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WILDLIFE & ENERGY DEVELOPMENT

Pronghorn of the Upper Green River Basin - Year 2 Summary

By Kim Murray Berger, Jon P. Beckmann, Joel Berger

Prepared for Shell Exploration & Production Company,
Questar Market Resources, and
Ultra Resources, Inc.

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Wildlife and Energy Development

Pronghorn of the Upper Green River Basin – Year 2 Summary

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LIST OF ACRONYMS

BLM	Bureau of Land Management
DA	Development Area
FC	Fecal Corticosteroids
FN	Fecal Nitrogen
GC	Glucocorticosteroid
GPS	Global Positioning System
GTNP	Grand Teton National Park
GYE	Greater Yellowstone Ecosystem
IDW	Inverse Distance Weighted
MCP	Minimum Convex Polygon
PAPA	Pinedale Anticline Project Area
RSPF	Resource Selection Probability Function
SEIS	Supplemental Environmental Impact Statement
UGRB	Upper Green River Basin
VHF	Very High Frequency
WCS	Wildlife Conservation Society
WGFD	Wyoming Game and Fish Department

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SYNOPSIS

The development of energy resources poses difficult challenges for society. In regions of the Rocky Mountains 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.

In 2005, at the request of Shell Exploration and Production Company, we initiated a 5-yr study of pronghorn in the Upper Green River Basin (UGRB) of western Wyoming to understand the potential for winter-related effects of gas field development and infrastructure. This report summarizes results of the second year, 2006. Our findings are preliminary and subject to further analyses. To date, they suggest the following:

- A growing array of gas fields, roads, and attendant human infrastructure is resulting in continued loss and fragmentation of native habitat in the UGRB.
- Snow depth has an overriding influence on pronghorn distribution during winter. Based on the results of the Resource Selection Probability Function (RSPF), habitat patches with the highest probability of use had on average a snow depth of 12 ± 2 cm during winter, compared to 19 ± 4 cm for patches that were rarely used.
- Based on location data generated by global positioning system (GPS) radio-collars, pronghorn continue to use areas within the Jonah Field, although some animals exhibit distribution patterns that suggest strong avoidance of areas of intense development. We detected no comparable distribution patterns that indicate avoidance of gas field areas within the Pinedale Anticline Project Area (PAPA) at current levels of development.
- Pronghorn rely disproportionately on habitat within the core development areas proposed by the Bureau of Land Management relative to outlying areas of the PAPA, and depend on specific parcels of federal and state land to facilitate major movements between summer and winter ranges. Thus, gas field development in some portions of the UGRB may have little impact on pronghorn, whereas

development in other areas may hinder pronghorn movements or limit pronghorn numbers.

- As in 2005, we detected no differences in survival rates or body mass of pronghorn captured in and among the gas fields (designated experimental animals) and those captured at sites far from petroleum activities (designated control animals). These results are not unexpected, as surface disturbance is currently limited to ~3% of the habitat within the PAPA, and much of the existing development has been concentrated outside pronghorn crucial winter ranges in areas along the northern and southern portions of the Anticline crest.

INTRODUCTION

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 strategies to mitigate consequent impacts. This is perhaps nowhere greater than in the Upper Green River Basin (UGRB) of western Wyoming (Fig. 1). More than 100,000 ungulates winter in the region including elk, mule deer, pronghorn, and moose, as well as

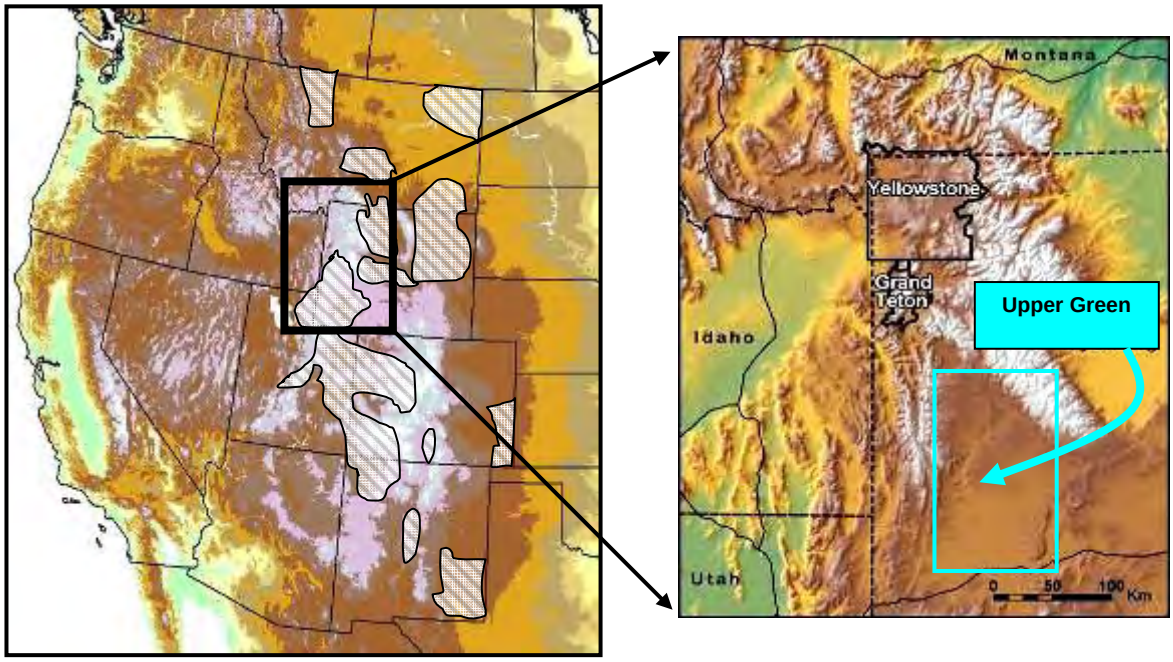


Figure 1. Public lands with energy development projects in the Rocky Mountains (stippled regions; left) and location of the UGRB (right).

dense populations of sage grouse. Indeed, migration spectacles within the UGRB are impressive with mule deer and pronghorn undertaking the longest migrations of any land mammals in the Western Hemisphere south of central Canada (Sawyer et al. 2005, Berger et al. 2006a). Primary statutory authority for the habitat used by these and other species is the Bureau of Land Management (BLM), who oversees the 198,000-acre region designated as the Pinedale Anticline Project Area (PAPA; Fig. 2) and recognizes the dual challenge of sustaining wildlife while developing energy resources. This challenge has proved difficult given the uncertainties involved in predicting the development potential of the PAPA. This is evident in the introduction of the Draft SEIS for the PAPA (BLM 2006) which states:

> *If any one word characterizes the PAPA EIS, it would be uncertainty… Potential development evaluated in the PAPA EIS was a maximum of 900 initial well pads and 700 producing well pads over 10 to 15 years, which some participants considered optimistic... …*[*I*]*t is possible that development within PAPA could go beyond the levels of development considered in this EIS, although few would consider such a level of development as reasonably foreseeable* (BLM 1999).

Indeed, the current Draft SEIS proposes an additional 4,399 wells to be drilled under Alternatives B and C, a five-fold increase of even the most optimistic development predictions proposed seven years ago (BLM 1999).

The challenge, therefore, is formidable – to understand relationships between energy developments and wildlife responses in a system that will remain dynamic in space and time due to increasing anthropogenic disturbance at less than predictable intervals. From a biological perspective, there is an additional problem, the lack of sufficiently fine-grained baseline information prior to gas field development on patterns of pronghorn abundance and distribution within and away from gas fields.

As the construction of facilities and infrastructure to harvest these resources continues, it is 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 broad-scale study, at industry's request, in the winter of 2005.

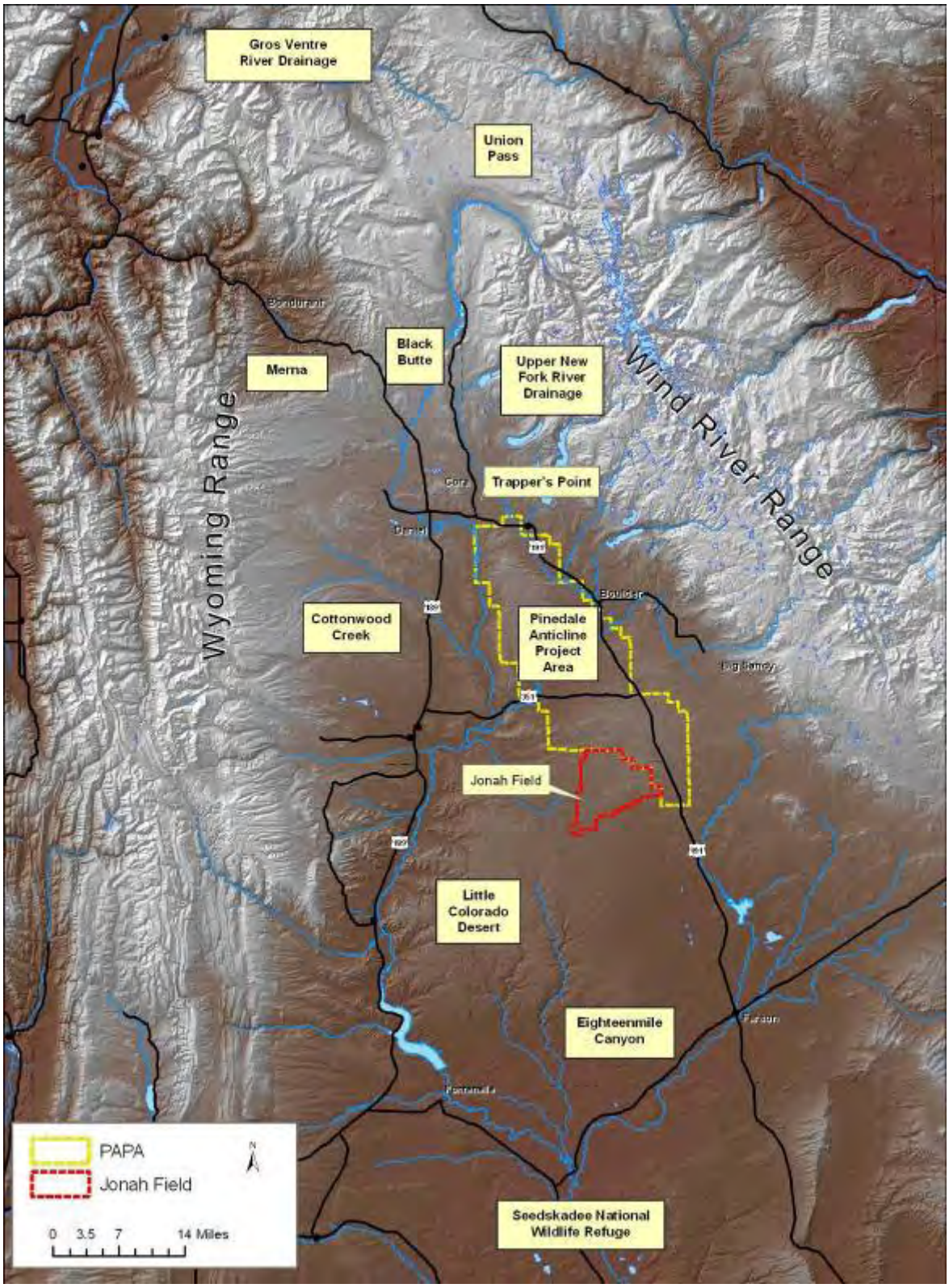


Figure 2. Overview of study area within the Upper Green River Basin showing areas mentioned in the text.

Aims and Goals

Given a lack of both short- and long-term site-specific information on pronghorn in the UGRB, we opted to address a broad set of questions with the intent that answers might assist in future conservation and planning efforts. These questions were designed in consort with wildlife managers from state (Wyoming Game and Fish Department [WGFD]) and federal (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. Our 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.

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

- Seasonal changes in movements, distribution, and migration patterns.
- Influences of gas field infrastructure, specifically (i) landscape-level changes and effects of habitat fragmentation, and (ii) behavioral responses.
- Adult and juvenile survival and correlates of population productivity.

The human dimension is obviously complex and involves more than the development of gas fields and attendant infrastructure. Other potential impacts include hunting pressure, traffic, and an indirect human footprint that is associated with housing, dogs, and fences. Along with these contemporary forces, ecological and bio-physical properties affect pronghorn.

Changes in Research Protocol

We elected to make two changes in our research protocol, one during 2006 and one that will be implemented in 2007.

- In 2005-2006 we developed and field-tested a remote scale complex for the purpose of garnering information about changes in pronghorn body mass throughout winter.

Much of our efforts were devoted to testing scale configurations, locations, and implementation procedures. We successfully generated data on weights in all seasons except winter despite 1) placement of scales in a wide variety of locations (e.g., along travel lanes, under fence crossings, parallel to fences, various habitat types, etc.); and 2) the use of attractants other than food (due to concerns over the impact of supplemental food on overall animal health, distribution, etc.). As a consequence, we have abandoned efforts to measure body mass in this fashion.

- Given our over-arching goal to examine potential effects of gas field infrastructure on pronghorn dynamics, we continue to focus on the possible vulnerability of different sex and age classes to ecological and anthropogenic-based stressors. Because our study has concentrated on adult females, we have little to no data on survivorship of adult males or over-winter survival of fawns. If differences in survival were to exist however, adult females are predicted to experience less mortality because they generally have greater amounts of body fat than adult males and juveniles (Byers 1997). As a consequence, in future years we will test predictions about differential survival abilities by conducting classification counts to contrast sex and age ratios during early, mid-, and late winter to evaluate over-winter survival of fawns, adult males and females. These surveys began in December 2006 and results will be presented in our Year 3 report.

CHAPTER 1

SEASONAL MOVEMENTS, DISTRIBUTION, AND MIGRATION

INTRODUCTION

Existing information on the locations of pronghorn migration routes and wintering areas in the UGRB is based on historical knowledge of WGFD employees and local residents, as well as two telemetry studies that focused on documenting the migration corridor between Grand Teton National Park and the Upper Green (Sawyer et al. 2005, Berger et al. 2006a). In November of 2006, the BLM withdrew two parcels intended for sale in the December 5 lease auction after WGFD raised concerns about potential impacts of development within these parcels on wildlife migration. In response, the BLM and WGFD requested that WCS submit information on pronghorn movement corridors, constriction zones, and important parcels of land, based on recent data collected from GPS-collared animals, to provide a more detailed basis upon which to base future leasing decisions and inform wildlife management.

METHODS

Study Area

The primary 4,000 km^2 study region within the UGRB extends well beyond the PAPA (Fig. 2**)**. Pronghorn use habitats that vary in elevation from about 2,100 to 2,800 m. During winter, animals are generally found at lower elevations where densities tend to be highest in areas adjacent to Cottonwood Creek, the rolling hills on the southeast edge of the Mesa, and from the Seedskadee Wildlife Refuge to the southwest of Eighteenmile Canyon and to Farson (Fig. 2). The region in and around the New Fork River in the PAPA has been formally designated by the WGFD as crucial winter range for pronghorn, defined as “the determining factor in a population’s ability to maintain itself at a certain level over the long term” (Fig. 3).

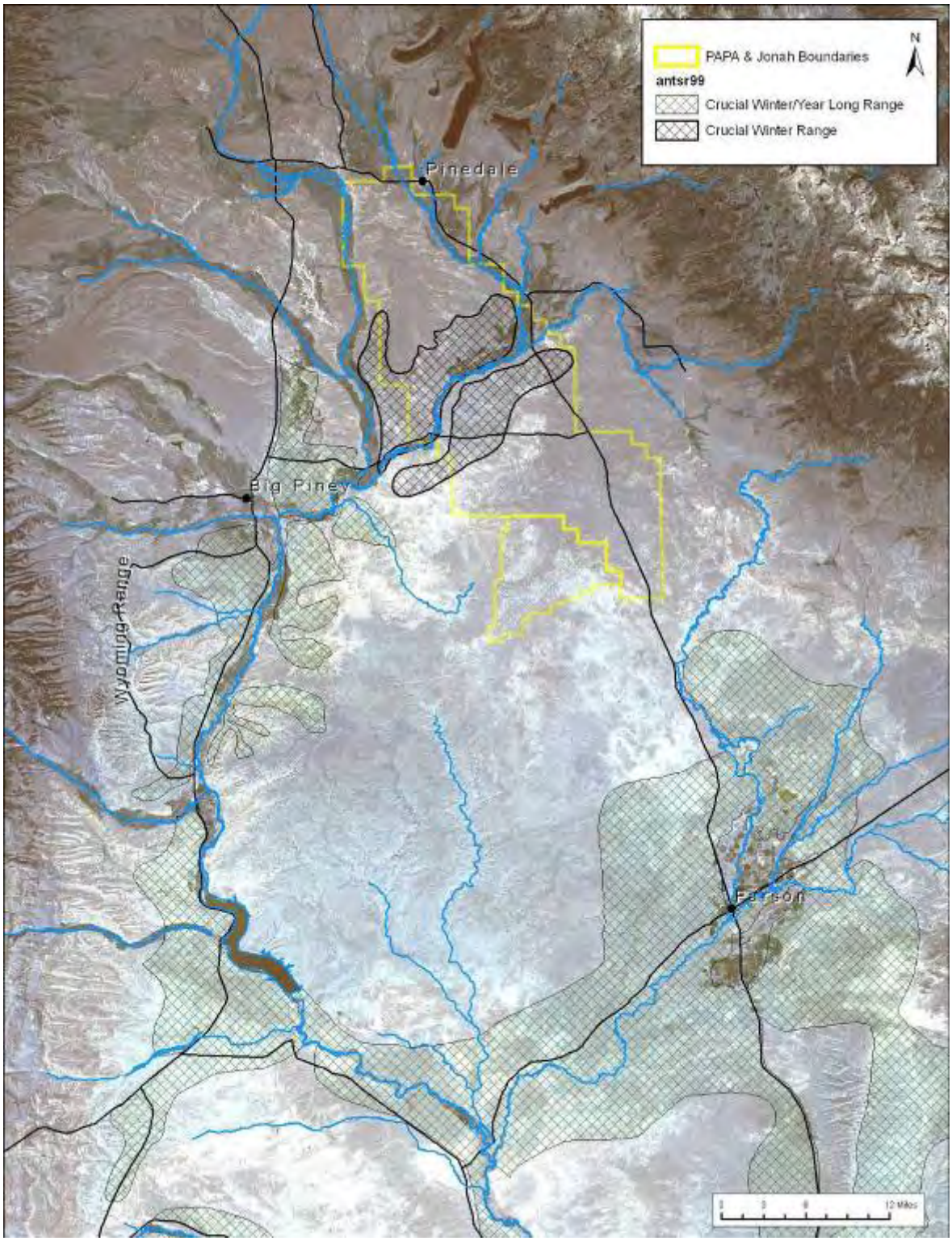


Figure 3. Location of areas designated as crucial winter and year long ranges for pronghorn by Wyoming Game and Fish.

Research Design — Control and Experimental Areas

To achieve project aims, we rely on two general types of contrasts: 1) before and after comparisons of animal distribution 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, whereas control animals are spatially segregated from gas fields. *A priori* classification schemes such as these 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., ≥90%) fall within a discrete home range that has been designated as either a control or experimental site (Beckmann and Berger 2003). For radio-collared pronghorn, we assessed fidelity to wintering areas using locations obtained from the GPS collars to determine whether animals captured in either gas field or non-gas field areas moved to other sites during winter. Furthermore, for control animals that moved to areas in the vicinity of gas fields during winter, we evaluated the extent of home range overlap with gas wells. Home ranges were estimated using the fixed-kernel method (95% contour; Worton 1989) with the Hawth's Tools extension in ArcInfo 9.2.

Animal Capture and Handling

In both February 2005 and January 2006, we captured adult female pronghorn using a net-gun fired from a helicopter, and equipped them with global positioning system (GPS) collars with 8-hour mortality sensors and remote release mechanisms (Advanced Telemetry Systems, Isanti, MN) In 2005, the collars were programmed to collect eight locations per day during winter and migratory periods (27 February – 31 May; 1 October – 4 December), and a single location per day during summer and early fall (1 June – 30 September). In 2006 the collars were programmed to collect twelve locations per day during winter and migratory periods (25 January – 15 May; 15 October – 7 November), and a single location per day during summer and early fall (16 May – 14 October). During captures, all animals were blindfolded and weighed, and blood and feces were

collected by a WCS veterinarian (Dr. William Karesh) for analysis of pregnancy rates and stress levels (Fig. 4).

Seasonal Distribution and Movements

We used ArcInfo 9.2 to plot GPS locations and create seasonal distribution maps for pronghorn. We produced maps showing the distribution of control and experimental animals during winter (December - March), spring (April - May), summer (June -

Figure 4. Net dropping over female (top left), a blindfolded and restrained female (top right), weighing a restrained female (bottom left), and attaching GPS collar (bottom right). Photos: B. Karesh.

August), and fall (September - November). In addition, we examined maps of individual experimental animals during winter to look for distribution patterns that would suggest avoidance of areas of intensive gas field development.

To assist the BLM and WGFD in their planning efforts, we plotted seasonal locations of pronghorn relative to federal and state land ownership as well as the five core development areas (DAs) proposed by the BLM in the Draft SEIS for the PAPA (BLM 2006). Ownership data were obtained from the Wyoming GAP Analysis Project (http://www.sdvc.uwyo.edu/wbn/gap.html).

To identify pronghorn movement routes, we used the Hawth's Tools extension in ArcInfo 9.2 to link consecutive locations for individual animals to construct travel trajectories. Population-level migration routes were hand digitized based on the collective routes of the individual animals. We classified routes into one of three categories based on our assessment of the importance of the route to pronghorn movement. We classified routes as Category 1 if they were invariant or appeared, based on our GPS data, to facilitate major movements of numerous pronghorn throughout the UGRB. Routes classified as Category 2 were locally important routes that facilitate movements within a specific area, such as funneling animals along the Wind River Front. We also classified routes as Category 2 if there were multiple paths leading to the same area, so that the loss of a single route would not extinguish migration to that area. Finally, we classified routes as Category 3 if they appeared to be ancillary tributaries off main routes that facilitate movement into very localized areas. The loss of an ancillary route might mean that pronghorn no longer use a specific parcel of land, but it would not completely eliminate pronghorn use of a major area such as the Wyoming or Wind River Fronts. Note that because pronghorn generally show a high degree of fidelity to wintering areas and migration routes, the resolution of our data, and hence our ability to accurately characterize routes, is influenced by the distribution of animals at the time of capture. Thus, some routes classified as Category 2 or 3 might warrant a higher classification, but a lack of data from radio-collared animals in that area precludes a more detailed assessment.

RESULTS

Captures

We captured 50 adult female pronghorn in February 2005 and 50 in January of 2006 (Fig. 5). Mean handling time of captured animals was 5.63 ± 1.04 minutes (mean ± standard deviation). Based on capture locations, the distribution of radio-collared pronghorn was 28 control and 22 experimental animals in 2005, and 25 control and 25 experimental animals in 2006 (Fig. 5).

Seasonal Distribution

GPS collars were recovered from 48 pronghorn in December 2005 and from 42 pronghorn in November 2006. The remaining 10 collars were not recovered because their release mechanisms failed or their very high frequency (VHF) signals disappeared. We programmed collars to release earlier in 2006 than in 2005 to allow adequate time for refurbishment prior to re-deployment in December 2006. A total of 122,348 data points were generated by the collars in 2005 and 2006 (Fig. 6), and acquisition rates exceeded 98%. For purposes of identifying migration routes, we also included 13,552 locations from 10 pronghorn that were equipped with GPS collars from October 2003 through September 2004 (Berger et al. 2006a).

