2005 Annual Report

SUBLETTE MULE DEER STUDY (PHASE II):
Long-term monitoring plan to assess potential impacts of energy development on mule deer in the Pinedale Anticline Project Area.

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LIST OF ACRONYMS

BACI	Before-After Control-Impact
BLM	Bureau of Land Management
CR	County Road
DAU	Data Analysis Unit
EIS	Environmental Impact Statement
GIS	Geographic Information System
GPS	Global Positioning System
MCP	Minimum Convex Polygon
MWRC	Mesa Winter Range Complex
NEPA	National Environmental Policy Act
NGO	Non-Government Organization
PAPA	Pinedale Anticline Project Area
PFWRC	Pinedale Front Winter Range Complex
QEP	Questar Exploration and Production Company
ROD	Record of Decision
RSPF	Resource Selection Probability Function
TPB	Trapper's Point Bottleneck
TRC	TRC Mariah Associates, Inc.
USGS	United States Geological Survey
UW	University of Wyoming
VHF	Very High Frequency
WEST	Western EcoSystem Technology, Inc.
WGFD	Wyoming Game and Fish Department

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1.0 OVERVIEW

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 intended 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 (NGOs) 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 (NEPA), initiated an Environmental Impact Statement (EIS) to assess natural gas development in the 300-mi^2 Pinedale Anticline Project Area (PAPA) (BLM 2000) (Figure 1.1). Because the PAPA provides important winter range to a large segment of the Sublette mule deer herd, there were concerns about the potential effects gas field development may have on the deer population.

The Sublette Mule Deer Study was originally designed to have two phases. The first phase of the study was intended to gather information needed by agencies to improve management of the Sublette deer herd, including the identification of seasonal ranges, determination of migration routes, and estimation of survival rates (Sawyer and Lindzey 2001). 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 treatment and control areas, with energy development as the treatment. The BLM completed the PAPA EIS and released their record of decision (ROD) in July of 2000 (BLM 2000). Phase I of the Sublette Mule Deer Study was completed in March of 2001 (Sawyer and Lindzey 2001). Following a 1-year pilot study funded by QEP, Phase II was initiated in December of 2002, as a Before-After/Control-Impact (BACI) study design (Green 1979, Morrison et al. 2001) that uses the PAPA as a treatment area and a portion of the Pinedale Front as the control area. Mule deer population characteristics (i.e., survival, reproduction, abundance) and habitat use in relation to development features will be measured in both areas, and over time, performance of mule deer in the PAPA will be compared to those in the control area, both before and after the treatment. This report summarizes the results from the 2005 study period.

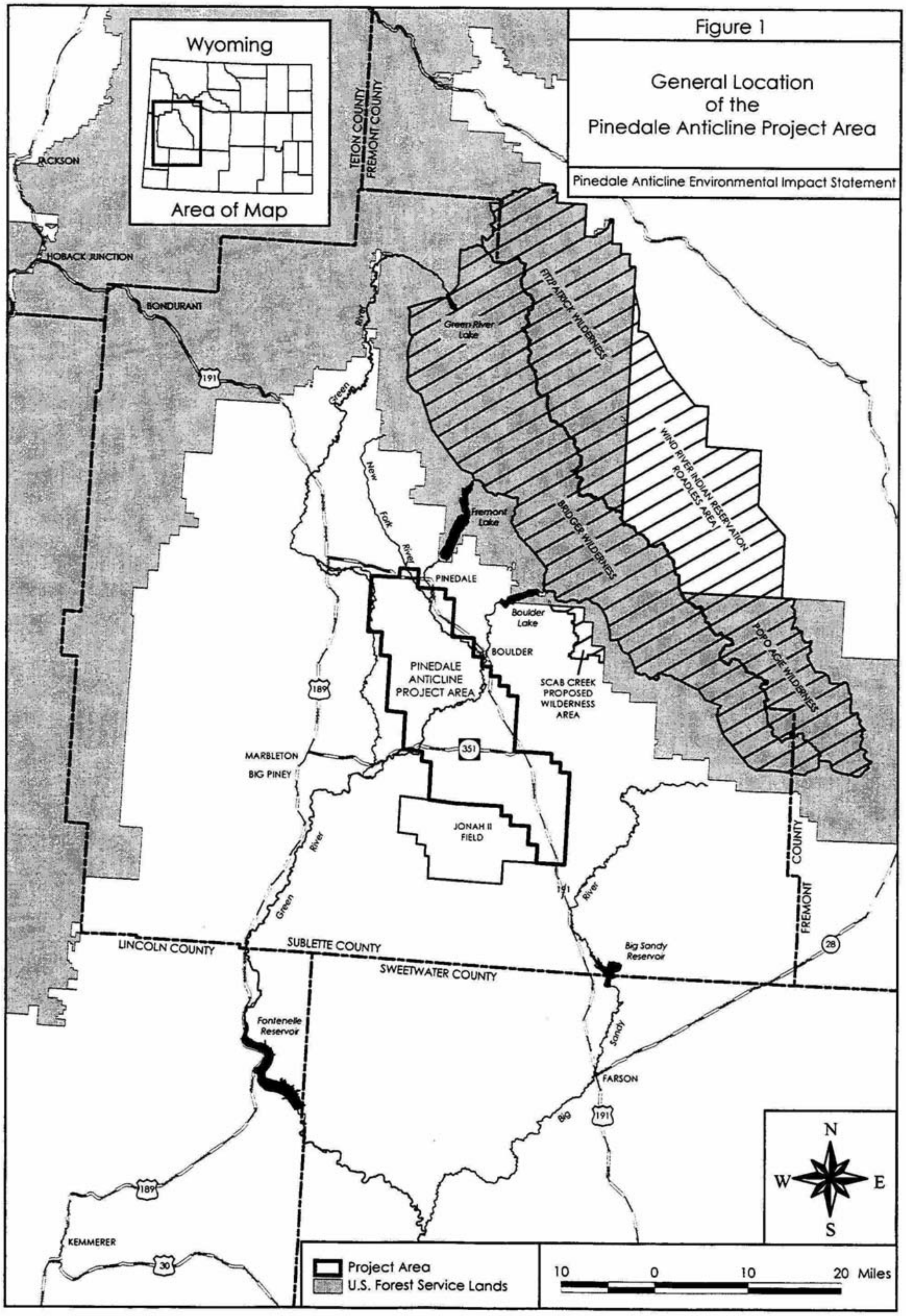

Figure 1.1 Location of Pinedale Anticline Project Area in western Wyoming (from BLM 2000).

2.0 SUBLETTE MULE DEER STUDY

2.1 INTRODUCTION

Western Wyoming is home to the largest, most diverse ungulate populations in the Rocky Mountain region. Maintenance of these populations and protection of their habitats are primary concerns among the public and state and federal agencies. Because of their large numbers and economic importance, mule deer continue to be a top priority for the Wyoming Game and Fish Department (WGFD). 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 (WGFD 2002). Results from the Sublette Mule Deer Study (Sawyer and Lindzey 2001) indicate that these mule deer seasonally migrate 60-100 miles from winter range near Pinedale, Wyoming to summer in portions of the Salt River Range, Wyoming Range, Wind River Range, Gros Ventre Range, and Snake River Range. 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. By late-fall, most mule deer annually converge in the Green River Basin to winter in one of two major complexes; the Mesa Winter Range Complex (the Mesa) and the Pinedale Front Winter Range Complex (the Pinedale Front) (Figure 2.1). Generally, the Mesa includes the PAPA 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.

Population parameters measured during the 3-year (1998-2000) Phase I study (WGFD 2002, Sawyer and Lindzey 2001) suggested the Sublette deer herd was a healthy and productive population prior to development of energy resources on the PAPA. Annual survival rates of radio-collared adult females (n=149) averaged 85% and were consistent with populations studied in other western states (Unsworth et al. 1999). Fawn:doe ratios, an indicator of reproductive success, were among the highest in the state, averaging >75 fawns per 100 does for the study period and approximately 70 fawns per 100 does over the last decade (WGFD 2002). Although the Sublette deer herd has been very productive in the past and recent studies have improved management, this deer herd is similar to others in the region in that habitat loss due to urban expansion and energy development continue to create major management concerns.

Natural gas production in Wyoming has steadily increased since the mid-1980s, particularly in the five counties that form the southwest quarter of the state: Sublette, Fremont, Lincoln, Uinta, and Sweetwater (BLM 2002). This area of the state contains some of the largest and most productive gas fields in the nation, including the Jonah, Continental Divide/Wamsutter, Fontenelle, Big Piney-LaBarge, Moxa Arch, Riley Ridge, Desolation Flats, and the Pinedale Anticline. Natural gas exploration, development, and production are at an all time high in Wyoming and expected to increase.

