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MOVEMENT AND DISTRIBUTION PATTERNS OF PRONGHORN ANTELOPE IN RELATION TO ROADS IN SOUTHWESTERN WYOMING

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EXECUTIVE SUMMARY

Pronghorn antelope (*Antilocapra americana*) evolved in response to variable food sources and weather conditions on the open, western high plains. Survival of the species is dependent on their ability to move in response to fluctuations in food supplies and weather conditions. Using global positioning system (GPS) collars and geographic information systems (GIS), the movement and distribution of adult female pronghorn (n=72) within a population in southwestern Wyoming was studied.

While unfenced roads did not appear to be a barrier to pronghorn movement in my study area, the combination of heavy traffic volume (Buechner 1950) and fences along roads can be barriers to movement and fragment habitat.

Fences in southwestern Wyoming influenced distribution and movement patterns of pronghorn. Fence density was found to be lower in seasonal home ranges than in the study area. Fence density influenced location of seasonal range with pronghorn choosing those areas within the study area with lowest densities. Fence density was greater within the periphery of home ranges than the remainder of the home range, suggesting home range conformation could be influenced by fences within the outer portion of home ranges. Most (64%, n=28) monitored pronghorn were migratory and their migration routes tended to encounter fewer fences than had they traveled randomly in the study area. The presence of fences and, in turn, the type of highway right-of-way fence determined whether roads were included in seasonal ranges and where pronghorn crossed roads within season and during migrations. Seasonal crossings of primary roads within the study area consistently occurred along unfenced sections.

These results support limiting fences on pronghorn range and maintaining unfenced sections of highways as movement corridors to reduce the potential for habitat fragmentation through loss of connectivity and allow access to crucial winter range within the study area.

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CHAPTER ONE

Problem Description

Today, with over 420,000 pronghorn, Wyoming claims the largest pronghorn population in the world (Reeve et al. 2003). As one of Wyoming's most visible species, pronghorn antelope have provided many benefits to tourists and residents, both aesthetic and monetary.

Along with bison, pronghorn antelope have historically occupied the western high plains. Adaptations to this open environment have enabled pronghorn to withstand periods of extremely low temperatures and low levels of nutrition. Loss of up to 30 percent of body weight has been found in Wyoming's Red Desert females that survived a particularly harsh winter (Creek 1967). When conditions become too harsh, pronghorn will travel long distances in search of forage and cover. However, man-made barriers such as fences and roads can hinder or block their movements.

As settlers moved west, fences were built on historical pronghorn ranges to regulate access along roads, railroads, mining operations, military installations, and private property (O'Gara and Yoakum 1992). The growing human population was soon followed by agricultural and livestock industries that used fences to divide rangeland and improve management. Extensive grazing of cattle and sheep has led to the construction of many miles of net-wire (also referred to as woven-wire, see Chapter Three for detailed description) and other fencing in Wyoming, especially on public land. More recently, concern for public safety has led to fencing of Wyoming highways and frequently traveled roads to prevent livestock from entering highway right-of-ways (ROWs).

Fences influence pronghorn movement patterns by either reducing the number of or eliminating previously used travel routes across highways (Buechner 1950**,** Ward et al. 1976, Ward et al. 1980, Guenzel 1986), thus reducing the carrying capacity of some ranges (Yoakum 1978). Caton (1877) noted the difficulty that pronghorn had negotiating fences as early as 1877. Pronghorn will generally walk along fence lines until an opening or a gap below the fence is discovered and this will often become a regular crossing point (Gregg 1955). If a pronghorn cannot find an opening under conditions of stress, it will attempt to cross these barriers by jumping or forcing their way under, which can result in death due to entanglement (Baker and Wrakestraw 1953).

The design, construction, and location of the fence determine the impact that it has on pronghorn populations (Hailey and DeArment 1972, O'Gara and Yoakum 1992). Fences can act as a partial or complete barrier to pronghorn movements to seasonal ranges, water sources, and foraging areas. Newman (1966) found Wyoming pronghorn numbers dropped substantially when livestock fences confined them to a particular area. Several studies have reported that pronghorn under such conditions are usually in poor physical shape and display signs of starvation (Russell 1951, Popowski 1959, Newman 1966, O'Gara and Yoakum 1992).

The impact to pronghorn may be most noticeable as movement is attempted during blizzards, droughts, or natural migrations to winter or summer ranges. The potential for net-wire fences causing extensive death among this highly mobile game species was noted by Russell (1951), who listed the prevalent net-wire fence as one of the main factors contributing to a drop in pronghorn populations throughout the west (Russell 1951).

Prior to 1960, the beginning of construction of net-wire fences in the Red Desert, pronghorn numbered at least 13,000. By 1970, fences were believed to have caused the loss of at least 2,000 and as many as 9,000 pronghorn (Sundstrom 1970). Over a 37 year period in New Mexico, pronghorn numbers declined by 90% within areas enclosed by net-wire fence (Howard et al.1990). Similar declines (57%) due to confinement by net-wire fences were reported by Hailey et al. (1966) during drought conditions in Texas. Net-wire fence designs are considered a serious barrier to pronghorn movement (Buechner 1950, Hailey et al. 1966, Newman 1966, Spillett et al. 1967, Riddle and Oakley 1973, Copeland 1980, Ockenfels et al. 1994).

Four-stranded barbed wire fences, commonly used to manage cattle, were observed to be a major obstacle to pronghorn in southeastern Alberta and northern Montana (Bruns 1977). Though usually passable, pronghorn were injured in their attempts to cross, becoming permanently crippled or dying (Spillett 1965, Bear 1969, Oakley 1973). Four-stranded barbed wire fences were regularly crossed by pronghorn during favorable weather conditions, where sufficient distance was available between the bottom wire and the ground (Gregg 1955: 22.5 inches; Cole 1956: 17 inches).

Regular use of established roads is reported to produce minimal disturbance among pronghorn due to habituation (Autenrieth 1978**,** Autenrieth 1983**,** Reeve 1984). However, females with fawns remained sensitive to vehicular traffic (Reeve 1984). Pronghorn became habituated to heavy machinery moving in a predictable manner on a coal strip mine in northeastern Wyoming. Perhaps because they moved in a less predictable manner, light vehicles and humans traveling on foot (i.e. hikers) elicited escape behavior in pronghorn (Segerstrom 1982). This was also reported in a highly explored and developed area in the Casper Wyoming district, where pronghorn were reported to have moved away from roads traveled by exploration crews (Pate 1975).

Increased public access (hunter and recreational) as new roads are constructed can result in greater wildlife disturbance and legal and illegal wildlife kills (Lees 1989). Road development has been linked to increased hunter success and subsequent reduction in elk (Leege 1976, Thiessen 1976), moose (*Alces alces*; Lynch 1973), and mountain goat numbers (*Oreamnos americanus*; Pendergast and Bindernagel 1977). Increased hunting pressure has been reported to disrupt pronghorn territoriality and breeding hierarchies (Copeland 1980).

Two of Wyoming’s major interstate highway systems, Interstate 80 (I-80) and Interstate 25 (I-25), were completed in the mid 1960s (Hepworth 1965). Even before construction was finished, potential impedance to pronghorn movements was a critical concern

(Hepworth 1965). According to Creek (1967), I-80 has stopped all pronghorn movements north and south. In addition, Guenzel (1986) noted that ROW fencing along I-80 restricted movement. However, according to Allderedge et al. (1980), pronghorn that stayed along I-80 during a mild winter did not behave as though overly stressed.

Habitat within the study area serves as crucial winter range to pronghorn as far north as Jackson Hole (Sawyer and Lindzey 2000). Within the study area there are miles of roads and fences, for which little is known about their daily influence on free-ranging pronghorn antelope. Understanding the spatial use of habitat, often indicative of the condition and availability of necessary resources, can lead to successful management of pronghorn populations. While roads may need to be fenced to ensure the safety of motorists and livestock management concerns, the identification and subsequent maintenance of movement corridors is critical to the long-term survival of pronghorn antelope populations.

CHAPTER 2

Objectives

The focus of this research effort was two-fold. In an attempt to reduce the impact of habitat fragmentation on the region's pronghorn population, the primary objective was to increase understanding of where along highways pronghorn were crossing during the study period. Secondarily, researchers attempted to document the influence of fences and roads on pronghorn movements and distribution. To address this last objective the following hypotheses were tested: (1) home ranges are randomly placed within the study area in relation to fences, (2) fences are randomly distributed within home ranges, (3) migration routes are randomly distributed with regard to fences, and (4) pronghorn movements and distribution in relation to roads are random.

Understanding how and when pronghorn use this area, especially the roads and fenced portions, will allow for improved management of the pronghorn population while meeting human safety and livestock management concerns.

CHAPTER THREE

Task Description

Study Area

The study area, approximately 2,800 km^2 (1,081 mi^2), is located in Sweetwater and Lincoln Counties in southwestern Wyoming (Figure 1). Primary roads, defined as state and federal highways, within the study area include U.S. Highway 30, U.S. Highway 189, Wyoming State Route 372, and Wyoming State Route 240 (Table 1). Interstate 80 lies south of the study area. Estimated average 24 hour traffic volume on the primary roads is between 416-2153 vehicles per day. Situated in the Green River Basin, the topography ranges from flats to escarpments with elevations between 1865-2448 m (6119-8032 ft). The desert shrub plant community is made up predominantly of sagebrush (*Artemisia* sp.), saltbush (*Atriplex* sp.), and greasewood (*Sarcobatus vermiculatus)*.

The area experiences cool, short summers and long, cold winters. Average low and high temperatures are -6.7º C (20º F) and 12.8º C (55º F), respectively. Annual precipitation varies from 15.2 cm (6.0 in) to 35.6 cm (14.0 in), one-third of which is snow (Bureau of Land Management, Kemmerer, WY). Southwest Wyoming has been under extreme drought conditions since 2001, with 2002 and 2003 having the two highest Palmer Drought Severity Index rankings since 1895 (National Oceanic and Atmospheric Administration 2005). During the study, summer (April-August) average daily high temperatures were similar to that found from 1948 to 2001 and winter (November to March) average daily low temperatures were 14° C (7° F) colder (High Plains Climate Center 2005). Total monthly precipitation was less in both winter and summer than in previous years (28% and 55% less, respectively). Although total monthly snowfall was higher (winter: 56% more, summer: 49% more), daily snowfall did not exceed 15 cm (6.0 in) in 2002 and 22 cm (8.7 in) in 2003.

Landownership is checkerboard with 32% private and 68% public. Most of the public land is under jurisdiction of the U.S. Bureau of Land Management (BLM). Cattle and sheep grazing occurs on both private and public land. Recreational use of the area (hunting, fishing, camping) occurs on BLM managed land, Seedskadee National Wildlife Refuge, and Fontenelle Reservoir, the latter two situated in the northeast corner of study area.

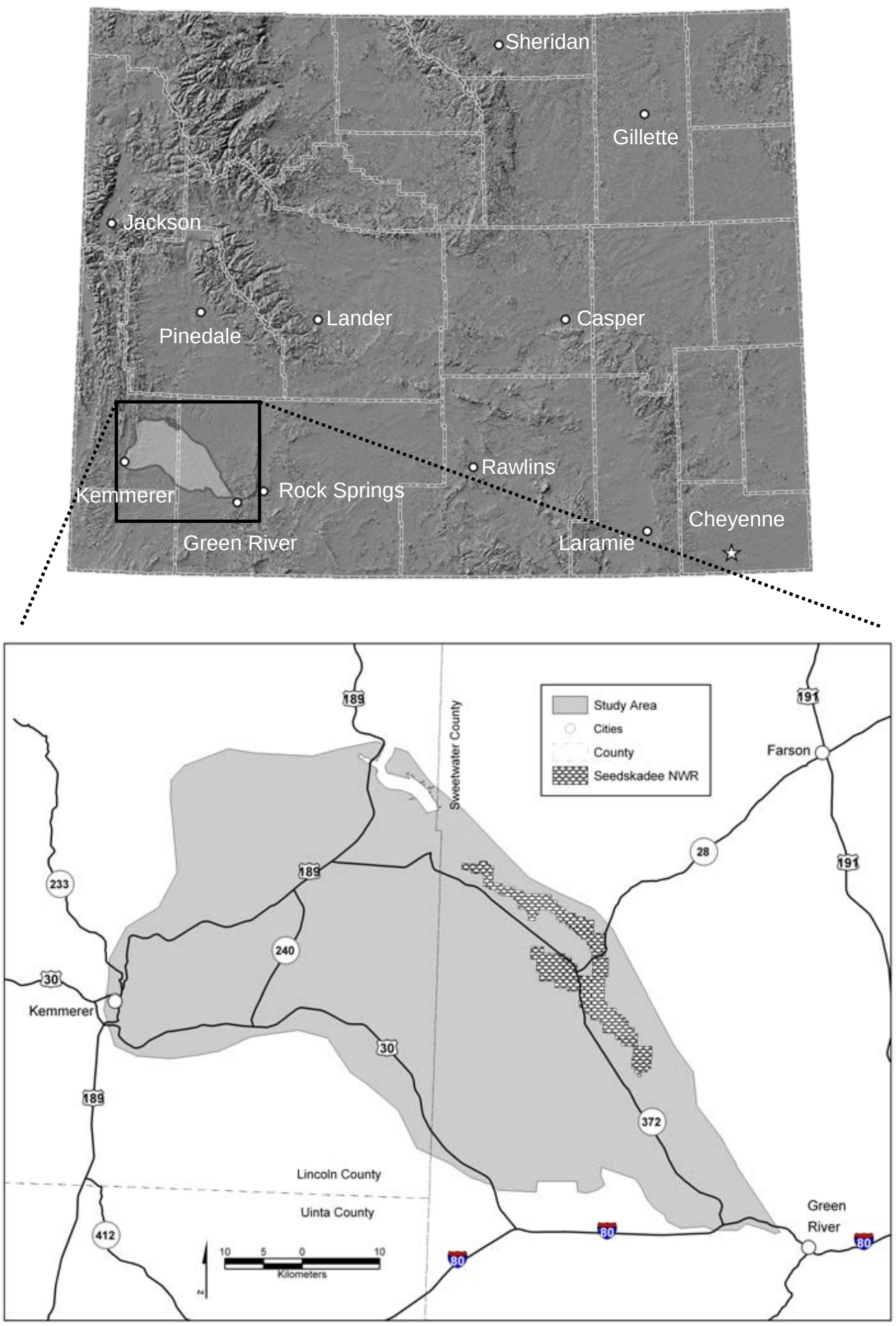


Figure 1. Study area location in southwestern Wyoming. Study area (inset) boundaries within which pronghorn were sampled and analyses were performed for 2002-2003.

Table 1. Total length (km) and estimated average 24-hour traffic volume of primary roads in the study area, southwestern Wyoming (2002-2003). Traffic data collected in 2002 by Wyoming Department of Transportation. (1 km = 0.6 mi)

Road	Length (%)	Total No.Vehicles/Day [a]	Range [b]
State Route 28	7.8 (3%)	460	460
State Route 240	22.5 (9%)	416	240-530
U.S. Highway 189	67.4 (27%)	767	650-890
U.S. Highway 30	75.4 (30%)	2153	1,840-2,450
State Route 372	78.0 (31%)	1030	250-2,300 [c]

% = proportion of major paved roads in study area

[a] Based on estimated average 24 hour traffic volume along portions of each road. Proportions of each stretch of road sampled is taken into account in calculating total.

[b] Range in traffic volume along given stretches of road.

[c] Greater traffic volume associated with resource extraction facilities along southern 10 miles of WY 372.

Natural gas development has been occurring in the Green River Basin since the 1920s, increasing in intensity within the study area in 1990 (Herren 1997). The Moxa Arch Natural Gas Field, making up one-third of the study area, has approximately 1300 wells (four wells per section, February 2005) and is authorized for another 1032 wells over the next 20-30 years (BLM, Kemmerer, WY). Smaller gas fields, individual gas wells, trona mines, and sand and gravel developments are also found throughout the study area. Nearby towns include Kemmerer and Green River (population 3,000 and 14,000, respectively).

The study area is located within the Sublette Antelope Herd Unit, which consists of 11 hunt areas. The Sublette herd has the largest number of pronghorn in the world (N= 42,500), some of which take part in the longest migrations in North America (150 air miles; Rudd 2001). The study area is within hunt area 93, located in the southwestern portion of the Sublette Herd Unit (Figure 2). Hunt area 93 makes up 20% of the Sublette Herd area and is utilized by 8,440 pronghorn. Wyoming Game and Fish Department (WGFD) designated much of the eastern and southern portions of the hunt area as crucial winter range for pronghorn.

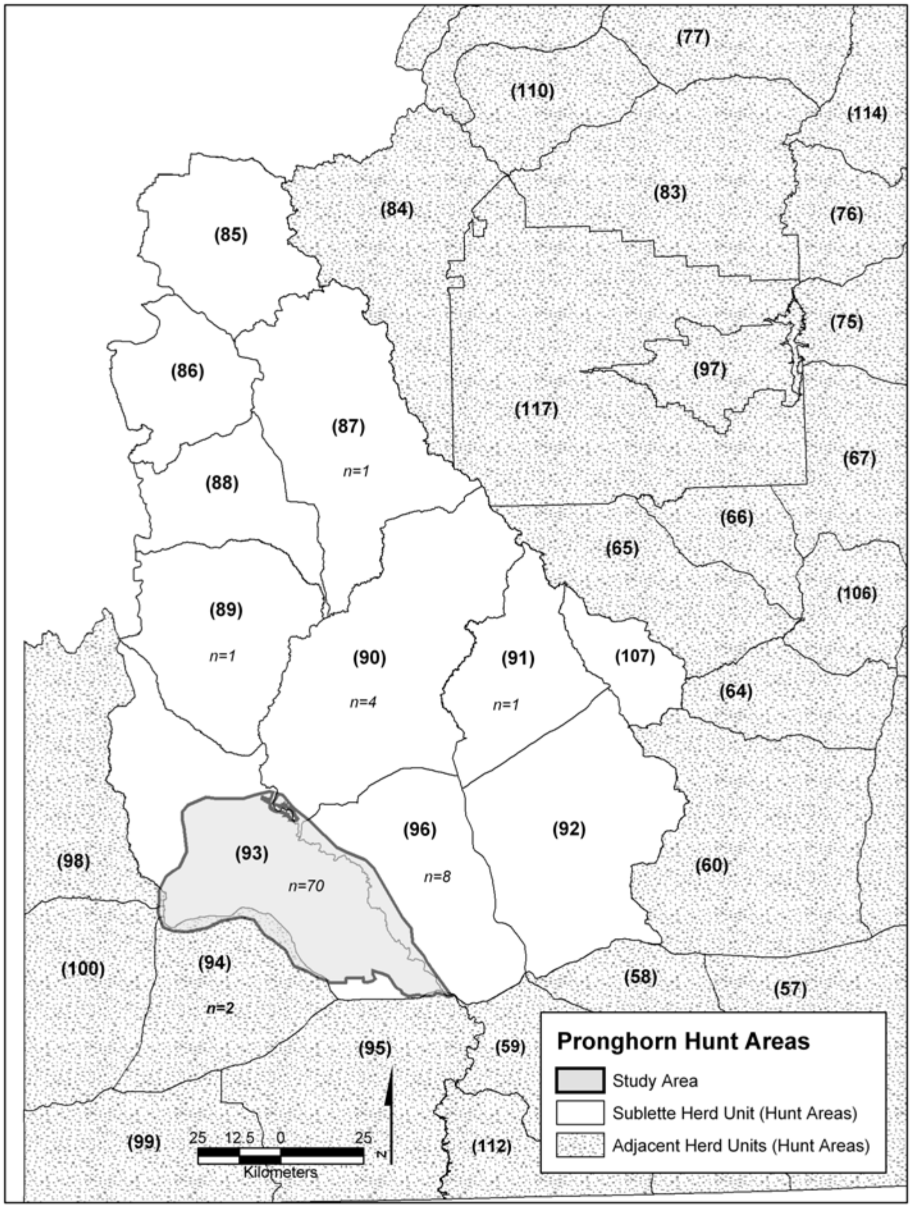


Figure 2. Wyoming Game and Fish Department pronghorn hunt area boundaries in southwestern Wyoming (2002-2003). The study area is located primarily in hunt area 93, Sublette Herd Unit. Pronghorn, captured within the study area and fitted with Global Positioning System (GPS) collars, were documented using hunt area 93 as well as adjacent hunt areas, including hunt area 94 in the Carter Lease Herd Unit. (*n*=# of pronghorn)

Twelve fence types existed within the study area (Table 2). Barbed wire fences were commonly used to restrain and manage livestock. The top wire is usually between 80-100 cm (32-39 in) above ground and all strands (2-7+) are barbed. There is great variation in the distance that the bottom barbed wire is from the ground. Generally, the more strands the fence has, the lower the bottom strand is to the ground and the greater potential for difficulty in crossing by pronghorn of all age classes. Net-wire (woven wire, sheep-tight, mesh) fences are common in Wyoming and the most prevalent fence type within the study area. Many miles of this fence were constructed throughout the west, especially where sheep were grazed because of its ability to contain livestock. The fence extends to the ground and generally has two to three strands of barbed wire on top, resulting in a fence that is commonly 90-120 cm (35-47 in) tall (Zobel 1963). Wildlife-friendly fences, built to facilitate pronghorn crossing underneath (Wilson 1995), is similar to a four-stranded barbed wire fence except the bottom wire is smooth and at least 41 cm (16 in) above the ground. Bottom wire to ground clearance of 41-46 cm (16-18 in) is generally considered passable to pronghorn (Anderson and Denton 1980). The bottom smooth wire and minimum clearance distance are criterion used to identify wildlife-friendly fence within the study area. The WYGF Department recommends this fence type on cattle ranges, where the total height is usually one meter (3.3 ft) and the bottom wire is 41 cm above the ground. Fences built along highway ROWs (Department of Transportation standard Type E fence) are usually one meter tall with wire spacing of 41-23-20-30 cm (16-9-8-12 in) from the ground.

Table 2. Fence types located within study area (2003), southwestern Wyoming. Total length (km) of individual fences types and combined fence types. Fences combined based on similarities in design. Net-wire fences make up the largest proportion of fences in the study area, followed by wildlife-friendly. (1 km = 0.6 mi)

Individual Fence Types	Length	Grouped Fence Types	Length (%)
2-stranded barbed wire	0.4	2-3 wire	29.6 (3%)
3-stranded barbed wire	29.2		
4-stranded barbed wire	106.1	4-wire	106.1 (10%)
5-stranded barbed wire	38.8	5-7 wire	60.4 (6%)
6-stranded barbed wire	7.1		
7-stranded barbed wire	14.5		
Net-wire	12.6	Net-wire	412.9 (41%)
Net-wire + 1 barbed wire	79.8		
Net-wire + 2 barbed wire	128.8		
Net-wire + 3 barbed wire	148.3		
Tall chain link	43.4		
Wildlife-friendly [a]	243.9 [b]	Wildlife-friendly	243.9 (24%) [b]
Unknown	164.3	Unknown	164.3 (16%)

[a] Wildlife-friendly fence defined as a four-wire fence with smooth bottom wire and at least 41 cm (16 in) above the ground.

[b] Values post-construction of 40 km (25 mi) of wildlife-friendly fence along WY 372 (mid-winter 2002).

Capture and GPS Collars

Fixed wing flights identified the distribution of pronghorn prior to capture, allowing adult female pronghorn to be proportionately sampled over the area. Pronghorn were captured during winter over a two-year period using a net-gun fired from a helicopter (Firchow et al. 1986) to maintain a desired sample size of 42. Upon capture, pronghorn were aged based on tooth replacement, marked with ear tags, and collared with global positioning system (GPS) receivers (Telonics, Inc. model TGW-3400). Collars were equipped with mortality sensors and programmed to collect three locations per day from 16 October to 31 May and one location every three days from 1 June to 15 October. In the last year, the collars were programmed to collect two locations per day from 16 October to 15 December 2003 to extend battery life. Winter periods were emphasized to improve the ability to describe pronghorn use of the area's important winter range and capture movement to and from seasonal ranges.

