SUBLETTE MULE DEER STUDY (PHASE II): FINAL REPORT 2007

Long-term monitoring plan to assess potential impacts of energy development on mule deer in the Pinedale Anticline Project Area, 2001-2007

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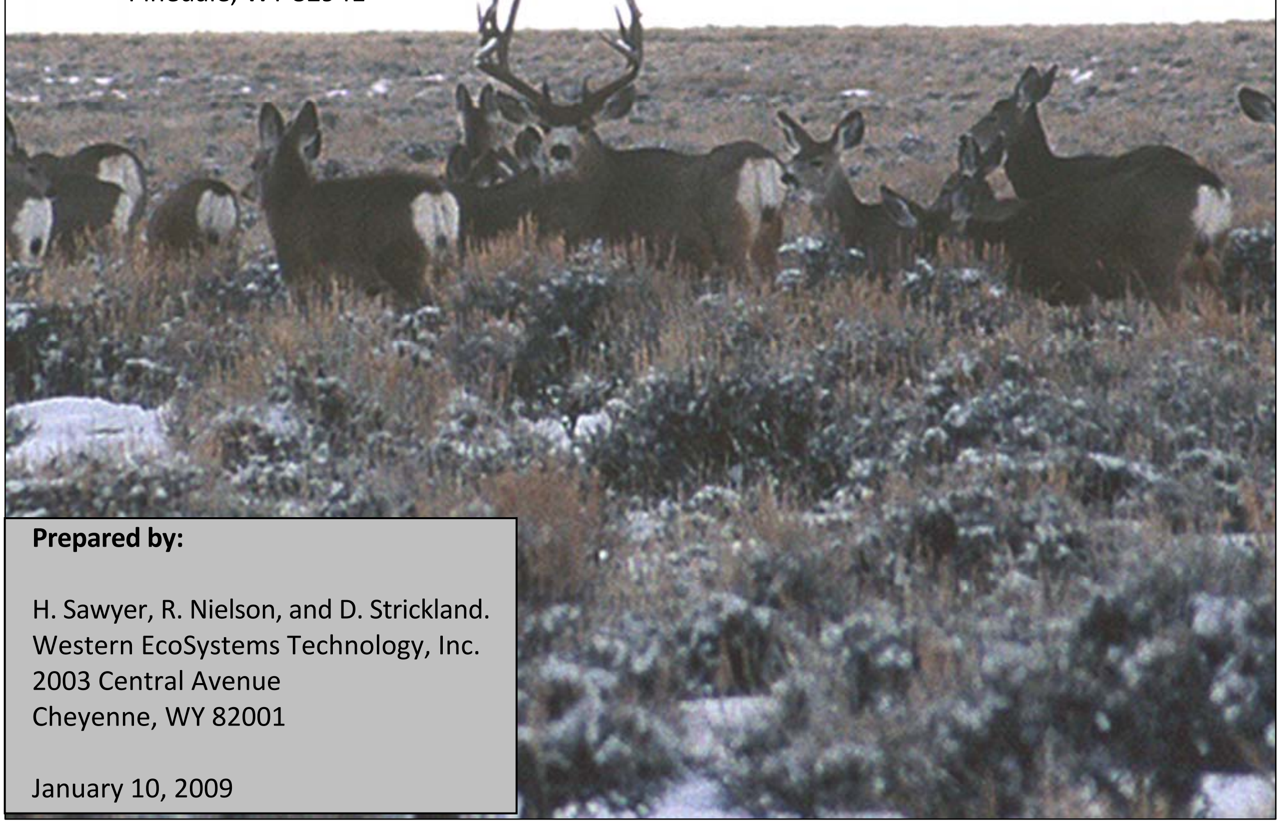

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EXECUTIVE SUMMARY

Through 2007, gas field development in the Mesa portion of the Pinedale Anticline Project Area (PAPA) resulted in 1,520 acres of direct habitat loss from the construction of well pads and access roads. Although 70 miles of roads were built on the Mesa between 2000 and 2007, most (83%) habitat loss was associated with well pads, particularly as gas field development progressed. Direct habitat loss represented less than 3% of the Mesa surface area, but did not include the relatively short-term losses from pipeline construction. Given the number of wells approved in the PAPA, directional drilling strategies have reduced direct habitat loss by drilling multiple wells (up to 28) from single pads.

Radiomarked deer avoided well pads 6 of the 7 years of development, resulting in indirect habitat loss that was substantially larger than the direct habitat loss. Mule deer avoidance of well pads appeared to be associated with the amount of human activity that occurred at the pads, as winter drill pads were avoided the most and producing pads with liquids gathering systems (LGS) were avoided the least. Our results suggest that efforts to minimize direct and indirect habitat loss should focus on technology and planning that reduce the number of well pads and the human activity associated with them. Specifically, our results indicate that indirect habitat loss associated with producing well pads may be reduced by 38-63% with the installation of LGS. Conversely, indirect habitat loss associated with winter drill pads were approximately 3 to 9 x greater than producing well pads. In short, LGS appeared to be an effective long-term (i.e., production phase) mitigation measure for reducing indirect habitat loss to wintering mule deer, while year-round drilling in crucial winter range created a short-term (i.e., drilling phase) increase in deer disturbance and indirect habitat loss. Despite changes in winter habitat selection and distribution patterns during years of gas field development, the migration routes of mule deer to and from the Mesa remained intact and functional.

Average daily movement rates of mule deer on the Mesa were approximately 1.6 km/day, while those on the Pinedale Front were 2.3 km/day. Within each winter range, the daily movement rates were consistent among months and years, even with the variable environmental and field development conditions (e.g., weather, truck traffic, drill rigs, and pad numbers) that mule deer were exposed to during the study period. Given that most mule deer on the Mesa did not move more than 1.6 km/day and that those movements were generally restricted to a relatively small home range, many small habitat treatments evenly distributed across the Mesa may benefit more mule deer than a few large treatments.

We attempted to examine and compare estimates of mule deer abundance, recruitment, adult female survival, and winter fawn survival between a treatment (the Mesa) and reference (Pinedale Front) area to determine if gas development affected population performance. However, problems with the reference area (i.e., no abundance estimates, more severe winter conditions, and consistent off-road snowmobile/ATV disturbance) made comparisons between the treatment and reference areas difficult. Nonetheless, data collected from the Mesa indicated that mule deer numbers declined during the first 4 years (2001-2004) of gas development and increased the following 3 years (2005-2007), for an overall decline of 30%. When survival and recruitment rates estimated from the Mesa were incorporated into a population growth model (White and Lubow 2002), the model predicted a 27% decline. During the same time period, the

Wyoming Game and Fish Department (WGFD) estimated a 10% decline for the larger Sublette Herd Unit, which included the Mesa and several other winter ranges. When we consider that 1) there was a negative trend in deer abundance (-30%) observed in the Mesa, 2) the population growth model indicated that the negative trend was plausible given the reproductive and survival rates we measured, 3) estimated emigration rates for the Mesa were only 1.5% per year, and 4) WGFD estimates for the entire Sublette Herd Unit indicated that deer numbers declined by only 10% over the same time period, we conclude that mule deer numbers declined in the Mesa and there is no evidence that suggests other segments of the Sublette mule deer population declined at a comparable rate.

INTRODUCTION

In 1998 the Wyoming Cooperative Fish and Wildlife Research Unit began the Sublette Mule Deer Study; a collaborative effort with industry, agencies, and private organizations with objectives to examine movement patterns and population characteristics of the Sublette mule deer herd in western Wyoming. Although a variety of agencies and non-government organizations contributed to the study, it was funded largely by industry (Ultra Petroleum). Concurrently, the Bureau of Land Management (BLM), in compliance with the National Environmental Policy Act, initiated an Environmental Impact Statement to assess natural gas development impacts in the 300-mi^2 Pinedale Anticline Project Area (PAPA; BLM 2000*a*). Because the PAPA provided winter range to several thousand mule deer, there were concerns about the potential effects gas development may have on the deer population and their winter range.

The Sublette Mule Deer Study was originally designed to have 2 phases. The first phase of the study was intended to gather information needed by agencies to improve management of the deer herd, including the identification of seasonal ranges, determination of migration routes, and estimation of survival rates (Sawyer and Lindzey 2001, Sawyer et al. 2005). Additionally, these data were collected so that pre-development information on the mule deer population would be available if Phase II of the study materialized. Phase II was envisioned as a long-term study that would examine the potential impacts of energy development on mule deer, using before and after development data on treatment and reference areas, with energy development as the treatment (BACI design; Morrison et al 2008). The BLM released their record of decision in July of 2000 (BLM 2000*b*) that approved development plans for the PAPA. Phase I of the Sublette Mule Deer Study was completed in March of 2001 and following a 1-year pilot study funded by Questar Exploration and Production (QEP), Phase II was initiated in December of 2002 as a collaborative effort among the BLM, QEP, Wyoming Game and Fish Department, and Western Ecosystems Technology, Inc.

Phase II of the Sublette Mule Deer Study identified 3 key components for assessing potential impacts to mule deer, including 1) direct habitat loss, 2) indirect habitat loss, and 3) population performance (Figure 1). The first component, direct habitat loss (i.e., surface disturbance), occurs when native vegetation is converted to infrastructure, such as access roads and well pads. We used satellite imagery to estimate the direct habitat loss that annually occurred from development activities (see Section 1). The second component included indirect habitat loss that occurs if or when mule deer use declines (i.e., avoidance or displacement) in areas adjacent to or near infrastructure. We used a combination of radio-collars equipped with GPS and statistical analyses to identify mule deer distribution and habitat selection patterns, and then evaluated how or if those patterns were influenced by gas development (see Sections 3 and 4). The third component included several measures of population performance, including estimates of mule deer abundance, survival, and recruitment in a treatment (the Mesa) and reference (the Pinedale Front) area. We used a weight-of-evidence approach that considered a variety of data collected from both the treatment and reference area to assess how or if mule deer population performance in the Mesa was affected by gas development (see Section 5).

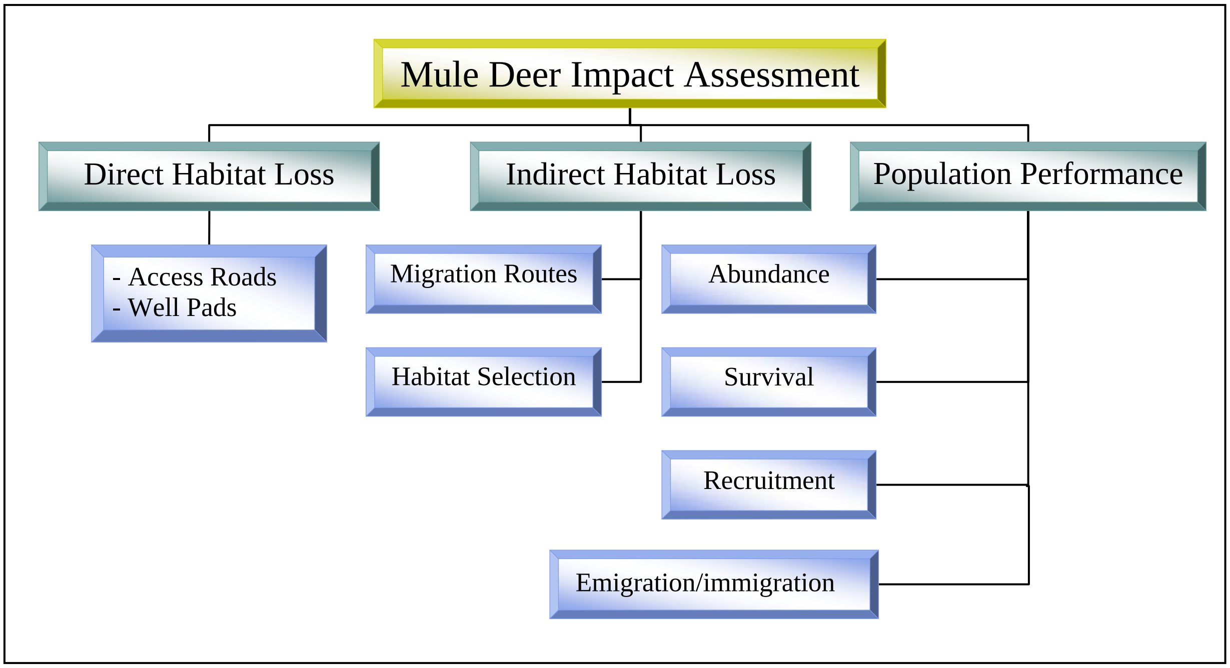

Figure 1. Organizational chart depicting the 3 key components of mule deer impact assessment for Phase II of the Sublette Mule Deer Study, including direct habitat loss, indirect habitat loss, and population performance.

This report summarizes the results from Phase II through the 2007 study period and was intended as a final report for Phase II. This format was intended to assist readers in accessing information about individual study topics without having to search the entire report, and to facilitate the peer-review and publication process when warranted.

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Section 1.0

Direct habitat loss on the Mesa

Section 1.0: Direct habitat loss on the Mesa

INTRODUCTION

Several potential impacts to wildlife that are associated with gas development include displacement, stress, and mortality, but the most predictable and easily-assessed impact is direct habitat loss. Direct habitat loss is often referred to as surface disturbance and occurs when native vegetation is converted to well pads, access roads, or other infrastructure. Direct habitat loss is of particular concern on winter ranges, where mule deer occur at high densities and their energetic requirements are difficult to meet. Beginning in 2000 we used satellite imagery to measure direct habitat loss associated with road networks and well pads on the Mesa portion of the Pinedale Anticline Project Area (PAPA). The purpose of this work was to provide accurate estimates of direct habitat loss to agencies and industry.

STUDY AREA

The PAPA is located in Sublette County, southwest of the town of Pinedale (Figure 1-1). The PAPA is characterized by sagebrush (*Artemisia sp.*) communities and riparian habitats associated with the Green and New Fork Rivers. Elevations range from 6,800 to 7,800 ft. The PAPA consists primarily of federal lands (80%) and minerals (83%) administered by the Bureau of Land Management (BLM). The state of Wyoming owns 5% (15.2 mi^2) of the surface and another 15% (46.7 mi^2) is private. The PAPA provides winter range for 3,000-5,000 mule deer. While the PAPA encompasses 309 mi^2, most deer occur in the northern third of the PAPA, an area locally known as “The Mesa”, which is bounded by the Green and New Fork Rivers. Our study was conducted in the Mesa portion of the PAPA. In July of 2000, the BLM approved the development of 700 producing well pads, 401 miles of pipeline, and 276 miles of access roads in the PAPA (BLM 2000).

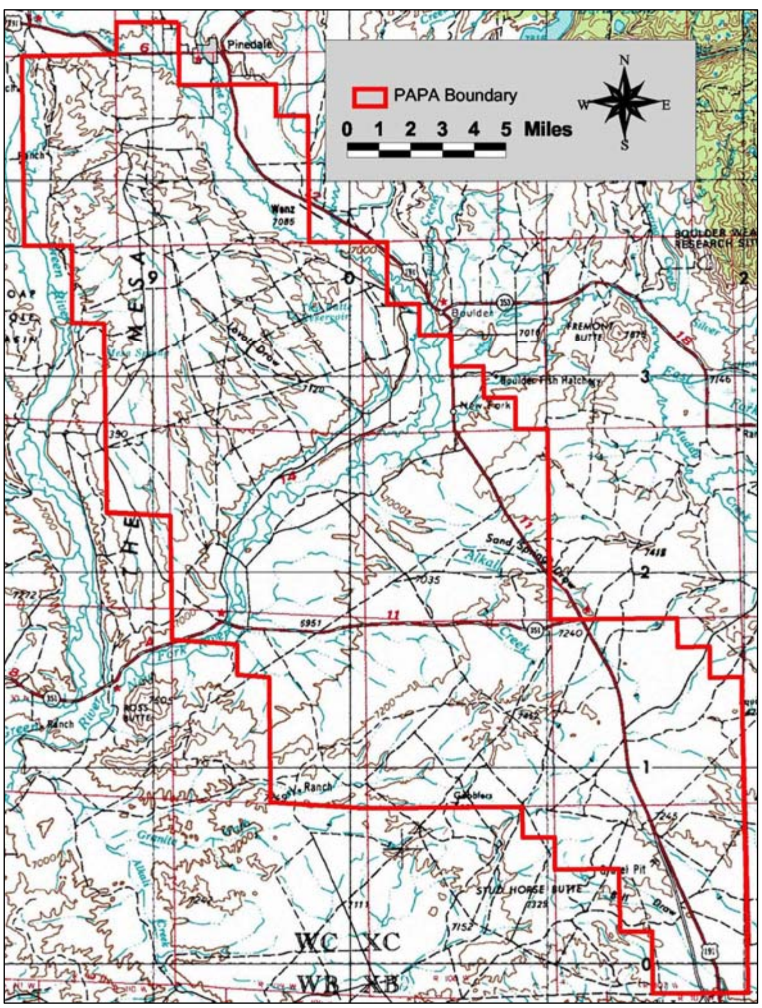

Figure 1-1. Location of the Mesa and Pinedale Anticline Project Area in western Wyoming.

METHODS

We used satellite imagery and ArcView® (ESRI, Redlands, California, USA) software to digitize road networks and well pads associated with natural gas development in the Mesa, 2000–2007. We did not include pipeline routes or seismic tracks in our analysis because the resolution of the imagery was not fine enough to delineate those features. Areas within the PAPA, but outside the Mesa were not considered. For years 1999–2004 we purchased Enhanced Thematic Mapper Landsat-5 and 7 images from the U.S. Geological Survey, which typically provide 30-m resolution. We began using higher resolution (10-m) images provided by Spot Image Corporation (Chantilly, Virginia, USA) in 2005. We collected images in early fall after most annual construction activities (e.g., well pad and road building) were complete, but prior to snow accumulation. Raw images were processed by SkyTruth (Sheperdstown, West Virginia, USA). Isolated compressor stations located among well pads were digitized and classified as well pads. Length of road segments and size of well pads were calculated in ArcView. Acreage estimates associated with road networks were based on an average road width of 30 ft. We recognize there may be small amounts of error associated with the digitizing process, however it is expected to be minimal and the resulting estimates are considered the best available data. During the digitizing process we assumed successful reclamation of well pads had not occurred. We defined successful reclamation as the re-establishment of the native plant species that occurred prior to the disturbance, i.e., sagebrush communities. We recognize that native shrub reclamation in arid environments is difficult and unlikely to occur during a short time period.

RESULTS

Year - 1999

Prior to development, The Mesa portion of the PAPA was relatively undisturbed, with few improved roads and approximately a dozen existing well pads (Figure 1-2).

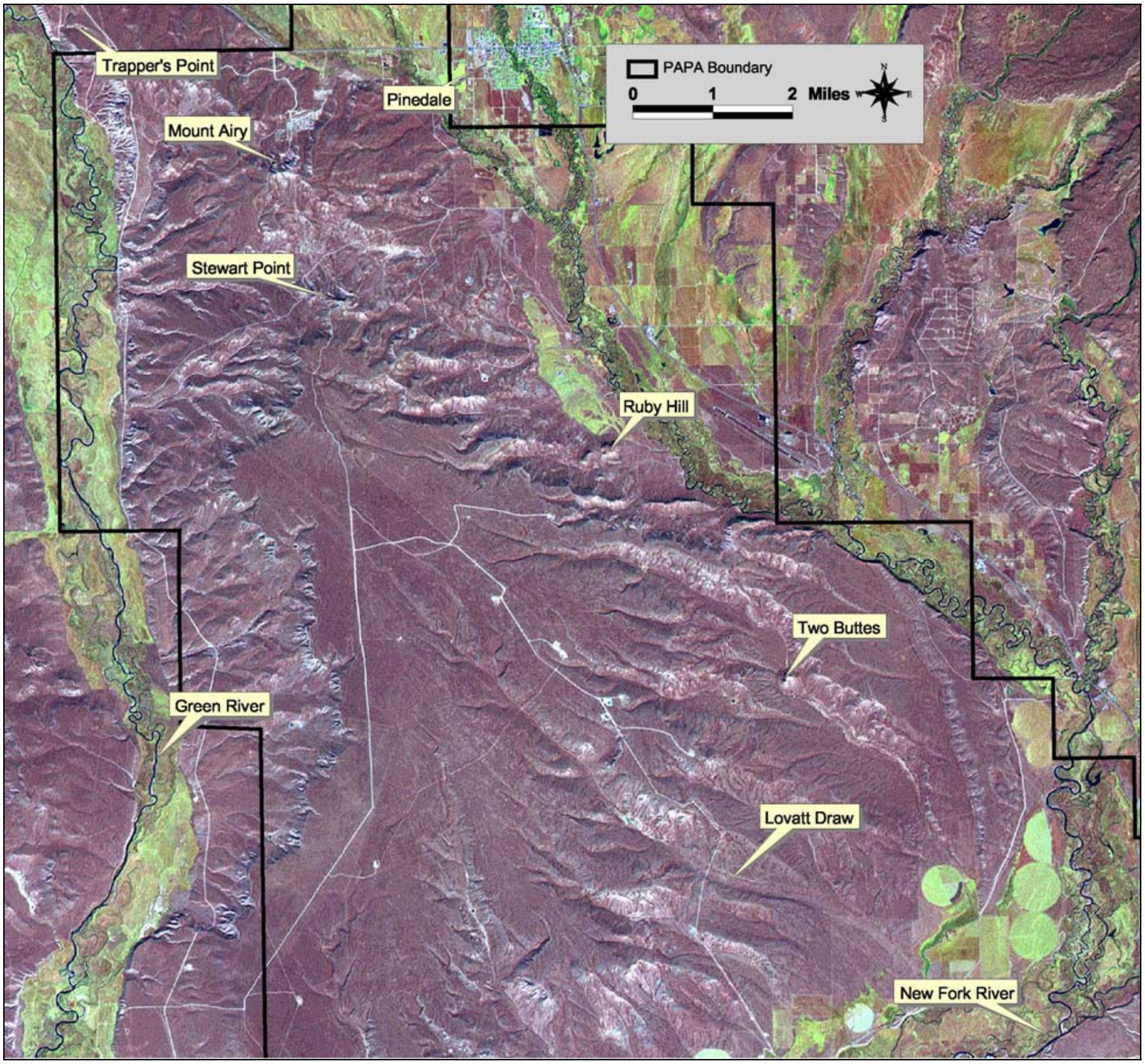

Figure 1-2. Satellite image of the Mesa prior to development of the Pinedale Anticline Project Area, October 1999.

Year - 2000

The BLM's Record of Decision for the PAPA was released in July of 2000 (BLM 2000). Accordingly, natural gas development was minimal during this year. We did not acquire imagery for this year, but based on field observations we estimate approximately 11.4 miles of new roads and 39 acres of well pads were constructed on the Mesa during 2000 (Table 1-1, Figure 1-10). Approximately 51% of the total surface disturbance was associated with road building while the other 49% was attributed to well pad construction (Table 1-1, Figure 1-11).

Year - 2001

2001 marked the first full calendar year of gas field development as authorized by the PAPA Record of Decision (BLM 2000). Most development occurred along the central portion of the Mesa, adjacent to Lovatt Draw (Figure 1-3). Based on satellite imagery, approximately 13.5 miles of new roads and 119 acres of well pads were constructed on the Mesa during the first nine months of 2001 (Table 1-1, Figure 1-10). Approximately 29% of the total surface disturbance was associated with road building while the other 71% was attributed to well pad construction (Table 1-1, Figure 1-11).

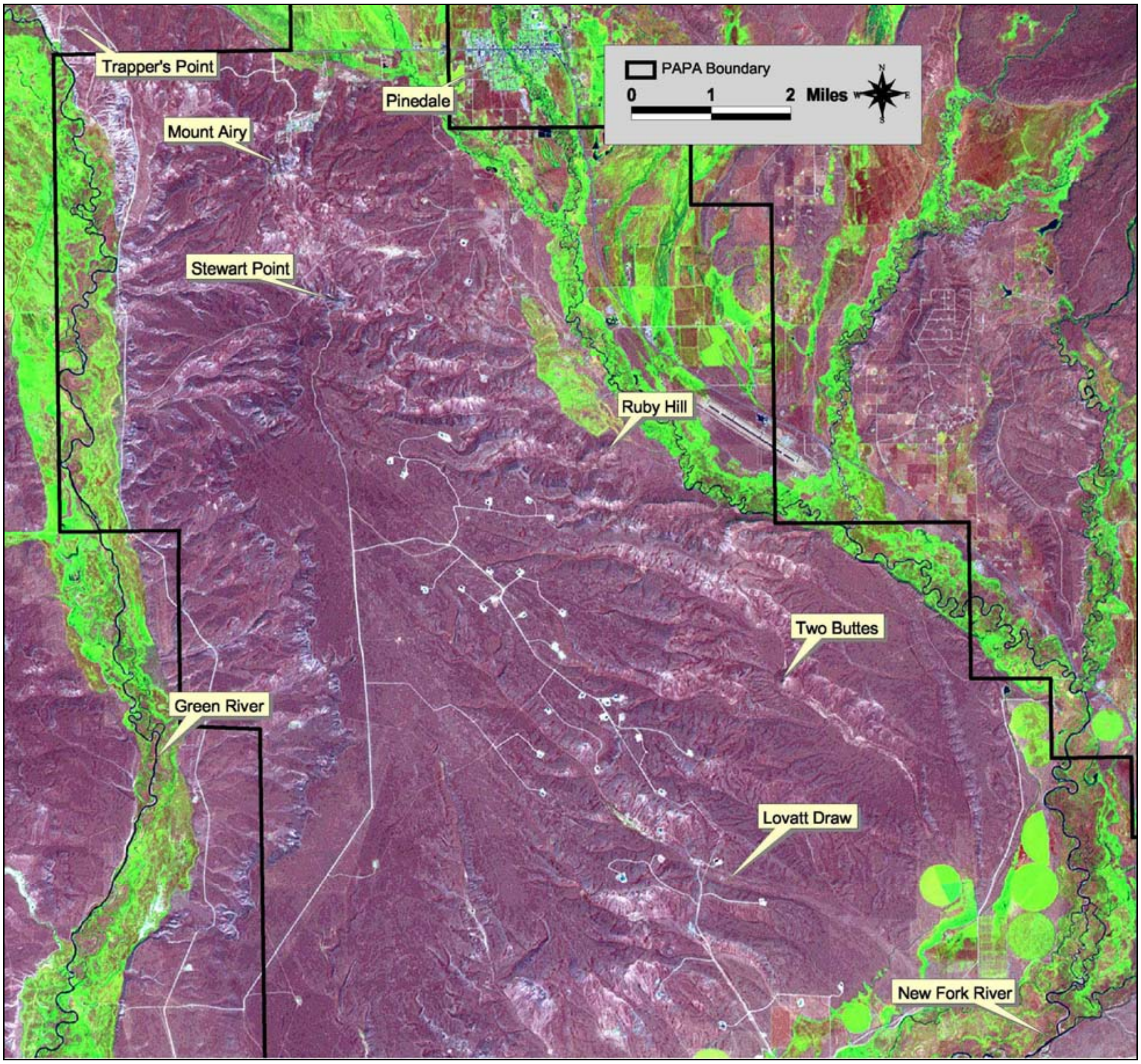

Figure 1-3. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, August 2001.

Year - 2002

Similar to 2001, most development in 2002 occurred along the central portion of the Mesa adjacent to Lovatt Draw (Figure 1-4). Drilling activity was also evident on the northern part of the Mesa, east of Stewart Point. Based on satellite imagery, approximately 19.9 miles of new roads and 215 acres of well pads were constructed on the Mesa between August 2001 and October 2002 (Table 1-1, Figure 1-10). Approximately 25% of the total surface disturbance was associated with road building while the other 75% was attributed to well pad construction (Table 1-1, Figure 1-11).

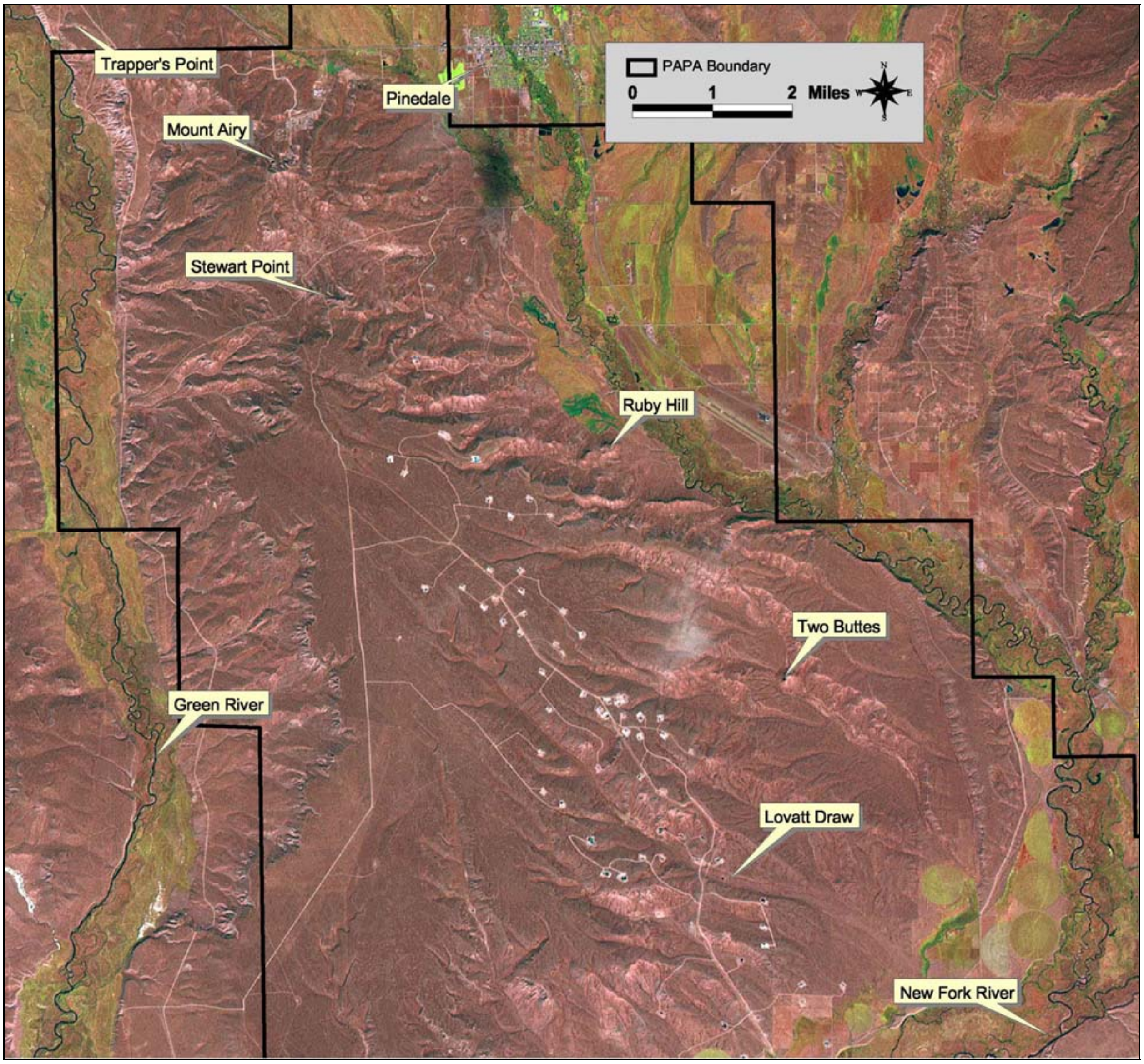

Figure 1-4. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, October 2002.

Year - 2003

Similar to 2001-2002, most gas development in 2003 occurred along the central portion of the Mesa adjacent to Lovatt Draw (Figure 1-5). Drilling activity was also evident on the northern part of the Mesa, east of Stewart Point. Based on satellite imagery, approximately 12.5 miles of new roads and 242 acres of well pads were constructed on the Mesa between October 2002 and September 2003 (Table 1-1, Figure 1-10). Approximately 16% of the total surface disturbance was associated with road building while the other 84% was attributed to well pad construction (Table 1-1, Figure 1-11).

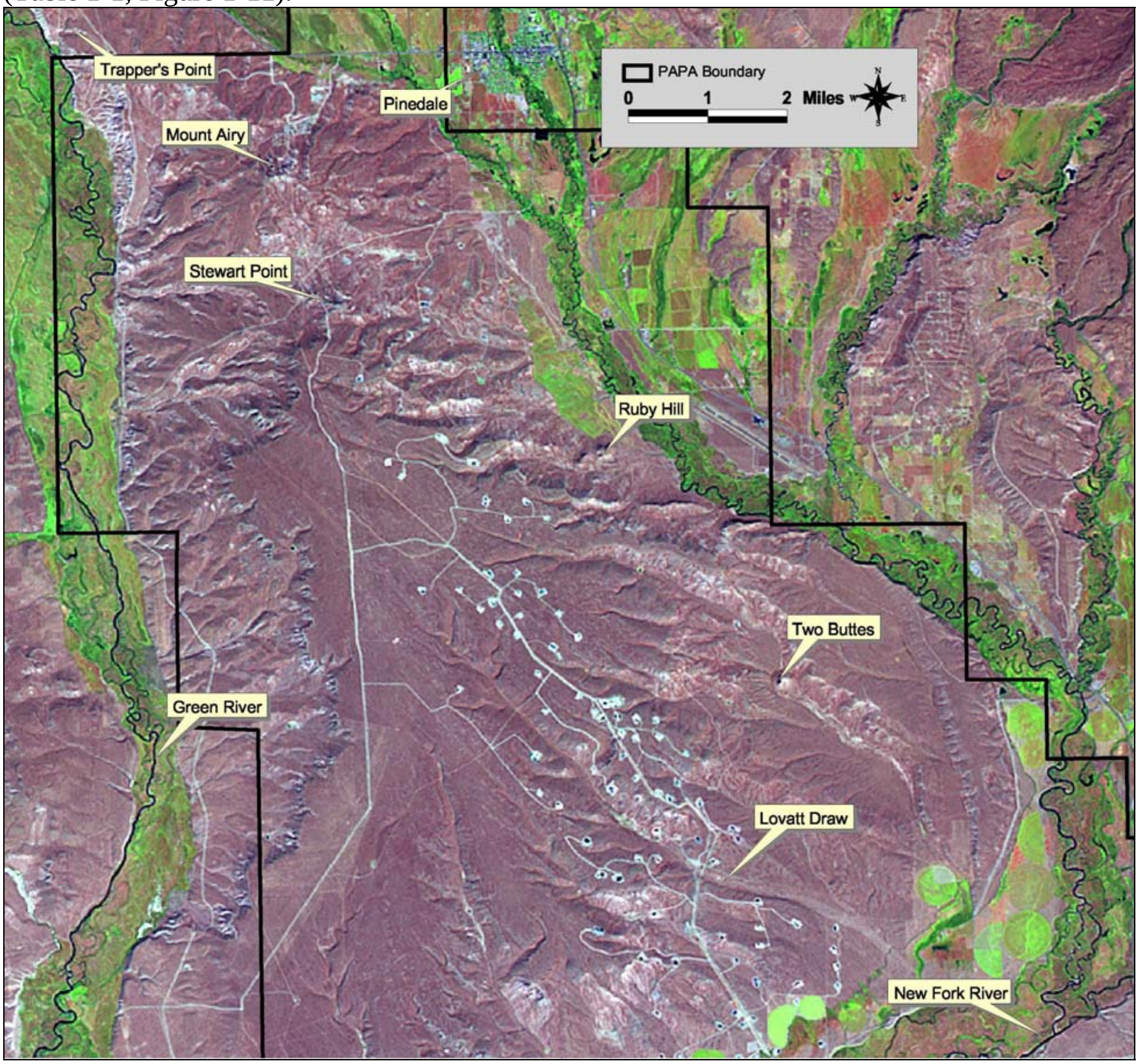

Figure 1-5. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, September 2003.

Year - 2004

Similar to 2001-2003, most gas development in 2004 occurred along the central portion of the Mesa adjacent to Lovatt Draw (Figure 1-6). Drilling activity was also evident on the northern part of the Mesa, east of Stewart Point. Based on satellite imagery, approximately 4.4 miles of new roads and 226 acres of well pads were constructed on the Mesa between September 2003 and August 2004 (Table 1-1, Figure 1-10). Approximately 7% of the total surface disturbance was associated with road building while the other 93% was attributed to well pad construction (Table 1-1, Figure 1-11).

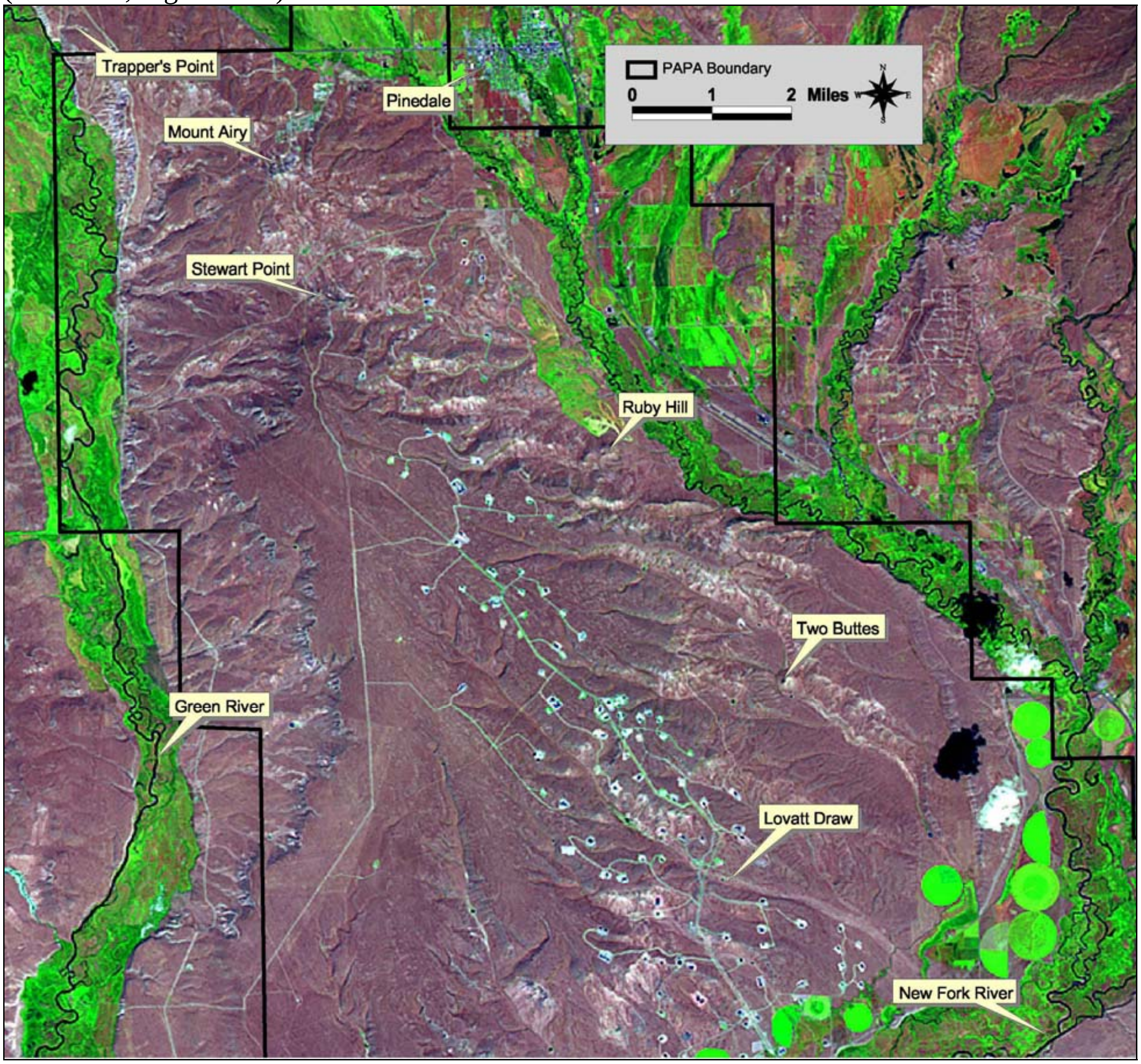

Figure 1-6. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, August 2004.

Year - 2005

Similar to 2001-2004, most gas development in 2005 occurred along the central portion of the Mesa adjacent to Lovatt Draw (Figure 1-7). Drilling activity was also evident on the northern part of the Mesa, east of Stewart Point. Based on satellite imagery, approximately 6.8 miles of new roads and 222 acres of well pads were constructed on the Mesa between August 2004 and October 2005 (Table 1-1, Figure 1-10). Approximately 10% of the total surface disturbance was associated with road building while the other 90% was attributed to well pad construction (Table 1-1, Figure 1-11).

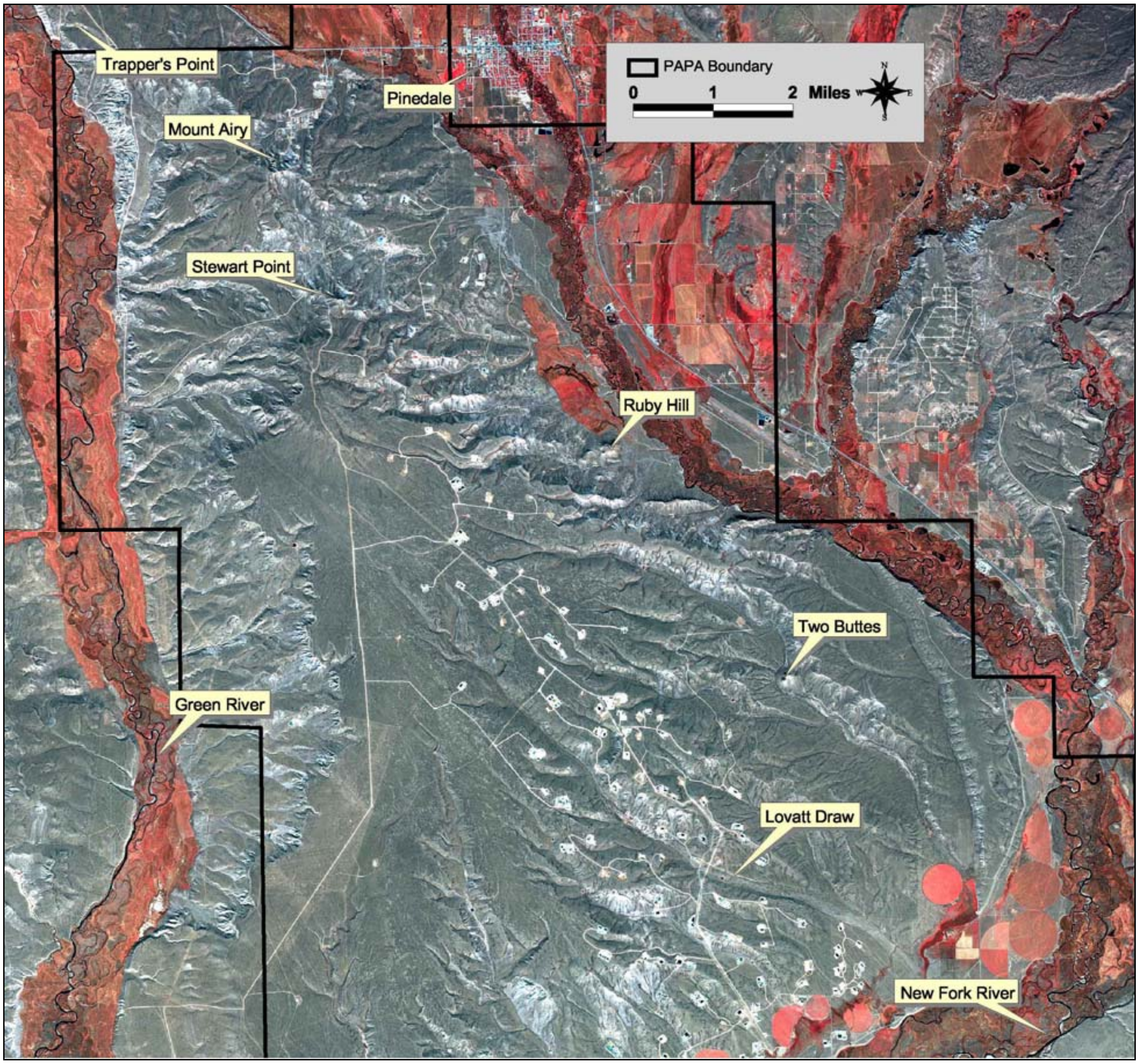

Figure 1-7. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, October 2005.

Year - 2006

Similar to 2001-2005, most gas development in 2006 occurred along the central portion of the Mesa adjacent to Lovatt Draw (Figure 1-8). Drilling activity was also evident on the northern part of the Mesa, east of Stewart Point. Based on satellite imagery, approximately 1.7 miles of new roads and 65 acres of well pads were constructed on the Mesa between October 2005 and September 2006 (Table 1-1, Figure 1-10). Approximately 9% of the total surface disturbance was associated with road building while the other 91% was attributed to well pad construction (Table 1-1, Figure 1-11).