Because the PAPA encompasses the Mesa, which is used by thousands of mule deer, pronghorn, and sage grouse, development of this area may have adverse impacts on wildlife. Impacts to wildlife include direct habitat loss to infrastructure (i.e., roads, well pads, pipelines) construction and indirect habitat losses that may occur if deer use declines (i.e., avoidance or displacement) in areas near infrastructure. The best way to evaluate the impact(s) of energy development on wildlife populations is through long-term studies where pre-development data, such as, estimates of survival and reproduction are available. Because these studies are by necessity observational, determining cause and effect relationships is very difficult. Simply documenting a behavioral response (e.g., avoidance, acclimation, displacement) to a disturbance adds very little to our knowledge of the impact, if it cannot be linked to the survival or reproductive success of the species involved. And conversely, documenting a change in reproduction or survival does not add significantly to our understanding of the impact if the cause (e.g., weather, habitat loss, disease) of the change cannot be determined. And, because of the difficulty with designing and funding long-term studies, impacts of energy development on free-ranging ungulate populations are poorly understood and often debated. However, both direct and indirect habitat losses associated with energy development have the potential to affect ungulate population dynamics, particularly when disturbances are concentrated on winter ranges, where energetic costs are great and animals occur at high densities.

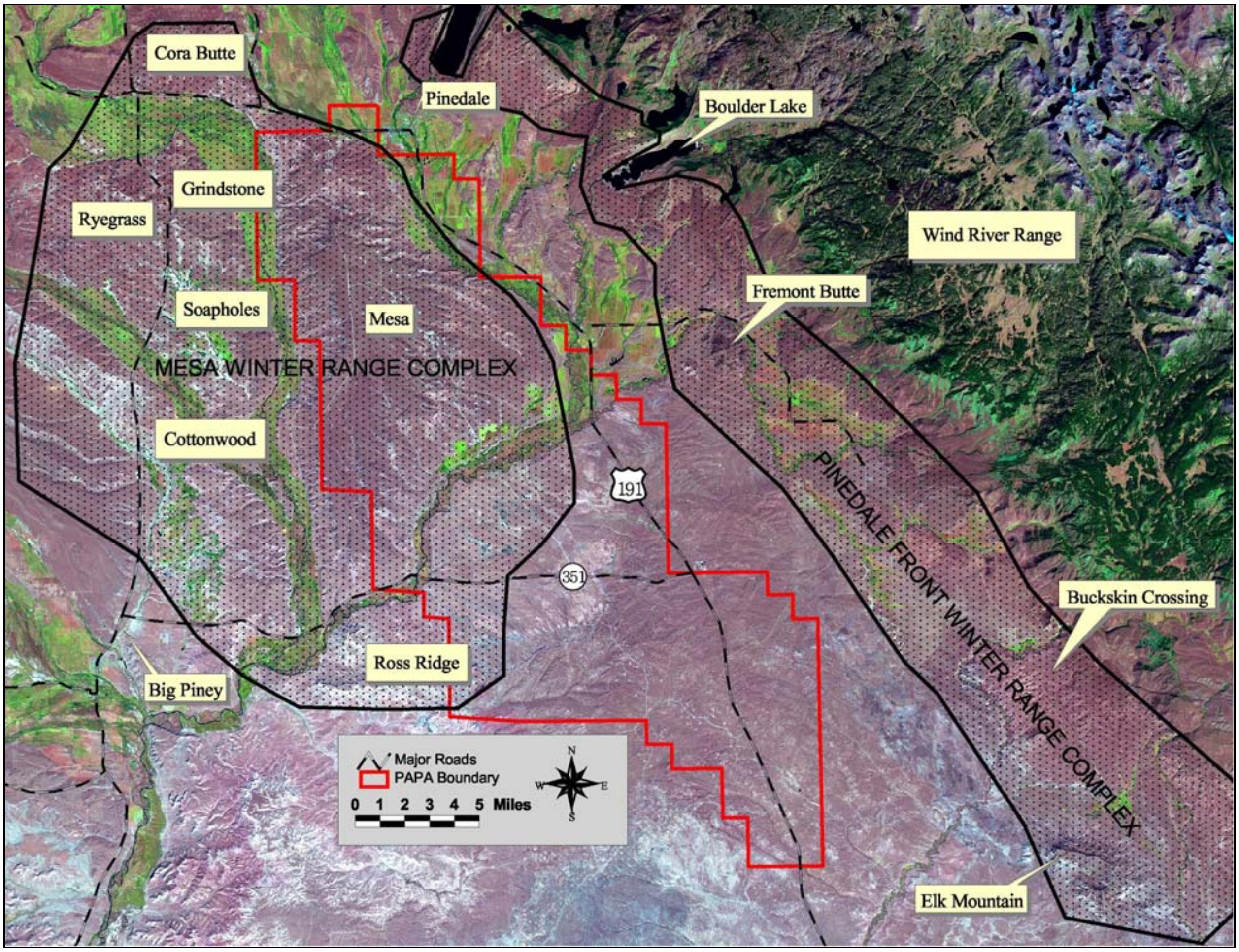

Figure 2.1 Location of the Mesa and Pinedale Front Winter Range Complexes.

The major shortcoming of efforts to evaluate the impact(s) of disturbances on wildlife populations is that they seldom are addressed in an experimental framework, but rather tend to be short-term and are almost always observational. Brief, post-development monitoring plans associated with regulatory work generally result in little or no 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 and commitment. Additionally, the acquisition of pre-development data on movement patterns and population characteristics, and identification of suitable control and treatment areas is extremely uncommon. The situation in the PAPA and upper

Green River Basin is unique because most of the necessary information is available to conduct a BACI study to suggest if, and if so, how natural gas development affects the PAPA mule deer population.

The basic idea with a BACI study design is that the potentially impacted (treatment) site is sampled both before and after the time of the disturbance (e.g., energy development), and one or more control sites that do not receive any disturbance are sampled at the same time (Manly 2001). The assumption is that any naturally occurring changes will be similar at the control and treatment sites, and in the absence of the treatment the parameters of interest will be similar for both areas, or at least the magnitude of the differences will be relatively constant from year to year. Thus, potential changes at the treatment site may be attributed to the disturbance. It is not critical that the control and treatment populations be identical, only that the subpopulations are independent and that both respond to the same environmental factors.

For this study, energy development on the Mesa is considered the treatment and a portion of the Pinedale Front serves as the control area. The Pinedale Front consists mostly of federal lands located along the southwest portion of the Wind River Range, where no energy development is anticipated. The Pinedale Front is a suitable control site because: 1) there is little or no exchange of deer between the Mesa and Pinedale Front, 2) the two deer subpopulations use separate winter ranges, but share common transition and summer ranges, so they have comparable foods available during parturition and arrive on winter ranges in similar condition, 3) although the two deer subpopulations occupy distinct winter ranges, they are in close proximity to one another (15-30 miles), so both are exposed to similar weather patterns and environmental conditions, 4) habitat characteristics on both winter ranges are similar and dominated by sagebrush communities, and 5) population characteristics of the two subpopulations have consistently tracked one another prior to development of the PAPA.

We believe four population parameters should be monitored to detect the potential impacts of energy development on mule deer, including: 1) adult doe survival, 2) over-winter fawn survival, 3) reproduction, and 4) abundance. As these parameters are measured in treatment and control areas, comparisons can be made, and over time, the potential impacts of energy development on mule deer may be assessed. If mule deer in the PAPA continue to function as well as before development and as well as those in the control area it would suggest that energy development has no adverse impacts on mule deer in the region. If however, mule deer survival or reproduction in the PAPA decreases, while the same parameters in the control area remain unchanged or increase, then energy development may be the cause of those declines. Again, this does not demonstrate a cause-effect relationship; rather it is simply one piece in a weight of evidence approach, where our study design examines several direct (e.g, survival, reproduction) and indirect (e.g., habitat use, displacement) parameters that are statistically analyzed and carefully interpreted.

Results from Phase I identified seasonal migration routes and distribution of deer in the Mesa and Pinedale Front (Sawyer and Lindzey 2001). Although mule deer migrations of >60 miles have been reported in parts of Idaho (Thomas and Irby 1990) and Montana (Mackie et al. 1998), mule deer on and adjacent to the PAPA are likely the most migratory deer in the western states, annually migrating 60-100 miles between winter and summer ranges. Because these deer are highly mobile and demonstrate strong fidelity to seasonal ranges, the potential for energy development, or other human disturbances, to disrupt migratory routes and/or winter distribution patterns exists. While changes in distribution or migratory patterns may not necessarily result in decreased deer survival or reproduction, it is useful to include within the monitoring plan to: 1) document if migration routes remain intact, 2) document if deer continue using pre-development winter ranges, 3) provide industry and agencies with accurate, precise movement data for site-specific analyses (e.g., seasonal range designation or comparison of effects of multiple well pads versus single well pad), 4) identify mitigation opportunities on and off-site treatment and control areas (e.g., migration corridors, habitat improvements), and 5) allow for analyses that estimate and describe indirect habitat loss (e.g., avoidance of roads or well pads) or changes in habitat use.

