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Wildlife and Energy Development
Pronghorn of the Upper Green River Basin – Year 1 Summary

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WILDLIFE AND ENERGY DEVELOPMENT

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LIST OF ACRONYMS

BLM   Bureau of Land Management
FC   Fecal Corticosteroids
FN   Fecal Nitrogen
GC   Glucocorticosteroid
GPS   Global Positioning System
GYE   Greater Yellowstone Ecosystem
IDW   Inverse Distance Weighted
PAPA   Pinedale Anticline Project Area
RFID   Radio Frequency Identification
UGRB   Upper Green River Basin
VHF   Very High Frequency
WCS   Wildlife Conservation Society
WGFD   Wyoming Game and Fish Department

ACKNOWLEDGEMENTS

SYNOPSIS

The development of energy resources poses difficult challenges for society. In regions like the Northern Rocky Mountains there are vast tracts of public lands which harbor unparalleled wildlife, some of the longest remaining migrations of big game in the Western Hemisphere, and such species as elk and bighorn sheep, wolverines and grizzly bears. These lands also contain trillions of cubic feet of natural gas and coal bed methane. The consequent mix of biotic and geological resources has produced unique conflicts that extend from Mexico to Canada. Chief among these is a lack of information about effects of development on wildlife. Nowhere has the ambiguity been greater than in the Upper Green River Basin (UGRB) of western Wyoming, an area comprising a portion of the Greater Yellowstone region where 100,000 ungulates spend their winters and development for natural gas has been rapid.

This report summarizes preliminary results of the first of a five-year project in the UGRB. The major aim is to understand how the footprint of gas field infrastructure and development affects one of the most prominent and wide-ranging species of the western sage-steppe ecosystem, pronghorn. Results to date suggest the following:

- A growing array of gas fields, roads, and attendant human infrastructure is altering the suitability of habitat for wildlife.

- Pronghorn habituate to human presence when not hunted or harassed, but the continual fracturing of previously undisturbed lands is leading to reduced usage and abandonment of small habitat parcels.

- Snow depth in excess of ~ 20 centimeters affects use of local habitats. However, once the density of gas wells and attendant infrastructure reaches a threshold, pronghorn no longer use these areas irrespective of snow depth.

- Based on 56,992 data points generated from global positioning system (GPS) radio-collars, none of the collared animals used areas within the Jonah Gas Field.

- The winter body mass of pronghorn captured in and among the gas fields (designated experimental animals) did not differ from animals captured at sites far from petroleum activities (designated control animals). Additionally, there was no evidence of variation between control and experimental animals in terms of mineral

deficiencies, disease prevalence, organophosphate concentrations, PCB levels, or stress hormones.

- Pregnant females had higher levels of fecal progestagens, and progestagen concentrations were positively correlated with body mass. No differences between control and treatment animals were detected.

- Pronghorn generally shunned concentrated gas fields, and there was no evidence to suggest animals altered their 24-hour activity patterns to utilize these areas at night when human disturbance was reduced.

- Because GPS collars were collected in December and the date of this summary is January, fine-grained analyses of movements will be included in a future report. The analyses reported here are preliminary and subject to change and interpretation.

INTRODUCTION

Backdrop

The extraction of resources for energy consumption is a complex issue, especially in the western USA. While America's energy needs continue to grow, great uncertainty remains regarding the effects of energy development on wildlife and the formulation of
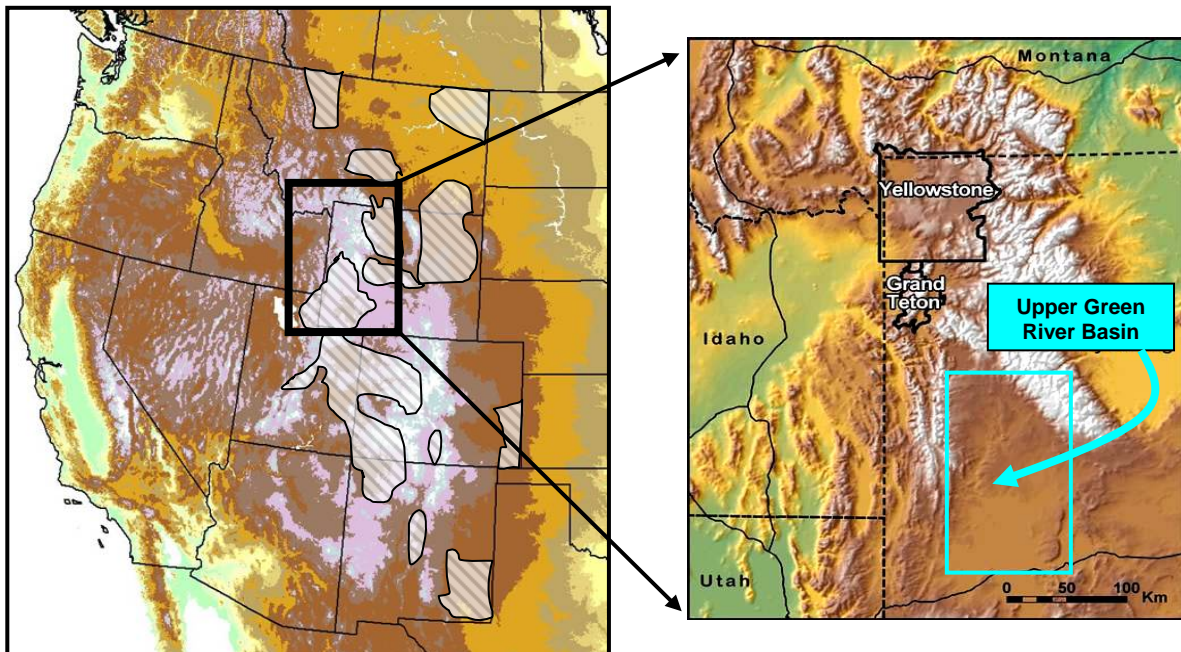
Figure 1. Public lands with energy development projects in the Rocky Mountains (stippled regions; left) and location of the UGRB (right).

strategies to mitigate consequent impacts. Numerous petroleum deposits exist across public lands from Otero Mesa and the San Juan Basin in New Mexico to the Rocky Mountain Front in Montana, and these typify the scope of the challenge within the contiguous USA (Fig. 1). Nowhere in this region are the issues more visible than in the UGRB of western Wyoming where more than 100,000 ungulates winter, including elk, mule deer, pronghorn, and moose, as well as the densest remaining populations of sage grouse. Indeed, migration spectacles within the UGRB are impressive (Fig. 2). Pronghorn and mule deer undertake the two longest migrations of any land mammal in the Western Hemisphere outside the Arctic. These sensational movements have occurred for at least 6,000 years (Miller and Sanders 2000; Berger 2004). Nevertheless, opportunities to minimize possible harmful effects on wildlife are formidable, particularly due to the paucity of baseline information on past trends in abundance, effects of weather, and site-specific responses to energy development.

While natural gas production has intensified in numerous areas of the United States, growth of gas fields has been rapid since the 1980s in southwestern Wyoming, an area where an estimated 25 - 30 trillion cubic feet of gas may exist. Two regions of spectacular growth are the Jonah and Pinedale Anticline regions of

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Figure 2. Pronghorn from the Upper Green have the second longest documented migration for a terrestrial mammal in the Western Hemisphere.

the UGRB (Fig. 1). As the construction of facilities and infrastructure to harvest these resources continues, it has become clear that the absence of biological data on wildlife is an impediment to prudent land use planning. As a consequence, the Wildlife Conservation Society (WCS) initiated a small-scale field project in fall 2002 and expanded the scope of the study in winter 2005.

Aims and Goals

Given a lack of both short- and long-term site-specific information on pronghorn in the UGRB, as well as for other wildlife in much of the Rocky Mountains, we opted to address a broad set of questions with the intent that answers might assist in future planning and conservation efforts. These questions were designed in consort with wildlife managers from state (Wyoming Game and Fish Department [WGFD]) and federal (Bureau of Land Management [BLM]) agencies. Additionally, the concerns of local groups that included sportsmen, environmental planners and activists, town and county officials, ranchers, scientists, and the general public at large were included in our initial efforts to address questions of common interest.

For the UGRB, we anticipate an over-arching project to evaluate how humans, ecological, and bio-physical properties affect pronghorn. The human dimension is complex and involves more than the development of gas fields and attendant infrastructure. Other potential impacts include hunting pressure, traffic, habituation by animals, and an indirect human footprint that is associated with housing, dogs, and fences. A simplified pathway by which different factors might affect wildlife is illustrated in Figure 3.

Specific goals of the five-year project are to assess:

- Seasonal changes in pronghorn distribution, movements, and migration routes
- Influences of the configuration of gas field infrastructure on pronghorn

- Threshold point(s) at which road and well pad densities alter habitat use

- Productivity and survival of pronghorn

- Physical and biotic correlates and the human footprint in areas used and avoided by pronghorn

- Interactive effects of human disturbance and weather on body condition, pregnancy rates, and subsequent affects on population dynamics

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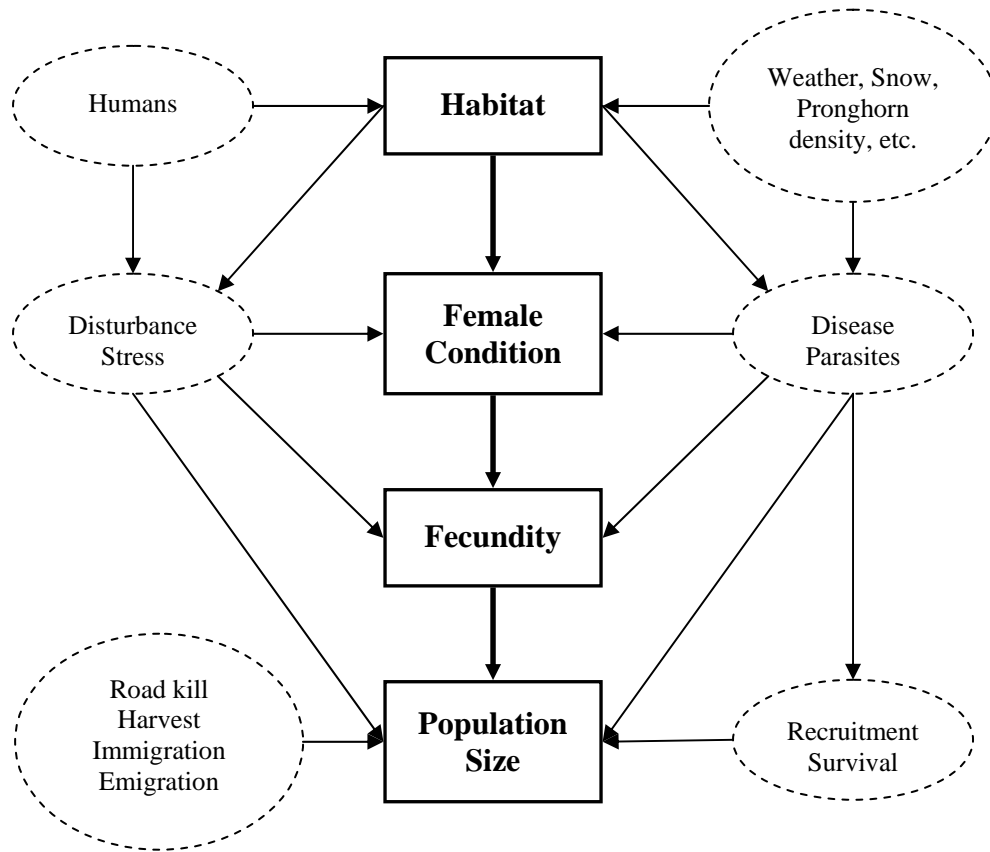
Figure 3. Overview of pathways through which different factors affect a population.

APPROACH AND RATIONALE

Scientific Standards & Meeting the Goals

Two primary issues -- one biological, the other based in human dimensions -- stand out. Each re-enforces a lack of existing knowledge. First, while numerous studies focus on relationships between animal distributions and human disturbance, findings are often limited in scope. This is because animals move for many reasons and even where humans drive the re-location, it remains unclear whether animals simply move to other habitats that remain suitable and whether altered movements ultimately result in population level effects. In other words, while suitable habitat is an obvious requisite to sustain populations (Fig. 3), only rarely have studies been designed to address demographic consequences or other potential effects of shifts in distribution or habitat use.

For studies to be valid, they must be well grounded in a design that includes falsifiable hypotheses, sufficiently large sample sizes, appropriate controls, and adequate

replication. Critically, they should be published in peer-reviewed journals. For studies on highly mobile species with large home ranges, high inter-annual variability in spatial use, clumped use of limited winter habitats, and no control over weather, the challenge of doing valid science is formidable (Jenkins 2004). Nevertheless, studies of species such as caribou, bighorn sheep, rhinos, and African lions demonstrate that it is possible to employ methodologies to obtain data and address the above major goals.

Limitations

Patterns of habitat use and behavior in ungulates vary due to natural variation and disturbance, whether caused by humans, predators, or other factors. Behavior and habitat use are also affected by snow cover, season, body condition, and history. Animals in national parks, for instance, tend to be more habituated and less likely to modify their behavior in the presence of humans than animals with less exposure; hunted or poached animals, by contrast, tend to exhibit a stronger response (Donadio & Buskirk 2006).

Studies of behavior, spatial use, and habitat abandonment have received less attention in relation to construction activities, especially at sites of petroleum development such as in Alaska (Berger et al. 2001) or Wyoming's UGRB (Sawyer et al. 2005). While notable exceptions exist such as long-term monitoring of caribou and oilfields (Cameron et al. 1992; Pollard et al. 1996; Cronin et al. 1998), effects of winter drilling and other factors associated with winter habitat use remain largely unexplored for wildlife throughout most of the Rocky Mountains.

Most available data do not enable a distinction as to whether effects are small, large, or nonexistent, nor have attempts to understand the relationship between habitat use and subsequent demography been especially robust. Investigations of habitat use within a single area can show whether patterns change over time, but they are often unable to discern the scale of possible effects and, critically, whether population sizes are compromised.

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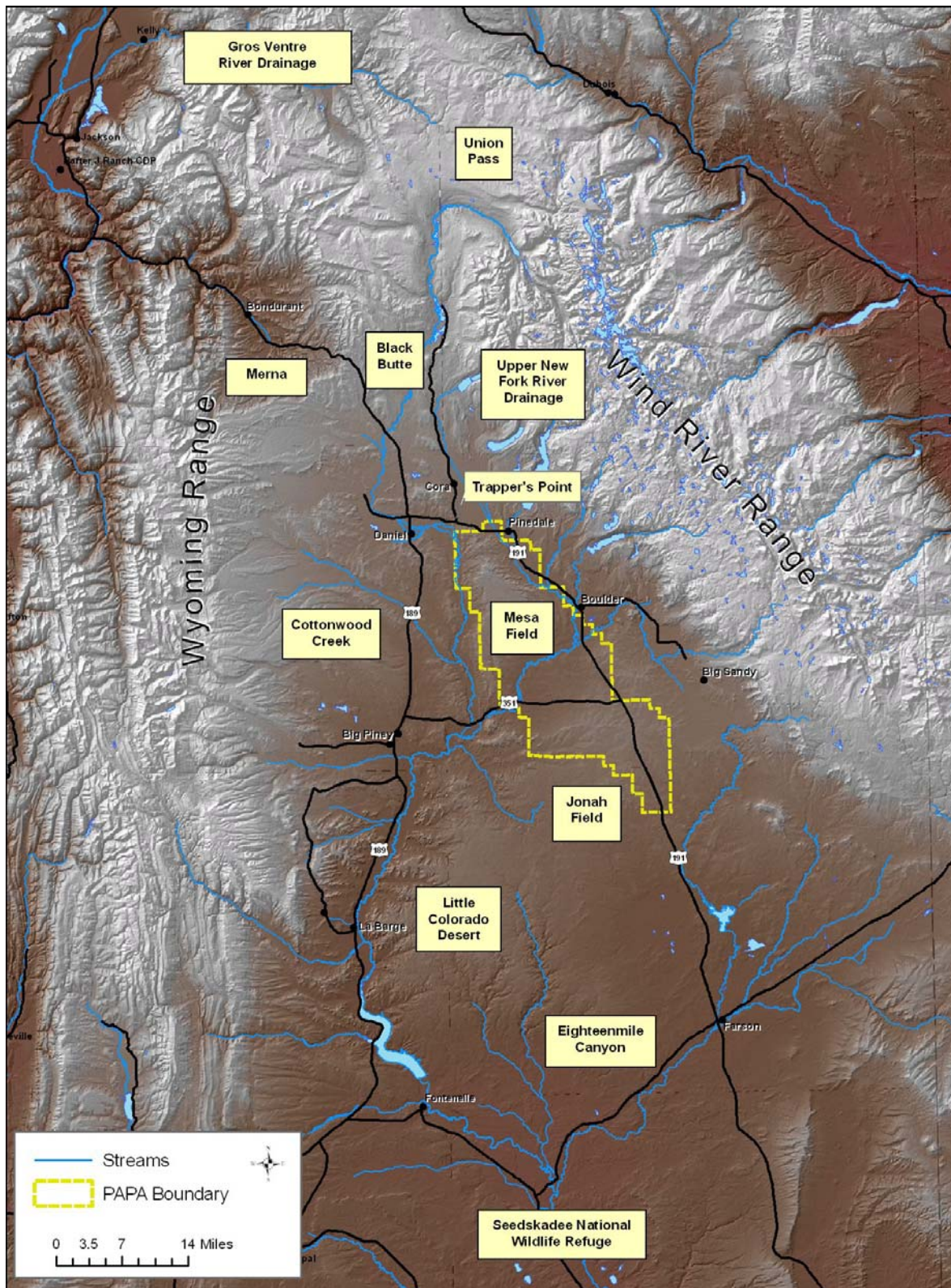
Figure 4. Overview of study area within the UGRB showing areas mentioned in the text. Note that the Jonah Field falls outside the region that the Bureau of Land Management designates the Pinedale Anticline Project Area (PAPA).