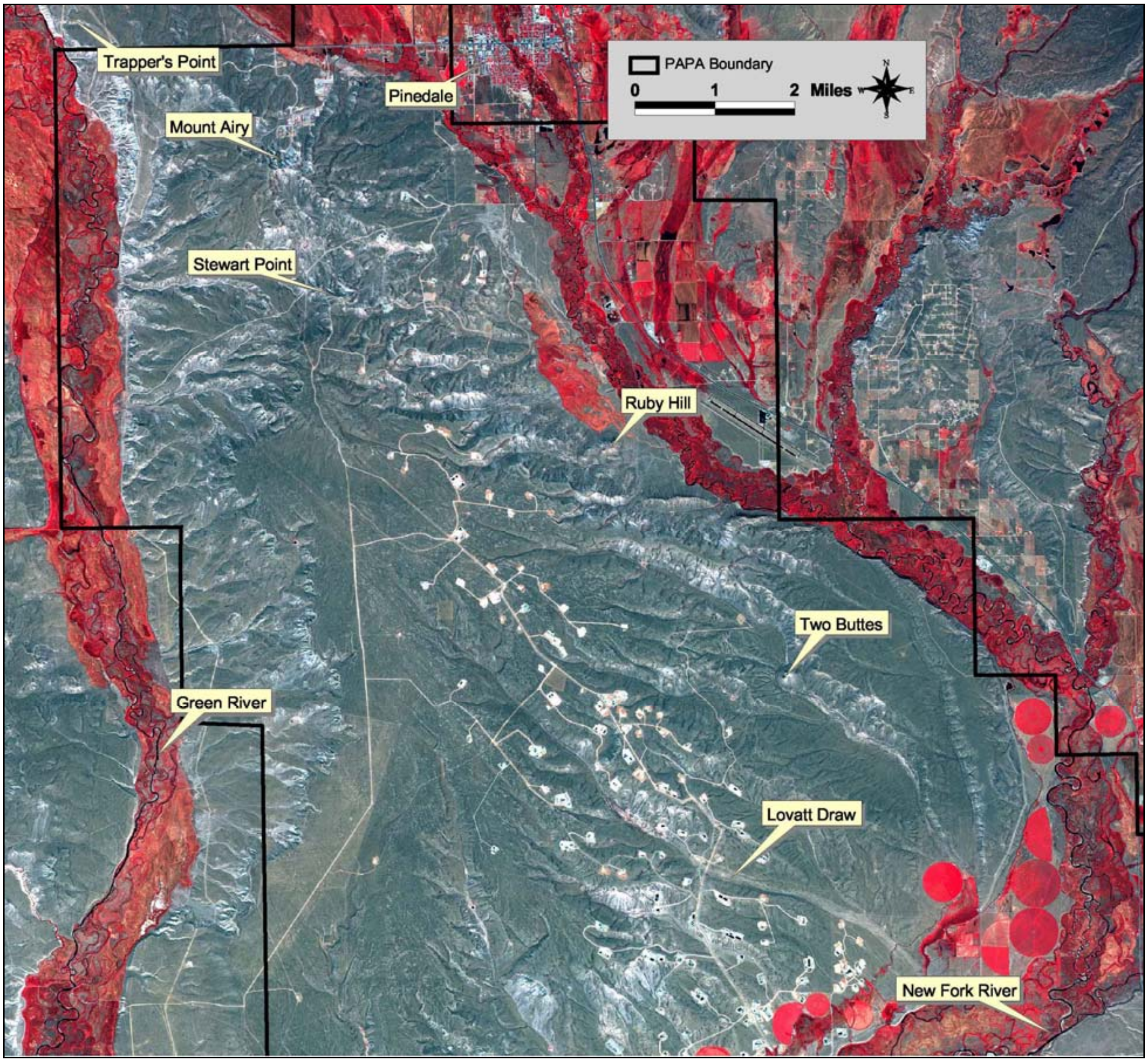

Figure 1-8. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, September 2006.

Year - 2007

Similar to 2001-2006, most gas development in 2007 occurred along the central portion of the Mesa adjacent to Lovatt Draw (Figure 1-9). Drilling activity was also evident on the northern part of the Mesa, east of Stewart Point. Based on satellite imagery, approximately 0.4 miles of new roads and 135 acres of well pads were constructed on the Mesa between September 2006 and September 2007 (Table 1-1, Figure 1-10). Approximately 1% of the total surface disturbance was associated with road building while the other 99% was attributed to well pad construction (Table 1-1, Figure 1-11).

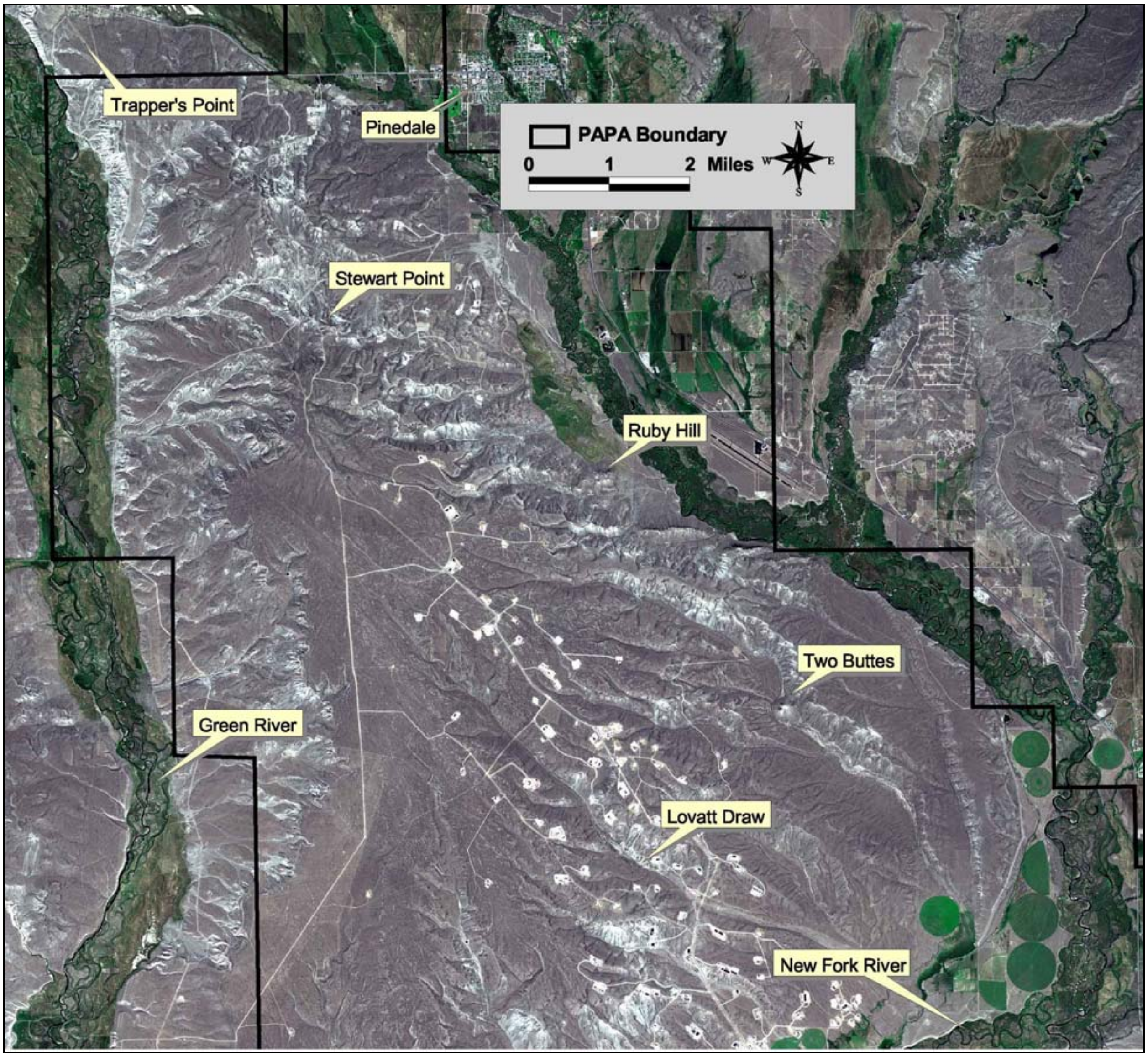

Figure 1-9. Satellite image of the Mesa and northern portion of the Pinedale Anticline Project Area, September 2007.

Table 1-1. Summary of annual and cumulative direct habitat loss (i.e., surface disturbance) associated with road networks and well pads on the Mesa, 2000-2007.

Year	Roads (mi)	Roads (acres)[a]	Well Pads (acres)	Total (acres)	% Roads	% Well Pads
2000	11.4	41	39	80	51%	49%
2001	13.5	49	119	168	29%	71%
2002	19.9	72	215	287	25%	75%
2003	12.5	45	242	287	16%	84%
2004	4.4	16	226	242	7%	93%
2005	6.8	25	222	247	10%	90%
2006	1.7	6	65	71	9%	91%
2007	.4	1	135	136	1%	99%
Total	70.6	257	1,263	1,520	17%	83%

[a] Based on an average road width of 30 feet.

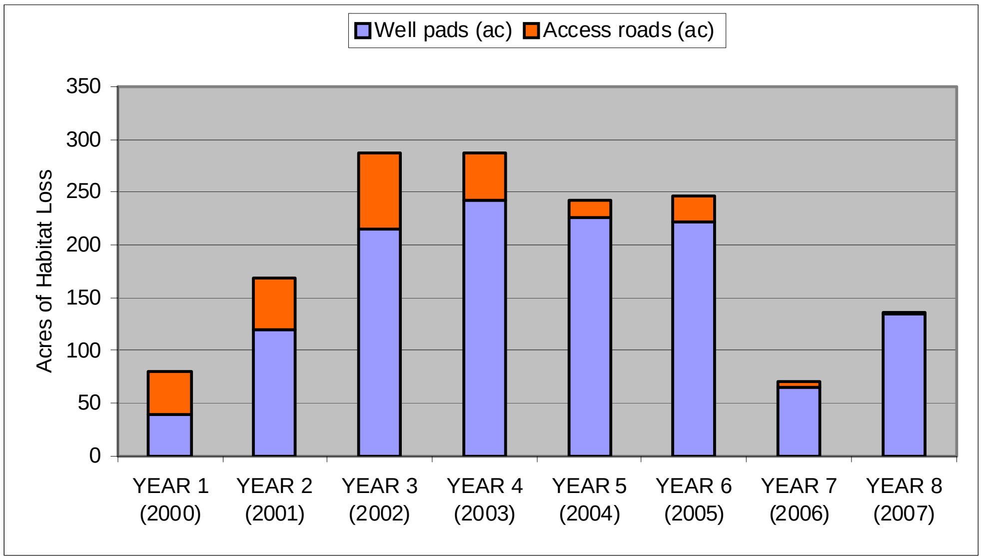

Figure 1-10. Proportion of habitat loss associated with well pads and access roads on the Mesa, 2000-2007.

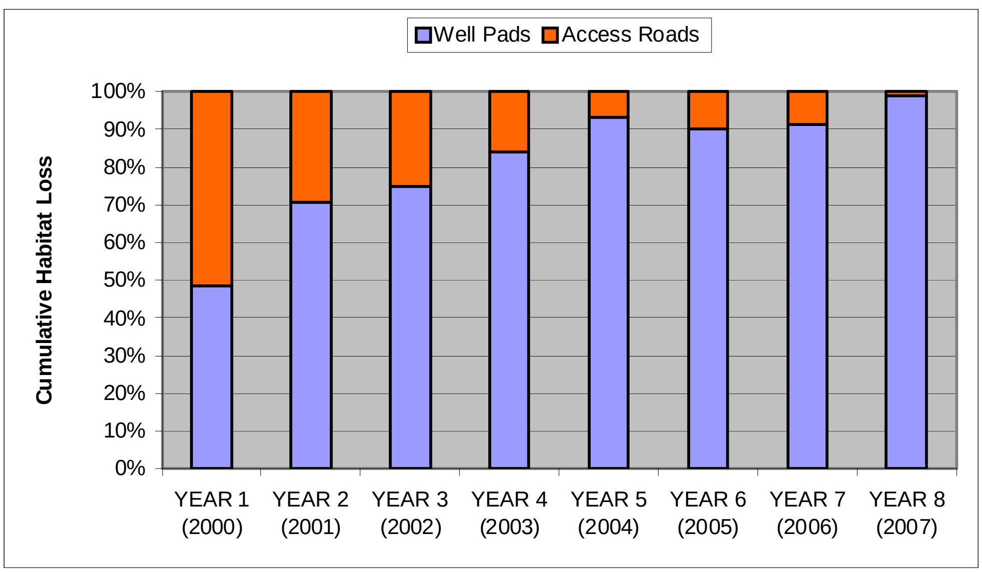

Figure 1-11. Cumulative percent of habitat loss associated with well pads and access roads on the Mesa, 2000-2007.

DISCUSSION

Sagebrush is the primary forage species for wintering mule deer on the Mesa and maintaining healthy sagebrush communities will be a key component for successful mule deer management. Because of the concentrated deer use on the Mesa during the winter, direct habitat loss may reduce the overall carrying capacity of the winter range. Since development of the PAPA began in 2000, well pad and road construction on the Mesa resulted in approximately 1,520 acres (2.4 mi^2) of direct habitat loss to mule deer winter range. Relative to the 100-mi^2 Mesa, this habitat loss represents 2.4% of the area. However, this estimate does not include the relatively short-term (i.e., < life of project) loss of habitat due to pipeline routes. Re-establishment of native plant species that occurred prior to the disturbance (i.e., sagebrush communities), which provide key winter habitat for mule deer, may take a decade or more to achieve.

Given that 83% of direct habitat loss on the Mesa was associated with well pads, our results suggest that efforts to minimize direct habitat loss should focus on technology (e.g., directional drilling) and planning that reduce the number of well pads. Questar Exploration and Production (QEP) and other companies have used directional drilling as an effective means to reduce direct habitat loss in portions of the Mesa. For example, the M15-20 and M3-20 well pads (Figure 1-12) are approximately 18 and 17 acres in size and have 26 and 28 wells completed from them, respectively. The current amount of road required to service these 2 pads and their combined 54 wells is approximately 2.05 miles. An alternative development strategy with no directional drilling and 54 single well pads would result in an estimated 189 acres (54 wells x 3.5 acres) of habitat loss (Figure 1-13). Additionally, assuming a basic road network was required to service the 54 single well pads, an additional 5.1 miles of road would be needed (Figure 1-13). Between these 2 development strategies that access the same gas resources, the directional drilling strategy used by QEP reduced habitat loss from well pads by approximately 82% and reduced the amount of service roads by 72%.

Combined with careful planning, directional drilling can substantially reduce the amount of direct habitat loss. However, because directional drill pads are larger than single well pads (12-20 acres versus 2-4 acres), implementing directional drilling to minimize direct habitat loss assumes that the total number of well pads across the project area will be considerably reduced. Economically viable directional drilling may also require year-around drilling, which may increase human activity and disturbance to wildlife during the winter (see Section 4).

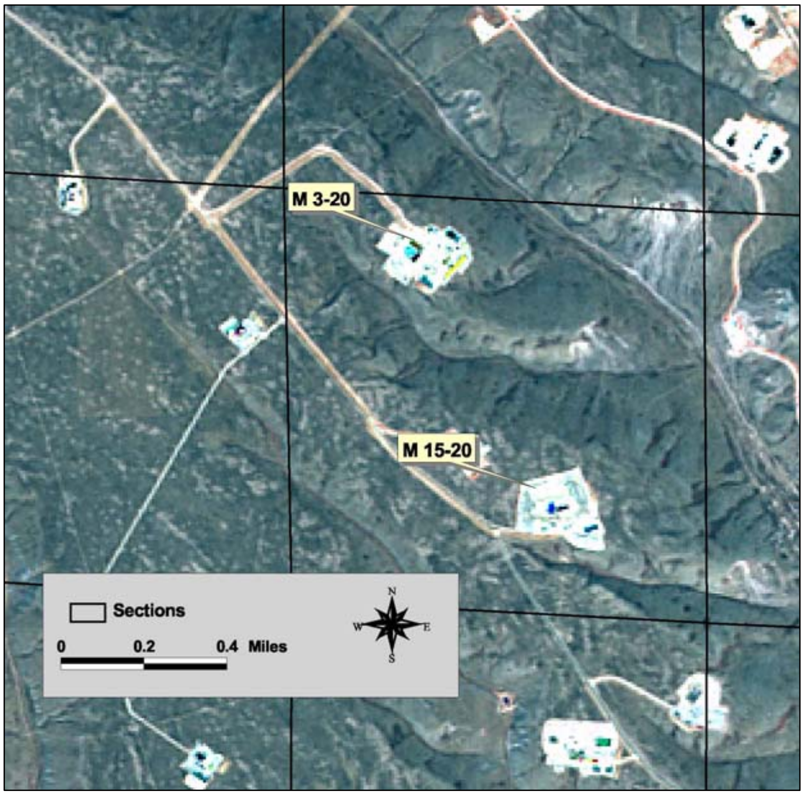

Figure 1-12. Location of M3-20 and M15-20 well pads. Both pads have been used for directional drilling. To date, 54 wells have been completed from the 2 pads.

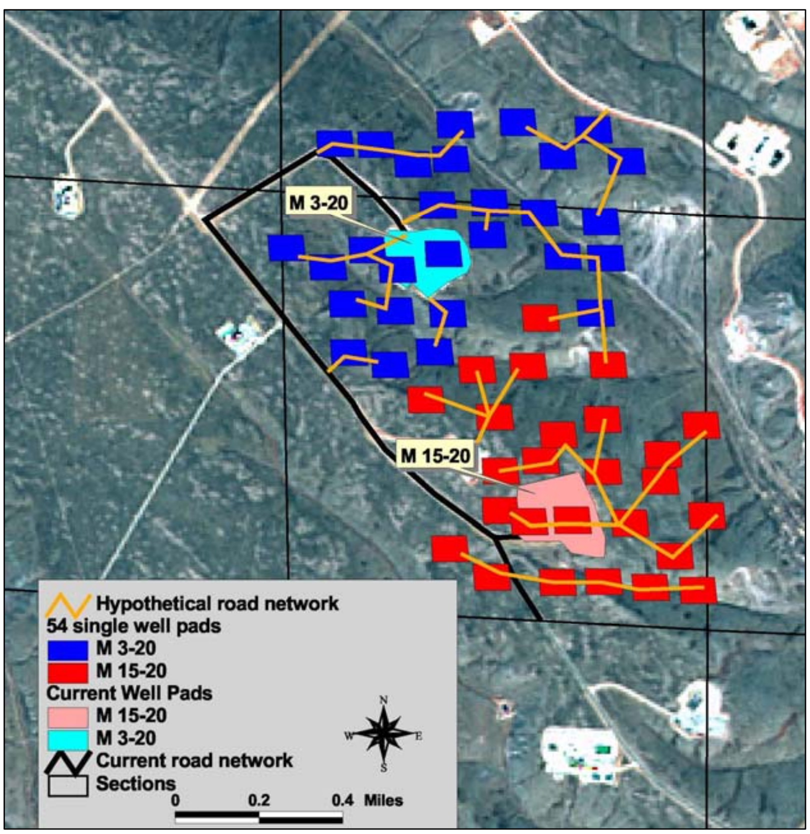

Figure 1-13. Representation of development scenario without directional drilling. The 54 single well pads were centered on actual bottom-hole locations and were sized at 3.5 acres.

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Section 2.0

Movement rates and distribution patterns of mule deer on the Mesa and Pinedale Front winter ranges

Section 2.0: Movement rates and distribution patterns of mule deer on the Mesa and Pinedale Front winter ranges.

INTRODUCTION AND STUDY AREA

The Sublette mule deer herd unit includes 15 hunt areas (130, 138-142, 146, 150-156, and 162) and has a post-season population objective of 32,000 (Wyoming Game and Fish Department [WGFD] 2005). Phase I of the Sublette Mule Deer Study found that a large portion of these mule deer seasonally migrate 60-100 miles from their winter ranges near Pinedale, to summer in portions of the Salt River Range, Wyoming Range, Wind River Range, Gros Ventre Range, and Snake River Range (Sawyer and Lindzey 2001, Sawyer et al. 2005). During the lengthy spring and fall migrations, mule deer spend a substantial amount of time, often 4-5 months out of the year, on mid-elevation transition ranges that connect summer and wintering areas (Sawyer et al. 2005). By late-fall, most mule deer annually converge in the upper Green River Basin to winter in 1 of 2 major complexes; the Mesa Winter Range Complex (the Mesa) or the Pinedale Front Winter Range Complex (the Pinedale Front) (Figure 2-1). Generally, the Mesa Winter Range Complex includes the Mesa and those wintering areas west of US 191, while the Pinedale Front includes those areas east of US 191 to the base of the Wind River Mountains. The purpose of this section was to provide information on the winter distribution and movement rates of mule deer in the Mesa and Pinedale Front winter ranges, 2002-2007.

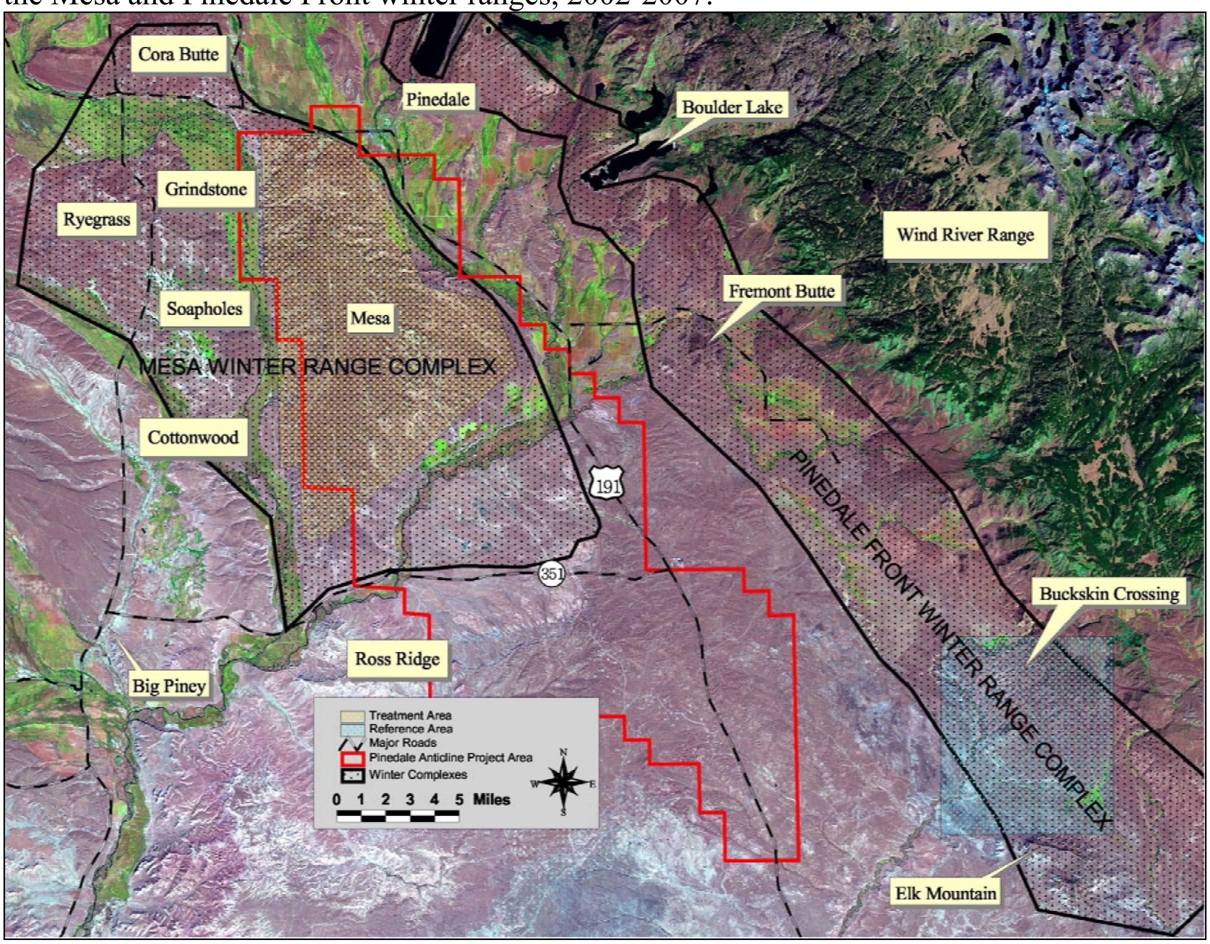

Figure 2-1. Location of the Mesa and Pinedale Front Winter Range Complexes.

METHODS

Helicopter net-gunning was used to capture adult (≥ 1.5 years) female mule deer across the Mesa and Pinedale Front winter ranges. Deer capture on the Mesa was restricted to the northern end of the PAPA in early winter, where deer congregated prior to moving on to their respective winter ranges. Deer capture in the Pinedale Front was restricted to the Big Sandy area; bounded to the north and west by the Big Sandy River, east to the Prospects, and south to Elk Mountain. Similar to the Mesa, deer congregated in this area during early winter. Captured deer in both areas were fitted with global positioning system (GPS) or traditional very high frequency (VHF) radio-collars. The primary purpose of the GPS collars was to provide accurate and reliable data to assess winter distribution patterns across years, while the VHF collars were monitored approximately once per month and intended to maintain an adequate sample size for estimating survival rates (see Section 5). Both types of collars were equipped with mortality sensors that changed pulse rate if the collar remained stationary for more than 8 hours. The GPS collars built after 2000 were store-on-board units capable of storing approximately 3,000 locations and programmed to obtain fixes every 1–3 hours during winter months (November 1– April 15), depending on model type (Generation II or III). Generation III models were upgraded in 2004 and 2005 to collect daily locations during the non-winter months. Each GPS collar was equipped with a remote release mechanism programmed to activate on a specified date (April 15), so that collars could be retrieved and data downloaded. We estimated emigration rates for the Mesa by determining how many radiomarked deer were initially captured on the Mesa and later moved off the Mesa to surrounding winter ranges.

We plotted GPS deer locations collected during each winter to generate winter distribution maps. For the purposes of this section we made 3 maps for most winter periods, including: 1) a map depicting all the GPS locations from the Mesa and Pinedale Front, color coded according to winter range, 2) a map depicting GPS locations in the Mesa winter range, color coded by individual animal, and 3) a map depicting GPS locations in the Pinedale Front winter range, color coded by individual animal.

We used the R statistics and graphing environment (R Development Core Team 2007) to calculate average daily movement rates. Daily movement rates of individual deer were calculated for each day and then averaged across months (January, February, March), such that our sample size was the number of GPS-collared deer. We used an ANOVA to examine differences between months, years, and study areas (Mesa vs. Pinedale Front).

Because winter severity can influence movement and distribution patterns we used field observations and consultation with agency field personnel to characterize each winter as mild, normal, or severe.

RESULTS

Winters 1998-99 and 1999-00

Capture: Between February 1998 and March 1999 we captured and radio-collared 65 (50 VHF, 15 GPS) mule deer on the Mesa. The GPS collars were not equipped with remote release mechanisms and the marked deer had to be re-captured to recover the collars. The programming schedule for the GPS collars was as follows:

Generation I GPS collars:

- obtain 1 location every 25 hours March 1 – March 31
- obtain 1 location every 9 hours April 1 – June 15
- obtain 1 location every 25 hours June 16 – September 30
- obtain 1 location every 9 hours October 1 – February 28

GPS Data Collection and Deer Distribution: We collected 1,435 locations from 15 GPS-collared deer during the 1998-99 and 1999-00 winters (Figure 2-2). The number of locations for each deer ranged from 2 to 259. We collected 1,026 locations from 50 VHF-collared deer during the 1998-99 and 1999-00 winters (Figure 2-2). The number of locations for each deer ranged from 1 to 48. We characterized both winters as normal. Because the capture efforts during the 1998-99 winter occurred late in the year (i.e., February and March), we grouped deer locations across winters. Winter distribution and movements were variable among deer. Most deer arrived in early to mid-December and began migrating north in late-March or early-April.

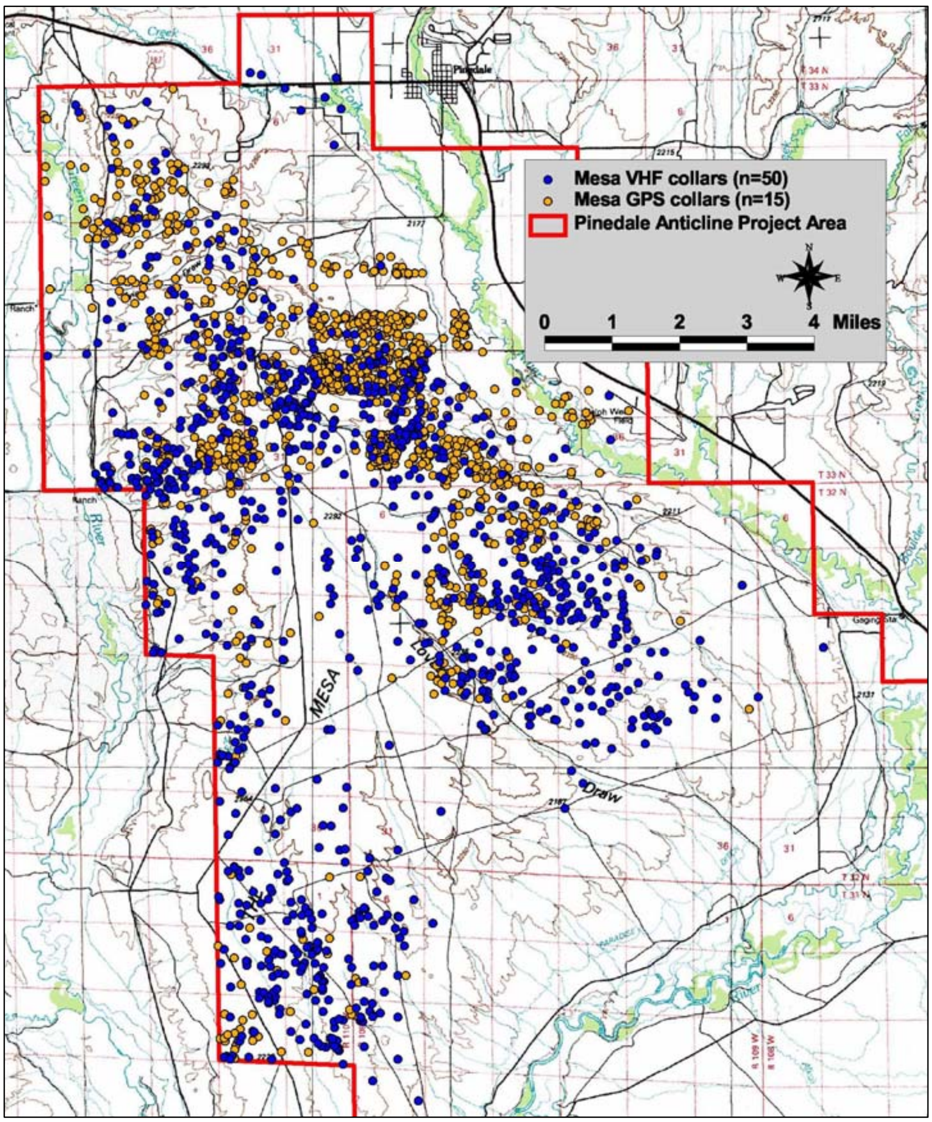

Figure 2-2. Winter locations (n=1,280) of 90 radio-collared deer on the Mesa, February 1998–April 2000.

Winter 2000-01

Capture: This was the final year of Phase I. We captured and radio-collared 10 mule deer on the Mesa on January 1, 2001. This was the first year the Generation II GPS collars were available. Collars were equipped with remote-release mechanisms programmed to activate on April 15, 2001. The programming schedule for collars was as follows:

Generation II GPS collars:

- obtain 1 location every hour January 1, 2001-April 15, 2001

GPS Data Collection and Deer Distribution: We collected 24,817 locations from 10 GPS-collared deer during the 2000-01 winter (Figure 2-3). We characterized this winter as normal. We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on the Mesa (Figure 2-3). Winter distribution and movements were variable among deer, but most deer occupied distinct winter home ranges after migrating through the north end of the Mesa in early and late-winter. Deer tended to move from north to south as winter progressed, and then returned north as winter conditions improved or spring migrations began. Most deer arrived in early to mid-December and began migrating north in late-March or early-April.

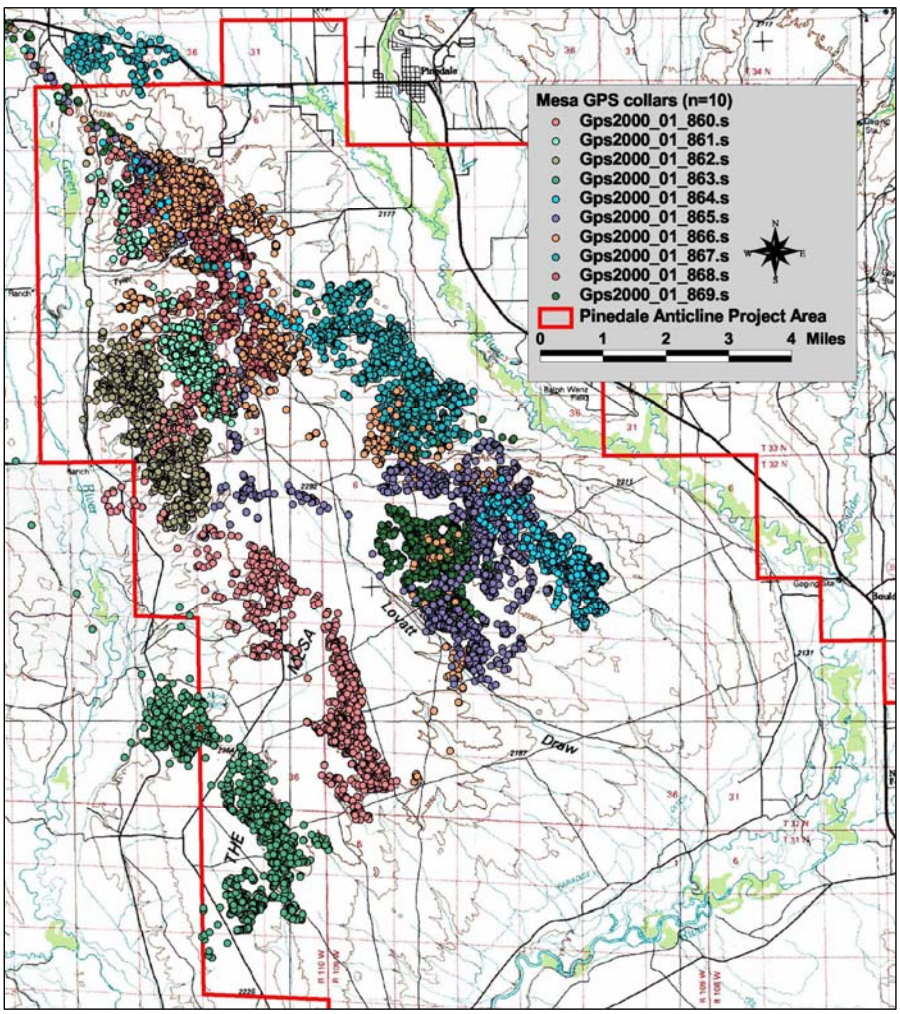

Figure 2-3. Winter locations of 10 GPS-collared deer on the Mesa, January 2001–April 2001.

Daily Movement Rates of GPS-collared Deer: Average daily movement rates of GPS-collared deer were 2.2 km/day in January, February, and March 2001 (Figure 2-4). Daily movement rates did not differ across months.

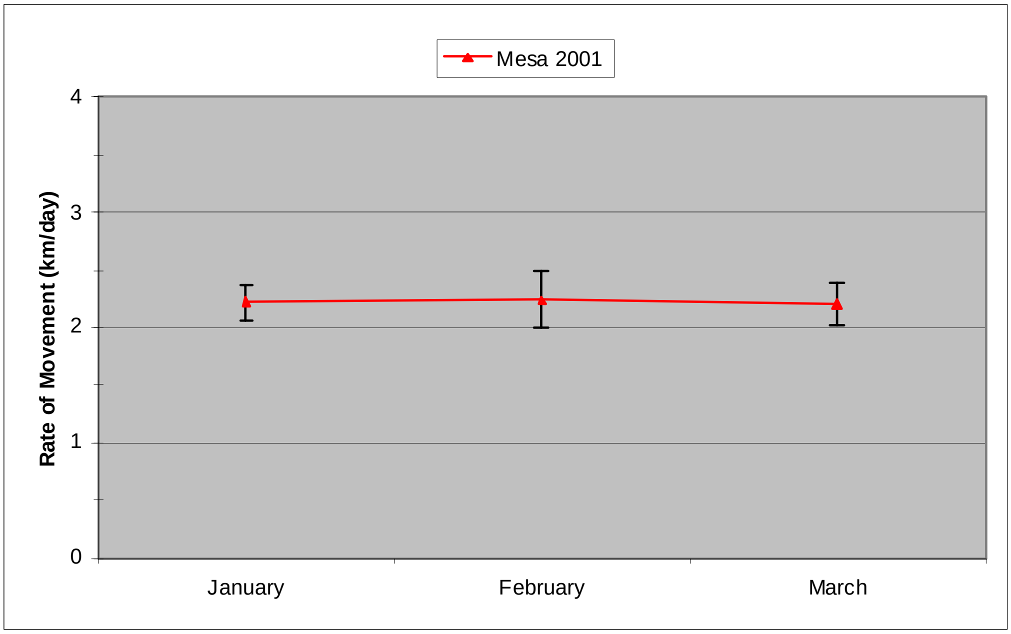

Figure 2-4. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa Winter Range, January – March, 2001.

Winter 2001-02

Capture: This year was considered a pilot study and no deer were captured in the Pinedale Front. We captured and radio-collared 15 mule deer on the Mesa on January 3, 2002. Of those, 9 were equipped with Generation II and 6 with Generation III GPS radio-collars. Collars were equipped with remote-release mechanisms programmed to activate on April 15, 2002. However, collars were programmed to collect locations for 2 consecutive winters such that we could easily place them on a new sample of deer following the first winter and to ensure data collection would continue in case the remote-release mechanism malfunctioned. The programming schedule for collars was as follows:

Generation II GPS collars:

- obtain 1 location every 3 hours January 3, 2002 – April 15, 2002
- obtain 1 location every 3 hours December 20, 2002-April 15, 2003

Generation III GPS collars:

- obtain 1 location every 2 hours January 3, 2002 – April 15, 2002
- obtain 1 location every 2 hours November 01, 2002-April 15, 2003

GPS Data Collection and Deer Distribution: We collected 17,341 locations from 16 GPS-collared deer during the 2001-02 winter (Figure 2-5), including 1 collar that operated for consecutive winters (2000-01 and 2001-02) on the same deer (#865). Deer (#865) was a

Generation II collar captured in 2000 that was not found during monitoring flights, but was eventually retrieved in the spring of 2002.

We characterized this winter as normal. We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on the Mesa (Figure 2-5). Winter distribution and movements were variable among deer, but most deer occupied distinct winter home ranges after migrating through the north end of the Mesa in early and late-winter. Deer tended to move from north to south as winter progressed, and then returned north as winter conditions improved or spring migrations began. Most deer arrived in early to mid-December and began migrating north in late-March or early-April.

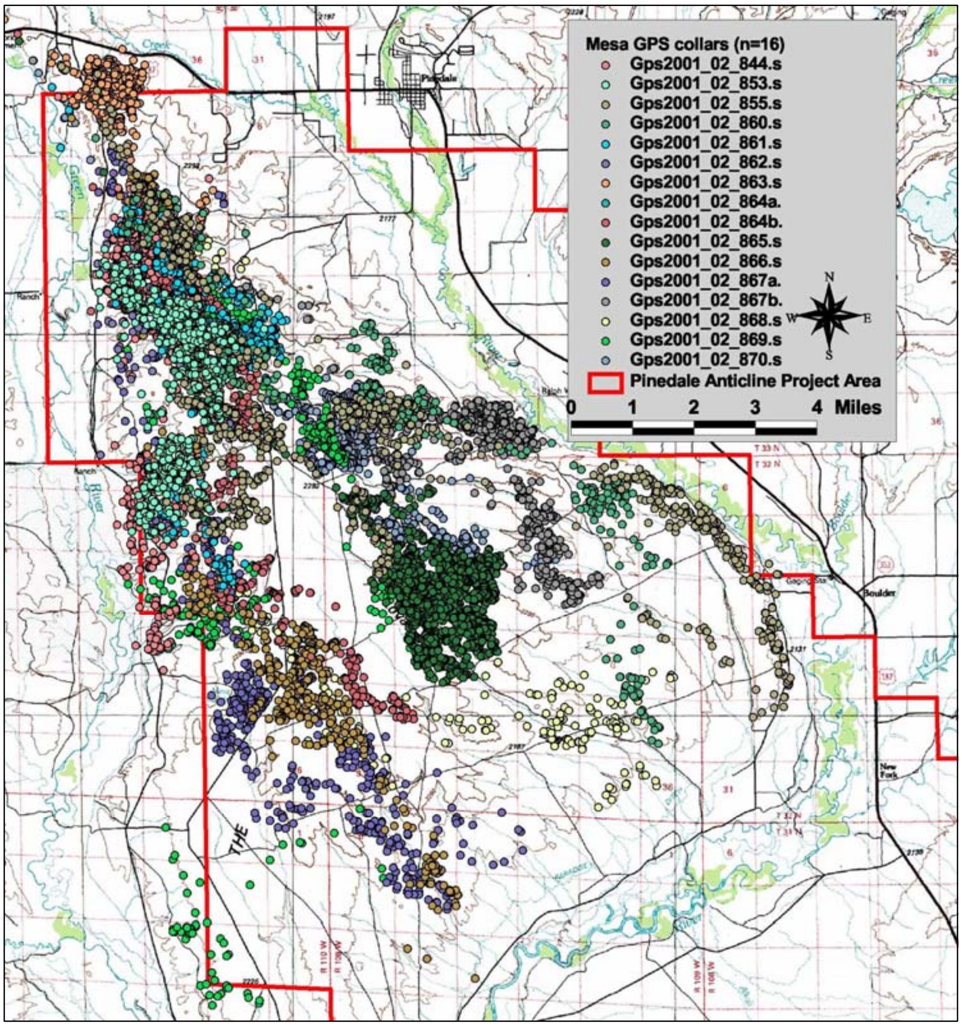

Figure 2-5. Winter locations of 16 GPS-collared deer on the Mesa, December 2001–April 2002.

Daily Movement Rates of GPS-collared Deer: Average daily movement rates of GPS-collared deer in January, February, and March of 2002 were 1.7, 1.8, and 1.8 km/day, respectively (Figure 2-6). Daily movement rates did not differ across months.

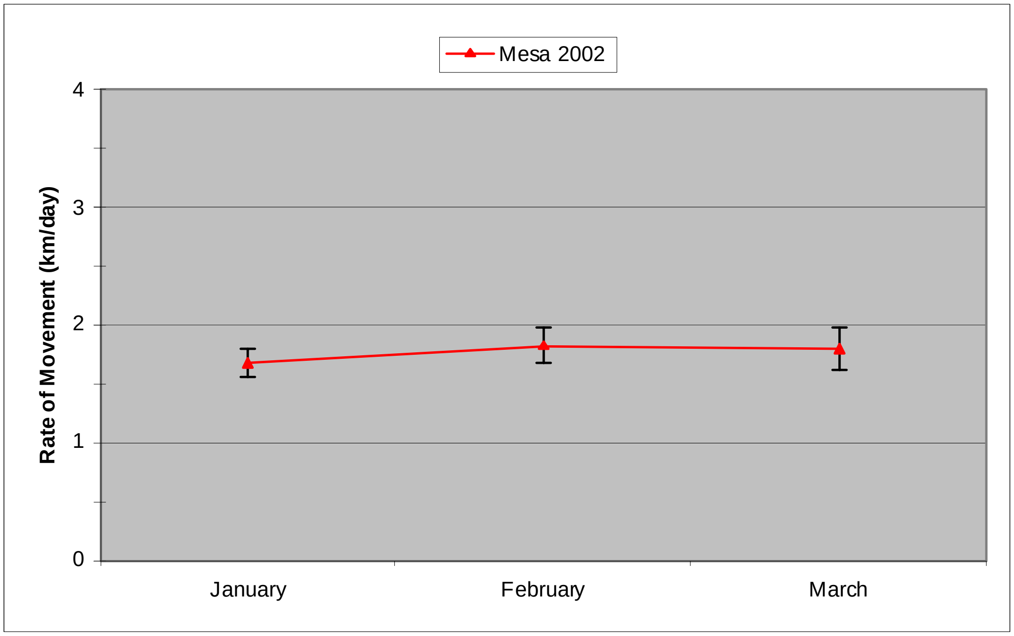

Figure 2-6. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa Winter Range, January – March, 2002.

Winter 2002-03

Capture: Beginning this year we attempted to supplement the number of radio-collars so that we could maintain a sample size of 30 deer in each winter range, including 10 GPS and 20 VHF radio-collars. We captured and radio-collared 54 mule deer on December 19-20, 2002, including 24 on the Mesa and 30 on the Pinedale Front. Of the 54 deer captured, 14 were equipped with GPS radio-collars (4 Mesa, 10 Pinedale Front) and 40 with traditional VHF radio-collars (20 Mesa, 20 Pinedale Front). All GPS collars were equipped with remote-release mechanisms programmed to activate on April 15, 2003. However, collars were programmed to collect locations for 2 consecutive winters such that we could easily place them on a new sample of deer following the first winter and to ensure data collection would continue in case the remote-release mechanism malfunctioned. The programming schedule for collars was as follows:

Generation II GPS collars:

- obtain 1 location every 3 hours December 20, 2002-April 15, 2003

Generation III GPS collars:

- obtain 1 location every 2 hours December 20, 2002-April 15, 2003

GPS Data Collection and Deer Distribution: We collected 19,726 locations from 17 GPS collars (8 Mesa, 9 Pinedale Front) during the 2002-2003 winter (Figure 2-7), including collars from 4 deer (#862, #863, #867b, #868) that operated for consecutive winters (2001-02 and 2002-03). Collar #863 failed to drop off in 2003, but continued to collect locations every 3 hours for 22 months (Figure 2-15; January 2002 - October 2003). It was later captured with helicopter net-gunning during the winter of 2003-04. Consistent with GPS performance in previous years, success rates for GPS fix attempts were very high (~99%) and locations precise (~80% 3-D). We characterized this winter as mild to normal in both the Mesa and Pinedale Front.