Data stored in the collars' subsystems were downloaded prior to placing collars on new pronghorn. Statistical analyses were performed using Minitab® statistical software (Minitab, Inc., State College, PA, USA). Analyses include paired *t*-tests and 2-tailed *t*-tests for equal variance; difference considered significant at α=0.05.

Geographic information system (GIS) software was used to geographically work with location data and improve understanding of relationships. ArcView® 3.2 (Environmental Systems Research Institute, Inc., Redlands, CA, USA) was selected because of the ability to incorporate preferred extensions.

To determine pronghorn use of hunt areas, all locations were plotted in relation to hunt area boundaries. Pronghorn with location(s) in hunt areas other than 93 were recorded. Proportions of locations were also documented within each hunt area and season of use.

Selection of Pronghorn *and* Home Range Analyses

Individual pronghorn were identified as resident or migrant based on location patterns. Migratory pronghorn exhibited distinct seasonal clusters of locations (seasonal ranges) that did not overlap, while those of resident pronghorn did. Beginning and ending dates of seasonal periods were defined for individual migratory pronghorn as the day they arrived and left their seasonal ranges. Seasonal periods for resident pronghorn were based on the preprogrammed GPS collar schedule: winter = 16 October to 31 May; summer = 1 June to 15 October.

Home range contours were determined using the fixed kernel home range estimator (Worton 1989), provided in ArcView's Animal Movement extension (Hooge and Eichenlaub 2000). Fixed kernel, using the least squares cross validation method to estimate the smoothing parameter, provided the lowest bias and highest precision in home range simulations reported by Seaman and Powell (1996). The fixed kernel method produces a density estimate that represents the amount of time that an animal spent at that location and thereby determines home range boundaries (Worton 1989). Home ranges were calculated at the 95% level, the area containing 95% of the utilization distribution (Worton 1987), and determined using ArcView's XTools extension (DeLaune 2003).

Area observation (AO) curves were constructed to determine the minimum number of days that a GPS collar must have collected locations for that pronghorn to be included in seasonal home range analyses (Odum and Kuenzler 1955). AO curves were based on the premise that home range sizes will increase asymptotically as the number of locations increase (Springer 1982). When the AO curve approaches the asymptote a sufficient number of locations have been used to calculate home range size (Laundré and Keller 1984).

Because pronghorn were trapped in the middle of winter 2001 and collars retrieved in middle of winter 2003, two winters were not sampled in entirety. The last half of winter was captured in winter 2001 and the first half captured in winter 2003. Recognizing behavior may differ between the first half and second half of winter, 15-day location increments were sequentially added from both the beginning and end of winter 2002, for which there was data for the entire winter, and applied the results to all pronghorn to determine those who met analysis requirements. For winter, four resident pronghorn were randomly chosen whose locations encompassed all of winter 2002. To establish summer requirements 12 resident pronghorn, six from summer 2002 and six from summer 2003, were randomly chosen. Home range size was repeatedly calculated for each pronghorn using the 15-day location increments until an asymptote was reached. An asymptote was achieved when three consecutive increments (totaling 45 days) were within 20% of the initial increment's home range size. The first day the asymptote was reached was assumed to indicate that an adequate number of days of locations were captured to represent home range size. The day the asymptote was reached, including from the beginning and end of each season, was recorded for each pronghorn. The mean, calculated from random pronghorn, became the estimate for the minimum number of days needed for each season. Depending on when pronghorn were captured, individuals needed a minimum of 30 days of locations collected since the beginning or 61 days from the end of winter to adequately delineate home range. Summer home range analyses required at least 76 days of locations since the beginning or 63 days from the end of the season.

After individual pronghorn locations were plotted in ArcView® 3.2 and 95% fixed kernel polygons (home ranges) created for all pronghorn using Animal Movement extension (Hooge and Eichenlaub 2000), pronghorn from the sample that had <80% of their seasonal range within the study area were removed. Migration analyses were restricted to pronghorn with $\geq$ 50% of their migration route within the study area and only those portions within the study area were analyzed for topography, fence density, and vegetation. Depending on the goals of particular analyses, limitations varied on which pronghorn could be included. Some analyses had no restrictions and included all sampled pronghorn. Analyses involving home ranges were limited to those individuals that met both the criterion for minimum number of days sampled and the second criterion that required >80% of the home range to be within the study area. Each pronghorn was treated as a sample unit.

To determine if migrant and resident pronghorn seasonal ranges differed in elevation, the true centroid (center of mass) of individual home ranges were produced using ArcView's Center of Mass extension (Jenness 2004a). The elevation at each centroid was calculated using the 30-meter National Elevation Dataset for Wyoming (U.S. Geological Survey 1999). Elevations of migrant home ranges were compared to residents for both winter and summer using 2 sample *t*-tests. Within migrants and residents, paired *t*-tests were used to independently examine for differences in winter and summer elevations.

Summer home ranges were overlaid onto a coarse GIS layer that contained information on Wyoming's land cover (1:100,000 scale; Wyoming Geographic Information Science Center 1996). For each pronghorn home range, the presence of riparian areas and irrigated crops was noted.

Migration

Clustered locations of migratory pronghorn were used to identify individual seasonal arrival and departure dates and dates of movement between seasonal ranges. Julian dates were used to calculate individual and general seasonal arrival/departure dates, length of time within each season, and dates of migration. In the calculation of general movement dates between seasons, pronghorn that had multiple spring or fall migrations recorded had these dates averaged and reported once. Thus, the general movement dates for spring and fall migrations are based on both 2002 and 2003 spring and fall migrations. Paired *t*-tests were performed to determine if arrival and departure dates varied from 2002 to 2003 within seasons.

The direction of movement, based on the straight-line distance or shortest path between seasonal ranges was found by applying the Bearing extension in ArcView (Schultz 2003). However, adjustments were made to the extension's output to allow for direction traveled to be reported in 360°.

For each migrating pronghorn, three migration characteristics were calculated - number of days spent on migration, distance traveled during migration (km), and daily rate of travel (km/day). Individual distances traveled during migrations were based on the summation of distances between consecutive locations, assuming a constant rate of motion in a straight line between locations. All migrating pronghorn were incorporated and all three calculations were summarized for each migration period.

Boxplots (Chatterjee et al. 2000) were used to identify outliers in days, distances, and rate of travel within each of the four migration periods. To identify outliers in regression analyses, leverage-residual plots were used in conjunction with DFITs (Ramsey and Schafer 1997). Outliers were removed from given analyses to better capture general population trends.

The influence of year on each of the three characteristics was determined by comparing values for individuals with both 2002 and 2003 data within each season and testing for differences between years with paired *t*-tests. If no difference existed, data from 2002 and 2003 were combined in further analyses. Data were combined such that each pronghorn was represented only once in the overall comparison of spring to fall values and those pronghorn with multiple years had data averaged to provide a single value. If difference existed, one of the two years of data was randomly selected to be reported for each pronghorn. Overall differences between spring and fall values for individuals were tested using paired *t*-tests.

Migration periods, fall and spring, were compared to determine during which collared pronghorn exhibited more exploratory travel. Exploratory travel was identified by the difference in distance between actual and short routes for individual pronghorn. Actual distances traveled during independently combined spring and fall migrations were compared to the shortest paths using paired *t*-tests. The shortest path between seasonal ranges was determined by connecting the ending and beginning date of successive seasons. All connections of locations were performed using Animal Movement extension.

To determine if a relationship between the initiation date of migration and distance traveled existed and the strength of the relationship, regression was run for spring and fall migrations. Similarly, the relationship of distance between seasonal ranges and summer home range size was examined. Finally, the strength of association between number of days spent on migration, distance traveled during migration, and daily rate of travel for individual pronghorn was calculated during migrations using correlation analyses.

The regressions and correlations combined information from 2002 and 2003 migrations. However, instead of averaging values for pronghorn with >1 spring or fall migration, one of the two years of data was randomly selected to maintain the distinct link association between variables.

All migration locations were plotted in ArcView® 3.2. Routes were created by connecting consecutive locations using Animal Movement extension. For descriptive purposes and to assist in visualizing movement patterns, migration routes were overlaid onto digital topographic maps (1:100,000 scale Enhanced Digital Raster Graphics; Beartooth Mapping, Inc. 1999). Similar routes were grouped together and topographic features associated with routes recorded.

The University of Nebraska's High Plains Climate Center provided daily weather data for 2002-2003 and the National Oceanic and Atmospheric Administration's Western Regional Climate Center monthly weather data for 1948-2001. Data from the Kemmerer weather station, located at the eastern edge of the study area, was compared to migration initiation dates to determine if movement was influenced by weather events such as temperature or precipitation.

Fences

Home Ranges

Habitat selection was first evaluated at the landscape scale (Johnson 1980) to determine if home range selection was being driven by the distribution of particular vegetation types. The composition of vegetation types was examined within a pronghorn's 95% home range to that available in the study area. The vegetation layer, upon which vegetation use was derived, was created from digital satellite data of the region (Landsat ETM+, 18 October 2002). Unsupervised classification (multivariate cluster analysis) and third Tasseled Cap Component (statistical transformation) were used to convert the satellite image into a vegetation map (layer). The Normalized Difference Vegetation Index (NDVI) was used to differentiate sagebrush, the dominant vegetation type in the study area, into low and high densities. The final vegetation layer was verified with an existing, more fine-scaled vegetation map that was created for the smaller Moxa Arch gas field area in 1994 (PIC Technologies 1996).

Three main vegetation types were identified within the study area (sagebrush: 71%, greasewood: 17%, saltbush: 8%). The density of sagebrush was found to be uniform across the study area. Each individual pronghorn home range was overlaid onto the vegetation GIS layer and ArcView's XTools extension was used to determine the amount of each vegetation type within the boundaries of the home ranges (DeLaune 2003). Selection ratios were calculated by dividing the used portion of vegetation by the available portion for each vegetation type (Manly et al. 2002). Based on individual pronghorn, separate confidence intervals were calculated for each vegetation type and each season. Mean selection ratios with confidence intervals that contained 1 indicated pronghorn were using the vegetation type in proportion to availability, confidence intervals >1 indicated selection for vegetation type, and confidence intervals <1 indicated selecting against vegetation type in each season independently. Results for all three years of winter data and two years of summer data were examined for consistent responses to each vegetation type.

To determine if fences were influencing pronghorn at the landscape and within-home range scales, a GIS layer was created that represented all known fence types and locations within the study area. The fence layer (1:100,000) was initially based on *Fences of Southwest Wyoming: 1990-1992*, an inventory of fences that was jointly conducted by the Wyoming Cooperative Research Unit and the Wyoming Game and Fish Department (WGFD) for the purpose of identifying fences that were potential barriers to pronghorn (Wyoming Geographic Information Science Center 2001). To improve accuracy and document changes that occurred since 1992, the roads throughout the study area were driven and location and type of fences present recorded using a hand-held GPS unit. In addition, the study area was flown in a fixed-wing plane and fence locations and types recorded using a mobile Trimble GeoExplorer 3 GPS unit (Trimble Navigation, LTD, Sunnyvale, CA). Maps and information provided by regional offices of the WGFD, BLM, Seedskadee National Wildlife Refuge, Pacific Union Railroad, and resource extraction companies in the area were also used to identify unknown stretches of fence. Fence density (fence length (m)/ area (km^2)) in home ranges was compared to that available in the study area. The area of each home range and length of fence within was calculated for each individual pronghorn using ArcView's X-Tools extension (DeLaune 2003). The number of home ranges that did not include fences was recorded for each season. All fence densities in remaining home range analyses were log-transformed (log(fence density+1)) before analyses to correct for non-normally distributed data (Figure 3). Data were back-transformed in reported results. Difference in fence densities (all fence types combined) was tested in 95% home ranges (used) and in the study area (available) using 1-sample *t*-tests. To determine if there was a difference among the fence types, data was examined for differences in densities by fence type in 95% home ranges and in the study area using 1-sample *t*-tests.

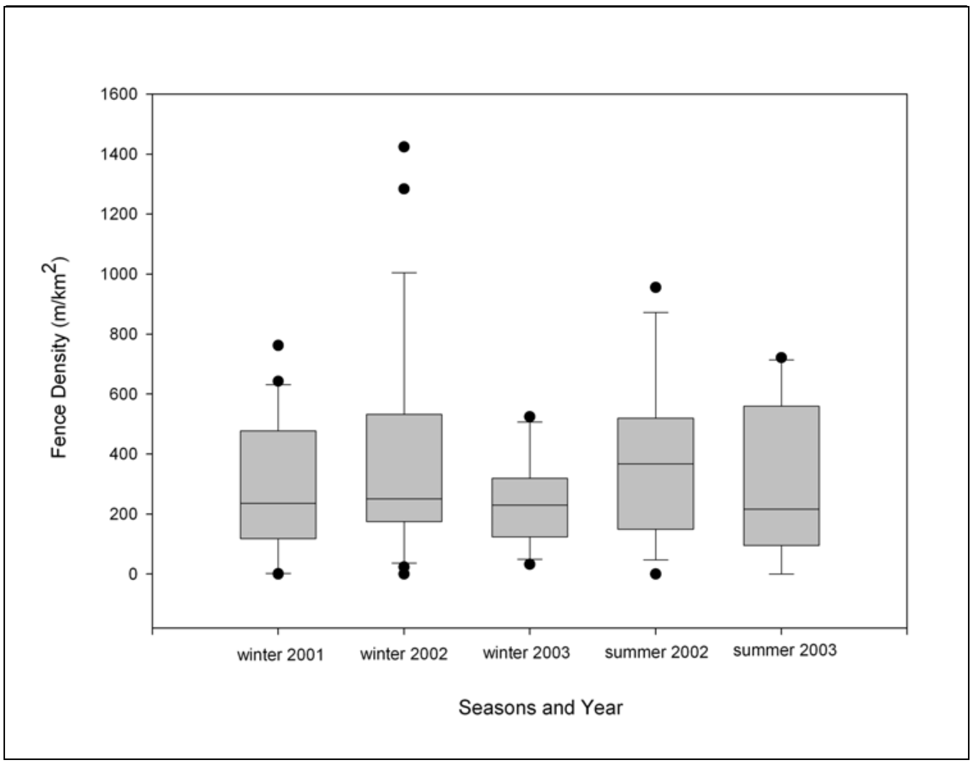


Figure 3. Boxplot of mean fence density (± standard error) within 95% fixed kernel home ranges (Worton 1989). Home ranges based on locations collected from pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming (2002-2003). Individual animals are treated as sampling unit. Data shown are raw and non-normally distributed.

Home ranges were divided into distinct portions that reflected intensity to test the question of whether fence densities were lowest in areas of home ranges with more intense use by the pronghorn. Using individual pronghorn locations and the fixed kernel density method, ArcView's Animal Movement extension (Hooge and Eichenlaub 2000) was used to create 50%, 70%, and 80% polygons for each pronghorn (Worton 1989). The 50% polygons were estimates of high use areas (core areas) or areas with the greatest intensity of locations within the larger home ranges. Level of intensity of use, reflected in location density, decreases as percentage increases. From these polygons, and the previously created home ranges (95% fixed kernel), each home range was divided into concentric rings based on intensity of use, hereon referred to as home range zones (Figure 4). For example, area of the home range defined as the 80% zone is the area contained between the boundaries of the 70% and 80% polygons. Three zones were created for each pronghorn: 95% zone (area between 95% and 80% polygons), 80% zone, and 70% zone (area between 70% and 50% polygon). The 50% polygon was not altered.

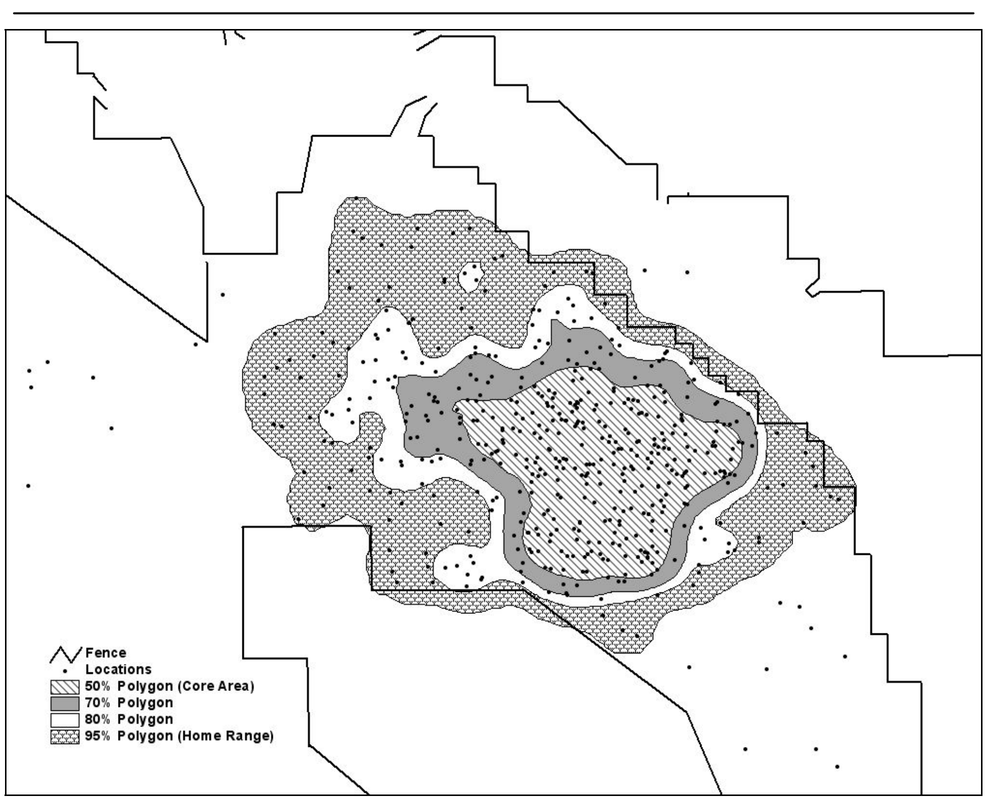


Figure 4. Example of individual home range divided into concentric rings based on density of locations. Level of intensity of use in home range zones decrease as percentage increases. Boundaries estimated using fixed kernel method (Worton 1989). Locations collected from pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming (2002-2003).

All home range zones and core areas were overlaid onto the fence layer and area and fence length (all fence types combined) calculated for each. Differences in fence densities were tested in each of the home ranges zones and core areas (used) to the study area (available) using 1-sample *t*-tests. Fence density was also compared at the within-home range scale (2nd order selection, Johnson 1980). In addition, data was examined for differences in fence density between the home range zones using 1-Way Analysis of Variance (ANOVA) and the strength of the relationship between fence density and home range zones using linear regression. Data was analyzed for differences in density of the two major fence types within the study area (wildlife-friendly and net-wire) between the home range zones using 1-Way ANOVA. Further analyses included comparing total fence density in each individual pronghorn's core area, 70% zone, and 80% zone to that found in the 95% zone using paired *t*-tests. Data for pronghorn that had a particular fence type present in only one home range zone were not included in analyses.

Because placement or shape of pronghorn home ranges may be determined by fences, researchers attempted to capture the potential influence of fences along the edges of home ranges by creating two additional rings that encircled the individual 95% home ranges at uniform distances with ArcView's X-Tools extension (DeLaune 2003). The first buffer zone extended out 500 meters (0.31 mi) from the border of home ranges. The second buffer zone began at the edge of the first buffer and extended out an additional 500 meters, thereby covering the area between 500 and 1000 meters (0.62 mi) from the border of home ranges. The difference in fence densities (all fences combined) in 95% home ranges (used) was tested to the 500 and 1000 meter buffered zones using 2-sample *t*-tests. Variance was considered either equal or unequal depending on the particular data. Researchers also examined for difference in fence densities in buffered rings compared to the study area (available) using 1-sample *t*-tests.

Migration Routes

Movement route locations of pronghorn identified as migratory were connected using ArcView's Animal Movement extension to identify paths taken during migration (Hooge and Eichenlaub 2000). Only pronghorn with > 50% of their migration route within the study area were included in migration route analyses. A 100-meter (328 feet) buffer was added to each side of migration routes and fence density within this area calculated with X-Tools extension (DeLaune 2003). Differences between fence density along migration routes and that within the study area were tested for both spring and fall migrations using 1-sample *t*-tests.

The initial examination of migration paths indicated pronghorn were not taking the most direct route between seasonal ranges. Analyses to identify the causal factor(s) was limited to four variables: route length (km), topography, vegetation, and fence crossing rate. Routes selected (actual) by individual pronghorn were compared to the most direct (shortest) path between seasonal ranges, alternate routes between seasonal ranges, and random routes within the study area. The shortest path between seasonal ranges was delineated by connecting beginning and ending dates of each pronghorn's migration route using ArcView's X-Tools extension (DeLaune 2003). ArcView's Alternate Animal

Movement Routes extension (Jenness 2004b) was used to create five alternate routes for each pronghorn. These alternate routes maintained the same beginning and ending points of the actual migration routes, but randomly rearranged the route segments, maintaining similar total lengths. Alternate routes represented other routes that each pronghorn could have taken, given that travel was limited by the beginning and ending points of the actual migration. Random routes, created using the Random Routes extension (Jenness 2004c), represented other routes that each pronghorn could have taken within the study area. Each pronghorn's actual route was replicated 20 times, where the shape was maintained and randomly placed within the study area. Starting points of random routes were randomly generated and direction of travel fell within a range of bearings that pronghorn were found to move during spring and fall migrations. The range of possible bearings was based on direction of travel taken by collared migrating pronghorn during the study to more accurately replicate how pronghorn could have migrated between seasonal ranges.

Comparison of length of travel routes was limited to actual and shortest routes since both alternate and random routes were the same lengths as the actual routes. Researchers calculated the lengths of both routes with ArcView's X-Tools extension (DeLaune 2003). Differences between actual and shortest routes were tested using paired *t*-tests.

An index of topographic roughness, defined as the amount of elevation change over a given straight-line distance, was created for all routes by overlaying them on a 30-meter (1:100,000 scale) National Elevation Dataset (U.S. Geological Survey, 1999). The cumulative change in elevation, which takes into account ascents and descents, of each route was determined from the NED using the Surface Tools extension (Jenness 2004d). Topographic roughness was then calculated by dividing cumulative change in elevation by straight-line distance. Comparisons between actual routes and other routes (shortest, alternate, random) were tested using paired *t*-tests, where the index of the actual route was compared to the mean of the other routes.

The potential influence of vegetation was addressed using the 100-meter (328 feet) buffer created to analyze fence densities (X-Tools extension: DeLaune 2003). Buffered migration routes were overlaid onto the vegetation GIS layer and ArcView's XTools extension used to determine the amount of each vegetation type within the buffered regions (DeLaune 2003). Proportions of sagebrush, greasewood, and saltbush were tested for differences between actual and other routes. When comparing vegetation in actual routes to random routes, 1-sample *t*-tests were used because random routes were considered to be a census of the study area. Paired *t*-tests were used for shortest and alternate routes.

Fence crossing rate was defined as number of crossings per one kilometer (0.62 mi) of route. The routes were overlaid onto the fence GIS layer and manually tallied the number and type of fences crossed for each pronghorn along actual migration routes and other routes. Previously calculated lengths of all routes were used to determine fence crossing rates. Using all fence types combined, paired *t*-tests were used to determine if differences existed between actual routes and others. To increase sample size, researchers combined migrations by year. Pronghorn with >1 fall or spring migration had one of the pair of data randomly selected to be included in analyses. Because net-wire fence was abundant within the study area and throughout the west, the differences in crossing rates associated with net-wire fences were closely examined. And, because wildlife-friendly fence is increasingly being built on pronghorn range, crossing rates of this fence type were studied using paired *t*-tests.