Research Design

To achieve project aims, we will continue to rely on two general types of contrasts: 1) before and after comparisons of animal performances at sites associated with gas field activities; and 2) contrasts between pronghorn designated as either control or experimental animals. The latter are animals reliant on areas in and around gas fields during winter. Control animals are spatially segregated from gas fields (see below for assignment of animals to respective treatments).

METHODS

Study Area, Sampling and Handling

The primary study region within the UGRB is approximately 4,000 km^2 (Fig. 4). Pronghorn use habitats that vary in elevation from about 2,100 to 2,800 meters. During winter, pronghorn are generally found at lower elevations where densities tend to be highest in areas adjacent to Cottonwood Creek, rolling hills associated with the Pinedale Anticline (Mesa and Jonah Fields), and the Seedskadee Wildlife Refuge to the southwest of Eighteenmile Canyon (Fig. 4). The region in and around the southern edge of the Mesa Field (~T31N, R109W) has been formally designated by the WGFD as crucial winter range for pronghorn. Crucial winter range has been defined as "the determining factor in a population's ability to maintain itself at a certain level over the long term."

For the purposes of this report, we refer to the two areas of greatest gas production as the Jonah Field and the Mesa Field (Fig. 4). The latter is contained within what the BLM has designated the Pinedale Anticline Project Area (PAPA).

Table 1. Covariates used to assess pronghorn distribution.		
Ecological	Biophysical	Anthropogenic
Patch Size	Snow Depth	Distance to Roads
Habitat	Temperature	Type of Road
Vegetation Height	Topography	Distance to Nearest Ranch
		Distance to Nearest Gas Pad
		Distance to Nearest Fence
		Traffic Volume
		Type of Vehicle

See Appendix for details concerning specific measures.

Our efforts to understand animal distribution concentrate on three types of related measures. First, all animals were noted during driving censuses along with a suite of biophysical, ecological, and anthropogenic characteristics (Table 1) that included snow depth (Fig. 5). Second, during winter we conducted bi-monthly aerial surveys (weather permitting). Pronghorn locations and group sizes were noted along fixed routes with strips separated by not more than 5 kilometers, at speeds less than 120 km/hr, and at altitudes generally less than 100 meters. Third, we outfitted 50 adult, female pronghorn with radio-collars with built in global positioning system (GPS) and VHF capabilities (Advanced Telemetry Systems, Isanti, MN). Each collar was equipped with a mortality sensor and was programmed to record up to 8 locations per 24-hour period.

All animals were net-gunned from a helicopter (Quicksilver Air, Fairbanks, AK). Animals were physically restrained, blindfolded and weighed, and blood was drawn (by WCS veterinarian William Karesh; Fig. 6). Handling time for 40 animals averaged less than 6½ minutes. For 10 animals in which ultrasound was used to determine litter size, mean handling time was 12 minutes. However, because we could only confirm litter size in five of ten animals using this method, the ultrasound procedure was abandoned.

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Figure 5. Pronghorn in snow at about the maximum tolerated.

Feces were collected from restrained animals to evaluate fecal corticosteroids (FC) as a surrogate for glucocorticosteroid (GC) levels. The secretion of GC is a useful marker of stress in mammals (Creel et al. 2002), as it is a product of the adrenal cortex. Increased chronic stress may result in a reduction in condition, immunity, and reproduction (Sapolsky 1992). We used FC levels to assess potential variation in chronic stress among pronghorn in different wintering areas. Baseline measures of FC will subsequently be confirmed by contrasting levels with those of other wintering populations and captive animals in zoological parks.

Assessment of Body Condition

To facilitate our understanding of a possible link between habitat use and demography (Fig. 3), we continue with the development of a remote scale system to track seasonal changes in female body mass. Mass is a well known parameter that affects life history and population dynamics, and empirical findings demonstrate that poorly-conditioned females produce fewer young, lighter offspring, and incur greater mortality (Festa-Bianchet et al. 1997; 1998). Although body mass and condition are not always

Figure 6. Net dropping over female (top left), a blindfolded and restrained female (top right), weighing a restrained female (bottom left), and drawing blood (bottom right). Photos: B. Karesh.

correlated (e.g., small animals can be fat, and large ones thin), studies of survival and fecundity suggest an overwhelming concordance between mass and condition (Clutton-Brock et al. 1982; Berger 1986). Indeed, starved pronghorn generally deplete all muscle and marrow fat (Depperschmidt et al. 1987). However, the relationship between body condition or mass during winter and subsequent fecundity in spring remains less certain (Zimmer 2004).

To date, we have developed and field-tested a remote scale complex that has successfully generated body mass data on pronghorn during summer (Fig. 7). The system operates on three 12 volt batteries via a Digi-Star computer connected to load bars and a weighing platform. There are four primary components: 1) a Digi-Star scale (measures are recorded by the computer stored in a weather-proof container at the site); 2) a solar panel to recharge batteries; 3) a scanner that records the identity of individuals wearing radio frequency identification (RFID) ear tags (Fig. 7), and 4) an autonomous digital camera that is triggered when a laser is broken so that the species and gender of the animal on the platform may be confirmed. Both the camera and the computer provide independent time/date stamps which allow validation of the time/date of visit. Much of our effort during the first year was devoted to testing different scale configurations, locations, and implementation procedures.

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Figure 7. Animals at scale (top; buried platform visible, scanner and computer camouflaged by sage), and RFID (bottom; button in ear).

Control and Experimental Animals

We tentatively classified animals as either control or experimental based upon *a priori* assessments of proximity to areas with energy development infrastructure. Those captured near or within the Jonah or Mesa Fields were designated experimental animals; those netted away from such sites were designated control animals. A priori classification schemes may suffer from numerous pitfalls, the most prominent being that animals assigned to a specific treatment may subsequently move to an area classified differently.

Similar classification assignments have, however, been used successfully for other species, particularly when a high proportion of locations (e.g., $\geq 90\%$) fall within a discrete home range that has been designated as either a control or experimental site (Beckmann & Berger 2003). For the radio-collared pronghorn, we used locations obtained from the GPS collars to determine whether animals captured in either gas field or non-gas field locations (Fig. 8) moved to other sites during winter. Animals showed remarkable fidelity during the winter months (Fig. 9); thus, we believe our assignment of animals to respective treatments was reasonable.

FINDINGS, PROGRESS, UNCERTAINTY

Assessments of Body Mass, Stress Hormones, and Pregnancy

Body mass in late February did not vary among animals using control or experimental sites. Irrespective of treatment, mean mass was 48.1 kg (*n*=53; Fig. 10). Mass changed seasonally, with an average weight gain of 2.88 kg between late February 2005 and early December 2005 (*n*=10 re-sampled animals; Fig. 11). Eight of the ten pronghorn had gained weight as they entered winter 2005/06 (Fig. 11).
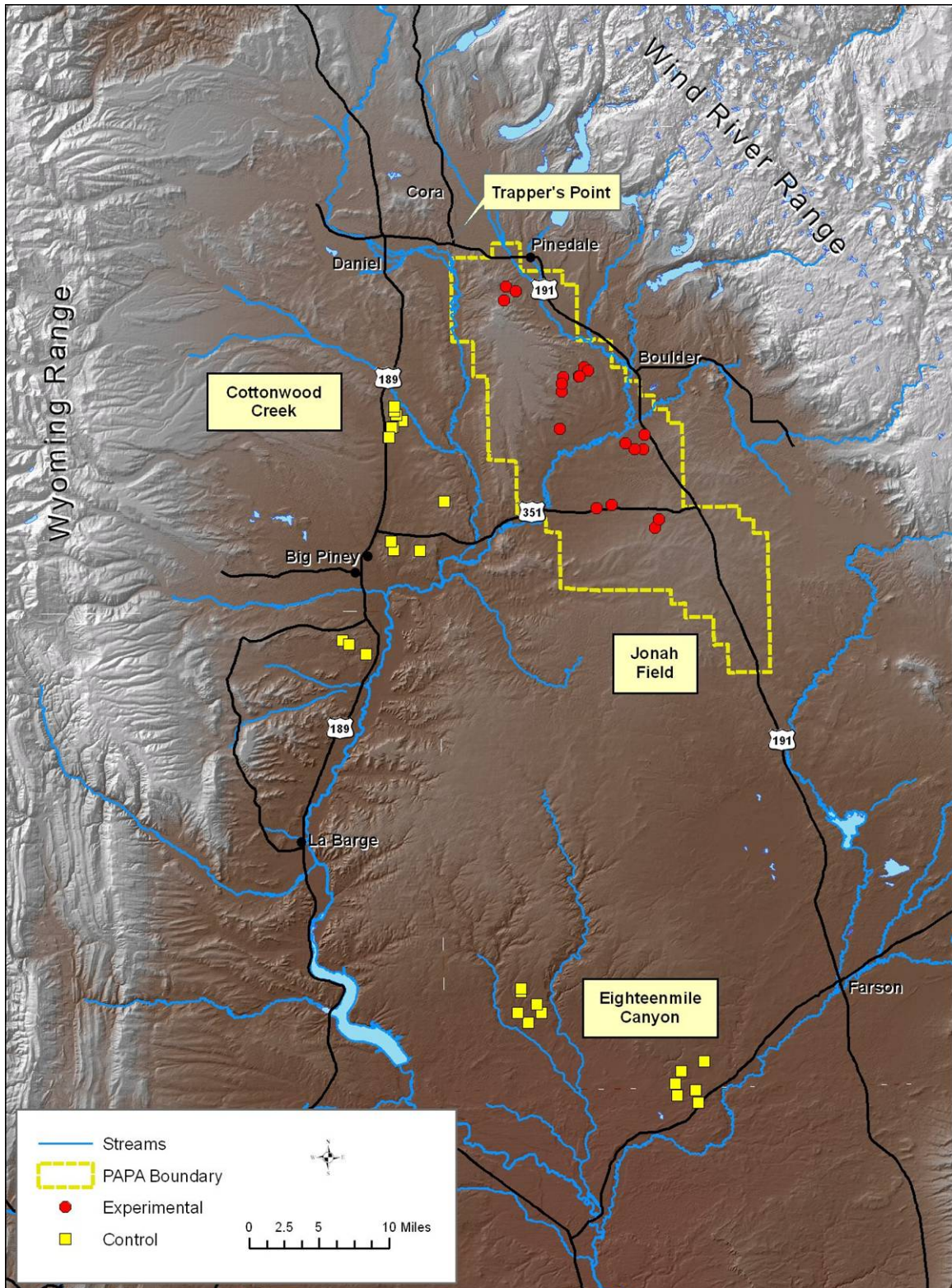
Figure 8. Locations of captures depicting experimental (red) and control (yellow) animals based on proximity to the PAPA (Mesa and Jonah Fields).
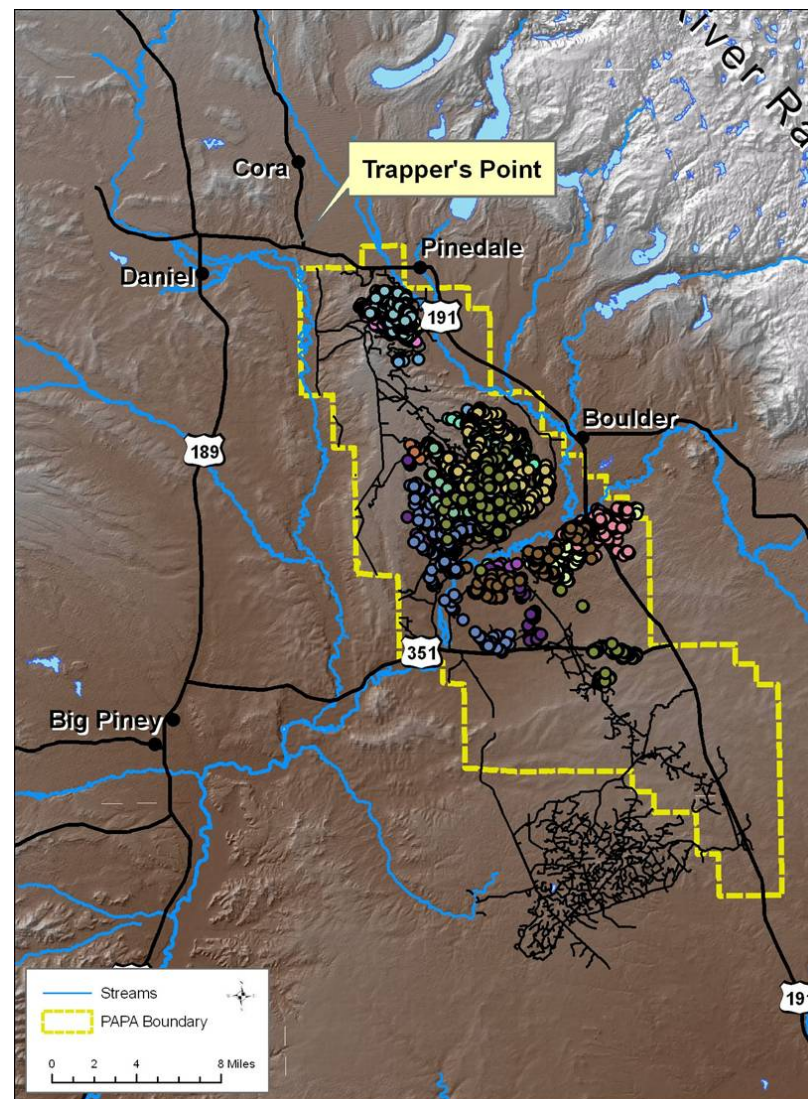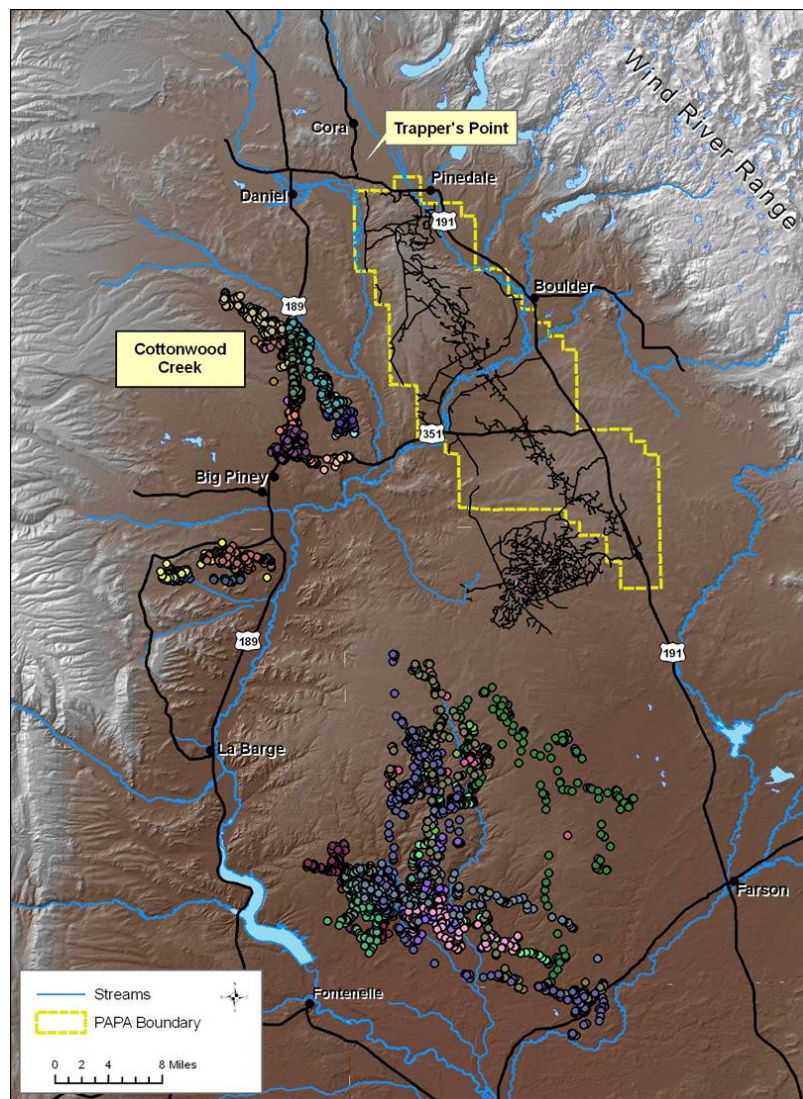
Figure 9. Winter (February and March) 2005 locations of collared animals reflecting philopatry to area of capture. Left depicts animals classified as 'control' and right those classified as 'experimental'.