In 2006, experimental animals remained in the vicinity of their capture sites during winter (Fig. 7), and then began migrating toward summer ranges in early April as snowmelt permitted (Fig. 8). In contrast, control animals exhibited much less fidelity to their capture sites, as most of the animals captured near Eighteenmile Canyon and the Little Colorado Desert moved north toward the gas fields in early March (Fig. 7). The remaining control animals began migrating toward their summer ranges in early April (Fig. 8). All animals reached their summer ranges by late May, with the exception of a single experimental animal that did not reach its summer range in Grand Teton National Park (GTNP) until early June (Fig. 9). In mid-October, both control and experimental animals began their return migrations to winter ranges in the UGRB (Fig. 10). Note that

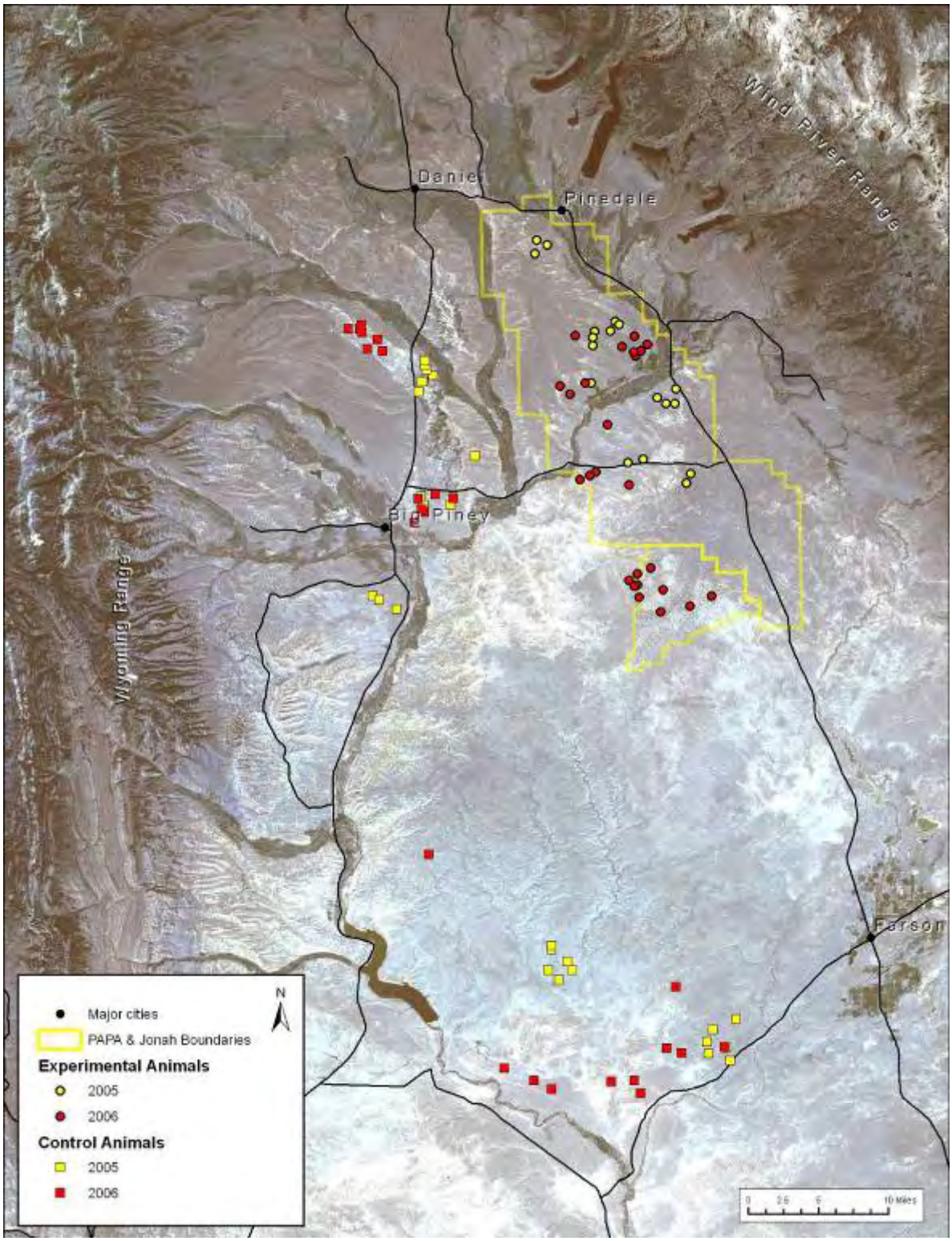


Figure 5. Locations of pronghorn captures in 2005 and 2006 indicating classification as experimental or control based on proximity of capture location to gas fields.

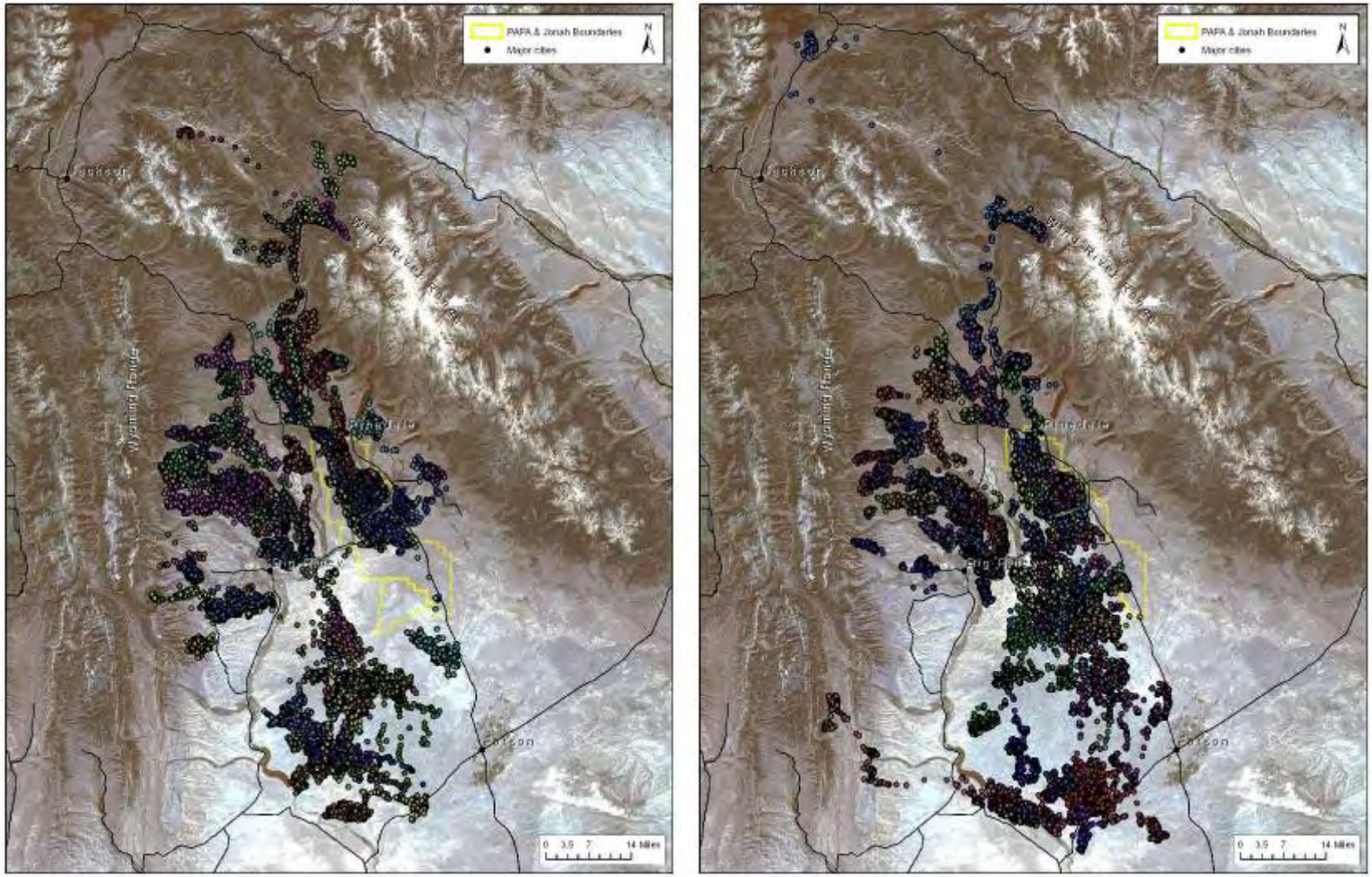


Figure 6. Comparison of annual locations of GPS collared animals in 2005 (left) and 2006 (right) .

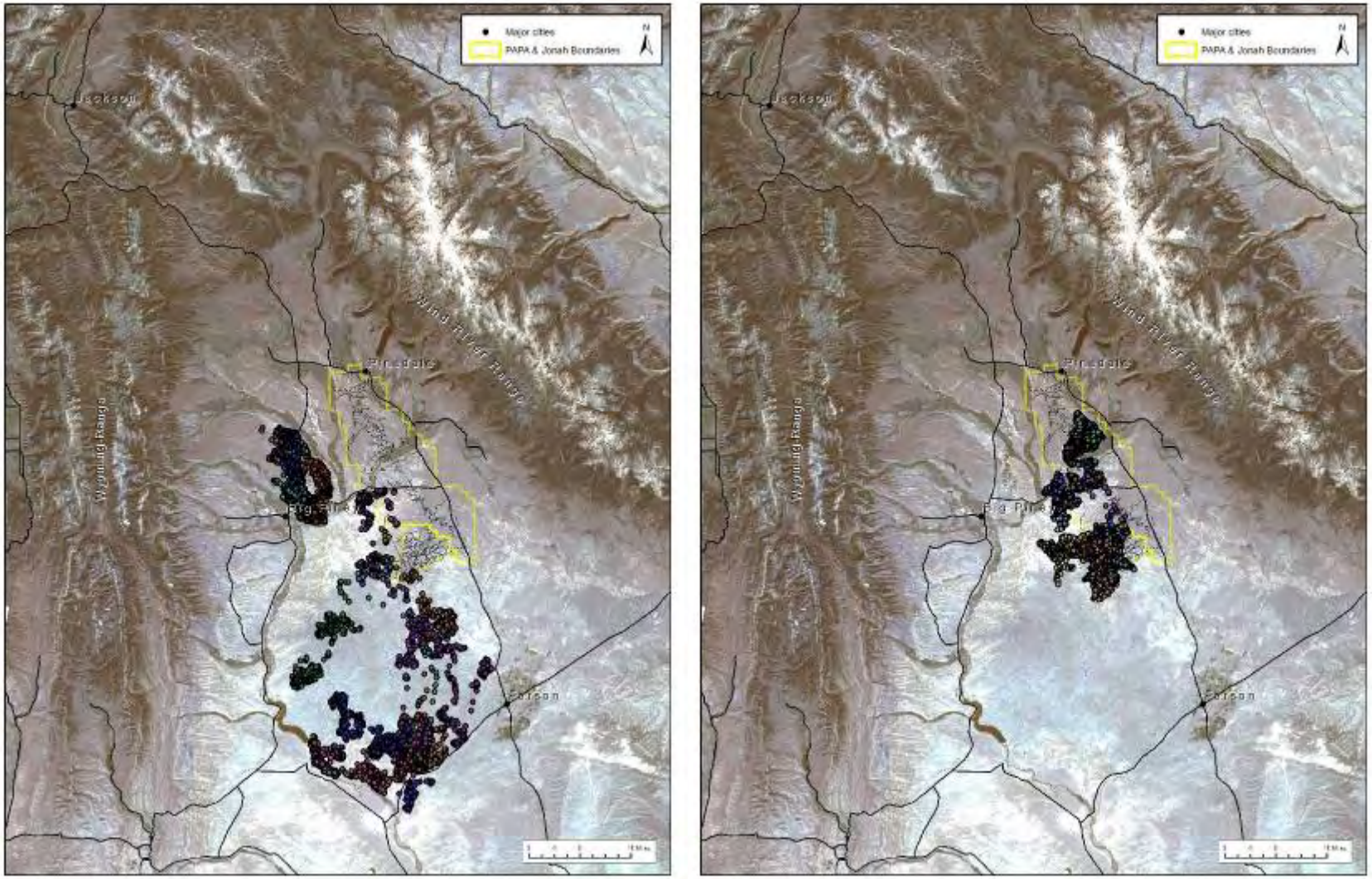


Figure 7. Winter (December—March) 2006 locations of control (left) and experimental (right) animals.

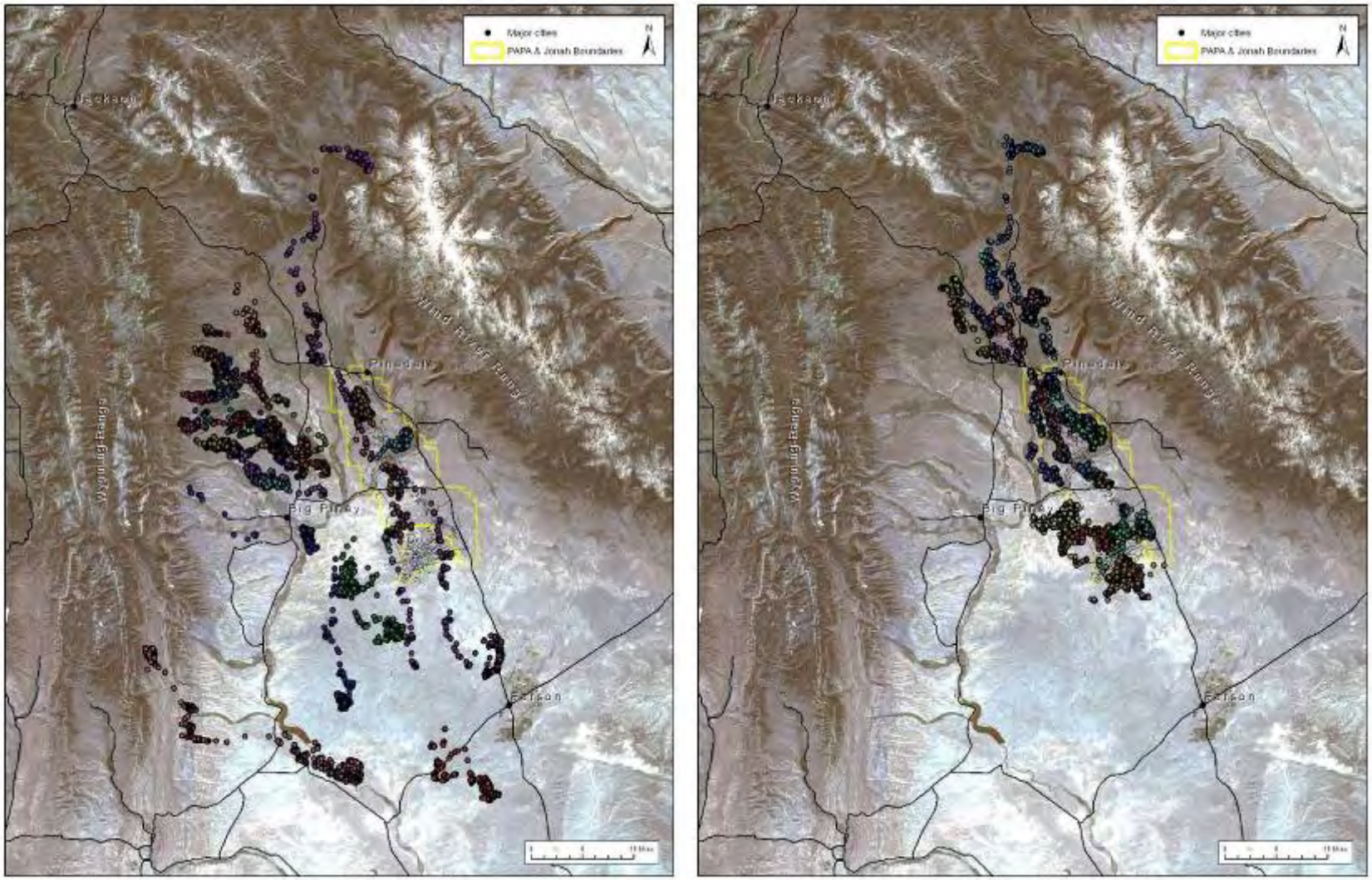


Figure 8. Spring (April—May) 2006 locations of control (left) and experimental (right) animals.

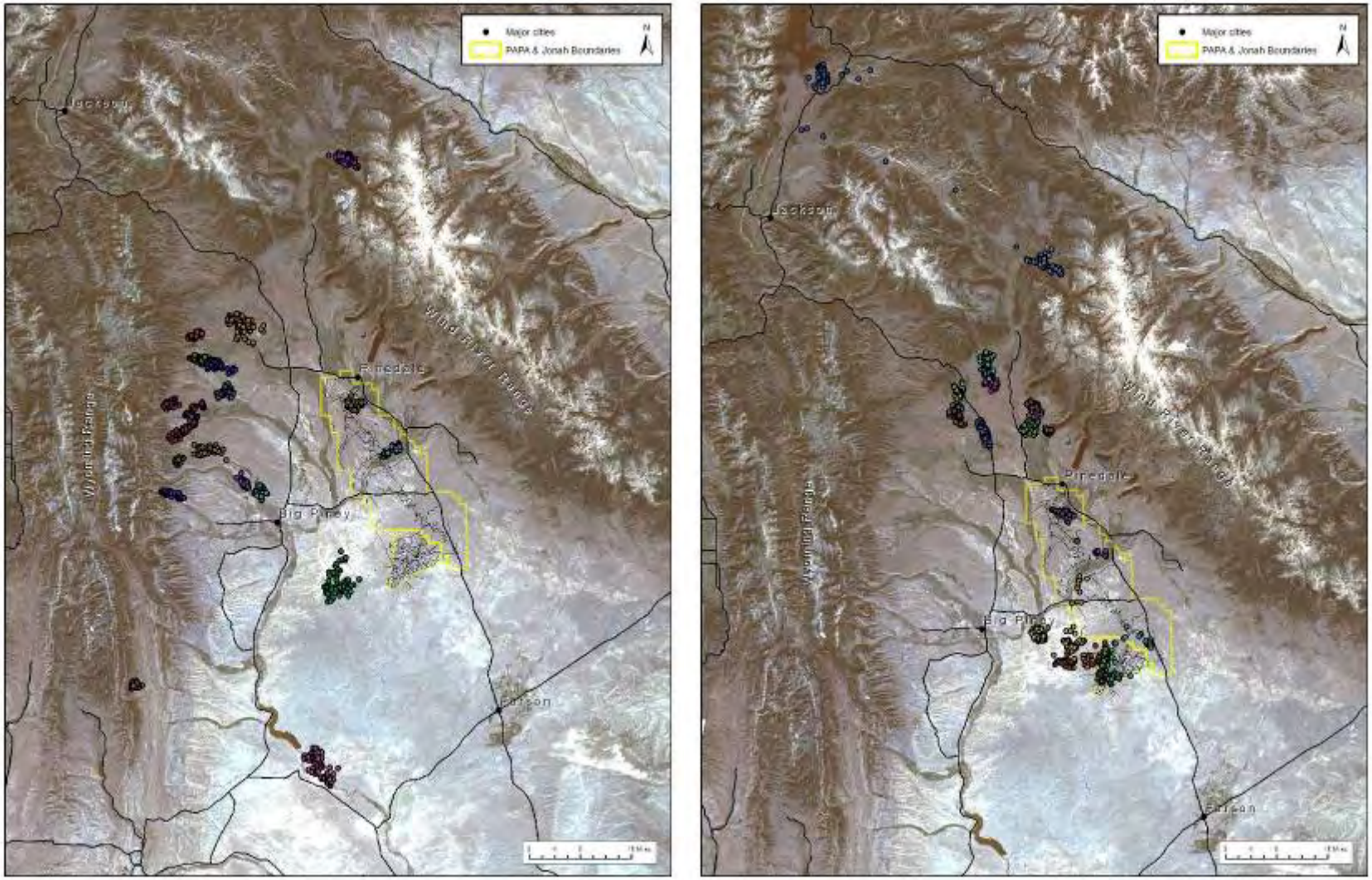


Figure 9. Summer (June—August) 2006 locations of control (left) and experimental (right) animals.

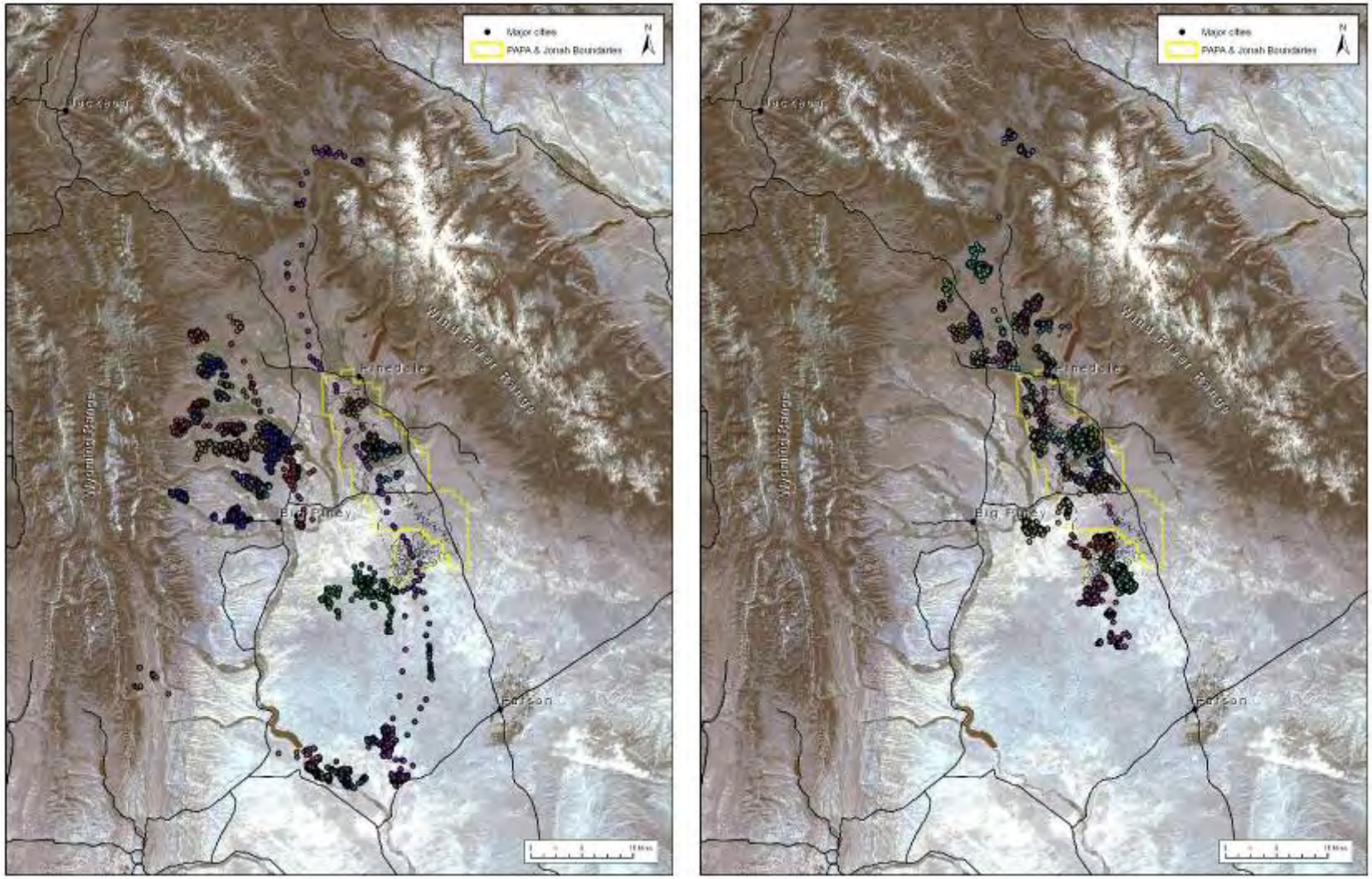


Figure 10. Fall (September—November) 2006 locations of control (left) and experimental (right) animals.

the GTNP animal is not evident on the fall distribution maps as it was struck by a car in the Park and killed in mid-August.