Roads

To establish if and when pronghorn were avoiding primary roads within seasonal ranges, ArcView was used to examine individual seasonal home range placement in relation to Wyoming State Route (WY) 372, U.S. Highway (US) 189, US 30, WY 28, and WY 240. Pronghorn that met the primary (number of days) and secondary (home range placement) criteria were included in this analysis. Pronghorn identification numbers and seasons were recorded when individual 95% fixed kernel home ranges overlapped a road.

The foundation of the GIS (Geographic Information System) road layer used in analyses was the TIGER Files (U.S. Census 1995). This layer was amended with information acquired from driving the study area and recording road locations using a mobile GPS unit and road maps provided by regional BLM offices (Moxa Arch Road and Well System), Seedskadee National Wildlife Refuge, and resource extraction companies in the area.

Fifty percent fixed kernel polygons were created using ArcView's Animal Movement extension to identify whether presence or absence of road differed with intensity of use within pronghorn home ranges. These 50% polygons were estimates of high use areas (core areas), or areas with the greatest intensity of locations within the larger home ranges. Core areas were overlaid on the road layer and noted number and seasons when roads were found. For each season, three winters and two summers, researchers recorded and compared the number of pronghorn that incorporated each road into home range and core area.

Initial analyses revealed that US 30, WY 30, and WY 240 were not used as intensely by sampled pronghorn as WY 372 and US 189. Therefore only the latter two were further examined to identify sections with high pronghorn crossings. Each road was divided into one kilometer (0.62 mi) sections in ArcView and created a representative new GIS layer. WY 372 and US 189 had sections numbered in respective southeasterly and northeasterly directions and associated fence types recorded.

Crossing of Primary Roads

All pronghorn were included in examination of seasonal crossings (defined as consecutive location on opposite side of road) of WY 372 and US 189. Locations for individual pronghorn were connected using ArcView's Animal Movement extension. Pronghorn identified as migratory had movement route locations connected to highlight highway crossings during migrations. Only pronghorn with $\geq$ 50% of their migration route within the study area were included in migration route analyses. Road sections crossed and season or migration period during which crossing occurred was recorded for each individual pronghorn.

A one kilometer (0.6 mi) buffer along each side of WY 372 and US 189 were created using ArcView's X-Tools extension to identify portions of the primary roads where pronghorn may have tried to cross but were unable. This one kilometer buffer represented the average distance (1157 meters or 0.7 mi) traveled between 8-hour locations for 40 individual pronghorn (winter 2001 = 20, winter 2002 = 20). Locations within the buffered region that did not have a consecutive location on the opposite side of the road represented pronghorn that had the potential to cross, but did not. All seasonal and migratory locations were plotted on top of the one kilometer buffered area. For those pronghorn that did not cross the road though they had locations within the one kilometer buffer, researchers recorded the closest road section, the individual pronghorn's identification number, and the season or migration period during which the location was recorded.

Pronghorn were placed into one of three categories based on placement of locations: (1) crossed, (2) had locations within the one kilometer buffered region (had potential) but did not cross the road during an entire season or migration period, and (3) had all locations outside the boundaries of the one kilometer buffered region (no potential) and never crossed. The number of pronghorn that fell into each of the three categories for each season and migration period was tallied.

Finally, the number of crossings associated with each road section was identified and data examined for potential patterns exhibited by pronghorn that had multiple seasons and migration periods of data. This provided insight as to where along WY 372 and US 189 pronghorn crossed most frequently, as well as where pronghorn may have been deterred from crossing.

Wyoming Department of Transportation (WYDOT) constructed wildlife-friendly fence along WY 372, starting at road section 58 (between mile marker 12-13) and extending south to I-80 in mid-winter 2002 (1 Nov – 13 Dec 2002). Pronghorn response to this change from unfenced to fenced road was noted when examining frequency and location of crossings.

Highway Right-of-Ways

To determine if highway ROWs influence pronghorn movements and distribution, researchers initially had to create a GIS layer of fences within the study area. The fence layer (1:100,000 scale) was based primarily on Fences of Southwest Wyoming: 1990-1992, an inventory of fences that was jointly conducted by the Wyoming Cooperative Research Unit and the Wyoming Game and Fish Department (WGFD) for the purpose of identifying fences that are potential barriers to pronghorn (Wyoming Geographic Information Science Center 2001). To improve accuracy and document changes that occurred since 1992, roads throughout the study area were driven and location and type of fences present were recorded using a hand-held GPS unit. In addition, the study area was flown and fence locations and types recorded using a mobile Trimble GeoExplorer 3 GPS unit (Trimble Navigation, LTD, Sunnyvale, CA). Maps and information provided by regional offices of the WGFD, BLM, Seedskadee National Wildlife Refuge, Pacific Union Railroad, and resource extraction companies in the area were also used to identify unknown stretches of fence.

From this fence layer, a right-of-way (ROW) layer was created upon which all home ranges were overlaid. The ROW layer displayed individual polygons that represented the width of the ROW and the types of fence on each side of the road. The width of each ROW polygon was based on the distance that fence lines were found from the road. These distances were measured at random with a 91 m (300 m) measuring tape, at 12 locations (each marked with a handheld GPS unit) along WY 372, WY 240, US 189, and US 30 and applied to the rest of the study area. The average ROW width was applied to create a ROW boundary for non-fenced portions of the road. ROWs were labeled based on associated fence types. For example, NF_4W represented a ROW polygon that had no fence on one side of the road and a 4-wire fence on the other.

Composition of ROWs in the study area changed in mid-winter 2002 when WYDOT fenced a portion of WY 372. The previously unfenced 20 km (12.4 mi) of the southern portion of the highway was fenced with wildlife-friendly fence along both sides of the road. All proportions of ROWs stayed constant throughout the duration of the study, except for NF_NF (no fences on either side of the road) and WF_WF (wildlife-friendly fencing on both sides of the road; Table 3).

Table 3. Description of rights-of-way (ROWs) found in study area (2002-2003), southwestern Wyoming. Proportion of ROWs in the study area changed in mid-winter 2002 as a result of construction of fencing along WY 372 by Wyoming Department of Transportation.

Original ROW Category [a]	Description	Proportion in Study Area (%) [b]	
		Pre-construction	Post-construction
5-7W_5-7W	5-7 stranded barbed wire fence, both sides	0.03	0.03
2-3W_4W	2-3 barbed wire fence, 4 barbed wire fence	0.05	0.05
4W_5-7W	4 barbed wire fence, 5-7 barbed wire fence	0.05	0.05
4W_4W	4 barbed wire fence - both sides of road	2.7	2.7
4W_Net	4 barbed wire fence, net-wire (woven) fence	0.2	0.2
4W_NF	4 barbed wire fence, no fence	1.2	1.2
5-7W_NF	5-7 barbed wire fence, no fence	1.3	1.3
2-3W_NF	2-3 barbed wire fence, no fence	2.9	2.9
WF_NF	wildlife-friendly fence, no fence	5.9	5.9
Net_NF	net-wire (woven) fence, no fence	8.3	8.3
WF_WF [c]	wildlife-friendly fence - both sides of road	12.0	22.0
NF_NF [c]	no fence - both sides of road	32.6	22.7
Net_Net	net-wire (woven) fence - both sides of road	32.7	32.7

[a] ROW categories based on fence type on each side of road.

[b] ROW areas based on distance of fences to roads. Average distance from random measuring efforts was applied to create an artificial boundary for unfenced ROWs.

[c] Change in proportion due to construction along WY 372.

Pronghorn that met primary (minimum number of locations) and secondary (placement of home range within study area) criteria were used to determine the number of pronghorn that incorporated ROWs into their home ranges. For initial examination of ROWs, associated fence types were disregarded and only boundaries and areas within ROWs were considered. Proportions of ROW within individual home ranges were compared to ROW proportions in the study area using 1-sample *t*-tests. To examine distribution of ROWs within home ranges, core areas were overlaid on to the ROW layer. The presence or absence of ROW within each individual pronghorn's core area and home range was recorded for each season.

Fence types along both sides of roads were incorporated into the next phase of ROW analyses to assess pronghorn response to different ROW categories within the study area. Chi-square analysis was used to compare actual number of winter pronghorn locations observed within ROWs to expected values. Expected number of locations within each category was based on the proportion of each ROW type within the study area and the total number of locations found within ROWs during winter. Winter was selected for analyses because of the large volume of data. All sampled pronghorn were used to calculate the observed number of locations within each ROW category. Two separate analyses, pre- and post-construction, were done to account for the changing proportions of unfenced and wildlife-friendly fenced ROWs in the study area due to construction of fencing along WY 372 in 2002. Original ROW categories with similar associated fence types were combined when appropriate (Table 4).

Crossing of highway ROWs were examined to determine if pronghorn were crossing certain types more than others. Three analyses focused on two roads and two time periods: pre-construction WY 372, post-construction WY 372, and US 189. As with location analysis, chi-square was used to compare observed number of crossings within each ROW category to expected values (based on proportion of ROW present in study area). All pronghorn were included in analyses and all crossings within seasons and during migrations were grouped together.

Pronghorn whose home ranges contained stretches of unfenced highway (NF_NF ROW) were examined closely because roads, independent of fences, may influence pronghorn distribution. Location density (number of locations per km^2) in unfenced ROWs were compared to location density in 95% home ranges for each individual season, three winters and two summers, using paired *t*-tests. Home range calculations excluded areas associated with all fenced ROW categories and locations within to isolate the influence of roads and reduce potential bias of fences. Prior to analysis, data were log-transformed (log(x+1)) to normalize distributions and reduce variance.

Table 4. Right-of-Way (ROW) proportions in overall study area and on distinct major paved roads (2002-2003), southwestern Wyoming. ROW names describe fence types on each side of the road. The proportion of ROWs in the study area changed in mid-winter 2002 as a result of construction of fencing along WY 372 by Wyoming Department of Transportation.

I. Grouping of ROWS and Proportions in Study Area

Original ROW Category [a]	Grouped ROW Category	Proportion in Study Area (%) [b]	
		Pre-construction	Post-construction
5-7W_5-7W 2-3W_4W 4W_5-7W 4W_4W 4W_Net	BRB_BRB [c]	3.07	3.07
4W_NF 5-7W_NF	≥4BRB_NF [c]	2.52	2.52
2-3W_NF	2-3W_NF [d]	2.93	2.93
WF_NF	WF_NF [e]	5.89	5.89
Net_NF	Net_NF	8.26	8.26
WF_WF [f]	WF_WF	12.03	21.98
NF_NF [f]	NF_NF	32.61	22.67
Net_Net	Net_Net	32.68	32.68

[a] ROW categories based on fence type on each side of road.
[b] ROW areas based on distance of fences to roads. Average distance from random measuring efforts was applied to create an artificial boundary for unfenced ROWs.
[c] BRB = barbed-wire fence
[d] 2-3W= 2-3 stranded barbed-wire fence, NF=no fence
[e] WF= wildlife-friendly fence
[f] Change in proportion due to construction along WY 372.

II. Proportion (%) of ROW Type Along Major Paved Roads

ROW [a]	WY 372 [g]	US 189	US 30	WY 240	WY 28
Net_Net	---	---	85.3	64.8	---
BRB_BRB	---	1.8	0.9	35.2	---
WF_WF	2.4 (30.4)	50.0	---	---	---
Net_NF	15.0	---	11.6	---	---
≥4BRB_NF	0.1	11.2	---	---	---
WF_NF	16.4	---	---	---	---
2-3W_NF	1.7	10.4	---	---	---
NF_NF	64.3 (36.6)	26.3	2.3	---	100.0

[g] Pre-construction (post-construction). --- not present along road

CHAPTER FOUR

Results of Data Analyses

Capture and GPS Collars

Global Positioning System (GPS) receivers were placed on 79 adult (>1 year) female pronghorn during six capture efforts between January 2002 and April 2003. Pronghorn (94%) were captured while on winter range. Of the 73 collars retrieved during capture efforts, dropped collars, and mortalities, one collar failed to collect locations due to initializing error. Researchers observed one collar-related injury, an ingrown collar that was removed upon recapture. Of the 21 (29%) pronghorn that died during the course of the study, cause of death could not be documented for 11 (52%). Hunter harvest accounted for four deaths, three were killed during recapture efforts, two died shortly after handling (probably capture-related), and one was killed by a vehicle.

Due to preprogrammed release mechanisms malfunctioning during initial capture efforts, 42 (58%) of the 73 collars were bolted together. Of the 31 (42%) pronghorn that did not have bolted collars, only two detonated and released as scheduled (January 2004), and most (74%) released earlier than programmed.

GPS collars collected 33,369 locations between January 2002 and December 2003. Depending on visibility of the GPS satellite constellation, pronghorn positions were recorded as two-dimensional (63%, signals from <4 satellites) or three-dimensional (37%, $\geq$ 4 satellites). Pronghorn were monitored an average of 256 consecutive days (range=4-688) with 461 locations (n=72, range=2-1255). Mean successful location acquisition rate ($\geq$ 2-dimensional) was 93%.

Nine of 72 (13%) pronghorn were documented using hunt areas other than 93 (Figure 2). Two of the pronghorn were located in an adjacent herd unit, Carter Lease - one pronghorn consistently (over 14 months) used hunt area 94 while the other had only a single location within Carter Lease herd unit. Seven of the remaining pronghorn utilized other hunt areas within Sublette Herd. Among pronghorn that utilized multiple hunt areas, intensity of use of 93 varied by season.

Selection of Pronghorn Antelope *and* Home Range Analyses

Examination of individual location clusters identified 16 (22%) pronghorn as residents and 28 (39%) as migrants; 28 (39%) had just one season of data and could not be categorized. Of the 72 pronghorn that provided location data, 48 met the criteria for minimum number of days for home range analyses: 16 (33%) residents, 26 (54%) migrants, and six (13%) had one season of data. A total of 43 pronghorn antelope had home ranges in at least one season that were $\geq$ 80% within the study area (winter 2001=21, winter 2002=26, winter 2003=17, summer 2002=14, summer 2003=15). Most of the ranges located outside the study area were summer ranges (75%).

Migrating pronghorn arrived on winter range by 21 October, stayed an average of 164 days, and departed on 2 April (*n*=27; Table 5). Summer ranges were reached by 21 April, and pronghorn remained an average of 169 days before departing on 7 October (*n*=27). Seasonal arrival and departure dates among migrating pronghorn varied slightly between years.

Comparisons of elevations of migrant and resident pronghorn seasonal home ranges did not yield a difference between winter ranges, but did find migrants to have significantly higher summer home ranges (winter: t=0.60, df=30, p=0.555; summer: t=4.49, df=30, $p<0.001$). Elevations at the true centroid of individual resident summer home ranges did not differ from winter (t=1.01, df=10, p=0.335). However, summer home ranges of migrants were at significantly higher elevations than winter ranges (difference=224m or 0.41 mi; t=7.09, df=20, $p<0.001$). Furthermore, most migrant summer home ranges contained riparian areas or overlapped irrigated cropland (riparian: 2002=8 of 13, 2003=12 of 18; cropland: 2002= 4 of 13, 2003=5 of 18).

Migration

Twenty-eight migratory pronghorn provided data during two spring and two fall migration periods between January 2002 and December 2003. Closer examination of the 65 individual migration periods revealed that 82% of the migrations were within the sampling period of three locations per day.

Spring migrations occurred between 2 April and 20 April (*n*=27) and fall migrations between 9 October and 20 October (*n*=23), with slight annual variations (Table 5). Beginning and ending dates for migrations were similar for those pronghorn with more than a single year of data (spring begin: t=-0.62, df=7, p= 0.556; spring end: t=-1.37, df=7, p=0.214; fall begin: t=-0.96, df=6, p=0.372; fall end: t=-2.39, df=6, p=0.054). Individual migrating pronghorn exhibited slight variations in migration dates for spring and fall during the study period (Appendix A).

Spring and fall initiation dates were examined in relation to 2002-2003 weather data. The initiation of the both spring 2002 (27 March) and 2003 (7 April) migrations occurred in association with increased, stabilized temperatures and reduced daily snowfall. Spring 2003 migration may have been delayed by a week as a result of 28 cm (11 in) of snowfall during the last week of March. Fall initiation dates differed by three weeks between 2002 (21 September) and 2003 (12 October). Although no snowfall was recorded within respective months, both fall migrations were preceded by a week of low temperatures.

Spring migrations generally occurred in a northwesterly direction (2002: *n*=12, 75%; 2003: *n*=11, 58%) and fall migrations were often in a southeasterly direction (2002: *n*=7, 58%; 2003: *n*=10, 71%).

Spring migrations averaged 20 days (*n*=27, range=1-76 days) and fall migrations 13 days (*n*=19, range=1-93; Table 5). Three outliers were identified in three of the four migration periods, all having migrations lasting more than 63 days. To provide general population trends, outliers were removed from data. Remaining data were examined for the influence of year on days spent on migration. No difference was found between 2002 and 2003 for either spring or fall migrations (fall: *t*=0.28, df=4, p=0.795; spring: *t*=-0.29, df=6, p=0.783) therefore years were combined to compare duration of spring to fall migrations. Among pronghorn with both seasons, spring migrations took significantly longer (mean=17 days) than fall migrations (mean=9; *t*=2.73, df=17, p=0.014).

Mean distance traveled was 82 km (51 mi) during spring migrations (*n*=27, range=6-304 km or 4-189 mi) and 55 km (34 mi) during fall migrations (*n*=19, range=8-150 km or 5-93 mi). Distances traveled by individual pronghorn and seasonal means varied between spring and fall migrations (Table 6). One outlier was identified in spring 2003 data and removed from further distance analyses. The comparison of distance traveled in 2002 and 2003 migrations among pronghorn that had both seasons yielded no difference between years (spring: *t*=0.31, df=6, p=0.770; fall: *t*=-0.33, df=6, p=0.750). With the combination of 2002 and 2003 migrations, lengths of migration routes were not statistically different between pronghorn with both spring and fall routes, though fall migrations were shorter (difference=21 km or 13 mi; *t*=1.42, df=17, p=0.174).

Since earlier analyses found no influence of year on distance, exploratory travel analyses involved grouping migrations across years. The difference between actual route and shortest routes for individual pronghorn was significant in both spring and fall migrations. The greatest difference of 52 km (32 mi) occurred in spring compared to 20 km (12 mi) in fall (spring: *t*=3.93, df=24, p=0.001; fall: *t*=4.36, df=16, p<0.001).

Migration initiation date was negatively related to distance traveled to the subsequent seasonal range. Although both relationships were weak, the spring relationship was significant (spring: r^2=22%, p=0.020; fall: r^2=19%, p=0.080). Five pronghorn were identified as outliers and removed prior to analyses (spring=3, fall=2). In addition, with the exclusion of two outliers, distance between seasonal ranges was not related to migrant summer home range size (r^2=0.0%, p=0.979).

Rate of travel was slightly higher during fall migrations (Table 6). The widest range in rates of travel occurred in fall 2002, with individuals moving from 1 to 21 km/day (0.62-13.0 mi/day). Overall rate of travel was 6 km/day for spring (3.7 mi/day, *n*=27) and 9 km/day for fall (5.6 mi/day, *n*=19).

Spring 2002 had one outlier removed from rate of travel analyses. Differences between years were not significant for either spring or fall migrations (spring: *t*=1.84, df=6, p=0.116; fall: *t*= -1.10, df=6, p=0.314). The combination of year data resulted in a significant difference in rate of travel between spring and fall migrations (*t*=-2.48, df=17, p=0.024). In this last analysis, mean rate of travel for spring was 6 km/day (3.7 mi/day) and for fall was 10 km/day (6.2 mi/day).

Table 5. Seasonal arrival and departure dates for migrating adult female pronghorn in southwestern Wyoming. Dates based on locations collected using Global Positioning System (GPS) collars. Migrations started later in 2003.

Time Period	Dates		Standard Deviation (Days)	Sample Size [a]
Winter 2001-2002	Arrival	unknown [b]		
	Departure	3/26/02	16	14
Spring 2002 Migration	Begin	3/27/02	15	16
	End	4/21/02	19	16
Summer 2002	Arrival	4/21/02	19	16
	Departure	9/19/02	56	13
Fall 2002 Migration	Begin	9/21/02	56	13
	End	10/4/02	52	12
Winter 2002-2003	Arrival	10/6/02	52	12
	Departure	4/7/03	23	19
Spring 2003 Migration	Begin	4/7/03	23	19
	End	4/23/03	23	19
Summer 2003	Arrival	4/24/03	23	19
	Departure	10/11/03	24	16
Fall 2003 Migration	Begin	10/12/03	22	17
	End	11/3/03	8	14
Winter 2003-2004	Arrival	11/4/03	8	14
	Departure	unknown [b]		

[a] Number of pronghorn used to calculate each season's average dates.

[b] Unable to determine because GPS collars were not on sampled pronghorn for the entire season.

Table 6. Migration of adult female pronghorn documented with Global Positioning System (GPS) collars in southwestern Wyoming. Duration, distance traveled, and rate of travel were variable among individuals. (1 km = 0.6 mi)

	Number of Days			
Descriptive	Spring Migration		Fall Migration	
Statistic	2002 (*n*=16)	2003 (*n*=19)	2002 (*n*=12)	2003 (*n*=14)
Mean	26	17	19	13
Std Deviation	24	19	26	20
Median	15	13	12	5
Range	2 - 76	1 - 63	1 - 93	1 - 79

	Total Distance Traveled (km) *			
Descriptive	Spring Migration		Fall Migration	
Statistic	2002 (*n*=16)	2003 (*n*=19)	2002 (*n*=12)	2003 (*n*=14)
Mean	111	62	54	58
Std Deviation	98	59	41	30
Median	80	50	48	52
Range	8 - 304	6 - 221	8 - 150	8 - 118

	Total Distance Traveled Per Day (km/day)			
Descriptive	Spring Migration		Fall Migration	
Statistic	2002 (*n*=16)	2003 (*n*=19)	2002 (*n*=12)	2003 (*n*=14)
Mean	5	6	7	10
Std Deviation	3	4	6	5
Median	5	5	6	9
Range	3 - 17	2 - 14	1 - 21	2 - 20

* Based on distances between consecutive locations.

Evidence of total number of days for migrations correlated to distance traveled was strong in both spring ($p<0.001$) and fall migrations ($p=0.005$). Although both were positive relationships, spring migrations exhibited a stronger relationship than fall ($r = 0.960$ and $r=0.615$, respectively). The correlation between number of days and rate of travel were moderately negative for spring ($r=-0.486$, $p=0.010$) and fall migrations ($r = -0.652$, $p=0.003$). Distance and rate were not correlated in either spring or fall migrations (spring: $p=0.083$, fall: $p=0.085$).

Five general migration routes were identified to show trends among sampled pronghorn. Most migrating pronghorn had winter home ranges along the eastern portion of the study area and summer ranges north and northwest of Kemmerer. Therefore, the primary migration routes ran from areas along WY 372 to Hams Fork drainage (towards Naughton Reservoir; n=6, 14 routes), to areas around Slate Creek drainage (n=6, 9 routes), and to areas near Fontenelle Creek drainage (n=4, 12 routes; Figure 5). Some individuals that participated in the Slate Creek and Fontenelle Creek migration also traveled further north, along Oyster Ridge. Four pronghorn (9 routes) traveled between winter ranges in the east and summer ranges in the west, requiring crossing of fenced WY 240. Two pronghorn wintered on land near WY 28 and traveled north to summer close to Boulder. Individuals with both summer and fall migrations revealed that pronghorn will not consistently return to seasonal ranges following the same route as previous years (Figure 6). The remaining pronghorn migrated short distances between seasonal ranges and did not have routes that were identifiable with previously described routes.