Among 50 adults examined for stress hormones via analyses of fecal corticosteroids, differences were not evident by treatment (Fig. 12). Despite the greater mean for control animals, considerable overlap exists due to substantial variation in corticosterone levels among animals (i.e., wide confidence intervals).

Figure 10. Mean body mass for control and experimental animals at time of capture (Feb. 2005). Bars represent 95% CI (*SEm*).

For five animals, we determined pregnancy status by ultrasound, and then compared these results with fecal progestagen levels (as indicated by P4 ug/g dry weight; Fig. 13). Progestagen concentrations were higher in known pregnant animals, and P4 levels were slightly higher in experimental than control animals (Fig. 13).
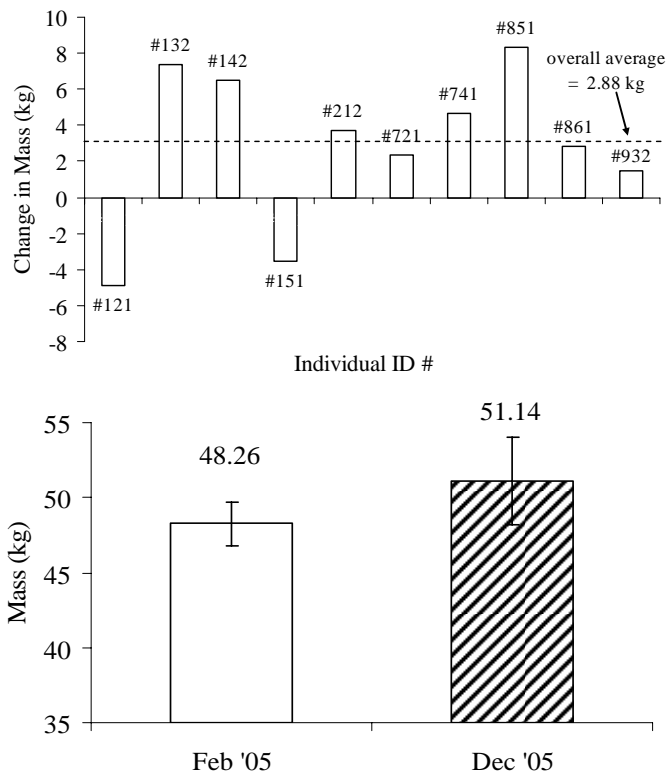
Figure 11. Changes in body mass of individual females (top) and average weights (bottom) for animals captured in February and re-weighed in December.

A positive relationship exists between February body mass and progestagen levels (Fig. 14), indicating that heavier animals are more likely to be pregnant. This sort of relationship is important as it suggests that lighter animals may be disadvantaged reproductively (i.e., they may be unable to conceive and/or produce fawns). In this first year of the study however, it remains unknown whether animals from either treatment are differentially susceptible to seasonal mass changes or the extent to which such changes may affect subsequent fecundity and survival.

Disease, Eco-toxicology and Nutritional Markers

Where animals become highly concentrated, whether due to artificial feeding, habitat loss, or naturally-limited range, density tends to affect population performance. Given the seasonal reliance of pronghorn on crucial winter range in and around gas fields, we tested whether

Figure 12. Average corticosterone levels for control and experimental animals.

individuals at experimental sites showed higher titers for disease or differed in other ways from control animals. Three general areas of health were investigated.
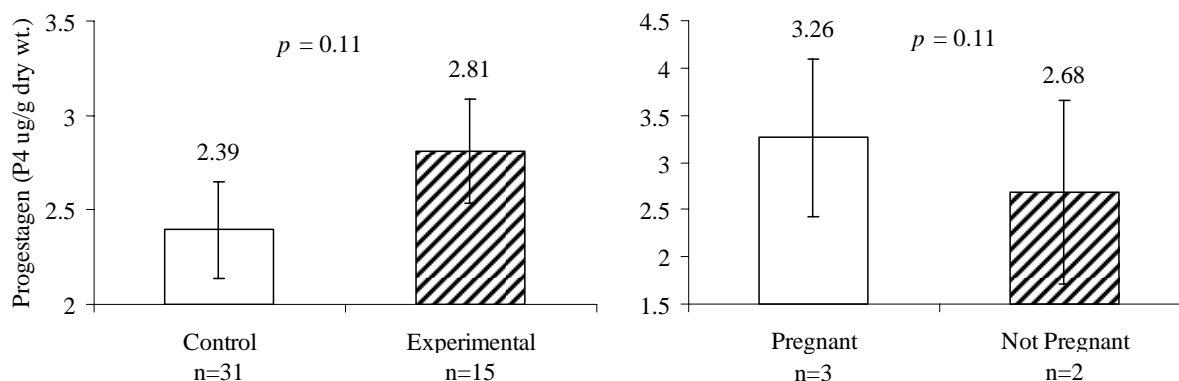
Figure 13. Differences in fecal progestagen levels among control and experimental animals (left) and pregnant and non-pregnant adult females (right).

First, we examined exposure to eight diseases (Table 2). Irrespective of treatment, antibodies were below detectable levels. Second, we assessed whether experimental and control animals varied in selected minerals and vitamins in blood sera (Table 3). No differences were noted except that experimental animals had significantly lower sodium levels ($\bar{x}_{ctrl}$ = 3,783 [n=27], $\bar{x}_{exp}$ = 3,683 [n=20], p=0.004). Finally, appreciable levels of polychlorinated biphenyls (PCBs) or other organochlorines were not detectable (Table 4). Because our evaluations were based exclusively on blood sera from live animals, the

possibility of bioaccumulation of these fat-soluble, stable compounds in tissues or other organs was not examined.

Variation in Summer Range

If nutrition in summer varies among areas, then animals may return to winter sites in different condition. As a consequence, differences in survival might

$y = 0.0883x - 1.703$
$r^2 = 0.127, p = 0.15$

Figure 14. Relationship between body mass and fecal progestagen levels.

spuriously be attributed to the effects of experimental or control treatments, whereas the true cause might be summer range conditions. Since fecal samples are easy to collect and reflect crude differences in diet quality (Cook et al. 1994), we examined whether female pronghorn using different summer ranges varied in fecal nitrogen (FN).

Table 2. Summary of diseases screened in serology tests.

Disease	Description
Epizootic Hemorrhagic Disease (EHD)*	Infectious, arthropod-borne virus causing acute hemorrhagic disease.
Bluetongue (BT)*	Similar to EHD in that it also produces acute and often fatal hemorrhagic disease. Cattle serve as reservoirs.
Bovine Respiratory Syncytial Virus (BRSV)	BRSV causes acute respiratory tract disease in cattle, producing emphysema and lung endema. Species susceptibility and transmission between cattle and pronghorn is unclear.
Bovine Virus Diarrhea (BVD)	Viral disease linked to areas where cattle are raised. Field recognition difficult due to clinical similarities with foot and mouth disease and infectious bovine rhinotracheitis.
Infectious Bovine Rhinotracheitis (IBR)	Virus affecting genital organs and upper respiratory tract where observed in range cattle. Most often spread by venereal transmission, except in feedlots and other areas of concentrated cattle where it can be spread through respiratory route and is usually more virulent.
Brucellosis	Contagious bacteria-related disease caused by Brucella spp. that leads to abortion in livestock.
Johne's Disease	Tuberculosis is an infectious, bacteria-related disease caused by mycobacterium, leading to lesions in the lungs and other organs.

*Note that EHD and BT are closely related viruses and therefore may cross-react on blood tests.
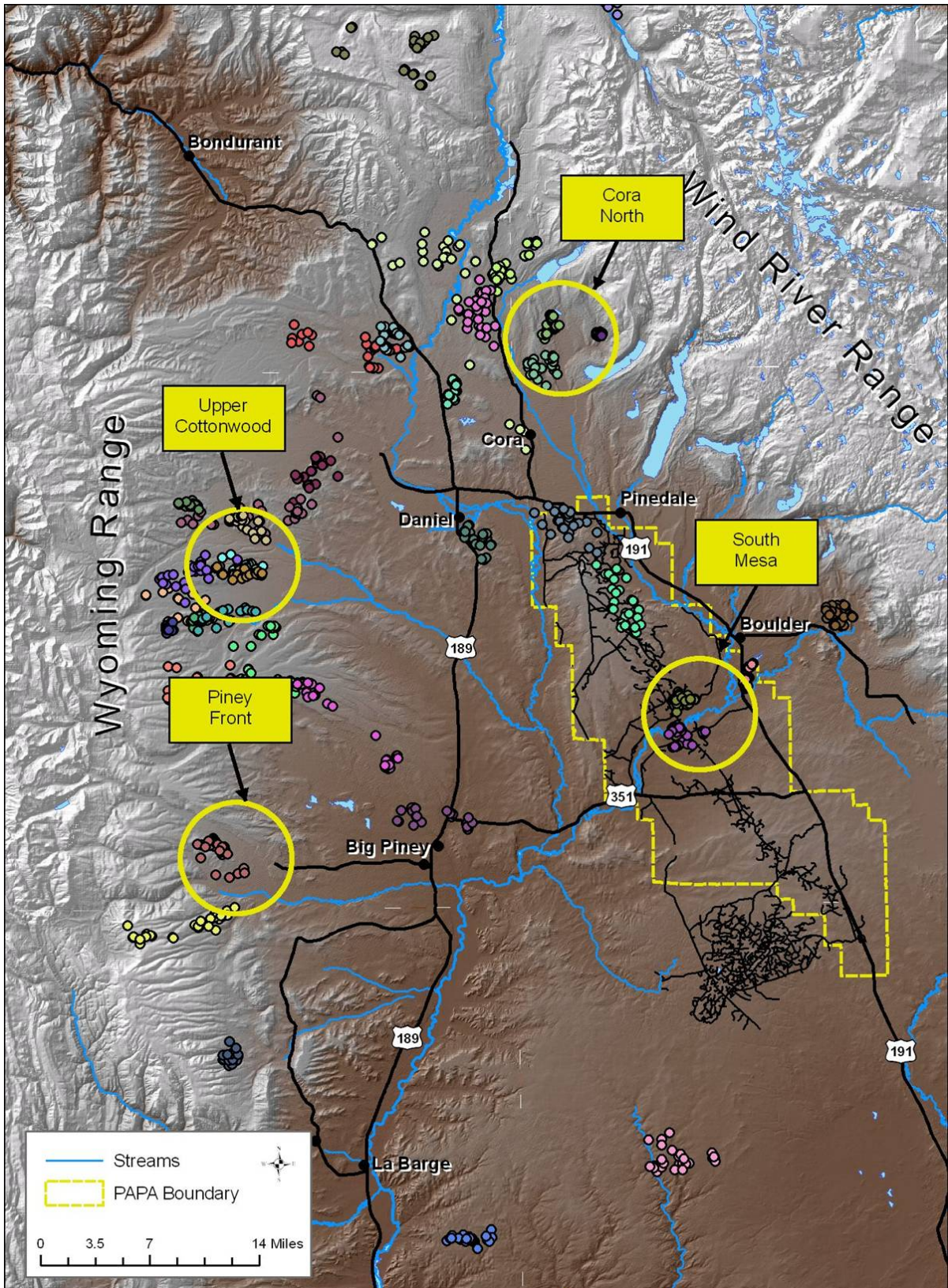
Figure 15. Select locations of summer ranges of animals tagged in control and experimental areas, and areas where fecal nitrogen samples were collected.

Table 3. Summary of role of vitamins and minerals in physiological function.

Name	Description
Iron	Trace element functioning in enzyme oxidation
Magnesium	Essential to enzyme activation relative to energy metabolism
Potassium	Functions in nerve and muscle excitability
Zinc	Trace element functioning in enzyme activation and synthesis of DNA and RNA
Calcium	Essential to skeletal formation
Vitamin E	Functions in cellular and subcellular membrane integrity
Sodium	Regulates blood fluids, acid/base balance, and tissue pH

Nevertheless, as a surrogate measure of nutrition, FN has limitations. Tannins and other secondary plant compounds bind to protein and may be indigestible, resulting in inflated estimates of FN (Hobbs 1987). Although shrubs contain secondary compounds and grasses have fewer, this should not be a serious concern since pronghorn summer diets tend to be forb or shrub dominated (Yoakum 2004). And, in at least one ungulate, total FN was associated with body mass gain during summer (Blanchard et al. 2003).

We concentrated on four major summering areas (Fig 15) and gathered fecal samples from 120 unidentified females within the ranges of known radio-collared females. The amount of variation in FN among sites was low $(\bar{x} = 2.45; SEm = 0.03)$.

Only the South Mesa and Upper Cottonwood sites differed significantly (Fig 16), but whether the absolute (0.24%) or relative (9%) difference in FN is biologically meaningful is unknown. Females using the South Mesa site have
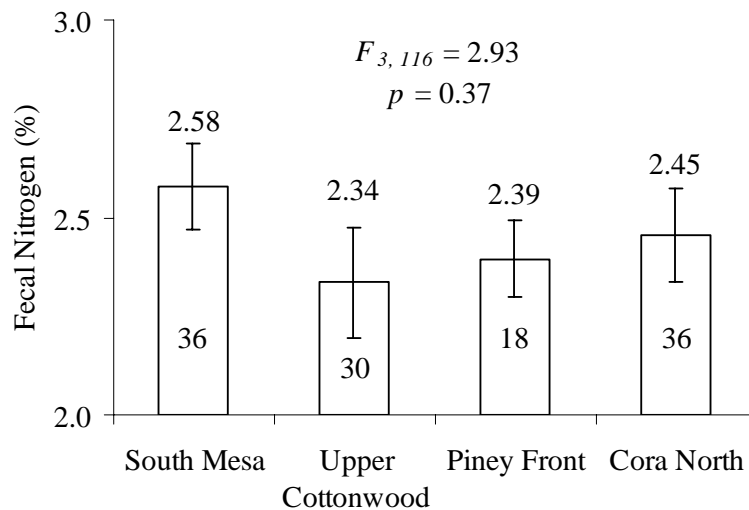
Figure 16. Comparison of fecal nitrogen levels in diets of pronghorn from four summering areas.

access to alfalfa, forbs, and shrubs whereas the Upper Cottonwood consists primarily of native rangeland at altitudes reaching almost 2,900 meters.

Table 4. Summary of ecotoxicological compounds screened for during laboratory testing.	
Ecotoxin	**Description[1]**
Cobalt[2]	Carcinogenic heavy metal compound.
Arsenic[3]	Heavy metal; carcinogen and developmental toxicant.
Cadmium	Heavy metal; carcinogen, developmental and reproductive toxicant.
Lead	Heavy metal; carcinogen, developmental and reproductive toxicant.
Thallium	Heavy metal; suspected blood, liver, and kidney toxicant. Suspected neuortoxicant and reproductive toxicant.
Selenium[4]	Heavy metal; suspected toxicant.
PCBs	Organic contaminant; suspected endocrine toxicant.
Organochlorines	Organic contaminant; suspected toxicant and carcinogen.

[1] Note that descriptions refer to known and suspected affects on humans.

[2] Cobalt is also a trace mineral, necessary for vitamin B12 production, but can be toxic if ingested at high levels.

[3] Arsenic is also a trace element that, in combination with other trace elements, is required in diet for hair growth, development, and bone formation. Toxic at high levels.

[4] Selenium is also a trace element that activates glutathione peroxidase. Toxic at high levels.

The Changing Landscape

Native habitat on both the Jonah and Mesa Fields has changed rapidly. Whether this region can continue functioning as crucial winter range now and in the future has been one of the prime factors motivating this project. Despite the minimization of the human footprint by directional drilling, infill developments will continue. To address habitat loss, we supplemented existing satellite imagery to evaluate recent changes in gas field development from 2002-2005 (Figs. 17-19). Specifically, we estimated the amount of change in two quantifiable parameters: 1) the number of gas pads, and 2) the amount of new roads (km) in our two primary experimental areas (The Mesa and Jonah Fields).

