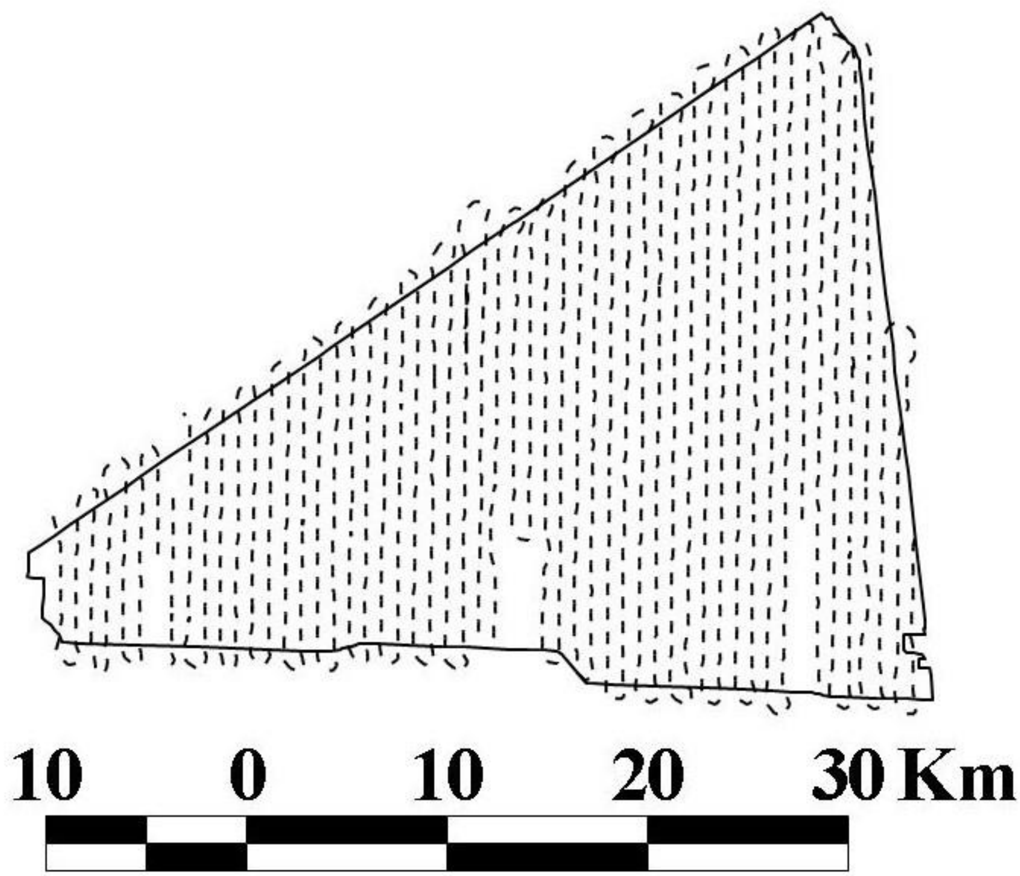

Figure II.2: The 2009 aerial survey route for Texas Parks and Wildlife Department pronghorn herd unit 8. The aerial survey routes are denoted by the dashed lines. Note how the survey was flown to maximize the area surveyed.