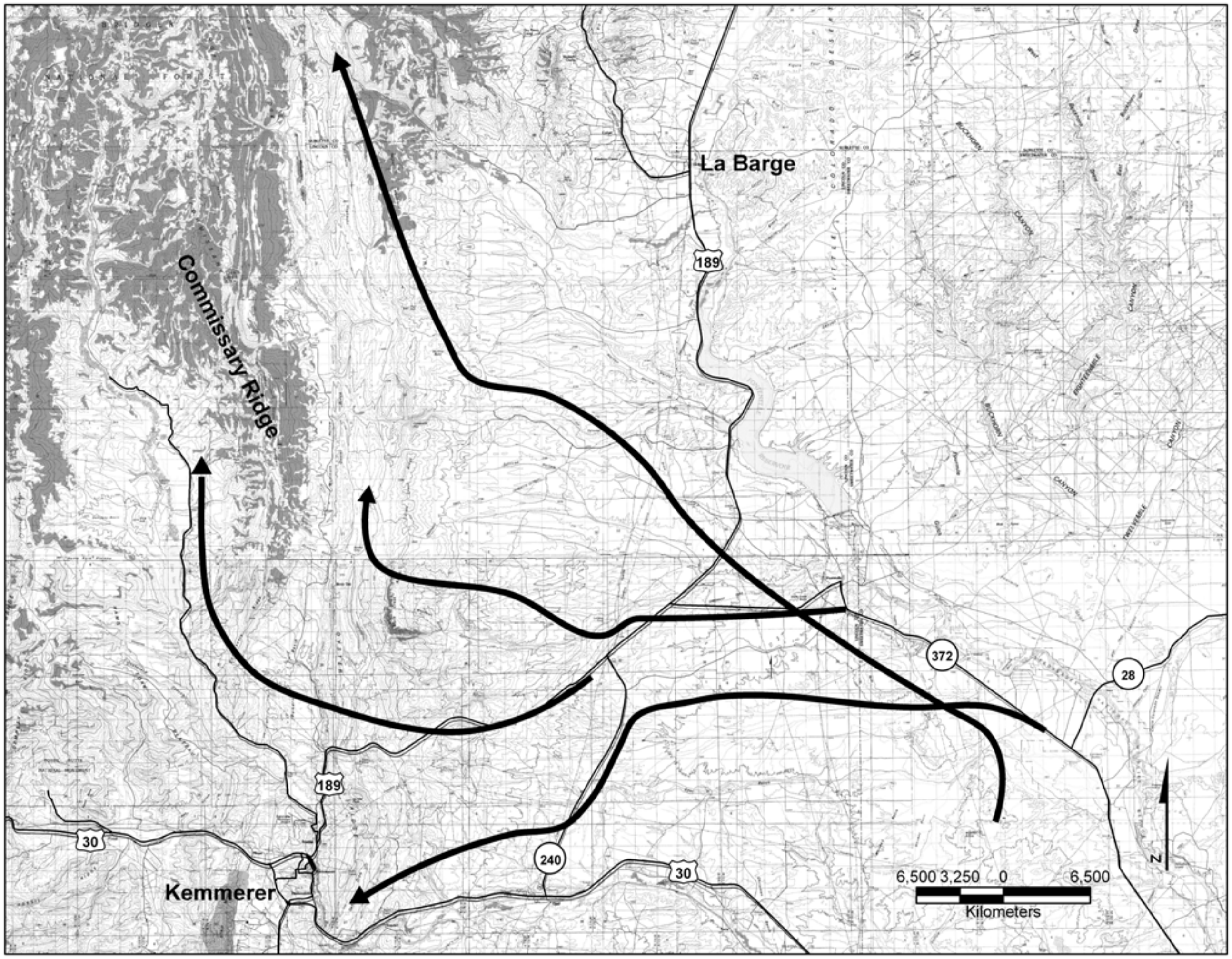


Figure 5. Example of four spring migration routes documented from pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming (2002-2003). Most sampled migratory pronghorn had winter home ranges in the east and traveled west or northwest to summer ranges.

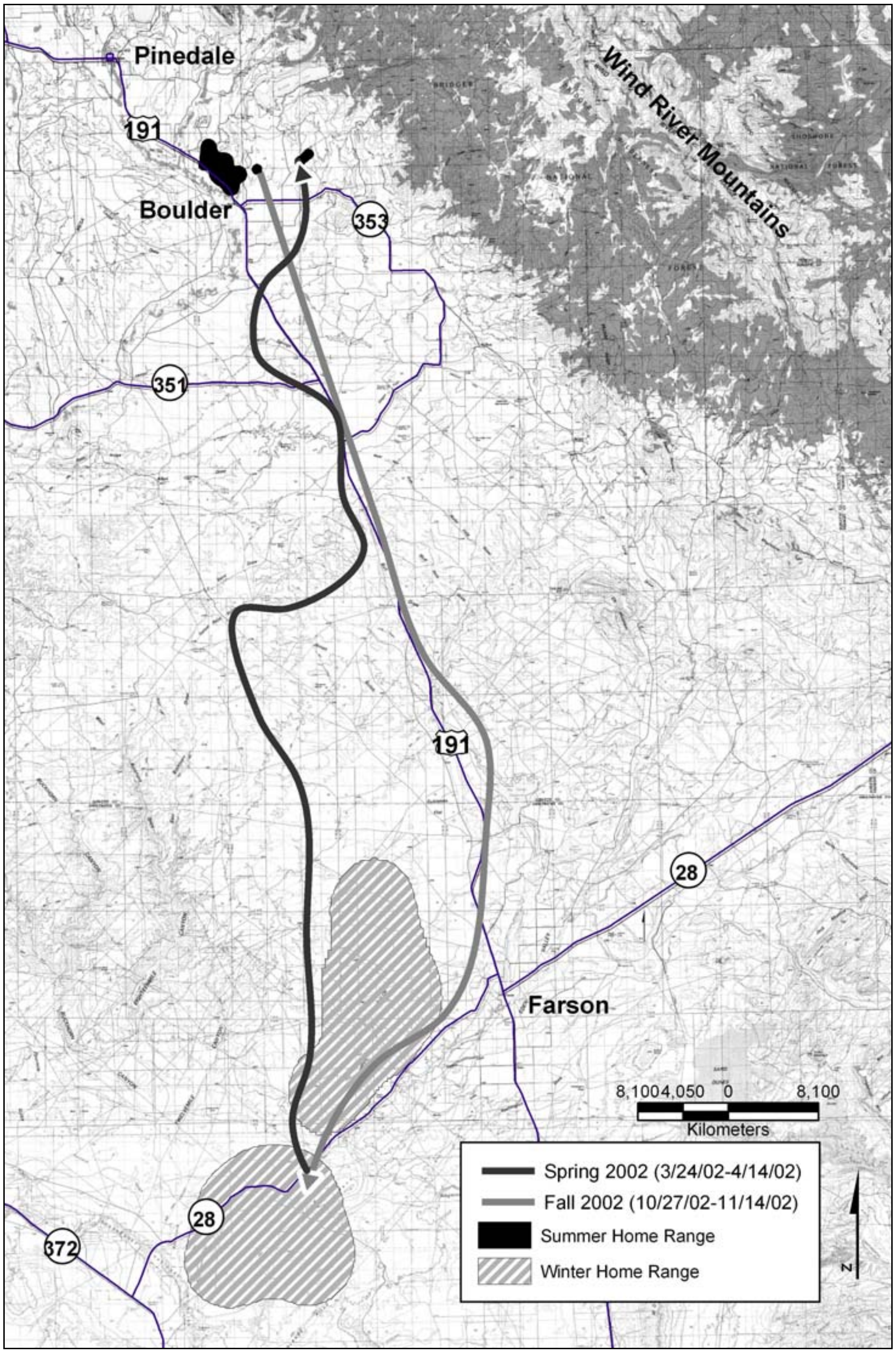


Figure 6. Example of the Boulder migration route documented from a pronghorn fitted with Global Positioning System (GPS) collar in southwestern Wyoming (2002-2003). This individual had its winter range near WY 28 and migrated north in the spring to summer near Boulder. Spring migration reveals a slightly different route than fall migration. One of two migration corridors identified by Raper et al. (1989).

Fences

Home Ranges

During all three winters, pronghorn used sagebrush and saltbush in proportion to availability. Greasewood was used in proportion in winter 2001 and 2003 and selected for in winter 2002. All three vegetation types were consistently used in proportion to availability in both summer 2002 and 2003. Pronghorn were nonselective in home range placement within the study area in regards to vegetation types.

Only one to two pronghorn (4-7%) in each season did not have fences in their home range. All pronghorn had fences in their winter 2003 home ranges. Overall, pronghorn selected winter home ranges with significantly lower total fence densities than available in the study area (t= -3.42, df =39, p=0.002; Table 7). Summer 2002 varied slightly from 2003, though summers generally did not have significantly different fence densities than the study area (t=2.02, df=20, p=0.057; Table 7). All fences types, except wildlife-friendly fence, were found in significantly lower densities in home ranges than in the study area (Table 8). Wildlife-friendly fence density was not significantly lower in winter 2001 (t=-1.59, df=20, p=0.128), winter 2003 (t=-0.97, df=16, p=0.344), and summer 2002 (t=-1.17, df=13, p=0.263).

Home range zones (70-95%) and core areas (50%) differed between each other and among years in total fence density compared to density within the study area (Table 9). Total fence densities within 95% home range zones were not statistically different from the study area in four of the five seasonal periods. Summer 2002 was the only season where 80% home range zones and lower were not statistically different. Within each year's individual season, *p*-values decreased as the intensity of use increased. The lowest *p*-values were associated with core areas of home ranges. Fence densities in all home range zones and core areas were lower than the study area.

No difference was found in three of five seasons in total fence density between the different zones (50%-95%) of home ranges (winter 2001: f(3,16)=2.45, p=0.070; winter 2002: f(3,21)=3.35, p=0.022; winter 2003: f(3,13)=2.17, p=0.100; summer 2002: f(3,9)=1.53, p=0.219; summer 2003: f(3,9)=3.05, p=0.037). Significant difference between zones was noted when seasons were averaged, however, especially between core areas and 95% zones (winter: f(3,35)=5.81, p=0.001; summer: f(3,14)=3.11, p=0.032). Individual examination of fence densities in 95% zones compared to 80% zones, 70% zones, and 50% core areas for individual pronghorn resulted in consistent trends within each season (Table 10). The 95% zones consistently had higher total fence density than core areas and comparisons often exhibited increasing *p*-values as zones extended further from the core.

Weak but significant relationships were found between total fence density and home range zones (winter 2001: r^2=8.6%, p=0.008; winter 2002: r^2=9.4%, p=0.002; winter 2003: r^2=8.6%, p=0.015; summer 2002: r^2=8.5%, p=0.036; summer 2003: r^2=15.8%, p=0.003).

During summer months, either individual or when summers were averaged, fence densities within home ranges (used) were not statistically different from those in the 500 (0.3 mi) or 1000 m (0.6 mi) buffer zones outside the home ranges (Table 11). Similarly, fence densities within the buffer zones that encircled averaged summer ranges were not found to be different than available in the study area (500m vs. study area: t=-0.91, df=19, p=0.373; 1000m vs. study area: t=-0.49, df=19, p=0.627). Although approaching significance, overall winter home range fence densities were not different from the buffer zones (home range vs. 500m: t=-1.87, df=55, p=0.066; home range vs. 1000m: t=-1.80, df=55, p=0.077; Table 11). Fence density in buffer zones of winter home ranges did not differ consistently with the study area across the three winter periods. When winter periods were combined, fence densities were found to be lower within buffer zones than in the study area (1000m vs. study area: t=-3.02, df=39, p=0.004; 500m vs. study area: t=-2.82, df=39, p=0.008).

Distribution within the home range (2nd-order selection, Johnson 1980) of wildlife-friendly and net-wire (includes one to three strands barbed wire on top) fences differed (Table 12). The density of net-wire fence was significantly different between home range zones (50% core area, 70% zone, 80% zone, 95% zone) for three of the five seasons and approaching significance in the other two. Wildlife-friendly fence density, on the other hand, differed between zones in only one of five seasons.

Table 7. Comparing fence density in 95% fixed kernel pronghorn home ranges (Worton 1989) to available fence density in the study area (364 m/km^2). Fence densities include all fence types. Locations used in home ranges estimates collected from adult pronghorn in southwestern Wyoming (January 2002 – December 2003). Overall, pronghorn selected winter home ranges with significantly lower fence densities than in the study area. (1 m/km^2 = 8.41 ft/mi^2)

Season	*n*	Mean [a]	95% Confidence Interval for Mean [a]		*p*-value [b]
			Upper	Lower	
Winter 2001	21	167	115	271	0.039
Winter 2002	26	221	80	348	0.094
Winter 2003	17	193	122	399	0.005
Winter 2001-2003 [c]	40	177	127	292	0.002
Summer 2002	14	219	82	580	0.280
Summer 2003	15	122	37	393	0.065
Summer 2002-2003 [c]	20	148	58	376	0.057

[a] Original data were log-transformed (log(fence density+1)) prior to analysis to correct for non-normally distributed data. Results presented were back-transformed.

[b] Statistical results are reported directly from log-transformed analyses.

[c] Pronghorn with multiple years had data averaged to provide a single value.

Table 8. Comparing fence density (m/km^2) by fence type in 95% fixed kernel home ranges (Worton 1989) to available densities in the study area. Locations used in home ranges estimates collected from adult pronghorn in southwestern Wyoming (January 2002 – December 2003). *P*-values of comparisons are reported. Pronghorn consistently selected significantly lower densities of all fence types except wildlife-friendly fence. (1 m/km^2 = 8.41 ft/mi^2)

I. Winter *p*-values [a]

Fence Type	2001-2003 [b] (*n*=40)	2001 (*n*=21)	2002 (*n*=26)	2003 (*n*=17)
2-3 Wire	< 0.001	< 0.001	< 0.001	< 0.001
Wildlife-Friendly	0.001	0.128	0.003	0.344
4 Wire	< 0.001	< 0.001	< 0.001	< 0.001
5-7 Wire	< 0.001	< 0.001	0.018	---
Net-Wire	< 0.001	< 0.001	0.011	0.027

II. Summer *p*-values [a]

Fence Type	2002-2003 [b] (*n*=20)	2002 (*n*=14)	2003 (*n*=15)
2-3 Wire	0.009	0.026	0.005
Wildlife-Friendly	0.003	0.263	0.005
4 Wire	< 0.001	< 0.001	< 0.001
5-7 Wire	< 0.001	< 0.001	< 0.001
Net-Wire	0.001	0.007	0.006

[a] Original data were log-transformed (log(fence density+1)) prior to analysis to correct for non-normally distributed data. Statistical results are reported directly from log-transformed analyses.

[b] Pronghorn with multiple years had data averaged to provide a single value.

Table 9. Comparing fence density in pronghorn home range zones compared to available density in the study area (364 m/km^2). Fence densities include all fence types. Locations used in home ranges estimates collected from adult pronghorn in southwestern Wyoming (January 2002 – December 2003). *P*-values are reported. As intensity of use increases within home ranges, so does statistical significance and difference from the study area. (1 m/km^2 = 8.41 ft/mi^2)

I. Winter *p*-values [a]

Home Range Zones [b]	2001-2003 [c] (*n*=40)	2001 (*n*=21)	2002 (*n*=26)	2003 (*n*=17)
95%	0.007	0.055	0.182	0.015
80%	< 0.001	0.026	0.031	0.019
70%	< 0.001	0.027	0.021	0.012
50%	< 0.001	0.001	0.001	0.002

II. Summer *p*-values [a]

Home Range Zones [b]	2002-2003 [c] (*n*=20)	2002 (*n*=14)	2003 (*n*=15)
95%	0.088	0.325	0.098
80%	0.008	0.140	0.015
70%	0.005	0.136	0.007
50%	< 0.001	0.024	< 0.001

[a] Original data were log-transformed (log(fence density+1)) prior to analysis to correct for non-normally distributed data. Statistical results are reported directly from log-transformed analyses.

[b] Home range zones initially created from fixed kernel home ranges (Worton 1989) were modified to represent distinct portions of home ranges. Level of intensity of use, reflected in location density, decreases as percentage increases.

[c] Pronghorn with multiple years had data averaged to provide a single value.

Table 10. Comparing total fence density in 95% home range zones to that in all other home range zones and core areas. Locations used in home ranges estimates collected from adult pronghorn in southwestern Wyoming (January 2002 – December 2003). *P*-values are reported. Fence densities were significantly different in all comparisons of 95% home range zones and core areas. In general, significance decreases as comparisons are made to zones that extend further from the core.

Seasons	95% vs. 50% [a,b]	95% vs. 70% [a,c]	95% vs. 80% [a,d]
Winter 2001	0.002	0.102	0.085
Winter 2002	0.003	0.057	0.056
Winter 2003	0.007	0.029	0.042
Winter 2001-2003 [e]	<0.001	0.002	0.001
Summer 2002	0.047	0.214	0.222
Summer 2003	0.002	0.069	0.122
Summer 2002-2003 [e]	0.001	0.026	0.054

[a] Home range zones initially created from fixed kernel home ranges (Worton 1989) were modified to represent distinct portions of home ranges. Level of intensity of use, reflected in location density, decreases as percentage increases.

[b] 95% Home Range Zone vs. 50% Core Area

[c] 95% Home Range Zone vs. 70% Zone

[d] 95% Home Range Zone vs. 80% Zone

[e] Pronghorn with multiple years had data averaged to provide a single value.

Table 11. Comparing total fence density in 95% home ranges to the areas bordering the home ranges. The buffered edges range from 0-500m and 500-1000m from the boundary of home ranges. Also comparing total fence density in buffered edges to the study area. Home ranges estimated using fixed kernel method (Worton 1989) and based on locations collected from adult pronghorn in southwestern Wyoming (January 2002 – December 2003). *P*-values are reported. Buffered edge of averaged winter home ranges had significantly lower fence densities than available in the study area. (500 m = 0.3 mi, 1000 m = 0.6 mi)

I. Home Range vs. Buffered Edge (Zone) [a]

	95% vs. 500m	95% vs. 1000m
Winter 2001	0.396 [b]	0.240 [c]
Winter 2002	0.438 [b]	0.855 [b]
Winter 2003	0.075 [b]	0.038 [b]
Winter 2001-2003 [d]	0.066 [c]	0.077 [c]
Summer 2002	0.357 [b]	0.229 [b]
Summer 2003	0.166 [b]	0.174 [b]
Summer 2002-2003 [d]	0.137 [b]	0.089 [b]

II. Buffered Edge (Zone) vs. Study Area [a]

	1000m vs. Study Area	500m vs. Study Area
Winter 2001	0.009	0.064
Winter 2002	0.116	0.135
Winter 2003	0.146	0.081
Winter 2001-2003 [d]	0.004	0.008
Summer 2002	0.617	0.683
Summer 2003	0.344	0.210
Summer 2002-2003 [d]	0.627	0.373

[a] Original data were log-transformed (log(fence density+1)) prior to analysis to correct for non-normally distributed data. Statistical results are reported directly from log-transformed analyses.

[b] Equal variance.

[c] Unequal variance.

[d] Pronghorn with multiple years had data averaged to provide single value.

Table 12. Evaluation of two fence types commonly found within the study area. Fence densities within individual home ranges zones were compared to the study area. Individual home ranges were divided into concentric rings (zones) based on density of locations (50% core area, 70% zone, 80% zone, 95% zone). Home range boundaries estimated using fixed kernel method (Worton 1989). Locations collected from pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming (2002-2003). Generally non-significant differences in densities of wildlife-friendly fence between home range zones.

Seasons	Wildlife-friendly [a,b]	Net-wire [a,c]
Winter 2001	0.427	0.036
Winter 2002	0.531	0.023
Winter 2003	0.001	0.063
Winter 2001-2003 [d]	0.034	<0.001
Summer 2002	0.655	0.060
Summer 2003	0.160	0.037
Summer 2002-2003 [d]	0.539	0.014

[a] Original data were log-transformed (log(fence density+1)) prior to analysis to correct for non-normally distributed data. Statistical results are reported directly from log- transformed analyses.

[b] Wildlife-friendly fence defined as a four wire fence with smooth bottom wire and at least 41 cm (16 in) above the ground.

[c] Includes one to three strands of barbed-wired on top.

[d] Pronghorn with multiple years had data averaged to provide single value.

Migration Routes

There was weak evidence that pronghorn antelope were selecting migration routes with different fence densities than found within the study area. Fence densities within buffered migration routes were not significantly different from the study area in any of the four migration periods (spring 2002: t=-2.00, df=11, p=0.071; fall 2002: t=-0.07, df=4, p=0.946; spring 2003: t=0.77, df=11, p=0.460; fall 2003: t=-1.34, df=11, p=0.206).

In addition, there was strong evidence that routes chosen by pronghorn during the four migration periods were longer than the most direct routes between seasonal ranges (spring 2002: t=2.85, df=11, p=0.016; fall 2002: t=2.88, df=4, p=0.045; spring 2003: t=2.99, df=11, p=0.012; fall 2003: t=2.93, df=11, p=0.014).

Topographic roughness values in the shortest routes did not differ from topographic values in actual routes in any of the four migration periods (spring 2002: t= -1.28, df=11, p=0.226; fall 2002: t=1.00, df=4, p=0.374; spring 2003: t= -1.39, df=11, p=0.193; fall 2003: t= -0.07, df=11, p=0.945). Comparison of actual to alternate routes generally yielded similar results, although actual routes in fall 2003 had greater roughness index than alternate routes (spring 2002: t= -0.73, df=11, p=0.480; fall 2002: t= -0.59, df=4, p=0.590; spring 2003: t= -1.55, df=11, p=0.149; fall 2003: t= -2.58, df=11, p=0.026). Topographic roughness was also similar between actual and random routes (spring 2002: t=1.61, df=11, p=0.136; fall 2002: t=2.07, df=4, p=0.107; spring 2003: t=1.84, df=11, p=0.093; fall 2003: t=0.66, df=11, p=0.520).

No difference was found in proportions of sagebrush, greasewood, and saltbush between actual and shortest migration routes during any of the four migration periods. In 12 comparisons of vegetation in actual and alternate routes, only saltbush differed and only in spring 2002 (t= -3.13, df=11, p=0.010) and fall 2003 (t= -2.50, df=11, p=0.030). Vegetation differed in three of the 12 comparisons of actual to random (census of study area) migration routes. Saltbush was found less in actual routes than random routes during spring 2003 (t= -6.45, df=11, $p<0.001$) and fall 2003 (t= -5.03, df=11, $p<0.001$) migrations. The proportion of sagebrush was more common in the actual routes than random routes in spring 2003 (t=4.62, df=11, p=0.001).

Fence crossing rate did not differ between actual and shortest routes during migration except in spring 2002 (spring 2002: t=-5.43, df=11, $p<0.001$; fall 2002: t=-0.45, df=4, p=0.677; spring 2003: t=-0.56, df=11, p=0.587; fall 2003: t=0.30, df=11, p=0.771). When years were combined, there was strong evidence of a difference in spring migrations, but not fall migration (spring: t=-2.24, df=19, p=0.037; fall: t=-0.09, df=15, p=0.929). Net-wire fence crossing rate was less in actual routes than on shortest routes for spring 2002 (t=-2.69, df=8, p=0.028), but not different in any other migration period (fall 2002: t=0.05, df=3, p=0.965; spring 2003: t=-1.82, df=8, p=0.106; fall 2003; t=-0.61, df=9, p=0.555). Wildlife-friendly fence crossing rates were similar among the various route types (spring 2002: t=-2.25, df=5, p=0.075; fall 2002: t=-0.45, df=3, p=0.681; spring 2003: t=0.50, df=4, p=0.645; fall 2003: t=2.27, df=5, p=0.072).