Changes in Gas Well Pads

Gas well pads were identified based on four criteria: 1) locations in either the Mesa or Jonah; 2) cleared vegetation; 3) association with a water pond; and 4) a visible road to the pad. As a consequence of these criteria, our estimates of the total number of gas well pads are highly conservative as more gas pads operate in the absence of these traits. Based on the latest available satellite images from 2005, and using 1999 for baseline values, there
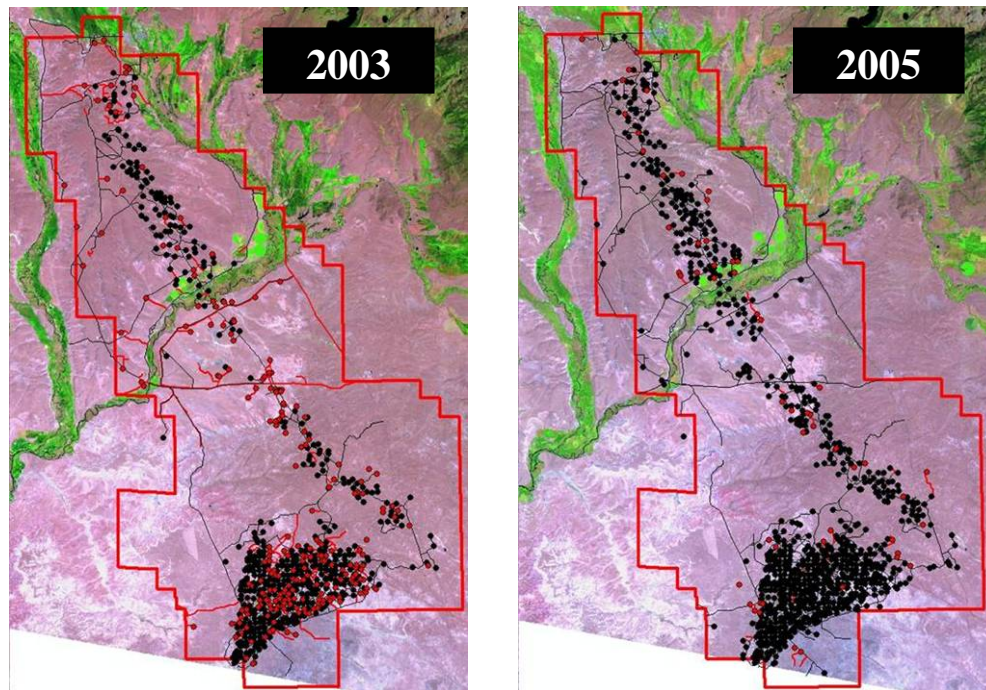
Figure 17. Overview of changes in well pad and road densities on the Mesa and Jonah Fields. Red dots/lines indicate the locations of new wells/roads.

has been a 108% increase in the number of pads in the Mesa, and an 89% increase in the number of pads in the Jonah. There are currently 685 total pads in the Jonah area and 200 total pads in the Mesa. Based on field measures, an average pad is 19,600 m^2 (140m x 140m). Thus, a conservative estimate of the total habitat loss due to well pads alone is 17.35 km^2. These measures do not account for habitat loss due to exploratory drilling or clearings for the construction of pipelines, values which have yet to be estimated.

Changes in Roads

Roads associated with gas development were identified based on three criteria: 1) location in the Mesa or Jonah; 2) lack of significant vegetation cover; and 3) at least 28.5 m wide (i.e., one pixel across). Because of these criteria, our estimate of the total amount of roads is conservative, as there are many more roads in existence than what were identified using these criteria. Using 1999 as a baseline, there has been a 36% increase in the total amount of roads (km) in the Mesa and a 100% increase in the total amount of roads in the Jonah Field. The rate of increase for new roads has slowed in recent years (Fig. 18) due to reliance on existing roads. However, unlike changes in the number of gas well pads, the rate of increase continues to be faster in the Jonah region than the Mesa (Fig.

18). A total of 743 km of roads exist in the two fields; Jonah contains 468 km and the Mesa 275 km.

Pronghorn Use of Habitat Fragments

Both conceptual and empirical approaches have been used to investigate patterns of land change and their consequent biological effects, particularly as mediated by habitat fragmentation (Fahrig 2003; Henle et al. 2004). These studies include a site-specific analysis within the UGRB (Thompson et al. 2005). One of our interests in examining how habitat fragmentation affects pronghorn stems from two differing impressions held by local

Figure 18. Relationships between year and cumulative changes in well pads (top) and roads (bottom), with 1999 as a baseline.

stakeholders: either pronghorn movements and distribution are unaffected by the gas field imprint, or the continued fracturing of suitable habitat reduces pronghorn use.
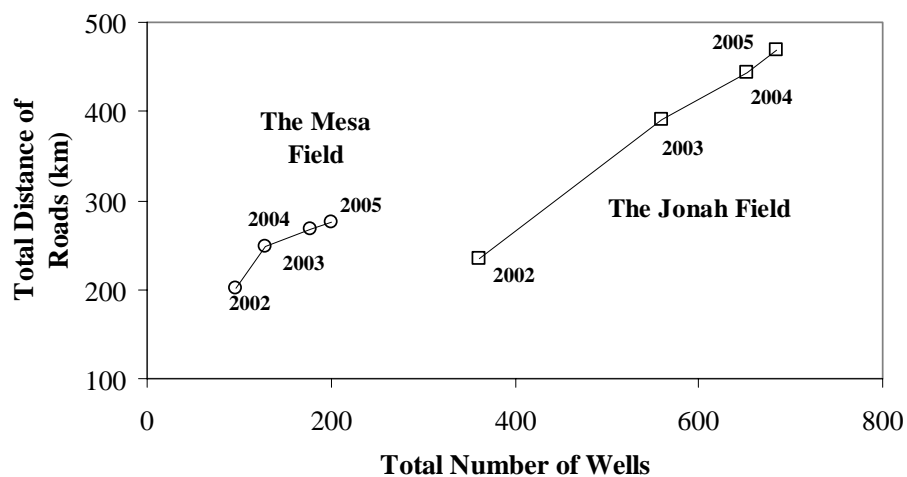
Figure 19. The human footprint in the UGRB - a depiction of relative changes in kilometers of roads and well pads between 2002 and 2005.

To help understand which scenario might be more apt, we used satellite imagery to create a series of grids that overlapped the Jonah and Mesa Fields and adjoining areas. Different grid sizes (e.g., 500m x 500m, 250m x 250m, and 125m x 125m) for the entire region were used in each of three independent analyses. From each grid, we estimated the proportion of area cleared of vegetation (roads included) relative to cell size, and remaining available habitat was then converted into separate individual polygons (see Fig. 20 for examples of fragmentation). The size of each patch was then estimated and assigned an identification number based on its area.
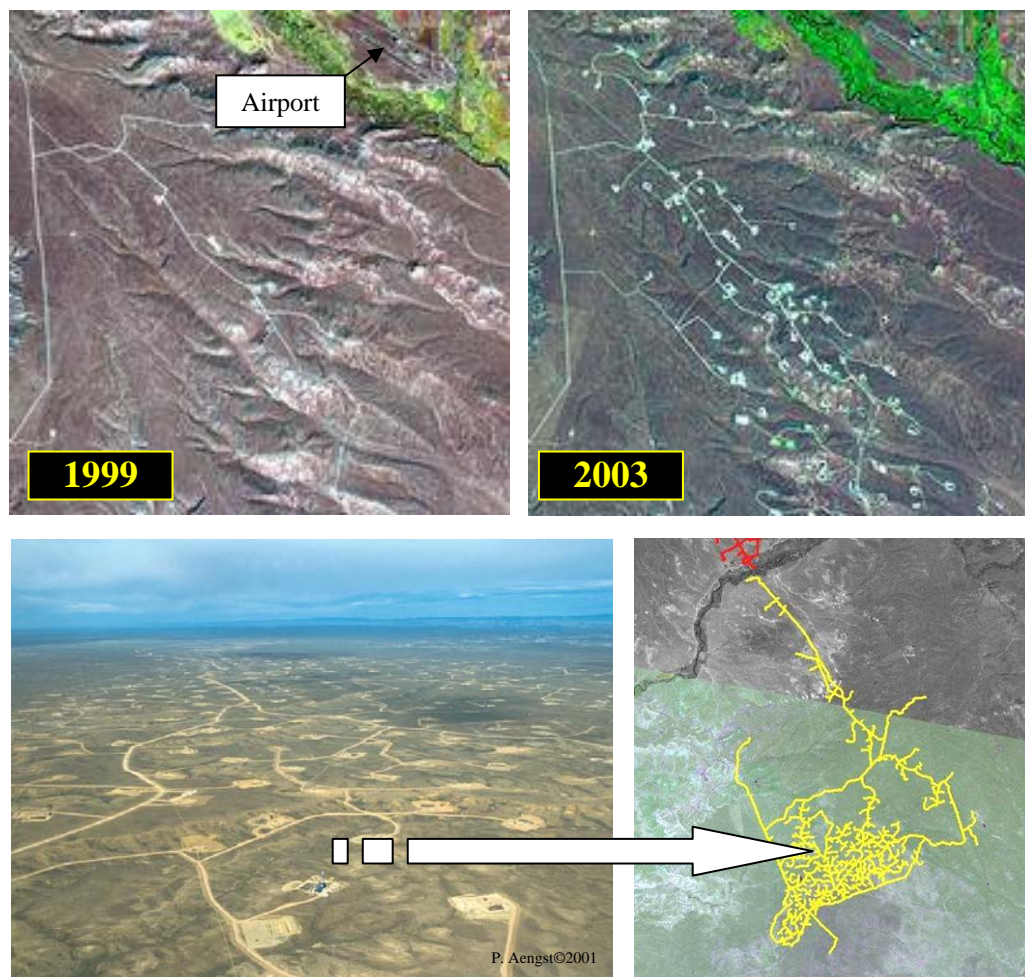
Figure 20. Select examples of habitat fragmentation. Changes in road distribution in the Mesa Fields (top). Aerial view of Jonah Fields (bottom left) with arrow indicating approximate location within the road network (bottom right). Images courtesy of John Amos, Sky Truth Aviation.

Logistics regression suggests that snow depth and fragment size explain 83% of the variation in pronghorn use of different habitat patches:

$$Y = -8.189 + 3.331X_1 - 0.184X_2$$

where Y is the natural log of the odds ratio reflecting the probability of occurrence,[1] X_1 is the $\log_{10}$ of fragment size (in acres), and X_2 is snow depth (in cm; Fig. 21; note that for purposes of these analyses the Mesa and Jonah Fields were treated as a single entity). Although animals could be found in fragments as small as 25 acres, at this scale usage was rare. When holding snow depth constant at 6 cm, the probability of an animal using a 40-acre fragment is less than 2%; for a 100-acre parcel the probability is only 6.7%, however, this increases to 49.2% for 600-acre fragments and 70.8% when fragment size equals or exceeds 1,000 acres. Annual variability in the general relationship between fragment size and probability of occurrence appears low (Fig. 22).

Figure 21. Logistic regression relating probability of pronghorn occurrence to fragment size (*n* = 581). The horizontal dashed line illustrates the probability of occurrence (0.067) for a fragment size of 100 acres.

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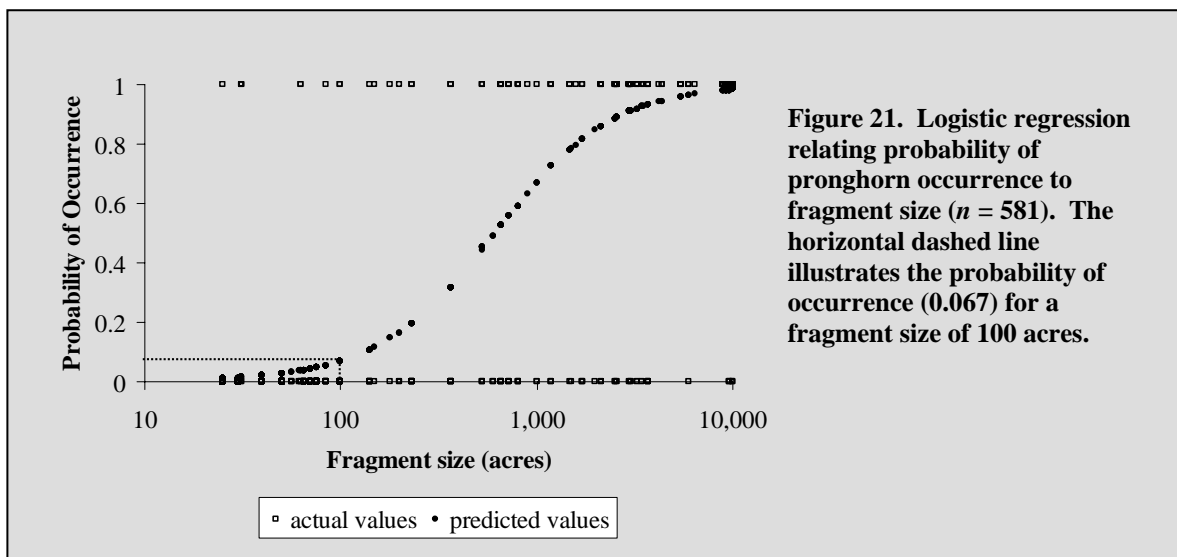
[1] Values produced by the logistic regression are the natural log of the probability of pronghorn being present in a fragment of a given size, divided by the probability of pronghorn not being present in a fragment of the same size. For instance, if we surveyed 100 50-acre habitat fragments and found pronghorn using 10 of these fragments, the log odds ratio would be:

$$\ln\left(\frac{\#\ of\ fragments\ used\ /\ \#\ of\ fragments\ surveyed}{\#\ of\ fragments\ not\ used\ /\ \#\ of\ fragments\ surveyed}\right) = \ln\left(\frac{10/100}{90/100}\right) = -2.198.$$

Odds ratios can be converted into probabilities using:

$$\frac{e^{\log\ odds\ ratio}}{1+e^{\log\ odds\ ratio}} = \frac{e^{-2.198}}{1+e^{-2.198}} = 0.10\ or\ 10\%.$$
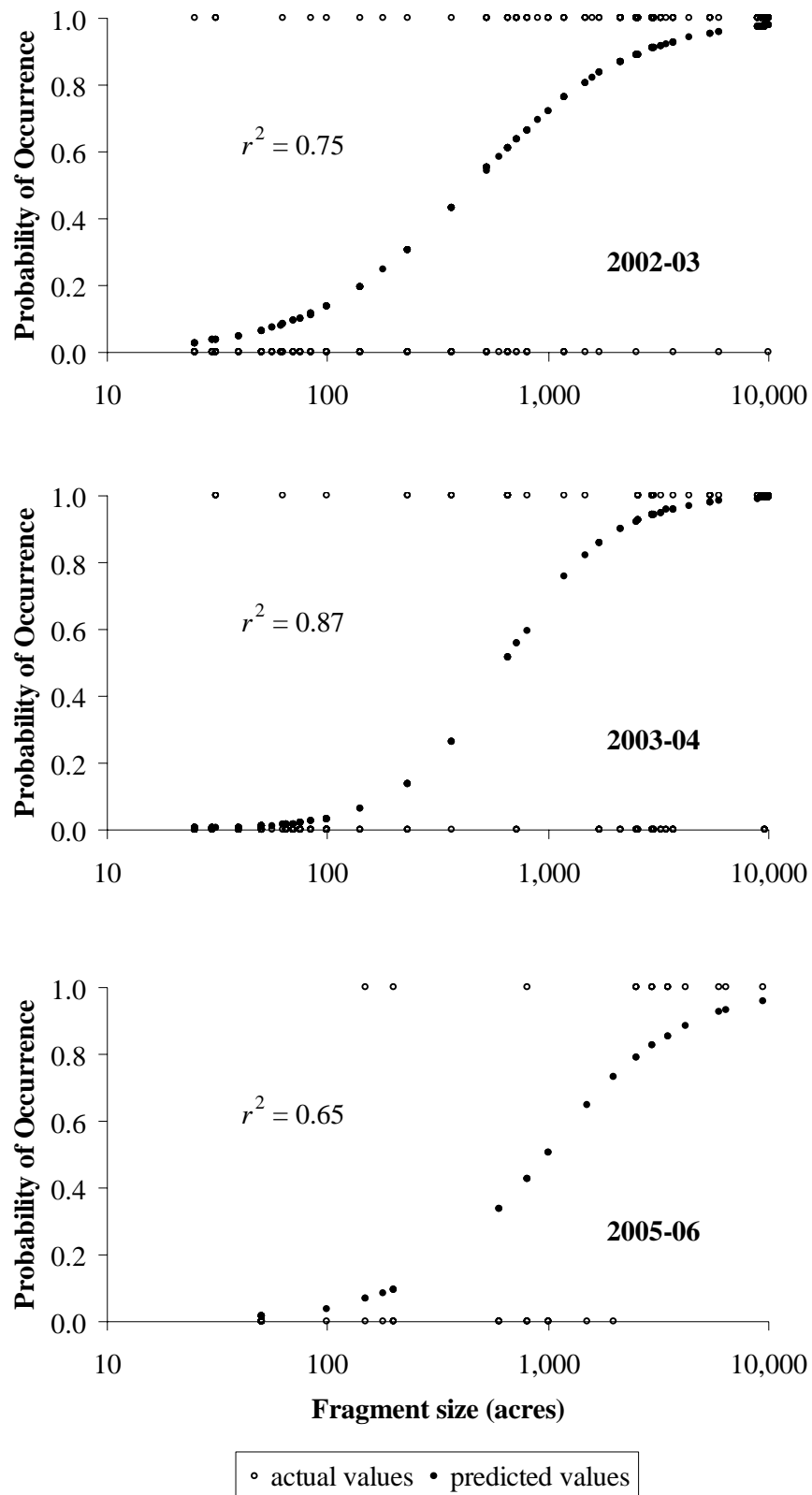
Figure 22. Logistic regression showing the relationship between fragment size and the probability that pronghorn are using a fragment for winter 2002-03 (top), 2003-04 (middle), and 2005-06 (bottom).