Control and Experimental Designations

Due to northward movements of animals captured near Eighteenmile Canyon and the Little Colorado Desert (Fig 5), control and experimental animals showed less spatial segregation in 2006 (Fig. 11) than in 2005 (Berger et al. 2006b). In particular, two control animals moved to areas in the vicinity of the PAPA and the Jonah Field in early March (Fig. 7). However, an analysis of home ranges for these animals revealed little or no actual overlap with gas field areas during the winter months, supporting their initial classification as control animals based on capture locations (Figs. 12-13).

While most control animals summered along the Wyoming Front from Calpet north towards Merna (n = 13), near Big Piney (n = 2), in the vicinity of Little Colorado Desert (n = 1), or on the Seedskadee Wildlife Refuge (n = 1), two animals summered in the PAPA north of the New Fork River, and a third summered near Union Pass (Fig. 9). Experimental animals summered primarily along the Wind Front (n = 4), in the vicinity of Black Butte (n = 2), near Merna (n = 3), southeast of Union Pass (n = 1), south of Hwy 351 near the Green River (n = 1), or in GTNP (n = 1; Fig. 9). Five experimental animals remained in the vicinity of the PAPA and the Jonah Field throughout the entire summer (Fig. 9).

Use and Avoidance of Gas Fields

Two experimental animals exhibited distribution patterns that suggested avoidance of areas of high-intensity gas field development in the Jonah Field during the winter of 2005-2006 (Fig. 14). Both animals utilized areas along the periphery of the Jonah Field extensively, as well as in the northern portion of the Jonah where well densities are lower (Fig. 14). This pattern was not characteristic of all pronghorn, however, as two other animals showed extensive use of areas of intensive development in the Jonah Field, suggesting indifference to the habitat fragmentation and human activity associated with

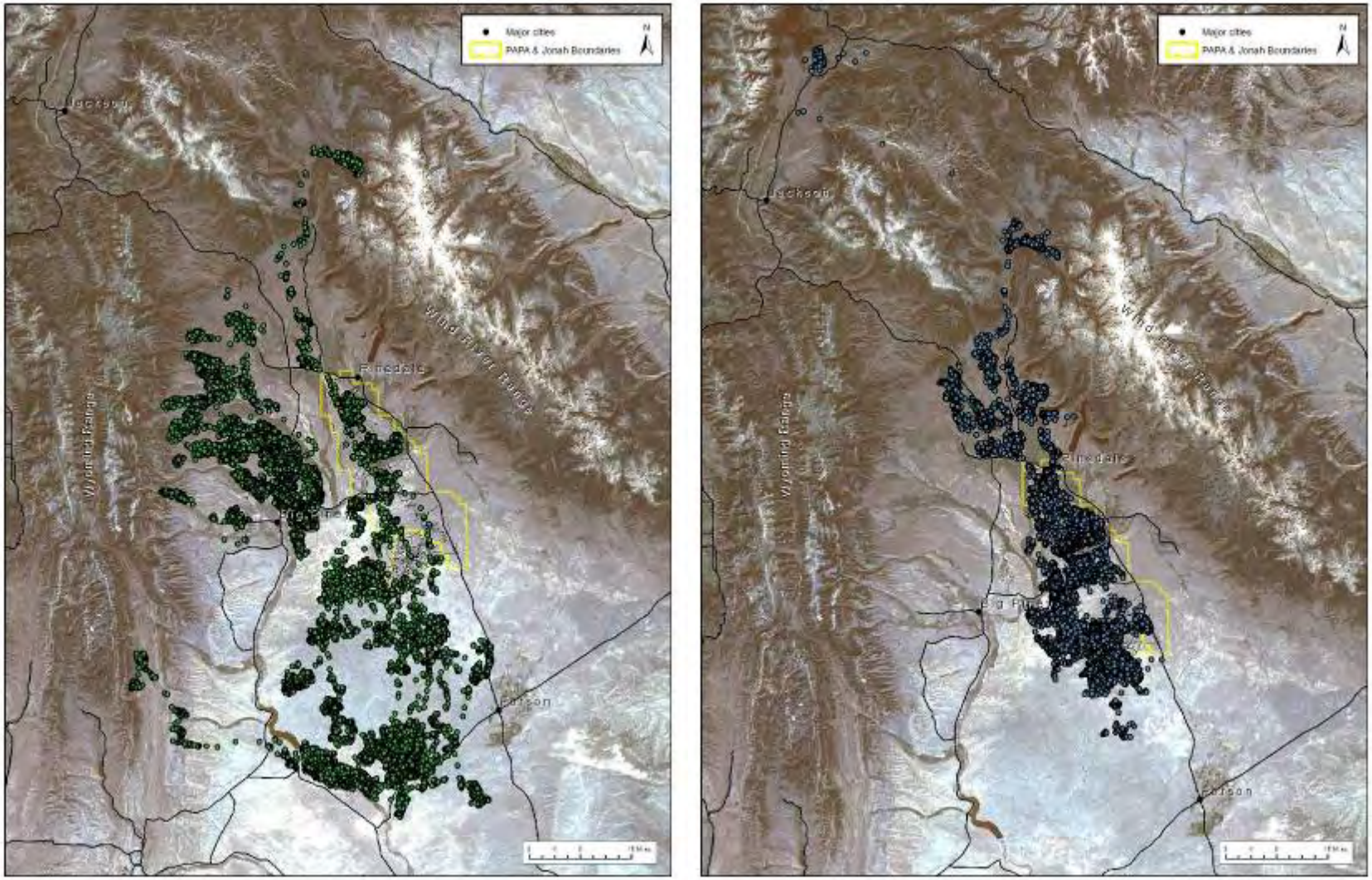


Figure 11. Annual locations of control (left) and experimental (right) animals during 2006.

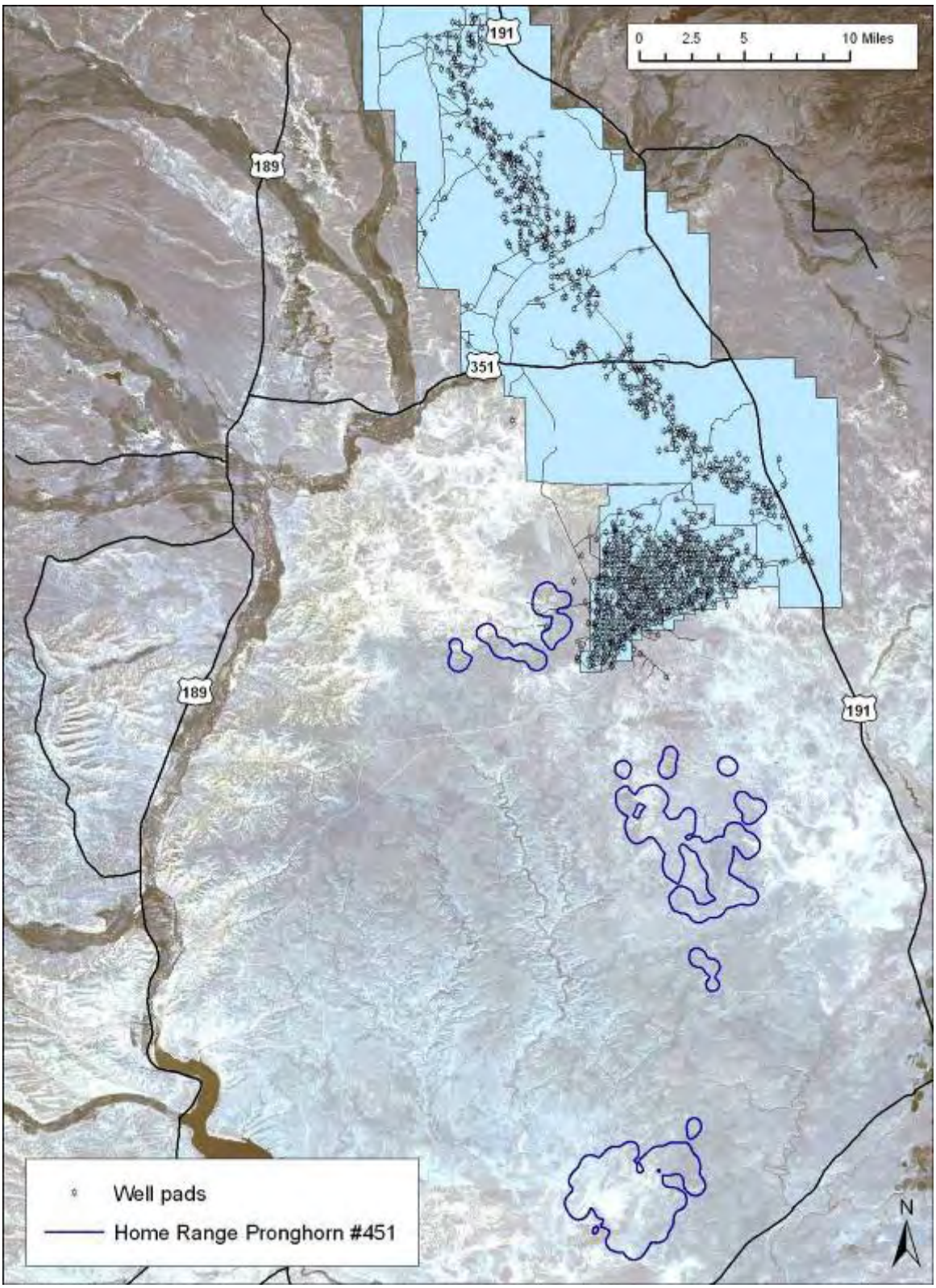


Figure 12. Home range (95% fixed kernel) of pronghorn #451 during winter. Although this animal moved near the Jonah Field following capture, its winter home range did not overlap the gas field.

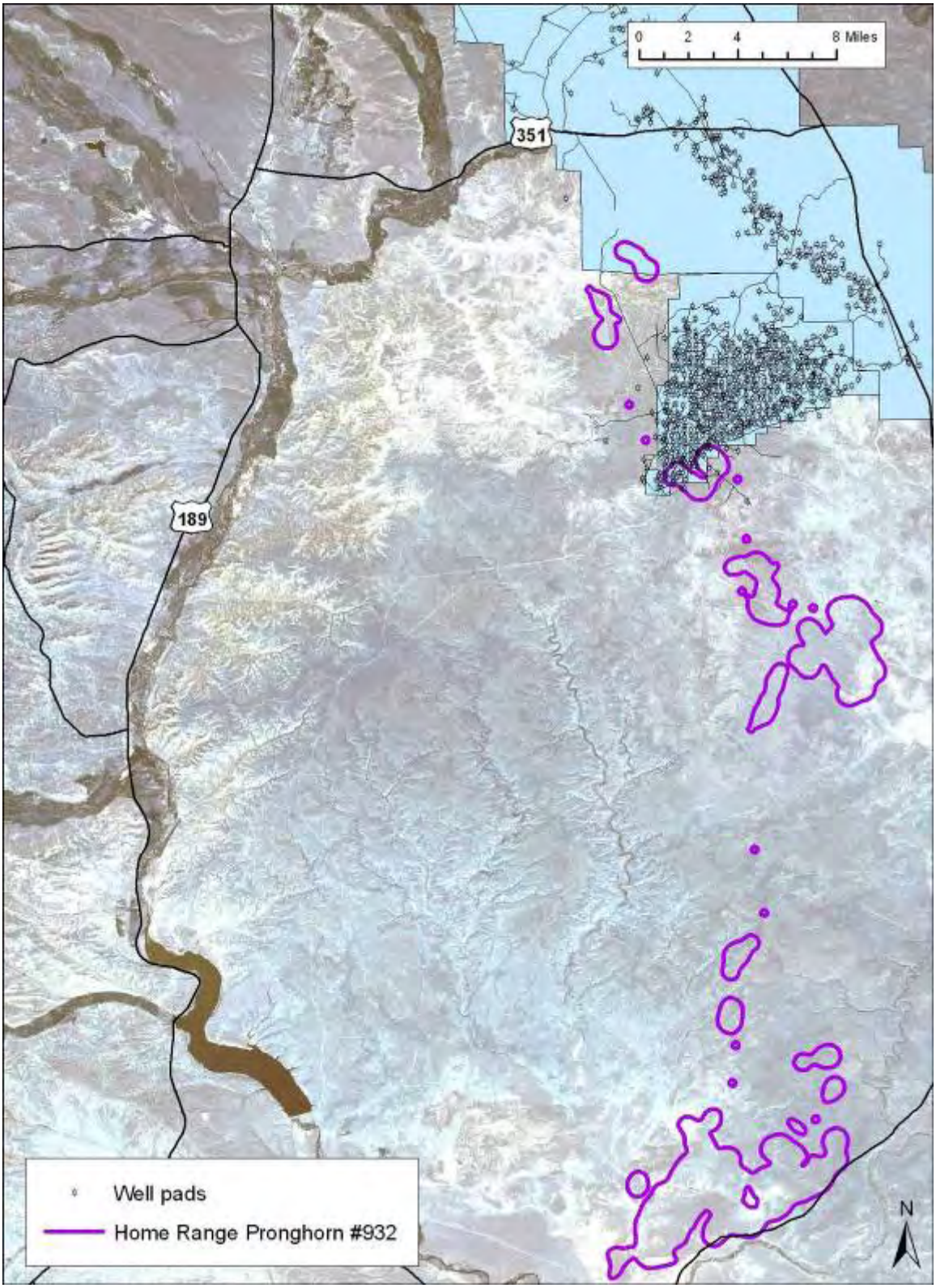


Figure 13. Home range (95% fixed kernel) of pronghorn #932 during winter. Although this animal moved near the Jonah Field following capture, its winter home range showed little overlap with the gas field.

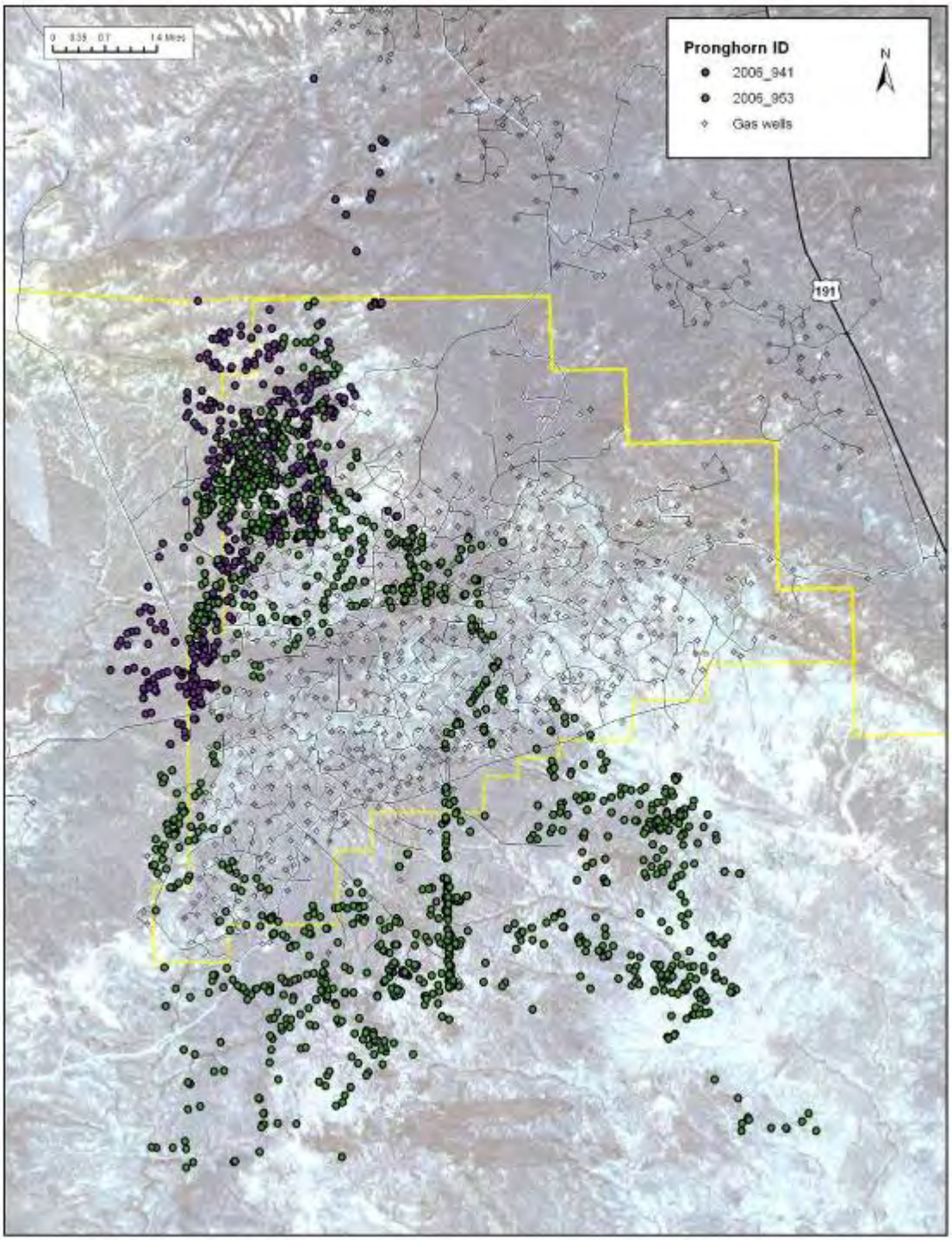


Figure 14. Winter 2005-2006 locations of pronghorn (*n* = 2) showing apparent avoidance of areas of high intensity development in the Jonah Field.

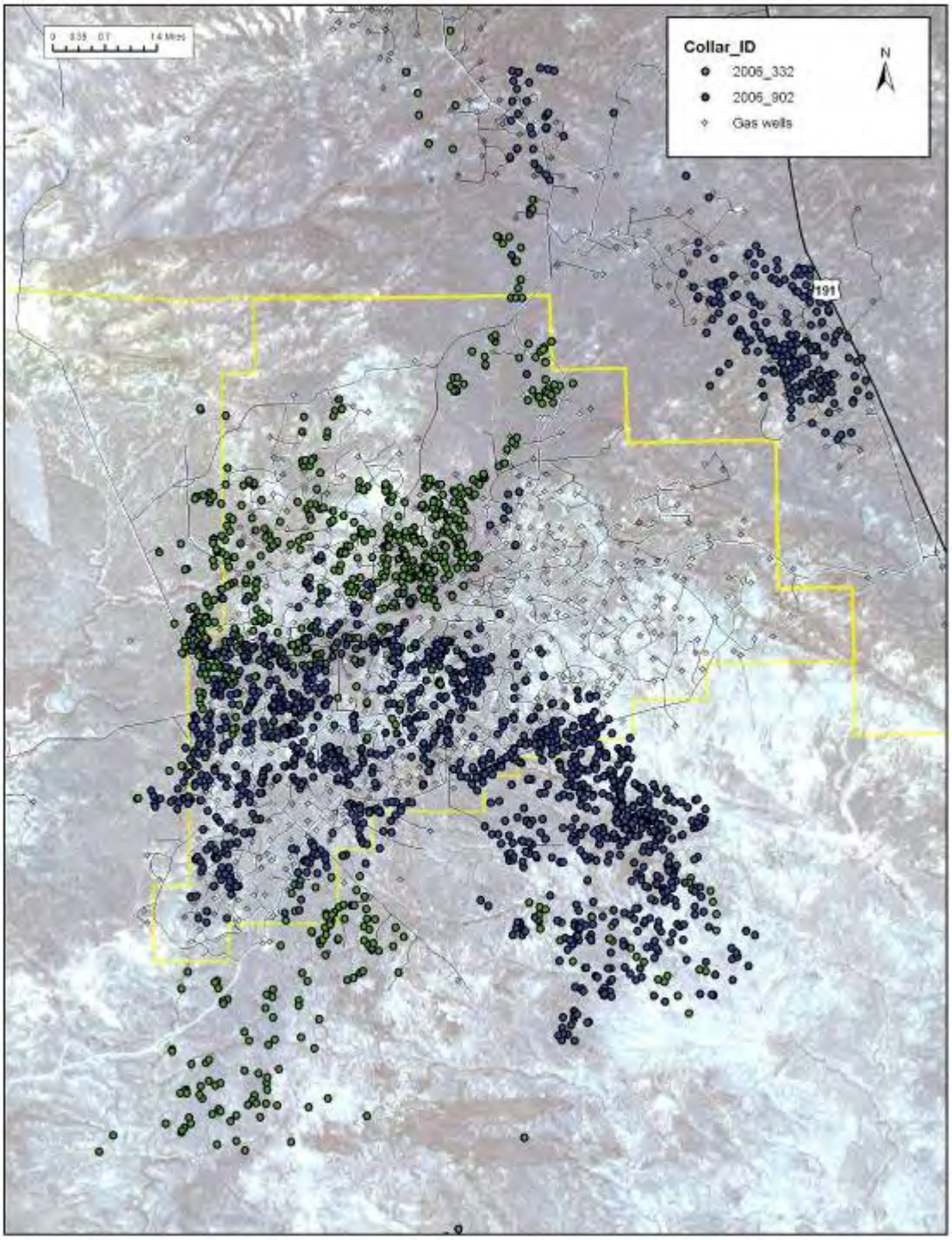


Figure 15. Winter 2005-2006 locations of pronghorn (*n* = 2) showing no avoidance of areas of high intensity development in the Jonah Field.

gas field development (Fig. 15). In addition, we detected no comparable distribution patterns that would indicate avoidance of gas field areas in the vicinity of the PAPA.

Use of Federal and State Lands

An examination of location data from 2004-2006 revealed several parcels of state and federal land that are of particular importance to pronghorn. Notably, pronghorn depend heavily on a parcel of State Trust land in the PAPA to facilitate movements across the New Fork River (Fig. 16). In addition, pronghorn make extensive use of several parcels of BLM and State Trust land north of Trapper's Point during their migration to GTNP and summering areas in the vicinity of Union Pass, and to access Forest Service lands in the vicinity of New Fork Lakes (Fig. 17).

Use of Proposed Development Areas

GPS locations from 2004-2006 reveal that pronghorn rely extensively on habitat within the core development areas proposed by the BLM in the PAPA SEIS (BLM 2006). Specifically, pronghorn utilize DAs 2 and 3 extensively, as well as portions of DAs 1 and 4, during winter months (December – March; Fig. 18). During spring (April – May), pronghorn rely primarily on habitat in DAs 1, 2, and parts of DA 3 (Fig. 19). In fall, pronghorn utilize DAs 1, 2, and 3 extensively, in addition to the northern portion of DA 4 (Fig. 20).