Spring 2002 was also the only migration period where fence crossing rate differed between actual and alternate routes (t= -3.15, df=11, p=0.009). When seasons across years were combined, there was moderate evidence of a difference in fence crossing rates during in spring and weak evidence of a difference during fall (spring: t= -1.85, df=19, p=0.080; fall: t= -0.94, df=15, p=0.363). Net-wire (spring 2003: t= -2.33, df=11, p=0.040) and wildlife-friendly fence (spring 2002: t= -2.87, df=11, p=0.015) were each found less in one of four migration periods.

Difference between actual and random routes occurred in two of four migration periods, with lower fence crossing rates in actual migrations routes (spring 2002: t= -3.71, df=11, p=0.003; fall 2003: t= -3.06, df=11, p=0.011). When 2002 and 2003 migrations were combined, there was strong evidence that both spring and fall migration had lower fence crossing rates on actual than random routes (spring: t=2.63, df=19, p=0.016; fall: t=3.61, df=15, p=0.003). Net-wire fences were crossed at lower rates on actual than random routes in both spring migrations (2002: t= -3.03, df=11, p=0.011; 2003: t= -2.76, df=11, p=0.019) and approaching significance in fall 2003 (t= -2.07, df=11, p=0.063). Crossing rates for wildlife-friendly fence did not differ between actual and random routes except in fall 2003 (t= -3.71, df=11, p=0.003).

Roads

Primary roads were found within home ranges more often than within core area. Furthermore, primary roads were incorporated into winter home ranges more often than summer ranges (Table 13). WY 372 was overlapped by more home ranges in winter and summer ranges although it was only 28% longer than US 189. Few pronghorn home ranges overlapped US 30 or WY 240. No summer home ranges overlapped WY 240 and no core areas overlapped US 30.

Crossing of Primary Roads

Average annual percentage of pronghorn that crossed WY 372 was higher in winter than summer (Table 14). Fifty-one (71%) pronghorn crossed WY 372 780 times between January 2002 - December 2003. Yearly average number of crossings per pronghorn ranged widely from 4-14 in winter, but averaged only five crossings in summer. Most pronghorn that did not cross WY 372 during a given season had locations >1 km (0.6 mi) from the highway (no potential), especially during summer (Figure 7). Fewer pronghorn crossed during migration periods (n=9, 33%) than within seasons (n=49, 68%). All migrating pronghorn either crossed WY 372 or had no locations <1 km (0.6 mi) of the highway.

Sections of WY 372 with the highest number of winter crossings (>30) over the three years were also crossed by the largest number of pronghorn ($\geq$10; Figure 8). Road sections repeatedly crossed during consecutive winters were unfenced (Figure 9). Additionally, seven pronghorn crossed the unfenced portion of WY 372, 84 times in winter 2001, the year before it was fenced. Pronghorn No.25, alone, crossed this area 23 times in four months. In winter 2002, midway through which both sides of the road were fenced with wildlife-friendly fence, two (5%) pronghorn crossed 16 times. Pronghorn No. 25, the only pronghorn still collared from winter 2001, crossed 15 times in winter 2002 (pre-construction=5, during construction=10, post-construction=0). In winter 2003, no collared pronghorn crossed this section of WY 372.

Pronghorn crossed WY 372 less frequently in summer and generally crossed the road during summer in the same sections as they had during the winter (Figure 10). Road sections crossed most frequently: fenced with wildlife-friendly fence on both sides, wildlife-friendly fence on one side, and net-wire fence on one side.

Overall, 12 (17%) of the collared pronghorn did not cross WY 372, but had locations <1 km (0.6 mi) from the highway. No pronghorn had locations <1 km from the highway that did not cross during migration periods. Sections of WY 372 with the highest number (n=3) of pronghorn with locations <1 km from the road were 18 and 40-45, all fenced on one side. One pronghorn did not cross WY 372 but had 538 (81%) winter and 40 (63%) summer locations <1 km from sections 40-46 (Figure 10).

Twenty-five pronghorn had summer ranges outside the study area, yielding 25 spring and 22 fall migration paths (Figure 11). All migrating pronghorn either crossed WY 372 or did not have the potential. Road sections with the largest number of crossings (≥2) and the highest number of pronghorn (≥2) were unfenced. Areas of crossing were concentrated along the northern portion (sections 1-30) of WY 372 during all four migration periods except in spring 2002, when pronghorn crossings were more evenly distributed along the highway.

Twenty-seven (38%) pronghorn crossed US 189 a total of 200 times from January 2002 to December 2003. Most pronghorn that did not cross the highway during seasons or migration periods had locations >1 km (0.6 mi) from the highway (Figure 12, Figure 13). Within-season crossings of US 189 were about twice as common during winter than summer (Table 15). Yearly average number of crossings per pronghorn ranged from four to eight in winter and averaged five crossings in summer.

Eight (29%) pronghorn crossed US 189 during the first winter, but then were located >1 km (0.6 mi) from the highway in the following winter and did not cross (Figure 12). Of the 18 pronghorn that crossed the road during winter, only one crossed during multiple winters. The area she crossed had only a 2-3 wire fence on one side of the highway. Road sections with the highest number of winter and summer crossings per pronghorn were either unfenced, 2-3 wire fence on one side, or wildlife-friendly fence on both sides of the road (Figure 14). Seasonal crossings of US 189 occurred in the northeastern portion, between sections 32-53, and especially near the intersection with WY 372 (section 39).

The proportion of pronghorn that did not cross the highway though they had locations <1 km (0.6 mi) away was higher within seasons (n=15, 21%) than during migrations (n=4, 15%). Road sections where pronghorn did not cross were central along US 189 during winter and on the ends in summer (Figure 15). Most uncrossed sections within seasons were associated with fenced highway, either fenced on both sides (wildlife-friendly or 4-wire) or one side (5-7 wire). Portions of the highway fenced on both sides with wildlife-friendly fence or 4-strands of barbed wire on one side were also not crossed during migration periods, though locations were found <1 km (0.6 mi).

Unlike WY 372, a greater proportion of pronghorn crossed US 189 during migration (n=15, 56%) than within seasons (n=22, 31%; Table 15). Annual migration periods were relatively consistent, with eight (47%) to nine (56%) of migrating pronghorn crossing US 189. All migration periods, except spring 2002, had pronghorn with locations <1 km (0.6 mi) of the road, but did not cross. Fall and spring migrations resulted in the largest proportion of pronghorn that consistently crossed the highway over multiple periods (57% and 63%, respectively). Both migrations included individuals that repeatedly crossed particular roads sections that were not fenced. Road sections with highest total number of crossings (5) were either wildlife-friendly fenced (both sides) or fenced with 4-stranded barbed wire (one side). The largest number of crossings per pronghorn occurred where the road had no fence, wildlife-friendly fence, or a 4-wire design. Unlike seasonal crossings of US 189, pronghorn crossings during migrations occurred along almost the entire highway (Figure 16).

Highway Rights-of-Way

Pronghorn consistently selected home ranges with lower proportion of ROWs than available in the study area (winter 2001: t = -233.3, df = 20, p<0.001; winter 2002: t = -264.3, df = 25, p<0.001; winter 2003: t = -311.2, df = 16, p<0.001; summer 2002: t = -170.4, df = 13, p<0.001; summer 2003: t = -231.6, df = 14, p=0.001).

To isolate the potential influence of roads, location density within home ranges were compared to density of locations within the unfenced (NF_NF) ROWs. For all three winters and both summers, location density within home ranges was higher than in the NF_NF ROWs (winter 2001: paired t = 2.82, df = 14, p=0.014; winter 2002: paired t = 3.06, df =1 7, p=0.007; winter 2003: paired t = 4.72, df = 12, p<0.001; summer 2002: paired t = 6.77, df = 6, p=0.001; summer 2003: paired t = 5.03, df = 6, p=0.002).

Thirty-four (85%) pronghorn had ROWs in at least one of their winter ranges. Core areas with ROWs was 57% (n=12) in winter 2001, 62% (n=16) in 2002, and 29% (n=5) in 2003. In summer 2002, the number of pronghorn that had ROWs in their home ranges was 11 (79%), with only five (36%) including ROWs in their core areas. The number of pronghorn that incorporated ROWs in their 2003 summer home ranges was the lowest of all seasons (n=8, 53%). The number of pronghorn including ROWs in their 2003 core areas dropped to five (33%).

Of the 72 pronghorn monitored, 32 were located 124 times during winter within ROWs. Based on these locations, ROWs were not used in proportion to their availability (pre-construction: χ^2 = 49.3, df = 7, p<0.001; post-construction: χ^2 = 264.6, df = 7, p<0.001). In both pre- and post-construction analyses (after 20 km, 12.4 mi, of wildlife-friendly fence was constructed in 2002 on WY 372), WF_NF and NF_NF ROWs were used more than expected and Net_Net ROWs less than expected (Table 16). WF_WF was also used less than expected in both analyses, although strong evidence was found in post-construction analysis. The number of locations within BRB_BRB, >4BRB_NF, and 2-3W_NF did not differ from expected. Net_NF ROWs were used as expected during pre-construction, but less than expected in post-construction.

WY 372, pre and post-construction, and US 189 ROWs were not crossed in proportion to their availability (WY 372 pre-construction: χ^2 = 172.4, df = 5, p<0.001; WY 372 post-construction: χ^2 = 318.5, df = 5, p<0.001; 189: χ^2 = 129.4, df = 4, p<0.001). Both highways had NF_NF ROWs crossed more than expected and WF_WF ROWs consistently crossed less than expected (WY 372:Table 17; US 189: Table 18). Pronghorn crossing of 2-3W_NF ROW was inconsistent - crossing it less than expected during pre-construction of WY 372 and similar to what was expected during WY 372 post-construction and on US 189. Net_NF ROW was found only on WY 372 and was crossed less than expected during pre-construction and similar to what was expected in post-construction. Crossing of US 189 along ROWs fenced with > 4-strands of barbed wire on one side and unfenced on the other was less than expected (Table 18).

Unlike WY 372, a greater proportion of pronghorn crossed US 189 during migration (n=15, 56%) than within seasons (n=22, 31%; Table 15). Annual migration periods were relatively consistent, with eight (47%) to nine (56%) of migrating pronghorn crossing US 189. All migration periods, except spring 2002, had pronghorn with locations <1 km (0.62 mi) of the road, but did not cross. Fall and spring migrations resulted in the largest proportion of pronghorn that consistently crossed the highway over multiple periods (57% and 63%, respectively). Both migrations included individuals that repeatedly crossed particular roads sections that were not fenced. Road sections with highest total number of crossings (5) were either wildlife-friendly fenced (both sides) or fenced with four-stranded barbed wire (one side). The largest number of crossings per pronghorn occurred where the road had no fence, wildlife-friendly fence, or a four-wire design. Unlike seasonal crossings of US 189, pronghorn crossings during migrations occurred along almost the entire highway (Figure 16).

Table 13. Proportion of pronghorn in each season with 50% and 95% fixed kernel (Worton 1989) home ranges that overlapped primary roads in study area. Based on location density, 50% home ranges represent core areas and 95% represents general home range boundaries. Home ranges based on locations collected using Global Positioning System (GPS) collars placed on adult female pronghorn in southwestern Wyoming (January 2002 – December 2003).

		50% Home Ranges			95% Home Ranges		
	Total [a]	*n* [b]	% [c]	% Average [d]	*n* [b]	% [c]	% Average [d]
WY 372							
Winter 2001	21	10	47.6		16	76.2	
Winter 2002	26	11	42.3	35.9	18	69.2	75.9
Winter 2003	17	3	17.6		14	82.4	
Summer 2002	14	2	14.3	13.8	8	57.1	45.2
Summer 2003	15	2	13.3		5	33.3	
US 189							
Winter 2001	21	1	4.8		3	14.3	
Winter 2002	26	6	23.1	11.2	12	46.2	22.1
Winter 2003	17	1	5.9		1	5.9	
Summer 2002	14	1	7.1	10.2	3	21.4	24.0
Summer 2003	15	2	13.3		4	26.7	
WY 28							
Winter 2001	21	3	14.3		4	19.0	
Winter 2002	26	1	3.8	10.0	2	7.7	24.6
Winter 2003	17	2	11.8		8	47.1	
Summer 2002	14	1	7.1	6.9	1	7.1	6.9
Summer 2003	15	1	6.7		1	6.7	
US 30							
Winter 2001	21	0	0.0		0	0.0	
Winter 2002	26	1	3.8	1.3	3	11.5	3.8
Winter 2003	17	0	0.0		0	0.0	
Summer 2002	14	0	0.0	0.0	0	0.0	3.3
Summer 2003	15	0	0.0		1	6.7	
WY 240							
Winter 2001	21	0	0.0		2	9.5	
Winter 2002	26	1	3.8	1.3	9	34.6	14.7
Winter 2003	17	0	0.0		0	0.0	
Summer 2002	14	0	0.0	0.0	0	0.0	0.0
Summer 2003	15	0	0.0		0	0.0	

[a] Total number of pronghorn in each season examined for home range overlap of road.

[b] Number of pronghorn with home ranges that overlapped road.

[c] Proportion of pronghorn in each season with home ranges that overlapped road (a/b).

[d] Average proportion of pronghorn grouped seasons with home ranges that overlapped road.

Table 14. Number of pronghorn that did and did not cross WY 372 while on seasonal ranges and during migrations. Crossing defined as consecutive locations on opposite sides of the road. Locations collected using Global Positioning System (GPS) collars placed on adult female pronghorn in southwestern Wyoming (January 2002 – December 2003).

I. Within Seasons [a]

	# Pronghorn Crossed	Mean (SD) Crossings/Pronghorn	No. of Pronghorn Not Crossed	
			No Opportunity [b]	Yes Opportunity [c]
Winter 2001	28 (52%)	13 (10.6)	18 (33%)	8 (15%)
Winter 2002	21 (55%)	14 (13.6)	16 (42%)	1 (3%)
Winter 2003	13 (62%)	4 (2.3)	4 (19%)	4 (19%)
Winters 2001-2003	43 (60%)			
Summer 2002	5 (16%)	6 (3.8)	21 (68%)	5 (16%)
Summer 2003	5 (17%)	3 (2.5)	22 (76%)	2 (7%)
Summers 2002-2003	9 (21%)			

II. Migration [d]

	# Pronghorn Crossed	Mean (SD) Crossings/Pronghorn	No. of Pronghorn Not Crossed	
			No Opportunity [b]	Yes Opportunity [c]
Fall 2002	2 (17%)	1 (0.0)	10 (83%)	0 (0%)
Fall 2003	4 (24%)	2 (1.0)	13 (76%)	0 (0%)
Falls 2002-2003	5 (23%)			
Spring 2002	8 (50%)	2 (1.2)	8 (50%)	0 (0%)
Spring 2003	3 (18%)	1 (0.0)	14 (82%)	0 (0%)
Springs 2002-2003	8 (32%)			

[a] Analysis used locations from all sampled pronghorn,
[b] Number of pronghorn that did not have locations within 1 km (0.6 mi) of road.
[c] Number of pronghorn that did have locations within 1 km (0.6 mi) of road.
[d] Analysis limited to pronghorn with $\geq$ 50% of migration route within the study area.

<u>Winter Period</u> (72 pronghorn sampled)

1. 44 (61%) pronghorn had one winter period of data: [2001=34, 2002=10, 2003=0]
   a. 22 (50%) crossed WY 372
   b. 2 (4.5%) had locations <1km away from the road but did not cross
   c. 20 (45.5%) had all locations >1km from the road (no potential)
2. 28 (39%) pronghorn had > 1 year of winter data: [2 years: n=15, 3 years: n=13]
   a. 10 (36%) consistently crossed WY 372
      → 6 crossed same road sections at least 2 years in a row (all unfenced)
   b. 1 (4%) consistently had locations <1km away from WY 372 (road sections 40-45 all 3 years) but did not cross
   c. 5 (18%) consistently had all locations >1km away from the road
   d. 12 (43%) alternated between (1) crossing, (2) no cross but locations <1 km away from WY 372, (3) no cross and all locations >1km away from WY 372
      → no consistent pattern

<u>Summer Period</u> (43 pronghorn sampled)

1. 26 (60%) pronghorn had one summer period of data: [2002=14, 2003=12]
   a. 6 (23%) crossed WY 372
   b. 1 (3%) had locations <1km away from the road but did not cross
   c. 19 (73%) had all locations >1km from the road (no potential)
2. 17 (40%) pronghorn had > 1 year of summer data: [both years]
   a. 1 (6%) consistently crossed WY 372 (wildlife-friendly & unfenced sections)
   b. 2 (12%) consistently had locations <1km away from WY 372 but did not cross
   c. 10 (59%) consistently had all locations >1km away from the road
   d. 2 (12%) exhibited pattern of year 1: all locations >1km away from WY 372, year 2: crossed WY 372
   e. 2 (12%) exhibited pattern of year 1: locations <1km away but did not cross, year 2: all locations >1km away

Figure 7. Summary of pronghorn response to WY 372 within season. Adult female pronghorn were captured in southwestern Wyoming and fitted with Global Positioning System (GPS) collars (2002-2003). Crossing defined as consecutive locations on opposite sides of the highway. More pronghorn crossed during winter than summer. Most pronghorn that did not cross while on seasonal ranges had all locations > 1km from the highway. (1 km = 0.6 mi).

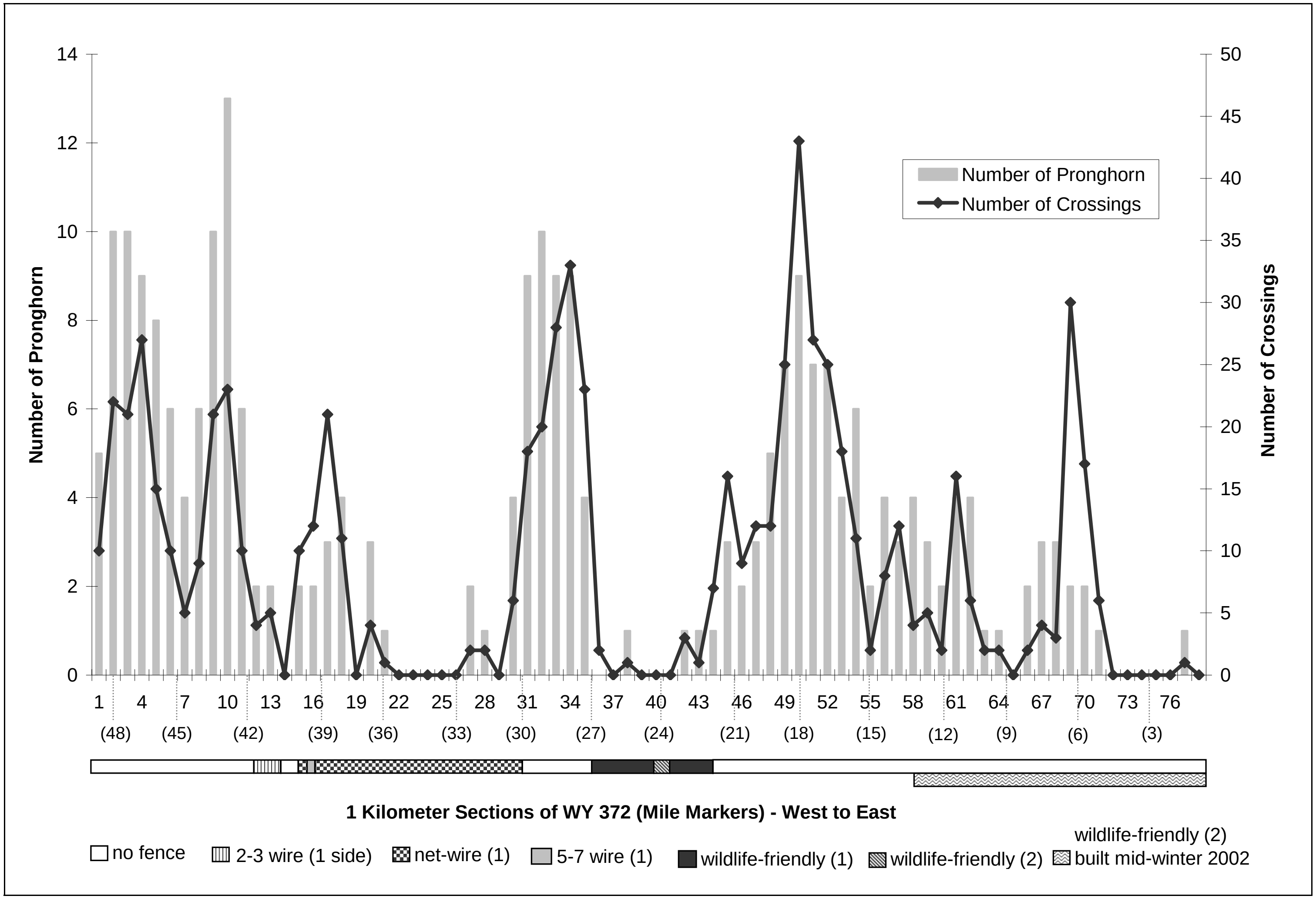


Figure 8. Pronghorn winter (2001-2003) crossing of WY 372. Crossing defined as consecutive locations on opposite sides of the road. Highway is divided into one kilometer sections (west to east) to allow for identification of high crossing areas. Peaks in both number of crossings and number of pronghorn are associated with unfenced sections. Data from adult female pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming. (1 km = 0.62 mi)

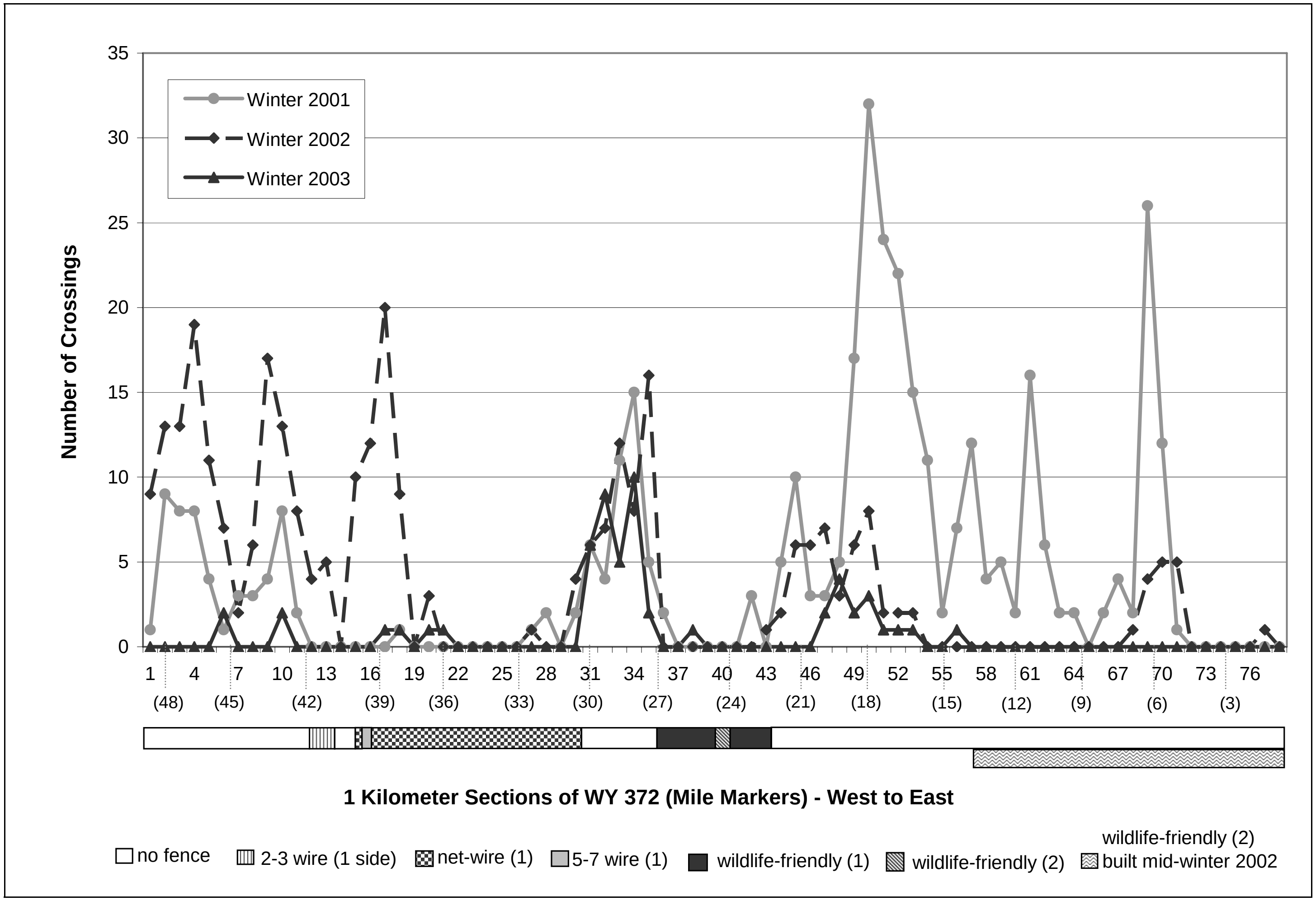


Figure 9. Pronghorn annual winter (2001-2003) crossing of WY 372. Crossing defined as consecutive locations on opposite sides of the road. Highway is divided into one kilometer sections to allow for identification of high crossing areas. Annual peaks in number of crossings consistently occur along unfenced sections. Documented crossing of eastern portion ceases after construction of wildlife-friendly fence (sections 58-78) on both sides of road in mid-winter 2002. Data from adult female pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming. (1 km = 0.62 mi)