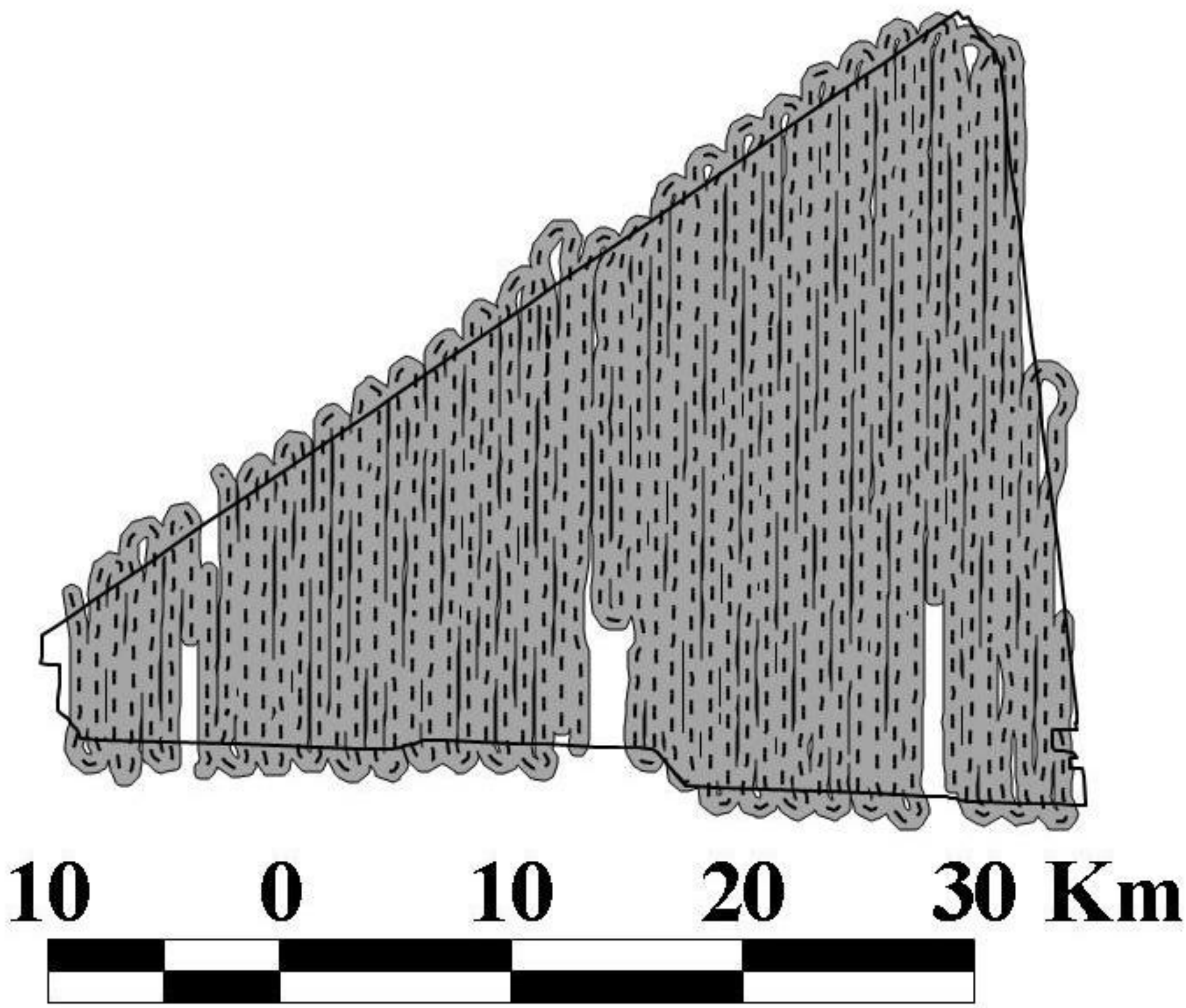

Figure II.3: The 2009 flight path for Texas Parks and Wildlife Department pronghorn herd unit 8 buffered by 400m.