Migratory Movements

We analyzed monthly movement trajectories for 75 migratory animals from 2004-2006, resulting in the identification of 28 migration routes (Fig. 21). We classified three of these routes as Category 1, eight as Category 2, and the remaining seventeen as Category 3 (Fig. 21). While some of these routes have been well-documented, such as the major migration through the Trapper's Point Bottleneck (Fig. 22), others have received much less attention. For instance, pronghorn primarily use a single route in the western portion of the Anticline to facilitate north-south movements throughout the winter range and to cross the New Fork River (Fig. 23). Similarly, pronghorn utilize a narrow swath of public land east of Big Piney to navigate the Green River, Hwy 351, and

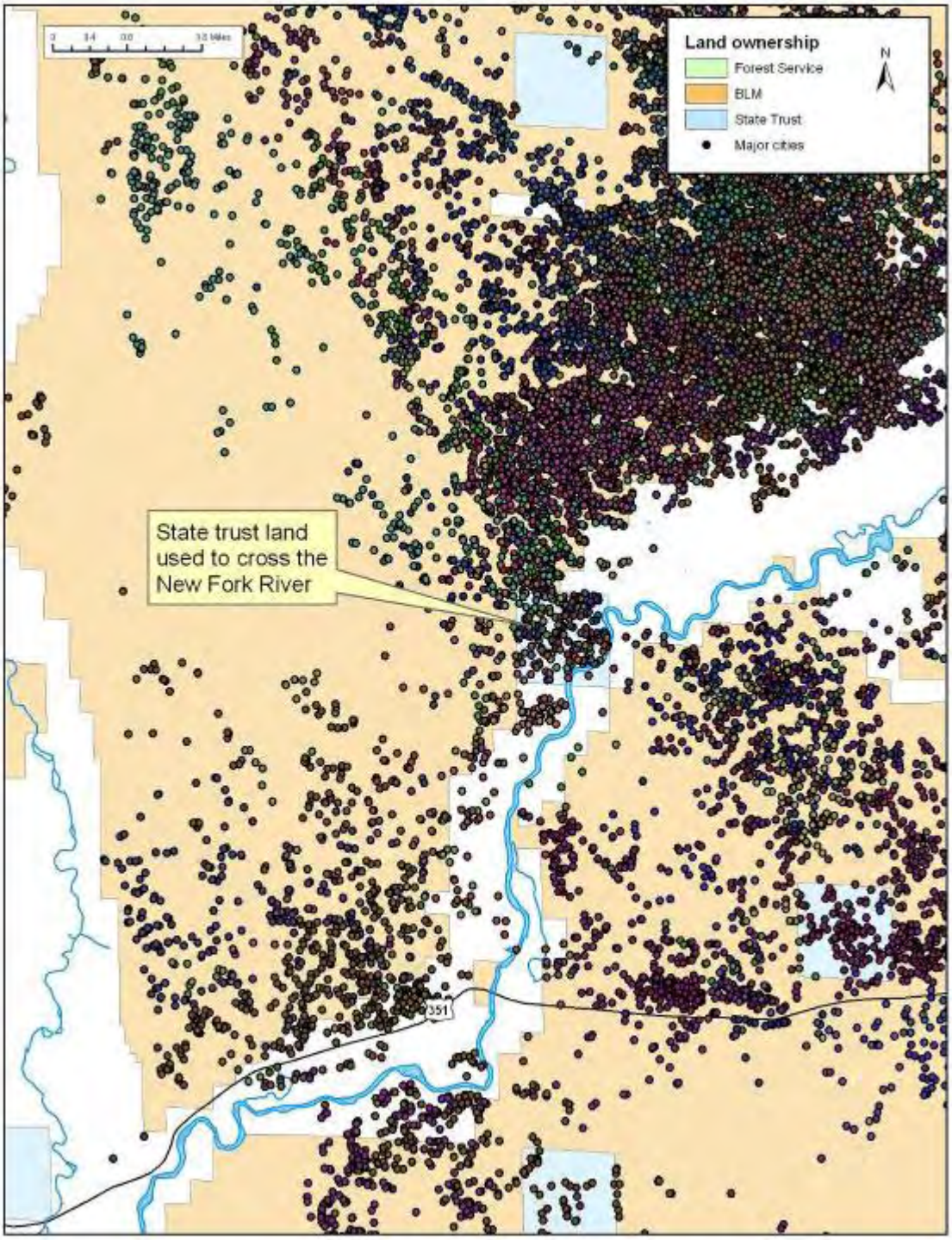


Figure 16. Winter locations of pronghorn showing extensive use of a parcel of State Trust land to cross the New Fork River.

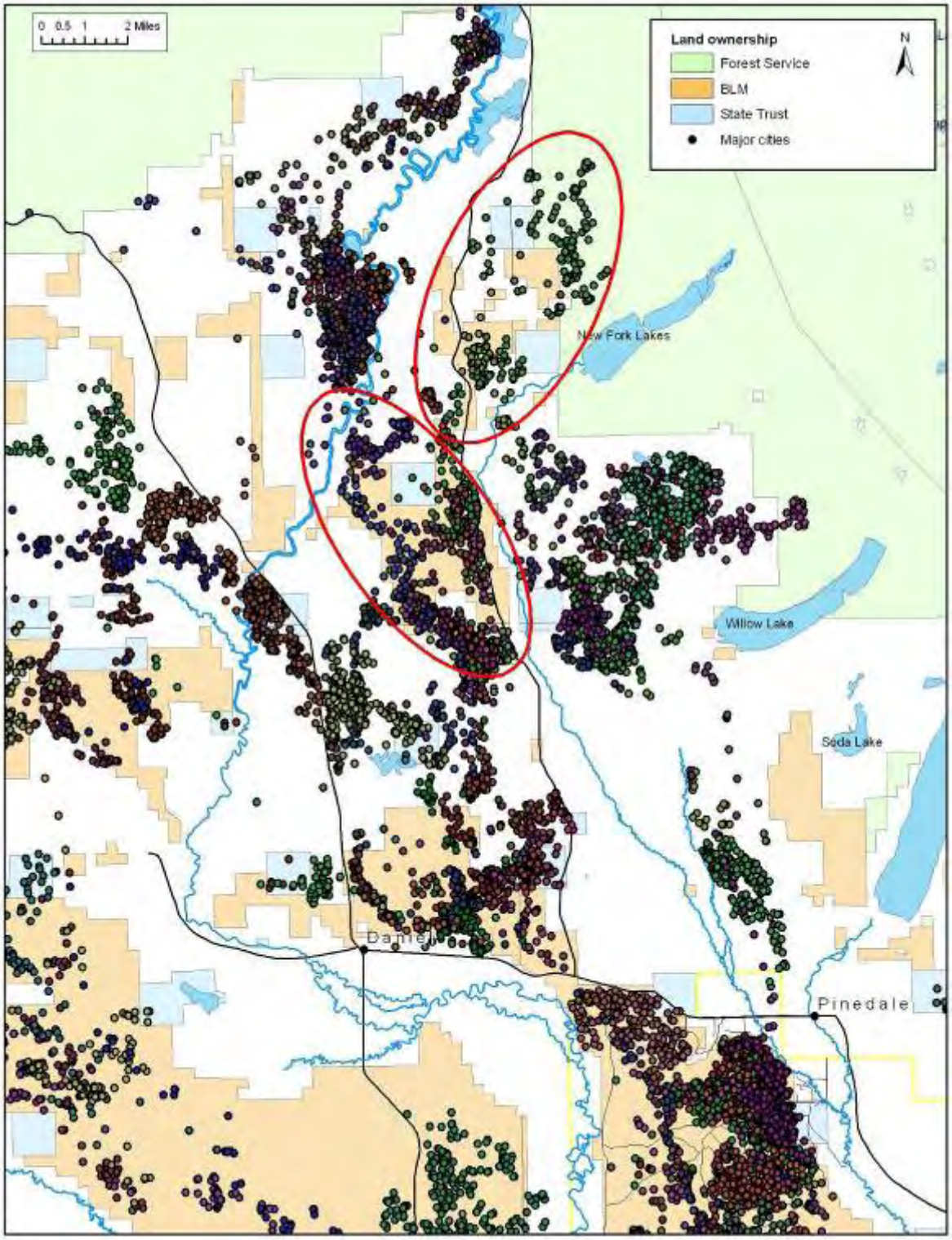


Figure 17. Pronghorn make extensive use of BLM and State Trust lands during their migration to Grand Teton National Park and to access Forest Service lands in the vicinity of New Fork Lakes.

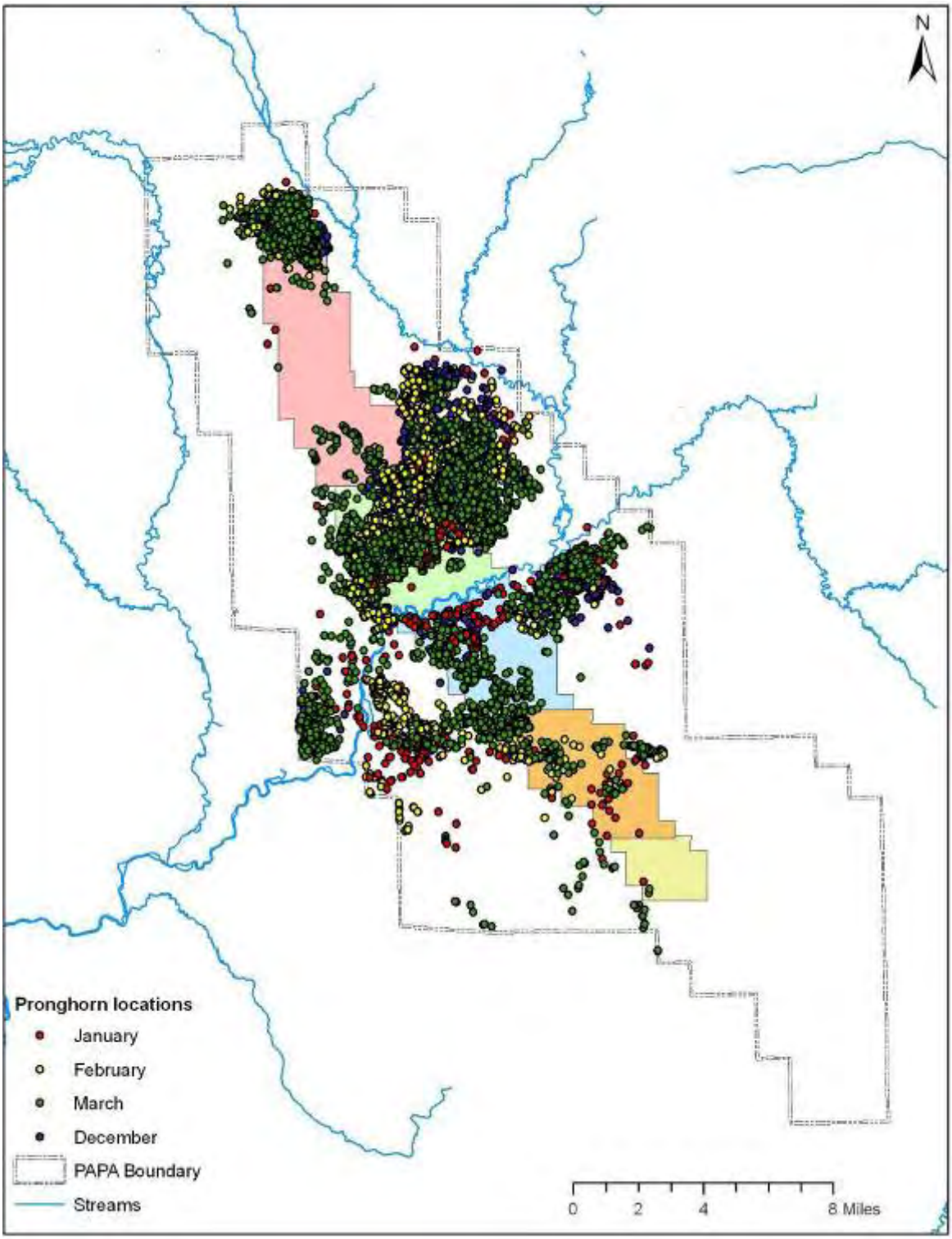


Figure 18. During winter, pronghorn rely extensively on habitat in BLM proposed Developments Areas 2 (green), 3 (blue), and 4 (orange), as well as the northern and southern portions of Development Area 1 (pink).

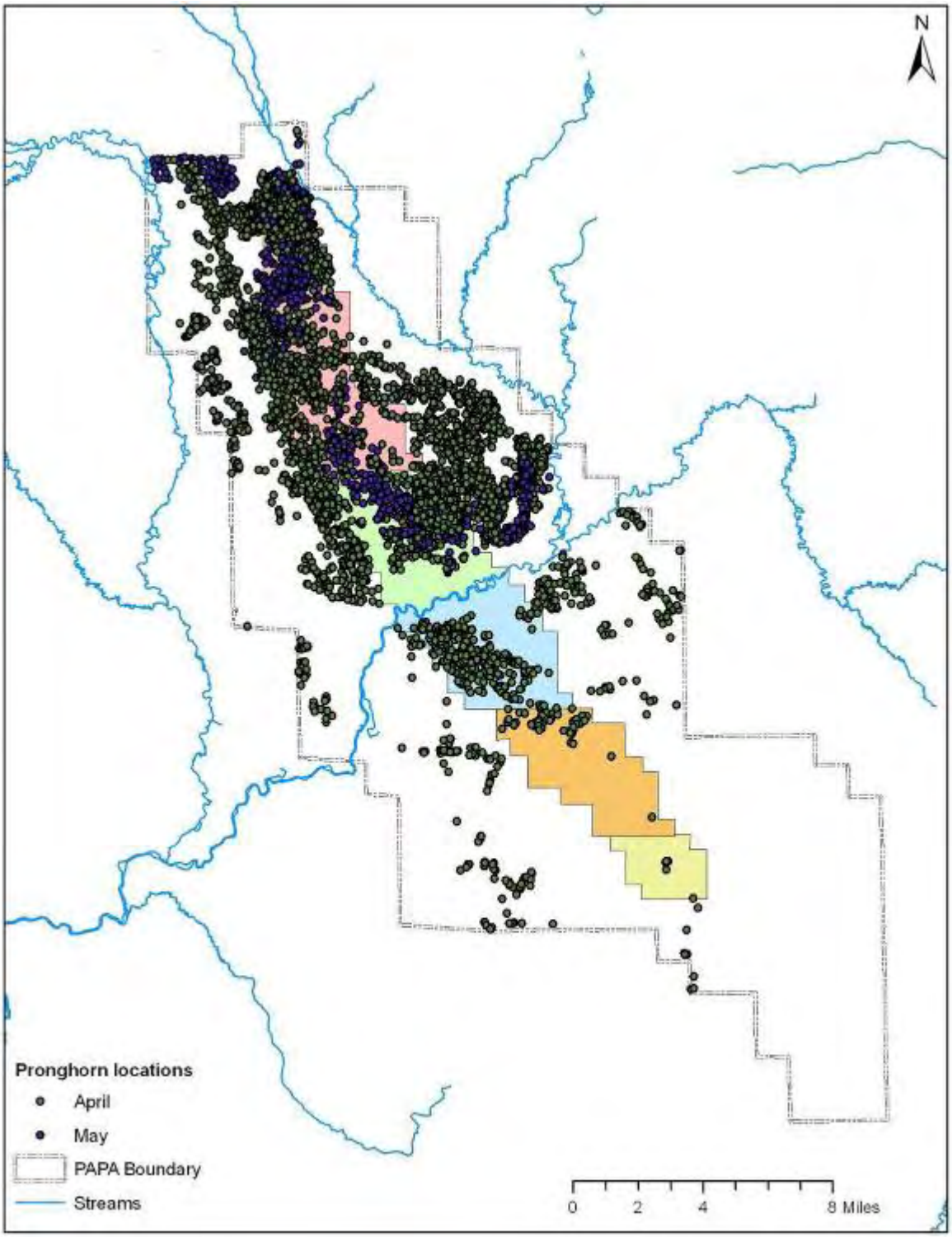


Figure 19. During spring, pronghorn rely extensively on habitat in BLM proposed Developments Areas 1 (pink), 2 (green), and 3 (blue).

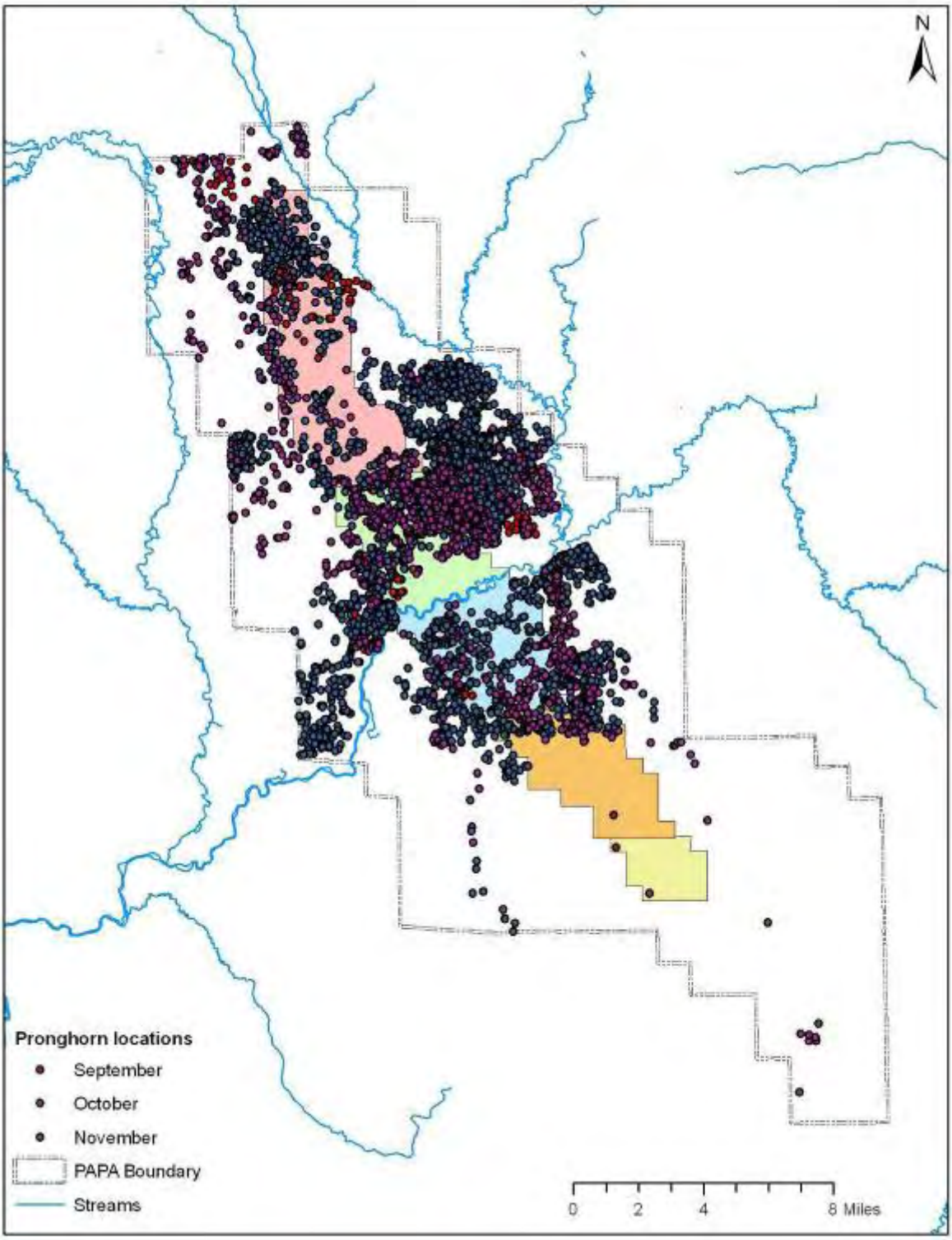


Figure 20. During fall, pronghorn rely extensively on habitat within BLM proposed Development Areas 1 (pink), 2 (green), and 3 (blue).

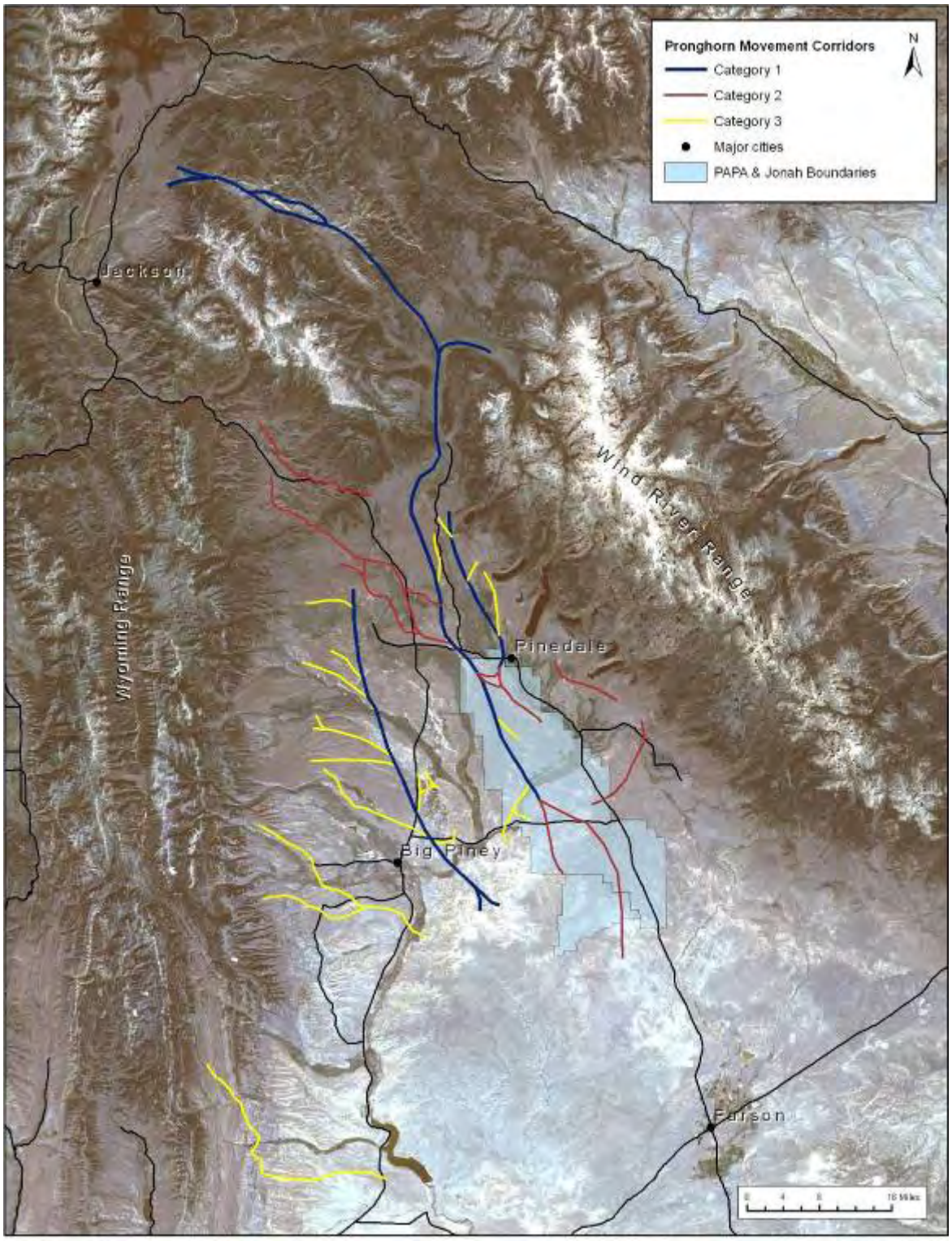


Figure 21. Overview of pronghorn migration routes in the Upper Green River Basin (UGRB). The different categories (1 to 3) indicate the relative importance of the routes to pronghorn movement. Routes classified as Category 1 facilitate major pronghorn movements.