Individual fragments are of course not independent units and the mosaic of habitat alteration is likely to operate cumulatively, especially if animals gather knowledge about specific locations. Hence, the concentrated frequency of small habitat parcels in the Jonah Field may be used differently than fragments in the Mesa Field because the two footprints are not identical (Figs. 17 and 19). The potential for differences between the Jonah and Mesa Fields will be examined in subsequent years.

The Distribution of Snow and Pronghorn

We sampled snow depth at an average of 60 locations on a bi-monthly basis from November into April, or whenever snow no longer covered the ground. Pronghorn locations by group size were mapped aerially and plotted subsequently in relation to monthly snow depth. To illustrate the patterns of variation given the uneven distribution of snow across the study region, we used an inverse distance weighted (IDW) technique which determines cell values using a linearly weighted combination of a set of sample points (Figs. 23-24; Philip & Watson 1982; Watson & Philip 1985). The circles on the maps represent pronghorn locations.
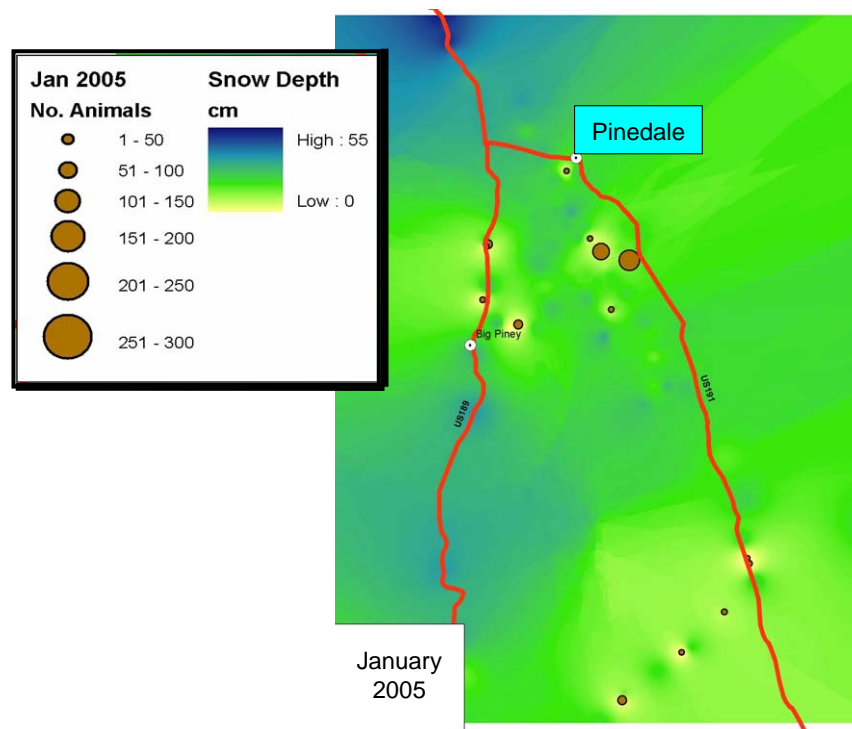
Figure 23. Distribution of pronghorn in relation to snow depth (from ground measures and subsequent IDW techniques) and group size (from aerial transects) in January 2005.
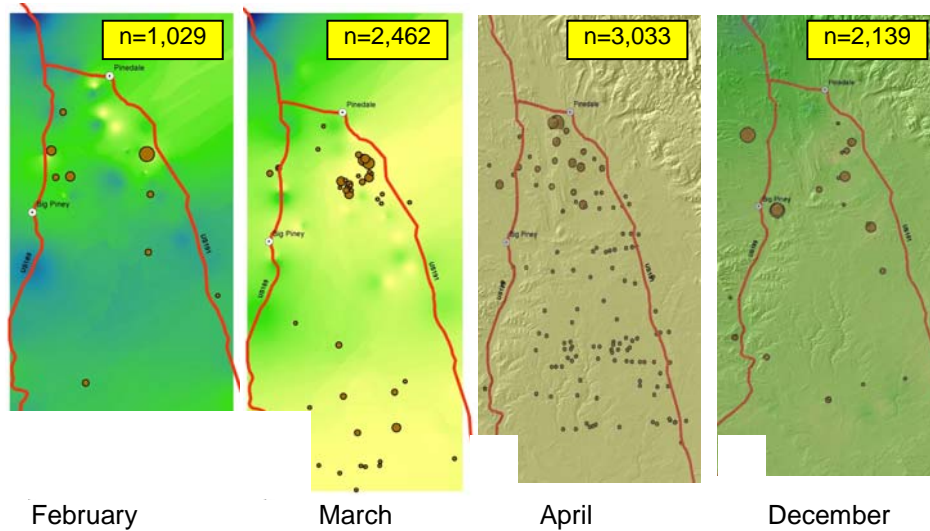
Figure 24. Distribution of pronghorn by month, snow depth, and group size during 2005. Legend for snow depth and relative size of circles is the same as Figure 23. Numbers reflect monthly pronghorn counts, unadjusted for sightability.

Snow is deeper at the north end of the study region and lightest at the south (Figs. 23-24). Generally, there is a trend toward larger groups when snow is deep, as animals congregate in the few remaining areas with access to forage. Dispersion of groups is greater when snow is lighter (for instance, April 2005 when snow was virtually absent from the study region; Fig. 24).

Bi-monthly aerial surveys during winter resulted in approximately 2,000 pronghorn being counted during each flight in the defined study area. However, these data have not yet been analyzed to determine the predicted number of animals present using a correction factor based on sightability. Pojar et al. (1995) suggested that in sage-steppe systems, line transect estimates for pronghorn from aircraft produced an undercounting bias.

Pronghorn Movements and Navigation of Gas Fields

The GPS collars from 48 females were recovered in December 2005. A total of 56,992 data points were generated by the collars and acquisition rates exceeded 98%.

Pronghorn remained in the vicinity of capture sites in the winter months of February and March (Fig. 9), and then began migrating toward summer ranges in April as snowmelt permitted (Fig. 26). All animals reached their summer ranges by late May, and remained in these areas throughout the summer (Fig. 27) and into fall (Fig. 28). Several control

animals (26%; *n*=7) used a 2.3 km area just north of the highway 189/351 junction to cross route #189 (Fig. 29), 22% of experimental animals (*n*=4) used a 2 km area west of Pinedale (i.e., Antelope Alley) to cross highway 191 (Fig. 29), and 4% of control (*n*=1) and 58% of experimental (*n*=11) animals navigated Trapper's Point during their spring and fall migrations (Fig. 30).

Control and experimental animals generally showed a high degree of spatial segregation throughout the year (Fig. 31). Control animals summered primarily along the Wyoming Front from Big Piney north towards Merna (*n*=18), near Big Piney (*n*=1), near Daniel (*n*=1), or in the vicinity of Little Colorado Desert (*n*=2; Fig. 27). However, two control animals briefly spent time on the Mesa in April (Fig. 26) before moving to summer ranges just south of Trapper's Point (*n*=1) and Union Pass (*n*=1; Fig. 27). In contrast, experimental animals summered primarily along the Wind River Front from Boulder north to the Upper New Fork Drainage (*n*=7), south of Black Butte (*n*=2), southeast of Union Pass (*n*=3), or in the Gros Ventre River Drainage (*n*=1; Fig. 27). Four experimental animals remained within the PAPA for the entire summer, three on the Mesa and one just east of highway 191 and south of Boulder (Fig. 27).

The high degree of spatial segregation suggests that should energy development affect pronghorn population trends, the effects will not be felt uniformly throughout the UGRB. Based upon current hunt area boundaries (WGFD Hunt Area Map), the distribution of experimental animals during summer 2005, and assuming our subsample is representative of the population at large, it appears that hunt areas 85 and 87, which span the region between Jackson Hole and Boulder, may be the only areas affected.