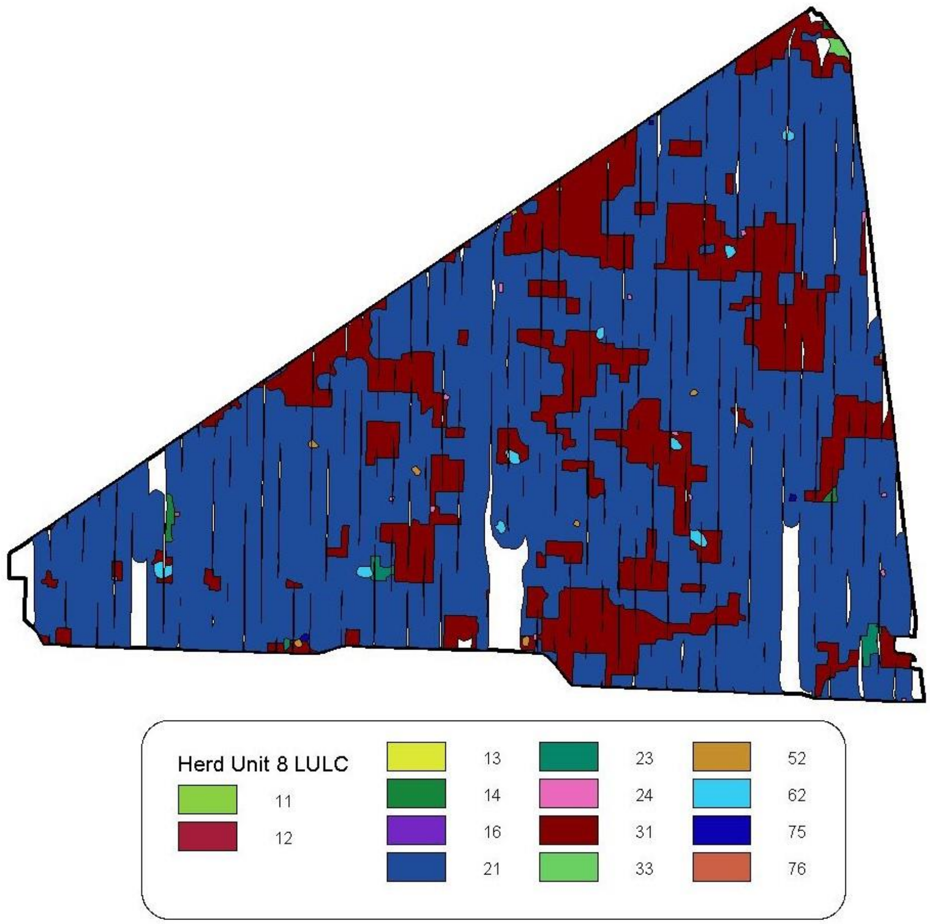

Figure II.4: The buffered flight path layer intersected with the land use land cover layer (LULC; 11 = residential, 12 = commercial services, 13 = industrial, 14 = transportation/communications, 16 = mixed urban of built-up land, 21 = cropland/pasture, 23 = confined feeding operations, 24 = other agricultural land, 31 = herbaceous rangeland, 33 = mixed rangeland, 52 = lakes, 62 = nonforested wetlands, 75 = strip mines, quarries, and gravel pits, and 76 = transitional areas) for Texas Parks and Wildlife Department pronghorn herd unit 8.