Many of the GPS locations collected during November, early-December, late-March, and April occurred on transition ranges and migratory routes located north of the core winter ranges (Figure 2-7). The length of the migratory route(s) adjacent to the winter ranges appeared to be much greater in the Pinedale Front, where late-fall and early-spring deer movements often extended 30 miles beyond the core winter range. Deer from the Mesa migrated through the Trapper's Point Bottleneck and deer along the Pinedale Front migrated along the base of the Wind River Range. Most deer arrived in the core winter ranges in early to mid-December and began migrating north in early-March.

We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on both the Mesa (Figure 2-8) and Pinedale Front (Figure 2-9). Within the Mesa, deer were distributed further north than usual, with no GPS locations occurring in the Lovatt Draw area. Collars (n=3) carried on the same deer for 2 consecutive winters (2001-02 and 2002-03) suggested that this northerly distribution pattern was markedly different than the previous year, and not just a reflection of a new sample of deer. Within the Pinedale Front winter range, deer were distributed from the south end of Muddy Ridge and Buckskin Crossing, south along the Big Sandy River to Elk Mountain. No GPS locations occurred southeast in the Long Draw, Prospects, and Elkhorn Junction areas.

Daily Movement Rates of GPS-collared Deer: Average daily movement rates of GPS-collared deer in the Mesa during January, February, and March of 2003 were 1.9, 1.9, and 2.0 km/day, respectively (Figure 2-10). Average daily movement rates of GPS-collared deer in the Pinedale Front during January, February, and March of 2003 were 2.3, 2.2, and 2.2 km/day, respectively (Figure 2-10). Daily movement rates did not significantly differ between the Pinedale Front and the Mesa.

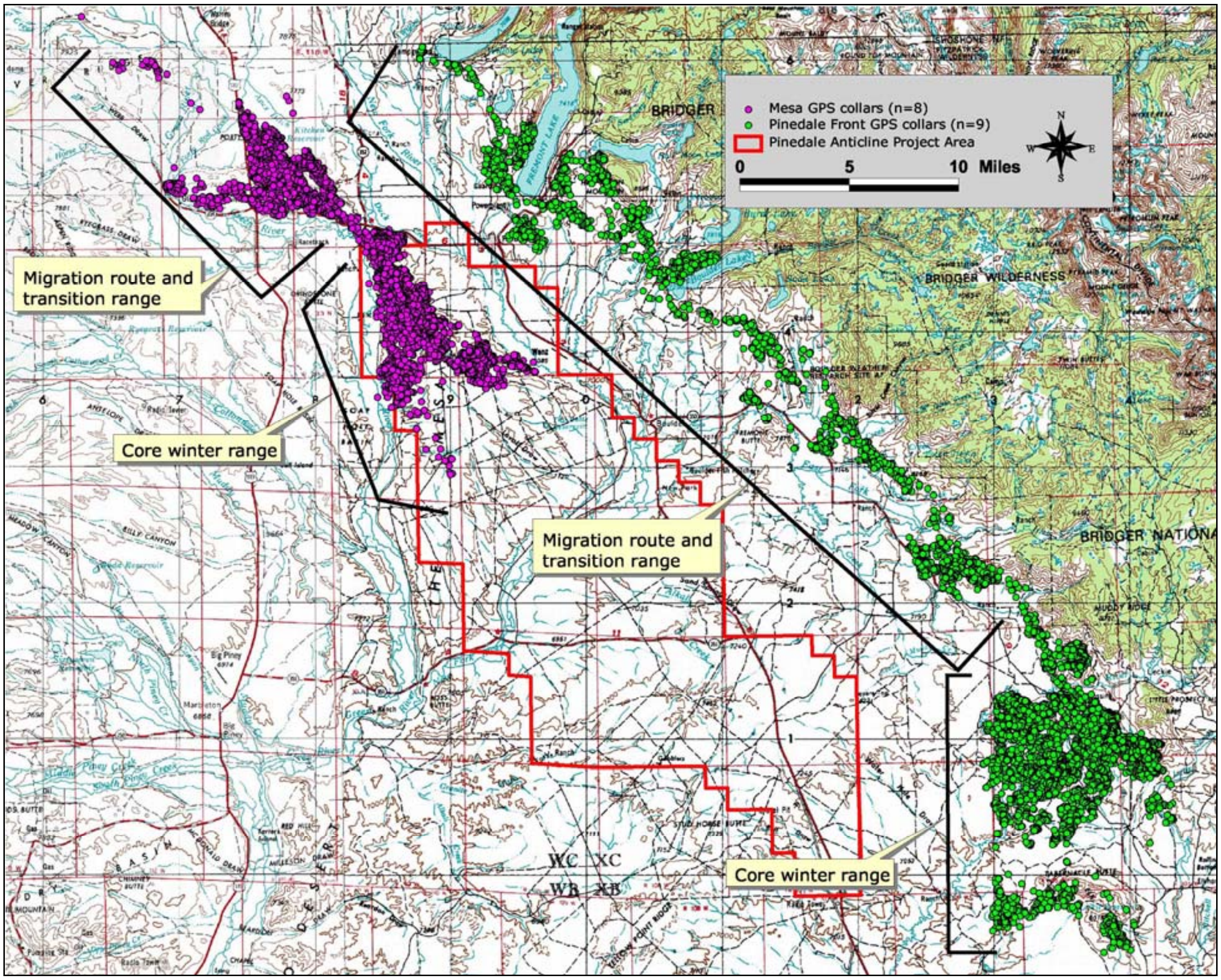

Figure 2-7. Winter locations of 17 GPS-collared deer in the Mesa and Pinedale Front Winter Ranges, November 1, 2002– April 15, 2003.

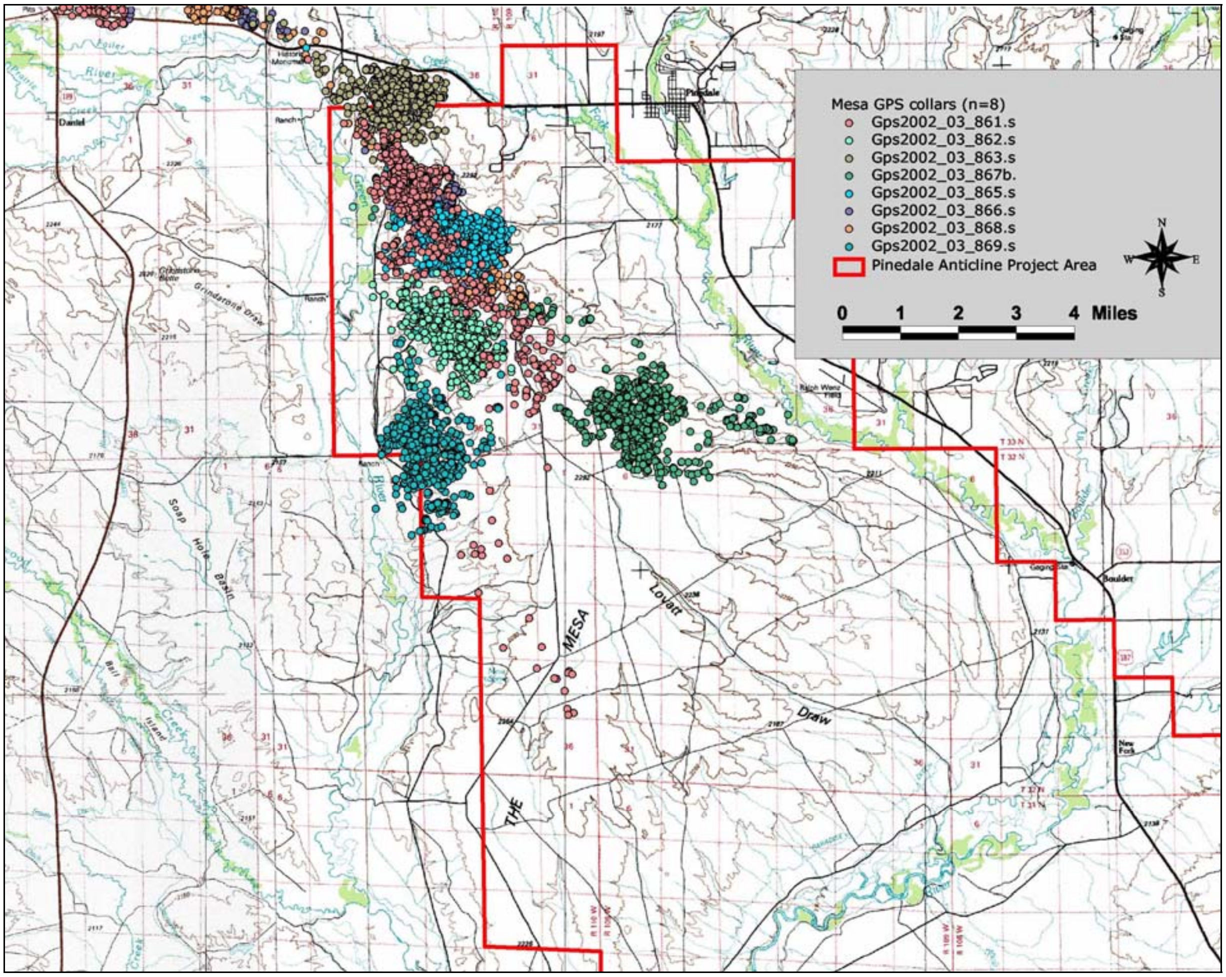

Figure 2-8. Winter locations of 8 GPS-collared deer on the Mesa, November 1, 2002– April 15, 2003.

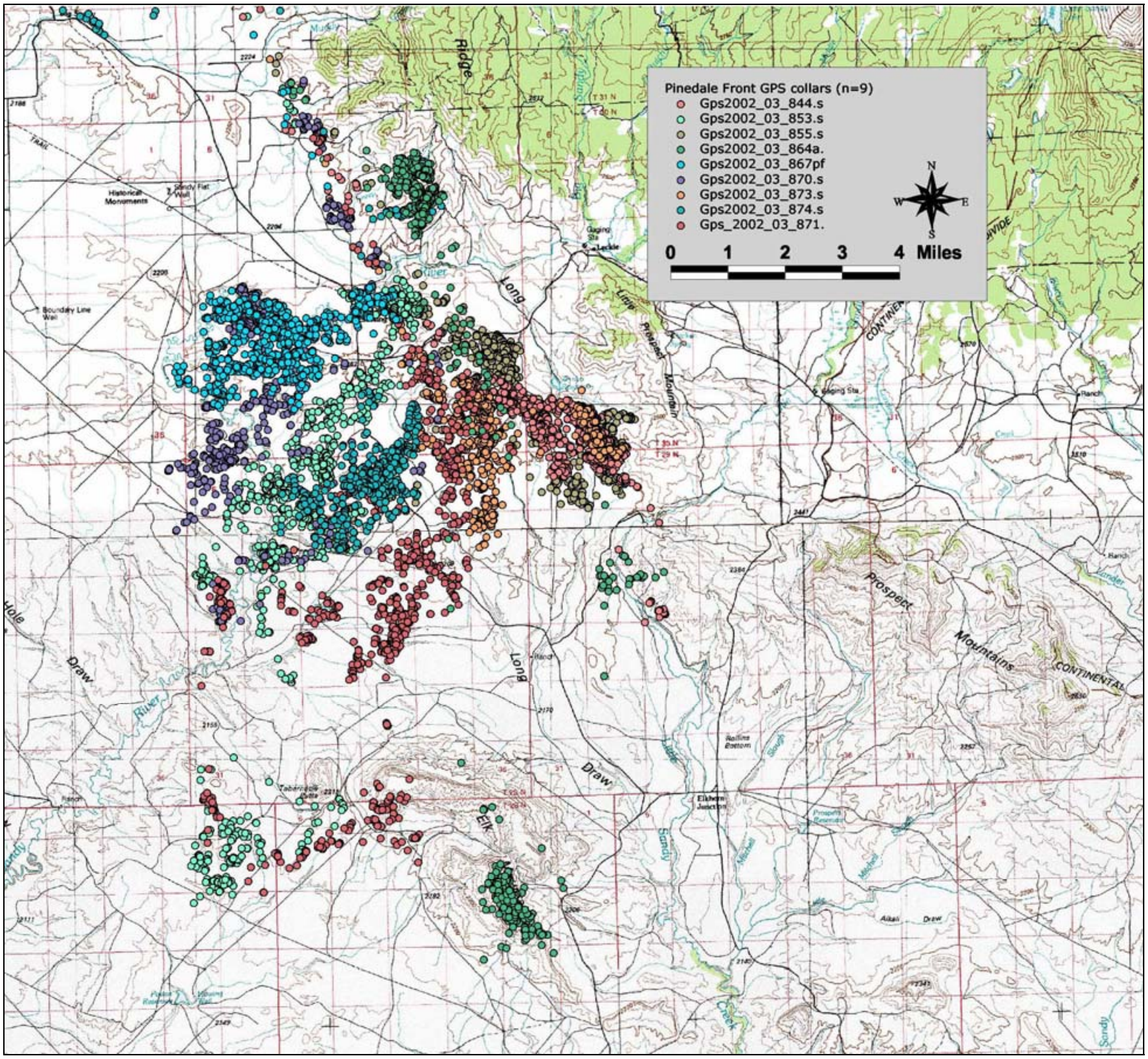

Figure 2-9. Winter locations of 9 GPS-collared deer on the Pinedale Front, November 1, 2002–April 15, 2003.

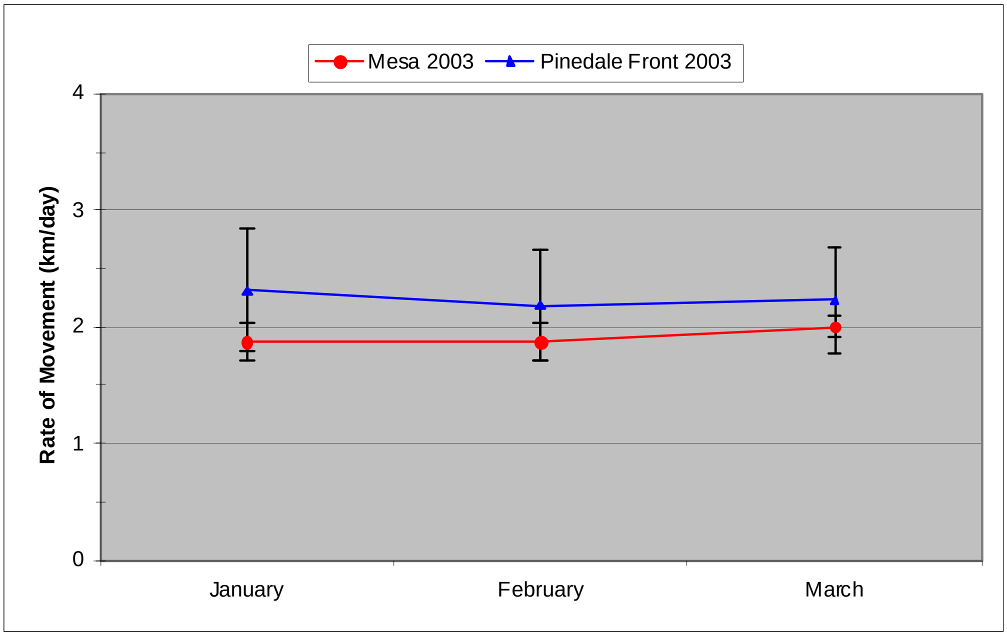

Figure 2-10. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa and Pinedale Front Winter Ranges, January – March, 2003.

Winter 2003-04

Capture: We captured and radio-collared 19 mule deer on December 15, 2003, including 12 on the Mesa and 7 on the Pinedale Front. Of the 19 deer captured, 18 were equipped with GPS radio-collars and 1 with a traditional VHF radio-collar. This year we began to operate approximately half of the GPS collars on the same deer for consecutive years, so we programmed half of the remote-release mechanisms to activate on April 15, 2004 and the other half on April 15, 2005. The programming schedule for collars was as follows:

Generation II GPS collars:

- obtain 1 location every 3 hours December 20, 2003-April 15, 2004

Generation III GPS collars:

- obtain 1 location every 2 hours November 01, 2003-April 15, 2004

GPS Data Collection and Deer Distribution: We collected 25,946 locations from 21 GPS-collared deer (12 Mesa, 9 Pinedale Front) during the 2003-04 winter, including 4 collars (#865, #871, #873, and #874) that contained data for consecutive winters (2002-03 and 2003-04). We characterized this winter as severe in both the Mesa and Pinedale Front, although snowcover melted earlier in the Mesa compared to the Pinedale Front.

Many of the GPS locations collected during November, early-December, late-March, and April occurred on transition ranges and migratory routes located north of the core winter ranges (Figure 2-11). The length of the migratory route(s) adjacent to the winter ranges were much greater in the Pinedale Front, where late-fall and early-spring deer movements extended 30 miles beyond the core winter range. Consistent with previous years, deer from the Mesa migrated through the Trapper's Point Bottleneck and deer along the Pinedale Front migrated along the base of the Wind River Range.

We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on both the Mesa (Figure 2-12) and Pinedale Front (Figure 2-13). Most deer on the Pinedale Front shifted areas of use through the winter and utilized a large portion of their winter ranges. Deer from both winter ranges tended to move from north to south as winter progressed, and then returned north as winter conditions improved or spring migrations began. Most deer arrived in the core winter ranges in early to mid-December and began migrating north in late-March or early-April.

Within the Mesa, deer were distributed across a large area. We documented 1 unusual movement event this winter. Deer #862 (Figure 2.9) was captured on the Mesa on December 18, 2003. This deer moved around the Mesa for 3 weeks after capture and then on January 9, 2004 it suddenly emigrated 20-25 miles southwest. This deer spent the remaining winter months in a different winter range located near the Calpet Road, south of Big Piney. In the spring of 2004 this deer used the same migration route to move back through the western edge of the Mesa, through the Trapper's Point Bottleneck, and onto summer ranges. This deer returned in the fall of 2004, but did not move into the central portion of the Mesa, rather it moved quickly down the western edge and returned to the Big Piney winter range via the migration route it used the year before. Deer #862 was the first GPS-collared deer to leave the Mesa and move on to a different winter range.

Within the Pinedale Front winter range deer were distributed from the south end of Muddy Ridge and Buckskin Crossing, south along the Big Sandy River to Elk Mountain. Deer were also distributed further south and east than previous years, occupying the Squaw Teat, Little Sandy, and Elkhorn Junction areas. The southwest faces of Little Prospect Mountain and the Prospects Mountains also had some deer locations.

Daily Movement Rates of GPS-collared Deer: Consistent with previous years, average daily movement rates of GPS-collared deer in the Mesa during January, February, and March of 2004 were 1.5, 1.5, and 1.5 km/day, respectively (Figure 2-14). Average daily movement rates of GPS-collared deer in the Pinedale Front during January, February, and March of 2004 were 2.1, 2.3, and 2.4 km/day, respectively (Figure 2-14). Daily movement rates were significantly higher in the Pinedale Front compared to the Mesa during February and March.

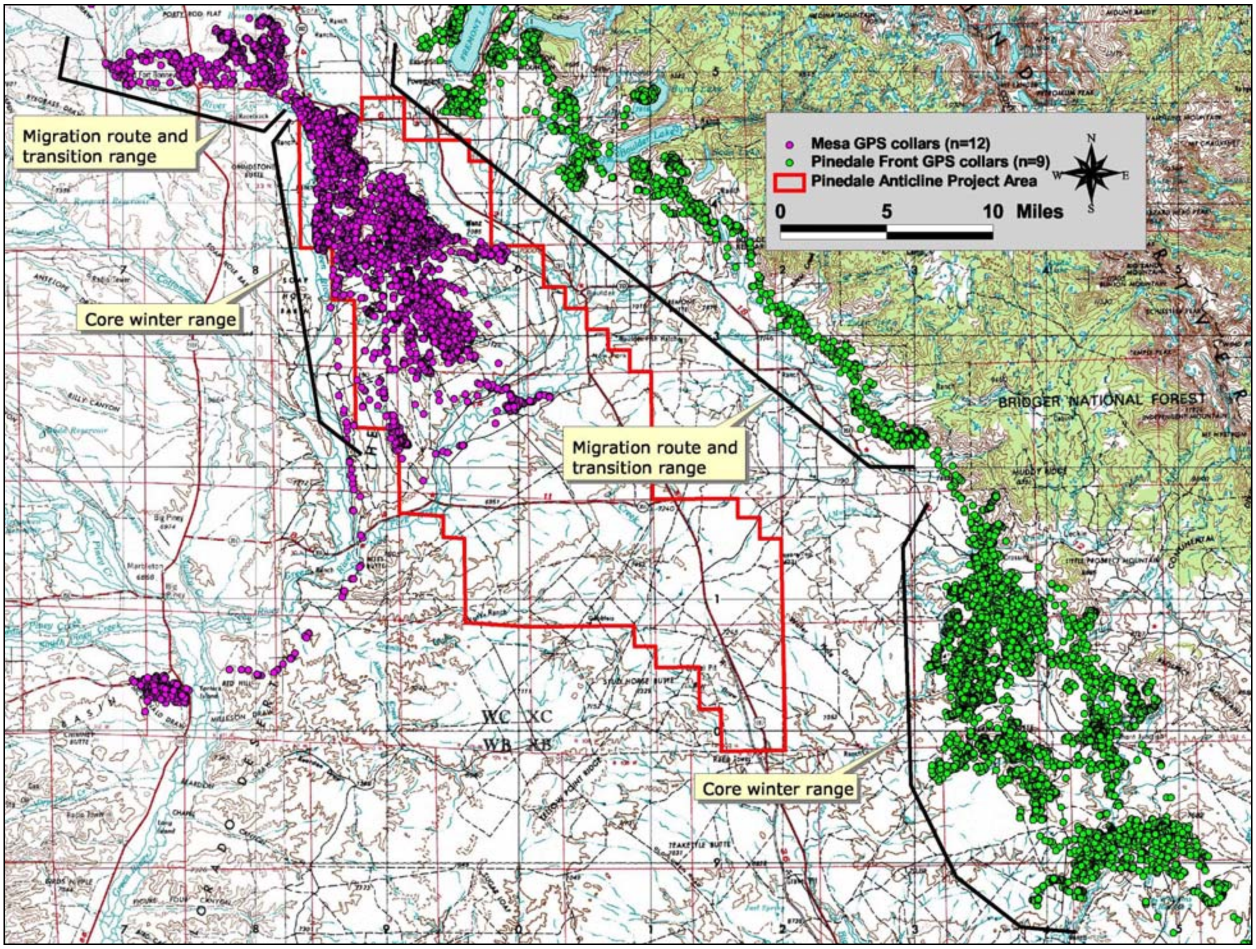

Figure 2-11. Winter locations of 21 GPS-collared deer in the Mesa and Pinedale Front Winter Ranges, November 1, 2003– April 15, 2004.

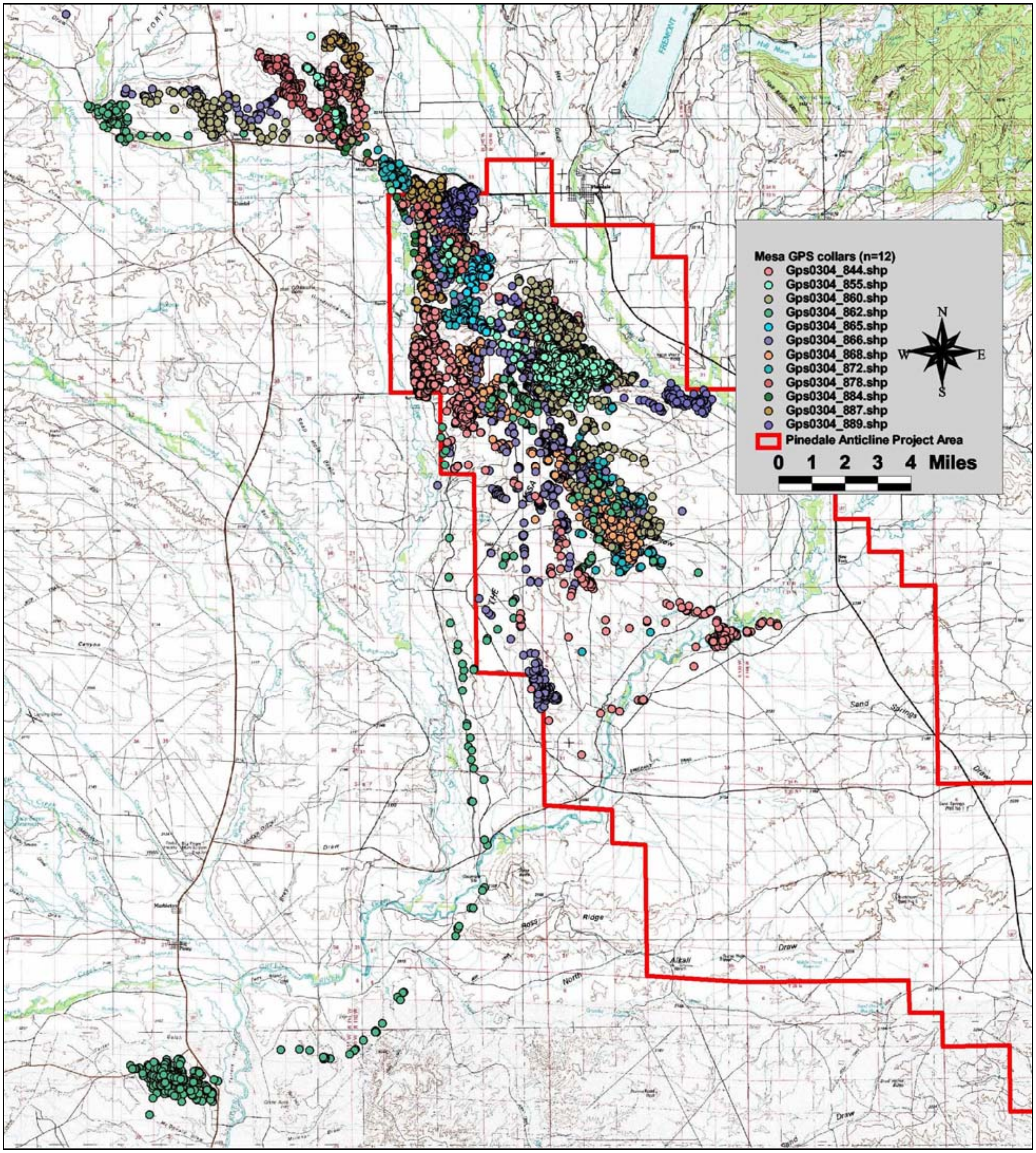

Figure 2-12. Winter locations of 12 GPS-collared deer on the Mesa, November 1, 2003– April 15, 2004.

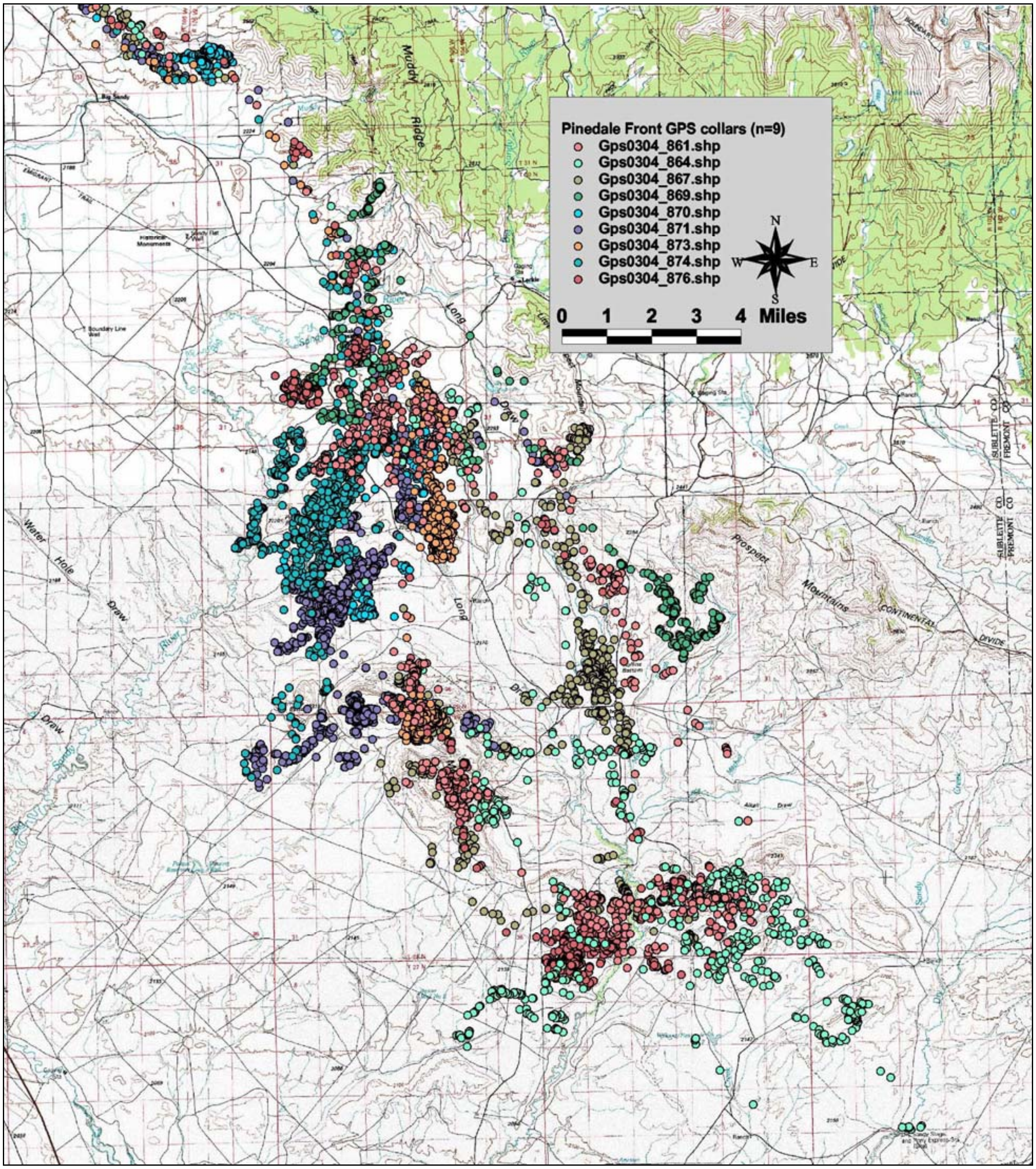

Figure 2-13. Winter locations of 9 GPS-collared deer on the Pinedale Front, November 1, 2003–April 15, 2004.

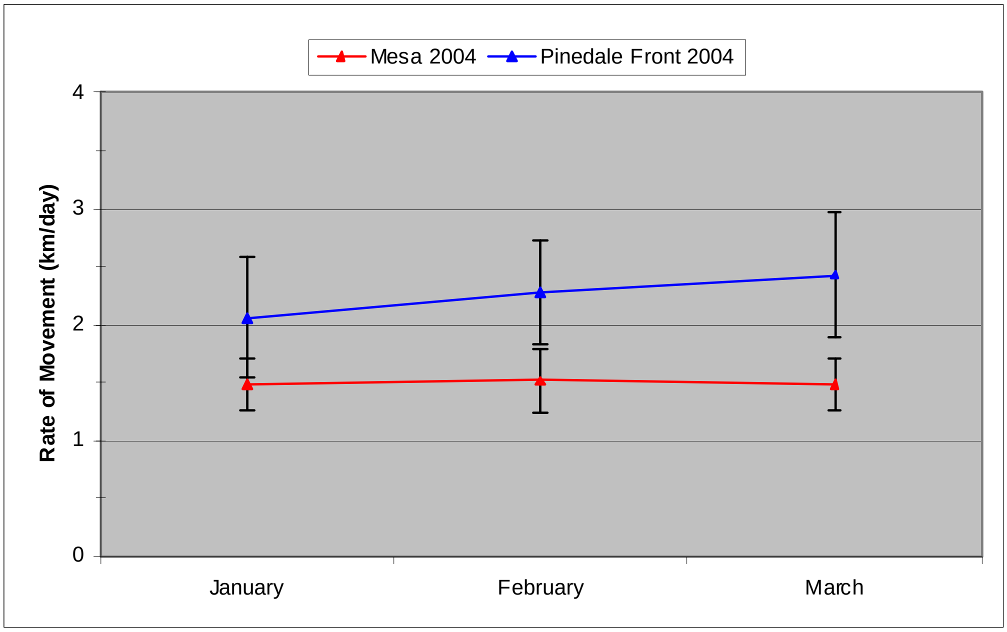

Figure 2-14. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa and Pinedale Front Winter Ranges, January – March, 2004.

Winter 2004-05

Capture: We captured and radio-collared 27 adult female deer on December 19, 2004, including 17 on the Mesa and 10 in the Pinedale Front. Of the 27 deer captured, 20 were equipped with GPS radio-collars and 7 with traditional VHF radio-collars. We programmed half of the GPS collars to drop off on April 15, 2005 and the other half to drop on April 15, 2006. The programming schedule for GPS collars was as follows:

- obtain 1 location every 2 hours December 20, 2004 – April 15, 2005
- obtain 1 location every 25 hours April 16, 2005 – October 31, 2005
- obtain 1 location every 2 hours November 01, 2005 – April 15, 2006

GPS Data Collection and Deer Distribution: We collected 46,688 locations from 32 GPS collars (22 Mesa, 10 Pinedale Front) during the 2004-05 winter, including 11 collars (#844, #855, #862, #864, #866, #867, #868, #870, #884, #887, and #889) that contained data for consecutive winters (2003-04 and 2004-05). We characterized this winter as normal in both the Mesa and Pinedale Front.

Many of the GPS locations collected during November, early-December, late-March, and April occurred on transition ranges and migratory routes located north of the core winter ranges (Figure 2-15). The length of the migratory route(s) adjacent to the winter ranges were much greater in the Pinedale Front, where late-fall and early-spring deer movements often extended 30 miles beyond the core winter range. Consistent with previous years, deer from the Mesa migrated through the Trapper's Point Bottleneck and deer along the Pinedale Front migrated along the base of the Wind River Range.

We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on both the Mesa (Figure 2-16) and Pinedale Front (Figure 2-17). Most deer in the

Pinedale Front shifted areas of use through the winter and utilized a large portion of their winter ranges. Deer from both winter ranges tended to move from north to south as winter progressed, and then returned north as winter conditions improved or spring migrations began. Most deer arrived in the core winter ranges in early to mid-December and began migrating north in late-March or early-April.

We documented 2 unusual movement events this winter in the Mesa. First, was Deer#862 which apparently emigrated off the Mesa last winter to occupy a different winter range. This deer returned in December of 2004, but did not move into the central portion of the Mesa, rather it moved quickly down the western edge and returned to the Big Piney winter range via the migration route it used the year before. The second unusual movement was a deer (#887) that occupied the western breaks of the Mesa during the 2003-04 winter and migrated through the Trapper's Point Bottleneck in the spring of 2004 on its way to summer range. However, in November of 2004 this deer returned to the Mesa via the Pinedale Front migration route that runs along the base of the Wind River Range. And then in the spring of 2005, Deer #887 again migrated off the Mesa through the Trapper's Point Bottleneck. Of all the GPS-collared deer (>70) we have monitored on the Mesa, Deer #887 was the first to migrate onto the Mesa from the Pinedale Front and leave via Trapper's Point. It is important to note that although this deer migrated onto the Mesa from the Pinedale Front, it did not winter on the Pinedale Front and it was not originally captured on the Pinedale Front. Data from marked deer still indicate that the Mesa and Pinedale Front winter ranges are distinct, with little or no interchange between them.

Within the Pinedale Front winter range deer were distributed from the south end of Muddy Ridge and Buckskin Crossing, south along the Big Sandy River to Elk Mountain. Deer were also distributed southeast, occupying the Squaw Teat, Little Sandy, and Elkhorn Junction areas.

Daily Movement Rates of GPS-collared Deer: Consistent with previous years, average daily movement rates of GPS-collared deer in the Mesa during January, February, and March of 2005 were 1.7, 1.7, and 1.7 km/day, respectively (Figure 2-18). Average daily movement rates of GPS-collared deer in the Pinedale Front during January, February, and March of 2005 were 2.4, 2.4, and 2.4 km/day, respectively (Figure 2-18). Daily movement rates were significantly higher in the Pinedale Front compared to the Mesa.

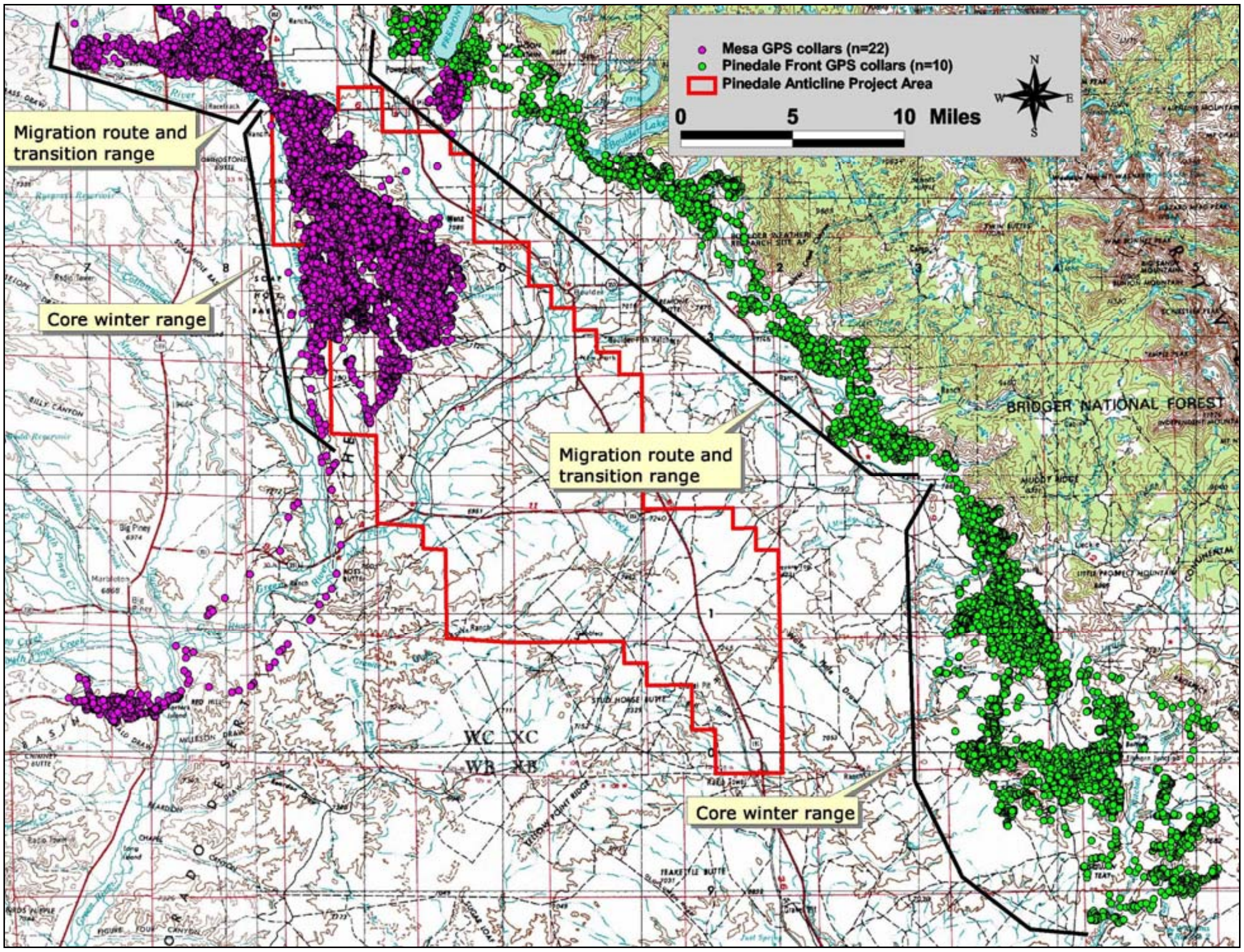

Figure 2-15. Winter locations of 32 GPS-collared deer in the Mesa and Pinedale Front Winter Ranges, November 1, 2004– April 15, 2005.

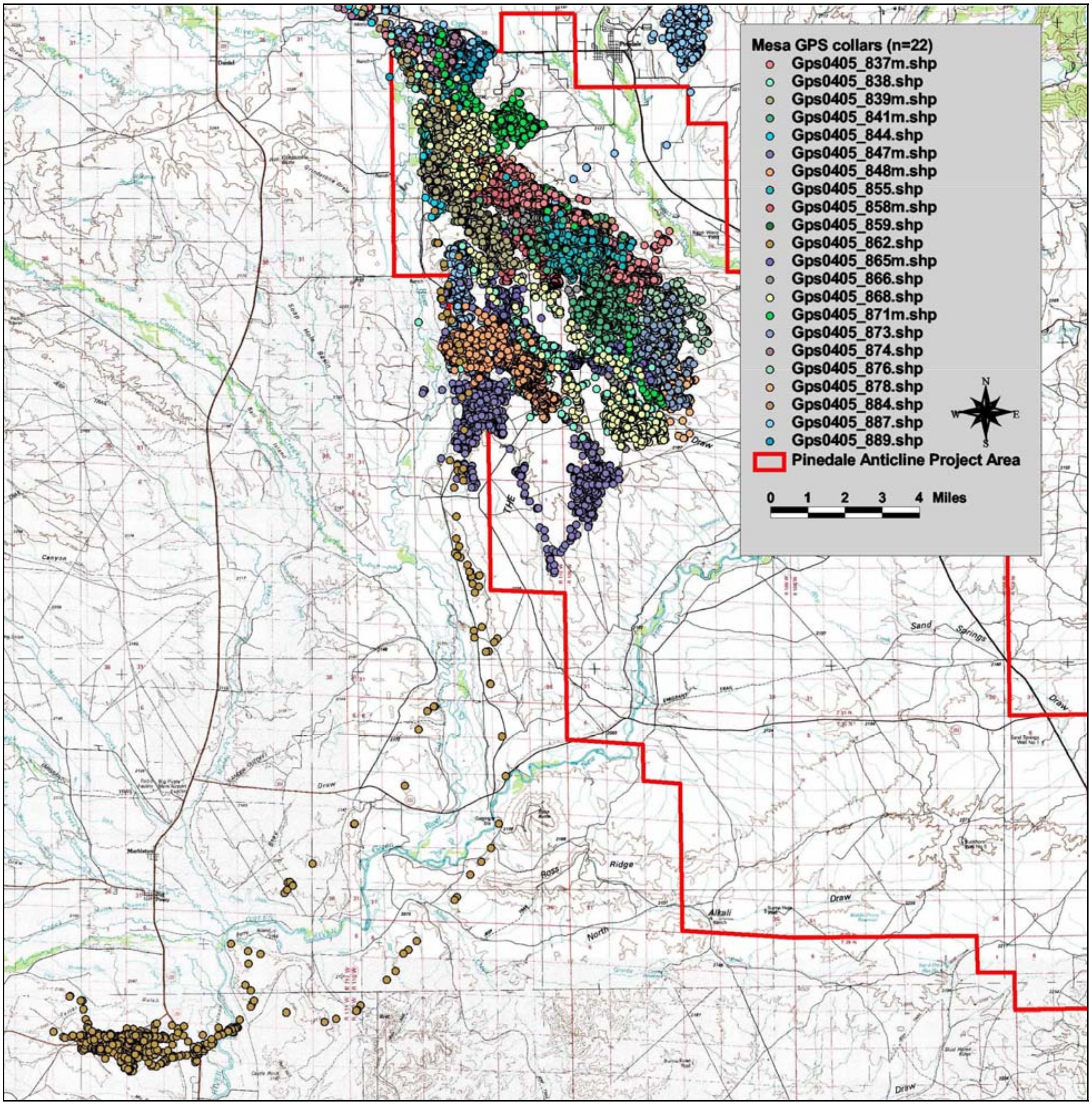

Figure 2-16. Winter locations of 22 GPS-collared deer on the Mesa, November 1, 2004 – April 15, 2005.