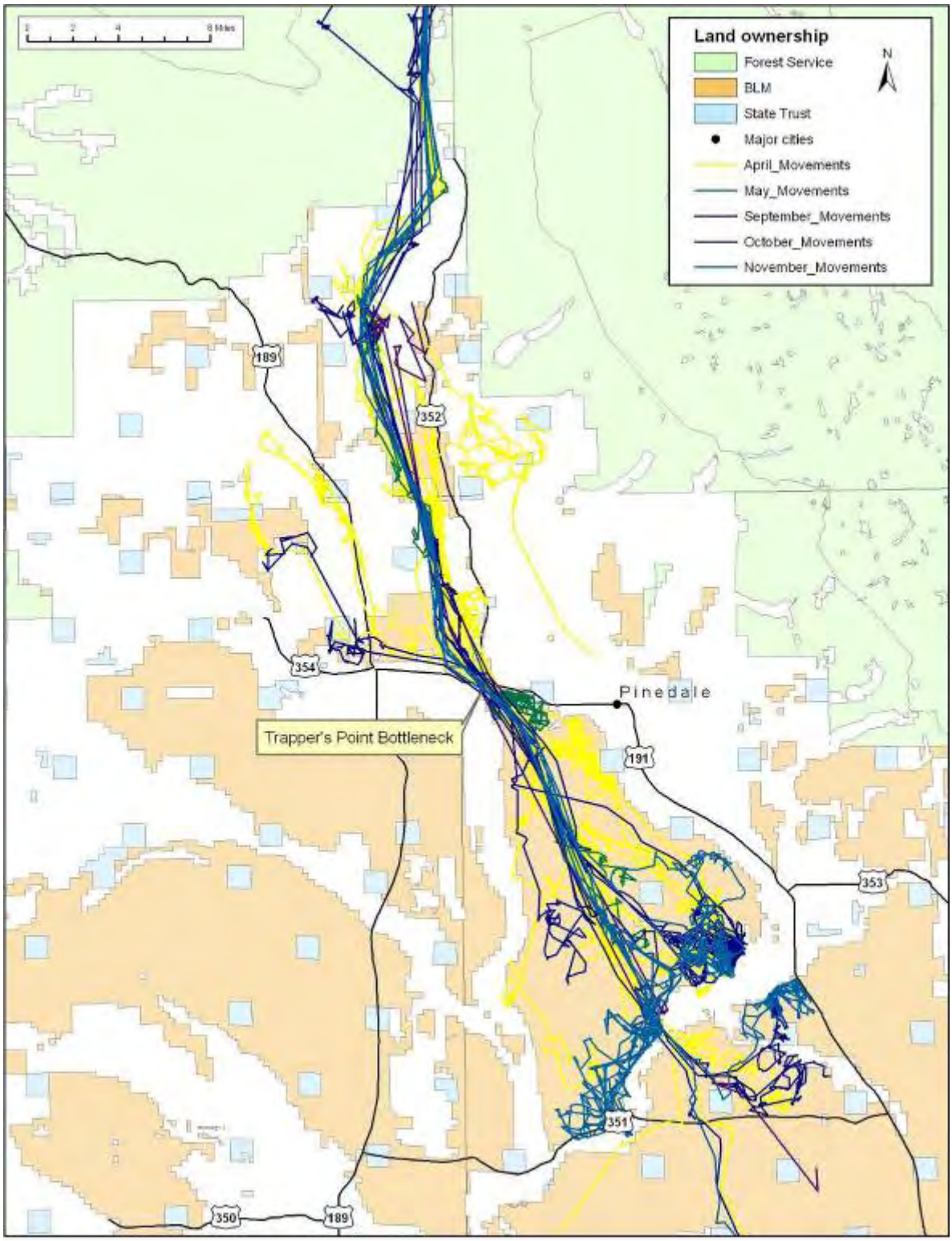


Figure 22. Spring and fall migratory movements of pronghorn through the Trapper's Point Bottleneck.

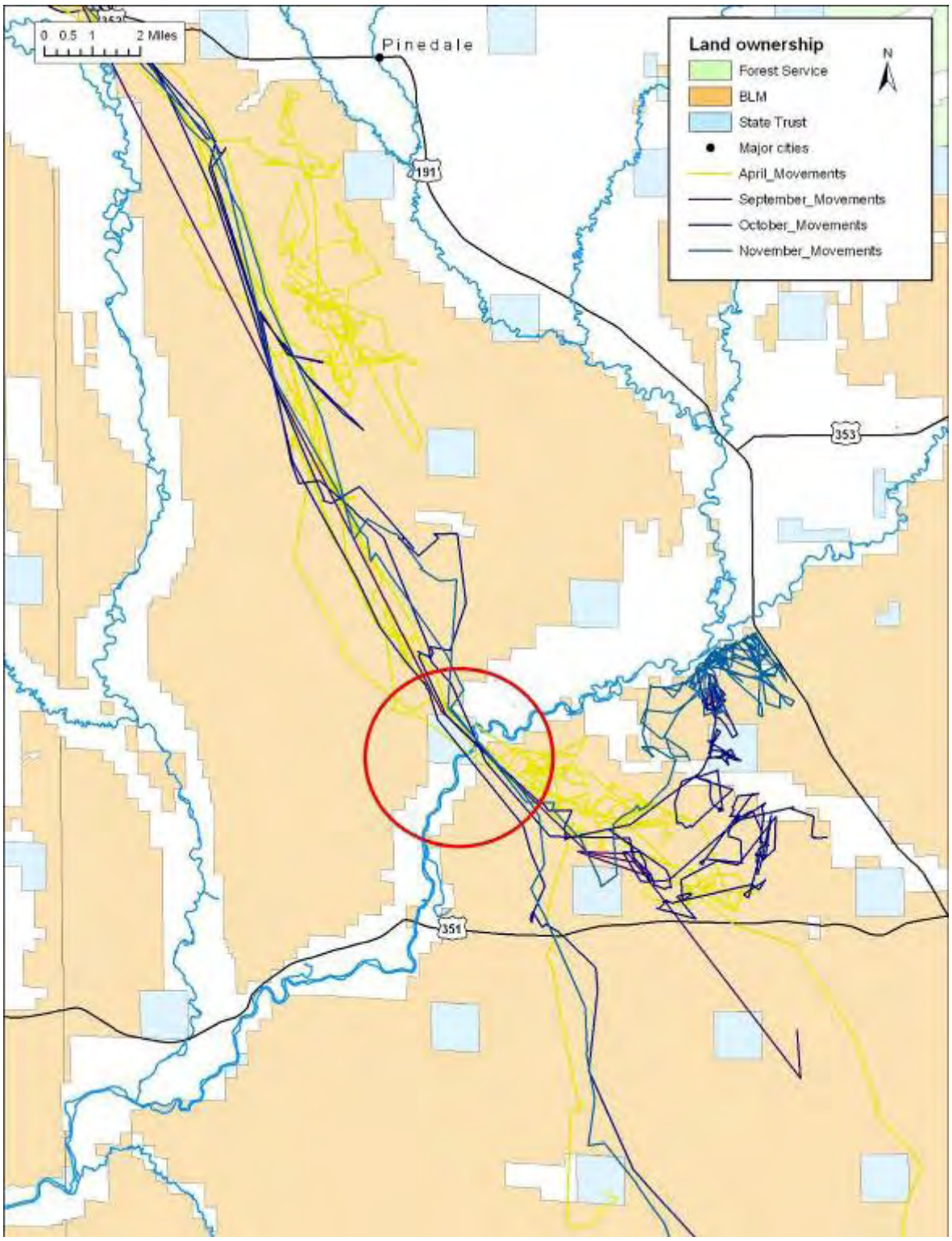


Figure 23. Spring and fall migratory movements of pronghorn in the western portion of the Anticline showing extensive use of a parcel of State Trust land to cross the New Fork River.

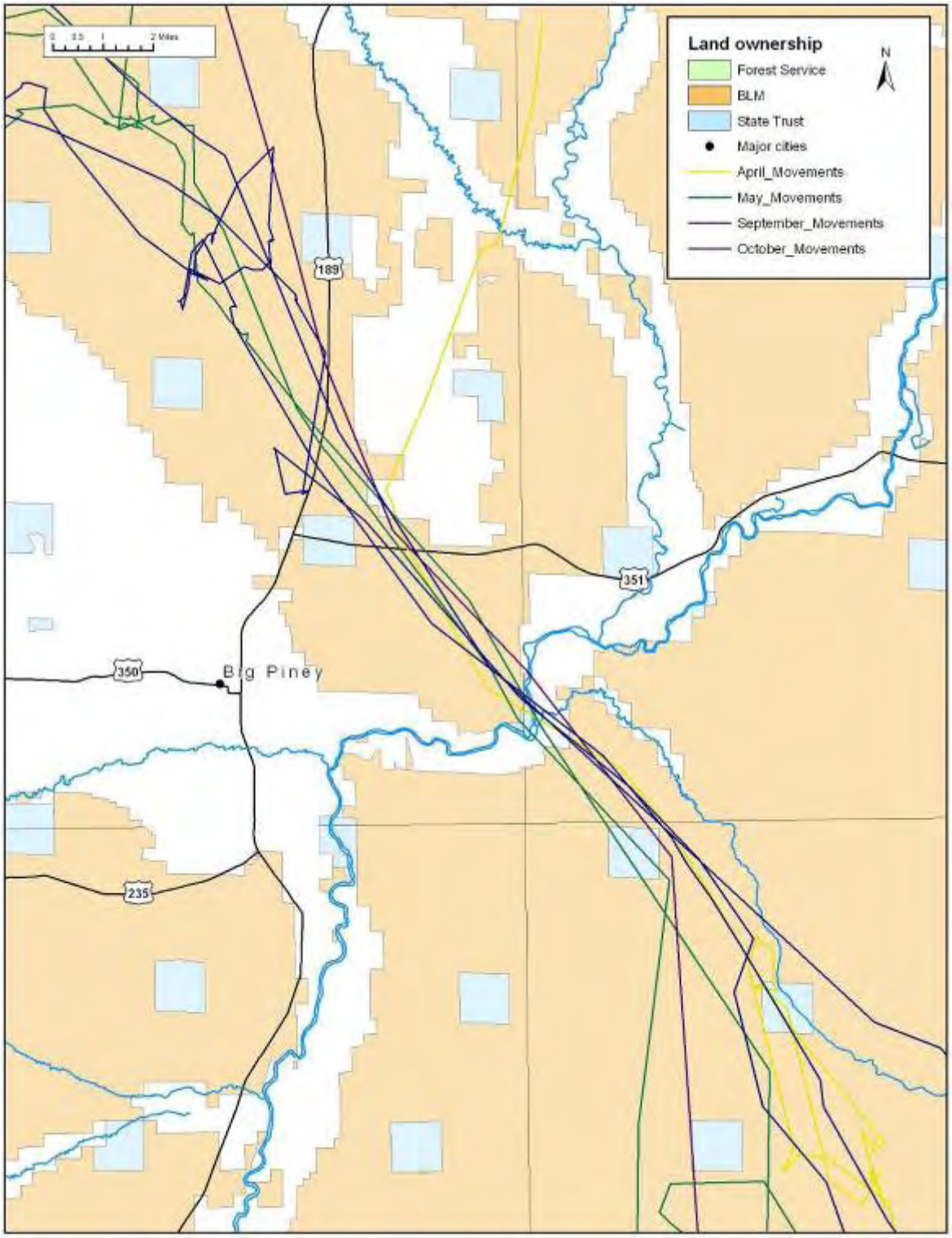


Figure 24. Pronghorn use a narrow swath of public land east of Big Piney to navigate the Green River, Hwy 351, and Hwy 189, on their spring and fall migrations to the Wyoming Front.

Hwy 189 on their migration between summering areas along the Wyoming Front and winter ranges in the southern portion of the UGRB (Fig. 24).

DISCUSSION

Location data collected in conjunction with this study are providing important insights into the seasonal distribution and movements of pronghorn in the UGRB. Most notable from a management perspective is that pronghorn do not utilize all areas within the PAPA uniformly. For instance, pronghorn rely disproportionately on habitat within the core development areas proposed by the BLM (2006) relative to outlying areas (Figs. 18-20), and depend on specific parcels of federal and state land to facilitate major movements between summer and winter ranges (Figs. 16-20, 22-24). Thus, gas field development in some portions of the UGRB may have little impact on pronghorn, whereas development in other areas may hinder pronghorn movements or limit the region's ability to support the population objective set by the WGFD. As noted in the SEIS, surface disturbance resulting from drilling and completion activities may result in the loss of 39.29% of the habitat within the core development areas (page C-31, BLM 2006). Given the extent to which pronghorn rely on habitat within the core development areas during winter, there is the potential for this habitat loss to result in a reduction in pronghorn numbers (Figs. 18-20). Whether or not these potential impacts actually occur will depend on a number of factors including the pace and extent of development versus habitat restoration, on-site habitat mitigation effectiveness, the extent to which restoration efforts are successful, the degree to which animals habituate to or avoid human activity associated with development, winter severity, and the extent to which surface disturbance occurs in high versus low use areas. The latter is discussed in more detail in Chapter 2 in conjunction with the resource selection probability function developed for pronghorn during the winter of 2005-2006.

Evidence collected to date on the impact of energy development on pronghorn distribution is not unequivocal. Some animals exhibit movement patterns that suggest almost complete avoidance of gas field areas of intensive development (Fig. 14) in the Jonah, whereas other animals apparently do not avoid areas with high levels of human

activity (Fig. 15) and may or may not be habituating to those areas. Furthermore, no such patterns of avoidance were noted for animals wintering in the PAPA. This spatial variation may be a consequence of differences in the level of development in the two fields, as well-densities in the Jonah (30,550 acres / 533 wells = 1 well/57 acres) are currently more than twice as high as those in the development areas in the PAPA (43,012 acres / 348 wells = 1 well/124 acres; based on information presented in the PAPA SEIS). Alternatively, factors unrelated to development such as traditional use of wintering areas, individual variation in behavior, or habitat fragmentation may account for the differential responses of animals in the two areas. Future efforts will continue to focus on evaluating the extent to which development is influencing pronghorn distribution and to clarify the importance of factors such as well densities, traffic volume, snow depth, etc.

CHAPTER 2

FACTORS INFLUENCING THE DISTRIBUTION OF PRONGHORN DURING WINTER

INTRODUCTION

Native habitat in the UGRB has been altered as a consequence of energy development as well as secondary impacts such as exurban development. Whether this region can continue to function as winter range for pronghorn, now and in the future, is one of the primary factors motivating this study. To understand pronghorn use of winter range, we examined distribution patterns in relation to ecological and topographical factors and snow depth. We also examined how different ecological, social, and physical factors influence feeding rates of individual pronghorn. Additionally, we used satellite imagery to evaluate changes in the level of gas field development from 2002-2006. Specifically, we estimated the amount of change in two quantifiable parameters: 1) the number of well pads; and 2) fragmentation of the landscape, including the spatial pattern of fragmentation and resulting metrics. We also developed a resource selection probability function (RSPF) model to assess the extent to which different factors influence pronghorn distribution.

METHODS

Changes in Well Pads

Well pads were hand-digitized on-screen as a point dataset. Active well pads were treated the same as pumping stations, transfer stations, etc. Well pads were identified based on four criteria: 1) location in the PAPA or Jonah Field; 2) areas cleared of vegetation; 3) association with a reserve pit with fluids; and 4) a visible road leading to the pad. Because of these caveats, our estimates of the total number of well pads is conservative, as there are more gas pads in operation then what we were able to identify using these criteria.

To convert point locations of gas structures to disturbed areas, the individual points were buffered with a radius of 70 m to create polygons 140 m in diameter. The dimension of 140 m was obtained by measuring a sample of cleared areas in the Jonah Field with hand-held GPS units and laser rangefinders, and represents an approximation of the spatial extent of an average cleared area. By using an area of only 140 m, our estimates of total habitat loss in the PAPA and Jonah Field are conservative, as the mean size of cleared areas is often substantially greater than a 140 m diameter circle. Additionally, due to GIS limitations, we had to use a circle with a 70 m radius (140 m diameter). However, because a circle with a 70 m radius underestimates the total habitat loss of a square pad with dimensions of 140 m x 140 m, in order to calculate the total habitat loss we used the square dimensions of 140 m x 140 m and not a circle with a radius of 70 m in our calculations to more accurately estimate the total loss of habitat. Thus, one pad on average resulted in a loss of 19,000 square m (the results 0f 140 m x 140 m).

Habitat Loss

To standardize the procedure for estimating the amount of area disturbed by well pads, we created a series of three grids with cells of varying sizes. This first grid was 125 m × 125 m, the second was 250 m × 250 m, and the third was 500 m × 500 m. The grids can be envisioned as different sized ‘cookie-cutters’ that punch through the underlying map and all of its associated data layers to cut cells (i.e., cookies) of different sizes (Fig. 25). The amount of habitat lost (*i.e.* disturbance level) due to well pads is then calculated for each cell. The various grid sizes can also be thought of as a magnifying glass or microscope. By changing the grid size we were able to adjust the scale of resolution when looking at disturbance levels. Depending on the metric used to examine disturbance levels and/or the arrangement of well pads and roads on the landscape, the different grid sizes can be either a conservative or liberal estimate of overall disturbance (Figs. 25-26). By selecting differing resolutions we avoided any biases that may result from relying on any one particular scale.

Habitat Fragments

A patch, or habitat fragment, is a given area of habitat undisturbed by either roads or well pads. To evaluate changes in patch size over time, we first combined all grid cells containing well pads and roads into a single 'disturbed area' dataset for each year. These disturbed areas were 'erased' from the available habitat for wildlife within the study area using the 'Erase' tool in ArcToolbox. The remaining available areas were considered patches and were converted into separate, individual polygons with a single dataset for each year and grid cell size. The area of each of these patches was calculated using the XTools extension in ArcInfo 9.2.

Spatial pattern and fragmentation metrics analysis

FRAGSTATS is a spatial pattern analysis program designed to compute a variety of landscape metrics. This program was used to determine landscape and patch level statistics for the habitat patches. In order to use the shapefiles in FRAGSTATS, the patch shapefiles for each year were first converted to 'assigned integer' raster grids using a cell size of 10 m. The 10 m cell size was determined to be small enough to sufficiently reduce variation in area between the shapefile patches and the grid patches, yet still

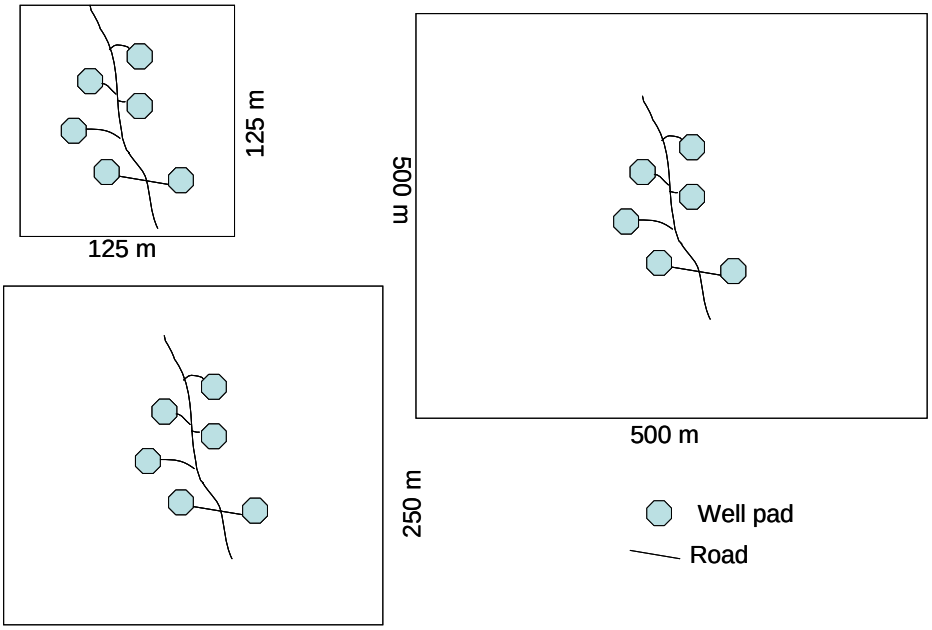


Figure 25. In this series of diagrams the same amount of disturbance by well pads and roads leads to differing results in the estimated percentage of area disturbed based on three different scales of grid size. The 500 m grid is most conservative in the estimate of percent of area disturbed, while the 125 m grid is the most liberal estimate.

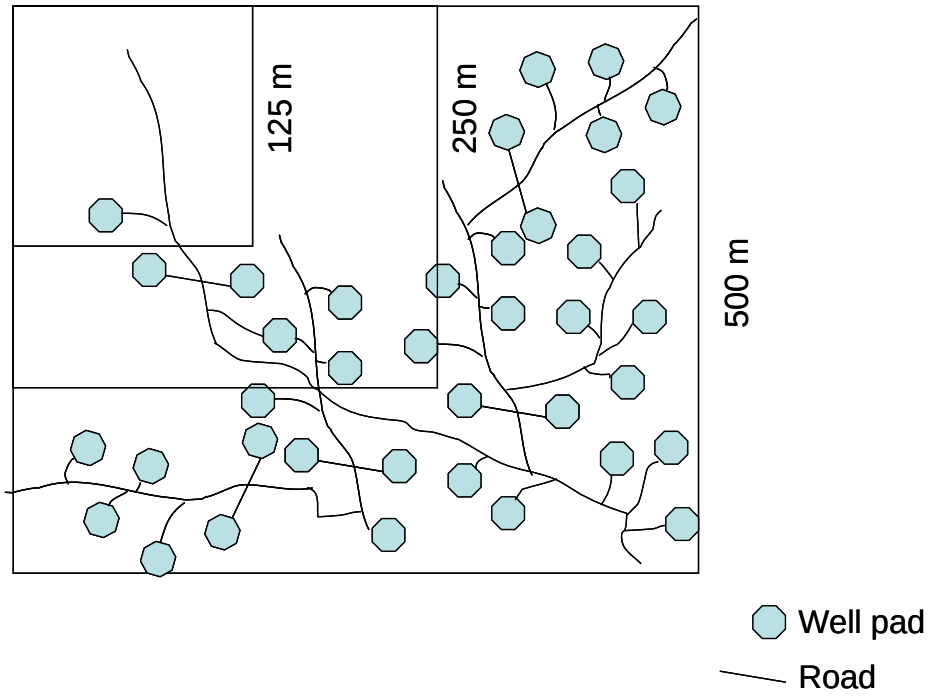


Figure 26. In this diagram the same amount of disturbance by well pads and roads leads to differing results in the estimated percentage of area disturbed based on three different scales of grid size. Unlike the previous figure, here the 500 m grid is now the most liberal in the estimate of percentage area disturbed, while the 125 m grid is the most conservative estimate. This demonstrates the importance of scale and its influence on results and interpretations when examining fragmentation and level of disturbance.

reduced processing time for calculating the metrics. For each patch, the following metrics were calculated: patch area, patch perimeter, perimeter-area ratio, and number of core areas. For the landscape, the following metrics were calculated: total area, number of patches, and number of disjunct core areas.

Core area is one of several spatial pattern metrics along with number of patches, patch area, patch perimeter, and perimeter-area ratio (see Calabrese and Fagan 2004). These metrics are measures of patch isolation, or the inverse, level of connectivity. Core area is the largest, well-defined segment of an irregular-shaped patch calculated using algorithms in FRAGSTATS. Because ecologists, let alone decision makers, have difficulty agreeing on the best definitions of connectivity and fragmentation, we present several metrics of isolation and connectivity.

Comparison between northern and southern gas-field areas

To compare development between the northern and southern portions of the study area, the merged roads and well pads datasets were divided based on the New Fork River boundary. To recalculate the metrics from FRAGSTATS for the separated areas, selected sets of habitat patches were exported from ArcInfo 9.2 using the New Fork River boundary as the division between the areas. Habitat patches that covered the river were selected based on the visual majority proportion (most of these went to the southern patch datasets). The exported shapefiles were saved and were then converted to raster grids for use in FRAGSTATS.

Snow Depth Modeling and Pronghorn Distribution

We sampled snow depths using a 1-meter probe at 81 fixed locations (Fig. 27) on a monthly basis from November to April, when snow was no longer present. All measures were taken at least 10 m from the road in a randomized direction.

During winter we also conducted monthly aerial surveys throughout the entire study region using fixed routes with strips separated by not more than 5 km, at speeds less than 120 km/hr, and at altitudes generally less than 100 meters. The intent of these surveys was not an enumeration of population size but, rather, to evaluate how snow depth affects pronghorn distribution and group size. Flights coincided with snow survey dates each month. We subsequently plotted pronghorn group size and location relative to monthly snow depth. To model the patterns of variation given the uneven distribution of snow across the study area, we used an inverse distance weighted (IDW) technique, which determines cell values using a linear weighted combination of a set of sample points (Philip and Watson 1982, Watson and Philip 1985). We used the IDW tool from Arc Toolbox in ArcInfo 9.2 to interpolate snow depth. The output cell size was set to 30, and resolution grid set to 30 meters.