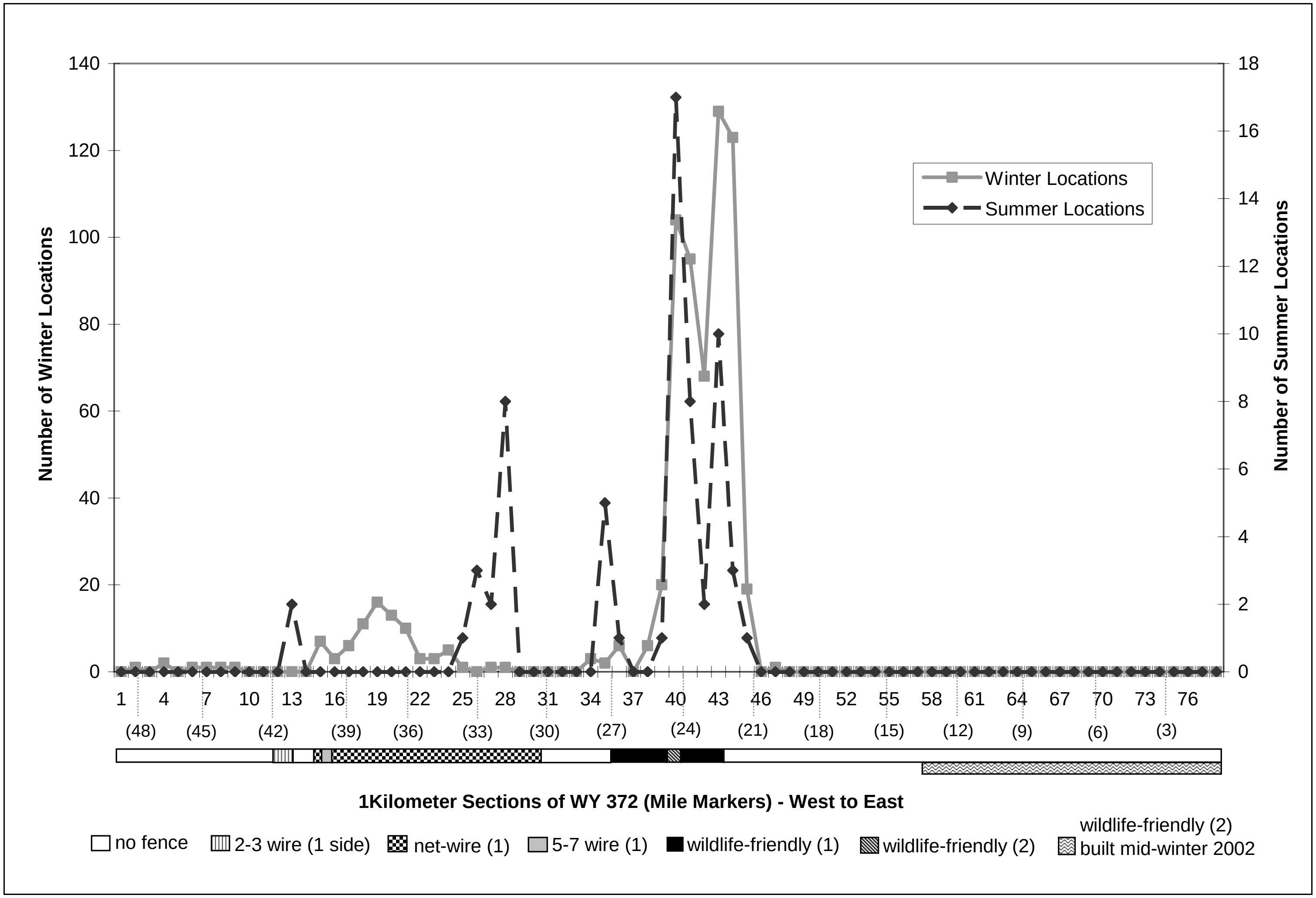


Figure 10. Pronghorn locations within one kilometer buffer along WY 372 (2002-2003). Pronghorn with locations in buffer were not documented crossing the highway during the given season. Highway is divided into one kilometer sections (west to east) to identify variations in pronghorn response. Peaks in number of locations are associated with fenced sections. Data from adult female pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming. (1 km = 0.62 mi)

Fall Migrations (22 pronghorn sampled)

1. 15 (68%) pronghorn had one period of fall migration data: [2002=5, 2003=10]
   a. 1 (7%) crossed WY 372
   b. 0 had locations <1km away from the road and did not cross
   c. 14 (93%) had all locations >1km from the road (no potential)
2. 7 (32%) pronghorn had > 1 year of fall migration data: [both years]
   a. 1 (14%) consistently crossed WY 372 (unfenced sections)
   b. 3 (43%) consistently had all locations >1km away from the road
   c. 2 (29%) exhibited pattern of year 1: locations >1km away from WY 372, year 2: crossed WY 372
   d. 1 (14%) exhibited pattern of year 1: crossed WY 372, year 2: all locations >1km away from WY 372

Spring Migrations (25 pronghorn sampled)

1. 17 (68%) pronghorn had one period of spring migration data: [2002=8, 2003=9]
   a. 3 (18%) crossed WY 372
   b. 0 had locations <1km away from the road and did not cross
   c. 14 (82%) had all locations >1km from the road (no potential)
2. 8 (32%) pronghorn had >1 year of spring migration data: [both years]
   a. 3 (38%) consistently crossed WY 372 (different road sections: unfenced and net-wire)
   b. 3 (38%) consistently had all locations >1km away from WY 372
   c. 2 (25%) exhibited pattern of year 1: crossed WY 372, year 2: all locations >1km away from WY 372

Figure 11. Summary of pronghorn response to WY 372 during migration. Adult female pronghorn were captured in southwestern Wyoming and fitted with Global Positioning System (GPS) collars (2002-2003). Crossing defined as consecutive locations on opposite sides of the highway. Fewer pronghorn crossed the highway during migrations than while on established seasonal ranges. All migrating pronghorn either crossed or had all locations > 1km (0.6 mi) from the highway.

Winter Period (72 pronghorn sampled)

1. 44 (61%) pronghorn had one winter period of data: [2001=34, 2002=10, 2003=0]
   a. 9 (20%) crossed US 189
   b. 7 (16%) had locations <1km away from the road but did not cross
   c. 28 (64%) had all locations >1km from the road (no potential)
2. 28 (39%) pronghorn had > 1 year of winter data: [2 years: n=15, 3 years: n=13]
   a. 15 (54%) consistently had all locations >1km away from US 189
   b. 9 (32%) had 1 year of winter data where they (1) crossed or (2) no cross but <1 km away from the road and the other year(s) of data, the 9 had locations that were all >1km away
      (1) 5 of the 9 crossed US 189 --- however, none crossed US 189 the next winter (all >1km away)
      (2) 4 of the 9 had locations <1km from US 89 but did not cross
         - however, 3 did not cross the next winter and 1 did not have data for the following winter
   c. 3 (11%) exhibited pattern of year 1: locations <1km away but did not cross, year 2: crossed US 189 (wildlife-friendly fence or no fence),
      year 3: all locations >1km from the road (1 did not have data)
   d. 1 (4%) crossed for 2 of 3 years of data, year 1: all locations >1km away, year 2: crossed US 189, year 3: crossed (2-3 wire fence)

Summer Period (43 pronghorn sampled)

1. 26 (60%) pronghorn had one summer period of data: [2002=14, 2003=12]
   a. 4 (15%) crossed US 189
   b. 0 had locations <1km away from the road but did not cross
   c. 22 (85%) had all locations >1km from the road (no potential)
2. 17 (40%) pronghorn had > 1 year of summer data: [both years]
   a. 13 (76%) consistently had all locations >1km away from the road
   b. 3 (18%) consistently had locations <1km away from US 189 but did not cross
   c. 1 (6%) exhibited pattern of year 1: all locations >1 km away from the road, year 2: crossed US 189

Figure 12. Summary of pronghorn response to US 189 within season. Adult female pronghorn were captured in southwestern Wyoming and fitted with Global Positioning System (GPS) collars (2002-2003). Crossing defined as consecutive locations on opposite sides of the highway. More pronghorn crossed during winter than summer. Most pronghorn that did not cross while on seasonal ranges had all locations > 1km (0.6 mi) from the highway.

Fall Migrations (22 pronghorn sampled)

1. 15 (68%) pronghorn had one period of fall migration data: [2002=5, 2003=10]
    a. 6 (40%) crossed US 189
    b. 2 (13%) had locations <1km away from the road but did not cross
    c. 7 (47%) had all locations >1km from the road (no potential)
2. 7 (32%) pronghorn had > 1 year of fall migration data: [both years]
    a. 4 (57%) consistently crossed US 189
    b. 2 (29%) consistently had all locations >1km away from the road
    c. 1 (14%) exhibited pattern of year 1: locations <1km away but did not cross, year 2: all locations >1km away from US 189

Spring Migrations (25 pronghorn sampled)

1. 17 (68%) pronghorn had one period of spring migration data: [2002=8, 2003=9]
    a. 5 (29%) crossed US 189
    b. 0 had locations <1km away from the road but did not cross
    c. 12 (71%) had all locations >1km from the road (no potential)
2. 8 (32%) pronghorn had > 1 year of spring migration data: [both years]
    a. 5 (63%) consistently crossed US 189
    b. 2 (25%) exhibited pattern of year 1: crossed US 189, year 2: all locations >1km away from US 189
    c. 1 (14%) exhibited pattern of year 1: all locations >1km away from US 189, year 2: locations <1km away but did not cross

Figure 13. Summary of pronghorn response to US 189 during migration. Adult female pronghorn were captured in southwestern Wyoming and fitted with Global Positioning System (GPS) collars (2002-2003). Crossing defined as consecutive locations on opposite sides of the highway. More pronghorn crossed the highway during migrations than while on established seasonal ranges. (1 km = 0.6 mi)

Table 15. Number of pronghorn that did and did not cross US 189 while on seasonal ranges and during migrations. Crossing defined as consecutive locations on opposite sides of the road. Locations collected using Global Positioning System (GPS) collars placed on adult female pronghorn in southwestern Wyoming (January 2002 – December 2003).

I. Within Seasons [a]

	# Pronghorn Crossed	Mean (SD) Crossings/Pronghorn	No. of Pronghorn Not Crossed	
			No Opportunity [b]	Yes Opportunity [c]
Winter 2001	7 (13%)	4 (3.5)	39 (72%)	8 (15%)
Winter 2002	11 (29%)	8 (6.8)	22 (58%)	5 (13%)
Winter 2003	1 (5%)	4 (---)	19 (90%)	1 (5%)
Winters 2001-2003	17 (24%)			
Summer 2002	2 (6%)	5 (0.7)	26 (84%)	3 (10%)
Summer 2003	3 (10%)	5 (2.5)	23 (79%)	3 (10%)
Summers 2002-2003	4 (9%)			

II. Migration [d]

	# Pronghorn Crossed	Mean (SD) Crossings/Pronghorn	No. of Pronghorn Not Crossed	
			No Opportunity [b]	Yes Opportunity [c]
Fall 2002	6 (50%)	1 (0.0)	5 (42%)	1 (8%)
Fall 2003	8 (47%)	1 (0.0)	7 (41%)	2 (12%)
Falls 2002-2003	10 (45%)			
Spring 2002	9 (56%)	1 (0.9)	7 (44%)	0 (0%)
Spring 2003	8 (47%)	4 (3.5)	8 (47%)	1 (6%)
Springs 2002-2003	12 (48%)			

[a] Analysis used locations from all sampled pronghorn.
[b] Number of pronghorn that did not have locations within 1 km (0.6 mi) of road.
[c] Number of pronghorn that did have locations within 1 km (0.6 mi) of road.
[d] Analysis limited to pronghorn with $\geq$ 50% of migration route within study area.

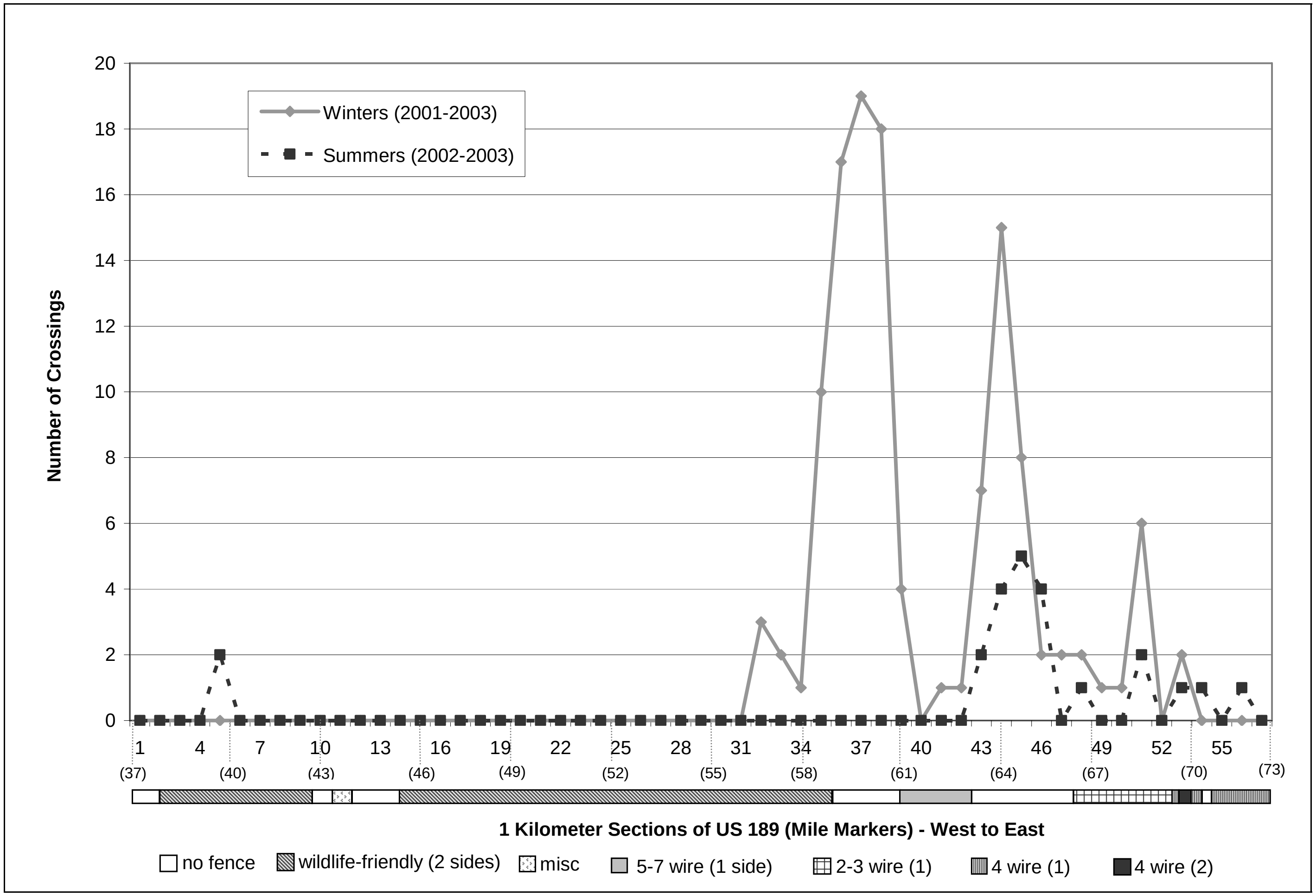


Figure 14. Pronghorn combined seasonal crossing of US 189. Crossing defined as consecutive locations on opposite sides of the road. Highway is divided into one kilometer sections to allow for identification of high crossing areas. Both winter and summer crossings occur primarily along the northeastern portion, near intersection with WY 372 and Fontenelle Reservoir. Peaks occur where road is either unfenced or fenced with 2-3 wire on one side. Data from adult female pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming. (1 km = 0.6 mi)

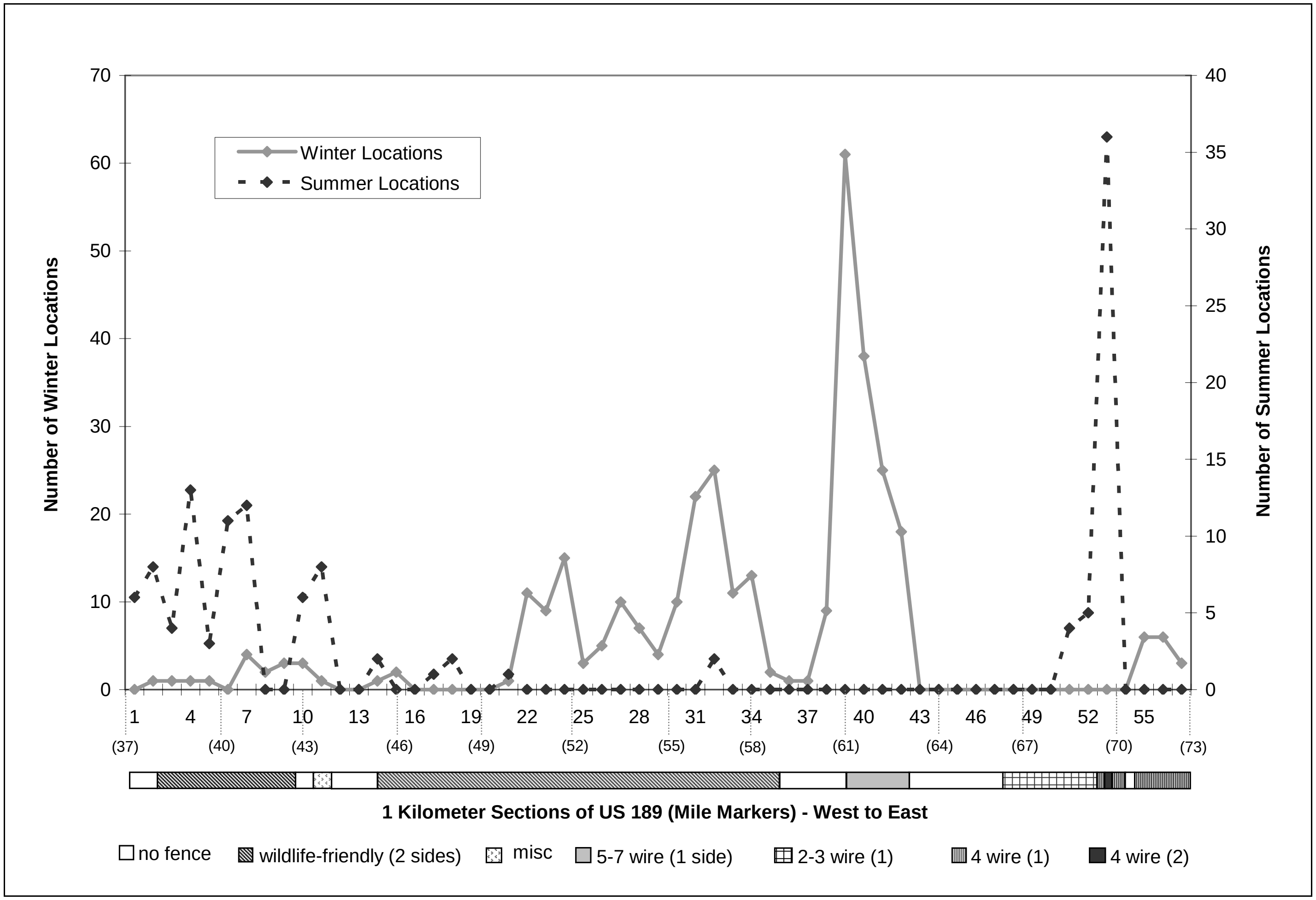


Figure 15. Pronghorn locations within one kilometer buffer along US 189 (2002-2003). Pronghorn with locations in buffer were not documented crossing the highway during the given season. Highway is divided into one kilometer sections (west to east) to identify variations in pronghorn response. Peaks in number of locations are associated with fenced sections. Data from adult female pronghorn marked with Global Positioning System (GPS) collars in southwestern Wyoming. (1 km = 0.6 mi)

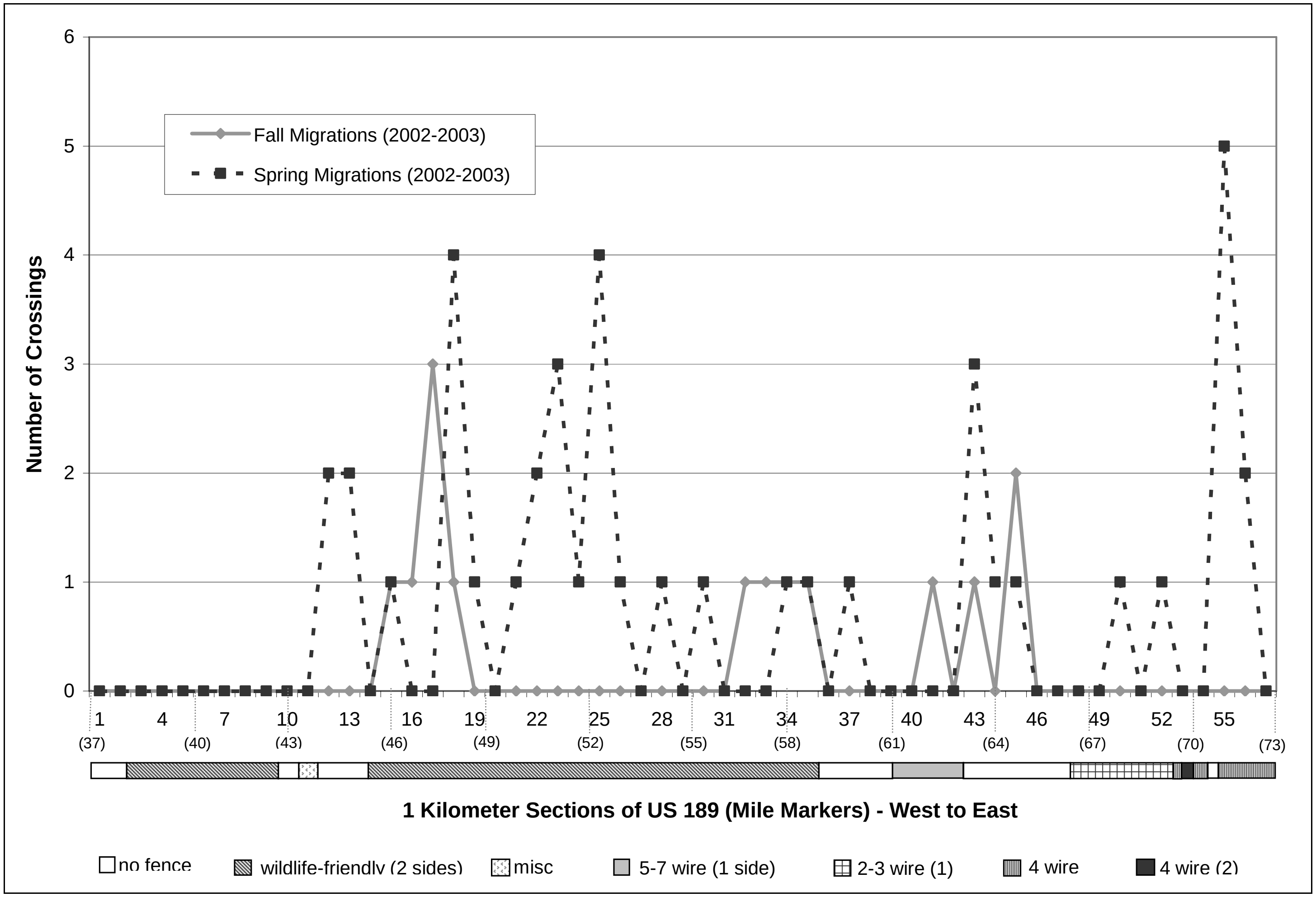


Figure 16. Pronghorn combined crossing of US 189 during fall and spring migrations. Crossing defined as consecutive locations on opposite sides of the road. Highway is divided into one kilometer sections to allow for identification of high crossing areas. Crossing peaks are distributed across most of the road and occur where road is either unfenced or fenced with wildlife-friendly fence on both sides. Data from adult female pronghorn fitted with Global Positioning System (GPS) collars in southwestern Wyoming. (1 km = 0.6 mi)

Table 16. Observed number of pronghorn winter locations vs. expected number of winter locations in highway right-of-ways (ROWs) in study area, southwestern Wyoming (January 2002-December 2003). Locations collected using Global Positioning System (GPS) collars placed on adult female pronghorn. Of 72 pronghorn sampled, 32 provided locations within ROWs.