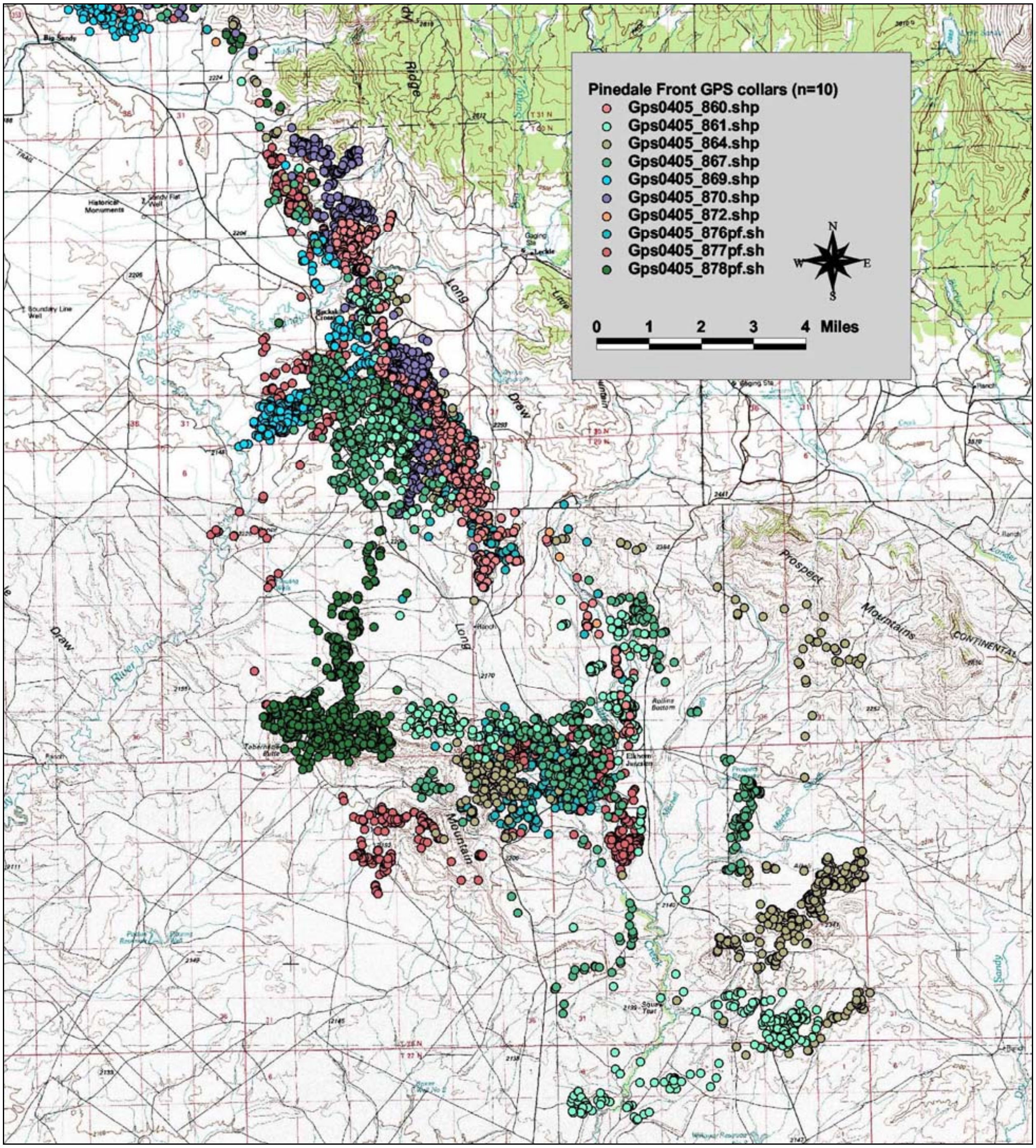

Figure 2-17. Winter locations of 10 GPS-collared deer on the Pinedale Front, November 1, 2004 – April 15, 2005.

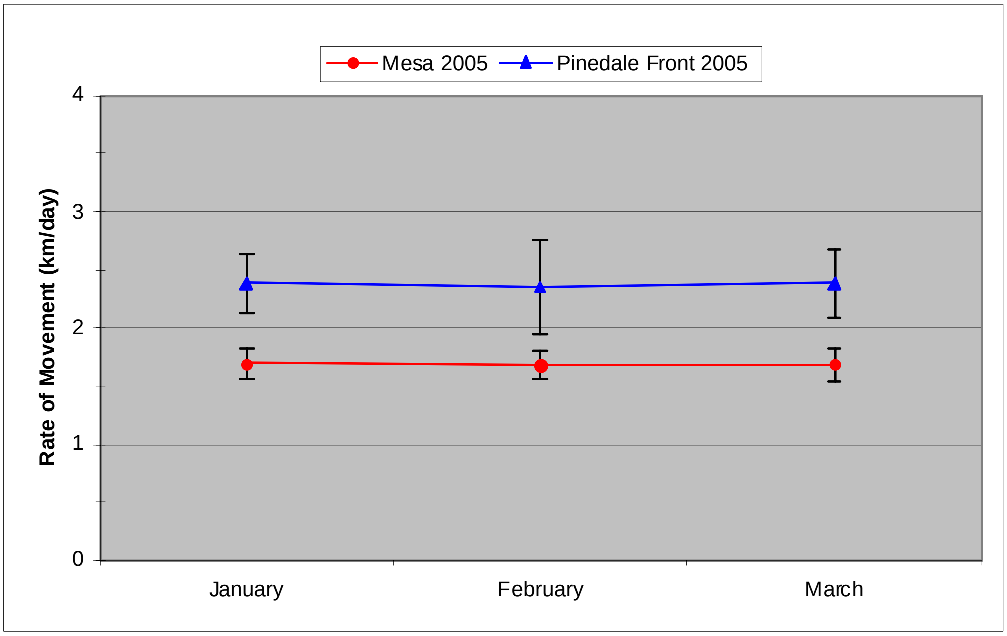

Figure 2-18. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa and Pinedale Front Winter Ranges, January – March, 2005.

Winter 2005-06

Capture: We captured and radio-collared 32 adult female deer on December 12, 2005, including 16 in the PAPA and 16 in the Pinedale Front. Of the 32 deer captured, 20 were equipped with GPS radio-collars and 12 with traditional VHF radio-collars. We programmed half of the GPS collars to drop off on April 15, 2006 and the other half on April 15, 2007. The programming schedule for GPS collars was as follows:

- obtain 1 location every 2 hours December 20, 2005 – April 15, 2006
- obtain 1 location every 25 hours April 16, 2006 – October 31, 2006
- obtain 1 location every 2 hours November 01, 2006 – April 15, 2007

GPS Data Collection and Deer Distribution: We collected 50,416 locations from 29 GPS collars (20 in the PAPA, 9 in Pinedale Front) during the 2005-06 winter, including 10 collars (#837, #839, #841, #847, #848, #858, #865, #871, #877 and #878) that contained data for consecutive winters 2004-05 and 2005-06, and 12 collars (#844, #855, #887, #870, #860, #862, #869, #867, #866, #861, #872, #896) that contained data for consecutive winters 2005-06 and 2006-07. Additionally, 23 of the collars collected daily locations during the non-winter months (15 April – 1 November, 2005).

We characterized this winter as normal in the Mesa and severe in the Pinedale Front. Many of the GPS locations collected during November, early-December, late-March, and April occurred on transition ranges and migratory routes located north of the core winter ranges (Figure 2-19). The length of the migratory route(s) adjacent to the winter ranges were much greater in the Pinedale Front, where late-fall and early-spring deer movements often extended 30 miles beyond the core winter range. Consistent with previous years, deer from the Mesa migrated through the Trapper's Point Bottleneck and deer along the Pinedale Front migrated along the base of the Wind River Range.

We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on both the Mesa (Figure 2-20) and Pinedale Front (Figure 2-21). Most deer in the Pinedale Front shifted areas of use through the winter and utilized a large portion of their winter ranges. Deer from both winter ranges tended to move from north to south as winter progressed, and then returned north as winter conditions improved or spring migrations began. Most deer arrived in the core winter ranges in early to mid-December and began migrating north in late-March or early-April.

We documented one unusual movement event this winter in the Mesa with Deer #838. This deer spent December and January on the Mesa and then migrated 1-6 miles south of the New Fork River and spent February and March on a small winter range located along US 191. We have never documented any migratory deer wintering in this area. During Phase I of the Sublette Deer Study (Sawyer and Lindzey 2001), we radio-collared 3 deer in that area between Sand Springs Draw and US 191. We monitored those deer for 3 years and found that they were part of a small (50-60) herd of resident deer. Deer#838 is the first deer we have captured on the Mesa and documented moving south along US 191.

Within the Pinedale Front winter range deer were distributed from the south end of Muddy Ridge and Buckskin Crossing, south along the Big Sandy River to Elk Mountain during the early part of the winter. By late-February however, winter conditions were severe and most deer moved to the south end of Elk Mountain and southeast into the Squaw Teat and Little Sandy River areas. We documented several unusual movement events this winter in the Pinedale Front with Deer #862, #866, and #877. These deer spent most of January and February in the core winter range of the Pinedale Front and then migrated another 10-15 miles south to US 28. Deer #877 continued south and spent March in an area just east of Pacific and Oregon Buttes. Deer #862 continued south to Rock Cabin Creek and Oregon Buttes. These deer were the first that we have documented moving this far south. These extreme southerly movements were assumed to be a response to the severe winter conditions along the Pinedale Front.

Daily Movement Rates of GPS-collared Deer: Consistent with previous years, average daily movement rates of GPS-collared deer in the Mesa during January, February, and March of 2006 were 1.6, 1.5, and 1.5 km/day, respectively (Figure 2-22). Average daily movement rates of GPS-collared deer in the Pinedale Front during January, February, and March of 2006 were 2.5, 2.1, and 2.1 km/day, respectively (Figure 2-22). Daily movement rates did not significantly differ between the Pinedale Front and the Mesa.

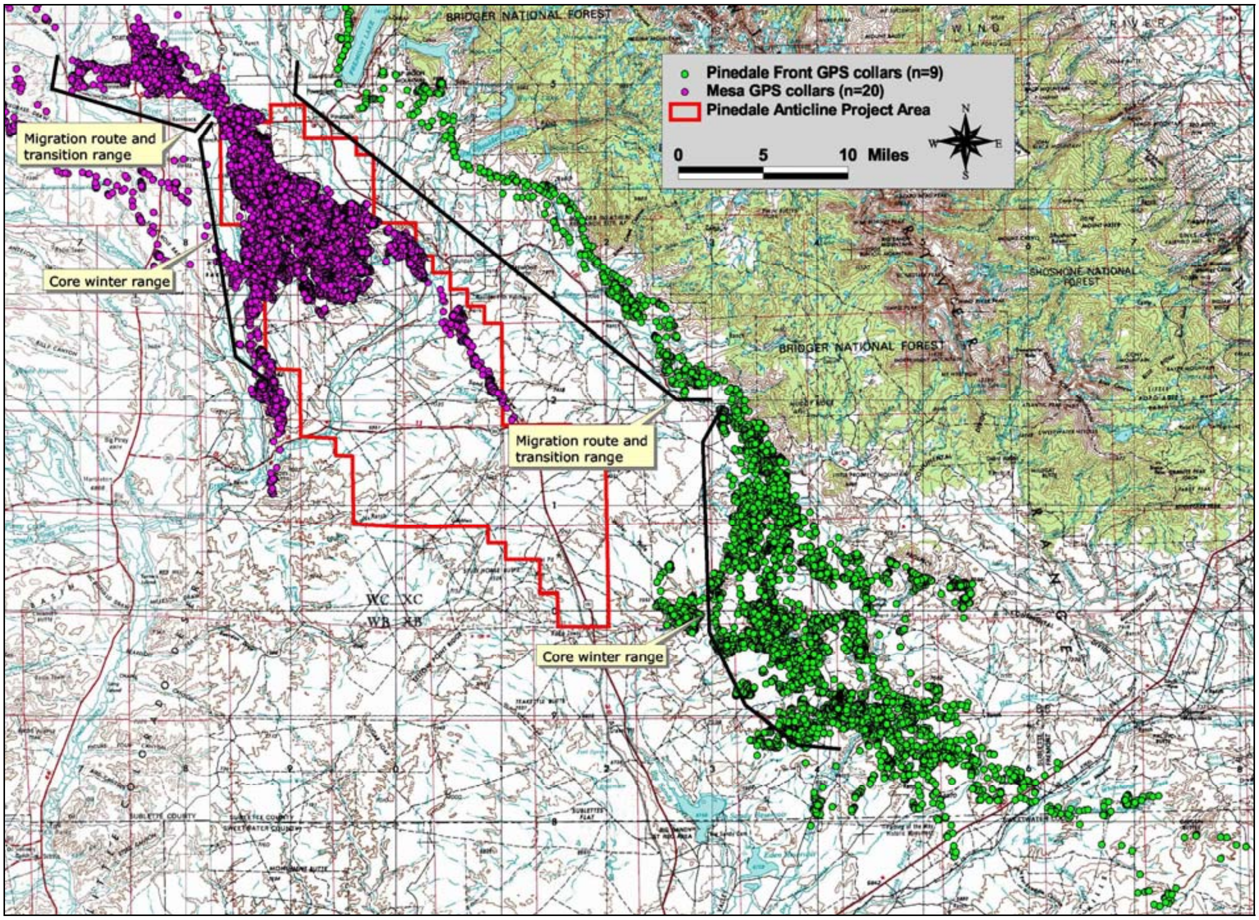

Figure 2-19. Winter locations of 29 GPS-collared deer in the Mesa and Pinedale Front Winter Ranges, November 1, 2005–April 15, 2006.

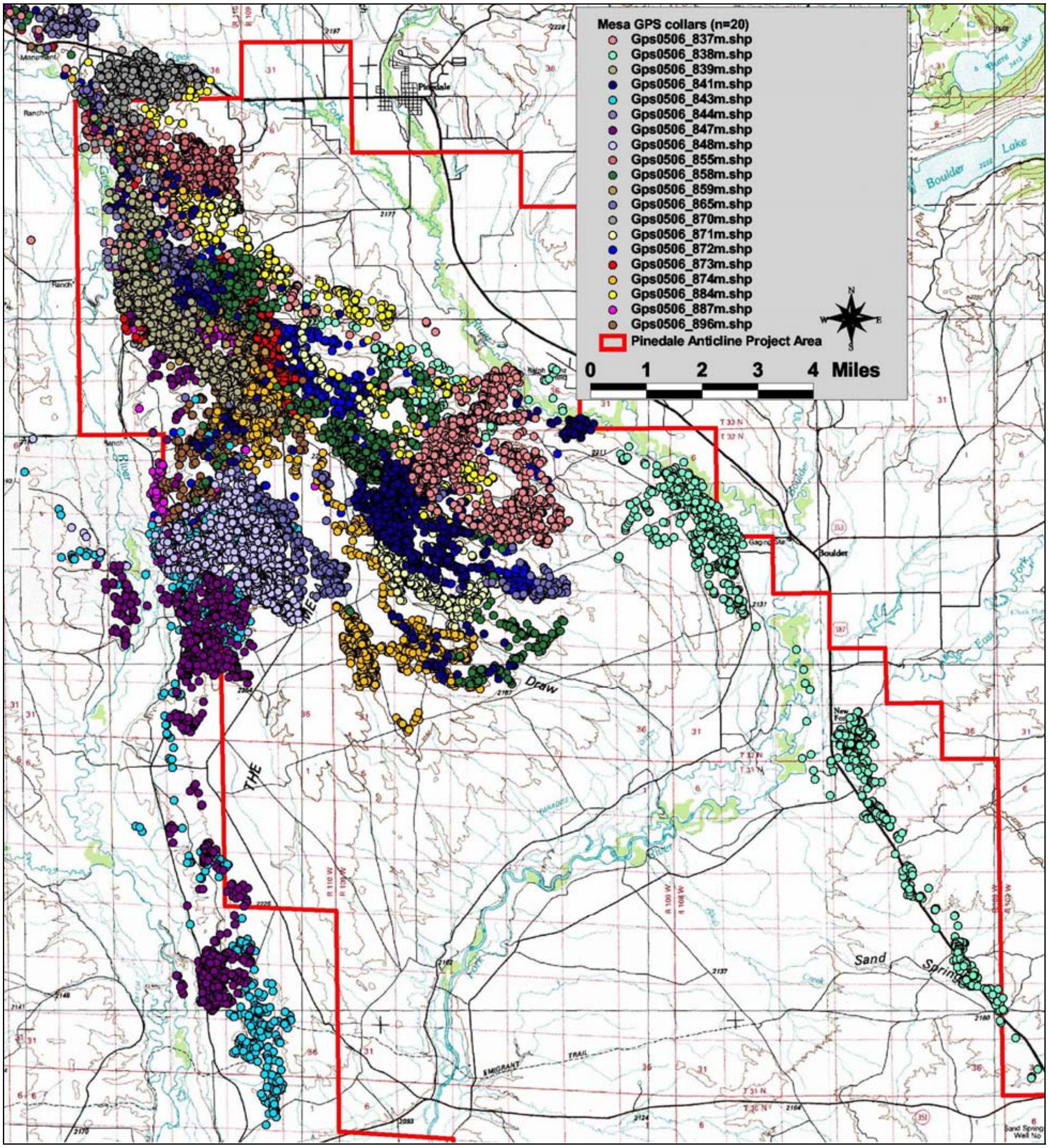

Figure 2-20. Winter locations of 20 GPS-collared deer on the Mesa, November 1, 2005–April 15, 2006.

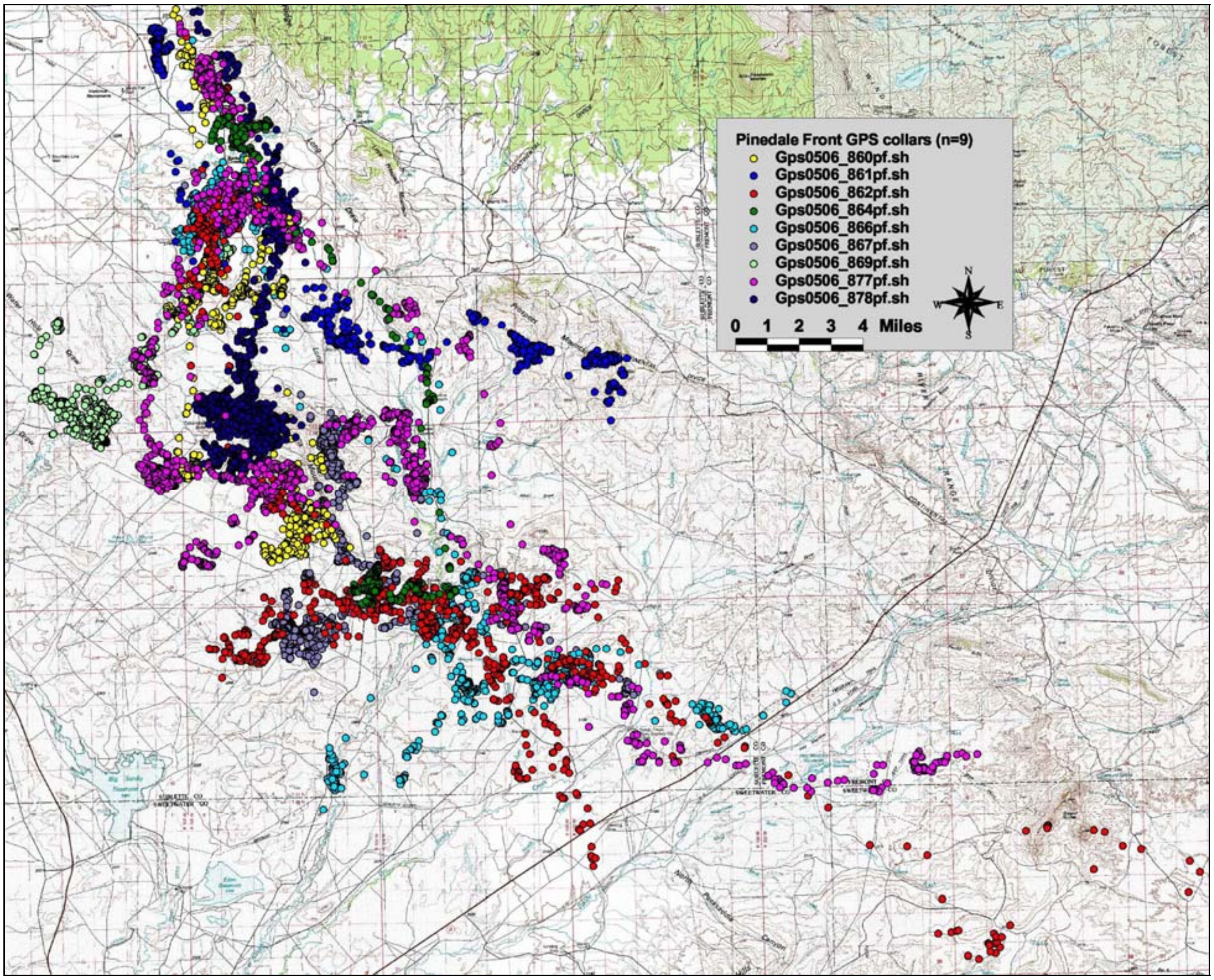

Figure 2-21. Winter locations of 9 GPS-collared deer on the Pinedale Front, November 1, 2005–April 15, 2006.

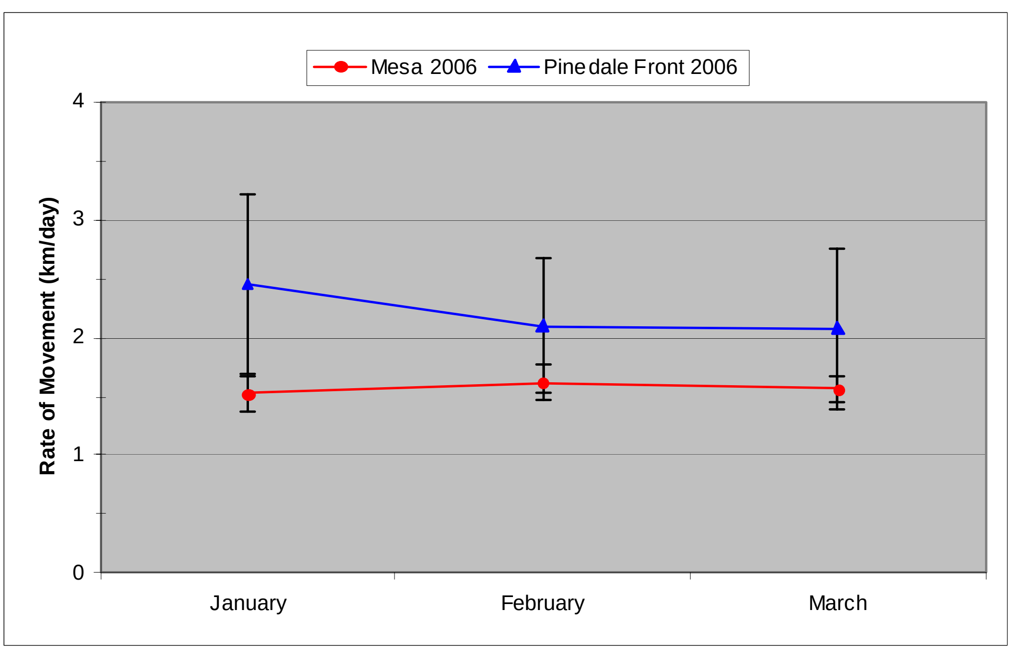

Figure 2-22. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa and Pinedale Front Winter Ranges, January – March, 2006.

Winter 2006-07

Capture: We captured and radio-collared 28 adult female deer on December 10, 2006, including 20 in the PAPA and 9 in the Pinedale Front. Of the 28 deer captured, 17 were equipped with GPS radio-collars and 11 with traditional VHF radio-collars. We programmed the GPS collars to drop off on April 01, 2007. The programming schedule for GPS collars was:

- obtain 1 location every 2 hours December 20, 2006 – April 15, 2007
- obtain 1 location every 25 hours April 16, 2007 – October 31, 2007
- obtain 1 location every 2 hours November 01, 2007 – April 01, 2008

We conducted a second capture on March 01, 2007 to equip 7 adult female deer with GPS collars in the Ryegrass/Grindstone/Soaphole area. We programmed the GPS collars to drop off on April 01, 2009. The programming schedule for these collars was:

- obtain 1 location every 4 hours March 01, 2007 – May 31, 2007
- obtain 1 location every 25 hours June 01, 2007 – October 31, 2007
- obtain 1 location every 4 hours November 01, 2007 – May 31, 2008
- obtain 1 location every 25 hours June 01, 2008 – October 31, 2008
- obtain 1 location every 4 hours November 01, 2008 – March 31, 2009

An additional capture was conducted March 1, 2007 in an effort to document possible interchange of mule deer between the Mesa and the Soapholes and Grindstone areas, west of the Green River. We captured 3 deer near Flying Heart Road and 4 in the Soapholes and Grindstone areas. Data from these collars will not be available until 2009.

GPS Data Collection and Deer Distribution: We collected 45,195 locations from 24 GPS collars (14 in the PAPA, 10 in Pinedale Front) during the 2006-07 winter, including 13 collars (#844, #855, #860, #861, #862, #866, #867, #868, #869, #870, #872, #887, and #896) that contained data for consecutive winters (2005-06 and 2006-07). All of the collars collected daily locations during the non-winter months (15 April – 1 November, 2005).

We characterized this winter as mild in the Mesa and Pinedale Front. Many of the GPS locations collected during November, early-December, late-March, and April occurred on transition ranges and migratory routes located north of the core winter ranges (Figure 2-23). The length of the migratory route(s) adjacent to the winter ranges were much longer in the Pinedale Front, where late-fall and early-spring deer movements often extended 30 miles beyond the core winter range. Consistent with previous years, deer from the Mesa migrated through the Trapper's Point Bottleneck and deer along the Pinedale Front migrated along the base of the Wind River Range.

We color-coded GPS locations by individual deer to illustrate winter distribution and movement patterns on both the Mesa (Figure 2-24) and Pinedale Front (Figure 2-25). Deer tended to move from north to south as winter progressed, and then returned north as winter conditions improved or spring migrations began. Most deer arrived in the core winter ranges in early to mid-December and began migrating north in late-March. Mule deer on the Mesa were concentrated on the north and west portions, while mule deer in the Pinedale Front were concentrated along the Big Sandy River between Buckskin Crossing and Elk Mountain.

Daily Movement Rates of GPS-collared Deer: Consistent with previous years, average daily movement rates of GPS-collared deer in the Mesa during January, February, and March of 2007 were 1.8, 1.7, and 1.7 km/day, respectively (Figure 2-26). Average daily movement rates of GPS-collared deer in the Pinedale Front during January, February, and March of 2007 were 2.3, 2.5, and 2.5 km/day, respectively (Figure 2-26). Daily movement rates were significantly higher in the Pinedale Front compared to the Mesa during February and March.

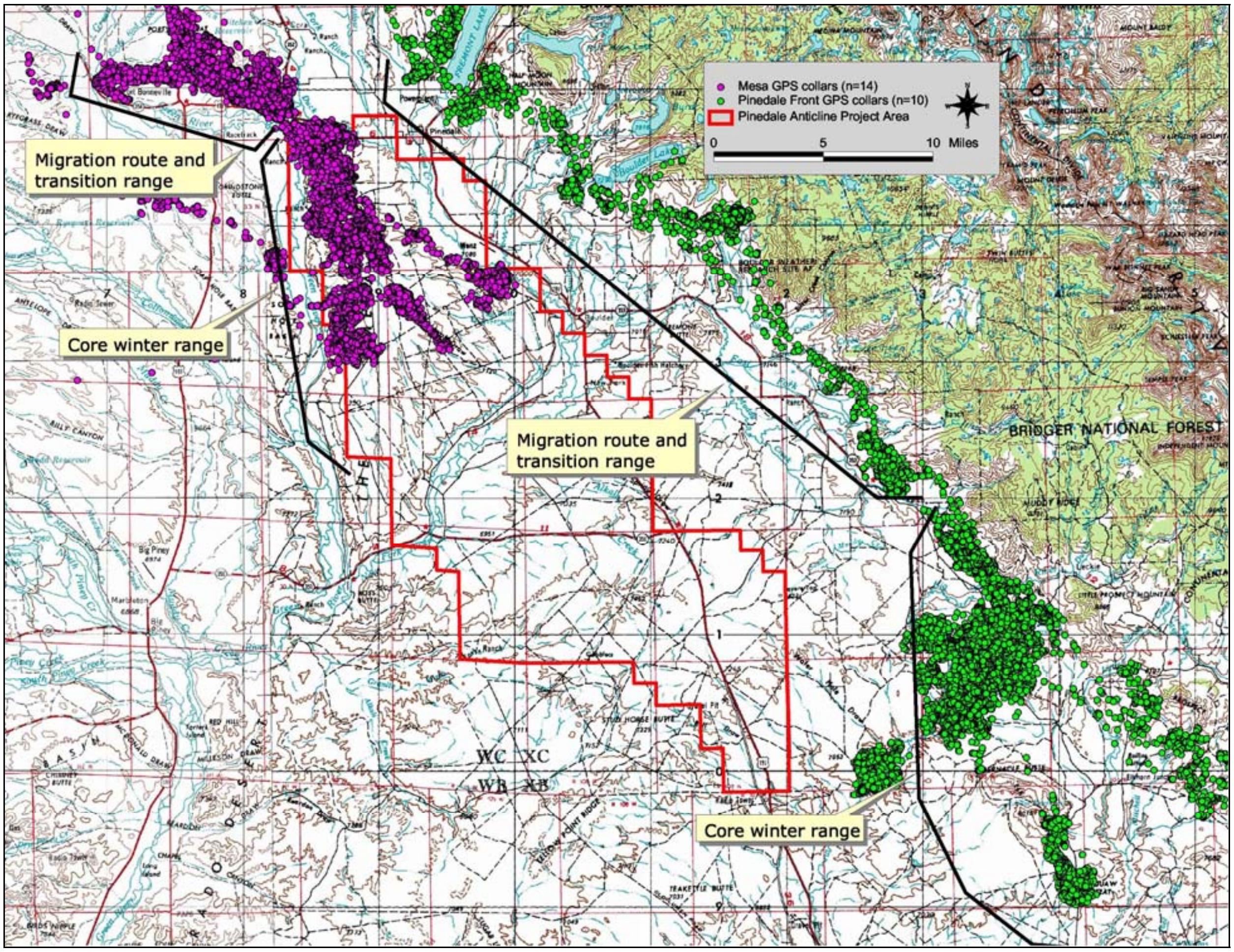

Figure 2-23. Winter locations of 24 GPS-collared deer in the Mesa and Pinedale Front Winter Ranges, November 1, 2006–April 15, 2007.

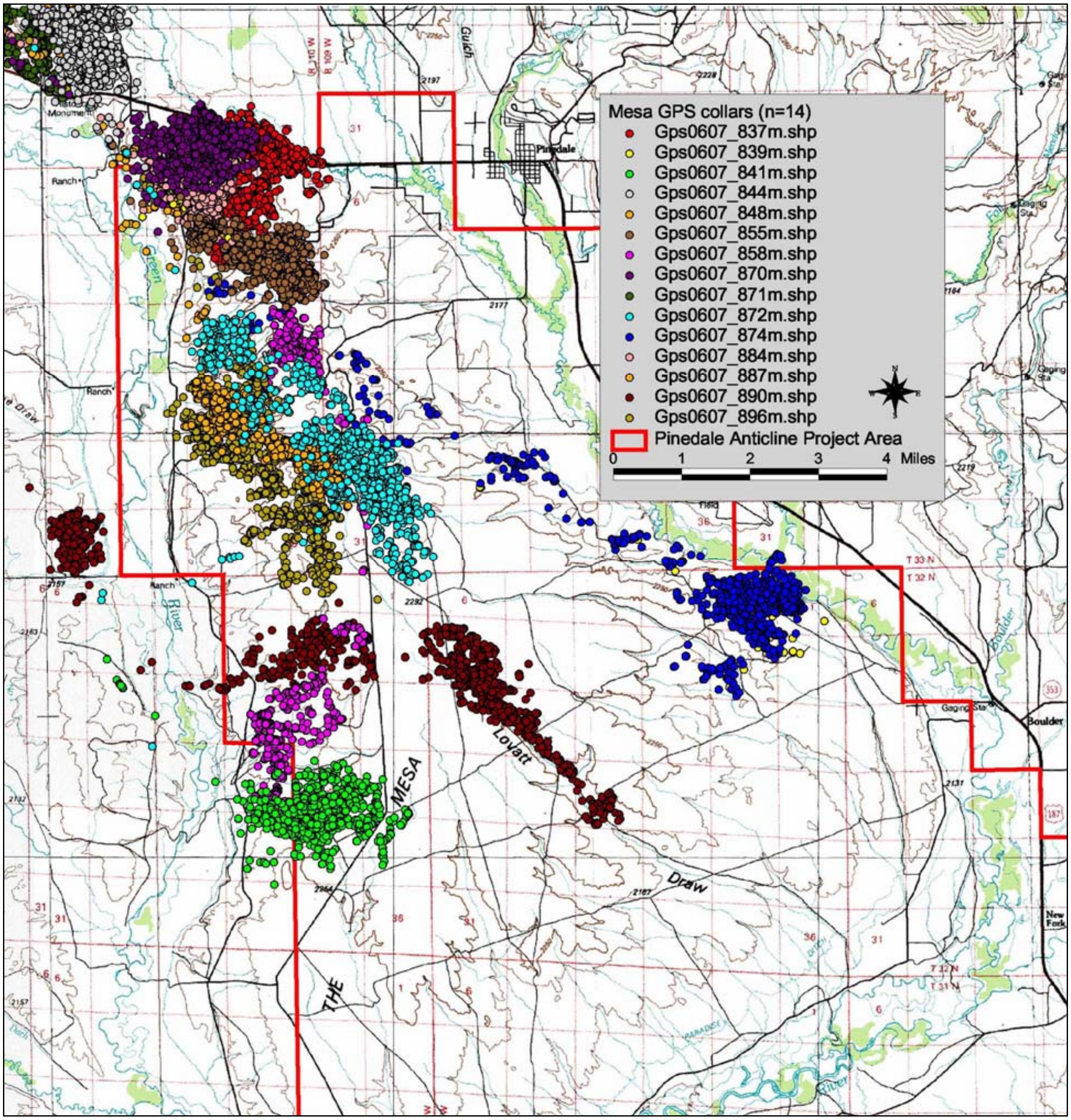

Figure 2-24. Winter locations of 14 GPS-collared deer on the Mesa, November 1, 2006–April 15, 2007.

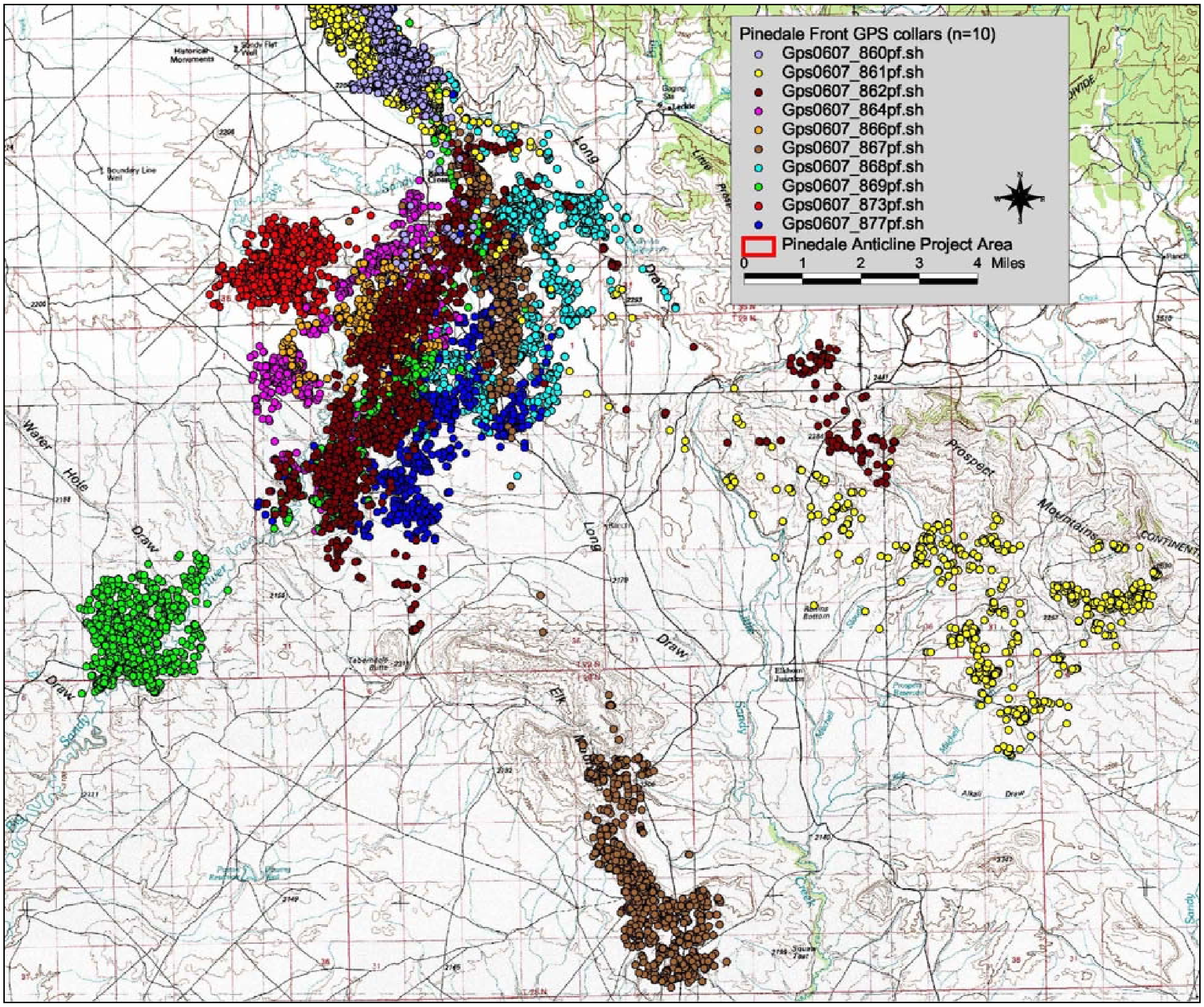

Figure 2-25. Winter locations of 10 GPS-collared deer on the Pinedale Front, November 1, 2006–April 15, 2007.

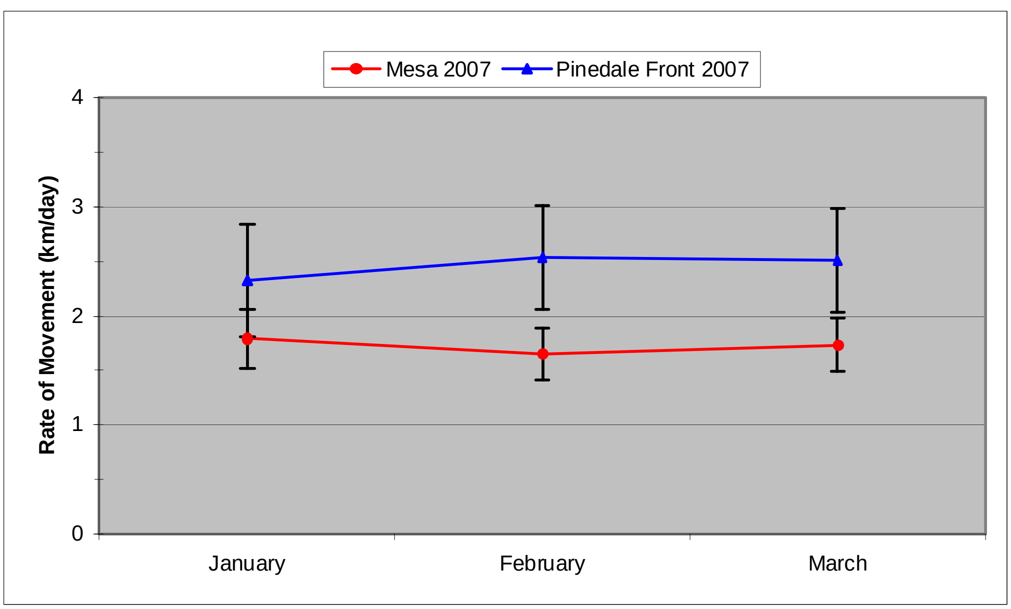

Figure 2-26. Average daily movement rates and associated 90% confidence intervals of GPS-collared mule deer in the Mesa and Pinedale Front Winter Ranges, January – March, 2007.

Daily Movement Rates

Daily movement rates of GPS-collared were consistent across months (F=0.057, P=0.944), but varied between years (F=4.036, P=0.003), and between the Mesa and Pinedale Front (F=101.757, P<0.001). Average daily movement rates of mule deer on the Mesa were approximately 1.6 km/day (Figure 2-27), while those on the Pinedale Front were 2.3 km/day (Figure 2-28). On average, mule deer in the Pinedale Front moved 0.64 km/day more than those on the Mesa. Among years, daily movement rates of deer in both areas were highest (1.7 km/day) during the 2006-07 winter (mild) and lowest (1.5 km/day) during the 2003-04 winter (severe).

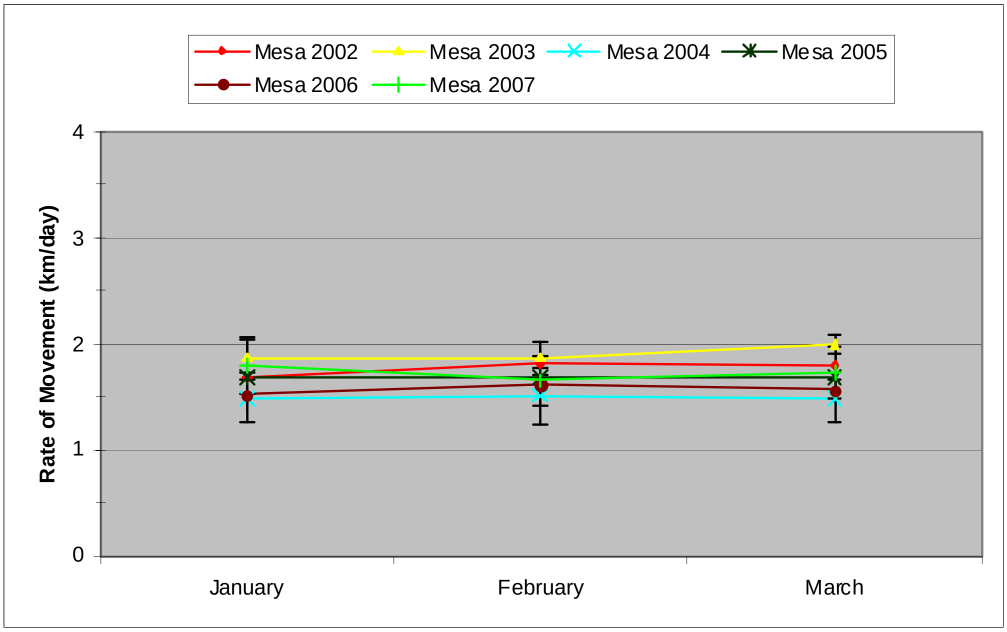

Figure 2-27. Average daily movement rates (m) and associated 90% confidence intervals of GPS-collared mule deer in the Mesa, January – March, 2002-2007.

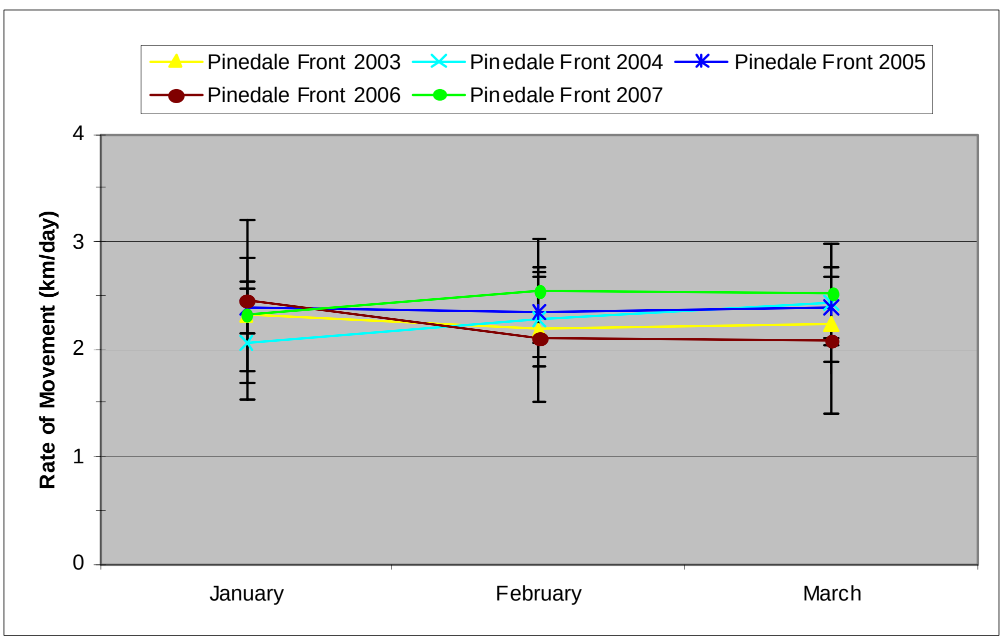

Figure 2-28. Average daily movement rates (m) and associated 90% confidence intervals of GPS-collared mule deer in the Pinedale Front, January – March, 2003-2007.

Emigration

We considered radiomarked deer that were captured on the Mesa and later left the Mesa to occupy surrounding winter ranges as emigrants. Between 2001 and 2007 we monitored 193 radiomarked deer on the Mesa and considered 3 (1.5%) to have emigrated, including #862 during the 2003–04 winter, #838 during the 2005–06 winter, and #847 during the 2005–06 winter.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Mule deer showed a strong fidelity to their respective winter ranges and no mixing of the Mesa and Pinedale Front winter ranges was documented. Within the 2 winter ranges, deer distribution was less predictable in the Pinedale Front where deer were more mobile and tended to shift areas of use through the winter, sometimes moving 5-15 miles south of what was previously considered their core winter range. While deer movements varied across the winter ranges and years, the migratory routes to and from the respective winter range were consistent. Most deer accessed the Mesa from the north via the Trapper's Point Bottleneck. This bottleneck is well-documented (Sawyer and Lindzey 2001, Berger 2004, Sawyer et al. 2005, Berger et al. 2006) and our data suggest that it continues to function as an effective migration corridor.