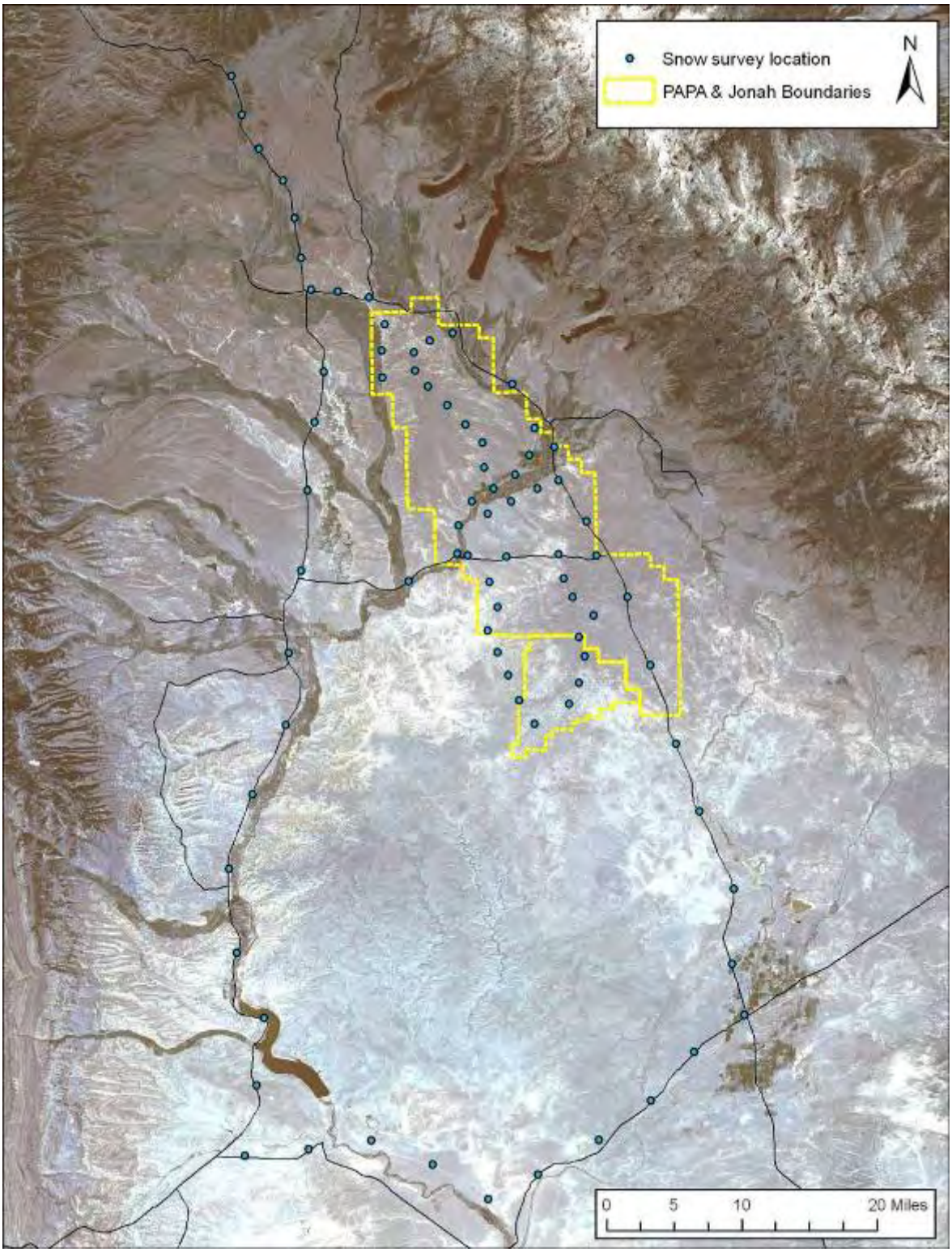


Figure 27. Locations at which snow depth measures were taken.

Habitat Selection of Pronghorn in Gas Fields

Defining the study area

To operationally define winter habitat available to pronghorn, we mapped 28,022 winter (January 1 - March 31) locations from 90 radio-collared pronghorn over a 5-year period [1998-2000 (Sawyer and Lindzey 2000) and 2004-2006]. Using these locations, we created a 100% minimum convex polygon (MCP) representing the actual area of pronghorn use in the vicinity of the PAPA and Jonah Field.

Habitat characteristics

We identified eight habitat characteristics as potentially important factors influencing pronghorn distribution during winter. These were: elevation, slope, aspect, distance to nearest road, distance to nearest well pad, habitat patch size, vegetation, and snow depth. Vegetation was classified as either sagebrush or a reference category that included riparian areas, irrigated crops, mixed grasslands, desert shrub, greasewood, exposed rock/soil, and human habitat (Reiners et al. 1999). We calculated slope and aspect from a 26 m digital elevation model using the Spatial Analyst extension in ArcInfo 9.2 (Environmental Systems Research Institute, Redlands, CA). We assigned grid cells with slopes ≥ 2 degrees to one of four aspect categories: northeast, southeast, southwest, or northwest. Grid cells with slopes < 2 degrees were classified as flat and included in the analysis as a reference category.

To assess factors associated with pronghorn habitat use, we first selected 12,000 random points within the study area defined by the MCP, with replacement, using the Hawth's Tools extension in ArcInfo 9.2. We used 12,000 points because this number provided good coverage of the entire study site. We measured the elevation, slope, aspect, habitat patch size, vegetation, road distance, well distance, and monthly snow depth attributes associated with each random point using Hawth's Tools and Spatial Analyst in ArcInfo 9.2.

To assess pronghorn use of habitats with differing characteristics, we created 12,000 sample plots by placing a circular buffer with a 100 m radius around each random point.

We counted the number of pronghorn locations during winter (January – March) within each of these sample plots using Hawth's Tools in ArcInfo 9.2. The analysis was performed on a monthly basis to incorporate different snow-depth measures for each month. This procedure resulted in a continuous response variable for each radio-collared animal that indicated relative use of the sample plots.

Model development

We developed a model of habitat use for each individual pronghorn using Poisson regression. We used a Poisson distribution rather than a negative binomial distribution because we saw no evidence of overdispersion in our data (Burnham and Anderson 2002). The data were analyzed by fitting a generalized linear model with a log link function in SAS using PROC GENMOD (SAS Institute Inc. 1999). This produced a log linear model of the form

$$\ln[E(r_{ij})] = \ln(total) + \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p,$$

where $E(r_{ij})$ is expected probability of use for habitat unit i by pronghorn j, r_{ij} is the number of recorded locations for pronghorn j within habitat unit i, *total* is the total number of locations for pronghorn j across the 12,000 sample plots, $x_1,\ldots, x_p$ are the predictor variables, and $\beta_1,\ldots, \beta_p$ are the estimated coefficients for the predictor variables. The offset term, ln(*total*), is a quantitative variable whose regression coefficient is set to 1. It is included in the model to adjust the dependent variable from actual use (e.g., number of locations in sample plot i) to relative use (e.g., number of locations in sample plot i / total locations in the 12,000 sample plots), and to account for differences in the total number of locations between marked animals (Ramsey and Schafer 1997, Millspaugh et al. 2006).

We developed models for individual pronghorn for the winter of 2005-2006 using a forward-stepwise process that involved fitting the same models to each pronghorn (Sawyer et al. 2006). We used a t-statistic to determine variable entry ($\alpha \leq 0.15$) and exit ($\alpha > 0.20$; Zar 1996).

We estimated coefficients for the population-level model from the coefficients for the individual radio-collared animals using

$$\hat{\bar{\beta}}_i = \frac{1}{n}\sum_{j=1}^{n}\hat{\beta}_{ij}$$

where is the estimate of coefficient *i* for pronghorn *j*, and is the mean coefficient averaged over all radio-collared animals (Millspaugh et al. 2006). We estimated the variance of the population-level model coefficients following Millspaugh et al. (2006)

$\hat{\beta}_{ij}$ $$Var\left(\hat{\bar{\beta}}_i\right) = \frac{1}{n-1}\sum_{j=1}^{n}\left(\hat{\beta}_{ij} - \hat{\bar{\beta}}_i\right)^2.$$ $\hat{\bar{\beta}}_i$

Based on the population-level model, we mapped the predicted probability of use across the PAPA and Jonah Field using a 104 × 104 m grid that covered the study area. Attributes associated with each grid cell were identified with the Spatial Analyst extension in ArcInfo 9.2. Predicted probability of use was estimated for each grid cell by applying the coefficients from the final population-level model using the raster calculator tool in Spatial Analyst. Grid cells were assigned to one of four relative use categories (high, medium, low, and rare) based on quartiles of the distribution of predicted values.

Assessment of Behavior

To investigate whether pronghorn were sensitive to potential human activities and infrastructure, we examined whether foraging rates differed among areas that varied in the intensity of gas field disturbance. We measured feeding rate, defined as the proportion of time an animal spent foraging (chewing, biting, or walking with head oriented in a food acquisition mode) per 180 second bout. The important point here is an animal's perception of its environment; the primary significant behaviors that detract from feeding are vigilance and flight, both bearing energetic costs since they sacrifice joules (Lima 1998, Berger 1999).

The rate of feeding, in and of itself, is not a very useful measure to assess the potential for disturbance because it is sensitive to the mitigating role of other factors. For example, habitat structure, group size, and topography all affect an animal's ability to find

food and escape predators (Caro 2005). Hence, we also measured the following variables: 1) distance of pronghorn groups to observers (measured in m), 2) distance to graded roads, 3) distance to paved roads, 4) distance to nearest fence, 5) vehicles/hr on graded roads (actual counts during collection of feeding data), 6) vehicles/hr on paved roads (actual counts during data collection of feeding data), 7) snow depth (cm), 8) vegetation height (expressed as height relative to the proportion of a standardized pronghorn leg), 9) position within a group (defined categorically as central or peripheral), 10) topography (defined categorically as flat or rolling hills), 11) distance to nearest gas well, and 12) group size (divided categorically as 1-10, 11-20, 21-50, 51+). Where the distribution of data did not meet the assumption of normality, the data were transformed and residuals examined (Table 1; Zar 1996).

RESULTS

Changes in Well Pads

In 2006, there were 122% of the well pads north of the New Fork River and 108% of the well pads south of the river that were present in 2002. The rate of increase for new

Table 1. Covariates and transformations used in analysis of foraging rates.

Covariate	Transformation	*F*[a]	*P*
Feeding Rate	arcsin transformation		
Distance to observers (m)	no transformation	0.573	0.450
Distance to graded roads (m)	log transformation	0.000	0.990
Distance to paved roads (m)	log transformation	3.497	0.064
Distance to nearest energy structure (m)	log transformation	2.522	0.115
Distance to nearest fence (m)	log transformation	14.169	0.000
Vehicles/hr on pavement	sq rt transformation	3.967	0.048
Vehicles/hr on graded roads	sq rt transformation	4.160	0.043
Snow depth (cm)	no transformation	1.423	0.235
Vegetation category	I to IV, increasing height	0.161	0.689
Position	in group central or peripheral	1.877	0.173
Topography	flat or rolling	3.692	0.057
Group size	1-10, 11-20, 21-50, 51+	4.310	0.040

[a] The *F* and *P* values reflect results discussed on page 61.

pads has been faster in the northern region (Fig. 28). There are currently 753 total pads south of the river, and 213 in the northern area (Fig. 28). A conservative estimate of the total habitat loss due to well pads is 18.934 km^2.

Fragmentation of the Landscape

The increasing level of fragmentation on the landscape can be seen in several metrics. First, mean fragment size (ha) has been decreasing across both the northern and southern portions of the gas fields as a result of increasing development from 2003-2006 (Tables 2-4). As fragment size decreases, the perimeter-to-area ratio increases and this shift is particularly evident at the finest resolution (125 m^2) of grid size (Tables 2-4).

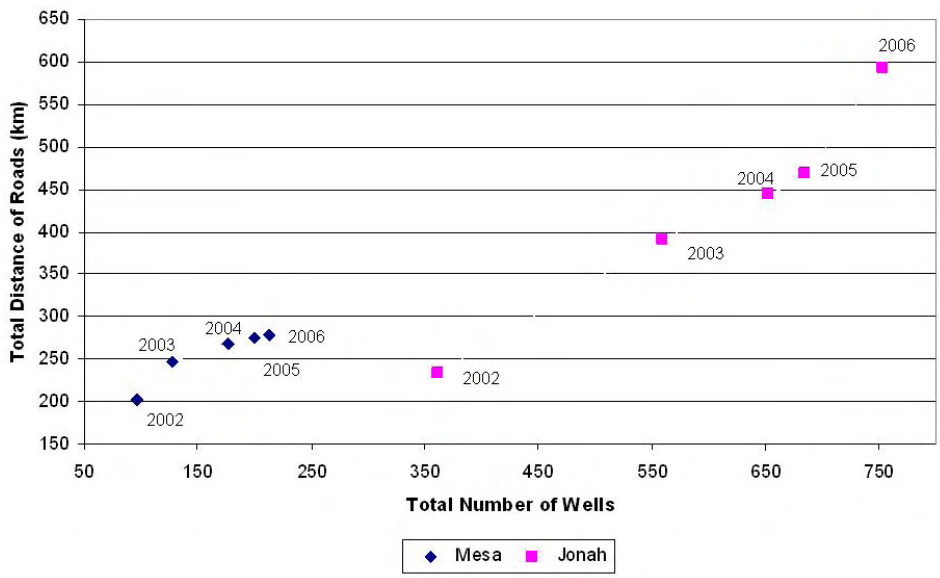


Figure 28. Relationships between number of well pads and road distances over time in the areas north and south of the New Fork River.

Consequences of this change in the amount of edge habitat on the landscape are unknown at this time for pronghorn. Similarly, the increasing level of fragmentation can be seen in the increase in the number of disjunct core areas (Tables 2-4).

Influence of snow depth on pronghorn distribution

Snow is deeper at the north end of the study region and lightest at the south (Figs. 29-30). 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 2006 when snow was virtually absent from the study region; Figs. 29-30).

Habitat Selection of Pronghorn in Gas Fields

We used 9,770 locations to construct individual RSPF models for 13 radio-collared pronghorn during the winter of 2005-2006. Ten of the thirteen pronghorn had negative coefficients for snow depth and positive coefficients for vegetation, indicating selection for sagebrush-dominated areas with less snow accumulation. Ten animals had positive coefficients for road distance and negative coefficients for well distance indicating greater use of areas near well pads that are located further from roads. Eleven of thirteen animals selected for lower elevation areas and southeast facing slopes, and twelve animals selected for southwest facing slopes, relative to flat areas. Most animals (n = 10) showed avoidance of slopes with a northwest aspect.

The population-level model contained variables for snow depth, aspect (NE, NW, SE, and SW), elevation, distance to road, and distance to well pad (Table 5). Thus of the eight predictor variables tested, only slope and habitat patch size were not retained in the final model. The latter was likely influenced by methodological limitations of the technique used to estimate habitat patch size that resulted in many pronghorn locations being assigned to fragments of size zero (See page 62 for further discussion). Habitat patches with the highest probability of use were located primarily in areas adjacent to the New Fork River, which is highly concordant with habitat classified as crucial winter range by WGFD (Figs. 31-32). Patches with the highest predicted probability of use had an average elevation of 2,140 ± 26 m (mean ± standard deviation) and snow depth of 12 ± 2 cm between late December and the end of March (Table 6). In contrast, habitat patches with the lowest probability of use had an average elevation of 2,233 ± 58 m and snow depth of 19 ± 4 cm. On average, habitat patches with the highest probability of use were

Table 2. Summary of spatial pattern and fragmentation metrics analysis for the entire study area using a series of multi-scale polygon grids used to standardize the overlay procedures for cleared areas across the entire study area. Figures were calculated using FRAGSTATS analytical software in ArcGIS 9.2.

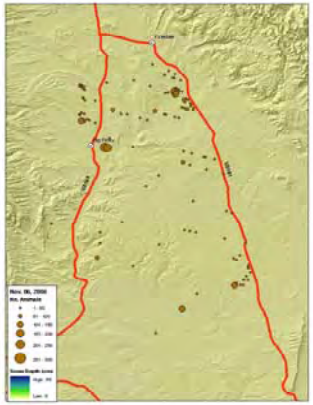
Year	Number of well pads	Number of fragments	Mean ± SE fragment size (hectares)	Mean ± SD fragment perimeter/ area ratio	Number of disjunct core areas	% of area disturbed
125 m^2 grid						
2003	687	237	395 ± 123	183 ± 97	320	12.1
2004	828	272	339 ± 105	186 ± 95	364	13.4
2005	884	286	320 ± 99	188 ± 95	386	13.9
2006	963	297	306 ± 95	192 ± 96	391	14.6
250 m^2 grid						
2003	687	125	675 ± 215	122 ± 134	164	20.8
2004	828	137	602 ± 192	122 ± 128	174	22.7
2005	884	137	600 ± 191	122 ± 128	174	23.5
2006	963	143	564 ± 181	123 ± 125	182	24.4
500 m^2 grid						
2003	687	46	1572 ± 495	45 ± 33	58	32.2
2004	828	53	1317 ± 422	51 ± 34	66	34.6
2005	884	51	1347 ± 433	50 ± 33	66	35.6
2006	963	49	1378 ± 443	50 ± 33	68	36.7

Table 3. Summary of spatial pattern and fragmentation metrics analysis for the area north of the New Fork River using a series of multi-scale polygon grids used to standardize the overlay procedures for cleared areas across the entire study area. % of area disturbed is the average across all areas. Figures were calculated using FRAGSTATS analytical software in ArcGIS 9.2.

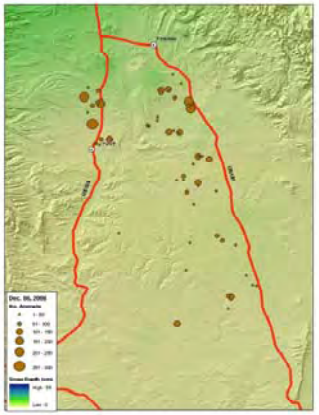
Year	Number of well pads	Number of fragments	Mean ± SE fragment size (hectares)	Mean ± SD fragment perimeter/area ratio	Number of disjunct core areas	% of area disturbed
125 m^2 grid						
2003	127	50	598 ± 265	132 ± 108	63	12.1
2004	176	58	507 ± 219	139 ± 108	74	13.4
2005	199	61	481 ± 208	143 ± 108	77	13.9
2006	210	61	479 ± 207	143 ± 108	77	14.6
250 m^2 grid						
2003	127	47	568 ± 253	93 ± 66	64	20.8
2004	176	52	502 ± 219	98 ± 64	68	22.7
2005	199	52	499 ± 218	98 ± 64	66	23.5
2006	210	53	487 ± 214	100 ± 64	67	24.4
500 m^2 grid						
2003	127	26	842 ± 373	50 ± 36	33	32.2
2004	176	29	726 ± 319	56 ± 35	37	34.6
2005	199	29	718 ± 315	56 ± 35	37	35.6
2006	210	28	738 ± 325	55 ± 35	37	36.7

Table 4. Summary of spatial pattern and fragmentation metrics analysis for the area south of the New Fork River using a series of multi-scale polygon grids used to standardize the overlay procedures for cleared areas across the entire study area. % of area disturbed is the average across all areas. All reported figures were calculated using FRAGSTATS analytical software in ArcGIS 9.2.

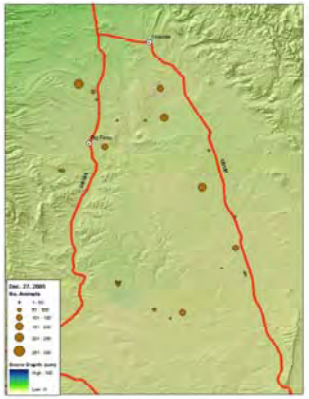
Year	Number of well pads	Number of fragments	Mean ± SE fragment size (hectares)	Mean ± SD fragment perimeter/ area ratio	Number of disjunct core areas	% of area disturbed
125 m^2 grid						
2003	560	187	341 ± 138	198 ± 89	257	12.1
2004	652	214	294 ± 119	200 ± 88	290	13.4
2005	685	225	278 ± 112	201 ± 88	309	13.9
2006	753	236	262 ± 107	206 ± 89	314	14.6
250 m^2 grid						
2003	560	78	740 ± 309	139 ± 158	100	20.8
2004	652	85	663 ± 278	137 ± 152	106	22.7
2005	685	84	663 ± 279	137 ± 153	106	23.5
2006	753	90	609 ± 258	137 ± 148	115	24.4
500 m^2 grid						
2003	560	20	2521 ± 991	38 ± 28	25	32.2
2004	652	24	2032 ± 825	46 ± 31	29	34.6
2005	685	22	2177 ± 883	44 ± 30	29	35.6
2006	753	21	2230 ± 906	43 ± 29	31	36.7



Early November

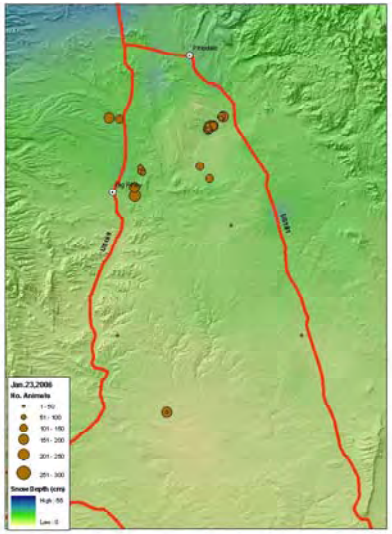


Early December

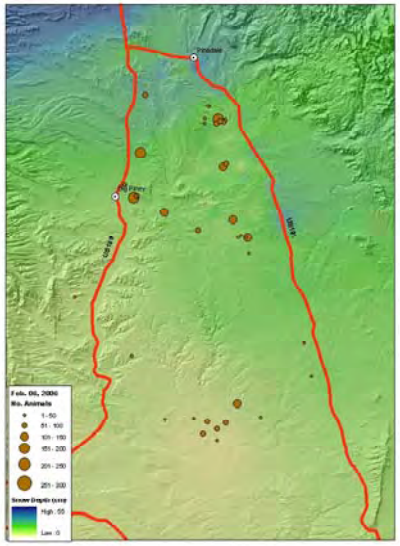


Late December

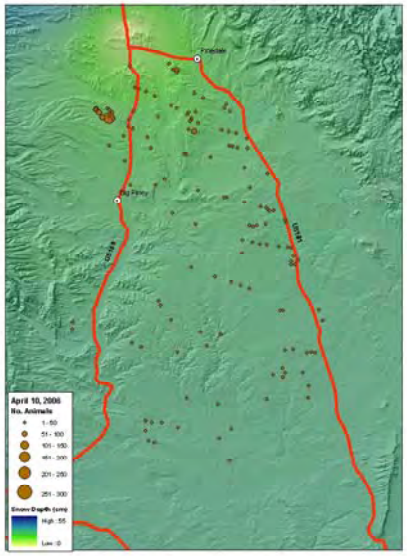
Figure 29. Distribution of pronghorn by month, snow depth, and group size during fall and early winter.