I. Pre-construction [a]

ROW [b]	Observed (# locations)	Expected (# locations)	χ^2	df	*p*-value
BRB_BRB	2	1	1.0	1	0.317
≥4BRB_NF	0	2	2.0	1	0.157
2-3W_NF	1	1	0.0	1	1.000
WF_NF	9	3	12.0	1	< 0.001
Net_NF	2	4	1.0	1	0.317
WF_WF	1	5	3.2	1	0.074
NF_NF	29	14	16.1	1	< 0.001
Net_Net	0	14	14.0	1	< 0.001
Overall	---	---	49.3	7	< 0.001

[a] Wyoming Department of Transportation constructed 20 km (12.4 mi) fence in mid-winter 2002. Locations and chi^2 analysis based on data collected 27 January – 1 November 2002.

[b] ROW categories based on fence type on each side of road.

II. Post-construction [c]

ROW	Observed (# locations)	Expected (# locations)	χ^2	df	*p*-value
BRB_BRB	0	2	2.0	1	0.157
≥4BRB_NF	0	2	2.0	1	0.157
2-3W_NF	3	2	0.5	1	0.480
WF_NF	38	5	217.8	1	< 0.001
Net_NF	0	7	7.0	1	0.008
WF_WF [d]	9	18	4.5	1	0.034
NF_NF [d]	29	18	6.7	1	0.009
Net_Net	1	26	24.0	1	< 0.001
Overall	---	---	264.6	7	< 0.001

[b] ROW categories based on fence type on each side of road.

[c] Wyoming Department of Transportation constructed 20 km (12.4 mi) fence in mid-winter 2002. Locations and chi^2 analysis based on data collected 2 November 2002 – 14 December 2003.

[d] Change in proportion from pre-construction.

Table 17. Observed number of pronghorn crossings vs. expected number of crossings of WY 372 right-of-ways (ROWs) in study area, southwestern Wyoming (January 2002-December 2003). Locations collected using Global Positioning System (GPS) collars placed on adult female pronghorn. Of 72 pronghorn sampled, 50 crossed WY 372.

I. Pre-construction [a]

ROW [b]	Proportion of Highway [c]	Observed (# crossings)	Expected (# crossings)	χ^2	df	*p*-value
2-3W_NF	1.7	0	7	7.0	1	0.008
≥4BRB_NF	0.1	0	1	1.0	1	0.317
Net_NF	15.0	13	61	37.8	1	<0.001
NF_NF	64.3	391	264	61.1	1	<0.001
WF_NF	16.4	6	67	55.5	1	<0.001
WF_WF	2.4	0	10	10.0	1	0.002
Overall	---	---	---	172.4	5	<0.001

[a] Wyoming Department of Transportation constructed 20 km (12.4 mi) fence in mid- winter 2002. Locations and chi^2 analysis based on data collected 27 January – 1 November 2002.

[b] ROW categories based on fence type on each side of road.

[c] Proportion of each ROW type along WY 372.

II. Post-construction [c]

ROW [b]	Proportion of Highway [d]	Observed (# crossings)	Expected (# crossings)	χ^2	df	*p*-value
2-3W_NF	1.7	6	6.4	0.0	1	0.860
≥4BRB_NF	0.1	1	0.5	0.6	1	0.430
Net_NF	15.0	61	55.5	0.5	1	0.459
NF_NF [e]	36.6	288	135.5	171.6	1	<0.001
WF_NF	16.4	1	60.8	58.8	1	<0.001
WF_WF [e]	30.4	13	111.3	86.8	1	<0.001
Overall	---	---	---	318.5	5	<0.001

[b] ROW categories based on fence type on each side of road.

[c] Wyoming Department of Transportation constructed 20 km (12.4 mi) fence in mid-winter 2002. Locations and chi^2 analysis based on data collected 2 November 2002 – 14 December 2003.

[d] Proportion of each ROW type for WY 372.

[e] Change in proportion from pre-construction.

Table 18. Observed number of pronghorn crossings vs. expected number of crossings of US 189 right-of-ways (ROWs) in study area, southwestern Wyoming (January 2002-December 2003). Locations collected using Global Positioning System (GPS) collars placed on adult female pronghorn. Of 72 pronghorn sampled, 26 crossed US 189.

ROW [a]	Proportion of Highway [b]	Observed (# crossings)	Expected (# crossings)	χ^2	df	*p*-value
BRB_BRB [c]	1.8	3	4	0.1	1	0.752
2-3W_NF [d]	10.4	15	21	1.6	1	0.206
$\geq$4BRB_NF [e]	11.2	13	22	3.9	1	0.049
NF_NF	26.3	123	53	94.2	1	<0.001
WF_WF [f]	50	46	101	29.7	1	<0.001
Overall	---	---	---	129.4	4	<0.001

[a] ROW categories based on fence type on each side of road.

[b] Proportion of each ROW type along sampled portion of US 189.

[c] BRB= barbed-wire fence (i.e. 4 wire fence)

[d] 2-3W= 2-3 stranded barbed-wire fence, NF=no fence

[e] $\geq$4BRB= 4-7 stranded barbed-wire fence

[f] WF= wildlife-friendly fence

CHAPTER FIVE

Discussion and Recommendations

Discussion

Home Ranges and Migration

Living in a highly variable environment, pronghorn have adopted a mixed evolutionary stable strategy (Sinclair 1983), whereby only a portion of the population migrates and the remainder is resident. Use of different strategies within a single population may improve the overall ability of the population to withstand variations in predator/hunting pressures, disease outbreaks, and better exploit ephemeral resources that may be separated by considerable distances (Sinclair 1983, Ockenfels et al. 1994). Individuals that migrate are moving in response to predictably changing resources (Sinclair 1983). However, some pronghorn may migrate one year and not the next (Irwin et al. 1984). Pronghorn are often described as opportunistic (Bruns 1977, Amstrup 1978, Hoskinson and Tester 1980), and according to Ryder (1983), can assess forage supplies and densities of other pronghorn in preferred habitats. The greater the winter severity, the farther individuals and herds travel to areas with less snow (Creek 1967, Yoakum 1978, Guenzel 1986, Raper et al. 1989, Sawyer and Lindzey 2000) to avoid mortality that is often associated with snow depths exceeding 40 cm (16 in, Yoakum et al. 1996). Therefore, the proportion of migrants in this study may be an under-representation of the extent of use that this area can experience during severe winters. Had winters been more severe a greater number of pronghorn might have been available for capture in the study area and perhaps, a greater proportion found to be migratory with greater distances traveled (Prenzlow 1965, Sundstrom et al. 1973**,** Taylor 1975, Autenrieth 1978, Guenzel 1986).

Rouse (1954) found pronghorn migrations in Wyoming occurred in response to storms, forage supplies, and availability of water. Timing of spring migrations in Idaho and southcentral Wyoming was dependent on snow not temperature (Hoskinson and Tester 1980, Guenzel 1986). During spring migration among the Grand Teton National Park and Gros Ventre River Drainage pronghorn, Sawyer and Lindzey (2000) noticed pronghorn "appeared to push the snowline north, moving as quickly as snow conditions allowed." This is reinforced by Bruns (1977), who reported that pronghorn in southeastern Alberta and northern Montana prefer areas of reduced snow accumulation and reduced snow hardness. Conversely, fall migrations in Idaho appeared to not be influenced by snowpack but instead were stimulated by percent moisture in vegetation (Hoskinson and Tester 1980). Among pronghorn in western and southwestern Wyoming, fall migrations were also unrelated to snow and described as unpredictable in timing (Raper et al 1989, Sawyer and Lindzey 2000).

The initiation of spring migration during this study may have been related to both temperature and snowfall patterns. Pronghorn began spring migrations when temperatures had increased and stabilized, resulting in increased snow melt that improved travel and access to new vegetation. Although initiation of fall 2002 and 2003 migrations differed by three weeks, temperature appears to have influenced both years. Both fall migrations had fluctuating temperatures and extremes in daily lows for the month preceding migration and followed by further decreases in temperature. Snowfall did not appear to stimulate fall migrations since snowfall did not occur in the month prior to either fall migration. Interestingly, within two weeks after the beginning of the 2002 and 2003 migrations, 13 (5 in) and 41 cm (16 in) of snow fell in the area, respectively. Historically, November brings in some of winter's first snow storms (Western Regional Climate Center). The high mortality reported for pronghorn caught in severe snow storms (Martinka 1967, Compton 1970, McKenzie 1970, West 1970, Wishart 1970, Oakley 1973) may be the selective force for pronghorn to migrate before winter, perhaps keyed by lowering temperatures.

Portions of the study area have been designated by Wyoming Game and Fish Department as crucial wintering range for pronghorn. Although intensity of use within the area was greatest during winter, it fluctuates depending on weather conditions (Raper et al. 1989). Given the mild to normal winters, the number (*n*=18, 53%) of migrating pronghorn that used the area was likely less than during a severe winter. Irwin et al. (1984) reported pronghorn in southcentral Wyoming making migrations to winter ranges because of heavy snow and remaining on summer ranges during subsequent, mild winters. Seasonal movements from crucial winter range could benefit food resources, since vegetation is able to rest when intensity of use decreases during mild to normal years (Raper et al. 1989).

Closer examination of migrant summer home ranges revealed that 74% (*n*=17) incorporated riparian areas and 35% (*n*=8) included irrigated crop, suggesting that migrating to higher elevations may enable pronghorn to take advantage of better resource conditions associated with greater moisture.

Individuals within the Sublette herd of southwestern Wyoming appear to make altitudinal migrations. Marked pronghorn generally selected one of five discernable migration routes (Figure 6). Most involved moving from winter ranges located near WY 372 and traveling west and northwest to summer ranges. A majority of the migrations involved crossing a primary, hard-surface road and followed drainages and ridges. Some pronghorn (*n* = 12, 43%) had locations clustered along migration routes, suggesting pronghorn delayed travel to use resources in particular areas rather than making direct migrations between seasonal ranges.

Sawyer and Lindzey (2000) documented two pronghorn wintering (1998-99) near Seedskadee National Wildlife Refuge (NWR) in western Wyoming that had summered 241 km (150 mi) north. Although attempts were made to sample proportionately from the distribution of pronghorn in the study area, including areas near Seedskadee NWR, captured pronghorn did not summer in Grand Teton National Park or the upper Gros Ventre River Drainage. The farthest north that a marked pronghorn traveled and summered was Boulder (Figure 5). The route used by this pronghorn, north and south along both sides of US 191 between Farson and Pinedale, was identified by Raper et al. (1989) as one of two major migration corridors used by the Sublette herd. It is unknown whether pronghorn migration patterns are learned from preceding generations, such as is reported for mule deer and white-tailed deer (McCullough 1985).

Fences

Fences in southwestern Wyoming influenced distribution and movement patterns of pronghorn. Topography was similar across the study area and vegetation types were found in similar abundance within home ranges and along migration routes compared to the study area. Fence density, however, including all fence types, was lower in seasonal home ranges overall than in the study area. Location of seasonal ranges was influenced by fence density, with pronghorn choosing those areas within the study area with lowest densities. Others have noted that pronghorn have difficulty in negotiating fences, sometimes injuring themselves or dying due to entanglement in fences (Spillett 1965, Bear 1969, Oakley 1973). In addition, fences limited day to day movements in winter for pronghorn in southeastern Alberta and northern Montana (Bruns 1977). The pattern of home range placement observed may have been different in more severe winters. Pronghorn may reduce their home range size during severe weather (Amstrup 1978, Barrett 1982) and it is likely that they would select even lower fence densities than observed in this study because accumulated snow would likely inhibit ability of pronghorn to crawl under fences. This appears to be supported by the general tendency for pronghorn to more intensively use those portions of their home range with lowest fence densities.

Based on initial examination of locations overlaid on the GIS fence layer, it appeared home ranges were bound by fences, as found by Ockenfels et al. (1997) and Ticer et al. (1999) in Arizona. Although it was predicted that buffers surrounding home ranges would have higher fence density than home ranges if home range conformation was being influenced by fences, no difference was found in fence densities between buffers and home ranges. However, fence density was greater within the 95% zones (outer portion of home ranges) than the remainder of the home range, suggesting home range conformation could be influenced by fences within the outer portion of home ranges.

Most (n=28, 64%) monitored pronghorn were migratory and their migration routes tended to encounter fewer fences than they would have had they traveled randomly in the study area. Given that seasonal ranges and buffers had lower fence densities than the study area and length of migration routes examined were relatively short because those used were limited to those that were >50% within the study area, there was little opportunity to detect a consistent difference in fence crossings between actual routes taken by pronghorn and alternative routes between seasonal ranges. Longer migrations, that primarily occurred outside the study area or that are more likely during severe winters (Creek 1967, Yoakum 1978, Guenzel 1986, Raper et al. 1989, Sawyer and Lindzey 2000), may yield differences in number of fences encountered between actual and alternate routes due to greater potential for variation in routes.

Fence crossing rates during spring and fall migrations did not differ for individual pronghorn. When fence crossing rates along actual routes were compared to shortest and alternative routes (between seasonal ranges), only fence crossing rates in spring differed between actual and other routes. Previously (chapter 1), spring migrations were found to be longer in duration and slower in rate of travel than fall migrations. Given the high mortality that has been reported for pronghorn caught in severe snow storms (Martinka 1967, Compton 1970, McKenzie 1970, West 1970, Wishart 1970, Oakley 1973), the incentive to arrive at winter ranges prior to snowfall may be a strong driving factor in fall migrations. The slower spring pace, also documented in Nevada (Tsukamoto 1983), may be indicative of pronghorn taking advantage of the new green-up of preferred forage prior to parturition. In addition, reduced threat of potential storms during spring may allow pronghorn the opportunity to select routes with a lower fence crossing rate than shortest or alternate routes.

Fences influence pronghorn movement patterns by either reducing or eliminating previously used travel routes across highways (Buechner 1950**,** Ward et al. 1976, Ward et al. 1980, Guenzel 1986), thus reducing the carrying capacity of some ranges (Yoakum 1978). The design, construction, and location of the fence determine the impact that it has on pronghorn populations (Hailey and DeArment 1972, O'Gara and Yoakum 1992).

Wildlife-friendly fence has been used by agencies throughout the west to allow passage of pronghorn. Strong evidence was found that pronghorn selected home ranges with lower densities of all fence types, except wildlife-friendly fence. In addition, wildlife-friendly fence was located throughout the home range, including areas used most intensively, indicating wildlife-friendly fence may be permeable to pronghorn. While pronghorn crossed roads fenced on one side with wildlife-friendly fence they were much less likely to cross sections fenced on both sides with this type of fence.

Crossing of wildlife-friendly fenced ROWs, especially of US 189 during migrations, suggests pronghorn were able to negotiate this fence type during favorable weather conditions. Pronghorn will generally cross under fences where there is a noticeable increase in distance between the bottom wire and the ground (Gregg 1955: 22.5 inches; Cole 1956: 17 inches). Given snow accumulation during an extreme winter, permeability of wildlife-friendly fence will be reduced. Strong winds and deep snow can fill the depressions under which pronghorn normally pass, causing wildlife-friendly fences to become formidable barriers. Unable to move ahead of the harsh weather in search of areas with quality forage and less snow, fences trap pronghorn on rangelands that provide little protection or available forage (Oakley 1973).

Finally, wildlife-friendly fence is not immediately permeable to pronghorn. Wildlife-friendly fence may be a barrier to some pronghorn during favorable weather and may require time for others to become familiar with the fence.

Net-wire fence, argued to be the most impermeable fence type for pronghorn (Buechner 1950, Hailey et al. 1966, Spillett et al. 1967, Riddle and Oakley 1973), is the most common fence type within the study area. Winter distribution of pronghorn in southcentral Wyoming were influenced by net-wire fences (Sundstrom 1970). Distribution of net-wire fence and pronghorn locations within home ranges in the study area suggested that areas of greater location density were associated with lower densities of this fence type. Pronghorn selected migration routes with lower crossing rates of net-wire fence than random routes throughout the study area.

Loss of connectivity of habitat because of net-wire fences has the potential to result in serious losses to pronghorn populations. The restrictive design of net-wire fences prevented pronghorn from escaping a heavy storm in the Red Desert of Wyoming (Oakley 1973) and extreme drought conditions in Texas (Hailey et al. 1966), ultimately causing large number of pronghorn deaths due to exposure and malnutrition.

Roads

Although most (*n*= 37, 86%) pronghorn had home ranges that overlapped primary hard-surface roads, the proportion of highway rights-of-way (ROWs) in home ranges was less than expected based on abundance of ROWs in the study area. Fewer pronghorn yet (*n*=27, 63%) had core areas of home ranges that overlapped roads. Additionally, for home ranges that overlapped unfenced ROWs, the density of locations was greater in the remainder of the home range than within the unfenced ROW portion. The presence of fences (Ockenfels et al. 1994, Ticer et al. 1999) and then, in turn, the type of ROW fence determined whether roads were included in seasonal ranges and where pronghorn crossed roads within season and during migrations. For example, US 30 is one of the longest roads in the study area and was fenced almost entirely by net-wire fencing (97%), but crossed by few pronghorn (*n*=4, 9%). Conversely, WY 372 had the longest proportion of non-fenced sections and no road sections that were fenced on both sides with either net-wire or multiple strands of barbed wire fencing. Possibly in response to the greater ability to move, the largest proportion of sampled pronghorn (*n*=35, 81%) included WY 372 in seasonal home ranges.

Seasonal crossings of WY 372 and US 189 occurred consistently in sections that were unfenced. Pronghorn crossings of WY 372 during migration were also associated with unfenced sections and occurred more frequently in the northwestern portion of the highway. Pronghorn crossings were distributed more evenly along US 189, with a majority of crossings associated with unfenced sections, wildlife-friendly fence (two sides), and 4-stranded barbed wire (one side).

Twenty-three pronghorn (32%) never crossed WY 372 or US 189 in a given season, though locations were <1 km (0.6 mi) from the road. These locations were most frequently near road sections that were fenced on both sides with wildlife-friendly fence or 4-stranded barbed wire. Four-stranded barbed wire fences, commonly used to manage cattle, were observed to be a major obstacle to pronghorn in southeastern Alberta and northern Montana (Bruns 1977). Though likely easier to cross than highways fenced on both sides, pronghorn also had locations near but did not cross roads that were fenced on one side with net-wire fence, a 5-7 stranded barbed wire, a 4-stranded barbed wire, or a wildlife-friendly fence. Many of these fence types have been suggested in the literature as being partial to complete barriers to pronghorn because of the difficulty pronghorn have in crawling underneath, especially during extreme weather (Buechner 1950, Russell

1951, Spillet et al. 1967, Howard et al.1990, O'Gara and Yoakum 1992). This study documented pronghorn traveling long distances, sometimes parallel to fenced roads, to ultimately cross where no fence was present. Similar observations have been made of pronghorn traveling long distances along fences in search of a hole or opening in which to cross (Bear 1969, Riddle and Oakley 1973, Irwin et al. 1984). Having evolved on open plains, few pronghorn antelope will make vertical jumps (Greenquist 1983, O'Gara and Yoakum 1992), choosing instead to go around fences or crawl under them (Irwin et al. 1984, Guenzel 1986).

While unfenced roads did not appear to be a barrier to pronghorn movement in the study area, similar to findings in Arizona (van Riper et al. 2001), the combination of heavy traffic volume (Buechner 1950) and fences along roads can be barriers to movement and fragment habitat.

Recommendations

Sufficient resources to maintain an individual or a herd may not exist in one location, which may explain the 11 (15%) pronghorn that used resources throughout the year in multiple hunt areas. Yoakum (1978) suggests that less than 10 percent of pronghorn herds travel between 80 km (50 mi) and 160 km (99 mi) and that those that do are doing so to ensure survival. Since some of the marked pronghorn traveled longer cumulative distances, free movement between seasonal ranges and hunt areas is critical to successful pronghorn management in southwestern Wyoming. Knowledge of where pronghorn are throughout the year can improve management. Apparent wandering of individuals between hunt areas may be an important method of identifying new habitat and a means of natural population regulation.

Marked migratory pronghorn generally took one of five major routes between seasonal ranges. The continued accessibility of these routes to pronghorn, three of which involved crossing US 189, should be considered in future management. Known movement corridors must be maintained. Creation of obstacles to pronghorn movement, including fences, roads, and development should be limited (Chapter 2). If fencing on rangelands is deemed necessary, the impact can be reduced by using the minimum amount needed to meet objectives and using a smooth bottom wire with a minimum clearance of 46 cm (18 in, Bruns 1977; Appendix B). Existing fences should be modified to allow for passage by all age classes, during all seasons, and under all weather conditions (Lee et al. 1998; Appendix C). Multiple guidelines have been published for fencing on pronghorn range, including Anderson and Denton (1980).