Locations obtained from GPS collars indicate that some pronghorn may be structuring their movements to avoid areas of high density infrastructure on the Mesa and Jonah Fields (Fig. 30). These patterns are not representative of all animals, however, as two of nineteen experimental animals (10.5%) spent extensive time in close proximity to roads and well pads (Fig. 32). Although 90% of the experimental animals were therefore not in the immediate vicinity of the well pads, it was possible that experimental animals adjusted their patterns of activity to capitalize on areas adjacent to pads when traffic volume and other human disturbances were diminished, such as occurs at night.
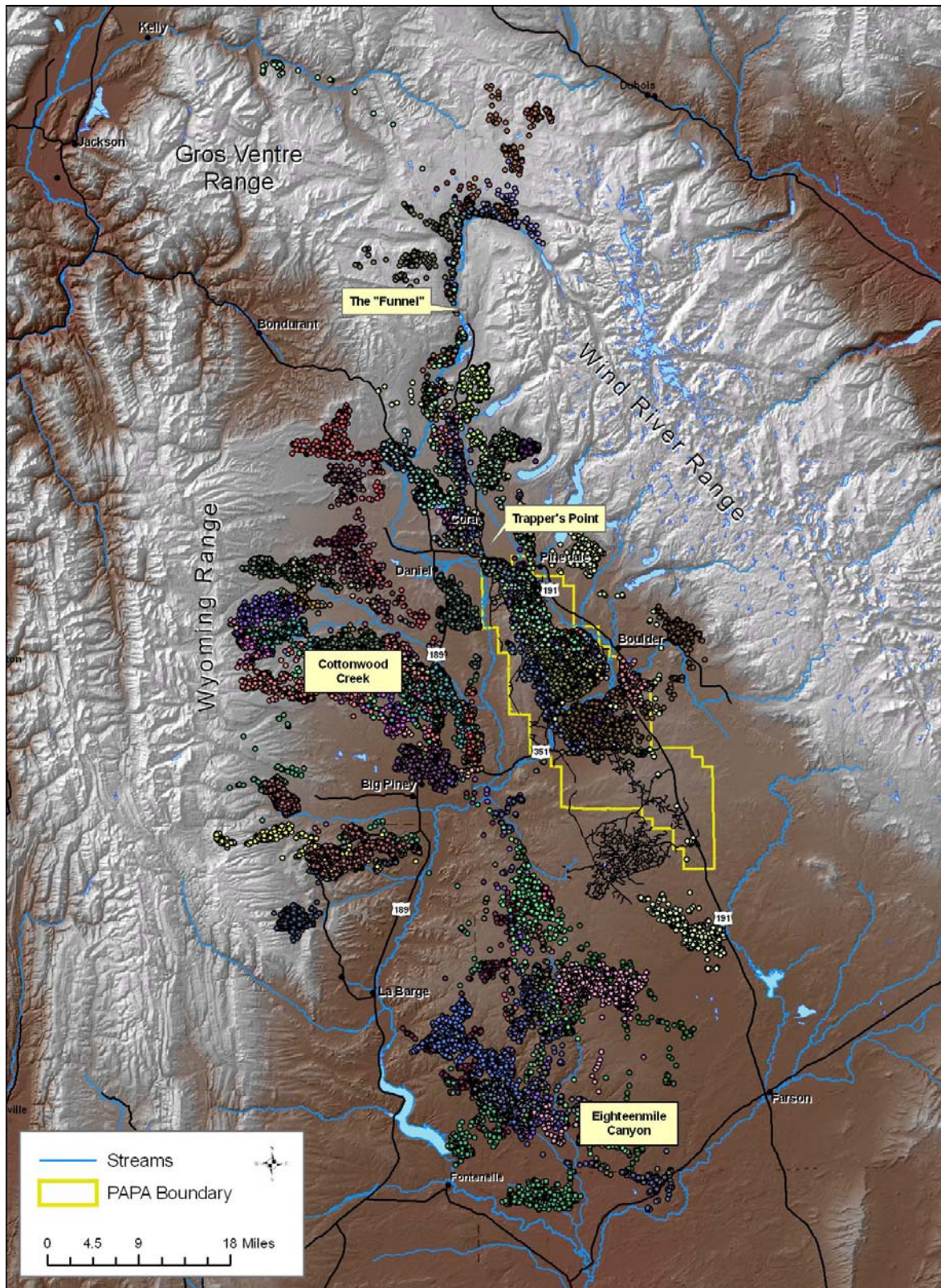
Figure 25. Overview of locations obtained from 48 pronghorn GPS collars. Note that of the 56,992 points recorded, none were located within the Jonah Field.
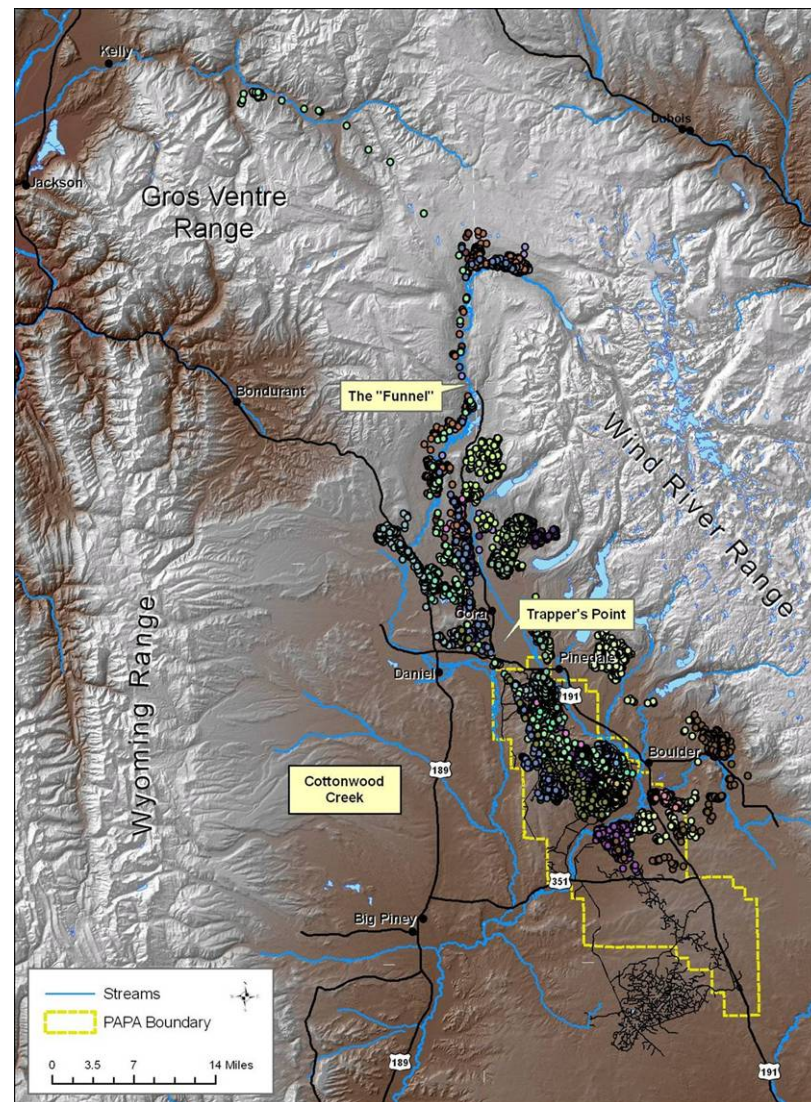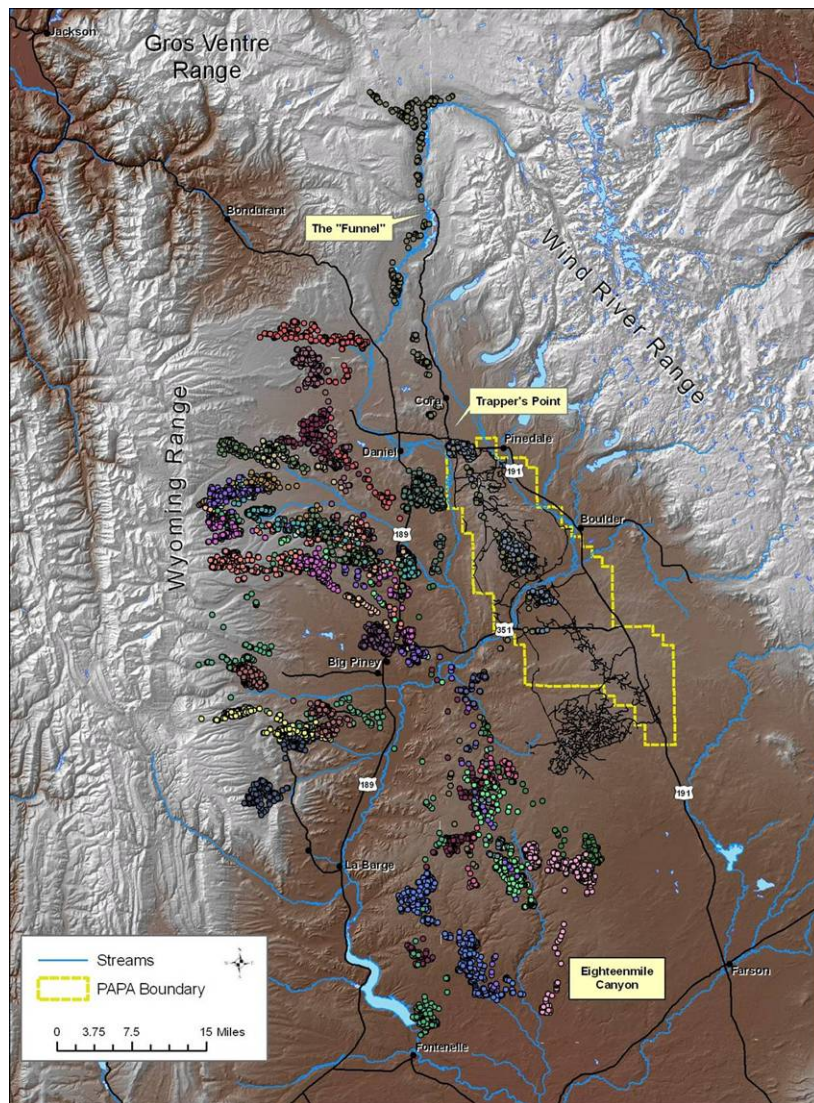
Figure 26. Locations of control (left) and experimental (right) animals during spring (April-May) 2005. Note that two control animals used portions of the Mesa during the spring migration.
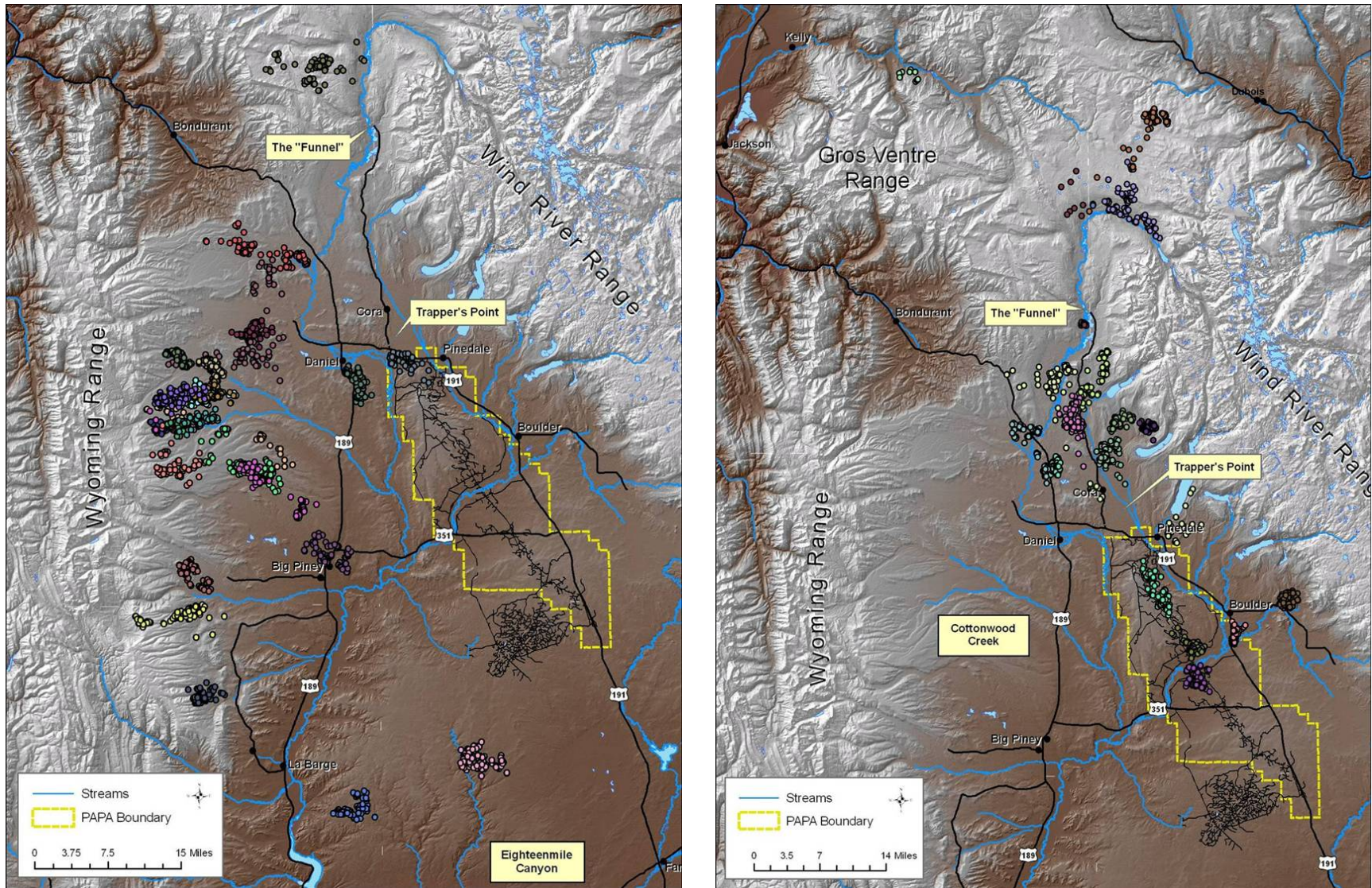
Figure 27. Locations of control (left) and experimental (right) animals during summer (June-August) 2005. Note that one control animal summered just south of Trapper's Point, and three experimental animals summered on the Mesa.
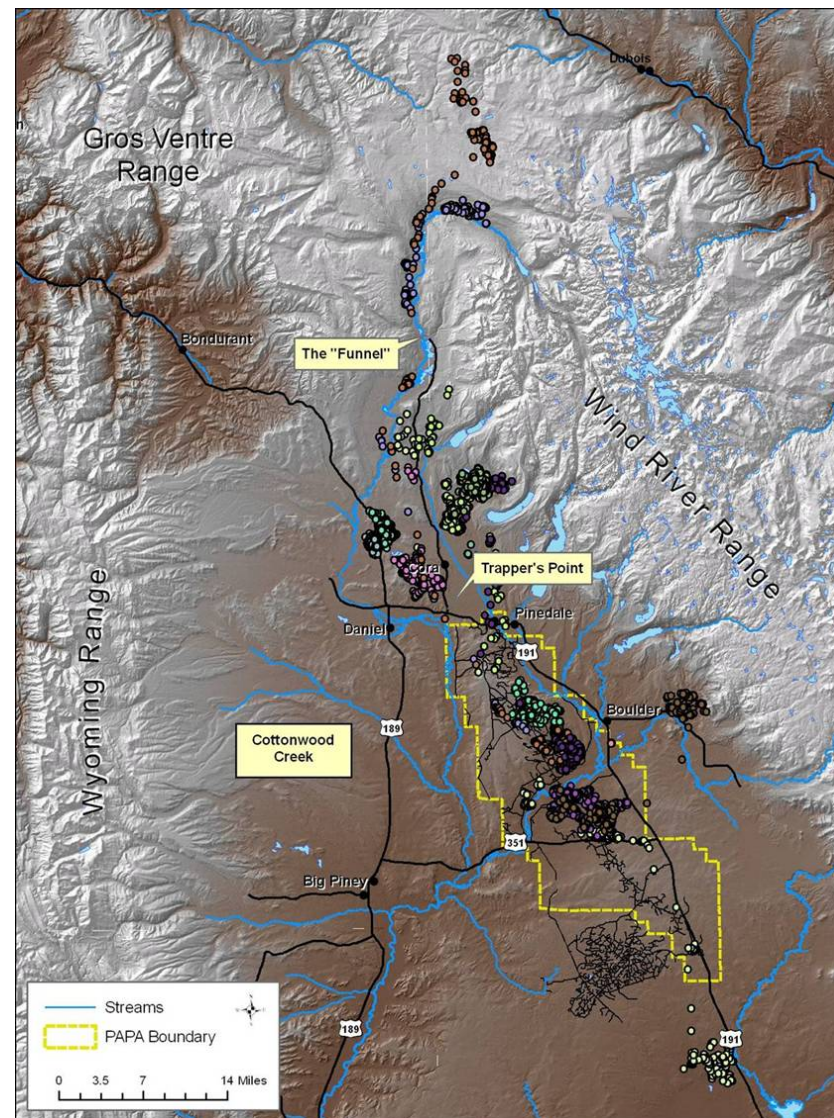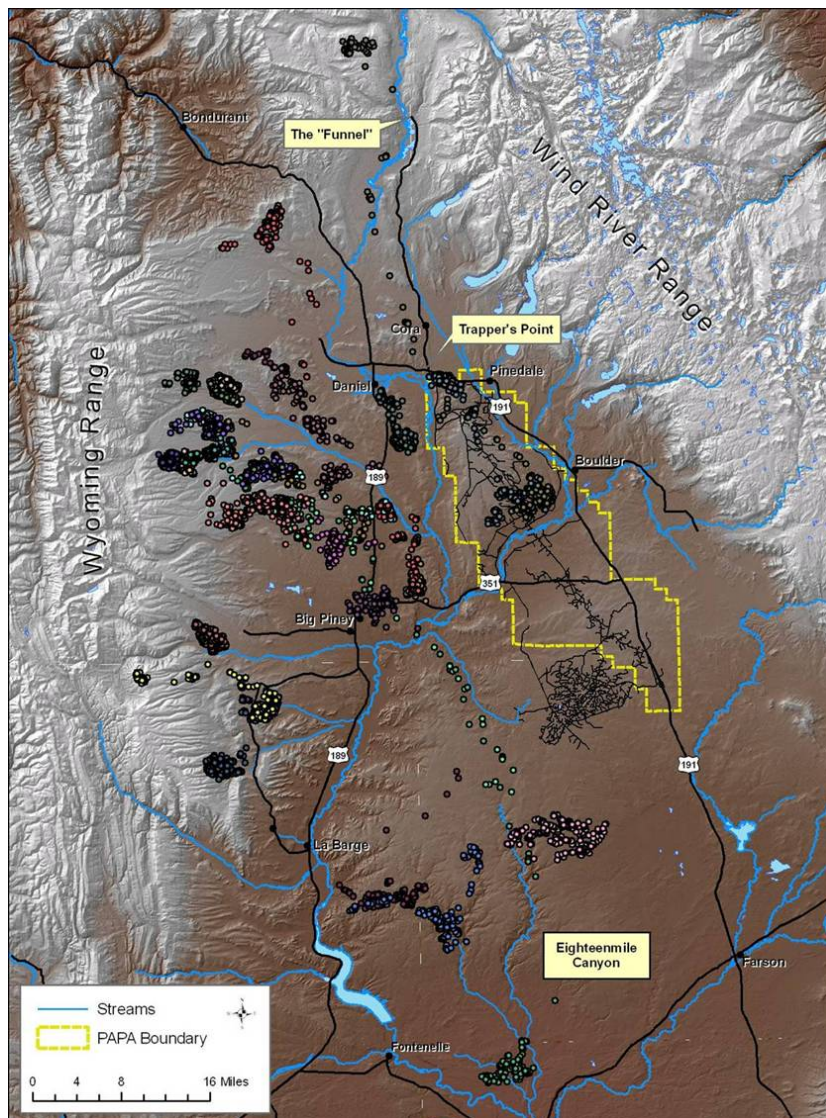
Figure 28. Locations of control (left) and experimental (right) animals during fall (September-October) 2005.
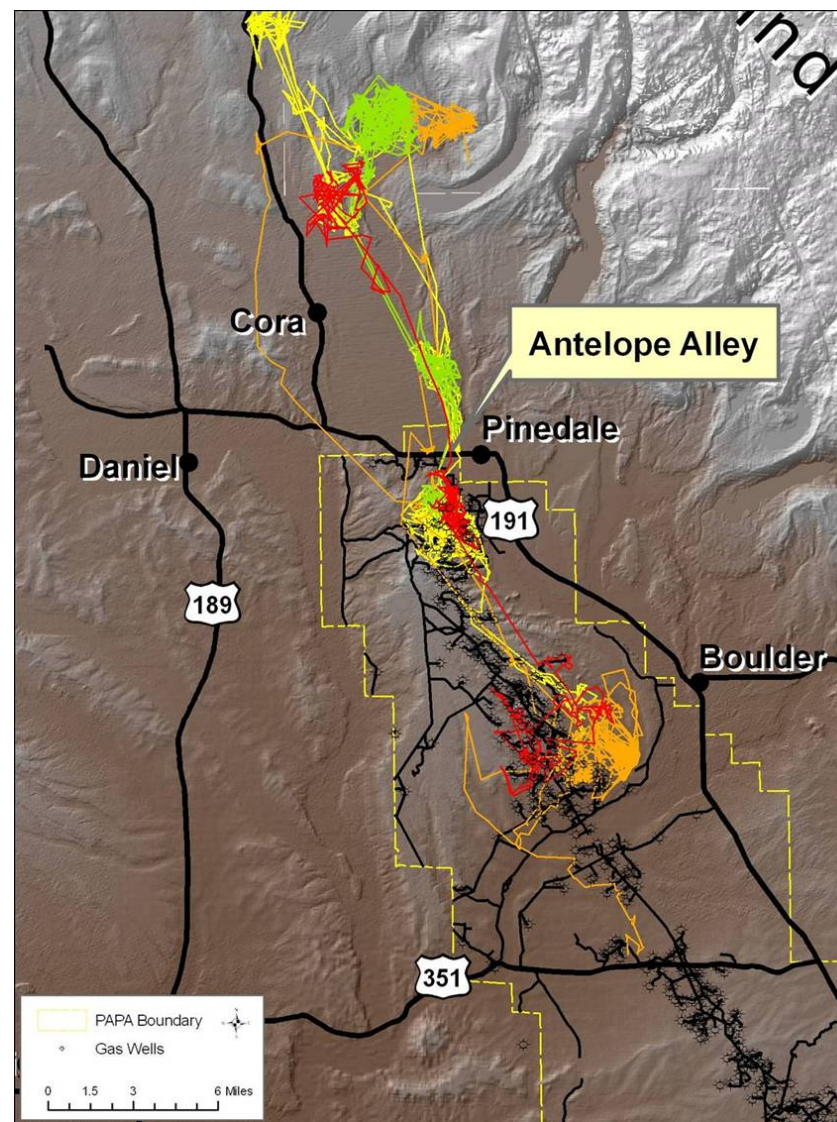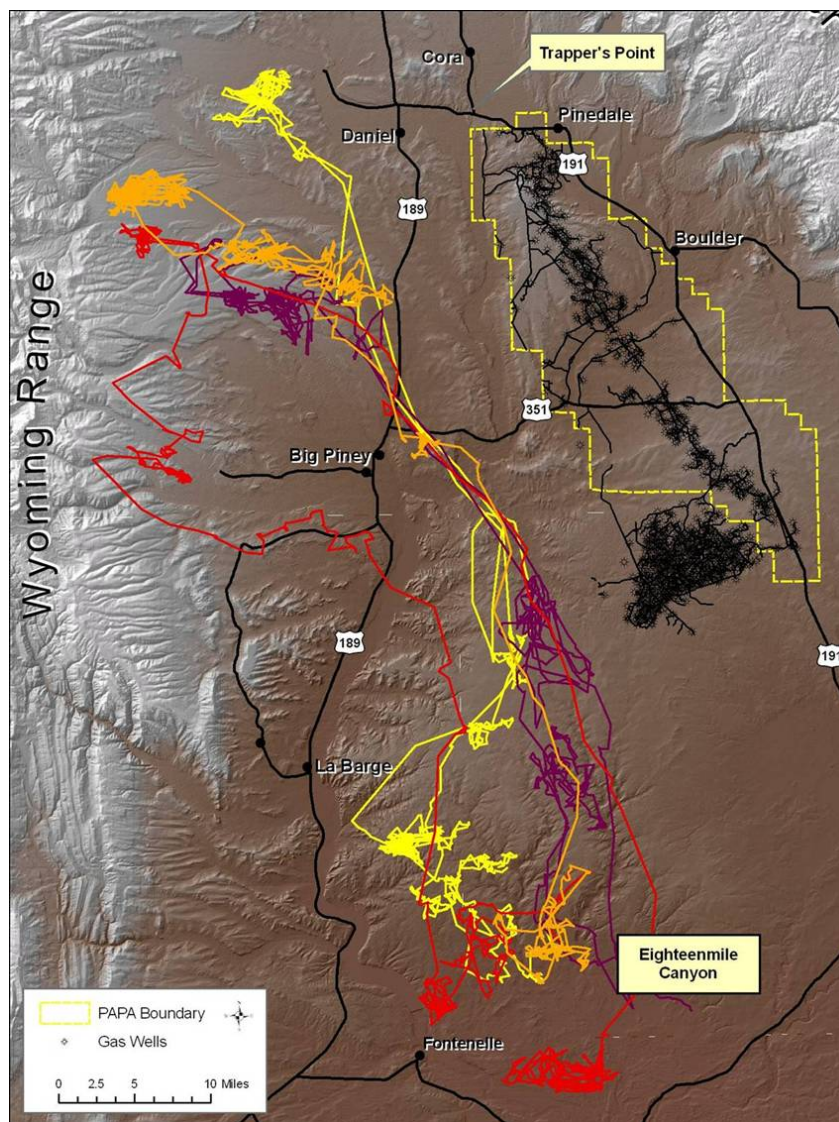
Figure 29. Annual movements of radio-collared pronghorn showing use of the area just north of the 351/189 junction to navigate the highway (left; *n*=4 of 7 animals that used the area are shown) and 'Antelope Alley' (right; *n*=4).
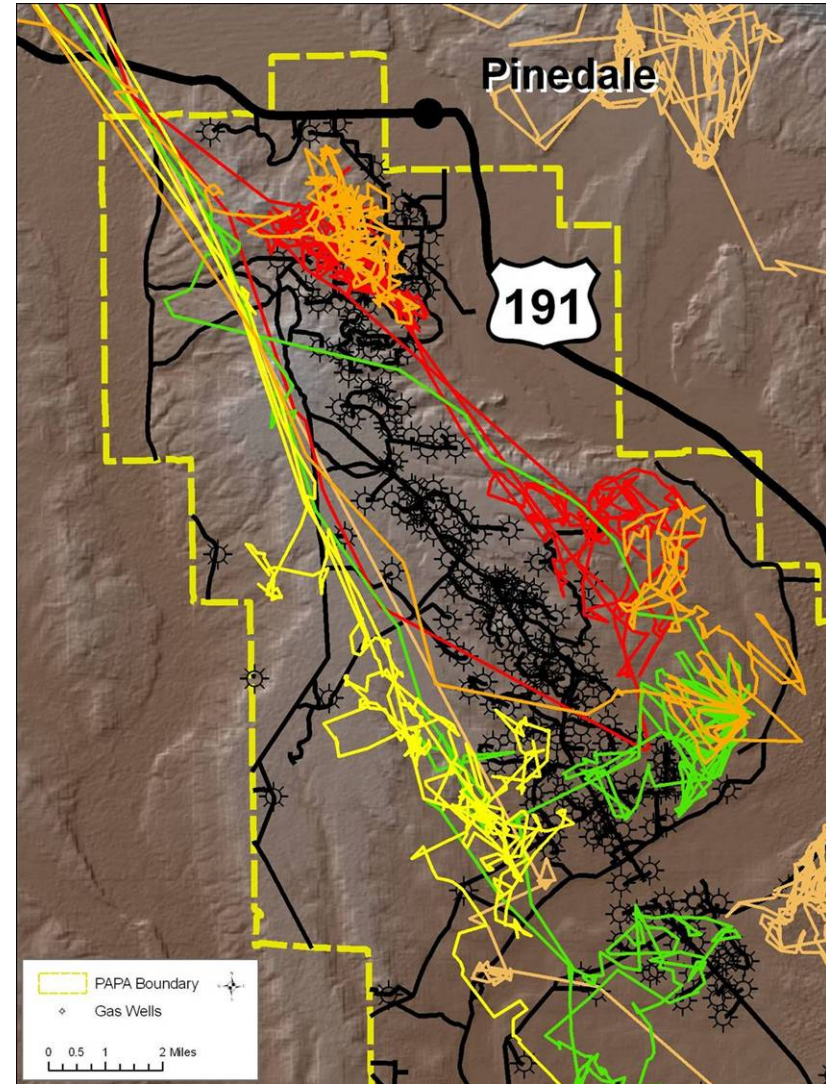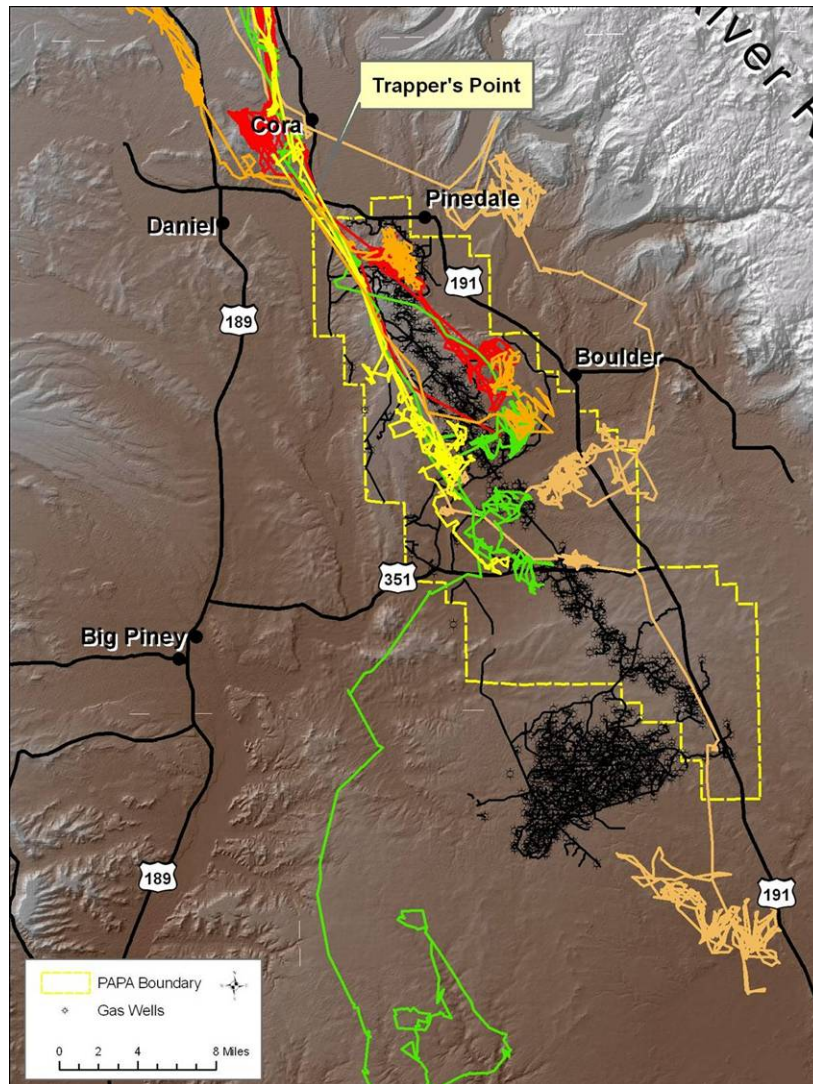
Figure 30. Movements of pronghorn (*n*=5) showing use of the Trapper's Point bottleneck and apparent avoidance of the Mesa and Jonah Gas Fields (left). At right, a close-up view of pronghorn movements in relation to gas wells and roads on the Mesa.
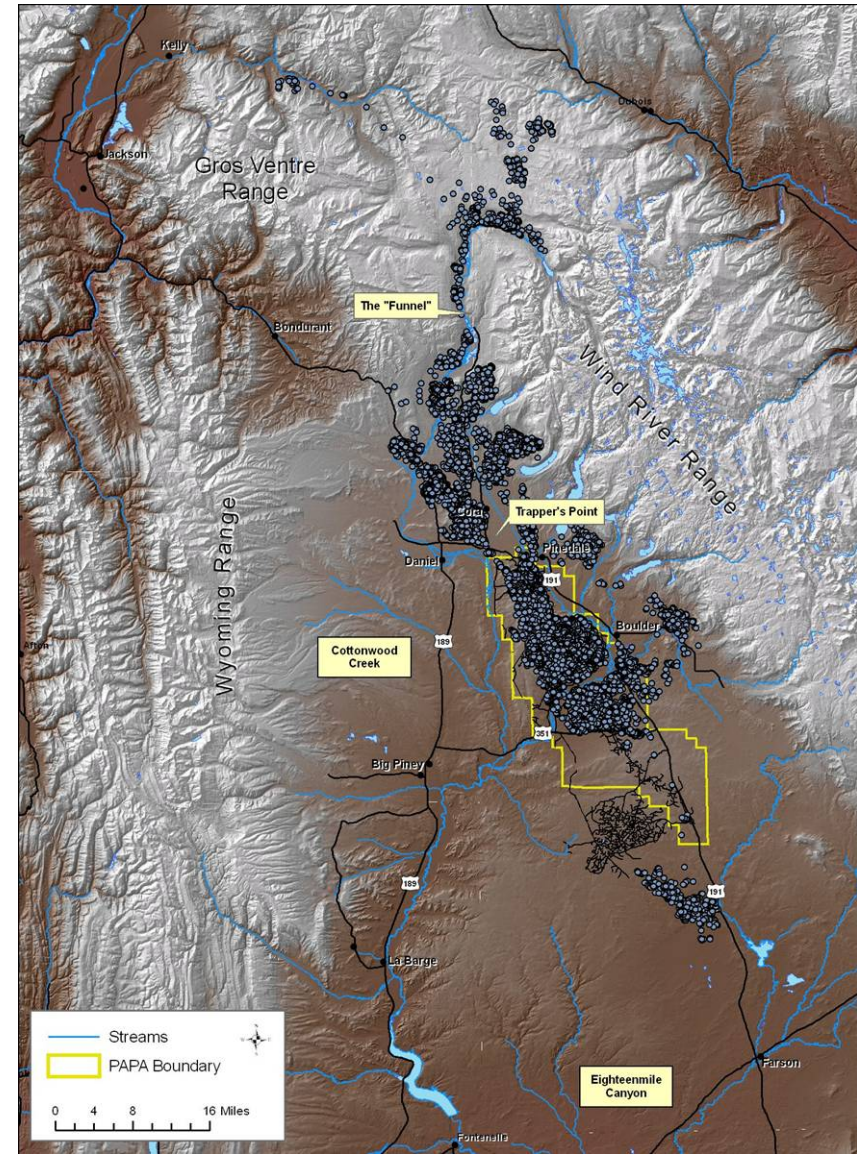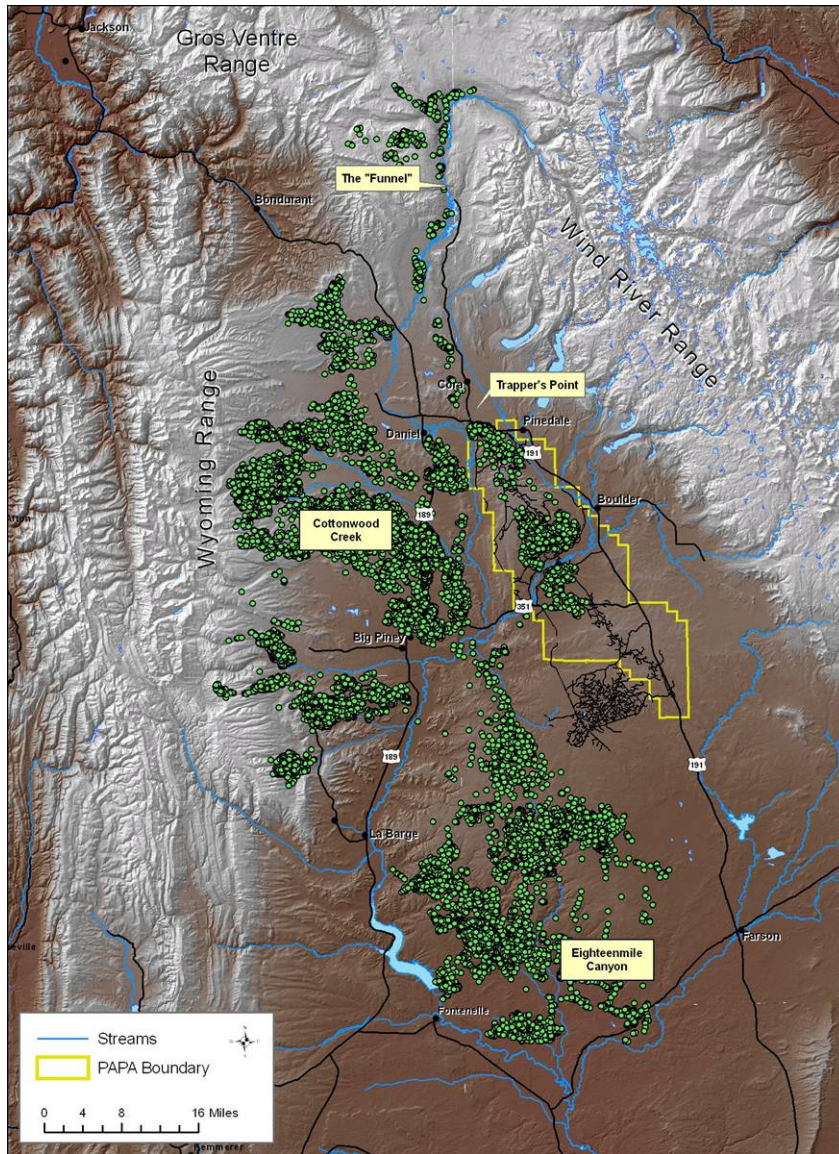
Figure 31. Annual locations of control (left) and experimental (right) animals showing a high degree of spatial segregation.
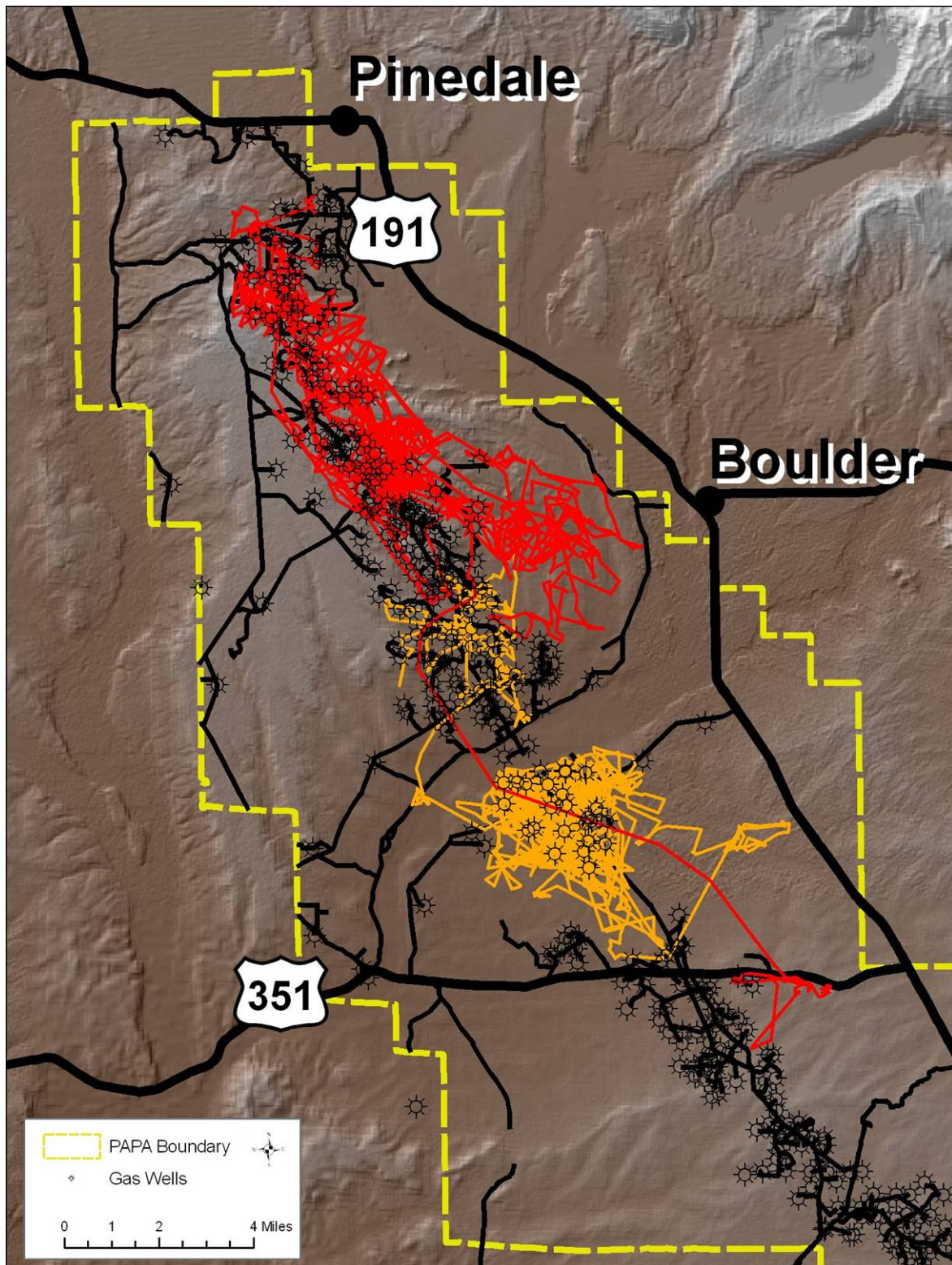
Figure 32. Annual movements of pronghorn (*n*=2) that extensively used areas in close proximity to gas wells.
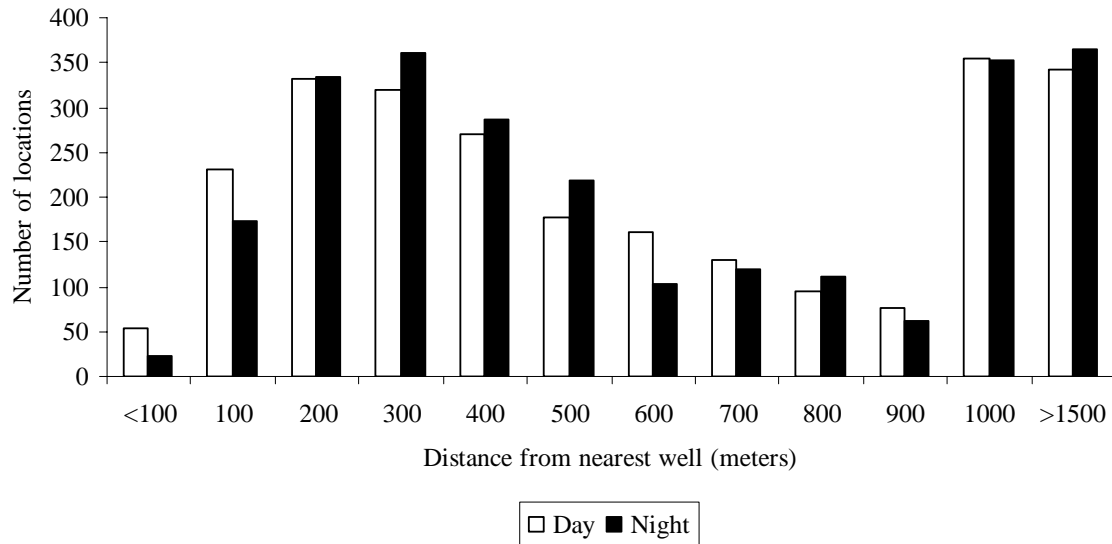
Figure 33. Distribution of distances between experimental animals and the nearest gas well during diurnal and nocturnal periods.