Late January



Mid-February



Early April

Figure 30. Distribution of pronghorn by month, snow depth, and group size during winter and early spring.

located 662 ± 711 m from the nearest road and 1,426 ± 1187 m from the nearest well pad (Table 6). Of the 85,389 104 × 104 m habitat patches available to pronghorn within the boundaries of the PAPA and Jonah, 52% were classified as having either high (20%) or medium (32%) probability of use during the winter of 2005-2006 (Table 6). Based on the RSPF model and the current distribution of roads and wells, much of the gas field development in the PAPA has occurred in habitat classified as rare or low use during winter (Fig. 33). Conversely, nearly all habitat in the Jonah Field, where development has been extensive, is classified a high or medium use (Fig. 33).

The RSPF model indicates that much of the habitat in BLM proposed core development areas (BLM 2006) 1, 5, and the southern half of 4 is rarely or infrequently used by pronghorn during winter (Fig. 34). In contrast, virtually all of development area (DA) 3 is classified as high use, and most of the habitat in DA 2 (exclusive of the riparian corridor) and the northern half of DA 4 is either high or medium use (Fig. 34). The RSPF further revealed that the east side of the Mesa was not used due to greater snow depth.

Assessment of Behavior

Despite our sample of radio-collared animals, most females remain indistinguishable. Therefore, to avoid the possibility of pseudo-replication by unwittingly sampling the same animals more than once, we recorded feeding rates in groups situated

Table 5. Parameter estimates for population-level resource selection probability function for pronghorn during the winter of 2005-2006.

Parameter	β	SE	*P*
Intercept	20.4672	10.6201	0.076
Slope	ns[a]		
Aspect (NE)	ns		
Aspect (NW)	-0.9241	0.3094	0.011
Aspect (SE)	0.6095	0.1812	0.005
Aspect (SW)	0.8001	0.1680	<0.001
Elevation	-0.0147	0.0049	0.010
Well distance	-0.0009	0.0002	0.001
Road distance	0.0003	0.0001	0.037
Snow depth	-0.0519	0.0251	0.059
Vegetation	1.7867	0.5371	0.006
Patch size	ns		

[a] Not significant.

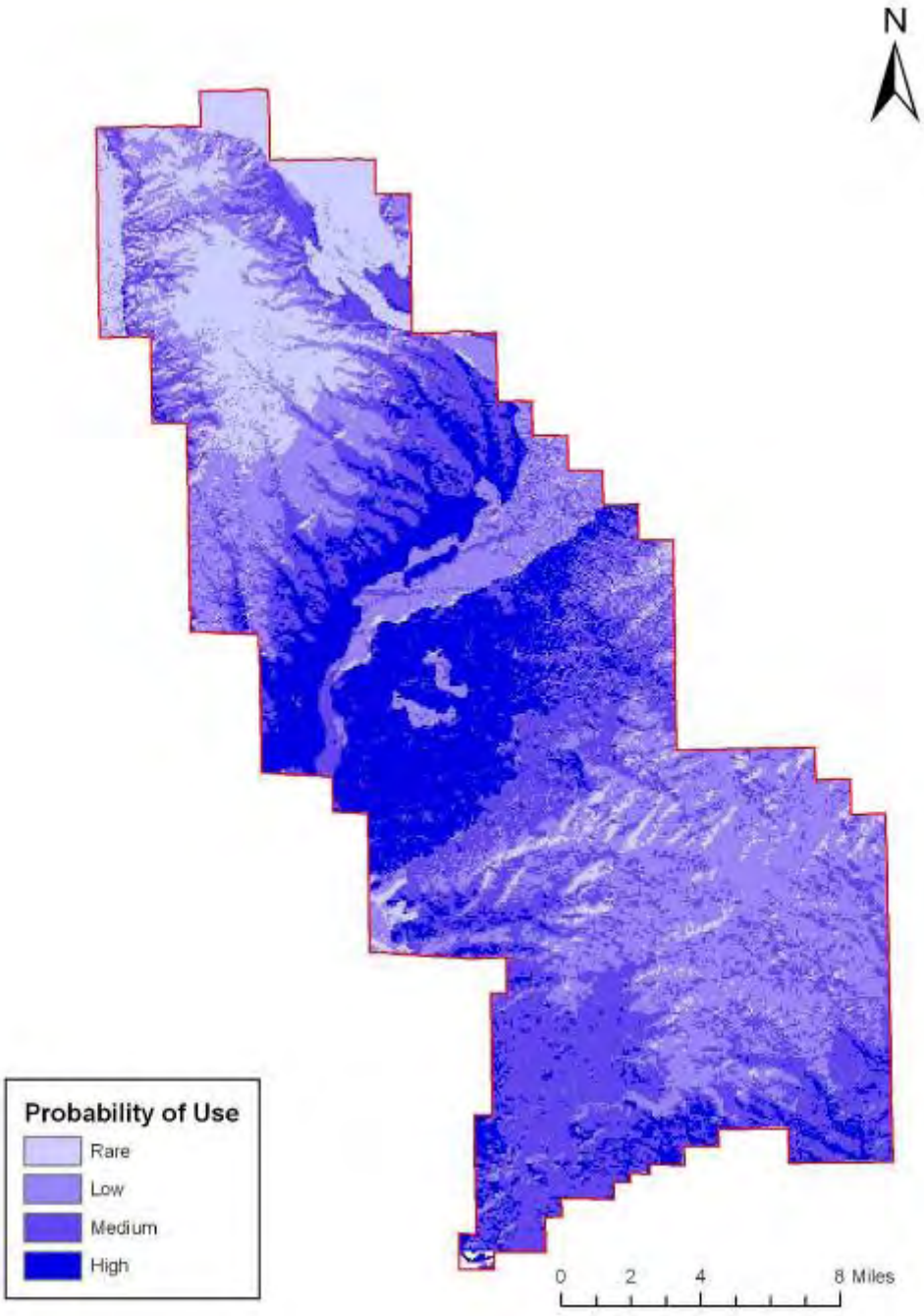


Figure 31. Predicted probabilities and associated categories of pronghorn use during the winter of 2005-2006.

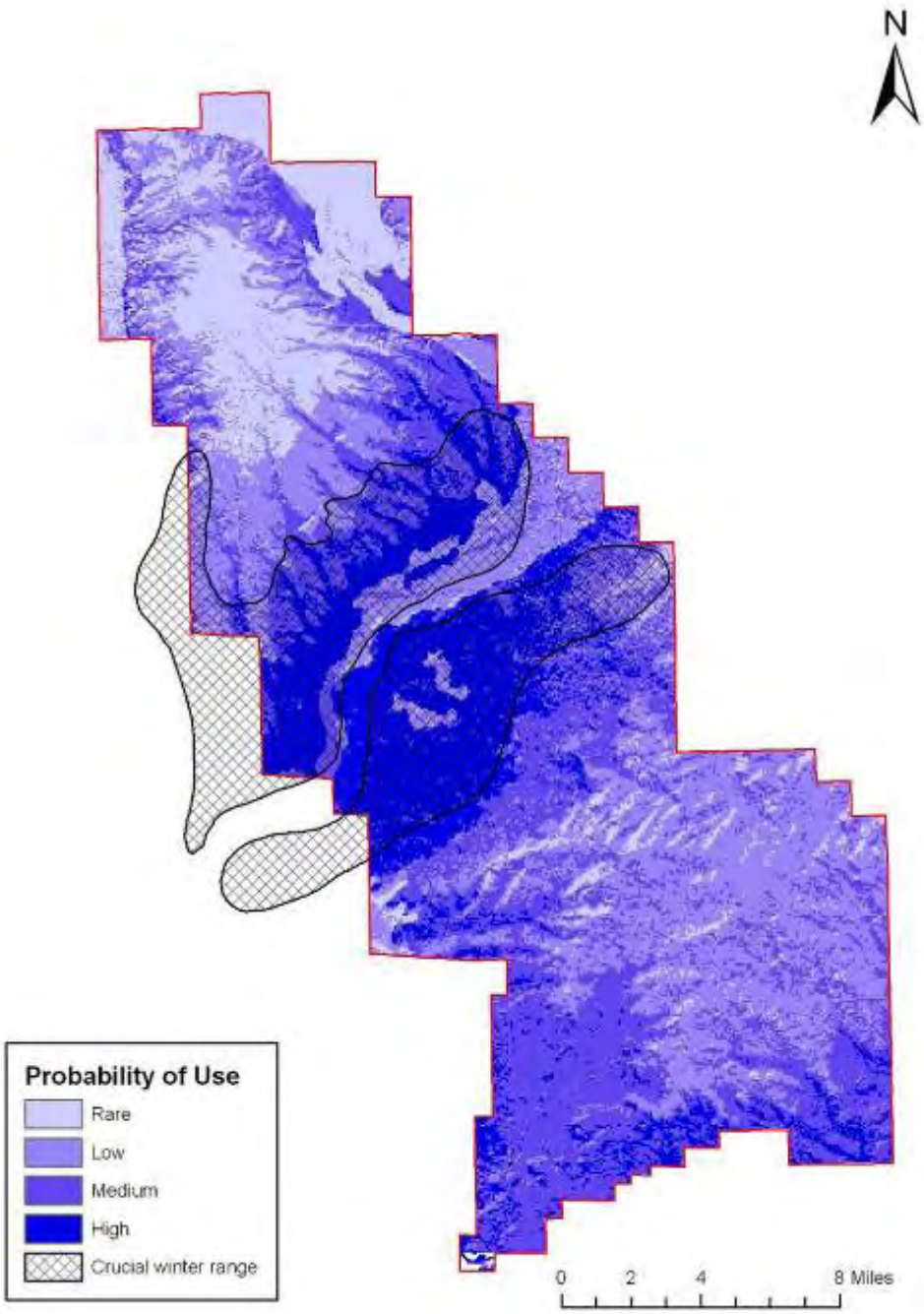


Figure 32. Location of crucial winter ranges in relation to predicted probabilities and associated categories of pronghorn use during the winter of 2005-2006.

Table 6. Average metrics associated with habitat patches based on relative probability of use by pronghorn during the winter of 2005-2006.

Use category	Patches %	Elevation	Snow depth	Road distance	Well distance
Rare	14	2,233	19	873	1,889
Low	34	2,210	15	991	1,875
Medium	32	2,184	14	848	1,523
High	20	2,140	12	662	1,426

beyond the daily distances in which individuals generally move during winter. Individuals were the sampled unit.

Foraging rates are displayed (Fig. 35) as the mean non-transformed percentage/bout by group size and area. For analyses, however, data were transformed as noted above (see Methods and Table 1).

Individuals in small groups were less likely to feed uninterrupted in contrast to conspecifics in larger groups, and a significant relationship between foraging and group size existed regardless of geographical location (Fig. 35). The corrected model based on data transformation accounted for 43.1% of the variation ($F_{12, 147} = 8.525$, $P < 0.0001$). With the effects of covariates removed (Table 1), factors – in order of increasing statistical influences that affected foraging were 1) distance to nearest fence ($P < 0.0001$), 2) group size ($P = 0.040$), 3) vehicle traffic on graded roads ($P = 0.043$), and 4) vehicle traffic on paved roads ($P = 0.048$). Topographical features had a slight influence ($P = 0.057$), and the inverse association between foraging rate and distance to the nearest energy structure was weak ($P = 0.115$). Neither snow depth nor vegetation height had detectable influences on foraging rates, as they do in other ungulates (Caro 2005). The dampened response for pronghorn is more likely a reflection of animal distribution in low snowfall regions and areas of black sage and other low vegetation during data collection.

These results are interesting because they suggest that both fences, many of which pre-date development, and increasing vehicular traffic affect pronghorn foraging with effects being strongest on the smallest groups. For instance, 80% of the groups that fled ambient disturbance contained fewer than 16 animals. These small groups were disproportionately sensitive, fleeing more than three times as often as larger groups ($G_{adj} = 14.06$, $P < 0.001$). In other words, small groups bear more of the costs of reduced

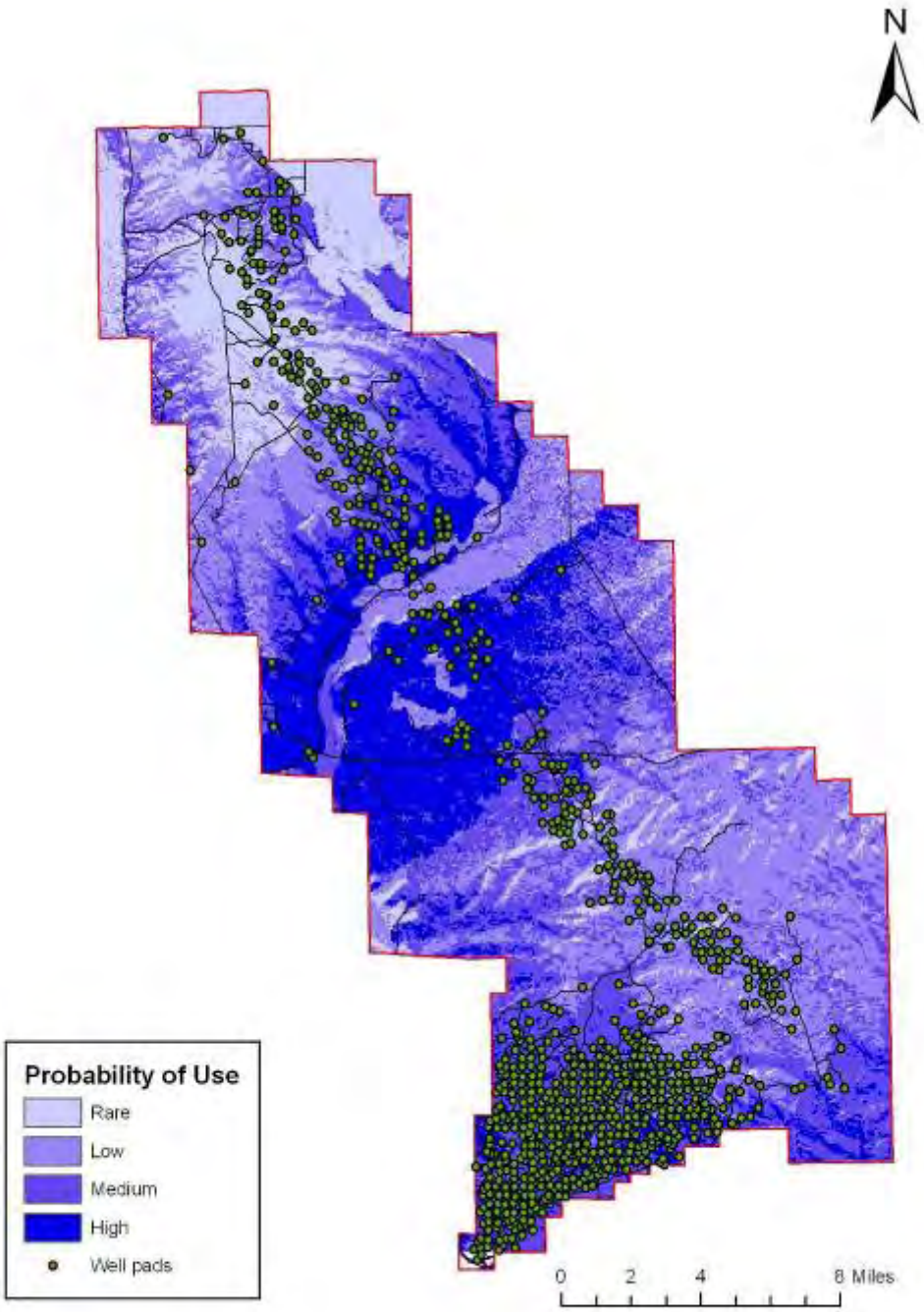


Figure 33. Locations of well pads and roads in relation to predicted probabilities and associated categories of pronghorn use during the winter of 2005-2006.

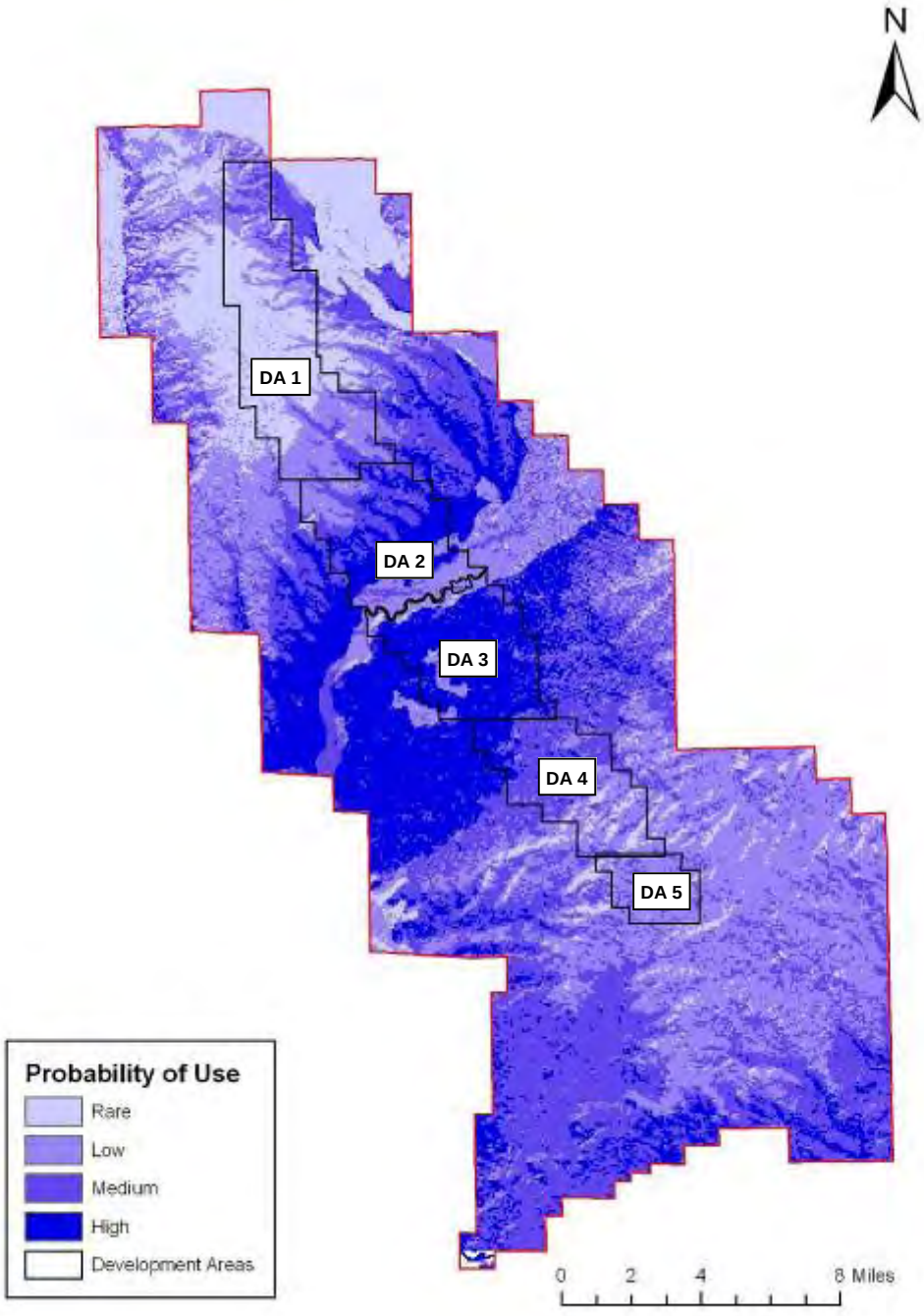


Figure 34. Location of BLM proposed core Development Areas in relation to predicted probabilities and associated categories of pronghorn use during the winter of 2005-2006.

foraging and increased flight. With increasing fencing and traffic, avoidance of these disturbances will become less possible for small groups unless they merge into larger ones, leave crucial winter range, or habituate to a greater extent than at present.

DISCUSSION

The increasing industrial footprint, as evidenced by the number of roads and gas pads across both the PAPA and Jonah regions, is resulting in an unavoidable decline in overall winter habitat available to pronghorn. While the loss has been incremental, less than 5% of anticipated wells during the life of the gas fields have been drilled at this juncture and considerable additional change is anticipated. To date, the ecological responses of pronghorn at both coarse and fine scales have not been large. Snow exerts strong effects on distribution and habitat selection (Figs. 29-30; Table 6).

As gas field development continues the level of fragmentation increases. Our

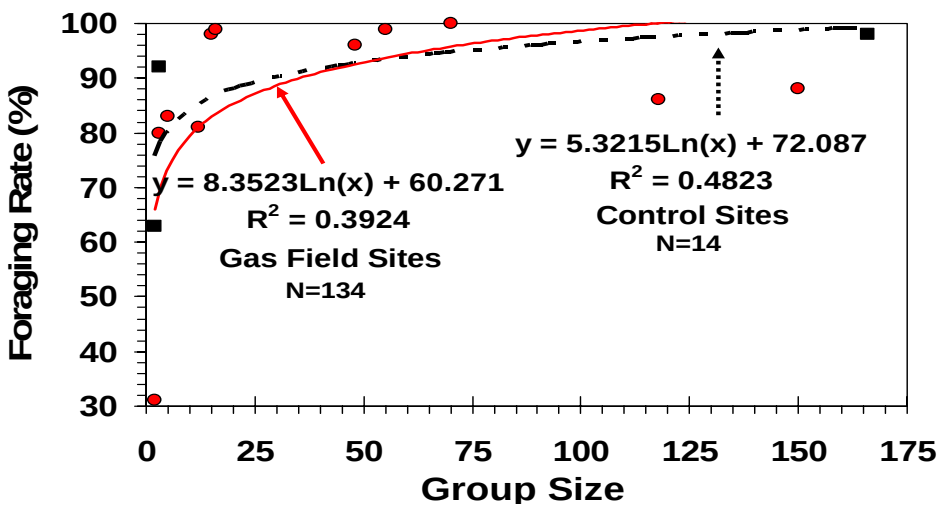


Figure 35. Relationship between foraging rate and group size, with the former expressed in transformed values.

analyses indicate the inevitable decline in overall mean patch (*i.e.* fragment) size of available habitat. During the early phases of gas field development, most fragmentation was the result of new roads, but during the past few years, the rate of increase has diminished due to the use of roads already in existence. During the current phase of

development, the addition of new well pads continues to drive the increasing level of fragmentation. Although new roads exacerbate levels of fragmentation per se, the volume and timing of traffic across the road network has both subtle and direct effects. For instance, traffic influences foraging rates, and patterns of habitat selection suggest that habitat use increases with increasing distance to the nearest road.

Our preliminary analyses of fragmentation, however, have several inherent limitations that will be addressed as the study progresses. First, the algorithm we used classifies any grid cell that contacts any portion of a road and/or well pad as unsuitable habitat, even if that grid cell contains only a very small part of a road or well pad. Hence, the cell is categorized as unsuitable when in reality it may function as intact habitat. As a consequence, the true impact of fragment size and habitat loss is masked (Fig. 36).

Second, when calculating the mean fragment size across the study area (Tables 2-4), small fragments that likely function independently are incorrectly classified as small peripheral spurs of larger fragments (Fig. 37). The result is that small fragments are under-represented in the sample for calculating mean fragment size. As such, the overall mean fragment size at the 125 m, 250 m, and 500 m grid sizes are over-inflated. As the grid size increases (*i.e.* resolution decreases) from 125 m to 500 m, more and more small fragments are attached as "spurs" to larger fragments; thus the error rate in estimating the true mean fragment size increases. Because of this, the resource selection probability function is based on the finest resolution (i.e. 125 m grid size). These two GIS limitations will be addressed and corrected in subsequent years, thus the relative impact of fragment size on pronghorn use of the landscape may become more important in future years' models.