Properly designed long-term monitoring and examination of adult survival, over-winter fawn survival, reproduction, abundance, and seasonal distribution/movement patterns will allow for population-level inferences concerning the potential impacts of energy development on mule deer.

2.2 STUDY AREA

The PAPA is located in west-central Wyoming in Sublette County, near the town of Pinedale (Figure 1.1). The PAPA is characterized by sagebrush communities and riparian habitats associated with the Green and New Fork Rivers. Elevations range from 6,800 to 7,800 feet. The PAPA consists primarily of federal lands (80%) and minerals (83%) administered by the BLM. The state of Wyoming owns 5% (15.2 mi^2) of the surface and another 15% (46.7 mi^2) is private. Aside from the abundant energy resources, the PAPA is an important area for agriculture and provides winter range for 4,000-6,000 mule deer, 2,000-3,000 pronghorn, and 3,000-4,000 sage grouse. While the project area is fairly large, most deer occur in the northern portion of the PAPA, an area locally known as "The Mesa", which includes approximately 100-mi^2. In July of 2000, the BLM approved the development of 700 producing well pads in the PAPA and recognized that this may require as many as 900 well pads to be constructed and drilled (BLM 2000). Additionally, 401 miles of pipeline and 276 miles of access roads were approved for development of energy resources on the PAPA.

2.3 METHODS

2.3.1 Deer Capture

Helicopter net-gunning was used to capture deer across winter ranges in treatment (Mesa) and control (Pinedale Front) areas. Captured deer were fitted with collars supporting either a GPS or VHF radio transmitter. Both types of collars were equipped with mortality sensors that change pulse rate if the collar remains stationary for more than 8 hours. The VHF collars (Advanced Telemetry Systems, Isanti, MN) were duty-cycled to transmit signals October 1 through May 31. The GPS collars (Telonics, Mesa, AZ) were store-on-board units capable of storing approximately 3,000 locations and programmed to obtain fixes every 2 hours during winter months (November-April) and every 25 hours during the remainder of the year. Additionally, each GPS collar was equipped with a remote release mechanism programmed to activate at a specified time, so that collars could be retrieved and data downloaded.

2.3.1 Winter Movement and Distribution Patterns

Data collected from GPS-collared deer accurately identified winter distribution, movement patterns, and migration routes of the marked deer on and adjacent to winter ranges. Because a portion (n=17) of GPS collars are to remain on the same deer for consecutive winters (2004-05 and 2005-06), some data for the 2004-05 winter will not be available until 2006.

2.3.3 Population Characteristics

2.3.3.1 Abundance and Density Estimates

Deer abundance and density were estimated in treatment (Mesa) and control (Pinedale Front) areas using aerial counts of deer in systematically sampled 1-mi^2 quadrat units. Winter distribution data collected from radio-collared deer in the study area between 1998 and 2003 was used to delineate 68-mi^2 and 70-mi^2 sampling frames for the treatment and control areas, respectively. Sampling frames were expected to contain high-densities of deer so stratification was unnecessary. We sampled 34 quadrats from each sampling frame, covering approximately 50% of the geographic area. Equations used to calculate abundance and density estimates were taken from Thompson et al. (1998). Standard 90% confidence intervals were calculated using a Z statistic.

The size of the sampling frame in the control area has changed over the course of the study (See Section 2.4.4.1). During the first year of surveys (2002) we identified a 35-mi^2 sampling frame that we believed represented the core winter range in the Pinedale Front. During 2003 we made some slight modifications to improve our sampling and used a similar 38-mi^2 sampling frame (Figure 2.2). However, during the 2003 surveys many of our marked deer moved out of the sampled area. At this time it became apparent that these deer utilize a much larger area than we originally thought. To accurately adjust the size and extent of our sampling frame we conducted a telemetry flight prior to the 2004 survey to adjust the size of our sampling frame based on locations of marked deer. The new sampling frame was 70-mi^2 (Figure 2.3), nearly double the size of the 2002 and 2003 frames and approximately the same size as the sampling frame for the treatment area.

Group size and vegetative cover may significantly influence visibility bias in ungulate helicopter surveys (Samuel et al. 1987). However, the treatment and control areas for this study consist of homogenous sagebrush stands with no tree cover. Additionally, telemetry data from Phase I indicated male and female deer did not winter in areas with different habitat characteristics, so potential group size variation resulting from sexual segregation should not influence counts. Further, when survey areas contain large concentrations of animals that are widely distributed, recognition of individual groups may be near impossible. Attempting to determine visibility correction factors for groups is likely not feasible in these situations (Samuel et al. 1987). Counts of animals within the sampled quadrats are assumed to provide valid indices on density and abundance. That is, if not all animals present were detected, we assume the same visibility bias in both treatment and control areas over time.

Counts were conducted from a piston-powered Bell helicopter flown approximately 100-150 feet above ground and at speeds of 20-40 knots. The northeast UTM coordinates for each quadrat were programmed into a GPS unit on the helicopter. Quadrat perimeters were then flown 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. Half of the deer detected on perimeter boundaries were considered in the quadrat. For each quadrat, the observer recorded total number of deer, number of deer groups, and total search time.

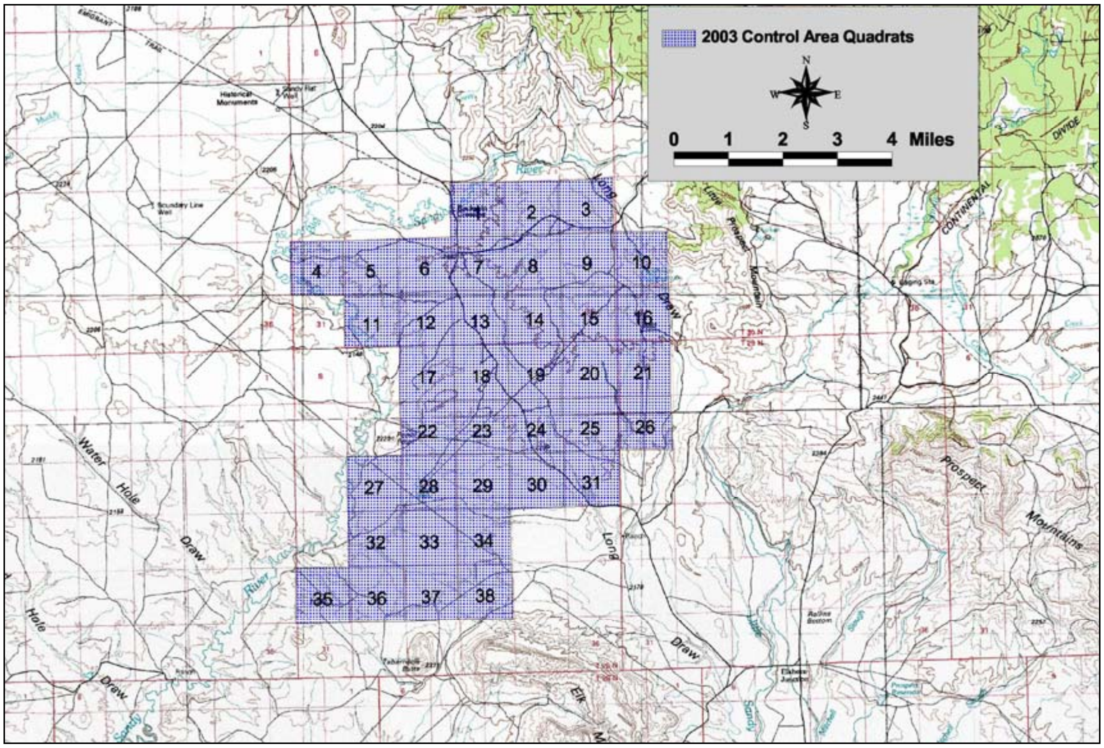

Figure 2.2 Location of 38 quadrats used in control area during 2003 helicopter surveys.