We investigated this possibility by contrasting the distances of experimental animals from the nearest gas well between periods of high and low human activity using diurnal (8 a.m. – 8 p.m.) and nocturnal (8 p.m. – 8 a.m.) winter locations. There were no differences in diurnal and nocturnal distances between
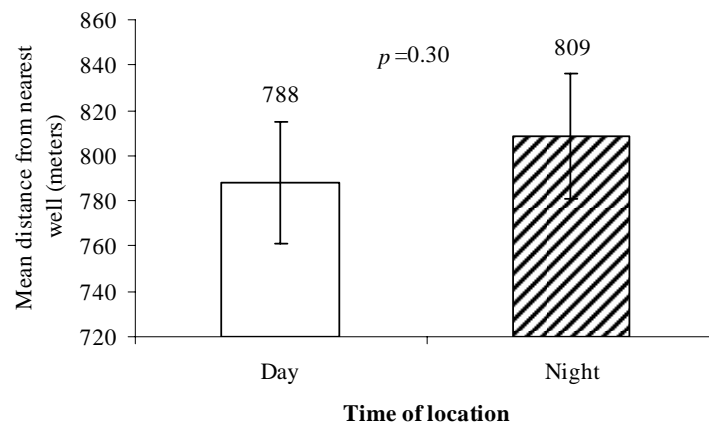
Figure 34. Average diurnal (*n*=2,545) and nocturnal (*n*=2,511) distances between experimental animals and the nearest gas well during winter.