Mule deer accessed the Pinedale Front from the north, moving along the base of the Wind River Range. Deer that winter along the Pinedale Front were known to migrate northerly along the Wind River Range to the New Fork Lake area before shifting their migration in a westerly route towards the Hoback Basin and adjacent mountain ranges (Sawyer and Lindzey 2001). However, specific details of this migration route, in terms of size, width, specific location, and deer fidelity were unknown prior to GPS data collected in this study. Our data indicate that deer migrate along a distinct 30-mile corridor located at the base of the Wind River Range. While deer sometimes remained in one area for a number of days, they appeared to follow a well-defined route that narrowed to ¼-mile in some areas (i.e., Boulder Lake, Fremont Lake), but rarely exceeded 1-2 miles in width. The migration route leads north from the Buckskin Crossing area, across the Big Sandy River, then northerly across the sagebrush flats below Sheep Creek and Muddy Creek. Deer then moved into slightly rougher terrain among the boulders and sagebrush draws east of CR 353, south of the East Fork, and west of Irish Canyon. Deer then moved northerly, crossing the East Fork and Pocket Creek approximately 2-3 miles east of CR 353. Once across Pocket Creek, deer contoured through the sagebrush slopes and aspen pockets, northerly through Cottonwood Creek and Silver Creek. From Silver Creek, deer continued northwesterly across Lovett and Scab Creek. Deer continued to contour across the sagebrush slopes below Soda Lake, towards the outlet of Boulder Lake. Deer crossed Boulder Creek near the outlet of Boulder Lake, and then moved north to Fall Creek, apparently to avoid an agricultural area between Fall Creek and Pole Creek. Deer crossed Fall Creek just below the confluence of Meadow Creek, and then moved northwesterly toward the outlet of Fremont Lake. Deer crossed Pine Creek at the Fremont Lake Bottleneck, as described by Sawyer and Lindzey (2001), and continued north along the Willow Creek Road and Fremont Ridge. Deer moved within ½-mile either side of the Willow Lake Road from Soda Lake to the outlet of Willow Lake. For additional information on this migration route, refer to Sawyer and Kauffman (2008).

We upgraded the GPS collars in 2005 to begin collecting daily locations during the non-winter months. These data continue to document specific migration routes used by deer on a year-around basis (Figure 2-29) and provide opportunities for improved management, planning, and conservation efforts. Mule deer management in western Wyoming is complicated by the fact that deer migrate long distances across a variety of habitats and land ownership (Sawyer et al. 2005). However, specific knowledge of migration routes and seasonal ranges will improve the ability of agencies to manage this deer herd and allow them to consider how localized land-use or management decisions may affect mule deer across a much larger region. Because mule deer that winter on the Mesa and Pinedale Front migrate 40-100 miles to their respective summer ranges, land-use decisions or management prescriptions made in those winter ranges or migration corridors may affect areas as far away as Kelly, Jackson Hole, the Snake River, Greys River, Gros Ventre Range, Wyoming Range, and Hoback Basin. Study cooperators are provided with a digital form of these data so they can be easily mapped and considered in local land-use planning (e.g., lease sales, highway crossings) or management prescriptions (e.g., fence modifications, habitat improvements).

While the seasonal activity patterns (Eberhardt et al. 1984, Kufeld et al. 1988, Hayes and Krausman 1993, Ager et al. 2003) and migratory behaviors (Garrot et al. 1987, Thomas and Irby 1990, Brown 1992, Merill et al. 1994, Nicholson et al. 1994, D'Eon and Serrouya 2005, Sawyer et al. 2005) of mule deer have been well-documented, we know very little about the fine-scale movement rates of free-ranging mule deer. However, with recent advances in GPS radio-collars, estimating the fine-scale movements of mule deer is limited only by the frequency at which GPS locations are collected and the storage capacity of the collar. Data collected from our GPS radio-collars provided new insight into the daily movement rates of mule deer across multiple years and 2 different winter ranges. Interestingly, average daily movement rates of mule deer in the Pinedale Front were significantly higher than those in the Mesa. But, within each winter range, the daily movement rates were surprisingly consistent among months and years, especially considering the variable environmental conditions that mule deer were exposed to during that 6-year period. Knowledge of daily movement rates during the winter may improve our understanding of mule deer energetics (Parker et al. 1984, Hobbs 1989) and provide some context for flight distances associated with human disturbances, such as bikers (Taylor and Knight 2003), snow mobiles (Freddy et al. 1986), and hikers (Freddy et al. 1986, Taylor and Knight 2003). For example, both Freddy et al. (1986) and Taylor and Knight (2003) reported flight distances of disturbed mule deer ranging from 100 to 200 m. A 100 or 200 m flight distance may seem trivial, but when we consider mule deer on the Mesa only move 1,600 m/day, a 200 m disturbance represents 12% of their daily movement and associated energetic requirements.

Knowledge of daily movement rates during the winter may also improve our ability to design and implement effective habitat treatments. As gas field development on the Mesa progresses, reclamation, re-vegetation, mechanical treatments, and sagebrush fertilization projects are becoming more common. Considering that most mule deer on the Mesa do not move more than 1.6 km/day and that those movements are generally restricted to a relatively small home range, many small habitat treatments evenly distributed across the Mesa may benefit more mule deer than a few larger treatments that are only available to mule deer in the immediate area.

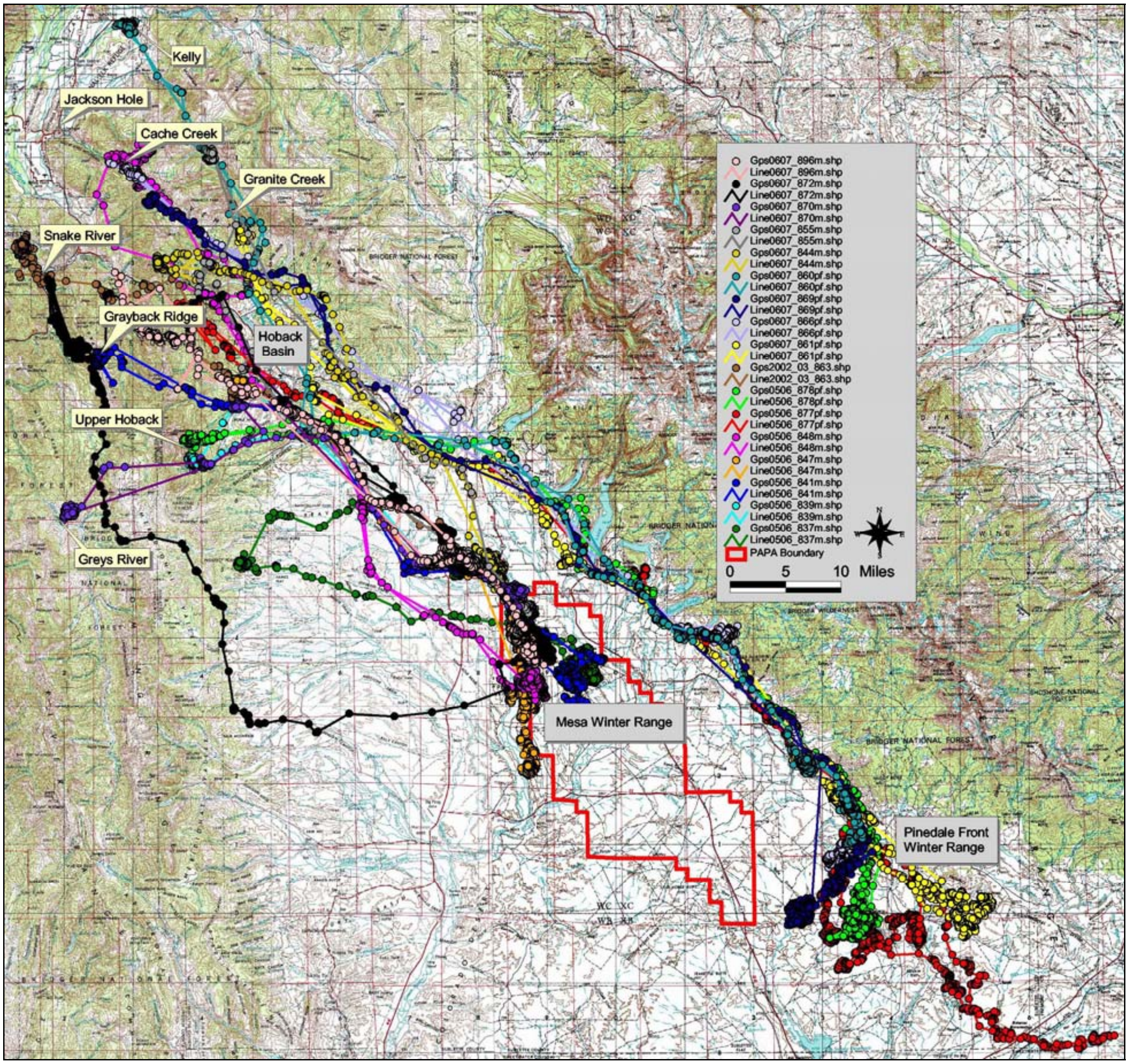

Figure 2-29. Mule deer migration routes estimated for 17 GPS-collars that collected locations year-around.

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Section 3.0

Winter habitat selection patterns of mule deer before and during gas development on the Mesa (1998-2004)

Section 3.0: Winter habitat selection patterns of mule deer before and during gas development on the Mesa (1998-2004)

INTRODUCTION

Natural gas development on public lands in Wyoming has steadily increased since 1984 (Bureau of Land Management [BLM] 2002, 2005) and created concern over potential impacts to wildlife. Public lands with high gas potential often coincide with regions that support large mule deer (*Odocoileus hemionus*) populations, such as the Green River Basin (BLM 2000*a*), Great Divide Basin (BLM 2000*b*), and Powder River Basin (BLM 2003). Impacts of natural gas development on mule deer may include the direct loss (i.e., surface disturbance) of habitat to well pad, access road, and pipeline construction. Additional indirect habitat losses may occur if increased human activity (e.g., traffic, noise) associated with infrastructure cause mule deer to alter their habitat use patterns. While it is relatively easy to quantify the direct habitat losses that result from conversion of native vegetation to infrastructure, it is much more difficult to document indirect habitat losses. Nonetheless, because indirect impacts may affect a substantially larger area than direct impacts, there is a need among agencies and industry to better understand how natural gas development may lead to indirect habitat loss to ensure informed land-use decisions are made, reasonable and effective mitigation measures are identified, and appropriate monitoring programs are implemented. Reducing indirect impacts may be a key component to maintaining mule deer populations in regions with high levels of natural gas development. Our objective was to determine if natural gas development affected the habitat selection patterns and distribution of wintering mule deer in the Mesa.

STUDY AREA

Beginning in 2000, the BLM approved the construction of 700 producing well pads, 645 km of pipeline, and 444 km of roads to develop a natural gas field in the Pinedale Anticline Project Area (PAPA; BLM 2000*a*). The PAPA contains one of the largest and highest density mule deer winter ranges in Wyoming and is located in the upper Green River Basin, approximately 5 km southwest of Pinedale (Wyoming Game and Fish Department [WGFD] 2006). The PAPA consists primarily of federal lands (80%) and minerals administered by the BLM (83%). The state of Wyoming owns 5% (39 km^2) of the surface and another 15% (121 km^2) is private (BLM 2000*a*). The study area contains the second largest natural gas field in the U.S. with approximately 25 trillion cubic feet of gas reserves (QEP, pers. commun.), supports a variety of agricultural uses, and provides winter range for 3,000 to 5,000 migratory mule deer that summer in portions of 4 different mountain ranges 80 to 200 km away (Sawyer et al. 2005). Although the PAPA covers 799 km^2, most mule deer winter in the northern one-third, an area locally known as the Mesa. The Mesa is 260 km^2 in size, bounded by the Green River on the west and the New Fork River on the north, south, and east, and vegetated primarily by Wyoming big sagebrush (*Artemisia tridentata* subsp *wyomingensis*) and sagebrush-grassland communities. Elevation ranges from 2,070 to 2,400 m. Our study was conducted in the Mesa portion of the PAPA.

METHODS

Capture

We captured adult (≥ 1.5 year) female mule deer using helicopter net-gunning in the northern portion of the PAPA where deer congregated in early winter before moving to their individual winter ranges throughout the Mesa (Sawyer and Lindzey 2001). Randomly capturing deer in this area during early winter provided the best opportunity to achieve a representative sample from the wintering population. In years prior to development (winters 1998-99 and 1999-00) we fitted deer with standard, very high frequency (VHF) radiocollars (Advanced Telemetry Systems, Isanti, Minnesota, USA). We located radio-collared deer from the ground or air every 7 to 10 days during the 1998-99 and 1999-00 winters (December 1 to March 31). During years of gas field development (2000-01, 2001-02, 2002-03, 2003-04, and 2004-05) we fitted deer with store-on-board global positioning system (GPS) radiocollars (Telonics, Inc., Mesa, Arizona, USA) equipped with VHF transmitters and remote-release mechanisms programmed to release at specified dates and times. We programmed GPS radiocollars to attempt location fixes every 1 or 2 hours, depending on model type.

Modeling Procedures

Defining Availability: We defined the study area by mapping 39,641 locations from 77 mule deer over a 6-year period (1998 to 2003), creating a minimum convex polygon, and then clipping the polygon to the boundary of the PAPA.

Habitat Variables: We identified 5 variables as potentially important predictors of winter mule deer distribution, including: elevation, slope, aspect, road density (or distance to road), and distance to well pad. We did not include vegetation as a variable because the sagebrush-grassland was relatively homogeneous across the study area and difficult to divide into finer vegetation classes. Further, we believed differences in sagebrush characteristics could be largely explained by elevation and slope. We used the Spatial Analyst extension for ArcView® (Environmental Systems Research Institute, Redlands, California, USA) to calculate slope and aspect from a 26 x 26 m digital elevation model (U.S. Geologic Survey [USGS] 1999). Grid cells with slopes > 2 degrees were assigned to 1 of 4 aspect categories; northeast, northwest, southeast, or southwest. Grid cells with slopes of ≤ 2 degrees were considered flat and assigned to a fifth category that was used as the reference (Neter et al. 1996) during habitat modeling. We obtained elevation, slope, and aspect values for each of the sampled units using the GET GRID extension for ArcView. Our sampling units consisted of approximately 4,500 circular units with 100-m radii distributed across the study area. We annually digitized roads and well pads from Landsat thematic mapper images acquired from the USGS and processed by SkyTruth (Sheperdstown, West Virginia, USA). The Landsat images were obtained every fall, prior to snow accumulation, but after most annual development activities were complete. We calculated road density by placing a circular buffer with a 0.5 km radius on the center of the sample unit and measuring the length of road within the buffer. We used ArcView to measure the distance from the center of each sampling unit to the edge of the nearest well pad. We did not distinguish between developing and producing well pads. We assumed habitat loss was similar among all well pads because development and reclamation of the field was in its early stages (i.e., < 5 years). Several abandoned well pads were included in the analysis for Years 1-3, but excluded in Years 4-5 because they received little or no traffic use.

Statistical Analyses: Our approach to modeling winter habitat use consisted of 4 basic steps: 1) estimate the relative frequency of use (i.e., an empirical estimate of probability of use) for a large number of sampling units for each radio-collared deer during each winter, 2) use the relative frequency as the response variable in a multiple regression analysis to model the probability of use for each deer as a function of predictor variables, 3) develop a population-level model from the individual deer models for each winter, and 4) map predictions of population-level models from each winter. Our analysis treated each winter period separately to allow mule deer habitat use and environmental characteristics (e.g., road density or number of well pads) to change through time. We treated radio-collared deer as the experimental unit to avoid pseudo-replication (i.e., spatial and temporal autocorrelation) and to accommodate population-level inference (Otis and White 1999, Erickson et al. 2001).

We estimated relative frequency of use for each radio-collared deer using a simple technique that involved counting the number of deer locations in each of 4,500 randomly selected circular sampling units across the study area. We took a simple random sample with replacement for each winter to ensure independence of the habitat units (Thompson 1992:51). We chose circular sampling units that had a 100-m radii; an area small enough to detect changes in animal movements, but large enough to ensure multiple locations could occur in each unit. Previous analyses suggested model coefficients were similar across a variety of unit sizes, including 50, 75, and 150-m radii (R. Nielson, Western Ecosystems Technology, Inc., unpublished data). Before modeling resource selection, we conducted a Pearson's pairwise correlation analysis to identify possible multi-collinearity issues and to determine whether any variables should be excluded from the modeling ($|r| > 0.60$).

The relative frequency of locations from each radio-collared deer found in each sampling unit was an empirical estimate of the probability of use by that deer and was used as a continuous response variable in a GLM. We used an offset term (McCullagh and Nelder 1989) in the GLM to estimate probability of use for each radio-collared deer as a function of a linear combination of predictor variables, plus or minus an error term assumed to have a negative binomial distribution (McCullagh and Nelder 1989, White and Bennetts 1996). We began our modeling by first estimating coefficients for each radio-collared deer. We fit the following GLM for each radio-collared deer:

$$\ln(E[r_i]) = \ln(total) + \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p, \qquad (1)$$

which is equivalent to:

$$\ln(E[r_i/total]) = \ln(E[\text{Relative Frequency}_i]) = \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p, \qquad (2)$$

where r_i is the number of locations for a radio-collared deer within sampling unit i (i = 1, 2, …, 4500), *total* is the total number of locations for the deer within the study area, β_o is an intercept term, $\beta_1,\ldots,\beta_p$ are unknown coefficients for habitat variables $X_1,\ldots,X_p$, and $E[.]$ denotes the expected value. The offset term, ln(*total*), was a quantitative variable for which the regression coefficient was set to 1 (Millspaugh et al. 2006). We used the same offset term for all sampled units of a given deer to ensure we were modeling relative frequency of use (e.g., 0, 0.003, 0.0034, …) instead of integer counts (e.g., 0, 1, 2, …). At the level of an individual animal, this approach estimates the true probability of use as a function of predictor variables, and is referred to as a resource selection probability function (RSPF; Manly et al. 2002).

To evaluate population-level resource selection we assumed GLM coefficients for predictor variable *k* for each deer were a random sample from a normal distribution (Seber 1984), with the mean of the distribution representing the average or population-level effect of predictor variable *k* on probability of use. We estimated coefficients for the population-level model by averaging the coefficients of the individual RSPFs,

$$\hat{\bar{\beta}}_k = \frac{1}{n}\sum_{j=1}^{n}\hat{\beta}_{kj}, \tag{3}$$

where $\hat{\beta}_{kj}$ was the estimate of coefficient *k* (*k* =1, 2, …, *p*) for individual *j* (*j* = 1, 2, …, *n*). We estimated the variance of each population-level model coefficient using the variation among radio-collared deer and the equation

$$\text{var}(\hat{\bar{\beta}}_k) = \frac{1}{n-1}\sum_{j=1}^{n}(\hat{\beta}_{kj} - \hat{\bar{\beta}}_k)^2. \tag{4}$$

Fitting the same model to each of the *n* individuals and then estimating population-level coefficients can provide a valid method for obtaining population-level inference (Marzluff et al. 2004, Millspaugh et al. 2006, Sawyer et al. 2006, 2007). Population-level inferences using equations (3) and (4) are unaffected by potential autocorrelation because temporal autocorrelation between deer locations or spatial autocorrelation between sampling units do not bias model coefficients for the individual radio-collared deer models (McCullagh and Nelder 1989, Neter et al. 1996).

Standard criteria for model selection such as Akaike's Information Criterion (Burnham and Anderson 2002) could be used for modeling individual deer, but is not easily adapted for building a population-level model with a common set of predictor variables within each winter. Therefore, we used a forward-stepwise model building procedure (Neter et al. 1996) to estimate population-level models for winters 2000-01, 2001-02, 2002-03, 2003-04, 2004-05. The forward–stepwise model building process required fitting the same models to each deer within a winter and using equations (3) and (4) to estimate population-level coefficients. We used a *t*-statistic to determine variable entry ($\alpha \leq 0.15$) and exit ($\alpha > 0.20$) (Hosmer and Lemeshow 2000). We considered quadratic terms for road density, distance to nearest well pad, and slope during the model building process and, following convention, the linear form of each variable was included if the model contained a quadratic form.

We conducted stepwise model building for all winters except for the pre-development period that included winters 1998-1999 and 1999-2000. The limited number of locations recorded for radio-collared deer during this period precluded fitting individual models. Rather, we estimated a population-level model for the pre-development period by pooling location data across 45 deer that had a minimum of 10 locations. We took simple random samples of 30 locations from deer with >30 locations to ensure that approximately equal weight was given to each deer in the analysis. We fit a model containing slope, elevation, distance to roads, and aspect for the pre-development period. Distance to well pad was not included as a variable in the pre-development model because there were only 11 existing well pads on the Mesa prior to development and most were >10 years old with little or no human activity associated with them. We used bootstrapping to estimate the standard errors and P values of the pre-development population-level model coefficients.

We mapped predictions of population-level models for each winter on 104 x 104 m grids that covered the study area. We checked predictions to ensure all values were in the interval [0, 1], to verify that we were not extrapolating outside the range of the model data (Neter et al. 1996). The model prediction for each grid cell was assigned a value of 1 to 4 based on the quartiles of the distribution of predictions for each map. We assigned grid cells with the highest 25% of the predictions a value of 1 and classified them as high use areas, assigned grid cells in the 51 to 75 percentiles a value of 2 and classified them as medium-high use areas, assigned grid cells in the 26 to 50 percentiles a value of 3 and classified them as medium-low use areas, and assigned grid cells in the 0 to 25 percentiles a values of 4 and classified them as low use areas. We used contingency tables to identify changes in the 4 habitat use categories across the 5 winter periods.

RESULTS

Pre-Development: Winters 1998-99 and 1999-00

The population-level model was estimated from 953 VHF deer locations collected from 45 adult female mule deer during the winters (1 December to 15 April) of 1998–99 and 1999–00 (Table 3-1). Areas with the highest predicted use had an average elevation of 2,275 m, an average slope of 5.53 degrees, and an average road density of 0.14 km/km^2 (Figure 3-1:Table 3-2). Aspects with the highest predicted use were northwest and southwest.

Table 3-1. Coefficients for population-level model prior to gas field development in the Mesa, 1998-2000.

Coefficients for average or population-level resource selection model									
Deer ID	β	Elevation	Slope	Slope^2	Road density	NE	NW	SE	SW
Average	-29.649	0.009	0.098	-0.004	-0.249	0.012	0.399	-0.301	0.194
SE	6.6372	0.0005	0.0102	0.0007	0.027	0.051	0.025	0.022	0.028
P	<0.001	<0.001	<0.001	<0.001	<0.001	0.818	<0.001	<0.001	<0.001

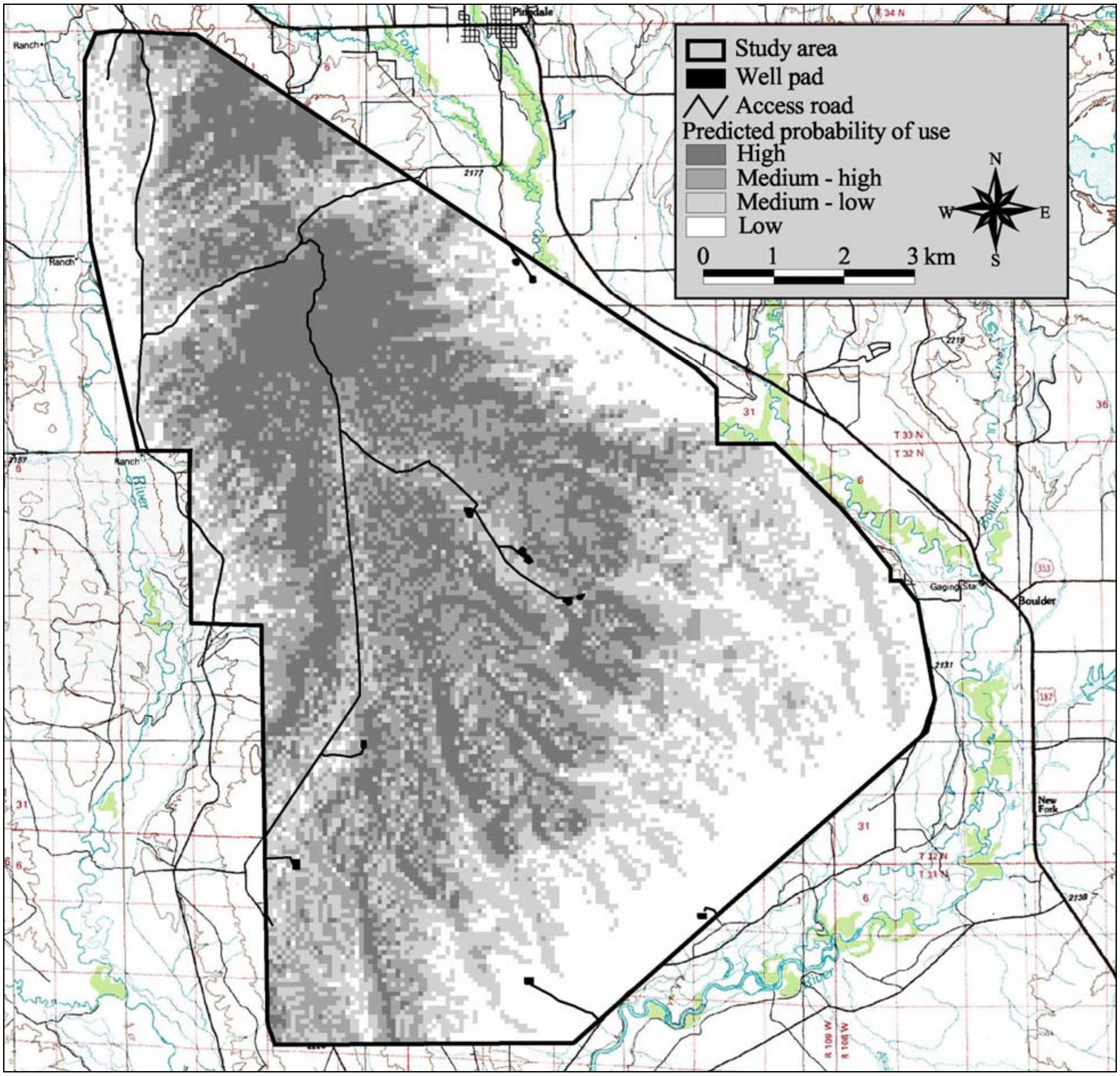

Figure 3-1. Population-level model predictions and associated categories of mule deer habitat use during 1998-99 and 1999-2000 winters, prior to natural gas field development in western Wyoming.

Table 3-2. Average values for resource selection model variables in low, medium-low, medium-high, and high use categories during the 1998-99 and 1999-2000 winters.

Variable	Predicted Mule Deer Use			
	Low	Medium-low	Medium-High	High
Elevation (m)	2,159	2,206	2,247	2,274
Slope^2 (degrees)	2.16	3.51	3.76	5.53
Road density^2 (km of rd/km^2)	0.21	0.25	0.20	0.14

Year 1 of Development: Winter 2000-01

Individual models were estimated for 10 radio-collared deer during the winter (January 1 to April 15) of 2000-01 (Table 3-3). Eight of the 10 deer had positive coefficients for elevation and negative coefficients for road density, indicating selection for higher elevations and lower road densities. Based on the relationship between the linear and quadratic terms for slope and distance to well pad variables, 10 of 10 deer selected for moderate slopes and 7 of 10 deer selected areas away from well pads.

The population-level model was estimated from 18,706 GPS locations collected from 10 radio-collared deer during the winter of 2000-01 (Table 3-3). The model included elevation, slope^2, road density, and distance to well pad^2. Deer selected for areas with higher elevations, moderate slopes, lower road densities, and away from well pads. Areas with the highest predicted levels of use had an average elevation of 2,266 m, slope of 5.09 degrees, road density of 0.16 km/km2, and were 2.70 km away from the nearest well pad (Table 3-4). Predictive maps indicate deer use was lowest in areas close to well pads and access roads (Figure 3-2). Shifts in deer distribution between pre-development and Year 1 of development were evident through the changes in the 4 deer use categories (Table 3-13). Of the habitat units classified as high deer use prior to development, only 60% were classified as high deer use during Year 1 of development. Of the areas classified as low deer use prior to development, 58% remained classified as low deer use during Year 1 of development.

Table 3-3. Coefficients for individual deer models and the population-level model during the 2000-01 winter.

Coefficients for individual deer resource selection probability functions							
Deer ID	β	Elevation	Slope	Slope^2	Road density	Dist to well	Dist to well^2
Gps2001_860	-93.977	0.036	0.416	-0.028	-1.115	3.126	-0.517
Gps2001_861	-224.054	0.086	0.666	-0.036	-1.510	9.309	-0.931
Gps2001_862	-139.525	0.044	0.394	-0.034	0.672	15.134	-1.674
Gps2001_863	-29.000	0.009	0.090	-0.005	-1.764	1.973	-0.865
Gps2001_864	-0.801	-0.007	0.722	-0.031	-2.099	4.495	-0.997
Gps2001_865	-75.159	0.030	0.184	-0.007	-1.796	-1.062	0.099
Gps2001_866	-89.367	0.035	0.352	-0.020	-0.082	0.711	-0.058
Gps2001_867	-5.357	0.000	0.380	-0.017	-1.720	-4.131	0.465
Gps2001_868	-115.606	0.042	0.633	-0.036	1.583	6.004	-0.775
Gps2001_869	-72.751	0.030	0.073	-0.006	-0.468	-4.267	0.606
Coefficients for average or population-level resource selection model							
Average	-84.560	0.031	0.391	-0.022	-0.827	3.129	-0.465
SE	21.124	0.008	0.073	0.004	0.387	1.899	0.229
P	0.003	0.005	<0.001	<0.001	0.061	0.134	0.073

Table 3-4. Average values for resource selection model variables in low, medium-low, medium-high, and high use categories during the 2000-01 winter.

Variable	Predicted Mule Deer Use			
	Low	Medium-low	Medium-High	High
Elevation (m)	2,179	2,207	2,234	2,266
Slope^2 (degrees)	2.79	3.17	3.93	5.09
Road density (km of rd/km^2)	0.60	0.31	0.17	0.16
Distance to well pad^2 (km)*	2.29	2.10	2.26	2.70

* see Figure 3-3 for boxplot of distance to well pad values in each use category

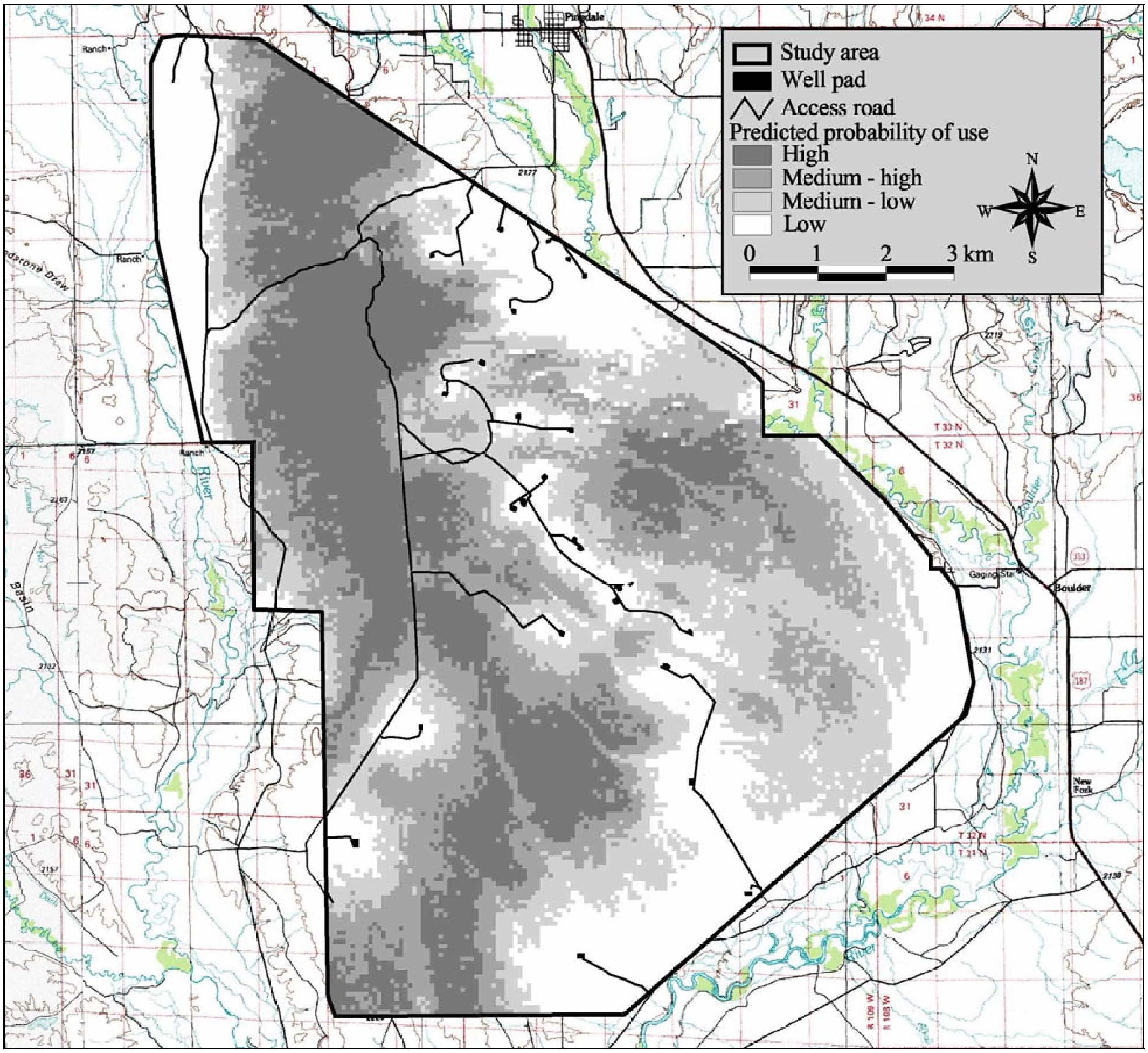

Figure 3-2. Population-level model predictions and associated categories of mule deer habitat use during Year 1 (winter of 2000-01) of natural gas development in western Wyoming.

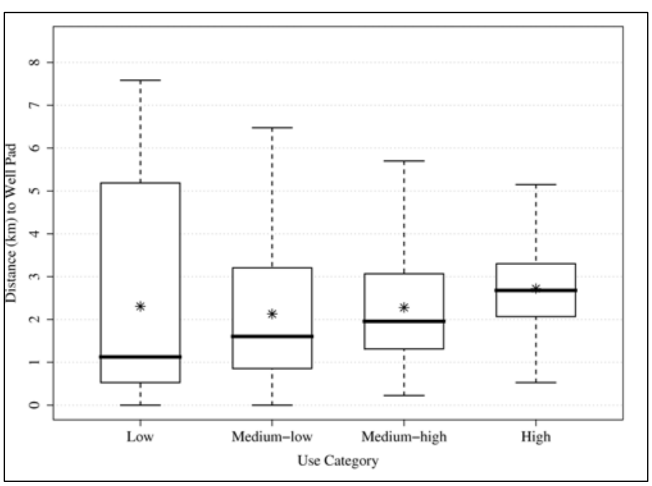

Figure 3-3. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line -) values. Box contains central 50% of distances.

Year 2 of Development: Winter 2001-02

Individual models were developed for 15 radio-collared deer during the winter (January 4 to April 15) of 2001-02 (Table 3-5). Fourteen of the 15 deer had positive coefficients for elevation, indicating selection of higher elevations. All 15 deer selected for moderate slopes and 12 of 15 deer selected areas away from well pads.

The population-level model was estimated from 14,851 GPS locations collected from 15 radio-collared deer during the winter of 2001-02 (Table 3-5). The model included elevation, slope^2, and distance to well pad^2. Deer selected for areas with higher elevations, moderate slopes, and away from well pads. Areas with the highest predicted levels of use had an average elevation of 2,256 m, slope of 4.98 degrees, and were 3.06 km away from the nearest well pad (Table 3-6). Predictive maps indicate deer use was lowest in areas close to well pads (Figure 3-4). Shifts in deer distribution between pre-development, Year 1, and Year 2 of development were evident through the changes in the 4 deer use categories (Table 3-13). Of the habitat units classified as high deer use prior to development, only 49% were classified as high deer use during Year 2 of development. Of the areas classified as low deer use prior to development, 48% remained classified as low deer use during Year 2 of development.

Table 3-5. Coefficients for individual deer models and the population-level model during the 2001-02 winter.

Coefficients for individual deer resource selection probability functions						
Deer ID	β	Elevation	Slope	Slope^2	Dist to well	Dist to well^2
Gps2001_02_860	-38.017	0.012	0.245	-0.009	1.070	-0.180
Gps2001_02_862	-136.745	0.047	0.323	-0.020	11.414	-1.357
Gps2001_02_864b	-97.441	0.037	0.130	-0.012	3.909	-0.481
Gps2001_02_867b	-0.310	-0.004	0.140	-0.003	0.757	-0.221
Gps2001_02_868	-34.069	0.011	0.127	-0.010	0.001	-0.022
Gps2002_844	-24.431	0.001	0.494	-0.036	6.393	-0.740
Gps2002_853	-148.224	0.051	0.331	-0.020	13.468	-1.653
Gps2002_855	-64.546	0.024	0.051	-0.004	0.829	-0.007
Gps2002_861	-99.482	0.036	0.380	-0.026	5.208	-0.679
Gps2002_864a	-165.494	0.061	0.656	-0.033	9.318	-1.149
Gps2002_865	-97.464	0.040	0.441	-0.031	-3.902	0.549
Gps2002_866	-41.544	0.014	0.129	-0.012	0.587	-0.092
Gps2002_867	-24.959	0.006	0.022	-0.003	1.417	-0.202
Gps2002_869	-57.439	0.021	0.164	-0.016	1.561	-0.267
Gps2002_870	-105.518	0.043	0.241	-0.013	-1.401	0.268
Coefficients for average or population-level resource selection model						
Average	-75.712	0.027	0.258	-0.017	3.375	-0.416
SE	12.931	0.005	0.046	0.003	1.264	0.156
P	<0.001	<0.001	<0.001	<0.001	0.018	0.019

Table 3.6. Average values for resource selection model variables in low, medium-low, medium-high, and high use categories during the 2001-02 winter.

Variable	Predicted Mule Deer Use			
	Low	Medium-low	Medium-High	High
Elevation (m)	2,192	2,222	2,218	2,256
Slope^2 (degrees)	3.04	3.29	3.64	4.98
Distance to well pad^2 (km)*	0.83	1.76	2.74	3.06

* see Figure 3-5 for boxplot of distance to well pad values in each use category

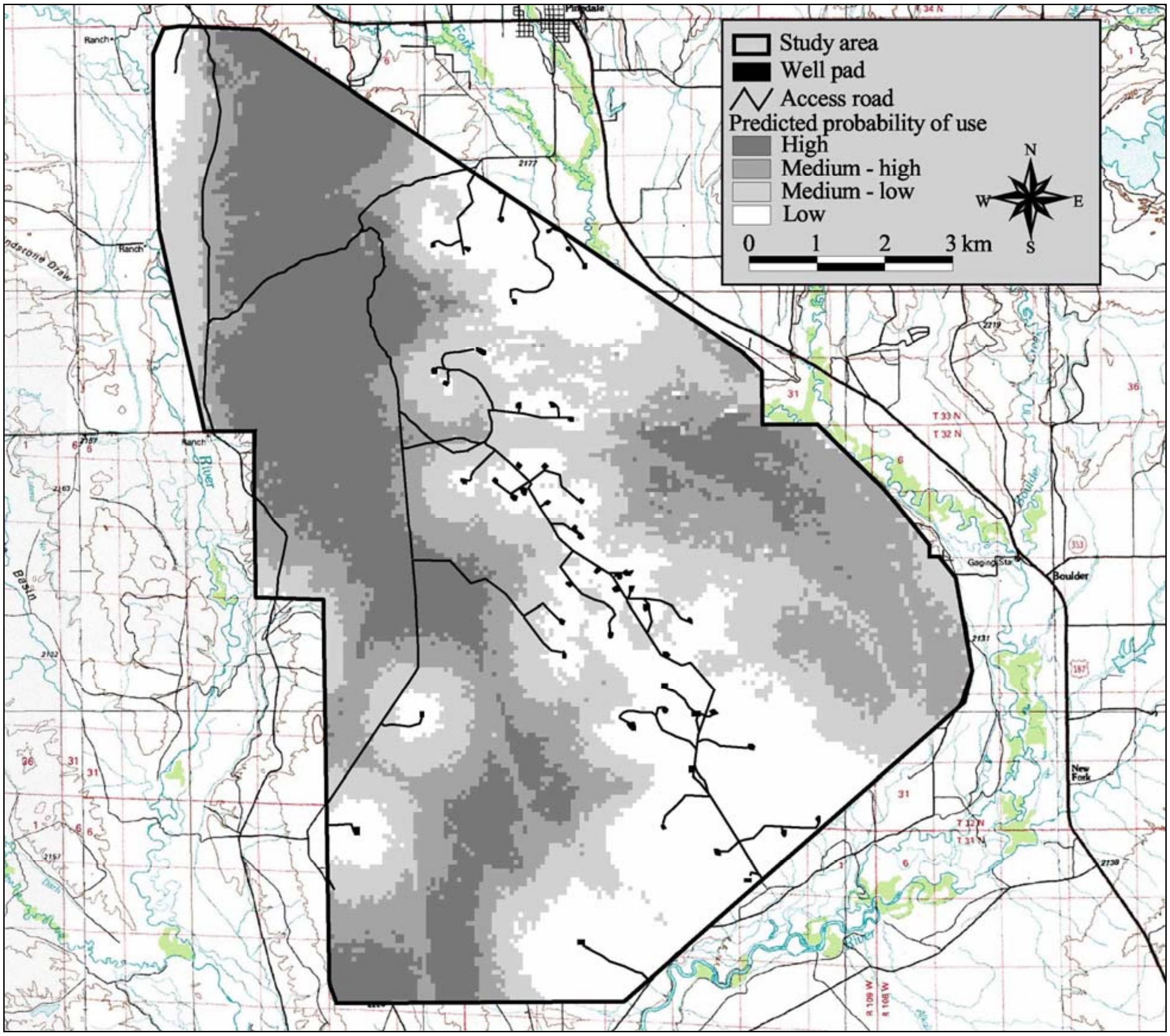

Figure 3-4. Population-level model predictions and associated categories of mule deer habitat use during Year 2 (winter of 2001-02) of natural gas development in western Wyoming.

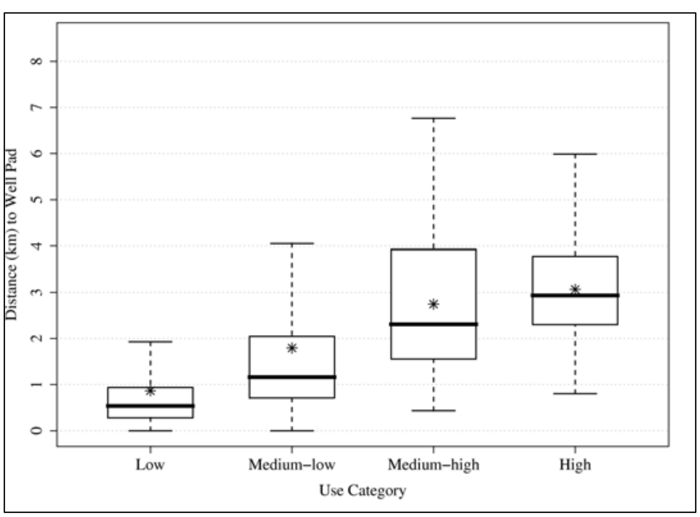

Figure 3-5. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line -) values. Box contains central 50% of distances.

Year 3 of Development: Winter 2002-03

Individual models were developed for 7 radio-collared deer during the winter (December 20 to April 15) of 2002-03 (Table 3-7). All 7 deer had positive coefficients for elevation, indicating selection of higher elevations. Based on the relationship between the linear and quadratic terms for slope and distance to well pad variables, 6 of 7 deer selected for moderate slopes and 6 of 7 deer selected areas away from well pads.

The population-level model was estimated from 4,904 GPS locations collected from 7 radio-collared deer during the winter of 2002-03 (Table 3-7). Our target sample of 10 marked animals was not met because 3 deer died early in the season. The model included elevation, $slope^2$, and distance to well pad^2. Deer selected areas with high elevations, moderate slopes, and away from well pads. Areas with the highest predicted levels of use had an average elevation of 2,233 m, slope of 5.15 degrees, and were 3.71 km away from the nearest well pad (Table 3-8). Predictive maps indicate deer use was lowest in areas close to well pads (Figure 3-6). Shifts in deer distribution between pre-development, Year 1, Year 2, and Year 3 of development were evident through the changes in the 4 deer use categories (Table 3-13). Of the habitat units classified as high deer use prior to development, only 37% were classified as high deer use during Year 3 of development. Of the areas classified as low deer use prior to development, 41% remained classified as low deer use during Year 3 of development.

Table 3-7. Coefficients for individual deer models and the population-level model during the 2002-03 winter.

Coefficients for individual deer resource selection probability functions						
Deer ID	β	Elevation	Slope	$Slope^2$	Dist to well	Dist to $well^2$
Gps0203_861	-110.965	0.043	0.266	-0.017	0.963	0.067
Gps0203_865	-90.891	0.029	0.692	-0.044	8.921	-1.160
Gps0203_866	-147.260	0.050	-0.175	0.009	11.847	-1.137
Gps0203_867b	-50.166	0.019	0.057	0.003	-2.004	0.266
Gps0203_868	-104.434	0.040	0.702	-0.034	1.633	-0.109
Gps0203_869	-102.684	0.030	0.248	-0.019	12.541	-1.395
Gps0203_862	-123.666	0.039	0.604	-0.029	13.086	-1.566
Coefficients for average or population-level resource selection model						
Average	-104.295	0.036	0.342	-0.019	6.712	-0.719
SE	11.316	0.004	0.128	0.007	2.394	0.289
P	<0.001	<0.001	0.036	0.042	0.031	0.047

Table 3-8. Average values for resource selection model variables in low, medium-low, medium-high, and high use categories during the 2002-03 winter.