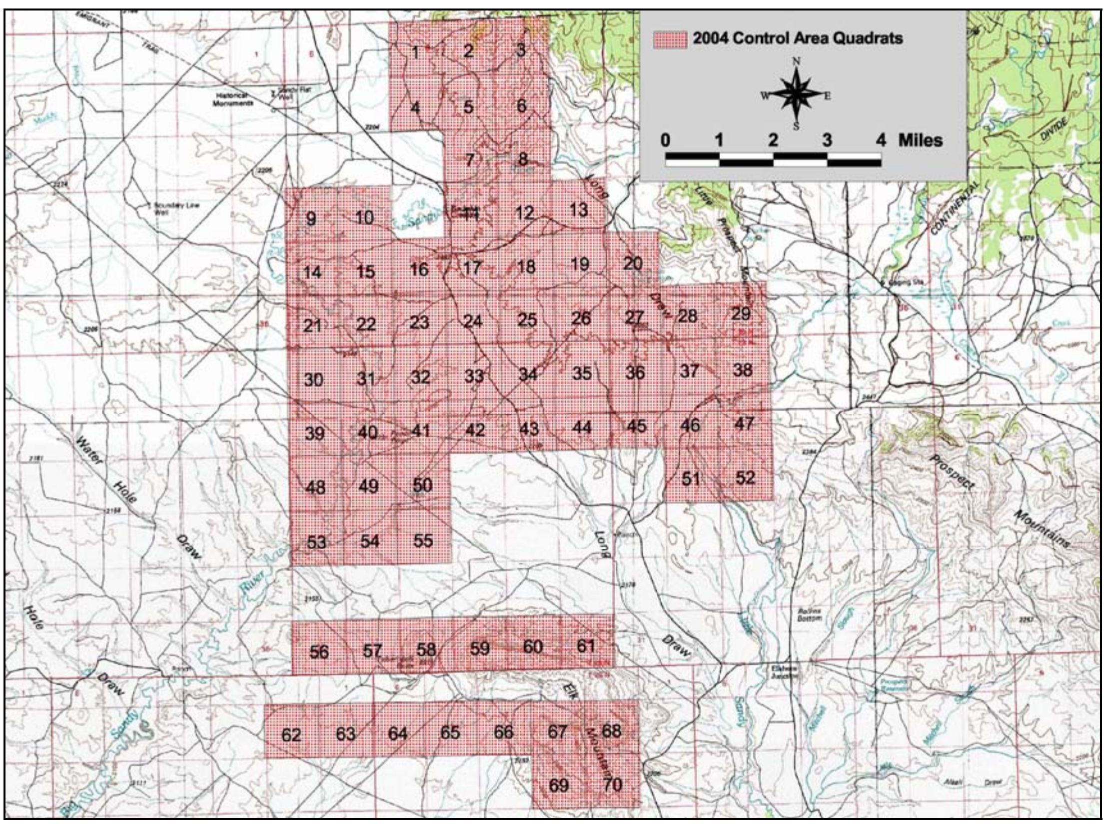

Figure 2.3 Location of 70 quadrats used in control area during 2004 helicopter surveys.

2.3.3.2 Reproduction

Doe:fawn ratios are commonly used as an index to herd productivity or reproduction. Doe:fawn ratios were calculated from composition data collected during the WGFD's annual helicopter surveys in December, consistent with the previous 10 years of WGFD data collection (WGFD 2002). Sample sizes were adequate to obtain desired levels of precision in ratio estimates (Czaplewski et al. 1983).

2.3.3.3 Adult Female Winter Survival

Adult doe survival was estimated from telemetry records using the Kaplan-Meier procedure (Kaplan and Meier 1985). We attempted to maintain a sample of 30 marked deer in both control and treatment areas. Marked deer were located at least once per month, December through May.

2.3.3.4 Over-winter Fawn Survival

Deer from both the Mesa and Pinedale Front congregate on the northern ends of their respective winter ranges every spring which allows large numbers (>1,000) of animals to be counted and classified. Ground-based composition surveys conducted in April were used to calculate post-winter adult:fawn ratios. These data were used in conjunction with adult survival rates and December adult:fawn 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

Adult survival rates were estimated from telemetry records, rather than carcass counts. The delta method (Seber 1982) was used to estimate variance.

2.3.4 Direct Habitat Loss

Satellite imagery and geographic information system (GIS) software were used to digitize road networks and well pads associated with natural gas development in the northern portion of the PAPA (i.e., The Mesa), from 2000 through 2003. Areas within the PAPA, but outside the Mesa were not considered. Landsat images were purchased from the United States Geological Survey (USGS) and processed by SkyTruth (Sheperdstown, West Virginia, USA). Images were generally obtained in early fall (i.e., September-October), after most annual construction activities (e.g., well pad and road building) were complete, but prior to snow accumulation. Pipelines and seismic tracks were not included in this analysis. Roads and well pads were digitized in ArcView®(ESRI, Redlands, California, USA). 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 is some error associated with the digitizing process, however it is expected to be minimal and the resulting digital GIS coverages are considered the best available data. During the digitizing process we assumed full reclamation of well pads had not occurred, since the gas field is only 3 years old and successful reclamation (i.e., re-establishment of native plant species) of native shrub communities in arid environments is extremely difficult and unlikely to occur during a short time period.

2.3.5 Resource Selection

2.3.5.1 Study Area Delineation

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 (MCP), and then clipping the MCP to the boundary of the PAPA. This was consistent with McClean et al. (1998)'s recommendation that study-area level of habitat availability should be based on the distribution of radiocollared animals. Additionally, the MCP generated from GPS data was consistent with winter distribution patterns documented for this deer population using >60 VHF radio-collars, between 1998 and 2000 (Sawyer and Lindzey 2001).

2.3.5.2 Predictor Variables

We identified 5 variables as potentially important predictors of winter mule deer distribution, including: elevation, slope, aspect, road density, 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, slope, and aspect. We used the SPATIAL ANALYST extension for ArcView® to calculate slope and aspect from a 26 x 26 m digital elevation model (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®. The sample units consisted of 4,500 circular units with 100-meter radii distributed across the study area. We annually digitized roads and well pads from LANDSAT® thematic satellite images acquired from the USGS and processed by SkyTruth. 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 the NEAREST NEIGHBOR extension for ArcView® to measure the distance from the center of each sampled 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 of the field was in its early stages (i.e., < 5 years) and there was no evidence of successful shrub reclamation. Additionally, there was no evidence that suggested the type of well pad was an accurate indicator of the amount of human activity (e.g., traffic) that occurred at each site. Without an accurate measure of human activity, we believed it was inappropriate to distinguish between producing and developing well pads.

2.3.5.3 Modeling Procedures

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 sample of habitat units for each radiocollared 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 radiocollared 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, Johnson et al. 2000, Erickson et al. 2001).

We estimated relative frequency of use for each radiocollared deer using a simple technique that involved counting the number of deer locations in each of approximately 4,500 randomly sampled circular habitat 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 habitat units that had a 100-meter 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-meter radii (R. Nielson, Western Ecosystems Technology, Inc., unpublished data). We measured predictor variables on of each of the sampled habitat units and conducted a Pearson's pairwise correlation analysis (PROC CORR; SAS Institute 2000) before modeling to identify multicollinearities and determine if any variables should be excluded from the modeling ($|r| > 0.60$).

The relative frequency of locations from a radiocollared deer found in each habitat unit was an empirical estimate of the probability of use by that deer and was used as a continuous response variable in a generalized linear model (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 preferred the negative binomial distribution over the more commonly used Poisson, because it allows for over–dispersion (White and Bennetts 1996).

We obtained a population–level model for each winter by first estimating coefficients for each radiocollared deer. We used PROC GENMOD (SAS Institute 2000) and the negative binomial distribution to fit the following GLM for each radiocollared deer during each winter period:

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

which was equivalent to:

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

where r_i was the number of locations for a radiocollared deer within habitat unit i ($i = 1, 2, \ldots, 4500$), *total* was the total number of locations for the deer within the study area, β_o was an intercept term, $\beta_1, \ldots, \beta_p$ were unknown coefficients for habitat variables $X_1, \ldots, X_p$, and $E[.]$ denotes the expected value . We used the same offset term for all sampled habitat units of a given deer, thus the term ln(*total*) was absorbed into the estimate of β_o and ensured we were modeling relative frequency of use (e.g., 0, 0.003, 0.0034, …) instead of integer counts (e.g., 0, 1, 2, …). Because some locations for each deer were not within a sampled habitat unit, inclusion of the offset term in equation (1) was not equivalent to conditioning on the total number of observed locations (i.e., multinomial distribution). In fact, one could drop the offset term and simply scale the resulting estimates of frequency of use by the total number of observed locations to obtain predictions of relative frequency identical to those obtained by equation (1). This approach to modeling resource selection estimates the relative frequency or absolute probability of use as a function of predictor variables, so we refer to it as a resource selection probability function (RSPF) (Manly et al. 2002).

We assumed GLM coefficients for predictor variable *k* for each deer were a random sample from a normal distribution (Seber 1984, Littell et al. 1996), 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 RSPF for each winter using

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

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

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

This method of estimating population–level coefficients using equations (3) and (4) was used by Marzluff et al. (2004) and Glenn et al. (2004) for evaluating habitat selection of Stellar's jays and northern spotted owls, respectively. Population–level inferences using equations (3) and (4) are unaffected by potential autocorrelation because temporal autocorrelation between deer locations or spatial autocorrelation between habitat units do not bias model coefficients for the individual radiocollared 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) might be appropriate for individual deer, but do not apply for building a model for population–level effects because the same model (i.e., predictor variables) is required for each deer within a winter. Therefore, we used a forward-stepwise model building procedure (Neter et al. 1996) to estimate population–level RSPFs for winters 2000–01, 2001–02, and 2002–03. 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 model coefficients. We used a *t*–statistic to determine variable entry ($\alpha \leq 0.15$) and exit ($\alpha > 0.20$) (Hosmer and Lemshow 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 radiocollared 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 RSPFs for each winter on 100 x 100-meter grids that covered the study area. We checked predictions to ensure all values were in the [0,1] interval, such that we were not extrapolating outside the range of the model data (Neter et al. 1996). The estimated probability of use 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 predicted probabilities of use 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 4 winter periods.