Our current assessments of behavior, on the other hand, offer insights about proximate responses of pronghorn to immediate conditions. Our findings that individuals in large groups forage at higher rates than those in smaller groups follows patterns typical of most other ungulates (Caro 2005). What is of particular interest, however, is that distance to nearest fence and vehicular traffic affected foraging rates, with the effects of group size, distance to roads, and other covariates removed. This suggests that pronghorn must perceive their safety to be compromised when close to fences, but not to roads per

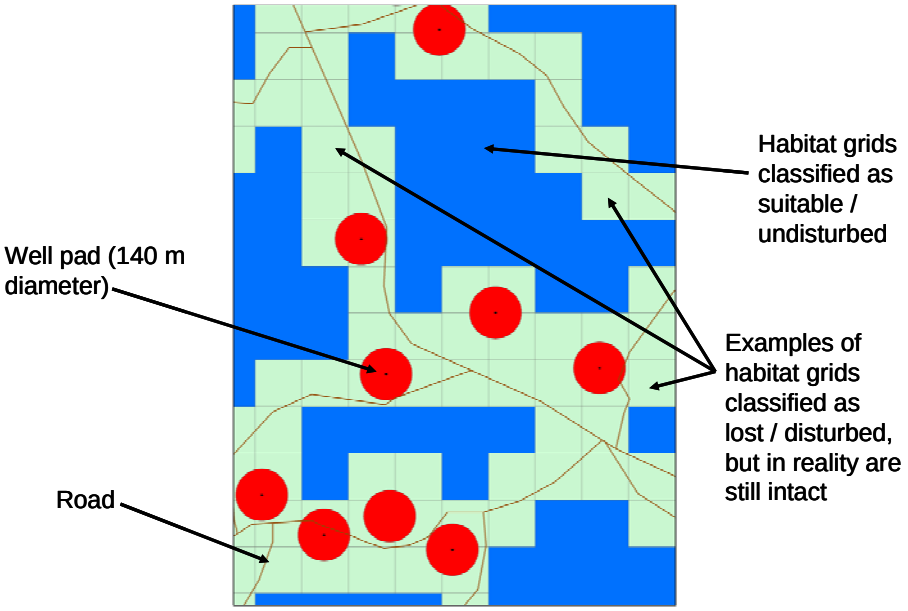


Figure 36. The overestimation of total area disturbed by well pads and roads leads to pronghorn locations occurring in habitat grids classified as unsuitable or lost, that in reality are still intact habitat. Pronghorn use of incorrectly classified grids [a result of limitations in current patch analyses methodology (see text for details)] masks the true impact of fragment size and habitat loss on pronghorn distribution and use of the study area.

se. Additionally, given that traffic affected foraging rates independent of group size and distance to roads, pronghorn may be showing increasing sensitivity to growing levels of traffic. That fences, independent of pronghorn distance to roads, had a greater effect on foraging rates suggests animals perceive security differently when close to fences. Additionally, based on about 2300 data points on foraging rates gathered in 2002 and 2003 (WCS unpubl.) there was a lack of relationship between traffic and foraging rate, perhaps because levels were lower then. The biological relevance, if any, of the present reductions in foraging are as yet unclear.

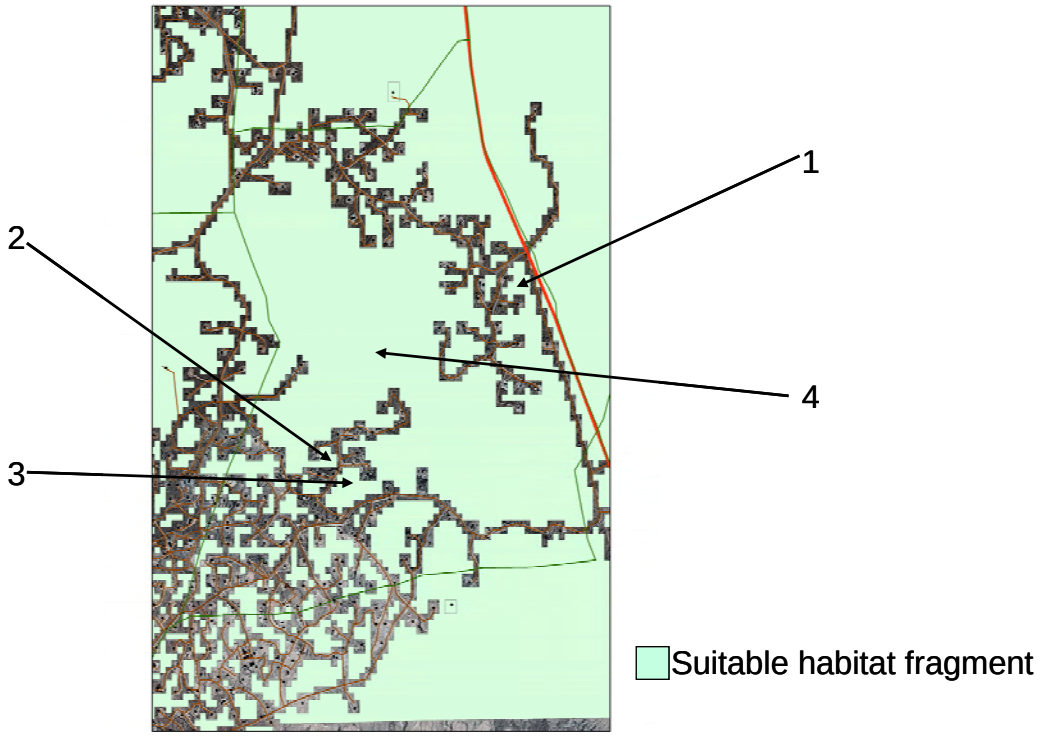


Figure 37. In this example, fragments 1, 2 and 3 likely ecologically function as small independent fragments. However, current methodological limitations in fragmentation analyses result in fragments 1, 2 and 3 being treated as part of fragment 4. Light green lines represent pre-existing fences.

CHAPTER 3

PRONGHORN SURVIVAL AND CORRELATES OF PRODUCTIVITY

INTRODUCTION

Many factors affect populations. Among these, pregnancy, birth mass, and fecundity are each directly linked to population processes since offspring production and survival are critical to sustain populations. While other factors also govern population performance, we elected to examine four relatively simple surrogate measures of population response to ambient conditions -- stress, body mass, pregnancy, and survival -- and their potential variation between control and experimental treatments.

Body mass, for instance, is a well known parameter that affects life history and population dynamics, and empirical findings consistently demonstrate a relationship between adult female mass and offspring birth weight and subsequent survival (Festa-Bianchet et al. 1997, 1998). Although female body condition is likely to be a more sensitive predictor of offspring performance because condition and mass are not always 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), although the relationship between spring mass and subsequent fecundity remains less certain (Zimmer 2004).

METHODS

Body Mass

Fifty adult, female pronghorn were captured on 24-25 January 2006. Once GPS data were subsequently downloaded, the preliminary classifications of control and experimental animals were confirmed. Sample sizes for the various comparisons (e.g., mass, stress hormones, and pregnancy) totaled less than 50 because the collars of 10 females were not recovered. In addition, we did not successfully collect data on all three measures for each of the remaining 40 animals, further reducing the sample size. Our

measures of body mass were obtained by weighing restrained animals during winter only and mass was recorded to the nearest kg.

Corticosteroids and Progesterone

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. Such non-invasive approaches have been used successfully to distinguish between stress-related responses of elephants in protected reserves and in areas with poaching (Foley et al. 2001). As a baseline for non-stressed animals, we used winter fecal samples from two adult pronghorn housed at the zoo in Pocatello, Idaho. Additional samples for baseline comparisons will be gathered from lower altitude sites in Montana in 2007.

We also evaluated potential variation in pregnancy rates by contrasting serum progesterone levels/individual (ng/ml) between control and experimental sites. All analyses were performed by the Smithsonian Institution's Conservation and Research Center (Front Royal, VA).

Survival of Control and Experimental Animals

Survival rates of radio-collared pronghorn in 2005 and 2006 were estimated using a known fate model in Program MARK (White and Burnham 1999). The analysis was based on monthly encounter histories where encounters represented either initial captures or relocations by radio-telemetry during subsequent months. We evaluated 14 models to assess the effects of site (control or experimental), season (spring [April - May], summer [June – August], fall [September – October] or winter [January - March]), year (2005 or 2006), and body mass on pronghorn survival. The most global model included parameters for year and site with interactions, $S_{year*site}$, where S was the estimated monthly survival rate of pronghorn. We used Akaike's Information Criterion adjusted for

small sample sizes (AIC_c) and Akaike weights to assess model fit (Burnham and Anderson 2002). Seasonal and annual survival estimates and standard errors were calculated from monthly survival estimates following Burnham et al. (1987).

RESULTS

Body Mass

Body mass in late January did not vary among control or experimental animals (P = 0.648). Control animals had a mean body mass of 50.80 ± 4.68 kg (n = 25) and experimental animals had a mean body mass of 50.11 ± 4.52 kg (n = 15; Fig. 38). Irrespective of treatment, mean mass was 51.04 kg (n = 40). Mean body mass of pronghorn was significantly higher in 2006 than in 2005 (P = 0.017; Fig. 38), which was due to differences in timing of captures.

Corticosteroids and Progesterone

Among 37 females examined for stress hormones via analyses of fecal corticosteroids in 2006, mean levels of control animals (1.69 ± 0.89 ng/g) were significantly higher than those of experimental animals (1.19 ± 0.176 ng/g; P = 0.0445;

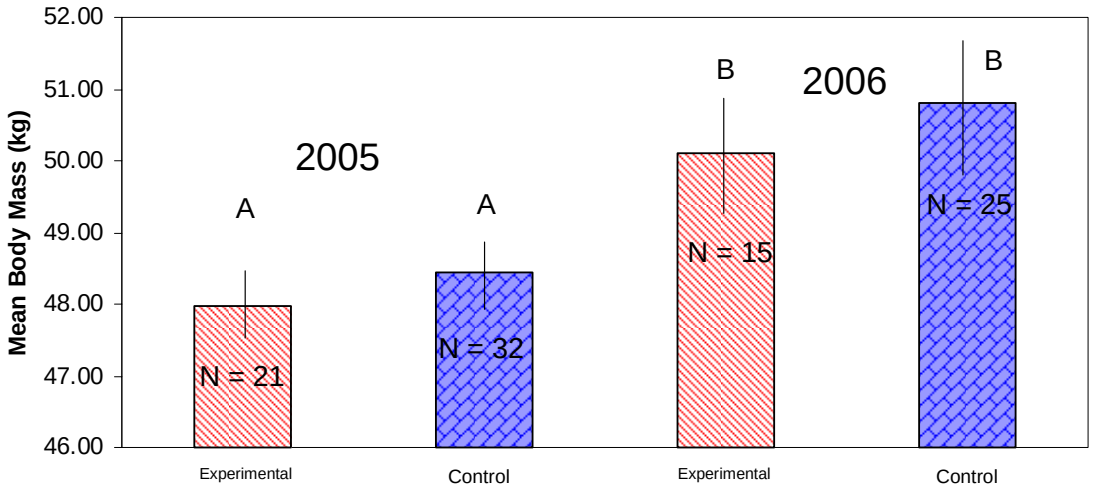


Figure 38. Comparison of mean body mass of control and experimental female pronghorn in the Upper Green River Basin between 2005 and 2006. Error bars represent ± SE and sample sizes are shown in each box. Mean body mass was significantly different (ANOVA, *F*= 3.56, *P* = 0.017; differences are shown by corresponding letters).

Fig. 39). Despite the greater mean for control animals and the degree of variance between control and experimental treatments, considerable overlap existed. In comparison to animals from the Pocatello Zoo, both control and experimental animals from the Upper Green River Basin had elevated stress levels (Fig. 39). Note, however, the small zoo sample (n = 2). Sample sizes will be increased in subsequent years by reliance on female pronghorn from the National Bison Range in northwestern Montana.

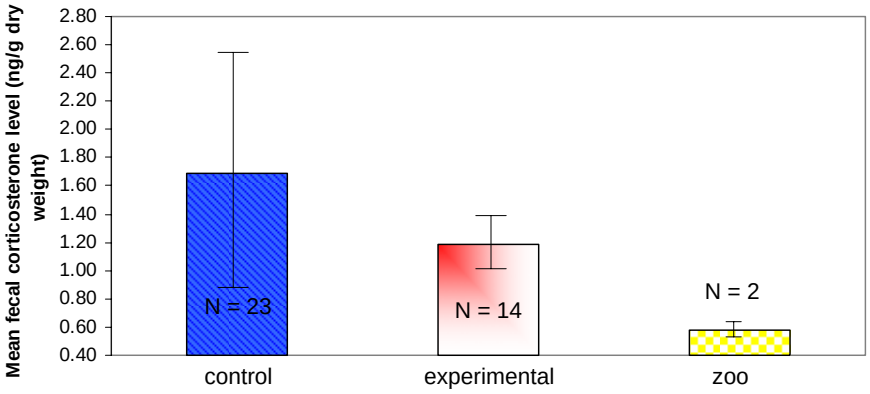


Figure 39. Mean fecal corticosterone levels of control, experimental, and Pocatello Zoo adult, female pronghorn. Error bars represent + 1 SD and sample sizes are shown in each box respectively. Mean corticosterone levels were significantly different between the groups (Kruskal-Wallis test, *W* = 8.19, *P* = 0.0445).

In 2006, we determined pregnancy status for 20 adult females using progesterone levels in blood serum (indicated as ng/ml; Fig. 40). There were no differences among the 20 females examined for pregnancy status (P = 0.504), with control animals having a mean serum progesterone level of 2.17 $\pm$ 0.82 ng/ml and experimental animals having a mean level of 2.46 $\pm$ 1.11 ng/ml (Fig. 40).

As in 2005, a positive relationship existed between body mass and progesterone levels in 2006 (Fig. 41; Berger et al. 2006b), indicating that heavier animals may be more likely to be pregnant. This relationship is important as it underscores the possibility that lighter animals in winter are reproductively disadvantaged, as they may be unable to conceive and/or produce fawns the following spring. However, at this point in the study we have detected no differences in body mass between control and experimental animals, and the extent to which changes in body mass subsequently affect fecundity remains unknown.

Survival of Control and Experimental Animals

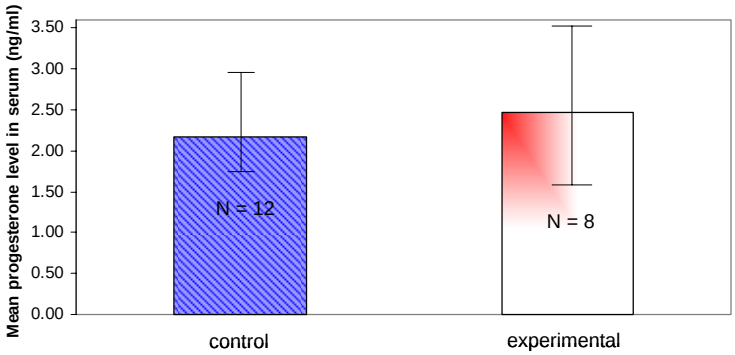


Figure 40. Mean progesterone levels of control and experimental adult, female pronghorn. Error bars represent + 1 SD and sample sizes are shown in each box respectively. Mean progesterone levels were not significantly different between the two groups (ANOVA, *F* = 0.6408, *P* = 0.504).

We included 98 marked individuals (48 in 2005 and 50 in 2006) in the survival analysis, distributed by site as follows: control - 53, experimental – 45. Two animals were censored in March 2005 because their VHF signals disappeared shortly after capture. A third animal was censored in September 2005 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 moved from the mortality site (e.g., perhaps by a scavenger), or whether the animal had slipped its collar (unlikely) and remained alive. On the basis of minimum AIC_c, the model of pronghorn survival that

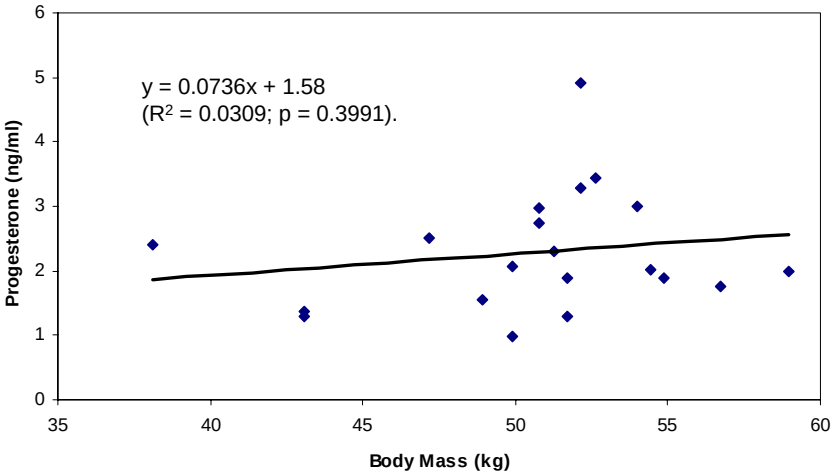


Figure 41. Relationship between body mass and serum progesterone levels for female pronghorn of the Upper Green River Basin in 2006.

best fit our data suggested that survival was the same for all animals in both years ($\hat{S}$ = 0.728 ± 0.050; Table 7). However, this model had just 16% of the Akaike weight and performed only slightly better than other top ranked models that suggested survival was higher in 2005 ($\hat{S}$ = 0.793 ± 0.065) than 2006 ($\hat{S}$ = 0.662 ± 0.076; ΔAIC_c = 0.317), was higher during winter than the remainder of the year (ΔAIC_c = 0.807), or increased with body mass (ΔAIC_c = 0.9606; Table 7). Together, the top four models accounted for 50% of the Akaike weights (Table 7). Estimated survival rates of pronghorn were lowest at the control site in 2006 ($\hat{S}$ = 0.614 ± 0.113), and highest at the control site during 2005 ($\hat{S}$ = 0.814 ± 0.084), but did not differ statistically between sites or among years (Fig. 42).

Ten animals died during 2005 due to human harvest (40%), predation (20%), and apparent starvation (20%; Table 8). In the remaining 20% of cases (*n* = 2), the cause of death could not be determined. Eleven animals died during 2006 due to human harvest (9%), injuries (18%), and apparent starvation (9%). In the remaining 64% of cases, cause of death could not be determined because the condition of the carcass was too poor for an accurate assessment (Table 8).

Table 7. Model selection results for survival of pronghorn in the Upper Green River Basin, 2005-2006.

Model	*K*	AIC_c	ΔAIC_c	Akaike weight	Model Likelihood	Deviance
$S(.)$	1	196.492	0.000	0.159	1.000	194.487
$S(_{year})$	2	196.809	0.317	0.136	0.854	192.794
$S(_{winter})$	2	197.299	0.807	0.106	0.668	193.284
$S(_{mass})$	2	197.452	0.961	0.098	0.619	193.438
$S(_{year+mass})$	3	197.684	1.193	0.088	0.551	191.656
$S(_{fall})$	2	197.826	1.334	0.082	0.513	193.812
$S(_{spring})$	2	198.240	1.748	0.066	0.417	194.225
$S(_{summer}$	2	198.316	1.824	0.064	0.402	194.301
$S(_{site})$	2	198.489	1.997	0.059	0.368	194.475
$S(_{year+site})$	3	198.761	2.269	0.051	0.322	192.732
$S(_{mass+site})$	3	199.397	2.905	0.037	0.234	193.368
$S(_{year+mass+site})$	4	199.685	3.193	0.032	0.203	191.637
$S(_{year+tmt+year*site})$	4	200.358	3.866	0.023	0.145	192.310
$S(_{year*site})$	38	231.520	35.028	0.000	0.000	151.842

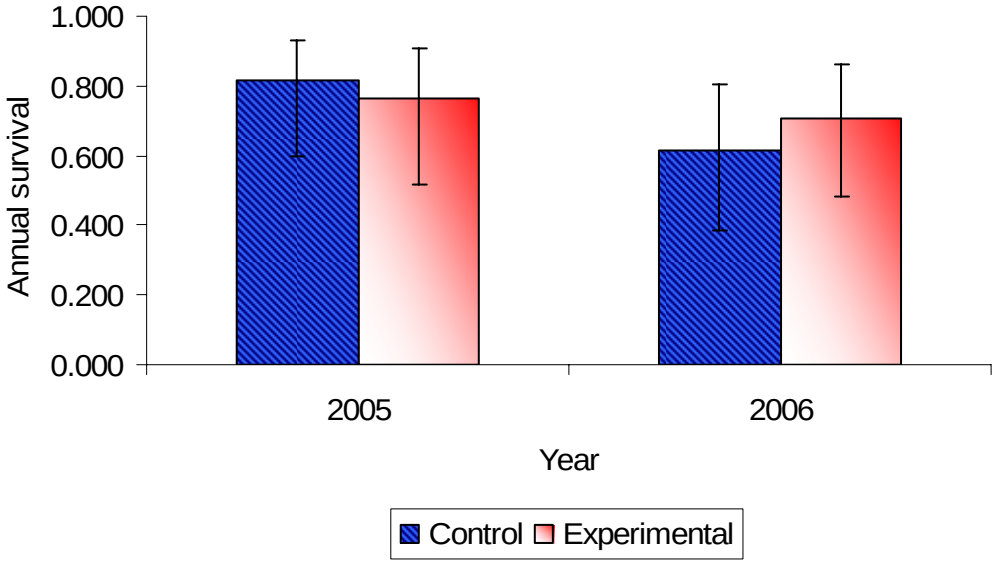


Figure 42. Annual survival rates estimated by Program MARK for control and experimental animals in the Upper Green River Basin, 2005-2006.

DISCUSSION

For the second consecutive year, we did not detect any biologically or statistically significant differences in correlates of productivity (survival rates, body mass, stress levels, progesterone levels) between control and experimental animals. These results are not unexpected, as development in the region is still at a relatively early stage. For instance, although the level of development within the PAPA may appear extensive based on a visual assessment of changes since the project's inception, to date only about 3% of the surface area in the PAPA has been disturbed (BLM 2006). Thus, in the absence of severe drought or winter weather, it is unlikely that the current scale of development would result in measurable impacts on pronghorn. This is particularly true given that much of the existing development in the PAPA has been concentrated along the northern and southern portions of the Anticline crest, whereas crucial wintering areas for

Table 8. Causes of mortality in radio-collared pronghorn, 2005-2006.

Year	Starvation[a]	Human Harvest	Predation	Injury[b]	Undetermined	Total
2005	2	4	2	0	2	10
2006	1	1	0	2	7	11

[a] Based red/gelatinous condition of bone marrow (Ransom 1965).
[b] One animal was struck by a vehicle and a second was caught in a fence.

pronghorn are located primarily in the vicinity of the New Fork River (Figs. 32-33). If future development encroaches upon these crucial wintering areas, detectable effects on pronghorn will be more likely, especially as the level of development proposed in the PAPA SEIS is projected to result in surface disturbance to ~40% of the available habitat within the core development areas (BLM 2006).

During the second year of the study, we did detect a few differences in overall animal health and correlates of productivity. First, animals captured in 2006 had a significantly higher mean body mass relative to animals captured in 2005. This was likely attributable to differences in the timing of captures between the two years, as captures were conducted a month earlier in 2006 (late January) than in 2005 (late February).

Second, both control and experimental animals had mean corticosterone levels that were significantly higher than the baseline levels of zoo animals from Pocatello, Idaho (Fig. 68). This may indicate that pronghorn of the UGRB are near the limit of their ecological range in terms of coping with Wyoming's harsh winters. Specifically, pronghorn in this region must contend not only with relatively high altitudes, but also temperatures that may approach their thermoregulatory limits, as the ability to maintain homeostasis (i.e., a constant body temperature) is more energetically costly at low ambient temperatures.

Finally, based on corticosterone levels, control animals appear to be more stressed than animals that winter in the vicinity of gas fields (Fig. 68). Although the underlying cause of this difference in unknown, it may stem from differential environmental conditions in control versus experimental areas. For instance, pronghorn in control areas may have access to poorer quality forage, which could result in higher baseline stress levels. Alternatively, the lower stress levels of experimental animals may be the result of habituation to constant human activity associated with gas field development. Efforts in future years will continue to focus on teasing apart these explanations.

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