Variable	Predicted Mule Deer Use			
	Low	Medium-low	Medium-High	High
Elevation (m)	2,203	2,234	2,217	2,233
$Slope^2$ (degrees)	3.01	3.43	3.37	5.15
Distance to well pad^2 (km)*	0.40	1.21	2.76	3.71

* see Figure 3-7 for boxplot of distance to well pad values in each use category

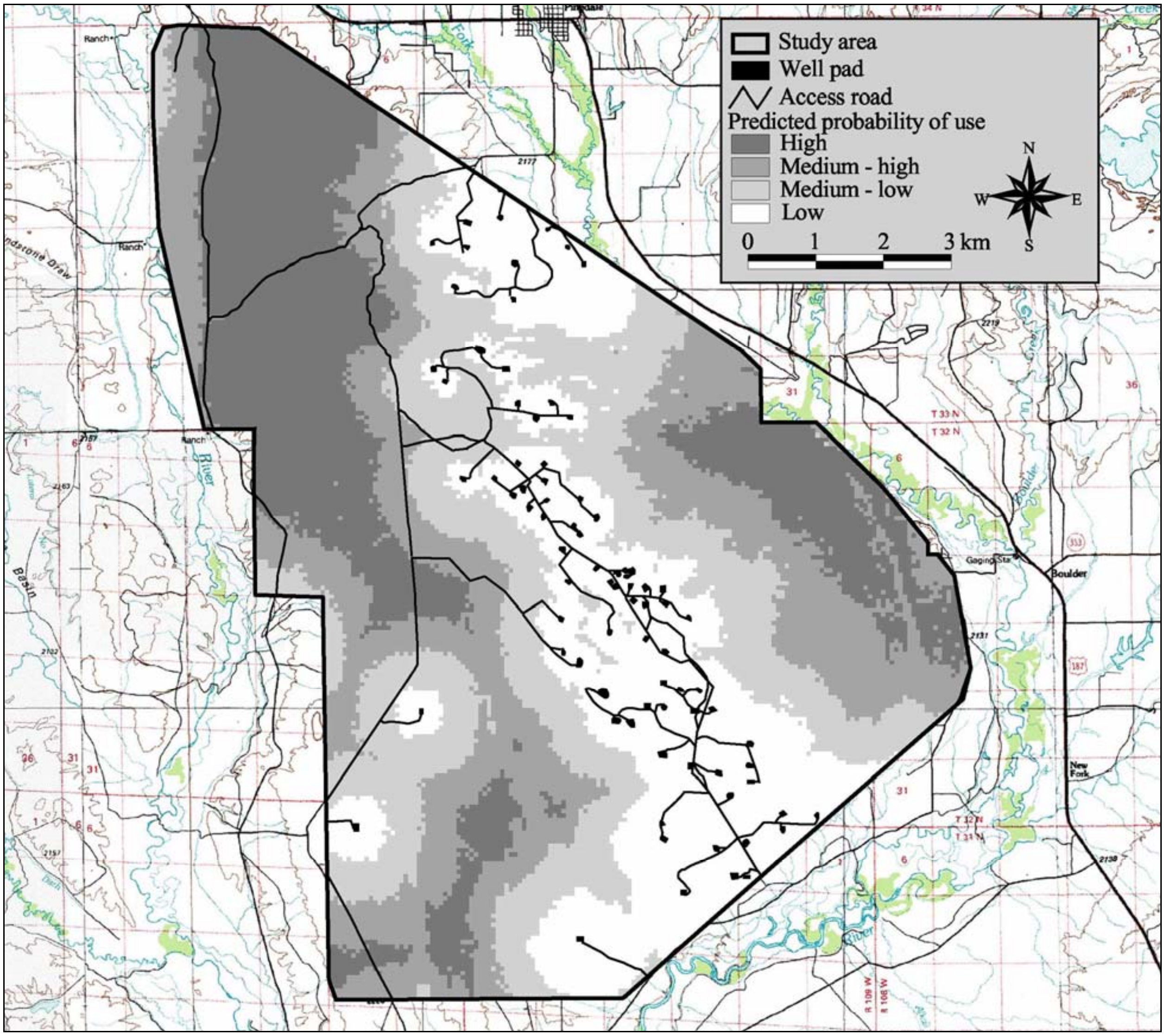

Figure 3-6. Population-level model predictions and associated categories of mule deer habitat use during Year 3 (winter of 2002-03) of natural gas development in western Wyoming.

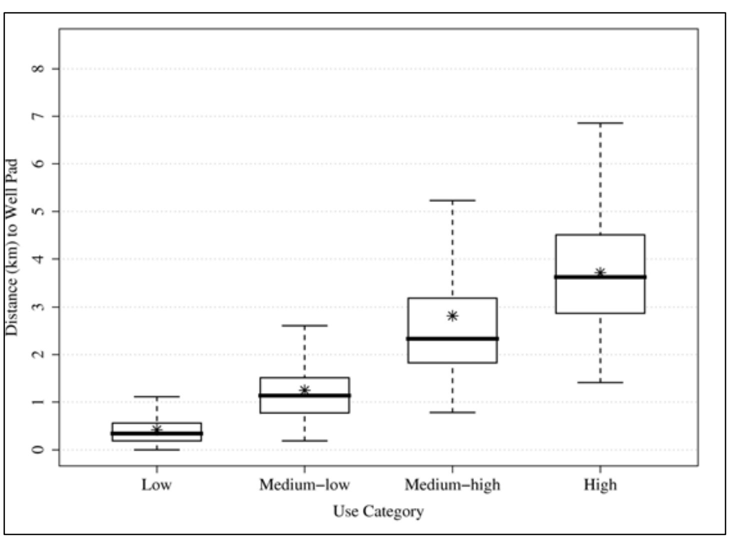

Figure 3-7. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line -) values. Box contains central 50% of distances.

Year 4 of Development: Winter 2003-04

Individual models were estimated for 10 radio-collared deer during the winter (December 20 to April 15) of 2003-04 (Table 3-9). And the road density metric was changed to distance to road. Eight of 10 deer had positive coefficients for elevation and 7 of 10 had negative coefficients for distance to well pad, indicating selection for higher elevations and habitats near well pads. Nine of 10 deer selected for areas with moderate slopes and 6 of 10 deer selected areas away from roads.

The population-level model was estimated from 9,837 GPS locations collected from 10 radio-collared deer during the winter of 2003-04 (Table 3-9). The model included elevation, slope^2, distance to road^2, and distance to well pad. Deer selected for areas with higher elevations, moderate slopes, away from roads, and close to well pads. Areas with the highest predicted levels of use had an average elevation of 2,272 m, slope of 5.23 degrees, 0.45 km away from roads, and 0.72 km away from well pads (Table 3-10). Predictive maps indicate deer use was lowest in areas with low elevations and away from well pads (Figure 3-8). Predictions of deer use between pre-development and Year 4 of development was more similar than during Year 3 of development, as evidenced through the changes in the 4 deer use categories (Table 3-13). Of the habitat units classified as high deer use prior to development, 54% were classified as high deer use during Year 4 of development. And, of the areas classified as low deer use prior to development, 57% remained classified as low deer use during Year 4 of development.

Table 3-9. Coefficients for individual deer models and the population-level model during the 2003-04 winter.

Coefficients for individual deer resource selection probability functions							
Deer ID	β	Elevation	Slope	Slope^2	Dist to road	Dist to road^2	Dist to well
Gps0304_844	0.409	-0.006	0.549	-0.031	1.042	-0.457	0.398
Gps0304_855	-74.089	0.029	-0.071	0.009	1.711	-0.489	-2.402
Gps0304_860	-26.664	0.008	0.213	-0.004	-0.920	0.125	-1.176
Gps0304_866	-64.753	0.025	0.058	-0.018	-0.029	-0.066	-0.104
Gps0304_868	-41.057	0.014	0.258	-0.014	2.865	-1.265	-0.500
Gps0304_872	-17.102	0.004	0.442	-0.023	-0.003	-0.052	-1.205
Gps0304_878	-35.308	0.011	0.557	-0.024	-0.291	-0.116	-0.614
Gps0304_884	-33.174	0.010	0.233	-0.005	6.962	-2.996	-1.697
Gps0304_887	2.462	-0.008	0.857	-0.048	6.278	-6.448	0.675
Gps0304_889	-58.375	0.020	0.791	-0.049	1.805	-0.762	0.388
Coefficients for average or population-level resource selection model							
Average	-34.765	0.011	0.389	-0.021	1.942	-1.253	-0.624
SE	8.196	0.004	0.096	0.006	0.860	0.646	0.316
P	0.002	0.019	0.003	0.007	0.050	0.084	0.080

Table 3-10. Average values for resource selection model variables in low, medium-low, medium-high, and high use categories during the 2003-04 winter.

Variable	Predicted Mule Deer Use			
	Low	Medium-low	Medium-High	High
Elevation (m)	2,181	2,199	2,234	2,272
Slope^2 (degrees)	3.01	3.58	3.12	5.23
Distance to road^2 (km)	1.45	0.95	0.62	0.45
Distance to well pad (km)*	4.26	2.76	1.22	0.72

* see Figure 3-9 for boxplot of distance to well pad values in each use category

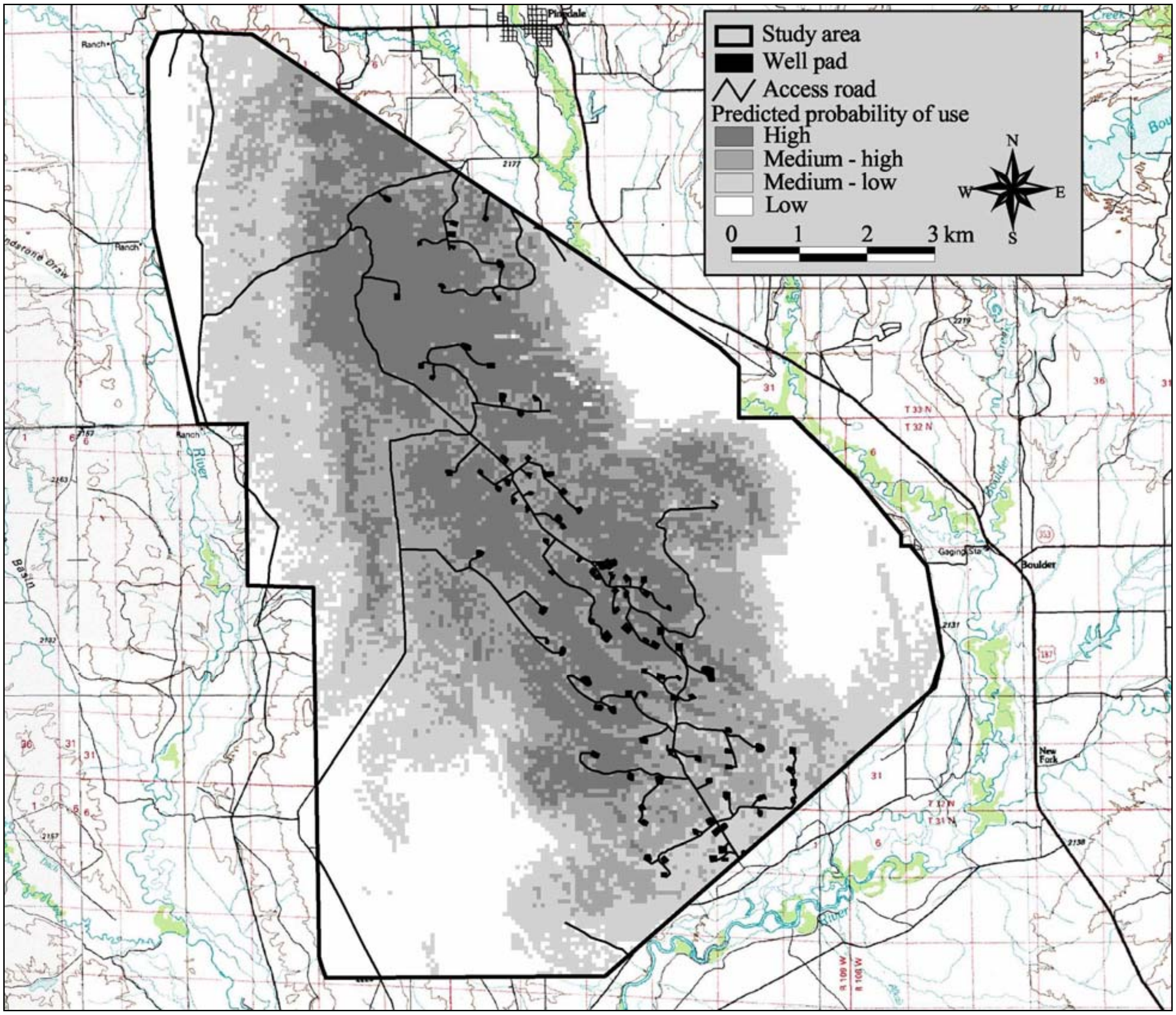

Figure 3-8. Population-level model predictions and associated categories of mule deer habitat use during Year 4 (winter of 2003-04) of natural gas development in western Wyoming.

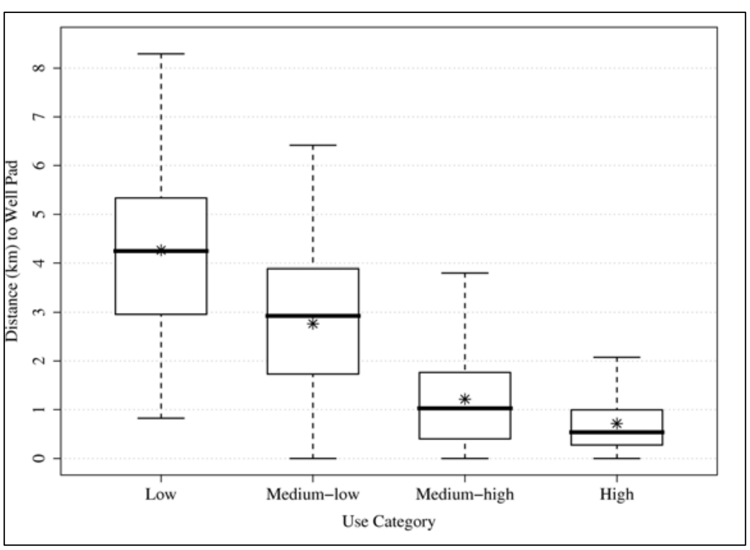

Figure 3-9. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line ‑) values. Box contains central 50% of distances.

Year 5 of Development: Winter 2004-05

Individual models were estimated for 19 radio-collared deer during the winter (December 20 to April 15) of 2004-05 (Table 3-11). Similar to 2003-04 the road density metric was changed to distance to road. Eighteen of 19 deer had positive coefficients for elevation, indicating selection for higher elevations. Based on the relationship between the linear and quadratic terms for the slope, distance to road, and distance to well pad variables, 16 of 19 deer selected for areas with moderate slopes, 14 of 19 deer selected for areas away from roads, and 9 of 19 deer selected areas away from well pads. Although 10 of 19 deer selected for areas close to well pads, the average coefficients (i.e., + linear term and – quadratic term) for this variable indicated a stronger selection away from well pads.

The population-level model was estimated from 22,289 GPS locations collected from 19 radio-collared deer during the winter of 2004-05 (Table 3-11). The model included elevation, slope^2, distance to road^2, and distance to well pad^2. Deer selected for areas with higher elevations, moderate slopes, away from roads, and away from well pads. Areas with the highest predicted levels of use had an average elevation of 2,264 m, slope of 4.36 degrees, 1.02 km away from roads, and 2.61 km away from well pads (Table 3-12). Predictive maps indicated deer use was lowest in areas with lower elevations and close to well pads (Figure 3-10). Shifts in deer distribution between pre-development and Year 5 of development were evident through the changes in the 4 deer use categories (Table 3-13). Of the habitat units classified as high deer use prior to development, 52% were classified as high deer use during Year 5 of development. And, of the areas classified as low deer use prior to development, 46% remained classified as low deer use during Year 5 of development.

Table 3-11. Coefficients for individual deer models and the population-level model during the 2004-05 winter.

Coefficients for individual deer resource selection probability functions								
Deer ID	β	Elevation	Slope	Slope^2	Dist to road	Dist to road^2	Dist to well	Dist to well^2
Gps0405_837	-55.800	0.021	0.123	-0.003	2.316	-0.865	-1.034	0.119
Gps0405_839	-41.237	0.011	0.008	-0.005	0.238	-0.555	5.148	-0.731
Gps0405_841	-54.990	0.022	-0.526	0.020	0.724	-1.371	-3.188	0.409
Gps0405_847	-18.504	0.002	0.415	-0.024	3.122	-0.630	0.799	-0.111
Gps0405_848	-35.791	0.009	0.059	-0.007	-1.606	-0.749	6.020	-0.905
Gps0405_855	-73.740	0.029	-0.124	0.009	-0.598	0.156	-2.238	0.288
Gps0405_858	-59.821	0.021	0.222	-0.018	1.299	-1.036	2.943	-0.660
Gps0405_859	-34.581	-0.002	0.705	-0.045	-0.748	-0.306	17.919	-2.499
Gps0405_865	-32.059	0.009	0.241	-0.017	-0.009	-0.586	2.861	-0.574
Gps0405_866	-86.975	0.034	0.162	-0.007	1.986	-0.794	-0.513	0.046
Gps0405_868	-31.556	0.009	0.340	-0.020	2.094	-0.899	0.270	-0.077
Gps0405_871	-59.153	0.022	0.244	-0.025	4.787	-1.544	-1.747	0.130
Gps0405_873	-48.035	0.018	-0.098	0.006	2.259	-0.406	-3.209	0.375
Gps0405_874	-65.004	0.025	0.151	-0.009	-0.119	-0.146	-1.568	0.228
Gps0405_876	-66.164	0.025	0.109	-0.004	10.121	-1.508	-5.841	0.157
Gps0405_878	-47.973	0.018	0.160	-0.014	0.144	-0.037	-2.894	0.346
Gps0405_884	-59.345	0.022	0.369	-0.015	8.310	-2.871	-5.374	0.584
Gps0405_887	-29.287	0.006	0.440	-0.036	0.185	-0.404	4.097	-0.486
Gps0405_889	-190.209	0.051	0.609	-0.052	5.656	-4.253	29.392	-3.215
Coefficients for average or population-level resource selection model								
Average	-57.380	0.019	0.190	-0.014	2.114	-0.990	2.202	-0.346
SE	8.373	0.003	0.063	0.004	0.717	0.239	1.945	0.227
P	<0.001	<0.001	0.008	<0.001	0.009	<0.001	0.272	0.145

Table 3-12. Average values for resource selection model variables in low, medium-low, medium-high, and high use categories during the 2004-05 winter.

Variable	Predicted Mule Deer Use			
	Low	Medium-low	Medium-High	High
Elevation (m)	2,183	2,209	2,224	2,264
Slope^2 (degrees)	3.24	3.46	3.88	4.36
Distance to road^2 (km)	1.02	0.86	1.06	1.02
Distance to well pad ^{2}(km)*	2.07	2.12	2.48	2.61

* see Figure 3-11 for boxplot of distance to well pad values in each use category

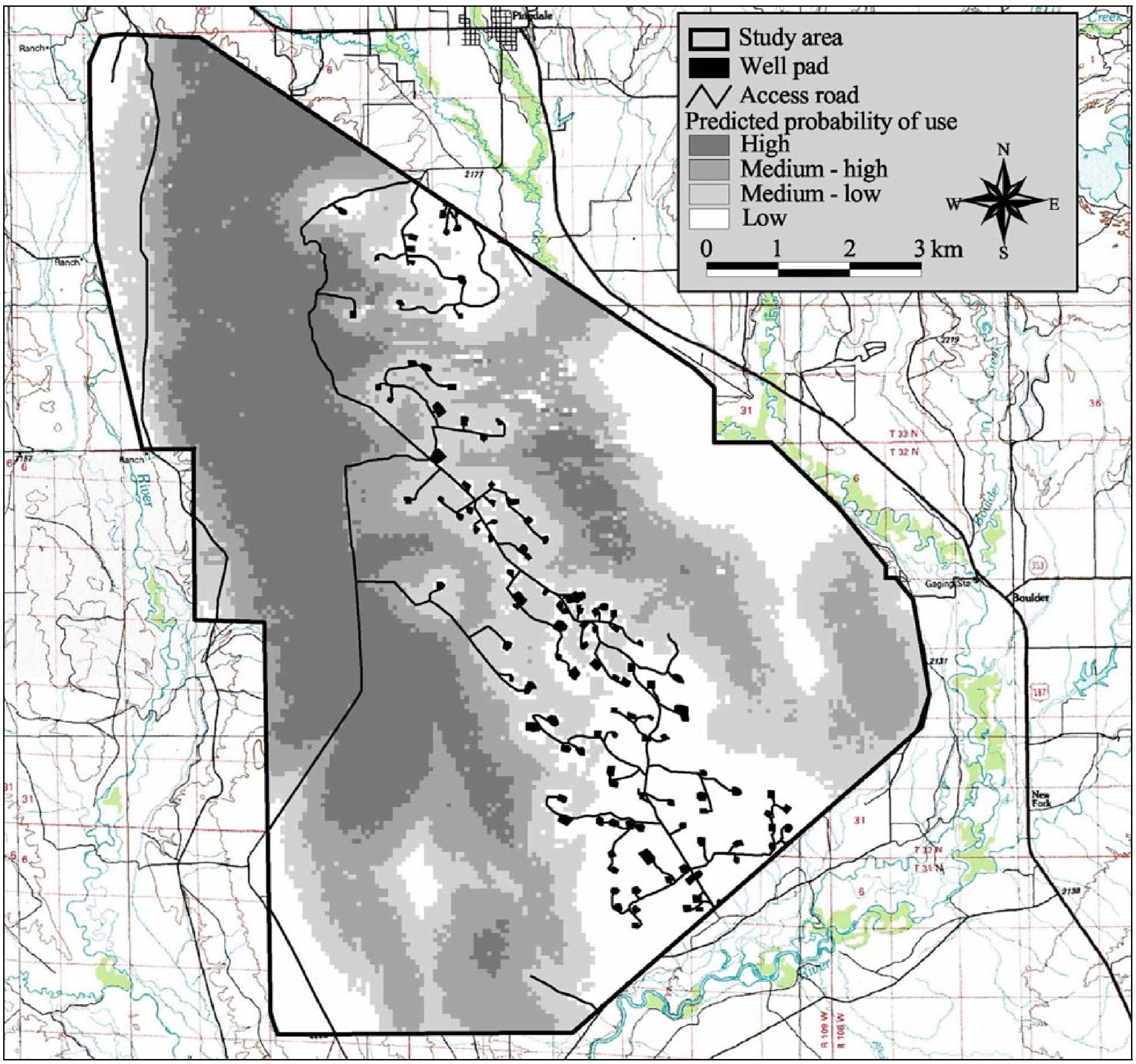

Figure 3-10. Population-level model predictions and associated categories of mule deer habitat use during Year 5 (winter of 2004-05) of natural gas development in western Wyoming.

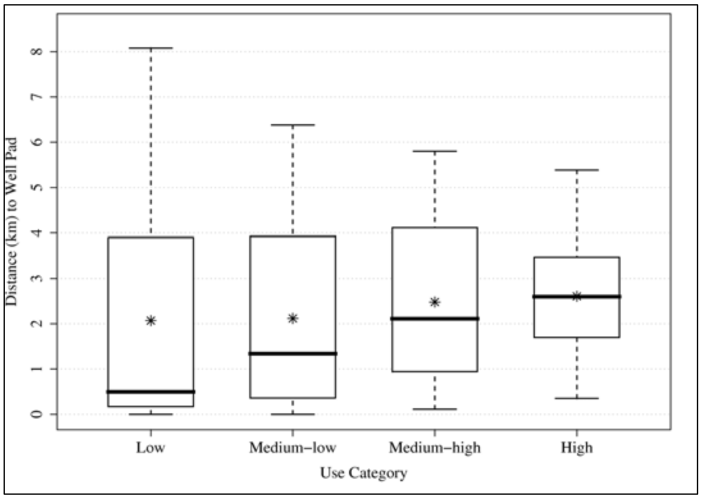

Figure 3-11. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line ‾) values. Box contains central 50% of distances.

Table 3-13. Percent change in the pre-development deer use categories through 5 years of natural gas development in western Wyoming.

Pre-development category[a]	Year of development	High	Medium-High	Medium-Low	Low
High	Year 1	60%	23%	13%	4%
	Year 2	49%	19%	23%	9%
	Year 3	37%	22%	27%	14%
	Year 4	54%	28%	14%	4%
	Year 5	52%	23%	19%	6%
Medium-High	Year 1	31%	36%	22%	11%
	Year 2	34%	23%	25%	18%
	Year 3	27%	22%	28%	22%
	Year 4	31%	33%	25%	11%
	Year 5	35%	27%	23%	15%
Medium-Low	Year 1	9%	34%	31%	26%
	Year 2	16%	35%	25%	25%
	Year 3	25%	27%	25%	23%
	Year 4	13%	27%	32%	28%
	Year 5	12%	30%	25%	33%
Low	Year 1	0%	7%	34%	58%
	Year 2	1%	23%	27%	48%
	Year 3	11%	29%	20%	41%
	Year 4	2%	12%	29%	57%
	Year 5	1%	20%	33%	46%

[a] Category rows may not sum to exactly 100% because of rounding error

DISCUSSION

Prior to this study, descriptions of how mule deer responded to gas development were based on anecdotal field observations. Two of the major shortcomings with anecdotal field observations are: 1) animals being observed may not be representative of the population (i.e., spatial bias) and 2) the movement patterns of animals outside the observation period are unknown (i.e., temporal bias). Our analysis accounts for the first shortcoming by obtaining a random sample of mule deer from the northern portion of the Mesa and treating the animal as the experimental unit. The random sample is more likely to be representative of the population than simply making observations of the most visible animals. Treating the marked animal as the experimental unit also ensures that all animals are weighted equally in the analysis. For example, some deer may use habitats in close proximity to roads and well pads, while others may use habitats away from roads and well pads. But, because all deer are treated equally, no one deer will influence model results more than another. Our analysis accounts for the second shortcoming by using GPS data that is collected every 2 hours for the entire winter, irrespective of time of day or weather conditions. This type of data collection provides accurate and unbiased documentation of animal movements through the entire winter period.

Traditional VHF radiocollars were used for the pre-development portion of the study, while GPS radiocollars were used for the post-development portion of the study. We would have preferred to use GPS radiocollars during all years of this study because they can systematically collect thousands of accurate deer locations, regardless of weather conditions or time of day. Although the VHF radiocollar locations used for the pre-development model were collected at irregular intervals and during daylight hours, we believe the resulting model provides a reasonable comparison to models estimated during years of development with GPS radiocollar locations. Hayes and Krausman (1993) suggested diurnal use of habitats by female mule deer were representative of overall patterns of habitat use, except in areas with high levels of human disturbance. Because human activity was low on the Mesa prior to development (i.e., no motorized use during winter), we believe the 953 VHF locations collected from 45 radio-collared deer accurately reflect overall deer use during that time period.

We view our resource selection analysis as an objective means to document mule deer response to natural gas development and quantify indirect habitat losses through time. Our results suggest winter habitat selection and distribution patterns of mule deer were affected by well pads and to a lesser degree, access roads. Changes in habitat selection appeared to be immediate (i.e., Year 1 of development) and mule deer consistently avoided well pads 4 of the first 5 years of development. The nonlinear relationship between probability of deer use and distance to well pad indicates deer selected areas away from well pads, but only out to a certain distance. This pattern may reflect the ability of mule deer to avoid localized disturbances and habitat perturbations without abandoning their home ranges entirely.

Year 4 of development was unusual in terms of winter conditions because it represented the most severe winter since inception of the study in 1998 and was characterized by above-average snow pack, cold temperatures, and crusty snow conditions. Unlike the other winters with more moderate weather conditions, mule deer habitat selection appeared less influenced by well pads. There are several potential reasons for this observed change in habitat selection during Year 4, including: 1) mule deer became habituated to the presence of human activity at the well pads, 2) human activity at well pads declined, or 3) the environmental conditions in Year 4 lead to the change in mule deer behavior and habitat selection. The first two explanations appear unlikely, given that mule deer avoided well pads in all subsequent years (Years 5, 6, and 7) and there was no change in development strategy that decreased the amount of human activity during Year 4.

To explain how the weather conditions may have elicited this change in habitat selection we first considered why mule deer avoid well pads. It is well-documented that mule deer and other ungulates avoid human disturbances, like vehicular traffic (Rowland et al. 2000, Nellemann et al. 2001, Dyer et al. 2002), bicyclists (Taylor and Knight 2003), and snowmobiles (Freddy et al. 1986, Seip et al. 2007). Our analysis is Section 4 suggests mule deer avoidance of well pads was influenced by the level of human activity at the well pads. There is a large body of literature that suggests wildlife respond to human disturbances similarly to how they respond to predation risk (e.g., Frid and Dill 2002). Like predation risk, human disturbance can divert time and energy away from foraging, resting, and other activities that improve fitness (Gill et al. 1996, Frid and Dill 2002), and therefore can be important to wintering mule deer, whose energy balance is closely linked to survival (Hobbs 1989). The predation risk literature suggests that antipredator behavior (e.g., fleeing, vigilance, habitat selection) has an energetic cost by reducing time spent in other energy positive activities (e.g., foraging, resting). Accordingly, prey animals must actively balance their foraging requirements with avoiding perceived risk (Lima and Dill 1990). As Lima (1998) and others (e.g., Brown and Kotler 2004) highlight, one of the best ways to demonstrate the tradeoffs between foraging and perceived risk is to experimentally deprive animals of food. Not surprisingly, hungry or malnourished animals are more likely to feed in riskier habitats in order to meet their energetic requirements and avoid starvation (Lima 1998, Brown and Kotler 2002). Given the variable nutritional condition of wintering ungulates, it is reasonable to expect those in poor body condition are less likely displaced by perceived risk because the benefit of foraging outweighs the risk of predation. Therefore, during harsh winters when mule deer are in poor body condition and forage availability is reduced, it is possible that deer ignore the perceived risk at well pads in favor of maximizing their foraging opportunities. Conversely, during mild or average winters when more habitats are available, it is reasonable to expect most deer to avoid the perceived risk (human disturbance) near well pads. We found mule deer response to well pads was consistent with predictions of predation risk theory (Lima and Dill 1990).

The models and associated predictive maps were useful tools for illustrating changes in habitat selection patterns through time and provided a framework for quantifying indirect habitat loss by measuring the changes (e.g., percent or area) in habitat use categories through time. Predictive maps suggest that some areas categorized as high-use prior to development, changed to low-use as development progressed, and other areas initially categorized as low use changed to high-use. For example, following Year 1 of development 17% of units classified as high-use before development had changed to medium-low or low use , and at Year 5 of development, 25% of those areas classified as high use before development had changed to medium-low or low-use. Conversely, at Year 5 of development, 21% of low use areas had changed to medium–high or high-use areas. Assuming areas with high predicted values of use prior to development were more suitable than areas with lower predicted values of use, these results suggest natural gas development on the Mesa displaced mule deer to less suitable areas.

Another consideration when interpreting the long-term trends in deer distribution and habitat use is that our analysis only included deer that had adequate numbers of GPS locations (>500) on the Mesa. Thus, we did not include deer that died early in the winter period because they had too few locations in the study area. This is an important consideration because the deer that may have been affected the most by gas development (i.e., those that emigrated or died) were not included in the analysis. Essentially our analysis reflects the habitat use patterns of deer that chose to occupy the Mesa and lived through most of the winter period in which they were collared.

A single-well pad typically disturbs 3 to 4 acres of habitat, however areas with the highest predicted levels of deer use were 2.7, 3.1, and 3.7 km away from well pads in Year 1, 2 and 3 respectively and 2.6 km away in Year 5. There are 2 potential concerns with the apparent avoidance of well pads by mule deer. First, the avoidance of areas near wells creates indirect loss of winter range that is substantially larger in size than the direct loss incurred when native vegetation is removed during construction of the well pad. Habitat loss, whether direct or indirect, has the potential to reduce carrying capacity of the range and result in population-level effects (i.e., survival or reproduction). Second, if deer do not respond by vacating winter ranges, distribution shifts may result in increased density in remaining portions of the winter range, exposing the population to greater risks of density-dependent effects (e.g., Bartmann et al. 1992).

Monitoring shifts in distribution or habitat use allows mitigation measures aimed at reducing impacts to be evaluated (e.g., liquids gathering system) and timely, site-specific strategies to be developed. The most common mitigation measure required by the BLM is seasonal timing restrictions, where development activities (e.g., construction, drilling, completion) are limited to non-winter months. This type of mitigation is common across federal lands and intended to reduce human activity and presumably the associated stress to big game during the winter months, typically November 15 through April 30. Even though drilling was largely restricted to non-winter months, we found that major shifts in the distribution of mule deer on the Mesa occurred due to significant levels of human activity during the winter as producing wells were serviced and maintained. Accordingly, mitigation measures other than seasonal timing restrictions may be needed to further reduce impacts to wintering mule deer.

MANAGEMENT IMPLICATIONS

The number of producing well pads and associated human activity may limit the potential effectiveness of timing restrictions on drilling activities as a means to reduce disturbance to wintering deer. Therefore, reducing disturbance to wintering mule deer will likely require approaches that reduce the number of well pads and limit the level of human activity throughout the production life of a gas field. Directional drilling technology offers a promising strategy for reducing surface disturbance, and installation of liquids gathering systems (LGS) on producing wells appears to be an effective approach for minimizing human activity (BLM 2004; see Section 4). Limiting public access and road management strategies may also be a useful part of mitigation plans. Future research and monitoring efforts should evaluate how different levels of human activity (e.g., traffic) at developing and producing well pads influence mule deer distribution (see Section 4). Understanding mule deer response to different levels of human activity and types of well pads would allow mitigation measures to be properly evaluated and improved.

Assuming there is some level of increased energy expenditure required for deer to alter their winter habitat selection patterns (Parker et al. 1984, Freddy et al. 1986, Hobbs 1989), the apparent displacement of deer from high use to low use areas has the potential to influence survival and reproduction. This relationship, however, needs to be documented (see Section 5). Accordingly, we recommend appropriate population parameters be monitored in areas with large-scale gas development so that changes in reproduction, survival, or abundance can be detected.

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Section 4.0

Influence of well pad activity on the winter habitat selection patterns of mule deer (2005-2007)

Section 4.0: Influence of gas field activity on the winter habitat selection patterns of mule deer (2005-2007).

NOTE: This section is essentially a continuation of Section 3, however beginning in 2005 a liquids gathering system (LGS) was installed and we were able to differentiate among well pad types (winter drilling, producing with LGS, and producing without LGS) and estimate the levels of traffic at each type. So rather than treat all well pads equally in the resource selection analysis, we treated them separately in an effort to better understand how mule deer respond to different well pad types and traffic levels.

INTRODUCTION

Increased levels of energy development on public lands, particularly natural gas, have become a source of concern for wildlife populations and their habitats. Because many of the largest natural gas reserves in the Intermountain West occur in shrub-dominated basins (e.g., Powder River Basin, Piceance Basin, Green River Basin), much of the concern has focused on native shrub communities and species that depend on them, such as passerines (Knick et al. 2003, Ingelfinger and Anderson 2004), sage grouse (Lyon and Anderson 2003, Holloran 2005, Kaiser 2006, Doherty et al. 2008, Walker et al. 2007), pronghorn (Sawyer and Lindzey 2005, Berger et al. 2007), and mule deer (Sawyer et al. 2006). Changes to the habitats on which these animals rely are often obvious, such as the replacement of native vegetation with well pads, access roads and pipelines. More difficult to quantify, however, is the indirect habitat loss that occurs when animals avoid areas around infrastructure due to increased human activity.

As gas development continues to expand across the Intermountain West, identifying mitigation measures that effectively reduce indirect habitat loss will become increasingly important, particularly in sensitive wildlife habitats like the Pinedale Anticline Project Area (PAPA; Bureau of Land Management [BLM] 2000). The Mesa portion of the PAPA provides crucial winter range for approximately 3,000 - 5,000 migratory mule deer that populate portions of 4 different mountain ranges in northwest Wyoming (Sawyer and Lindzey 2005). The PAPA also contains the 2nd largest natural gas reserve in the nation (20-25 trillion cubic feet of reserves), which the BLM approved for development in 2000 (BLM 2000). Four years following the BLM's record of decision to allow development of 700-900 wells (BLM 2000), it became apparent that natural gas reserves were greater than originally anticipated on portions of the PAPA and Questar Exploration and Production (QEP) requested that recovery plans for those reserves be modified (BLM 2004*a*). Among the proposed changes were: 1) expand directional drilling to year-round operations on multiple well pads, including those occurring in crucial mule deer winter range, and 2) construct a 107-mile liquids gathering system (LGS) to gather condensate and produced water from a portion of the producing wells, effectively eliminating 25,000 truck trips per year (BLM 2004*a*). The BLM conducted a supplemental environmental assessment on this new development strategy (BLM 2004*a*) and a finding of no significant impact soon followed (BLM 2004*b*). The development strategies were then implemented in 2005 and during the 2005-06 and 2006-07 winters, our study area contained a mix of LGS, non-LGS, and winter drill pads.

Given the high levels of human activity associated with drilling well pads and the relatively lower levels at producing well pads, these new development strategies provided a range of human activity levels across the PAPA and presented an excellent opportunity to evaluate how mule deer responded to varying levels of human activity. In Section 4 we present an evaluation of how the habitat selection patterns of mule deer were affected by well pads receiving varying levels of traffic during winters of 2005-06 and 2006-07. Additionally, we provide a quantitative assessment of how mule deer respond to winter drilling operations and the installation of a LGS, such that future development and mitigation strategies may be improved.

STUDY AREA

The PAPA is located in the upper Green River Basin, approximately 5 km southwest of Pinedale, and consists primarily of federal lands (80%) and minerals administered by the BLM (83%). The state of Wyoming owns 5% (39 km^2) of the surface and another 15% (121 km^2) is private (BLM 2000). The PAPA contains 20 to 25 trillion cubic feet of gas reserves, supports a variety of agricultural uses, and provides winter range for 3,000 to 5,000 migratory mule deer that summer in portions of 4 different mountain ranges 80 to 200 km away (Sawyer et al. 2005). Although the PAPA covers 799 km^2, most mule deer wintered in the northern one-third, an area locally known as the Mesa and one of the largest and highest density mule deer winter ranges in Wyoming (Wyoming Game and Fish Department [WGFD] 2006). The Mesa is 260 km^2 in size, bounded by the Green River on the west and the New Fork River on the north, south, and east, and vegetated primarily by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) and sagebrush-grassland communities. Elevation ranges from 2,070 to 2,400 m. Our study was restricted to the Mesa portion of the PAPA. During the 2005-06 winter the Mesa contained approximately 66 non-LGS well pads, 60 LGS well pads, and 6 winter drill pads (winter drill pads also had simultaneously producing wells with LGS).

METHODS

Capture and Collaring

We captured adult (≥ 1.5 year) female mule deer using helicopter net-gunning in the northern portion of the PAPA where deer congregated in early winter before moving to their individual winter ranges throughout the Mesa (Sawyer and Lindzey 2001). Capturing deer in this area during early winter provided the best opportunity to achieve a representative sample from the wintering population. We fitted deer with store-on-board global positioning system (GPS) radiocollars (Telonics, Inc., Mesa, Arizona, USA) equipped with remote-release mechanisms and programmed to collect locations every 2 hours.

Traffic Monitoring

We used active infrared sensors (Trailmaster® TM 1550 sensor, Lenexa, Kansas, USA) to monitor vehicular traffic at 43 sites during the winter of 2005-06 (January 13 – March 27; Figure 4-1) and at 44 sites during the winter of 2006-07 (January 10 – March 17; Figure 4-2). Mean daily traffic volume was estimated for access roads and well pad types (LGS, non-LGS, and winter drilling). We used a cluster analysis on the traffic data to categorize roads into 3 traffic categories (low, medium, or high). Monitors were situated approximately 1.2 m (4 ft.) off the ground and set at a sensitivity level that required the infrared beam be broken for 0.30 seconds.

This configuration was designed to minimize the probability of the monitor recording multiple hits for trucks hauling 1 or more trailers and reduce the likelihood of the monitor recording hits caused by mule deer or pronghorn when they occasionally travel on the road in front of the infrared beam. We developed a QA/QC program that plotted the distribution of hits for each counter across days and across a 24-hour period using the R language and environment for statistical computing (R Development Core Team 2006). This allowed us to identify blocks of hits that were obviously caused by a spurious event (e.g., heavy frost, raptor perched on monitor, etc.) rather than a vehicle. Traffic counters were downloaded and examined for QA/QC every 7 to 10 days and data associated with spurious events were removed. Additionally, we visually observed 235 traffic crossings across the 43 sites to help assess the accuracy of the monitoring system. Of the 235 vehicle observations, 97% were accurately recorded.

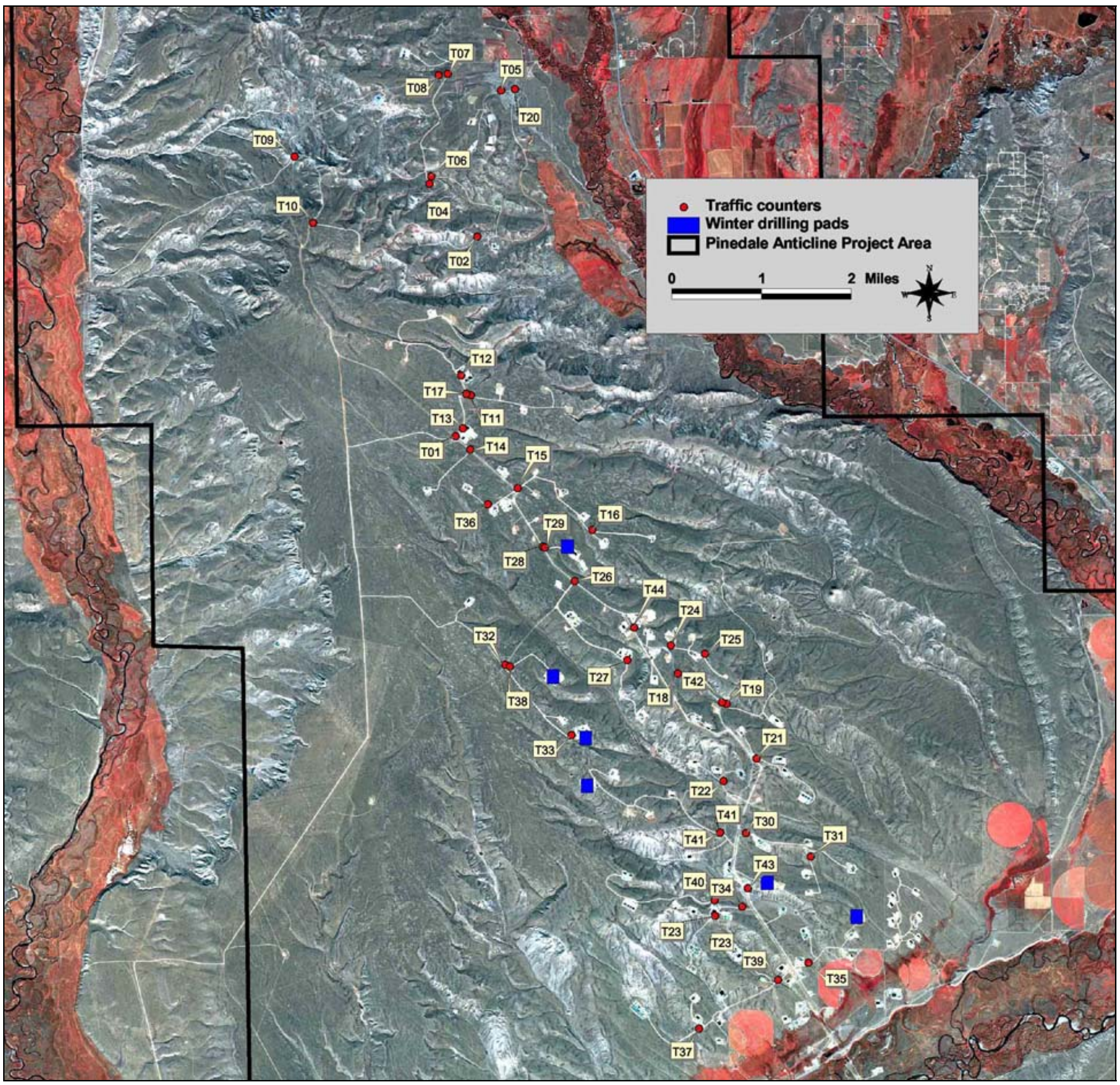

Figure 4-1. Locations of 43 traffic counters on the Mesa, January 13 – March 27, 2006.