2.4 RESULTS

2.4.1 Deer Capture

We captured and radio-collared 27 adult female deer on December 19, 2004. Deer capture (n=17) in the PAPA was restricted to those areas where deer congregate across the northern end of the PAPA in early winter, as they move onto the Mesa from Trapper's Point and/or the Ryegrass/Grindstone area. We assumed this represented a random sample of deer in the subpopulation because the deer were congregated on the north end, before they moved south to their respective winter ranges. For the same reason, deer capture (n=10) 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. Of the 27 deer captured, 20 were equipped with GPS radio-collars and 7 equipped with traditional VHF radio-collars. All GPS collars were store-on-board units equipped with VHF transmitters on 12-hour duty cycles, 8-hour mortality sensors, and remote-release mechanisms programmed to drop collars on April 15, 2005 or April 15, 2006. The programming schedule for GPS collars was as follows:

- obtain 1 location every 2-3 hours December 20, 2004 – April 15, 2005
- obtain 1 location every 25 hours April 16, 2005 – October 31, 2005
- obtain 1 location every 2-3 hours November 01, 2005 – April 15, 2006

Consistent with previous years, our goal was to maintain a sample size of 30 deer in each area, including 10 GPS and 20 VHF radio-collars (Table 2.1).

Table 2.1 Number and type of radio-collars functioning in treatment and control areas during the 2004-05 winter.

Treatment Area (The Mesa)		**Control Area** (Pinedale Front)	
Deer ID	Collar Type	Deer ID	Collar Type
801	VHF	804	VHF
805[a]	VHF	807	VHF
806	VHF	8071	VHF
809	VHF	811	VHF
813	VHF	818	VHF
815	VHF	820	VHF
817	VHF	821	VHF
822	VHF	825	VHF
827	VHF	833	VHF
830	VHF	835*	VHF
837	GPS	836	VHF
838	GPS	850	VHF
839	GPS	853	VHF
841	GPS	860	GPS
842	VHF	861	GPS
843	GPS	864	GPS
844	GPS	867	GPS
845	VHF	869	GPS
847	GPS	870	GPS
848	GPS	872	GPS
849	VHF	876	GPS
852	VHF	877	GPS
853	VHF	878	GPS
854	VHF		
855	GPS		
8553	VHF		
858	GPS		
859	GPS		
862	GPS		
863	GPS		
865	GPS		
866	GPS		
868	GPS		
870[a]	VHF		
871	GPS		
873	GPS		
874	GPS		
876	GPS		
878	GPS		
884	GPS		
886	VHF		
887	GPS		
889[b]	GPS		
892	VHF		
905[a]	VHF		
989	VHF		
VHF = 22 GPS = 24 Total = 46		VHF = 13 GPS = 10 Total = 23	

[a] Radio-collars left over from Phase I (Sawyer and Lindzey 2001).
[b] Missing and not included in survival analysis

2.4.2 GPS Data Collection

We collected data from 17 GPS collars following the 2004-05 winter, including 16 that were released on April 15, 2005 and one (#8.74) that was recovered from a dead deer in early April. One collar (#8.89) that was supposed to be released in 2005 could not be located. Of the 17 collars obtained this year, 10 (#844, #855, #862, #864, #866, #867, #868, #870, #884, and #887) contained data for consecutive winters (2003-04 and 2004-05).

Of the 17 collars that were retrieved, all functioned properly and collected the expected number of locations. Consistent with GPS performance in previous years (Sawyer et al. 2004), success rates for GPS fix attempts were very high (99%) and locations precise (88% 3-D locations). A minimum of four satellites are needed to generate 3-D locations, which typically have less than 20-meter error (Di Orio et al. 2003).

2.4.3 Winter Movement and Distribution Patterns

2.4.3.1 Treatment Area (Mesa):

We mapped GPS locations collected from 10 deer that used the Mesa during the 2004-05 winter (Figure 2.4). Data from 8 additional deer were not mapped because their collars will not be recovered until April 15, 2006. Distribution and movement patterns were variable among deer, and generally, deer shifted areas of use through the winter and utilized a large portion of the Mesa.

Figure 2.5 includes locations (r = 3,657) from all 10 deer and illustrates the importance of BLM lands to this mule deer population. Boundaries between private and BLM lands generally correspond with habitat type and topography; with private lands consisting of flat river bottoms and agricultural areas, whereas BLM lands contain sagebrush hills in drier, more rugged terrain. Mule deer demonstrated a strong affinity to the sagebrush-dominated BLM lands.

Consistent with previous years, all deer traveled to the Cora Butte area via the Trapper's Point Bottleneck (TPB) (Sawyer and Lindzey 2001, Sawyer et al. 2004). Figure 2.5 clearly defines the TPB, located 7 miles west of Pinedale, near the junction of US 191, WYO 352, and CR 110. Sawyer and Lindzey (2001) defined bottlenecks as *"those areas along migration routes where topography, vegetation, development and/or other landscape features restrict animal movements to narrow or limited regions."* Bottlenecks create management concerns because the potential to disrupt or threaten established migratory routes are much greater in these areas. This naturally-occurring bottleneck is approximately 1 mile in width and length, restricted to the southwest by the Green River riparian complex and to the northeast by the New Fork/Duck Creek riparian complex. Sagebrush habitats north and south of US 191 are used extensively by mule deer during certain times of the year (Sawyer and Lindzey 2001). Mule deer use the narrow strip of sagebrush connecting the two areas to cross US 191. Development of small, fenced house lots adjacent to BLM lands has narrowed the effective width of the TPB to < ½ mile.

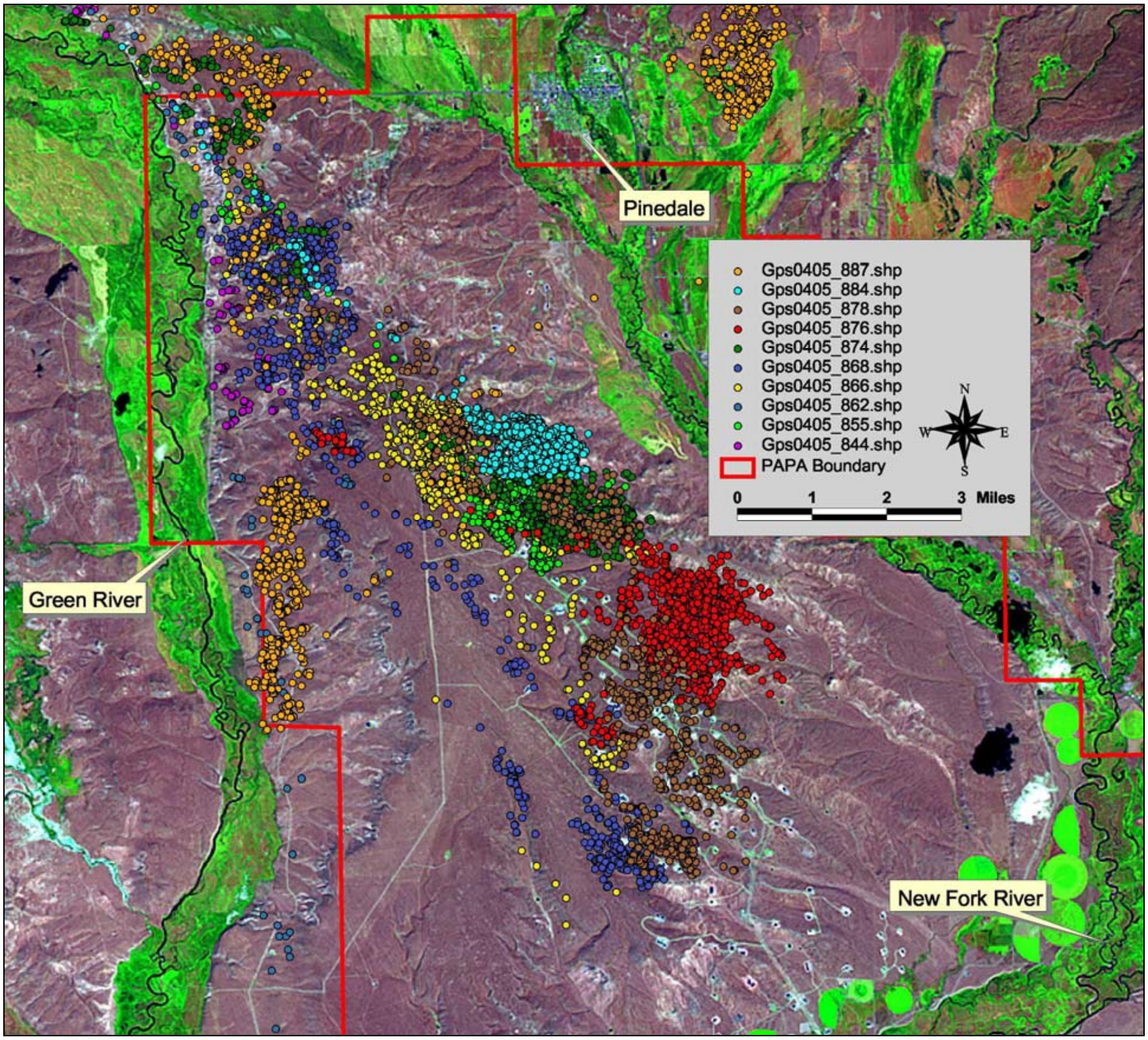

Figure 2.4. GPS locations (r = 15,974) collected from 10 deer on the Pinedale Anticline Project Area (PAPA), November 1, 2004 – April 15, 2005, overlaid on satellite image taken August 28, 2004.