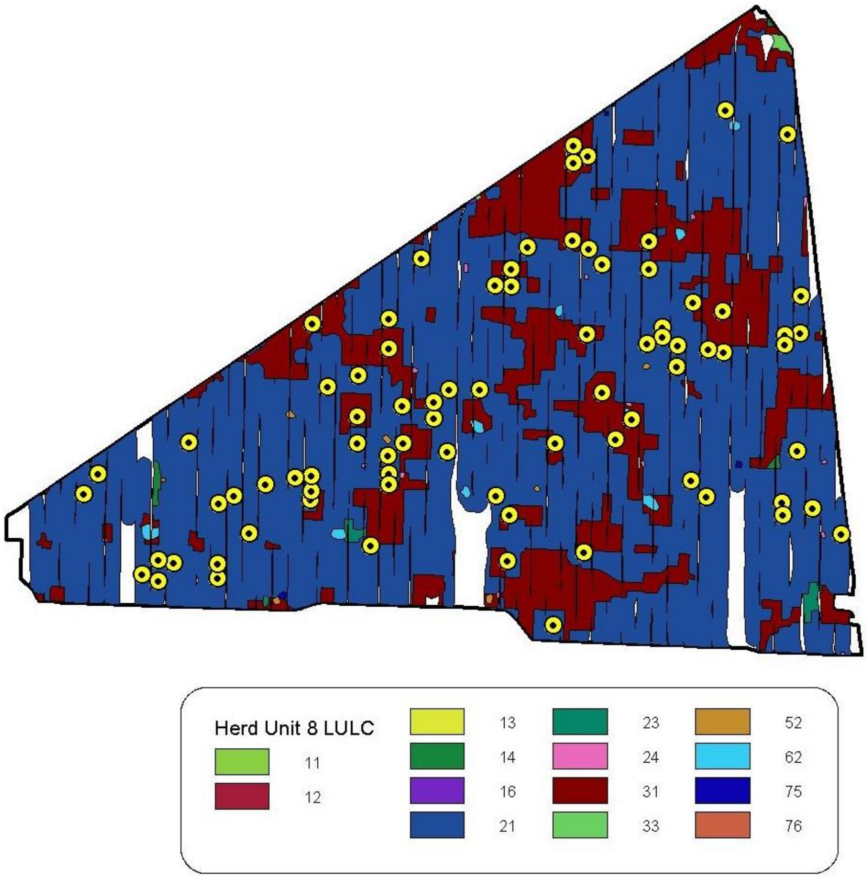

Figure II.5: Pronghorn sighting locations for Texas Parks and Wildlife Department pronghorn herd unit 8 overlaid onto Land use land cover (LULC; 11 = residential, 12 = commercial services, 13 = industrial, 14 = transportation/communications, 16 = mixed urban of built-up land, 21 = cropland/pasture, 23 = confined feeding operations, 24 = other agricultural land, 31 = herbaceous rangeland, 33 = mixed rangeland, 52 = lakes, 62 = nonforested wetlands, 75 = strip mines, quarries, and gravel pits, and 76 = transitional areas).

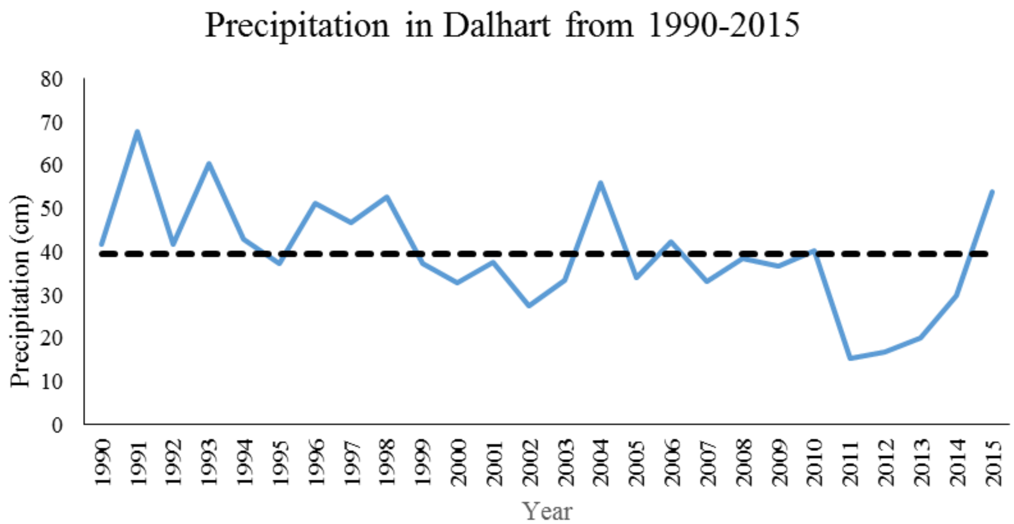

Figure II.6: Yearly total precipitation in Dalhart from 1990-2015. Yearly precipitation is indicated by the solid line, and the 25 year average is represented by the dashed line. Note the severe drought from 2011 through 2014.

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