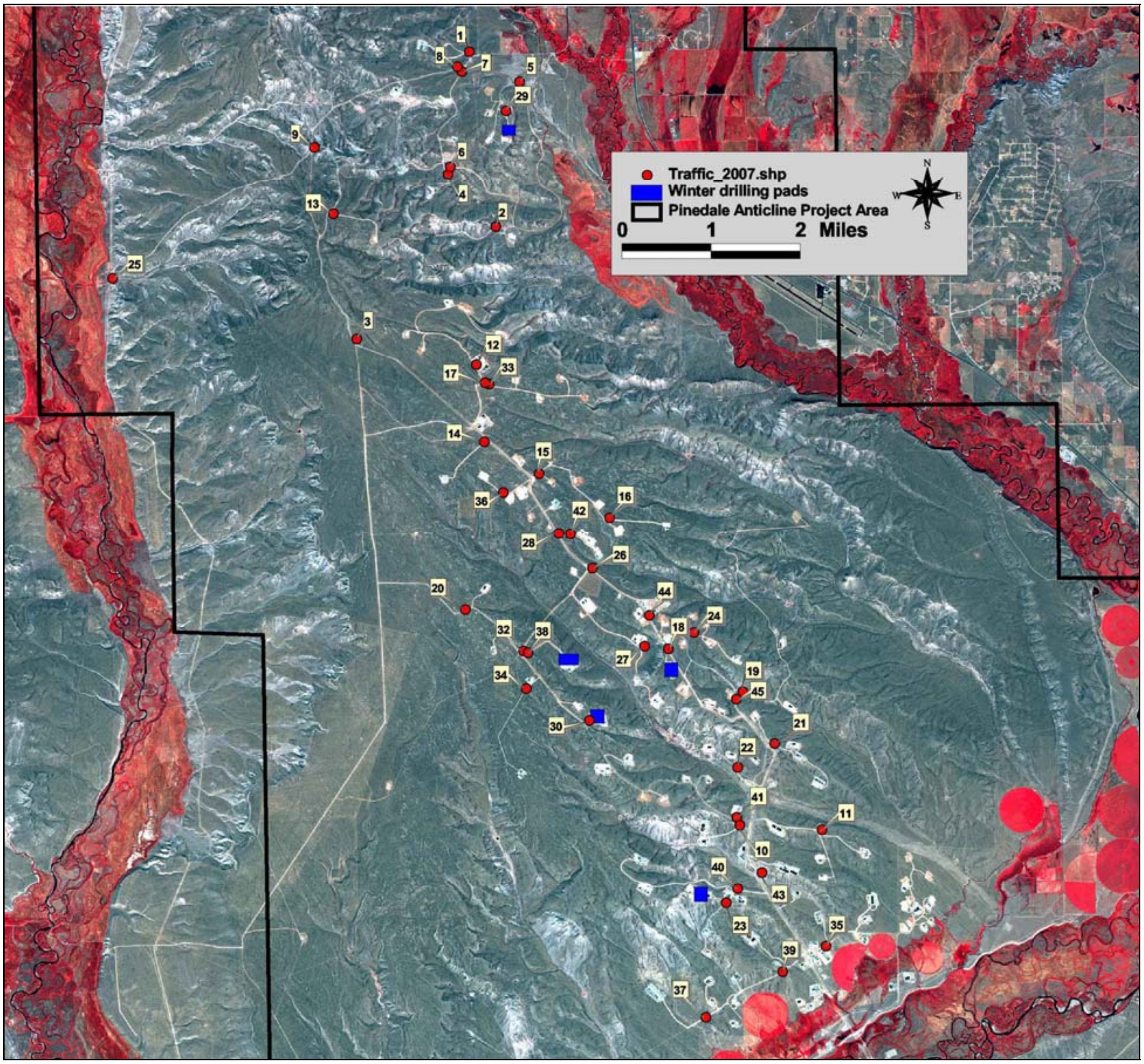

Figure 4-2. Locations of 44 traffic counters on the Mesa, January 10 – March 17, 2007.

Modeling Procedures

While traditional resource selection function (RSF) methods (Manly et al. 2002) commonly use logistic regression to compare a discrete set of used units with a set of unused or available units (Thomas and Taylor 2006), our approach modeled probability of use as a continuous variable in a generalized linear model (GLM; Sawyer et al. 2006, 2007). Our approach consisted of 5 basic steps where we: 1) measured predictor variables at 4,500 randomly selected circular sampling units, 2) estimated the relative frequency of use in the sampling units for each radiocollared deer, 3) used the relative frequency as the response variable in a multiple regression analysis to model the probability of use for each deer as a function of predictor variables, 4) averaged the coefficients of individual models to develop a population-level model, and then 5) mapped predictions of the population-level model. This method treats the marked animal as the experimental unit, thereby eliminating 2 of the most common problems with resource selection analyses, pooling data across individuals and ignoring spatial or temporal correlation in animal locations (Thomas and Taylor 2006). An additional benefit of treating each animal as the experimental unit is that inter-animal variation can be examined (Thomas and Taylor 2006) and population-level inference can be made by averaging coefficients across individual models (Millspaugh et al. 2006, Sawyer et al. 2006). Finally, by modeling use as a continuous variable, resource use is considered in a probabilistic manner that relies on the actual time spent by an animal in a sampling unit, rather than the presence or absence of the animal (Marzluff et al. 2004, Millspaugh et al. 2006, Rittenhouse et al. 2008).

Defining Study Area: We used the same study area defined in previous years (Section 3), that was based on the distribution of 39,641 locations collected from 77 mule deer over a 6-year period (1998 to 2003).

Habitat Variables: We identified 3 variables as potentially important predictors of winter mule deer distribution, including elevation, slope, and distance to well pad type. We did not include vegetation as a variable because the sagebrush-grassland was relatively homogeneous across the study area and difficult to divide into finer vegetation classes. Further, we believed subtle differences in sagebrush characteristics could be largely explained by elevation and slope. We used the Spatial Analyst extension for ArcView® (Environmental Systems Research Institute, Redlands, California, USA) to calculate slope from a 26 × 26 m digital elevation model (U.S. Geologic Survey [USGS] 1999). We digitized roads and well pads from a high resolution (10-m) satellite image provided by Spot Image Corporation (Chantilly, Virginia, USA). Images were collected in September 2005 and 2006, after most annual construction activities (e.g., well pad and road building) were complete, but prior to snow accumulation. Images were processed by SkyTruth (Sheperdstown, West Virginia, USA). We categorized well pads into 3 classes: winter drilling, LGS, and non-LGS.

Our sampling units for measuring habitat variables consisted of 4,500 circular units with 100-m radii randomly distributed across the study area. These sampling units were small enough to detect changes in animal movements, but large enough to ensure multiple locations could occur in each unit (Millspaugh et al. 2006, Sawyer et al. 2006). We took a simple random sample with replacement to ensure independence of the sampling units (Thompson 1992:51). We measured elevation, slope, and distance to well pad type at the center of each sampling unit.

Statistical Analyses: We estimated relative frequency of use for each radiocollared deer by counting the number of deer locations in each circular sampling unit. Before modeling resource selection, we conducted a Pearson's pairwise correlation analysis to identify possible multi-collinearity issues and to determine whether any variables should be excluded from the modeling ($|r| > 0.60$). Within the well pad variables, distance to active drilling and non-LGS pads were highly correlated in the 2005-06 ($r = 0.72$) and 2006-07 ($r = 0.90$) winters. However, we used all three will pad variables in the 2005-06 model-building process because it made the model more interpretable and the correlation between active drilling and non-LGS pads did not appear to influence model stability (i.e., regression coefficients did not switch signs and standard errors did not increase substantially as variables were added to the model). Inclusion of active drilling and non-LGS well pad types affected the stability of the 2006-07 model, so only LGS and non-LGS pads were included that year.

The relative frequency of locations from each radiocollared deer found in each sampling unit was an empirical estimate of the probability of use by that deer and was used as a continuous response variable in a GLM. We used an offset term (McCullagh and Nelder 1989) in the GLM to estimate probability of use for each radiocollared deer as a function of a linear combination of predictor variables, plus or minus an error term assumed to have a negative binomial distribution (McCullagh and Nelder 1989, White and Bennetts 1996). We began our modeling by first estimating coefficients for each radiocollared deer. We used the following GLM for each radiocollared deer:

$$\ln(E[r_i]) = \ln(total) + \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p, \qquad (1)$$

which is equivalent to:

$$\ln(E[r_i/total]) = \ln(E[\text{Relative Frequency}_i]) = \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p, \qquad (2)$$

where r_i is the number of locations for a radiocollared deer within sampling unit i (i = 1, 2, …, 4500), *total* is the total number of locations for the deer within the study area, β_o is an intercept term, $\beta_1,\ldots,\beta_p$ are unknown coefficients for habitat variables $X_1,\ldots,X_p$, and $E[.]$ denotes the expected value. The offset term, ln(*total*), was a quantitative variable for which the regression coefficient was set to 1 (Millspaugh et al. 2006). We used the same offset term for all sampled units of a given deer to ensure we were modeling relative frequency of use (e.g., 0, 0.003, 0.0034, …) instead of integer counts (e.g., 0, 1, 2, …). At the level of an individual animal, this approach estimates the true probability of use as a function of predictor variables, and is referred to as a resource selection probability function (RSPF; Manly et al. 2002).

To evaluate population-level resource selection we assumed GLM coefficients for predictor variable *k* for each deer were a random sample from a normal distribution (Seber 1984), with the mean of the distribution representing the average or population-level effect of predictor variable *k* on probability of use. We estimated coefficients for the population-level model by averaging the coefficients of the individual RSPFs. We estimated the variance of each population-level model coefficient using the variation among radiocollared deer.

Fitting the same model to each of the *n* individuals and then estimating population-level coefficients can provide a valid method for obtaining population-level inference (Marzluff et al. 2004, Millspaugh et al. 2006, Sawyer et al. 2006, 2007). Population-level inferences using equations (3) and (4) are unaffected by potential autocorrelation because temporal autocorrelation between deer locations or spatial autocorrelation between sampling units do not bias model coefficients for the individual radiocollared deer models (McCullagh and Nelder 1989, Neter et al. 1996).

We used a forward-stepwise model-building procedure (Neter et al. 1996) that required fitting the same models to each deer. We used a *t*-statistic to determine variable entry ($\alpha \le 0.15$) and exit ($\alpha > 0.20$; Hosmer and Lemeshow 2000), where the variable with the lowest α value was the first to enter the model. The *t*-test evaluates whether or not the coefficient is different than zero. We considered quadratic terms for distance to well pad and slope variables during the model-building process and, following convention, the linear form of each variable was included if the model contained a quadratic form.

We mapped predictions of population-level models for each winter on a 104 × 104 m grid that covered the study area. We checked predictions to ensure all values were in the interval [0, 1], to verify that we would not extrapolate outside the range of the model data (Neter et al. 1996). The model prediction for each grid cell was then assigned a value of 1 to 4 based on the quartiles of the distribution of predictions for each map. We assigned grid cells with the highest 25% of the predictions a value of 1 and classified them as high use areas, assigned grid cells in the 51 to 75 percentiles a value of 2 and classified them as medium-high use areas, assigned grid cells in the 26 to 50 percentiles a value of 3 and classified them as medium-low use areas, and assigned grid cells in the 0 to 25 percentiles a values of 4 and classified them as low use areas. We calculated the mean value of model variables for each of the 4 categories and used the high-use values as a reference for assessing how mule deer responded to different well pad types. Additionally, we used the predicted high-use areas to assess how deer were distributed relative to 4 road categories, including closed (no traffic), low use (1-13 vehicle hits/day), medium use (18-43 vehicle hits/day), and high use (76-325 vehicle hits/day). All statistical analyses were performed in the R language and environment for statistical computing (R Development Core Team 2006).

RESULTS

Traffic Monitoring: Winter 2005-06

Traffic levels were variable across the Mesa and ranged from 2 to 325 vehicle hits/day (Table 4-1). Mean daily traffic volume at LGS, non-LGS, and winter drill pads was 3.3 (SE = 0.30, $n = 9$), 7.3 (SE = 0.62, $n = 6$), and 112.4 (SE = 17.3, $n = 3$), respectively. Mean daily traffic volumes differed across well pad types ($P \leq 0.001$) and 95% confidence intervals did not overlap. A vehicle 'hit' represents anytime a vehicle passed by, such that one round-trip entering and exiting an access road would equal 2 vehicle hits.

Traffic Monitoring: Winter 2006-07

Traffic levels were variable across the Mesa and ranged from 1 to 191 vehicle hits/day (Table 4-1). Mean daily traffic volume at LGS, non-LGS, and winter drill pads was 3.5 (SE = 0.49, $n = 8$), 8.4 (SE = 1.16, $n = 7$), and 85.3 (SE = 2.91, $n = 3$), respectively. Mean daily traffic volumes differed across well pad types ($P \leq 0.001$) and 95% confidence intervals did not overlap.

Table 4-1. Mean number of vehicle hits per day and assigned use-level for 43 traffic monitors on the Mesa, January – March 2006 and 2007.

Winter 2005-06				Winter 2006-07		
Counter ID	Mean hits/day	Assigned Use-Level		Counter ID	Mean hits/day	Assigned Use-Level
t20	2	Low		t14	1	Low
t25	2	Low		t22	2	Low
t02	3	Low		t04	3	Low
t04	3	Low		t13	3	Low
t10	3	Low		t34	3	Low
t16	3	Low		t36	3	Low
t22	3	Low		t42	3	Low
t36	3	Low		t02	4	Low
t14	4	Low		t16	4	Low
t27	4	Low		t19	5	Low
t32	4	Low		t01	6	Low
t12	5	Low		t23	6	Low
t05	6	Low		t27	6	Low
t06	7	Low		t33	6	Low
t15	7	Low		t12	7	Low
t26	7	Low		t21	8	Low
t31	7	Low		t32	8	Low
t11	8	Low		t37	8	Low
t19	8	Low		t06	9	Low
t23	8	Low		t15	9	Low
t37	8	Low		t24	9	Low
t40	8	Low		t10	10	Low
t07	9	Low		t17	10	Low
t21	9	Low		t26	10	Low
t18	10	Low		t07	12	Low
t13	11	Low		t11	12	Low
t17	11	Low		t40	12	Low
t08	13	Low		t03	13	Low
t24	13	Low		t08	20	Medium
t09	18	Medium		t09	20	Medium
t30	18	Medium		t39	23	Medium
t01	19	Medium		t25	24	Medium
t34	23	Medium		t05	26	Medium
t39	27	Medium		t28	29	Medium
t28	43	Medium		t35	30	Medium
t35	76	High		t29	32	Medium
t29*	87	High		t44	43	Medium
t33*	105	High		t30*	81	High
t42	114	High		t18*	86	High
t44	118	High		t38*	90	High
t38*	145	High		t45	104	High
t41	244	High		t41	135	High
t43	325	High		t43	191	High

* denotes winter drill pad locations

Habitat Selection Modeling: Winter 2005-06

We used 24,955 locations collected from 20 GPS-collared mule deer to estimate individual and population-level models during the 2005-06 winter (Table 4-2). Models included elevation, slope, distance to LGS pad, distance to non-LGS pad, and distance to winter drill pad. Coefficients from the population-level model suggested that deer selected for areas with higher elevations, moderate slopes, and away from all well pad types. Areas with the highest predicted level of use had an average elevation of 2,239 m, slope of 4.98 degrees and were 2.61 km from LGS well pads, 4.30 km from non-LGS well pads, and 7.49 km from winter drill pads (Table 4-3). Within habitats predicted as high use, deer used areas relatively closer to LGS pads compared to non-LGS or winter drill pads (Table 4-3). On average, high use areas were closer to roads with no or low levels of traffic compared to roads with high levels of traffic (Table 4-3). The predictive map indicated that deer use was lowest in areas with low elevations and close to clusters of non-LGS and winter drill pads (Figure 4-3).

Table 4-2. Coefficients for individual deer models and population-level model during the 2005-06 winter.

Coefficients for individual deer models										
Deer ID	β	Elevation	Slope	Slope^2	Non-LGS Pad	Non-LGS Pad^2	LGS Pad	LGS Pad^2	Winter Pad	Winter Pad^2
GPS0506_370	10.920	-0.010	-0.036	0.000	2.286	-0.173	1.955	-0.855	-0.867	0.018
GPS0506_380	24.184	-0.023	-0.019	0.005	4.413	-0.460	-1.061	0.083	3.691	-0.275
GPS0506_390	-64.602	0.020	0.008	-0.006	-3.690	0.744	5.868	-1.283	2.181	-0.156
GPS0506_410	-33.397	0.012	0.060	-0.008	0.236	0.017	-1.133	0.041	-1.293	0.089
GPS0506_430	-68.396	0.008	0.268	-0.009	0.471	-0.121	6.954	-0.748	8.944	-0.747
GPS0506_440	-20.856	-0.035	0.053	-0.009	10.237	-0.829	2.988	-0.645	10.861	-0.501
GPS0506_470	-53.570	0.007	0.254	-0.017	6.438	-0.513	0.179	-0.047	3.004	-0.214
GPS0506_480	-106.652	0.027	0.551	-0.033	1.087	-0.283	12.109	-1.311	3.329	-0.275
GPS0506_550	-28.095	0.005	0.205	-0.007	-0.670	0.120	1.425	-0.508	-0.343	0.109
GPS0506_580	-39.749	0.015	-0.056	0.000	-1.874	0.412	0.100	-0.421	-0.121	0.013
GPS0506_590	-239.065	0.049	0.430	-0.027	12.634	-0.717	-5.887	0.304	20.803	-1.177
GPS0506_650	-51.445	0.016	0.402	-0.026	0.311	-0.162	2.419	-0.355	0.875	-0.080
GPS0506_700	-131.955	0.023	-0.107	0.007	23.264	-1.564	-3.426	0.124	0.627	-0.041
GPS0506_710	-43.019	0.016	0.613	-0.042	0.626	-0.070	0.312	-0.948	-1.801	0.147
GPS0506_720	-51.847	0.019	0.192	-0.014	-0.200	0.136	-1.585	0.080	0.626	-0.061
GPS0506_730	-106.041	0.032	-0.052	0.002	1.742	0.191	-1.038	-0.255	4.794	-0.291
GPS0506_740	-63.736	0.023	0.495	-0.046	0.533	-0.102	4.344	-1.171	-1.049	0.068
GPS0506_884	-8.123	0.000	0.197	-0.009	0.710	0.071	-1.260	-0.313	-0.935	0.100
GPS0506_887	-55.866	0.014	0.106	-0.020	1.018	-0.047	0.677	-0.141	3.440	-0.240
GPS0506_896	-70.468	0.018	-0.195	0.004	1.622	-0.299	2.382	-0.380	5.655	-0.425
Coefficients for population-level model										
Average	-60.089	0.012	0.168	-0.013	3.060	-0.182	1.316	-0.437	3.121	-0.197
SE	12.640	0.004	0.052	0.003	1.368	0.109	0.880	0.109	1.204	0.073
p-value	<0.001	0.010	0.004	0.001	0.037	0.110	0.151	<0.001	0.178	0.014

Table 4-3. Average values of model variables and distance to road classes in predicted low, medium-low, medium-high, and high use deer categories during the 2005-06 winter.

Model Variables	Predicted Mule Deer Use			
	High	Medium-High	Medium-Low	Low
Elevation (m)	2,239	2,224	2,238	2,183
Slope (degrees)	4.98	3.64	3.26	3.07
Distance to LGS pad (km)*	2.61	3.33	2.87	4.03
Distance to non-LGS pad (km)*	4.30	3.53	2.50	1.44
Distance to winter drill pad (km)*	7.49	5.47	3.93	2.78
Road Classes				
Distance to closed road (km)	1.68	1.60	1.81	2.69
Distance to low traffic (km)	2.16	2.45	1.55	1.07
Distance to medium traffic (km)	1.69	2.68	2.32	1.45
Distance to high traffic (km)	7.32	4.69	3.17	1.56

* see Figure 4-4 for boxplot of distance to well pad values in each use category

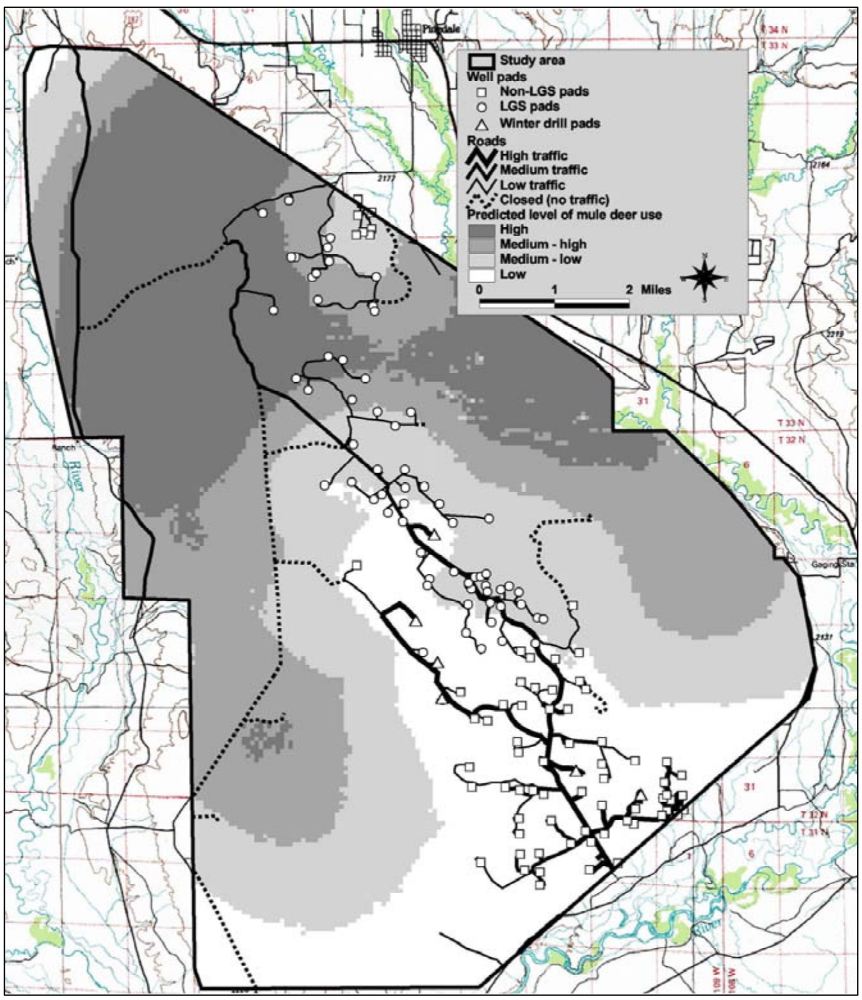

Figure 4-3. Predicted level of mule deer habitat use during Year 6 (winter of 2005-06) of natural gas development in western Wyoming.

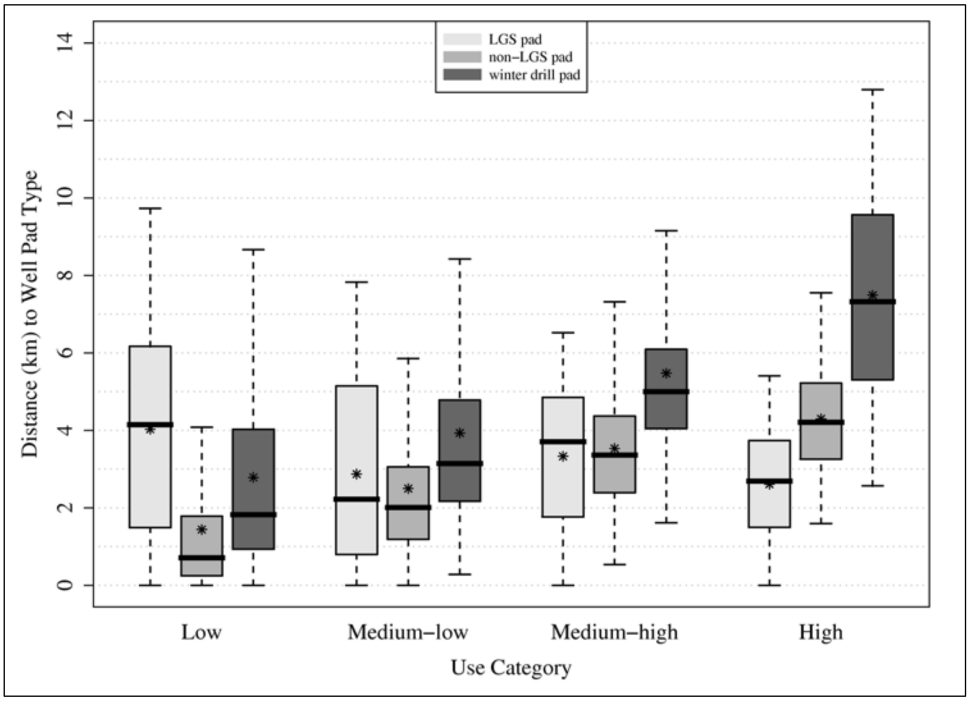

Figure 4-4. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line ‑) values. Box contains central 50% of distances.

Using the predicted high-use areas as a reference, mule deer distanced themselves from all types of well pads and tended to select areas progressively further away from well pads that received higher levels of traffic. Specifically, areas with the highest predicted deer use 2.61, 4.30, and 7.49 km away from LGS, non-LGS, and winter drill pads, respectively. We used these avoidance distances as a metric to assess indirect habitat loss associated with well pad types. Using a straight line distance, mule deer avoidance of LGS pads was approximately 40% less than that of non-LGS pads (i.e., 1-[2.6/4.3] = 0.40; Figure 4-5). However, assuming a circular area of behavioral response from the point of disturbance (well pad), the indirect habitat loss is reduced by 63% (i.e., 1-[21/58] = 0.63; Figure 4-5) relative to non-LGS pads. Conversely, the straight line distance mule deer selected away from winter drill pads was approximately 2.8 × greater than LGS pads and 1.7 × greater than non-LGS pads. Assuming a circular area of behavioral response, indirect habitat loss associated with winter drill pads was about 3.0 × more than non-LGS pads (i.e., 176/58 = 3.03) and 8.4 × more than LGS pads (i.e., 176/21 = 8.38).

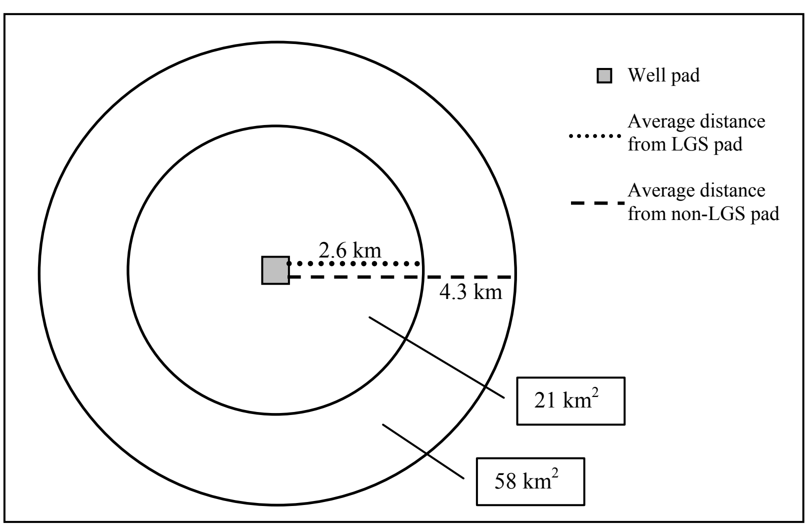

Figure 4-5. Graphical illustration of the relationship between straight-line avoidance distances and circular area of impact as a measure of indirect habitat loss.

Habitat Selection Modeling: Winter 2006-07

We used 11,744 locations collected from 11 GPS-collared mule deer to estimate individual and population-level models during the 2006-07 winter (Table 4-4). Models included elevation, slope, distance to LGS pad, and distance to non-LGS pad. Distance to winter drill pad was not included as a variable because it was strongly correlated with distance to non-LGS well pads. Coefficients from the population-level model suggest that deer selected for areas with higher elevations, moderate slopes, and away from LGS and non-LGS well pads. Areas with the highest predicted level of use had an average elevation of 2,243 m, slope of 4.55 degrees and were 3.46 km and 4.35 km from LGS and non-LGS well pads, respectively (Table 4-5). Within high use habitats, deer used areas relatively closer to LGS pads compared to non-LGS (Table 4-5). On average, high use areas were closer to roads with no or low levels of traffic compared to roads with high levels of traffic (Table 4-5). The predictive map indicated that deer use was lowest in areas with low elevations and clusters of non-LGS well pads (Figure 4-6).

Table 4-4. Coefficients for individual deer models and population-level model during the 2006-07 winter.

Deer ID	β	Slope	$Slope^2$	Non-LGS Pad	Non-LGS Pad^2	LGS Pad	LGS Pad^2	Elevation
Coefficients for individual deer models								
GPS0607_390	-73.536	0.202	-0.021	3.732	-0.408	6.124	-0.624	0.019
GPS0607_410	-63.133	0.008	-0.007	10.270	-1.347	9.064	-1.265	0.009
GPS0607_480	-166.579	0.672	-0.034	0.462	0.001	7.149	-0.605	0.060
GPS0607_550	-134.118	0.439	-0.028	2.062	-0.325	5.502	-0.619	0.049
GPS0607_580	-8.523	0.406	-0.032	6.769	-0.888	0.474	-0.087	-0.006
GPS0607_720	-79.250	0.402	-0.024	6.360	-0.713	-0.566	0.038	0.025
GPS0607_740	12.478	0.257	-0.014	6.526	-0.952	0.515	-0.127	-0.015
GPS0607_760	-85.705	0.401	-0.029	0.923	-0.151	3.876	-0.277	0.029
GPS0607_870	-105.555	0.509	-0.028	15.364	-1.455	0.802	-0.205	0.025
GPS0607_900	-53.206	0.324	-0.029	-0.884	0.028	-0.279	0.032	0.020
GPS0607_960	-56.536	0.329	-0.018	11.644	-0.974	4.707	-0.897	0.004
Coefficients for population-level model								
Average	-73.969	0.359	-0.024	5.748	-0.653	3.397	-0.421	0.020
SE	15.364	0.052	0.003	1.545	0.156	1.013	0.126	0.007
p-value	<0.001	<0.001	<0.001	0.004	0.001	0.007	0.007	0.012

Using the predicted high-use areas as a reference, mule deer distanced themselves from LGS and non-LGS well pads and tended to select areas progressively further away from well pads that received higher levels of traffic. Specifically, areas with the highest predicted deer use were on average 3.46 and 4.35 km away from LGS and non-LGS well pads, respectively. We used these avoidance distances as a metric to assess indirect habitat loss associated with well pad types. Using a straight line distance, mule deer avoidance of LGS pads was approximately 21% less than that of non-LGS pads. However, assuming a circular area of behavioral response from the point of disturbance (well pad), the indirect habitat loss is reduced by 38% relative to non-LGS pads.

Table 4-5. Average values of model variables and distance to road classes in low, medium-low, medium-high, and high use deer categories during the 2006-07 winter.

Model Variables	Predicted Mule Deer Use			
	High	Medium-High	Medium-Low	Low
Elevation (m)	2,243	2,203	2,233	2,206
Slope (degrees)	4.55	3.61	3.52	3.27
Distance to LGS pad (km)*	3.46	3.43	2.53	2.12
Distance to non-LGS pad (km)*	4.35	3.97	2.83	0.69
Road Classes				
Distance to closed road (km)	1.82	2.02	1.91	2.01
Distance to low traffic (km)	2.82	2.31	1.37	0.50
Distance to medium traffic (km)	2.20	2.74	1.87	1.22
Distance to high traffic (km)	4.52	4.13	3.44	1.43

* see Figure 4-7 for boxplot of distance to well pad values in each use category

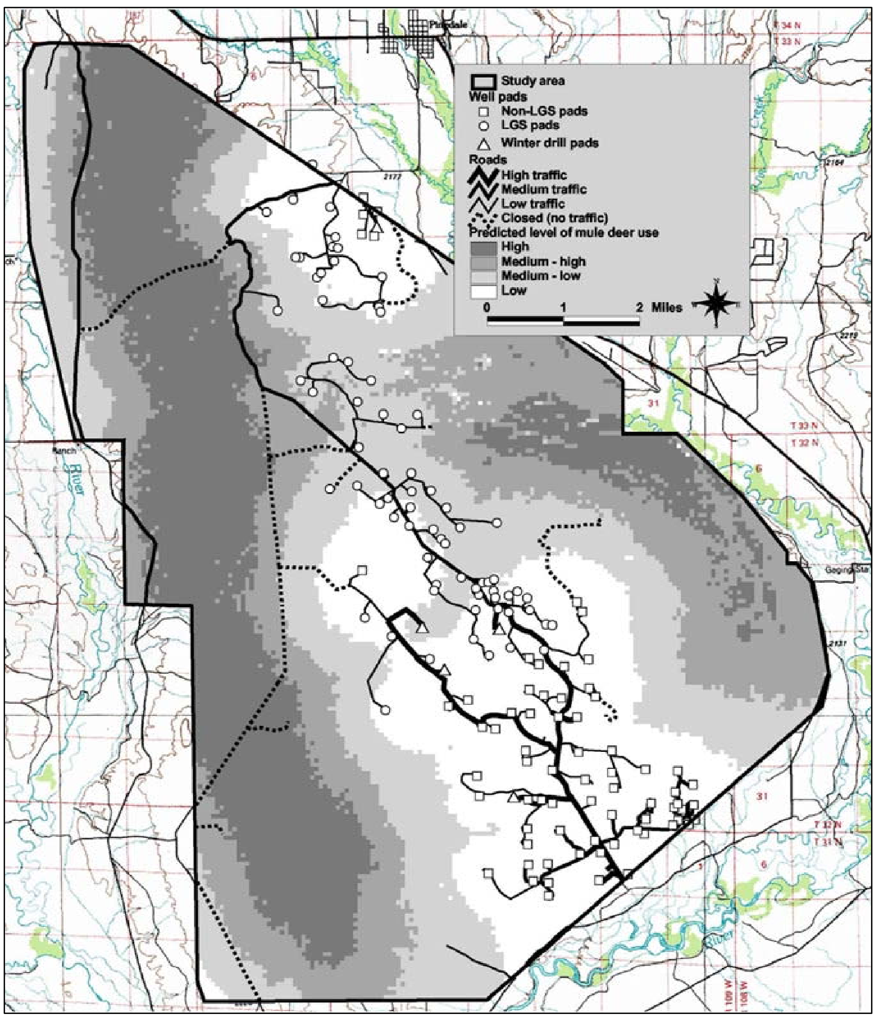

Figure 4-6. Predicted level of mule deer habitat use during Year 7 (winter of 2006-07) of natural gas development in western Wyoming.

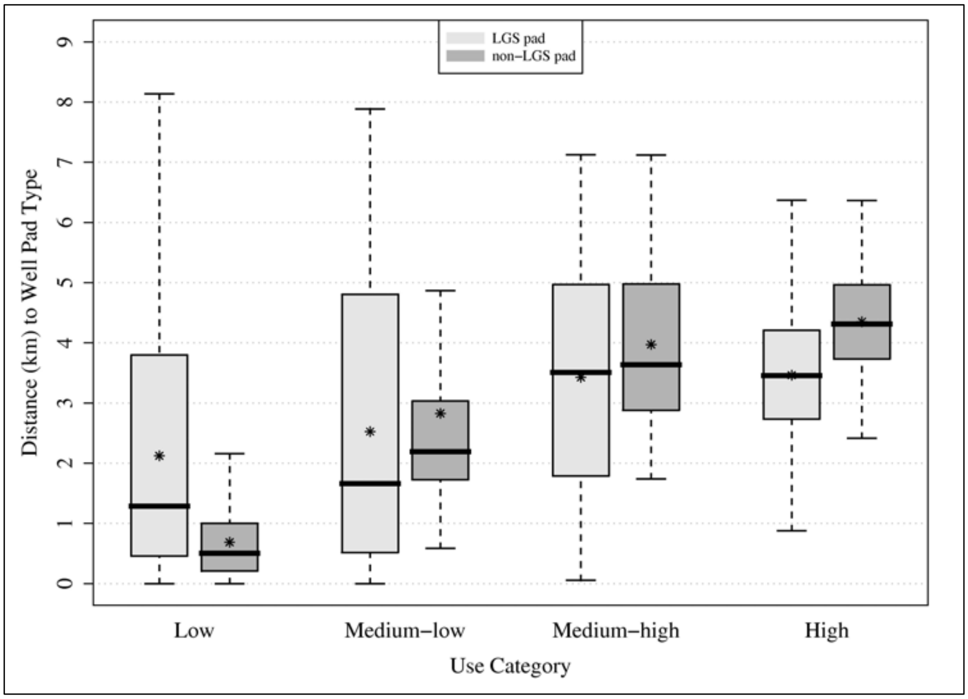

Figure 4-7. Boxplot illustrates the distribution of distances to well pads in each use category and shows the mean (asterisk*) and median (dark line -) values. Box contains central 50% of distances.

DISCUSSION

Consistent with previous years of study on the Mesa (see Section 3), we found that habitat selection patterns of mule deer were influenced by well pads. Mule deer avoided all types of well pads, but tended to select areas farther from well pads with higher levels of traffic. Avoidance distances calculated from predicted high-use areas provided a useful metric to assess indirect habitat loss associated with different types of well pads. Indirect habitat loss associated with LGS well pads was 38-63% less than with non-LGS well pads, which is noteworthy given that the expected production life of gas wells in the PAPA is 40 years (BLM 2006). Winter drilling pads had 85-112 vehicle hits per day (i.e., 42-56 roundtrips) and the indirect habitat loss associated with them was much higher than those at producing well pads; about 3 × more than non-LGS pads and 8 × more than LGS pads. However, it should be noted that all winter drill pads in the PAPA were used for directional drilling, which is generally a short-term (6 months to 2 years) process, whereas producing well pads represent a long-term (decades) source of disturbance. Additionally, drilling multiple wells from a single pad may be necessary to construct a LGS that is economically feasible (D. Hoff, QEP, personal communication).

Evaluating mule deer response to traffic disturbance is conceptually similar to how ecologists have evaluated prey response to predation risk (Lima and Dill 1990, Lima 1998). For example, the habitat selection patterns of elk are affected by the presence of wolves (Creel et al. 2005, Winnie and Creel 2006), which may vary spatially or temporally, just as levels of human disturbance may vary across a gas field. Like predation risk, human disturbance can divert time and energy away from foraging, resting, and other activities that improve fitness (Gill et al. 1996, Frid and Dill 2002), and therefore can be important to wintering mule deer, whose energy balance is closely linked to survival (Hobbs 1989). Here, we briefly consider the risk perception of mule deer to help understand and predict their behavioral responses to varying levels of traffic in the PAPA.

Our results suggest that the response of mule deer to well pads was functionally similar to how prey animals respond to the risk of predation (e.g., Lima and Dill 1990, Gill et al. 1996) in that mule deer appeared to perceive varying levels of risk (traffic) and scaled their behaviors accordingly. Given that the risk of predation can vary greatly across seasons, days, or even hours, prey species should be sensitive to the current risk of predation (Lima and Dill 1990) or level of disturbance. Our results suggest that reducing traffic from 7-8 (non-LGS well pads) vehicle hits per day to 3 (LGS well pads) was sufficient for mule deer to alter their habitat selection patterns such that LGS well pads were avoided less than non-LGS well pads, effectively reducing indirect habitat loss associated with producing well pads.

Drilling during the winter (November 15- April 30) in areas designated as crucial winter range is a recent phenomenon. Traditionally, seasonal timing restrictions have limited development activities (e.g., construction, drilling, well completion) to non-winter months and represent the most common, and sometimes the only, mitigation measure required by the BLM for reducing disturbance to wintering ungulates on federal lands. Because of seasonal timing restrictions, drilling in crucial winter ranges located on federal lands has typically not been an option for industry. However, winter drilling will likely become a more common practice across the Intermountain West, as evidenced by recent National Environmental Policy Act decisions in western Wyoming (BLM 2004*a*, 2004*b,* 2006), where stakeholders identified year-round directional drilling as the preferred method to develop the necessary number of wells to recover the natural gas, regardless of winter range designation. Wildlife managers have expressed concerns about year-round drilling in crucial winter range because seasonal timing restrictions would be waived and the levels of human disturbance would increase substantially during winter (BLM 2004*a*), when mule deer are most vulnerable to stress, additive energy expenditure, and reduced foraging opportunities (Parker et al. 1984, Hobbs 1989). While significant indirect habitat losses may occur with seasonal timing restrictions in place (see Section 3), our results suggest that wintering mule deer are sensitive to varying levels of disturbance and that indirect habitat loss may increase by a factor of >3 when seasonal restrictions are waived. However, drilling is considered a short-term disturbance and according to industry, year-around directional drilling is necessary to construct an economically-feasible LGS (D. Hoff, QEP, personal communication).

Given the increased levels of energy development across the Intermountain West (BLM 2005), experimentation or manipulative studies will be necessary to advance our understanding of wildlife response to varying levels of human disturbance associated with different development strategies and habitat perturbations. Unfortunately, many of the systems we study are too large to manipulate or the expense of such an experiment is prohibitive (Macnab 1983). Additionally, when experiments are conducted at large spatial scales, such as the 799-km^2 PAPA, replication and randomization are rarely options (Nichols 1991, Sinclair 1991, Gotelli and Ellison 2004). When the treatment or manipulation is commodity driven, such as mineral extraction or gas development, randomization becomes especially difficult to achieve. Recognizing the constraints that limit our ability to conduct large-scale manipulative experiments, researchers have been encouraged to treat management prescriptions, such as fire or harvest regimes, as a form of experimentation (Macnab 1983, Nichols 1991, Sinclair 1991) and as an opportunity to learn as we go (Walters and Holling 1990). Of course, inferences from these types of studies are weaker than those possible with true experiments that have both replication and randomization components. Notwithstanding, the opportunity to advance wildlife science and gain reliable knowledge still exists with careful design, analysis, and interpretation (Morrison et al. 2008). Gas development has become and will continue to be, one of the dominant land uses on federal lands across the Intermountain West. As such, we encourage researchers to consider energy development strategies and mitigation measures as large-scale experimentation that, if properly monitored, can improve our knowledge of energy impacts to wildlife.

MANAGEMENT IMPLICATIONS

Access roads and well pads are the 2 dominant infrastructure features in most gas fields, including the PAPA. However, given that well pads contribute a much larger percentage to the overall surface disturbance (83%; see Section 1) and they represent the destination source(s) for traffic within the gas field, well pads appear to be more influential to mule deer habitat selection than do access roads. Therefore, the most effective mitigation measures for reducing impacts to mule deer will likely involve technology and planning that minimize the number of well pads and the human activity associated with them. Combined with careful planning, LGS and directional drilling represent 2 development strategies that provide effective means for reducing the number of well pads needed to recover gas resources and minimizing the amount of human activity at producing pads. Our results suggest indirect habitat loss to mule deer may be reduced by approximately 38-60% when water and condensate products are collected in pipelines rather than being stored at well pads and hauled off with tanker trucks. Additionally, because a LGS can be installed underground and usually in existing pipeline corridors, the associated direct habitat loss is minimal. When directional drilling technology is used to drill multiple wells from a single pad, the amount of habitat loss is significantly reduced compared to a scenario where single wells are drilled from multiple pads. However, given the high levels of human activity associated with drilling, wildlife managers should expect considerable short-term displacement of wintering mule deer if year-round drilling is permitted in crucial winter range. Recognizing how mule deer respond to different types of well pads and traffic regimes may improve the ability of agencies and industry to estimate cumulative effects and quantify indirect habitat losses associated with different development scenarios (e.g., clustered development; Theobald et al. 1997).

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Section 5.0

MULE DEER POPULATION PERFORMANCE ON THE MESA

Section 5.0: Mule deer population performance on the Mesa.

INTRODUCTION

Natural gas development on public lands in Wyoming has rapidly increased since the mid-1990s (Bureau of Land Management [BLM] 2005). Because public lands with high gas potential often coincide with regions that support large mule deer (*Odocoileus hemionus*) populations, such as the Green River Basin (BLM 2000*a*), Great Divide Basin (BLM 2000*b*), and Powder River Basin (BLM 2003), there has been concern over potential impacts to mule deer habitat and population performance. We have some knowledge of the direct (see Section 1) and indirect habitat loss (see Sections 3 and 4) associated with natural gas development, but despite the dozens of National Environmental Policy Act (NEPA) analyses prepared for energy development projects in Wyoming, we know little about the actual impacts of gas development on the demographics of mule deer populations.

This information gap makes it difficult for agencies and industry to improve their planning process and it may limit their ability to develop energy resources in ways that are environmentally sensitive to mule deer. In this section we present an assortment of mule deer data collected across an 7-year period and use a weight-of-evidence approach to provide an interpretation of how natural gas development in winter ranges may affect mule deer population performance. By the very nature of observational studies, cause and effect is difficult to demonstrate (Morrison et al. 2008), but considering multiple population parameters it may be possible to detect likely effects that are biologically significant.

STUDY AREA

The Sublette mule deer herd unit is situated in the upper Green River Basin of western Wyoming and supports approximately 27,000-30,000 mule deer during the winter (WGFD 2007). Mule deer from 5 different mountain ranges annually converge on major winter ranges in the Sublette herd unit (Sawyer et al. 2005), including the Mesa Winter Range Complex (MWRC) and the Pinedale Front Winter Range Complex (PFWRC; Figure 5-1). The MWRC included wintering areas west of US 191, while the PFWRC included those areas east of US 191 to the base of the Wind River Range (~8,000 ft in elevation). Sawyer and Lindzey (2001) reported <2% interchange between the 2 complexes during the winters prior to gas development. Winter ranges in both areas were characterized by rolling topography dominated by sagebrush (*Artemisia tridentata*) communities and interspersed with riparian corridors and irrigated croplands. Elevations ranged from 2,100 to 2,350 m and mean annual precipitation was approximately 25 cm.