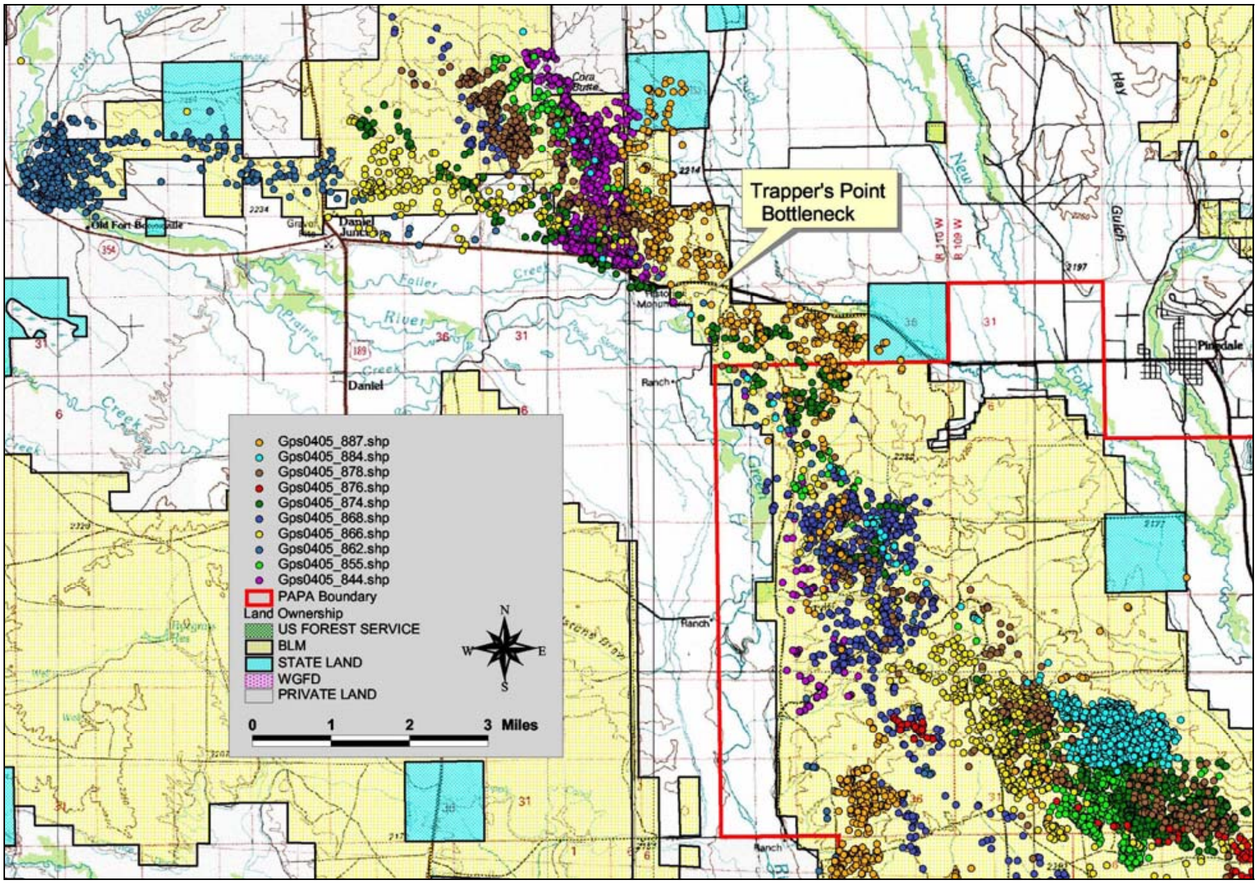

Figure 2.5. Distribution of land ownership and GPS locations collected from 10 deer on the Pinedale Anticline Project Area (PAPA), November 1, 2004 – April 15, 2005.

Several unusual movement events were documented from GPS collars recovered this spring. First, was Deer #862 (Figure 2.6) that was captured on the Mesa on December 18, 2003. Deer #862 moved around the Mesa for 3 weeks after capture, then left the project area and migrated 20-25 miles southwest. This deer spent the remaining winter months in a different winter range characterized by sagebrush draws and 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 TPB, and onto summer ranges. This deer returned in the fall of 2004 through the TPB, 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. Interestingly, in the spring of 2005, this deer used a different migration route between Big Piney and the Mesa. Deer #862 was the first GPS-collared deer to have left the Mesa and on moved on to a different winter range.

The second unusual movement was that of Deer #887 (Figure 2.7), captured on the Mesa on December 18, 2003. Deer #887 occupied the western breaks of the Mesa during the 2003-04 winter and migrated through the TPB in the spring of 2004 on its way to summer range. However, in the fall of 2004, this deer returned to the Mesa via the typical 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 TPB. Of all the GPS-collared deer (>50) we've monitored on the Mesa in the last 5 years, Deer #887 was the first to and from summer ranges using both Trapper's Point and the Pinedale Front migration routes.