Province and state agency personnel throughout pronghorn range ranked severe winters and droughts second, after loss of habitat, in overall threats to pronghorn (O'Gara and Yoakum 2004). In addition to being a survival strategy, migrating to different areas has been argued to be an adaptation to improve physical condition before breeding and to improve long-term reproductive success (Sinclair 1983). Inaccessibility of varying and important habitat can have long-term detrimental impacts to a population (Newman 1966, Sundstrom 1970, Howard et al. 1990).

Portions of hunt area 93 were appropriately designated as crucial winter range for pronghorn. The area is used by migrating pronghorn from multiple hunt areas during mild years and offers relief to large numbers of pronghorn during severe winters (Raper et al. 1989). Winter mortality rates among pronghorn can be as high as 62% (Oakley 1973) when extended periods of deep snow combine with strong winds (increase chill factors) or no winds (required to expose forage), low forage availability or quality, no water source, low temperatures, alternate freezing and thawing, and movement barriers (Hailey et al. 1966, Compton 1970, McKenzie 1970, West 1970, Riddle and Oakley 1973, Bruns 1977). For pronghorn throughout western Wyoming, which have already been documented as using the area, hunt area 93 and adjacent land must remain accessible (Raper et al. 1989, Sawyer and Lindzey 2000). If the appropriate amount of wintering grounds is not maintained for a given pronghorn population there may be an increase in mortality (Compton 1970).

Based on previous research efforts, fenced roads have the potential to fragment habitat and restrict pronghorn movements, even leading to the isolation of populations (Buechner 1950, O'Gara and Yoakum 1992, van Riper and Ockenfels 1998). Because movement between hunt areas, and herd units to a lesser extent, has been documented (Chapter 1) pronghorn within hunt area 93 currently are not isolated. However, movement throughout the range and between areas requires crossing of predominantly fenced roads. Pronghorn are dependent on unfenced sections of highways as movement corridors between potentially fragmented habitats. The movement of individuals between populations should be protected to allow for genetic diversity and provides a buffer to fluctuating and extreme weather conditions, hunting pressures, disease outbreaks, and habitat degradation and loss (Ockenfels et al. 1994).

Modifications to major paved roads themselves, which appeared to cause only minimal restrictions on pronghorn distributions in southwestern Wyoming, are cost-prohibitive and unlikely to occur on a large scale throughout pronghorn range. However, modifications to fences associated with major roads are a more feasible option that should be considered and applied. Various guidelines have been published on ways to facilitate pronghorn movement if fencing on rangelands is deemed necessary (Appendix B) or if an existing fence has been identified as restricting passage (Appendix C). Bruns (1977) recommends all fences have a smooth bottom wire with a minimum clearance of 46 cm (18 in). Others have stressed that net-wire fences not be used on pronghorn range because of the inability of most pronghorn to negotiate it (Payne and Bryant 1994, Lee et al. 1998, U.S. Bureau of Land Management. 1985). Additional fence specifications and suggestions have been presented by Anderson and Denton (1980), Kindschy et al. (1982), Autenrieth (1983), and Lee et al. (1998). No universal fence design has been found due to the problems encountered with pronghorn of different age classes (Spillett et al. 1967), different types of livestock and local topographic variations (Autenrieth 1978). Where pronghorn share their range with cattle, recent research by Karhu and Anderson (2002) suggests the potential for 3-wire electric fences to allow for passage of pronghorn while effectively containing cattle and bison.

Currently, fencing of US 189 is being extended north to LaBarge, Wyoming. The highway is being widened, resurfaced, and wildlife-friendly fence constructed on both sides of the road. Based on data collected, the new fence will restrict within and between season movements of pronghorn in hunt area 93. Construction of wildlife-friendly fence on US 189 will likely result in fragmentation of home ranges that currently include the unfenced portion in home ranges and reduced seasonal crossing by pronghorn. However, migrating pronghorn are expected to still be able to negotiate US 189 during favorable weather. Pronghorn movements and distributions should be examined along US 189 and in adjacent areas post-construction. Increased pressure along adjacent roads or along particular sections of the newly fenced portion of US 189 may require improvements and modifications. Suggestions for fence modifications, should they be deemed necessary, include adjustable fence segments and let-down panels (Appendix C). Managers and biologists are encouraged to establish protocols for situations, such as severe winter weather, when pronghorn are unable to cross the highway and are at risk of mortality.

Additional fencing of WY 372 has been proposed in the past (Lockwood 1994). This study documented extensive crossing of this highway, within seasons and during migrations. Similar concerns on impact to resident and migrant pronghorn exists as were stated for US 189. The addition of new fences will restrict movement and reduce the area's carrying capacity (O'Gara 1978, Taylor 1975). The ability of the area to serve as crucial winter range may be lowered if pronghorn are unable to negotiate fences, which could have serious impacts on the pronghorn population (Oakley 1973). Additional fencing of WY 372 may require reducing the population size because of the additional pressure placed by potentially captive pronghorn on forage and resources (Lockwood 1994).

Net-wire fences should not be constructed on pronghorn range (Buechner 1950, Lee et al. 1998). Results indicate that pronghorn have difficulty in negotiating net-wire fences and select home ranges with lower fence densities. Within home ranges, pronghorn were found to spend a majority of the time in portions of the home range with lower fence densities than less utilized portions. Removal of unnecessary fences on pronghorn range is the most valuable mitigation measure available to biologists and managers. Baker and Wrakestraw (1953) found long stretches of net-wire fences and right-of-way fences near highways to be the most "serious obstruction to pronghorn's normal activity."

As little fencing as possible should be constructed on pronghorn range. If fencing is deemed necessary, after a thorough review of implications and alternatives, the selected fence design should ideally allow movement under the fence for all age classes during all conditions (Appendix A, Appendix B). When fencing on cattle range, wildlife-friendly fence is a viable option. Data suggest that pronghorn are able to negotiate wildlife-friendly fence and incorporate it within home ranges, especially where roads are fenced on one side instead of both and weather conditions are mild.

Although no previous study has gathered the amount of data on pronghorn movement and distribution (>33,000 locations) provided by the GPS collars in this study, it should be noted that the study was conducted over a short time-frame (two years). Variability among pronghorn, within and between populations, may be exacerbated by environmental and anthropogenic factors. Results presented here are for both resident and migrant pronghorn that have endured drought conditions prior to and during the study. Home range and migration analyses probably reflect responses to changes in normal forage composition and low levels of water availability during the study period. Therefore, pronghorn monitored during non-drought conditions or over a longer period of time may yield different results.

APPENDIX A. Movement Dates of Migrating Pronghorn (2002-2003)

Dates for individual pronghorn, downloaded from Global Positioning System (GPS) collars in Wyoming.

ID	Winter 2001	Spring 2002 Migration	Summer 2002	Fall 2002 Migration	Winter 2002	Spring 2003 Migration	Summer 2003	Fall 2003 Migration	Winter 2003
26	**1/28** - 2/19	2/19 - 5/6	5/6 - 10/8	10/11 - **10/14**[H]					
17	**1/27** - 4/4	4/5 - 4/8	4/8 - **5/7**[D]						
34	**1/28** - 3/22	3/23 - 4/4	4/5 - 9/29	10/5 - 10/8	10/11 - 3/13	3/13 - 5/14	5/15 - 10/14	10/16 - 11/4	11/4 -**12/16**
3	**1/27** - 3/23	3/24 - 4/23	4/23 - 10/22	10/23	10/23 - 4/13	4/13 - 4/28	4/29 - **9/20**[H]		
43	**2/26** - 3/23	3/23 - 5/6	5/6 - 10/2	10/5 - 10/25	10/26 - 3/12	3/13 - 4/27	4/27 - 10/29	10/30 - 11/4	11/5 - **12/15**
37	**1/28** - 3/24	3/24 - 4/14	4/15 - 10/26	10/27 - 11/14	11/15 - **1/3**[D]				
4	**1/27** - 3/26	3/27 - 4/9	4/10 - 10/11	10/16 - 10/23	10/24 - 4/1	4/1 - 4/13	4/14 - 9/23	9/26 - 10/11	10/14 - **11/22**[MF]
45	**2/26** - 3/26	3/26 - 4/6	4/7 - 5/6	5/6	5/7 - **12/4**[M]				
28	**1/28** - 3/26	3/26 - 3/29	3/30 - **9/2**[M]						
47	**4/1** - 4/9	4/9 - 4/24	4/24 - 10/11	10/14	10/16 - 3/24	3/24 - 5/14	5/15 - 8/15	8/18 - 11/1	11/2 - **12/15**
39	**1/28** - 4/10	4/10 - 6/10	6/13 - 9/17	9/20 - 10/25	10/26 - **4/1**[D]				
58	**4/2** - 4/25	4/25 - 4/27	4/28 - 9/14	9/17 - 9/23	9/26 - 4/16	4/16 - 4/19	4/20 - 10/31	11/1 - 11/3	11/3 - **12/14**
11[C]	**resident**							10/17 - 11/2	11/3 - **12/15**
29	**1/28** - 2/28	3/1 - 4/26	4/26 - **5/13**[D]						

Bold dates not used in calculations of average seasonal arrival and departure dates [C] Changed from resident to migrant [D] Dropped collar
[H] Harvest date [M] Mortality date [MF] collar malfunction, failed to collect additional locations → no recorded locations

ID	Winter 2001	Spring 2002 Migration	Summer 2002	Fall 2002 Migration	Winter 2002	Spring 2003 Migration	Summer 2003	Fall 2003 Migration	Winter 2003
41	**1/28** - 3/29	3/29 - 3/31	3/31 - **6/22**[D]						
51		**4/2** - 4/11	4/12 - 6/7	6/10 - 9/5	9/8 - 5/14	5/15 - 6/4	6/7 - 11/15	11/15	11/16 - **12/15**
53		**4/1** - 5/7	5/8 - 10/20	10/21	10/22 - 4/12	4/13 - 4/25	4/25 - 10/30	10/31 - 11/2	11/3 - **12/16**
65					**1/15 -** 3/14	→	3/15 - 11/1	11/2	11/3 - **12/15**
74					**1/15 -** 3/22	3/23 - 4/11	4/11 - 10/17	10/18 **- 11/10**[M]	
72					**1/15** - 3/22	3/22 - 4/9	4/10 - 10/31	11/1 - 11/4	11/5 - **12/15**
63					**1/15** - 3/22	3/22 - 4/26	4/26 - 9/14	9/17 **- 10/15**[MF]	
68					**1/15** - 3/24	3/24 - 3/25	3/26 - 11/3	11/3 - 11/5	11/6 - **12/15**
66					**1/15** - 4/7	4/8 - 4/12	4/12 - 10/30	10/30 - 11/2	11/3 - **12/15**
64					**1/15** - 4/19	4/19 - 4/20	4/20 - 9/29	10/2 **- 10/16**[M]	
79					**4/15** - 4/21	4/22	4/23 - **6/16**[MF]		
71					**1/15** - 5/16	5/16 - 5/17	5/17 - 11/6	11/7 - 11/15	11/16 - **12/15**
67					**1/15** - 5/30	5/30 - 6/1	6/4 - 10/31	10/31 - 11/2	11/3 - **12/15**
56			**4/1** - 11/17	→	11/18 - 3/13	→	3/14 - **9/8**[MF]		

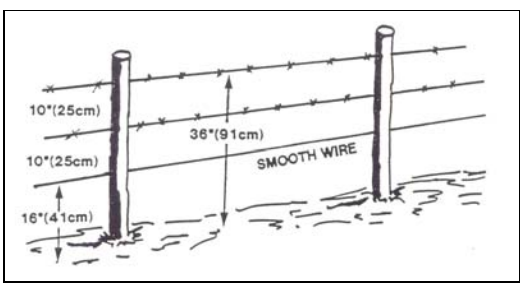
GPS collar location schedule → 16 October – 31 May: 3 locations per day, 1 June – 15 October: 1 location every 3 days

APPENDIX B. Guidelines to Fence Construction: A Literature Review

A comprehensive evaluation of the proposed site should be made prior to fencing to determine the likely effect on pronghorn and the benefit to other parties involved, such as the livestock operators or in the case of highways, the public (Lee et al.1998). Consideration should be given to current food habits and behavior patterns of livestock and wildlife, as well as terrain and weather conditions (Autenrieth 1983). Alternatives, such as herding, should be considered in place of or to reduce the amount of fencing.

If fencing on pronghorn range is deemed necessary, the following are various guidelines to reduce habitat fragmentation caused by fences and thereby reduce the impact on pronghorn. Most recommendations were provided by Payne and Bryant (1998) and Lee et al. (1998), unless otherwise noted:

1. Avoid use of net-wire fence.
2. Consider use of electric fence.
   a. Under controlled conditions, 72% (n=18) of pronghorn crossed electric fences that consisted of two smooth wires at 38 cm (15 in) and 81 cm (32 in) above the ground. The fence allowed free movement of fawns while being restrictive to mature sheep (Spillett et al. 1967) .
   b. In free-ranging pronghorn, low aversion rates were documented for 3 (8.7%) and 4-wire (8.9%) electric fences but relatively high aversion to 2-wire (60%) fences. Aversion rates to 2-wire fences did not decrease over a 20-month monitoring period indicating that pronghorn may need more time to establish crossing locations (Karhu and Anderson 2003).
3. Use smooth wire instead of barbed to reduce cuts and scrapes.
4. Be minimal: use as few strands as possible to reduce entanglement and facilitate passage while meeting original objectives of fence.
5. Fence dimensions and wire spacing should be specific to livestock that pronghorn are sharing range with (Yoakum 1980).

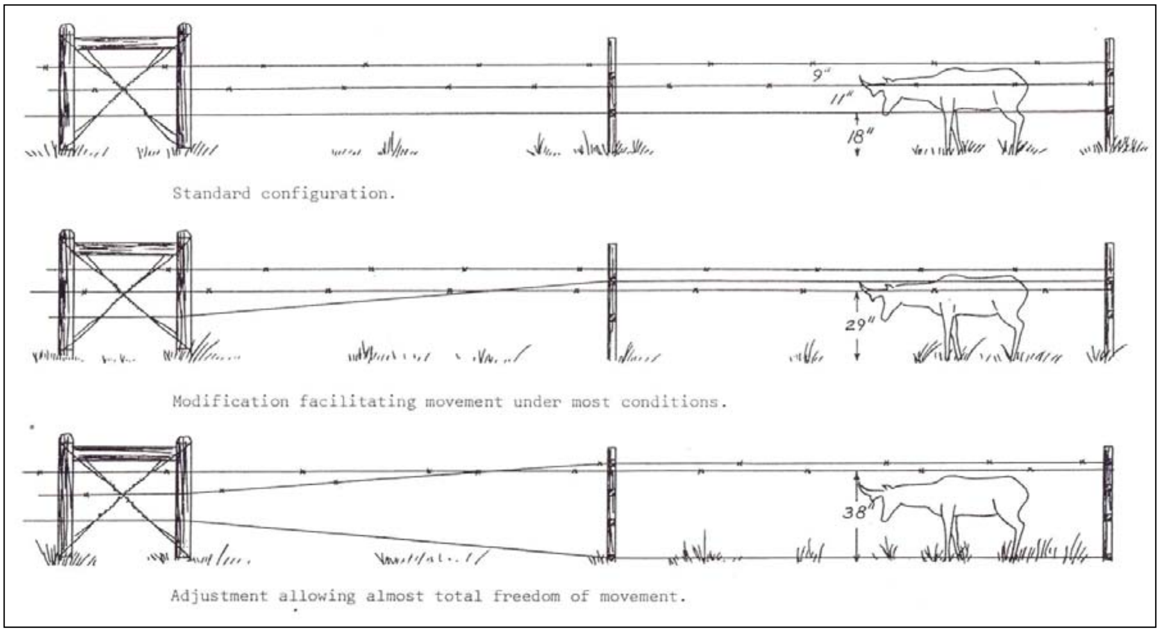


Suggested specifications for barbed-wire fences built on rangeland occupied by both pronghorn and cattle (Kindschy et al. 1982)

6. Be minimal: if fencing along roads, fence only one side of road.
7. If fencing along roads, place fences > 400 m (0.25 mi) away from paved roads to create a buffer between motorists and pronghorn (Ockenfels et al. 1994, Ticer et al. 1999).
8. Fencing across migration routes should be avoided but if deemed necessary, fencing should not exceed a 3-wire fence (U.S. Bureau of Land Management 1985).
9. Locate fences where naturally windswept to keep snow clear from fence.
10. Areas with snow accumulation, muddy conditions, or high stress circumstances should not be fenced with 4-wire fencing (U.S. Bureau of Land Management 1985).
11. Flag newly built fences along the top wire between posts with white rag flagging to alert pronghorn.
12. If fence does not allow unrestricted movement for all age classes, during all years, provisions should be made…

    a. Let-down panels/fences can be constructed from barbed and net-wire, and are recognized as alternatives to 4-wire and net-wire fences on ranges where these fence types are deemed necessary (Wilson 1995). However, this method is time intensive and requires a long-term commitment to let fences down and put back up prior to and post movements. The effectiveness is dependent on good knowledge of daily and seasonal movement patterns. Benefits to this design are contingent on timing – most likely to occur during migration periods and possibly during severe weather. Although found to be a benefit to deer, let-down fences are used less with pronghorn (Wilson 1995). Let down-panels will have better success if placed along an established and predictable movement corridor.

    b. Adjustable fence segments can be used when livestock are not on rangelands. Wire of fences can be adjusted to allow for unimpaired seasonal movement of antelope (Anderson and Denton 1980). This technique is especially valuable in areas that can experience snow depths of 30 cm (12 in) or more since any of the wires can be raised and temporarily fastened. The ability of one person to adjust one wire for one mile in 30 minutes makes this modification a realistic option on pronghorn range. Since pronghorn are generally selecting crossing points where the lower wire is higher, the adjustments made at these points are quickly adapted to by pronghorn (Yoakum 1980).



Three-stranded, 97 cm (38 in) high barbed-wire fence with modifications onto posts to allow adjustments to wire spacing and facilitate pronghorn movement (Anderson and Denton 1980).

Post-Construction Evaluation:

Pronghorn movements and distributions should be examined post-construction to determine areas of concern and potential need for improvements.

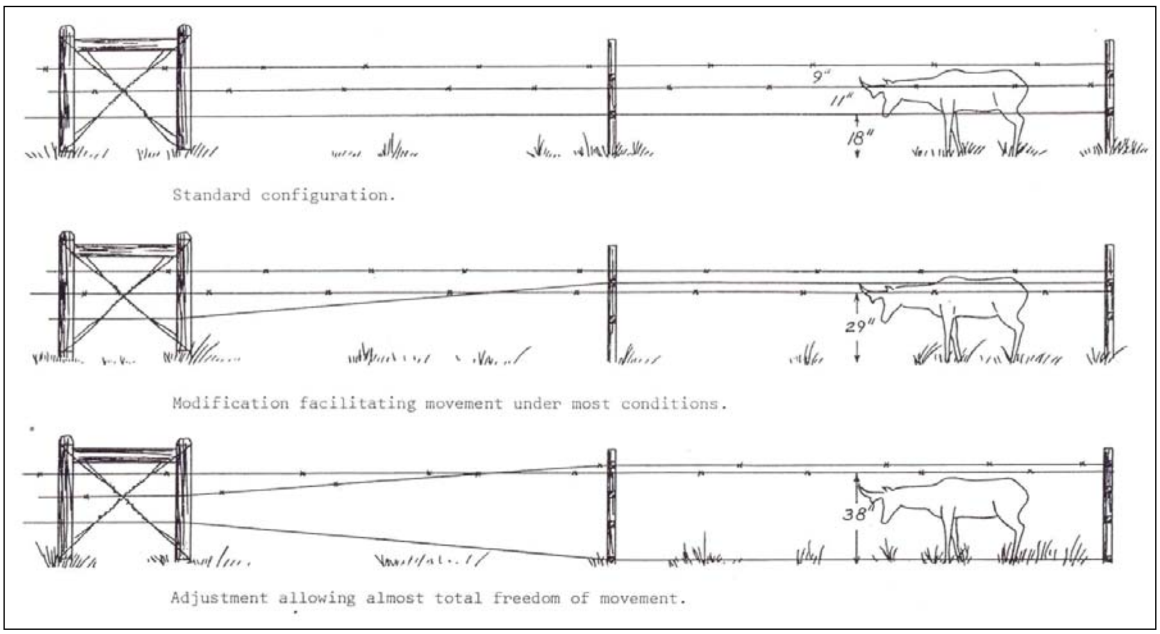
APPENDIX C. Modifications to Existing Fences: A Literature Review

The following are various recommendations to reduce habitat fragmentation caused by existing fences and thereby reduce the impact on pronghorn. Most recommendations were provided by Payne and Bryant (1998) and Lee et al. (1998) unless otherwise noted:

1. Unnecessary fences should be removed
2. Excess wire strands should be removed to ensure bottom wire is at least 41 cm (16 in) above ground level and top wire is no more than 91 cm (36 in) height from ground. To facilitate crossing, pronghorn will select crossing points where the bottom wire is farthest from the ground (Gregg 1955: 57 cm or 22 in; Cole 1956: 43 cm or 17 in; Ockenfels pers. comm: 56 cm or 22 in).
3. Replace barbed wires, especially bottom wire, with smooth wire to facilitate movement.
4. Wires should be taught to reduce potential of entanglement, which could lead to crippling and death.
5. If modifying fencing along roads, place fences at least > 400 m (0.25 mi) away from paved roads to create a buffer between motorists and pronghorn (Ockenfels et al. 1994, Ticer et al. 1999).
6. Net-wire fence can be quickly modified by folding up the bottom of the fence to leave at least a 41 cm (16 in) opening above the ground (Hailey 1979). At one-half mile intervals, the staples can be removed from the bottom and the wire restapled up higher to allow for 91 m (100 yd) stretches of the fence to be raised and allow for pronghorn to cross underneath.
7. Portions of less permeable fence designs (e.g. net-wire) can be replaced with more permeable fence designs (e.g. 2-3 wire). Larger openings are more readily apparent to pronghorn, especially initially, and stress during crossing is reduced. However, if narrower openings in fences are used, placement should be in fence corners for maximum effectiveness since pronghorn will be directed to the location by merging fences (Mapston et al. 1970).
8. Installation of passage devices if existing fence does not allow unrestricted movement for all age classes, during all years….

   a. Let-down panels/fences can be constructed from barbed and net-wire, and are recognized as alternatives to 4-wire and net-wire fences on ranges where these fence types are deemed necessary (Wilson 1995). However, this method is time intensive and requires a long-term commitment to let fences down and put back up prior to and post movements. The effectiveness is dependent on good knowledge of daily and seasonal movement patterns. Benefits to this design are contingent on timing – most likely to occur during migration periods and possibly during severe weather. Although found to be a benefit to deer, let-down fences are used less with pronghorn (Wilson 1995). Let down-panels will have better success if placed along an established and predictable movement corridor.

b. Adjustable fence segments can be used when livestock are not on rangelands. Wire of fences can be adjusted to allow for unimpaired seasonal movement of antelope (Anderson and Denton 1980). This technique is especially valuable in areas that can experience snow depths of 30.5 cm (12 in) or more since any of the wires can be raised and temporarily fastened. The ability of 1 person to adjust one wire for 1.6 km (1 mile) in 30 minutes makes this modification a realistic option on pronghorn range. Since pronghorn are generally selecting crossing points where the lower wire is higher, the adjustments made at these points are quickly adapted to by pronghorn (Yoakum 1980).



Three-stranded, 97 cm (38 in) high barbed-wire fence with modifications onto posts to allow adjustments to wire spacing and facilitate pronghorn movement (Anderson and Denton 1980).

9. All modifications should be flagged with white rag flagging along the top wire between posts to alert pronghorn.

Post-Modification Evaluation: Pronghorn movements and distributions should be examined post-modifications to determine the effectiveness and potential need for improvements.

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