Beginning in 2000, the BLM approved the construction of 700 producing well pads, 645 km of pipeline, and 444 km of roads to develop a natural gas field in the Pinedale Anticline Project Area (PAPA; BLM 2000*a*). The Mesa portion of the PAPA is considered the core of the MWRC and contains one of the largest and highest density mule deer winter ranges in Wyoming. The PAPA consists primarily of federal lands (80%) and minerals administered by the BLM (83%). Although the PAPA covers 799 km^2, most mule deer winter in the northern one-third, an area locally known as the Mesa. The Mesa is approximately 260 km^2 in size and was considered our treatment area (Figure 5-1), with natural gas development (i.e., roads, well pads, drill rigs, and other infrastructure) being the treatment. We chose a reference area located in the PFWRC (Figure 5-1) because it consisted mostly of federal lands and had no ongoing energy development. Our reference area consisted of a 300 km^2 area identified by earlier telemetry studies as the core wintering area in the PFWRC (Sawyer and Lindzey 2001). We initially believed this was a suitable reference site because: 1) there was little exchange of deer between the MWRC and PFWRC, 2) the 2 segments of the Sublette herd used separate winter ranges, but shared common transition and summer ranges, so it was reasonable to assume they had comparable foods available during non-winter periods and arrived on winter ranges in similar condition, 3) although the 2 population segments occupied distinct winter ranges, they were in close proximity to one another (15-30 miles), so we assumed both were exposed to similar weather patterns and environmental conditions in most years, and 4) topography and vegetation on both winter ranges was similar.

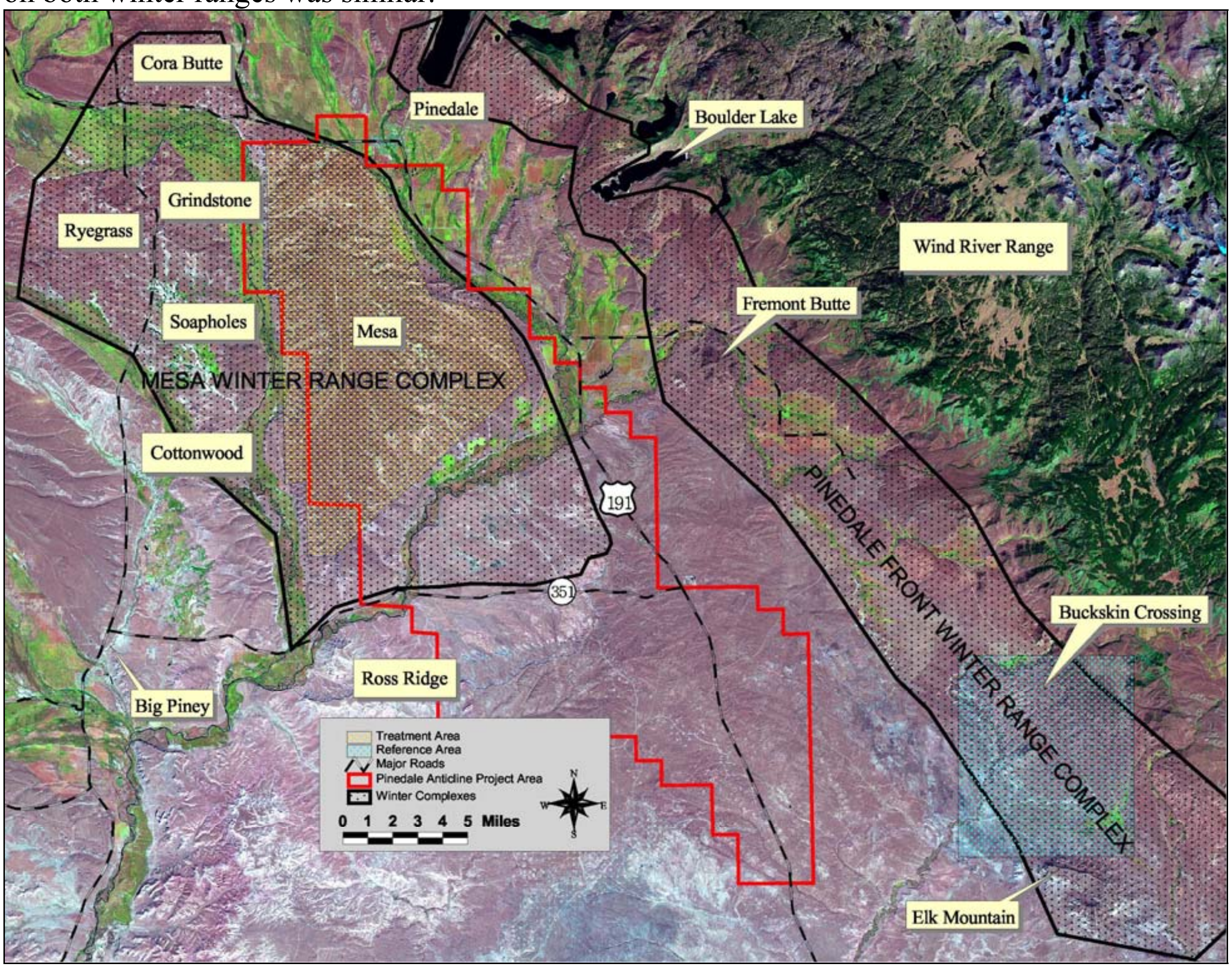

Figure 5-1. Locations of treatment and control areas within the Mesa and Pinedale Front Winter Range Complexes.

METHODS

We used a weight of evidence approach to assess effects of gas development and production on the treatment group of mule deer. We considered a number of comparisons with data accumulated over time from both the reference and treatment areas. The weight of evidence approach emphasizes detection of biological significance when statistical significance may be marginal (Morrison et al. 2008).

Capture

We captured adult (≥ 1.5 year) female mule deer using helicopter net-gunning in the northern portion of the treatment area where deer congregated in early winter before moving to their individual winter ranges (Sawyer et al. 2005). Capturing deer in this area during early winter provided the best opportunity to achieve a representative sample from the wintering population. A similar concentration area did not exist in the reference area so we distributed our capture effort across the study area in proportion to the abundance of deer and assumed a representative sample. We fitted deer with a combination of very high frequency (VHF; Advanced Telemetry Systems, Isanti, Minnesota, USA) and store-on-board global positioning system (GPS; Telonics, Inc., Mesa, Arizona, USA) radiocollars. Between February 1998 and December 2007, we radiomarked 333 mule deer, including 207 (109 GPS, 98 VHF) in the treatment and 126 (41 GPS, 85 VHF) in the reference area. We attempted to maintain a minimum sample of 30 marked deer in both reference and treatment areas. Both types of collars were equipped with mortality sensors that changed the pulse rate if the collar remained stationary for > 8 hours. We programmed GPS collars to collect locations every 2 hours. We used fixed-wing aircraft to locate radiomarked deer approximately every 30 days during the winter (i.e., November – May) and every 60 days during the summer (June – October). However, during 2001 and 2002 relocation flights were less frequent and during the winter of 2000-01, GPS collars were located 3 times and VHF collars were only located once. Beginning in 2003 a portion (n=40) of VHF collars were duty-cycled not to transmit live signals from July 1 through September 30, however if these collars remained stationary for > 8 hours, a mortality signal would over-ride the duty cycle. No relocation flights were conducted during the summer of 2001 and the 2001-02 winter and 2002 summer flights were restricted to GPS collars.

Population Characteristics

Abundance. We estimated abundance in both the treatment and reference areas using aerial counts similar to Freddy et al. (2004), where mule deer were systematically sampled by helicopter in 1-mi^2 (2.59 km^2) quadrat units. We used winter distribution data collected from radiomarked deer in the study areas between 1998 and 2001 (Sawyer and Lindzey 2001) to delineate sampling frames for the treatment and reference areas. We expected sampling frames to contain high-densities of mule deer so stratification was unnecessary. We conducted counts from a piston-powered Bell helicopter flown approximately 40-50 m above ground and at speeds of 20-40 knots. Counts were conducted in mid to late February of each winter. We exported ArcView® 3.2 (Environmental Systems Research Institute, Redlands, California, USA) files of the quadrats into a handheld GPS unit that was used for navigation. We flew quadrat perimeters clockwise, such that the observer was positioned on the inside, while the pilot navigated. A real-time flight path was traced into the on-board GPS and once the perimeter was established the quadrat interiors were systematically searched. Observer and navigator collectively detected deer groups and determined whether groups were inside or outside quadrat boundaries. Deer detected inside and moving out were considered in the quadrat, while deer detected outside and moving in the quadrat were considered out. For each quadrat, the observer recorded the number of deer groups, the size of each group, and total search time.

We recognize that group size and vegetative cover may significantly influence the probability of detection in ungulate helicopter surveys (Samuel et al. 1987), however we did not correct for visibility bias because the treatment and reference areas did not contain forest vegetation; rather they were characterized by homogenous sagebrush stands and snow cover. Further, when survey areas contain large concentrations of animals that are widely distributed, recognition of individual groups may be nearly impossible and attempting to determine visibility correction factors for groups is likely not feasible in these situations (Samuel et al. 1987).

During aerial counts we attempted to sample the core wintering areas for deer in both the treatment and reference areas. The size of the sampling frame in the treatment area was 68 mi^2. We attempted to sample 50% of the geographic area of the sampling frame each year. The size of the sampling frame in the reference area changed over the course of the study as we observed mule deer wintering over a larger area each year. We attempted to adjust the sampling frame accordingly each year, but we were not able to delineate a sampling frame that contained most of our radiomarked deer from year to year. In short, we were unsuccessful at chasing a moving target. Consequently, we were not confident in our estimates of abundance in the reference area and could not use them for trend detection or comparison with the treatment area.

We used equations from Thompson et al. (1998:340-341) to calculate abundance and variance estimates. Abundance estimates from 2001 through 2007 were used to fit a least-squares regression line and test whether or not the line (i.e., trend) had a slope that differed from zero. We assumed that errors were independent, normally distributed, and had constant variance over time.

Recruitment. We considered fawns to be recruited into the population in mid-December (White and Lubow 2002) and used the ratio of fawns to adult females as an index to recruitment. We conducted composition surveys across the treatment and reference areas during December of each year using a piston-powered Bell helicopter flown approximately 40-50 m above ground and at speeds of 20-40 knots. We classified deer as adult male ($\geq$ 1 year), adult female ($\geq$ 1 year), or fawn. Sample sizes were adequate to obtain desired levels of precision in ratio estimates as described by Czaplewski et al. (1983).

Adult survival. We used the Kaplan Meier procedure (Kaplan and Meier 1985, Pollock et al. 1989) to estimate annual (June 1 – May 31) and winter (December 15 – April 15) survival of radiomarked deer. We chose the Kaplan-Meier procedure because it allowed for staggered entry, data censoring, and estimates for different time intervals. Radiomarked deer that were not found during one or more relocation flights were censored and returned to the risk group once they were relocated (e.g., Johnson et al. 2004). We assumed that 1) our radiomarked deer were representative of the population, 2) survival of radiomarked deer were independent, 3) data censoring was random and independent of survival, and 4) censoring and time of death were estimated without bias. We used the SURVIVAL package in R (R Development Core Team 2007) to calculate estimates of survival. VHF collared deer were not located between June 6, 2001 and November 15, 2002, so survival estimates for biological years 2001 and 2002 were estimated by taking the square root of the survival estimate for both years combined (i.e., survival for the period June 1, 2001 to June 1, 2003). This required us to assume that survival in these 2 years was similar. Nine VHF collared deer were found dead during a relocation flight on November15, 2002, but the time of deaths could not be accurately determined. We estimated the variance by bootstrapping individual animals 5,000 times and calculating 90% confidence intervals using $\hat{S} \pm 1.64(SE)$ since distributions of bootstrap estimates were approximately normal. Because the Kaplan Meier estimator produces a survival estimate of 1.0 with SE = 0.0 for periods where no deaths occurred, we calculated a 90% confidence interval for a survival probability of 1.0 using a one-sided binomial inverse hypothesis test (Lehmann 1986:93).

We used an information theoretic approach (Burnham and Anderson 2002) to determine if, on average, adult survival was consistently different in the treatment area compared to the reference. We compared a Cox proportional hazards model (Anderson and Gill 1982) with different survival rates in each year and study area to a model with different survival rates in each year but the same across study areas. We used years 1998-2000 and 2003-2007, but excluded 2001 and 2002 in model selection because annual survival estimates for those years were averaged.

Fawn survival. Deer from both the treatment and reference areas congregated on the northern ends of their respective winter ranges every spring, which allowed large numbers (>1,000) of animals to be counted and classified. We conducted ground-based composition surveys in April that were used to calculate post-winter fawn:adult ratios. We used these data in conjunction with adult survival rates and December fawn:adult ratios to estimate over-winter fawn survival, using the change-in-ratio estimator from White et al. (1996):

$$\hat{S}_f = \hat{S}_a x \frac{B}{A}$$, where A = count of December fawns/count of December adults

B = count of April fawns/count of April adults

$\hat{S}_a$ = estimate of adult survival

We modified the White et al. (1996) approach by using adult survival rates estimated from telemetry records rather than carcass counts. This estimation procedure assumes that 1) fawns and adults are accurately distinguished during December and April counts, 2) over winter adult survival is equal among males and females, and 3) the period for which winter conditions influence fawn survival ends at the end of April. Given these assumptions, we used the delta method (Seber 1982) to estimate variance.

RESULTS

Abundance

We conducted helicopter flights during the winters of 2001 through 2007 to count deer in selected 1-mi^2 quadrats of both treatment and reference areas. As discussed earlier, the sampling frame in the reference area did not consistently reflect the area(s) occupied by radiomarked deer and, despite our attempts to alter the size of sampling frame, we were unsuccessful at delineating a sampling frame that could yield reliable estimates of density or abundance. However, our sampling frame in the treatment area consistently contained radiomarked deer through all the years of study. Abundance estimates in the treatment area declined 2001 through 2004 and increased from 2005 through 2007. Increases in deer abundance coincided with installation of the liquids gathering system (LGS) described in Section 4. Estimated deer abundance and 90% confidence interval in the treatment area was 5,228 ± 1,350 in 2001, 4,676 ± 1,010 in 2002, 3,564 ± 650 in 2003, 2,818 ± 536 in 2004, 2,894 ± 513 in 2005, 3,156 ± 774 in 2006, and 3,638 ± 698 in 2007 (Table 5-1, Figure 5-2). Differences between the 2001 and 2007 abundance estimates indicate a 7-year, 30% reduction in deer numbers.

Table 5-1. Summary statistics for abundance estimates in the treatment area, 2001-2007.

Summary Statistics	**Treatment Area**						
Year	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***
Total Quadrats (*U*)	68	66	68	68	68	68	68
Quadrats Sampled (*u*)	18	32	34	34	34	34	34
Deer Counted (*N*)	1,384	2,267	1,782	1,409	1,447	1,578	1819
Density Estimate ($\hat{D}$)	77	71	52	41	43	46	54
Variance ($V\hat{a}r(\hat{D})$)	145.73	86.58	33.81	22.98	21.03	47.82	38.98
Standard Error ($SE(\hat{D})$)	12.07	9.30	5.82	4.79	4.59	6.91	6.24
90% Confidence Interval	(57, 97)	(56, 86)	(42, 62)	(33, 49)	(35, 51)	(35, 57)	(44, 64)
Abundance Estimate($\hat{N}$)	5,228	4,676	3,564	2,818	2,894	3,156	3,638
Variance($V\hat{a}r(\hat{N})$)	673,863	377,132	156,318	106,246	97,232	221,103	180,225
Standard Error ($SE(\hat{N})$)	820.89	614.11	395.37	325.95	311.82	470.22	424.53
90% Confidence Interval	(3,878 - 6,578)	(3,666 - 5,686)	(2,914 - 4,214)	(2,282 - 3,354)	(2,381 – 3,407)	(2,382 – 3,930)	(2,940 – 4,336)
Coefficient of Variation ($CV(\hat{N})$)	16%	13%	11%	12%	11%	15%	12%

The regression equation calculated for the treatment area ($E[\hat{N}] = 4922 - 303(year)$, $R^2 = 51\%$) had a slope that was different from zero (SE = 132.7, $t = -2.28$, $P = 0.07$) at the 90% confidence level, but not at 95%. If the increasing trend continues from 2006 and 2007, then a polynomial or non-linear regression may be more appropriate in future analysis. Until then, the linear model continues to function as an appropriate statistical test for determining whether the overall 7-year trend is increasing or decreasing.

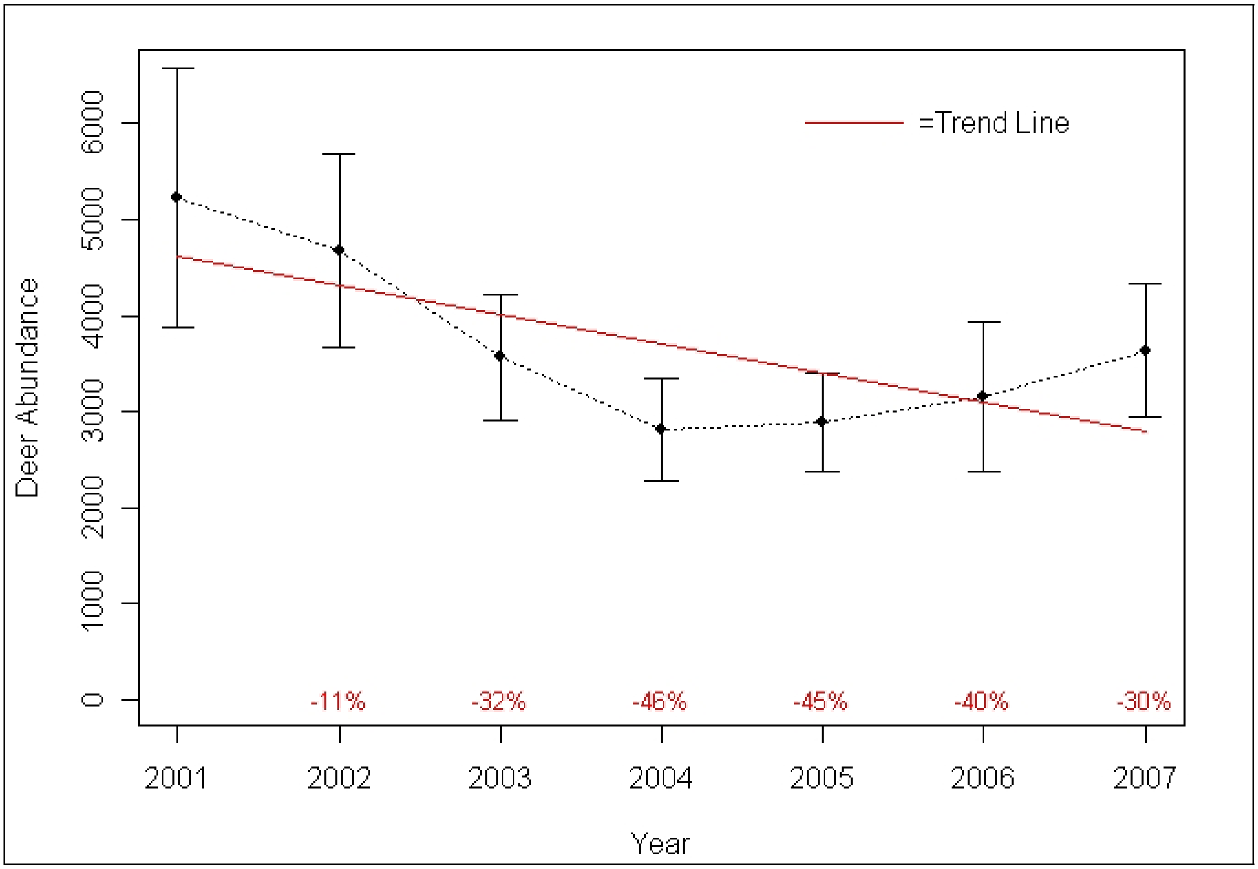

Figure 5-2. Point estimates and 90% confidence intervals of mule deer abundance on the Mesa, 2001-2007. The percent changes relative to the 2001 estimate are labeled in red and the 7-year trend line is decreasing.

Recruitment

We conducted helicopter composition surveys in December of each year to estimate fawn:doe ratios. We classified 4,469, 4,097, 3,878, 3,821, 2,778, 3,264, 3,345, 3,211, 3,568, 4,215 deer in the treatment area in 1998-2007, respectively. We classified 4,489, 4,215, 4,622, 7,048, 5,378, 6,440, 5,277, 5,364, 5,303, 6,585 deer in the reference area in 1998-2007, respectively. Additionally, we supplemented our pre-development sample with data collected by the WGFD in years 1992-1997. Pre-development (1992-2000) fawn:doe ratios in the treatment ($\bar{x}$ = 69.8, SE=5.03, n=9) and reference ($\bar{x}$ = 70.7, SE=3.40, n=9) areas did not differ between fawn:doe ratios in the treatment ($\bar{x}$ = 70.7, SE=2.01, n=7) and reference ($\bar{x}$ = 72.0, SE=2.43, n=7) areas during development (2001-2007). Among individual years, recruitment rates did not differ between the treatment and reference areas, except for 2007 when recruitment was higher in the reference area (Figure 5-3).

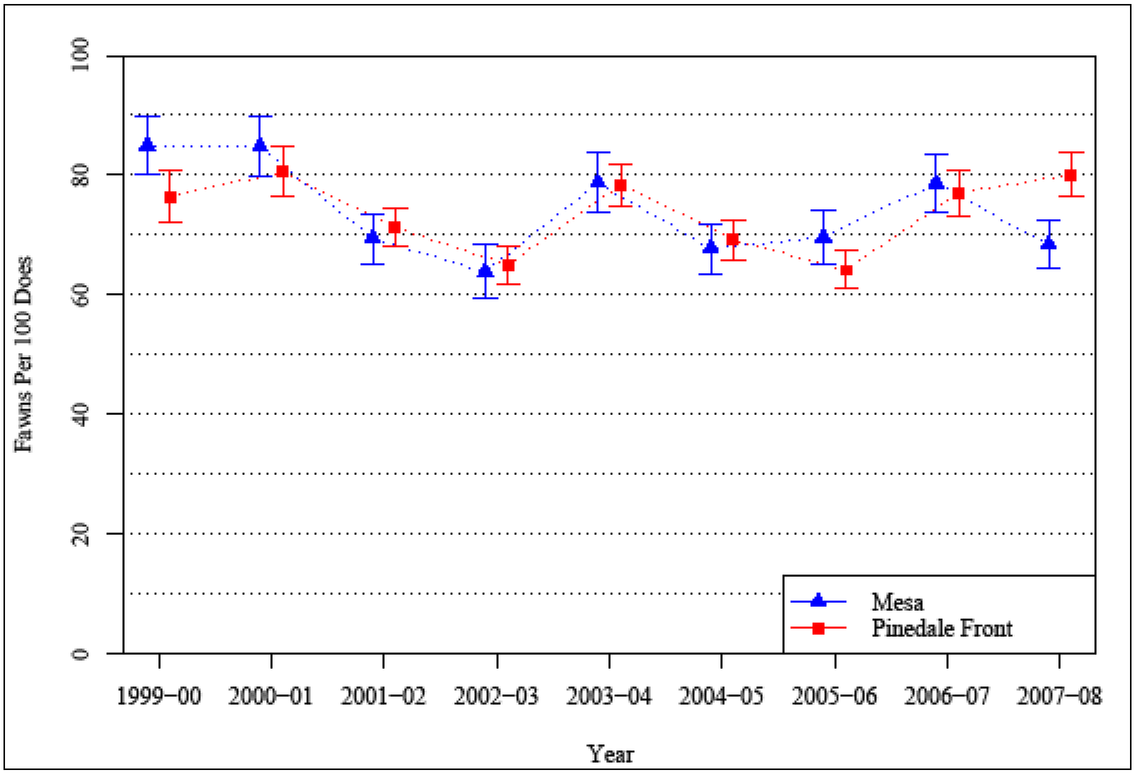

Figure 5-3. Estimated fawn:doe ratios for treatment and reference areas 1999–2007.

Adult Survival

Annual survival rates were variable from year to year and area to area, but the 90% confidence intervals for the annual and winter survival estimates in the treatment and reference areas overlapped (Table 5-2; Figure 5-4).

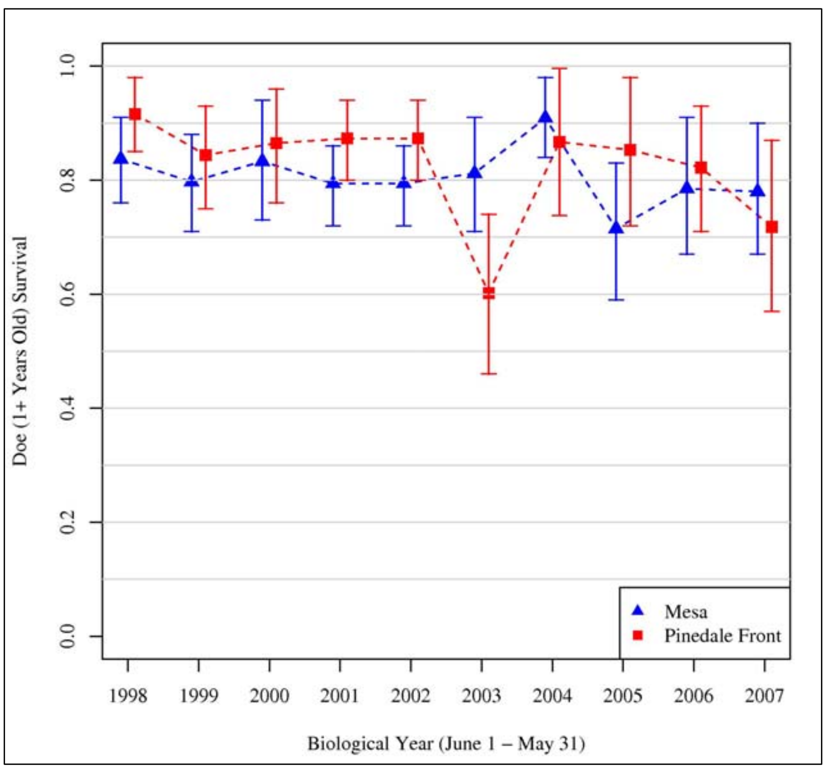

Figure 5-4. Point estimates and associated 90% confidence intervals of annual (June 1–May 31) adult female survival.

The AICc value (1408.15) for the Cox proportional hazards model with equal survival rates for the treatment and reference areas was lower than the AICc value (1408.23) for a model with different survival rates for the two areas, further indicating that no significant differences between the treatment and reference area survival rates could be detected. Annual survival rates were consistently lower than winter survival rates in both areas (Table 5-2). Of the 150 deaths that we were able to accurately date, 60% (n=90) occurred outside the winter (December 15 – April 15) period.

Table 5-2. Estimated annual (June 1 – May 31) and winter (December 15 – April 15) survival rates, standard errors, and 90% confidence intervals for radiomarked deer in the treatment (Mesa) and reference (Pinedale Front) areas.

Year	Period	Pinedale Front				Mesa			
		n	$\hat{S}$	SE	90% CI	*n*	$\hat{S}$	SE	90% CI
1998	Annual	47	0.92	0.039	(0.85, 0.98)	66	0.84	0.046	(0.76, 0.91)
1998-99	Winter	41	1	*	(0.95, 1.00)	66	0.95	0.026	(0.91, 0.99)
1999	Annual	45	0.84	0.055	(0.75, 0.93)	59	0.8	0.053	(0.71, 0.88)
1999-00	Winter	38	1	*	(0.92, 1.00)	52	0.96	0.05	(0.88, 1.00)
2000	Annual	37	0.86	0.06	(0.76, 0.96)	52	0.83	0.064	(0.73, 0.94)
2000-01	Winter	30	0.97	0.087	(0.83, 1.00)	51	0.92	0.067	(0.81, 1.00)
2001	Annual	48	0.87	0.042	(0.80, 0.94)	53	0.79	0.043	(0.72, 0.86)
2001-02	Winter		n/a				n/a		
2002	Annual	48	0.87	0.042	(0.80, 0.94)	53	0.79	0.043	(0.72, 0.86)
2002-03	Winter	46	0.87	0.048	(0.79, 0.95)	53	0.92	0.073	(0.80, 1.00)
2003	Annual	38	0.6	0.086	(0.46, 0.74)	48	0.81	0.06	(0.71, 0.91)
2003-04	Winter	26	0.81	0.056	(0.72, 0.90)	46	0.9	0.049	(0.82, 0.98)
2004	Annual	30	0.87	0.079	(0.74, 1.00)	47	0.91	0.043	(0.84, 0.98)
2004-05	Winter	30	1	*	(0.91, 1.00)	47	0.94	0.046	(0.86, 1.00)
2005	Annual	32	0.85	0.078	(0.72, 0.98)	44	0.71	0.074	(0.59, 0.83)
2005-06	Winter	31	0.9	0.027	(0.85, 0.94)	44	0.91	0.042	(0.84, 0.98)
2006	Annual	32	0.82	0.07	(0.71, 0.93)	41	0.79	0.073	(0.67, 0.91)
2006-07	Winter	32	0.97	0.05	(0.89, 1.00)	41	0.95	0.035	(0.89, 1.00)
2007	Annual	26	0.72	0.09	(0.57, 0.87)	41	0.78	0.07	(0.67, 0.90)
2007-08	Winter	26	0.81	0.09	(0.66, 0.93)	41	0.85	0.035	(0.79, 0.91)

Fawn Survival

The 90% confidence intervals for estimates of winter fawn survival in treatment and reference areas overlapped each year (Tables 5-3 and 5-4). Winter conditions were considered severe in the reference area during 2003-04, 2005-06, and 2007-08 (see Section 2) and resulted in lower fawn survival (Figure 5-5). Winter conditions were considered severe in the treatment during 2003-04 (see Section 2) and also resulted in lower fawn survival (Figure 5-5). Because estimates of adult survival were not available for the 2001 winter, we estimated winter fawn survival using the average adult survival rate (0.85).

Table 5-3. Mule deer count data and change-in-ratio calculations for winter fawn survival in the reference area, 1998–2007.

Year	December Adults	December Fawns	April Adults	April Fawns	*A**	*B***	$\hat{S}_a$	$\hat{S}_f$	90% CI ($\hat{s}_f$)
1998	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1999	2,698	1,517	959	494	0.56	0.52	1.00	0.92	(0.79, 1.00)
2000	2,853	1,769	955	478	0.62	0.50	0.97	0.78	(0.64, 0.93)
2001	4,593	2,455	790	300	0.53	0.38	0.85	0.60	(0.51, 0.70)
2002	3,565	1,813	704	254	0.51	0.36	0.87	0.62	(0.52, 0.72)
2003	3,977	2,463	1,771	441	0.62	0.25	0.81	0.33	(0.28, 0.37)
2004	3,394	1,883	1,565	687	0.55	0.44	1.00	0.79	(0.68, 0.91)
2005	3,551	1,813	1,564	405	0.51	0.26	0.90	0.47	(0.40, 0.51)
2006	3,308	1,995	1,680	674	0.60	0.40	0.97	0.65	(0.57, 0.72)
2007	4146	2439	1056	446	0.59	0.42	0.81	0.58	(0.46, 0.70)

* *A* = count of December fawns/count of December adults ** *B* = count of April fawns/count of April adults

Table 5-4. Mule deer count data and change-in-ratio calculations for winter fawn survival in the treatment area, 1998–2007.

Year	December Adults	December Fawns	April Adults	April Fawns	*A*	*B*	$\hat{S}_a$	$\hat{S}_f$	90% CI ($\hat{s}_f$)
1998	2,996	1,473	1,982	828	0.49	0.42	0.95	0.81	(0.73, 0.88)
1999	2,550	1,547	1,390	764	0.61	0.55	0.96	0.87	(0.76, 0.98)
2000	2,420	1,458	1,685	707	0.60	0.42	0.92	0.64	(0.54, 0.74)
2001	2,546	1,275	1,366	460	0.50	0.34	0.85	0.57	(0.49, 0.65)
2002	1,864	914	1,489	470	0.49	0.32	0.92	0.59	(0.49, 0.69)
2003	2,063	1,201	1,215	319	0.58	0.26	0.90	0.41	(0.34, 0.47)
2004	2,162	1,183	1,477	547	0.55	0.37	0.94	0.64	(0.55, 0.72)
2005	2,099	1,112	1,288	458	0.53	0.36	0.91	0.61	(0.53, 0.69)
2006	2,233	1,335	1,838	772	0.60	0.42	0.95	0.67	(0.59, 0.74)
2007	2,830	1,385	1,460	671	0.49	0.46	0.85	0.80	(0.70, 0.90)

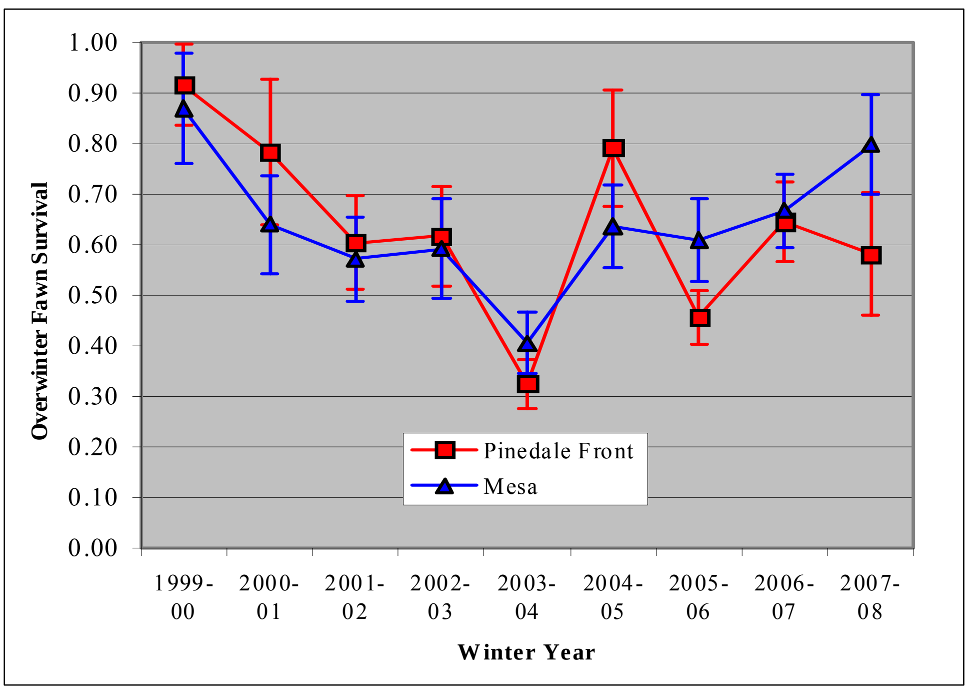

Figure 5-5. Estimates of winter fawn survival and associated 90% confidence intervals for treatment and reference areas, 1999–2007.

DISCUSSION

Weight-Of-Evidence and Data Interpretation

Our helicopter count data indicate that mule deer abundance in the treatment area (Mesa) declined by 30% during the first 7 years of gas development. Considering the changes in mule deer distribution (see Sections 3-4) and the net loss of winter range (see Section 1) resulting from gas field development, we hypothesized that this segment of the deer population would not perform as well as it did prior to development or as well as a nearby segment of the deer population that occupy a similar winter range with no gas development. There is little doubt that deer numbers declined in the treatment area (Mesa) between 2001 and 2007, but unfortunately this trend could not be directly compared to abundance estimates in the reference area. However, we can make comparisons with the WGFD population estimates for the larger Sublette Herd (which includes the treatment area), that showed a -10% population change during the same 7-year period (WGFD 2007; Figure 5-6).

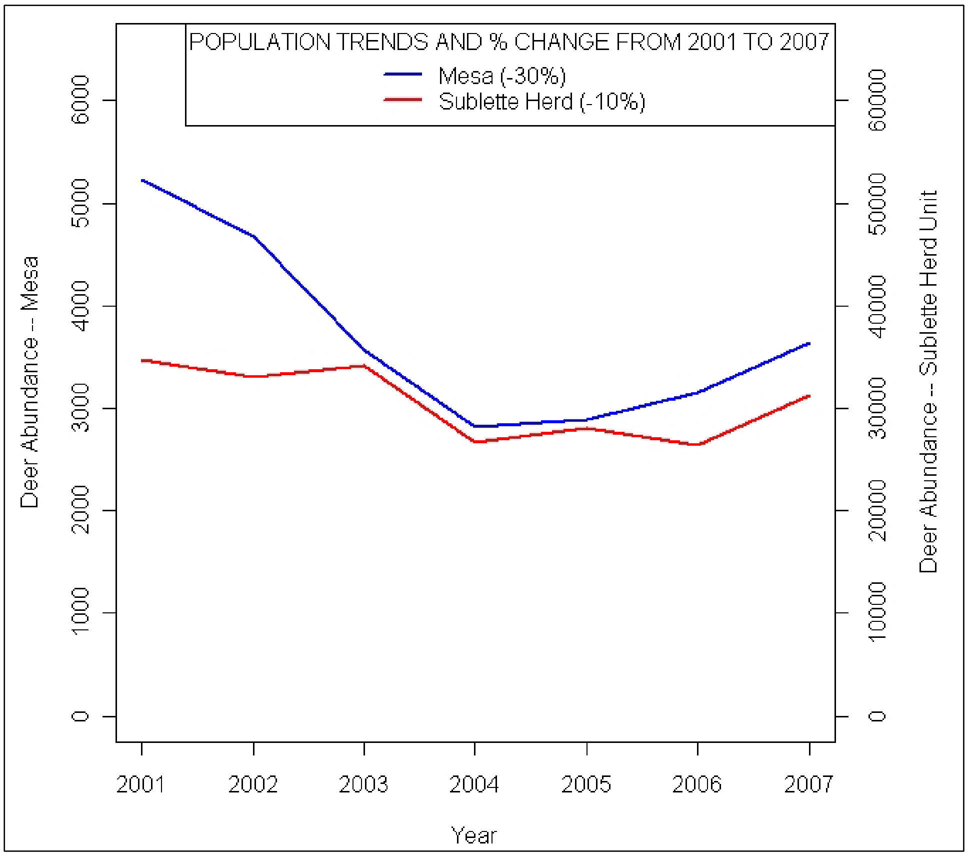

Figure 5-6. Trends in mule deer abundance across the Mesa (treatment) and Sublette Herd Unit, 2001-2007. Deer abundance in the Mesa and Sublette Herd Unit declined by 30% and 10%, respectively.

Because the Sublette Herd actually contains the treatment area, the 10% decline estimated by the WGFD includes the 30% decline observed in the treatment area. Nonetheless, we would expect at least a 30% decline in the Sublette Herd Unit if all segments of the population were declining at a rate comparable to the treatment. Based on this comparison, there is no evidence that suggests any segments of the Sublette Herd Unit have declined at a rate comparable to that in the treatment area. Accordingly, the observed decline of mule deer in the treatment area was likely due to gas development, rather than drought or other environmental factors that have affected the entire Sublette Herd Unit. It is worth noting that mule deer numbers have not declined in the treatment since the LGS system was installed in 2005. The LGS significantly reduced the amount of traffic in the treatment area and appeared to reduce disturbance to wintering mule deer (see Section 4). Whether or not the reduced traffic levels associated with the LGS translated into improved population performance is unknown, but it is certainly possible.

Do the other population parameters support this observed decline in the treatment? With the exception of 2007 recruitment rates, there were no statistically significant differences when we compared point estimates of recruitment, annual adult survival, and winter fawn survival between treatment and reference areas. Absent the abundance data, this could be interpreted as a lack of a significant difference between the treatment and reference areas. However, we recognize that the precision of our recruitment and survival estimates was not high enough to detect small (<10%), but biologically significant differences.

To better understand the implications of this lack of precision, we used a population growth model developed by White and Lubow (2002) to predict what the population growth rate would be between 2001 and 2007, given our estimates of survival and recruitment, and associated error. This modeling exercise illustrated 2 important points. First, it demonstrated that the 30% decline we observed in the treatment area was plausible, given our measures of recruitment, annual adult survival, and winter fawn survival. In fact, the population model predicted a 27% decline. And second, it illustrated how sensitive mule deer population growth is to adult female survival, relative to fawn survival or recruitment. A change in adult female survival of ±5% can determine whether a population is increasing or decreasing, and will always be the most sensitive parameter in mule deer population models (White and Bartmann 1998). Unfortunately, obtaining survival estimates precise enough to detect a 5% change is extremely difficult.

An alternative explanation of the decline in the treatment area is that a portion of the mule deer simply abandoned the area. We were able to estimate emigration rates from deer that were radio-marked for multiple years (see Section 2). The low emigration rate of 1.5% per year contributed to the observed population decline, but a combination of reduced adult and fawn survival appeared to be the driving factors.

Shortcomings of Study

Problematic Reference Area: Incorporating a reference area in impact assessment studies strengthens inference, but identifying appropriate reference areas for large free-ranging populations can be difficult. Through the course of study we identified 3 weaknesses with our reference area, including:

- Until 2007, we were not able to define an accurate sampling frame (i.e., winter distribution of mule deer) for estimating abundance. We found that the marked animals unexpectedly expanded their range in several years and we were unsuccessful at delineating sampling frames that accurately reflected the distribution of most marked animals. As a result our estimates of abundance for the reference area were highly variable and unsuitable for comparisons with the treatment area.

- Our field observations through the first 3 years of study supported the assumption that the treatment and reference area were exposed to similar winter conditions. However, in 3 of the last 4 years, the winter severity was considerably worse in the reference area compared to the treatment (see Section 2). Thus, our assumption of comparable winter conditions was violated. Given the strong influence of winter conditions on mule deer survival, this made comparisons with the treatment area problematic.

- Our field observations indicated that human-related disturbance was minimal in the reference area during the first 3 years of study, thereby making it an appropriate comparison to the treatment area, where deer were exposed to traffic and human-related disturbance associated with gas development. However, the intensity of recreational antler hunting dramatically increased during the last 4 years of study, and because our reference area had no restrictions on motorized vehicle use (on- or off-road), the deer population was exposed to consistent off-road snowmobile and ATV disturbance from late-January through April. Our helicopter surveys documented snowmobile tracks in every square mile of occupied mule deer winter range in the reference area, and field observations documented heavy off-road ATV use across the entire reference area. While the deer population in the treatment area was exposed to traffic and gas field activity, those disturbances were restricted to maintained roads and well pads. Additionally, all non-industry motorized vehicles are prohibited in the treatment area until May 1, so deer are not disturbed by snowmobiles and ATVs through the course of the winter. In short, the fact that both deer populations were exposed to consistent human disturbance was not conducive for treatment-reference comparisons.

Indirect Measure of Fawn Survival: We initially believed that we could accurately estimate winter fawn survival using a change-in-ratio estimator (White et al. 1996) modified with adult survival estimates from telemetry records. While the method is certainly improved when direct measures of adult mortality are used, rather than carcass counts, we concur with White and Bartman (1998) who suggest measuring fawn mortality directly with radiomarked animals is preferable to indirect measures such as change-in-ratio estimators.

Inconsistent Survival Monitoring: Consistent with other mule deer modeling efforts (White and Lubow 2002) we presumed that most adult mortality would occur during the winter period (December 15- April 15) and we designed our monitoring and relocation schedule around that assumption. However, we found that 60% of our adult female mortality occurred outside the winter period, and unfortunately our monitoring schedule was not as intensive during the non-winter period which made survival analysis difficult and estimates less precise. The lack of precision in our survival estimates made it difficult to make meaningful comparisons between the treatment and reference areas. We recommend a longer winter season for estimating winter survival (e.g., December through May; Bishop et al. 2005) and frequent year-around monitoring of radiomarked adults for estimating annual survival. Given that adult female survival is the most sensitive factor in mule deer population dynamics, obtaining reliable estimates of annual survival is essential for modeling populations or verifying observed counts with matrix models (e.g., Morris and Doak 2002).

Overview of Impacts and Impact Studies

The major shortcoming of efforts to evaluate the impact(s) of disturbances on wildlife populations is that they seldom use an experimental framework, but rather tend to be short-term and are almost always observational (Morrison et al. 2008). Brief, post-development monitoring plans associated with regulatory work generally result in little quantitative information that allow agencies and industry to assess impacts on wildlife or identify new, and potentially more effective, mitigation measures. On the other hand, long-term studies are difficult to implement because they are expensive and require interagency and industry cooperation. The preferred approach to evaluating the potential impact(s) of energy development on wildlife populations is the before-after control-impact (BACI) design, where pre and post-development data, such as estimates of survival, reproduction, and abundance are available for both treatment and reference areas (Morrison et al. 2008). However, the acquisition of pre-development data on relevant population parameters, and availability of suitable reference and treatment areas is extremely uncommon. Provided all the difficulties with designing and funding long-term studies, it is not surprising that impacts of energy development on free-ranging ungulate populations are poorly understood and often debated.

Our relatively imprecise measures of survival and problematic reference area weakened our study design and made comparisons between the treatment and reference areas difficult. However, when we consider that 1) there was a negative trend in deer abundance (-30%) observed in the treatment area, 2) the population growth model indicated that the negative trend was likely, given the reproductive and survival rates we measured, 3) emigration rates for the treatment area were only 1.5% per year, and 4) population estimates made by the WGFD for the Sublette Herd indicate that deer numbers declined by 10% over the same time period, we conclude that mule deer numbers in the treatment area declined and there is no evidence that suggests other segments of the Sublette deer herd declined at a comparable rate.

MANAGEMENT IMPLICATIONS

While our study area is not necessarily representative of all areas where gas development may occur on mule deer winter range, we encourage wildlife and habitat managers to consider the following when gas development is planned within the range of mule deer.

1. Winter ranges are often the limiting factor (i.e., crucial) for migratory mule deer populations. Given the direct and indirect habitat losses associated with gas development, maintaining mule deer herds at pre-development population levels when large-scale gas development occurs on crucial winter ranges will be difficult. We recommend that abundance be measured directly, rather than estimated from survival rates.

2. Liquids gathering systems (LGS) effectively reduce traffic levels and the amount of indirect habitat loss to mule deer (see Section 4), which may minimize the potential negative effects on mule deer survival.

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