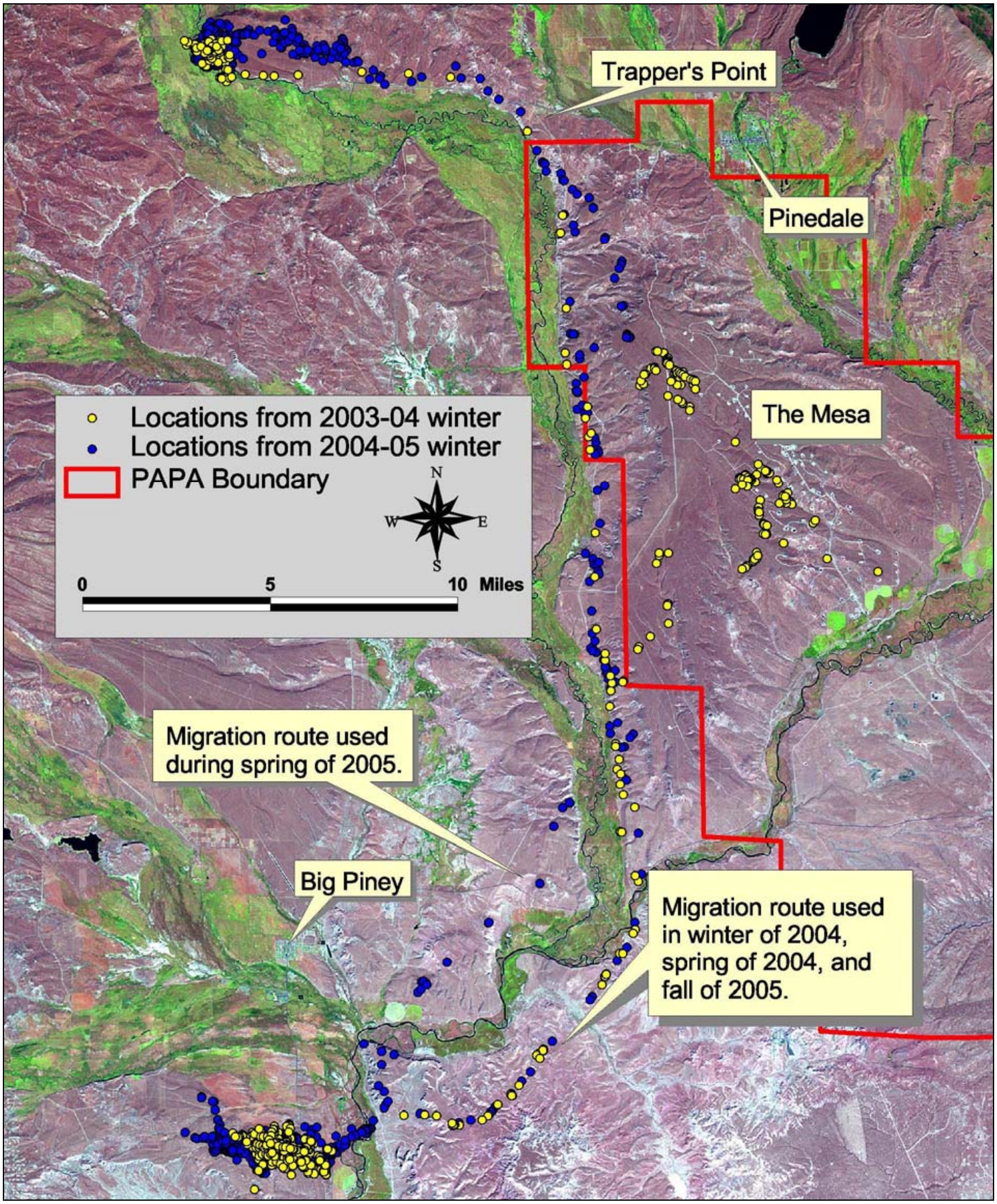

Figure 2.6 GPS locations (r = 2,253) of deer #862 in the Pinedale Anticline Project Area (PAPA), December 18, 2003 – April 15, 2004 (yellow) and November 1, 2004 – April 15, 2005 (blue).

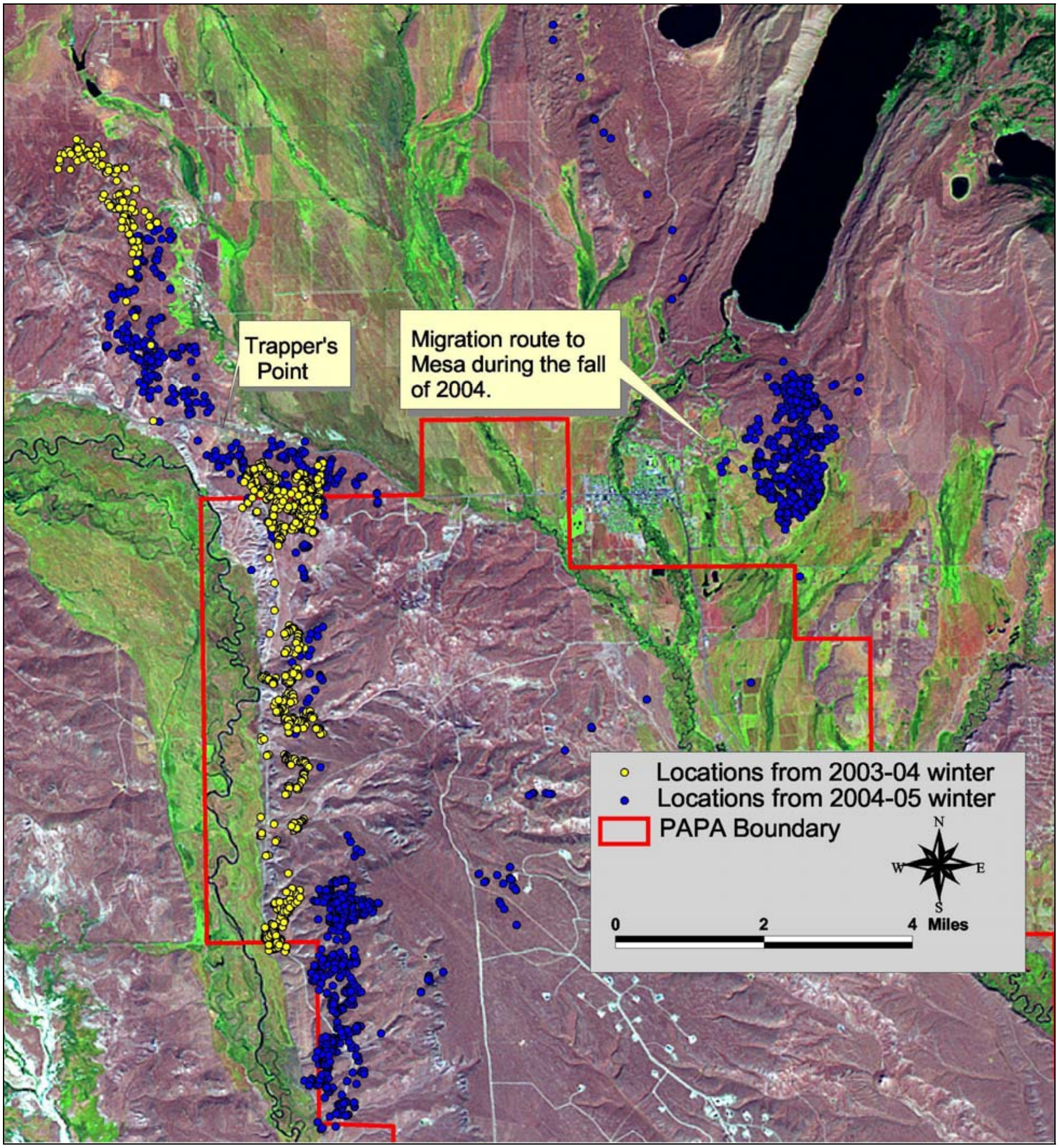

Figure 2.7 GPS locations (r = 2,368) of deer #887 in the Pinedale Anticline Project Area (PAPA), December 21, 2003 – April 15, 2004 (yellow) and November 1, 2004 – April 15, 2005 (blue).

2.4.3.2 Control Area (Pinedale Front):

We mapped GPS locations collected from 7 deer that used the Pinedale Front during the 2004-05 winter (Figure 2.8). Data from 3 additional deer were not mapped because their collars will not be recovered until April 15, 2006.

Consistent among deer was their mobility and tendency to shift areas of use through the winter, utilizing areas that exceeded 100-mi^2. And, similar to previous years (Sawyer et al. 2004), deer moved outside the core winter range area around Buckskin Crossing to peripheral areas, such as Elk Mountain, Little Sandy Creek, and areas along the west side of the Prospects. While distribution patterns of deer were variable across the winter range, the migratory routes to and from the winter range were nearly identical among deer (Figure 2.9).

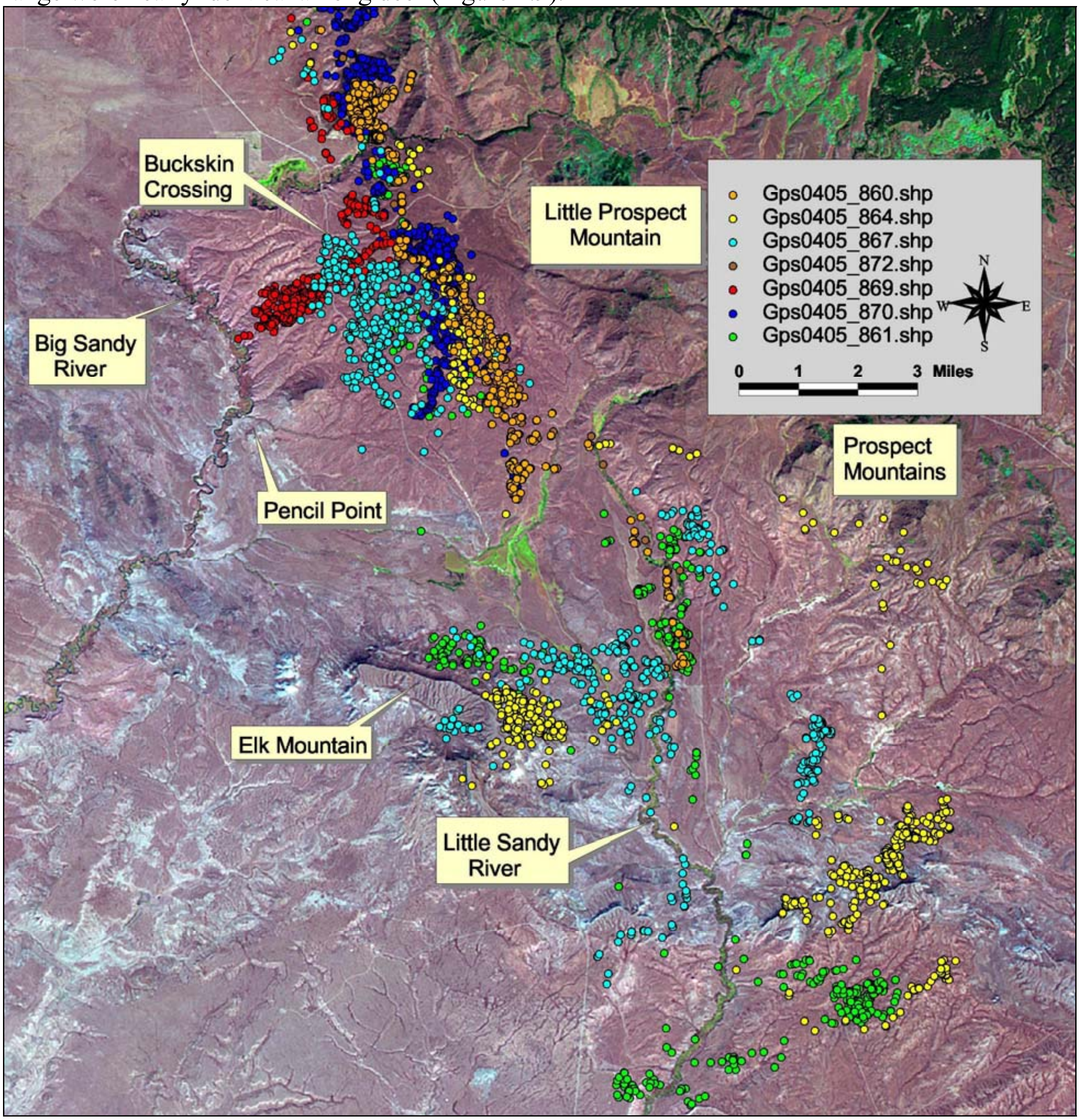

Figure 2.8. GPS locations (r = 8,695) collected from 7 deer on the Pinedale Front Winter Range Complex (PFWRC), November 1, 2004 – April 15, 2005.