animals and well pads (Figs. 33-34). This absence of a shift in movements suggests that pronghorn were not altering their 24-hour activity patterns to take advantage of habitat in the vicinity of well pads during periods when human activity and traffic were reduced. They consistently avoided areas within 100 m of gas wells (Fig. 33). Notably, of the 56,992 points retrieved from the GPS collars, not a single location was recorded in the Jonah Field (Fig. 25), an area where we documented more than 600 pronghorn during low snowfall in 2002-03.

Survival of Control and Experimental Animals

We estimated survival for radio-collared pronghorn for the period 2/27/05 – 12/3/05 using the known fate model in Program MARK (White and Burnham 1999). Of the 50 animals collared in late February, 37 were known to have survived into early December. Two animals were censored in March because their VHF signals disappeared shortly after capture. A third animal was censored in September when its collar was recovered and there was no sign of a carcass at the collar retrieval location. Consequently, we could not determine whether the animal had died and the collar had been moved from the mortality site (e.g., perhaps by a scavenger), or whether the animal had slipped its collar (unlikely) and remained alive. Ten animals died during the first year of the study due to human harvest (40%), predation (20%), and apparent starvation (20%; Table 5). In the remaining 20% of cases ($n=2$), the cause of death could not be determined. Survival of control and experimental animals did not differ significantly between treatments. Survival averaged 69.3% (95% CI = 44.4 - 84.9%) for experimental animals, and 86.2% (95% CI = 67.4 - 94.6%) for control animals (Fig. 35).
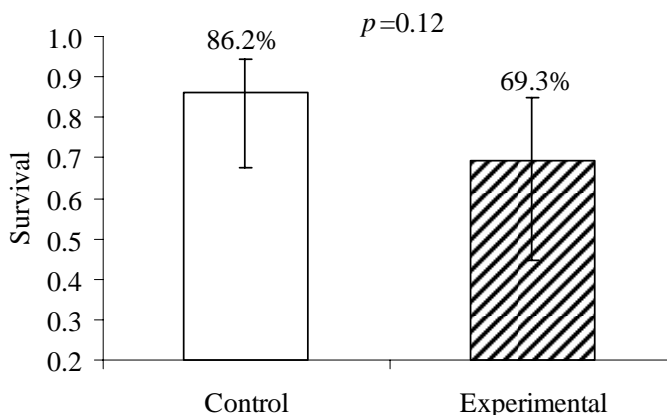
Figure 35. Survival rates of control and experimental animals between 2/27/05 and 12/3/05.

Table 5. Causes of mortality of ten radio-collared pronghorn.			
ID	Group	Month of Death	Cause
582	Control	March	Apparent starvation
412	Control	March	Apparent starvation
612	Control	October	Human harvest
771	Control	October	Human harvest
961	Experimental	May	Coyote predation
901	Experimental	May	Undetermined
112	Experimental	June	Apparent cougar predation
890	Experimental	August	Human harvest
451	Experimental	August	Undetermined
591	Experimental	October	Human harvest

CONCLUSIONS

During the past couple of decades, much of the national focus on petroleum development in North America has been on Alaska, particularly the Arctic National Wildlife Refuge, with less attention focused on the Rocky Mountain region. Recent rapid development of natural gas fields and coal bed methane in the Intermountain West has brought new attention to the United States' resource management policies on public lands. The Rocky Mountain region contains vast deposits of natural gas and oil stretching from the Canadian border to Mexico, with most deposits occurring in Montana, Wyoming, Utah, Colorado, and New Mexico. Many of these vast oil and gas deposits lay beneath some of the most rugged and beautiful areas of the West that often provide safe refuges for large, charismatic wildlife. For example, several of the largest natural gas deposits are found at the southern terminus of the Greater Yellowstone Ecosystem (GYE) in the UGRB.

The UGRB remains contentious due to the mix of precious energy resources and substantive wildlife. Situated between the Wind River Mountain Range on the east and the Wyoming Range to the west, the region is significant for its 100,000 wintering ungulates which include elk, pronghorn, mule deer, moose, and bighorn sheep. Because the natural gas reserves in the UGRB lie directly beneath critical wintering range for the majority of pronghorn and mule deer in the region, there is a high degree of concern over the amount of habitat loss and fragmentation due to an increasing human footprint. The loss of critical winter range could have serious energetic costs for ungulates trying to survive the harsh winters of western Wyoming where temperatures drop below -30 C.

Thus, the aim of this project is to investigate the impacts of habitat alteration by natural gas development on over-wintering pronghorn in the UGRB. This report summarizes the first year of a five-year study; therefore the analyses reported here are preliminary and subject to change and interpretation. To date the data suggest that a growing array of gas fields, roads, and attendant human infrastructure is altering the suitability of habitat for wildlife. Specifically, 56,992 data points generated for pronghorn from GPS collars showed avoidance of heavily developed areas in that none of 48 collared animals used areas within the Jonah Gas Field. Aerial flight distribution data corroborated a lack of use of areas with intense gas production. Additionally, continual

fracturing of previously undisturbed lands is leading to reduced usage and abandonment of habitat parcels, particularly those less than ~600 acres in size. This estimated threshold in patch size prior to abandonment was obtained by statistically modeling pronghorn use of various fragment sizes at differing spatial scales after controlling for key environmental factors such as snow depth.

Factors other than habitat use can affect population trajectories. To obtain a more complete picture of the complex array of conditions that influence populations, a study must be robust enough to account for all relevant variables, including those such as body mass, stress, disease, eco-toxicology, nutritional markers of summer and winter range quality, and anthropogenic development. Thus we are attempting to address these features in this study.

A myriad of factors can influence body condition. Although we have detected site abandonment by pronghorn in heavily developed areas, several of the factors that we examined did not vary between experimental and control animals. Body mass in late February did not vary among control or experimental sites, and among 50 adults examined for stress hormones via analyses of fecal corticosteroids, differences were not evident. When we tested for exposure to eight diseases to which pronghorn are susceptible, we found that in all instances antibodies were below detectable levels. Additionally, we assessed whether experimental and control animals varied in selected minerals and vitamins in blood sera. No differences were noted except for sodium, with experimental animals having significantly lower levels. To assess the effects of summer range on body condition, we concentrated on four major summering areas to gather fecal samples from 120 unidentified females within the ranges of known radio-collared animals. The amount of variation in fecal nitrogen among sites was low although it remains unknown at this time if small differences are biologically meaningful.

In sum, this first year of data helps to establish values toward developing a more complete understanding of the relationships among habitat fragmentation, anthropogenic activities, habitat use, and population demography. Subsequent investigation will allow a more comprehensive picture of the impacts of natural gas development on pronghorn demography and health.

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About the Authors

Trained as a scientist, Joel completed his Ph.D. in Colorado, worked as a Smithsonian Research Associate for 7 years, and was a professor at the University of Nevada-Reno for 16 years. He has written three books, published more than 100 scientific papers, and has studied species as diverse as black rhinos, wild horses, and porcupines. During the last ten years he has focused on comparative effects of predation on moose in Alaska and Wyoming, as well as on bison and caribou. His current scientific focus is on long distance migration dynamics, particularly the maintenance of connectivity in and beyond Greater Yellowstone. jberger@wcs.org

Kim is a research ecologist who specializes in population modeling and assessment, predator-prey dynamics, and livestock-carnivore conflicts. She received her B.S. in Natural Resource Economics and her M.S. in Environmental Science and Policy. She has done field work in Alaska, Norway, Argentina and Wyoming, and has studied species ranging from caribou and pronghorn, to coyotes and wolves. Kim is currently completing her Ph.D. at Utah State University where her research focuses on the effects of recolonizing wolves on coyote-pronghorn interactions and pronghorn persistence in Jackson Hole. kberger@wcs.org

Jon grew up on a farm in Kansas. In college, he studied biology and wildlife, and joined the WCS team after receiving his Ph.D. from the University of Nevada-Reno in 2002. He is actively involved in carnivore conservation, and has published on topics that range from human-induced changes on black bear ecology and homing behavior to the mating systems of birds. Jon's current work centers on the use of applied research to affect conservation through public policy. This includes the use of scat-sniffing dogs to identify carnivore scats and landscape analyses to understand how energy development affects demography of ungulates. jbeckmann@wcs.org

Appendix

<u>Methodological Details - Covariates and Sampling</u>

Information was gathered on three categories of covariates (ecological, biophysical, and anthropogenic) to assess pronghorn distribution in both experimental and control areas.

Ecological Covariates

1) Group size was calculated via monthly aerial surveys during winter that have resulted in approximately 1000 to 3000 pronghorn counted during each flight in the defined study area. However, these data have not yet been imported into a program (e.g. Program MARK) to correct for potential biases. Pojar et al. (1995) suggested that in sagebrush steppe systems, wide (1.6 km wide) line transect estimates for pronghorn from aircraft produced undercounts. Although this bias was numerically larger than quadrat estimates, the bias was not statistically larger (Pojar et al. 1995).

2) Habitat was categorized as sagebrush steppe, forest cover or bare ground using GIS programs, the National Landcover Dataset (NLCD), and subsequent ground-verification at points where pronghorn occurred. We also classified habitat into these categories as we documented pronghorn distribution from the ground while driving.

3) Vegetation height was measured at locations where pronghorn groups occurred and at random sites. Vegetation heights were grouped into four categories and corresponded to points along the anterior skeletal frame of an adult female, as follows: Category 1 - the phalanges; Category 2 - mid-point of the cannon; Category 3 - the carpal joint; Category 4 - the humerus.

Biophysical Covariates

1) We sampled snow depth at an average of 60 locations monthly from November into April, or when snow no longer covered the ground. Pronghorn locations by group size were mapped aerially and plotted subsequently in relation to monthly snow depths as more than half the surveys were conducted within a day of flights. To illustrate the patterns of variation, especially, given the uneven distribution of snow across the study region, we used an inverse distance weighted (IDW) technique which determines cell values using a linearly weighted combination of a set of sample points (Phillip & Watson, 1982; Watson & Philip, 1985). Greater sampling intensity for snow will obviously reduce variance in the snow depth models.

2) Topography was simply classified as either flat or rolling based on field measures.

3) Size of habitat was estimated using satellite imagery to create a series of grids that overlapped the Jonah and Mesa Fields and adjoining areas. Different grid sizes (e. g. 500 x 500m, 250m x 250m, and 125m x 125m) for the entire region were used in each of three independent analyses. From each grid, we estimated the proportion of area cleared of vegetation (roads included) relative to cell size, and remaining available habitat was then converted into separate individual polygons. The size of each patch was then estimated and assigned an identification value based on its area.

Anthropogenic Covariates

1) Distances to various anthropogenic structures (roads, nearest ranch, nearest gas pad, and nearest fence) were based on field estimates using laser rangefinders. We have yet to estimate distances to each structures for which a data layer exists (roads, gas pads, ranches) using GIS for the 57,000 data points generated from the 50 GPS collared adult females.

2) Type of road was a categorical variable: paved; unpaved and graded; and unpaved and not graded (dirt).

3) Traffic volume was calculated by counting the number of vehicles that passed along each road during 15-minute sampling bouts as we gathered data on the efficiency of pronghorn foraging bouts. We also gathered traffic volume measures at randomly generated road sites. Traffic was classified by vehicle type -- semi-truck, heavy-duty truck, small truck, or car.

<u>**Literature Cited**</u>

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<u>Sampling and Independence in Spatial Analyses</u>

It is not totally clear whether the Mesa and Jonah Gas Fields are perceived by pronghorn as independent or a single larger region. For this report we treated the two areas as a single en-

tity. Habitat fragments within this larger array are of course not independent units and the mosaic of habitat alteration is likely to operate cumulatively especially if animals gather and retain knowledge about specific locations. Hence, the concentrated frequency of small habitat parcels in the Jonah Fields may be used differently than fragments in the Mesa Fields because the two footprints are dissimilar. The potential for differences between the Jonah and Mesa Fields will be examined in subsequent years, both as independent units to evaluate whether different-sized fragments are used in a relatively similar fashion, and lumped.

The sampling challenges are far from ideal and arise as a consequence of the lack of true multiple independent study sites for appropriate contrasts. In this specific case, our approach has been to treat lands fragmented by development as discrete habitat parcels that are available for use by pronghorn. The fragments vary in size from a few acres to thousands depending on the extent to which they have been fractured by roads and attendant gas pads. Given our goal to assess the extent to which the changing human footprint affects pronghorn, in subsequent years we shall examine the extent to which individually identifiable animals move between the two fields, and the comparative effects of biophysical and ecological covariates.