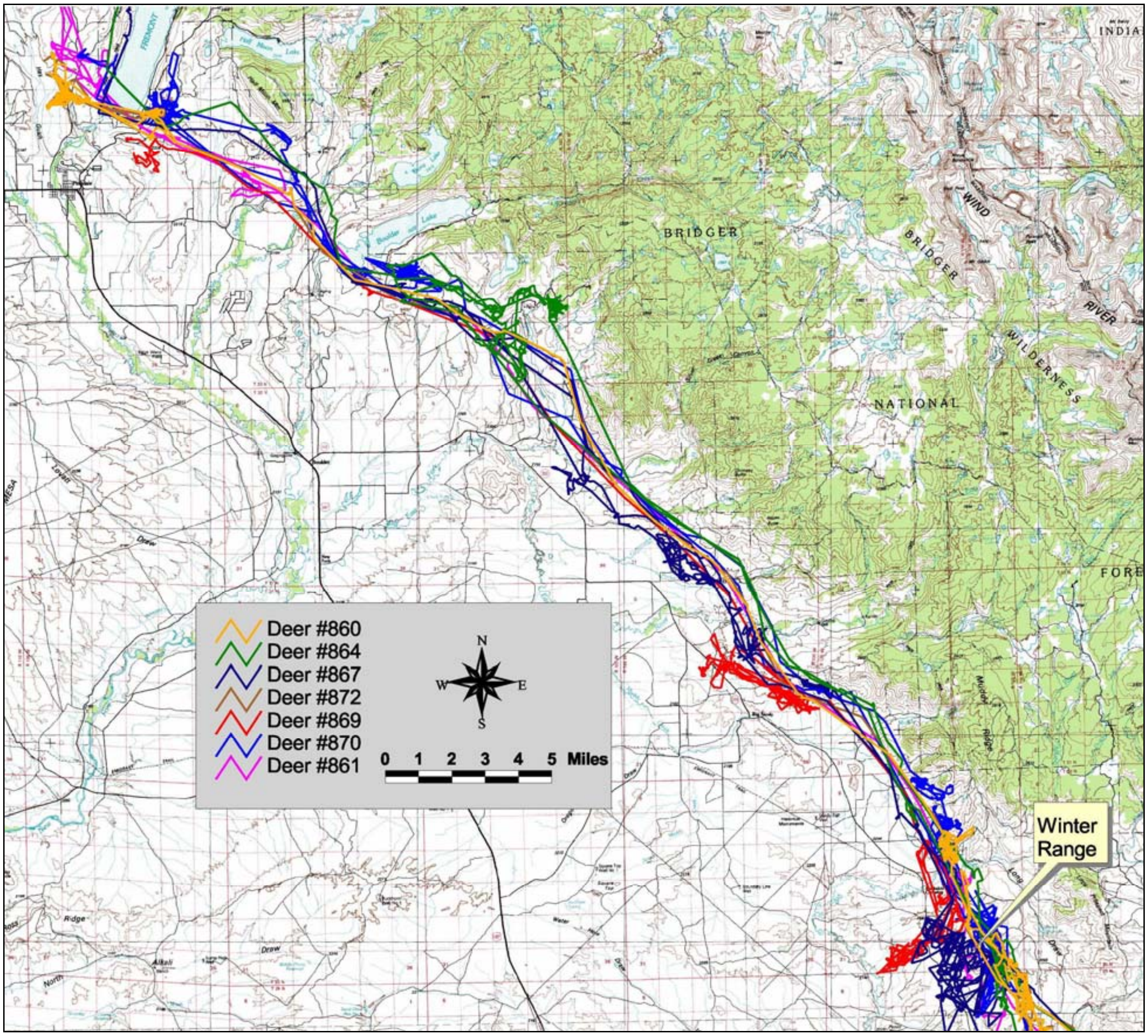

Figure 2.9. Migration routes from 7 GPS-collared deer on the Pinedale Front Winter Range Complex (PFWRC), November 1, 2004 – April 15, 2005.

Most deer began migrating north along the Pinedale Front in mid-March. 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). Details of this migration route, in terms of size, width, specific location, and deer fidelity were unknown prior to GPS data collected over the last 3 years. Consistent with the last 2 years, all 7 GPS-collared deer migrated along a distinct 50-mile movement 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 (Figure 2.9).

The migration route leads deer 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.

2.4.4 Population Characteristics

2.4.4.1 Abundance and Density Estimates

Helicopter flights were conducted on February 23-24, 2005 to count deer in selected 1-mi^2 quadrats of both treatment and control areas. Average flight time per quadrat was 10 minutes. Estimated deer abundance ($\hat{N}$) in the treatment area was 2,818 ± 536 and deer density ($\hat{D}$) was 41 ± 8 deer/mi^2 (Table 2.2, Figure 2.10). Deer abundance and density in the treatment area were lower than previous years. Estimated deer abundance ($\hat{N}$) in the control area was 4,281 ± 723 and deer density ($\hat{D}$) was 61 ± 10 deer/mi^2 (Table 2.3, Figure 2.11). Abundance and density estimates for the control area were significantly higher than last year, but have been variable since 2002. Because the sampling frame in the control area did not reflect the area utilized by our marked population prior to 2004, abundance and density estimates are expected to be biased high during 2002 and biased low during 2003.

We used the abundance estimates from 2002 through 2005 to fit weighted least-squares regression lines (Figures 2.10 and 2.11) and test whether or not the lines (i.e., trend) had slopes that differed from zero. The regression equation for the treatment area was: Y = 5335 – 845(yr[a]). The line from this equation had an R^2 of 98.5% and a slope that was significantly different from zero (t = -12.67, P = 0.006), indicating a declining deer population through the course of study. The negative slope and associated coefficient indicates deer abundance decreased at an average rate of 845 animals per year between 2002 and 2005, resulting in a 4-year 46% reduction. The regression equation for the control area was: Y = 1685 + 582(yr). The line from this equation had an R^2 of 26.6% and a slope that was not significantly different from zero (t = 0.85, P = 0.484), indicating that the estimated positive trend was not statistically significant. A comparative test between the trend lines from the control and treatment areas, indicated the trends (i.e., slopes) were not statistically different at a 90% confidence level (t = -1.989, P = 0.117, df =4), but would be considered different at a confidence level ≤ 88%.

[a] yr = year of study (i.e., 0, 1, 2, 3)

Table 2.2 Summary statistics for abundance and density estimates in the treatment area, February 2002 - 2005.

Summary Statistics	**Treatment Area** (The Mesa)			
Year	***2002***	***2003***	***2004***	***2005***
Total Quadrats (*U*)	68	66	68	68
Quadrats Sampled (*u*)	18	32	34	34
Deer Counted (*N*)	1,384	2,267	1,782	1,409
Density Estimate ($\hat{D}$)	***77***	***71***	***52***	***41***
Variance ($V\hat{a}r(\hat{D})$)	146	87	34	23
Standard Error ($SE(\hat{D})$)	12.07	9.30	5.82	4.79
90% Confidence Interval	(57, 97)	(56, 86)	(42, 62)	(33, 49)
Abundance Estimate($\hat{N}$)	***5,228***	***4,676***	***3,564***	***2,818***
Variance ($V\hat{a}r(\hat{N})$)	673863	377132	156318	106246
Standard Error ($SE(\hat{N})$)	821	614	395	326
90% Confidence Interval	(3,878 - 6,578)	(3,666 - 5,686)	(2,914 - 4,214)	(2,282 - 3,354)
Coefficient of Variation ($CV(\hat{N})$)	16%	13%	11%	12%

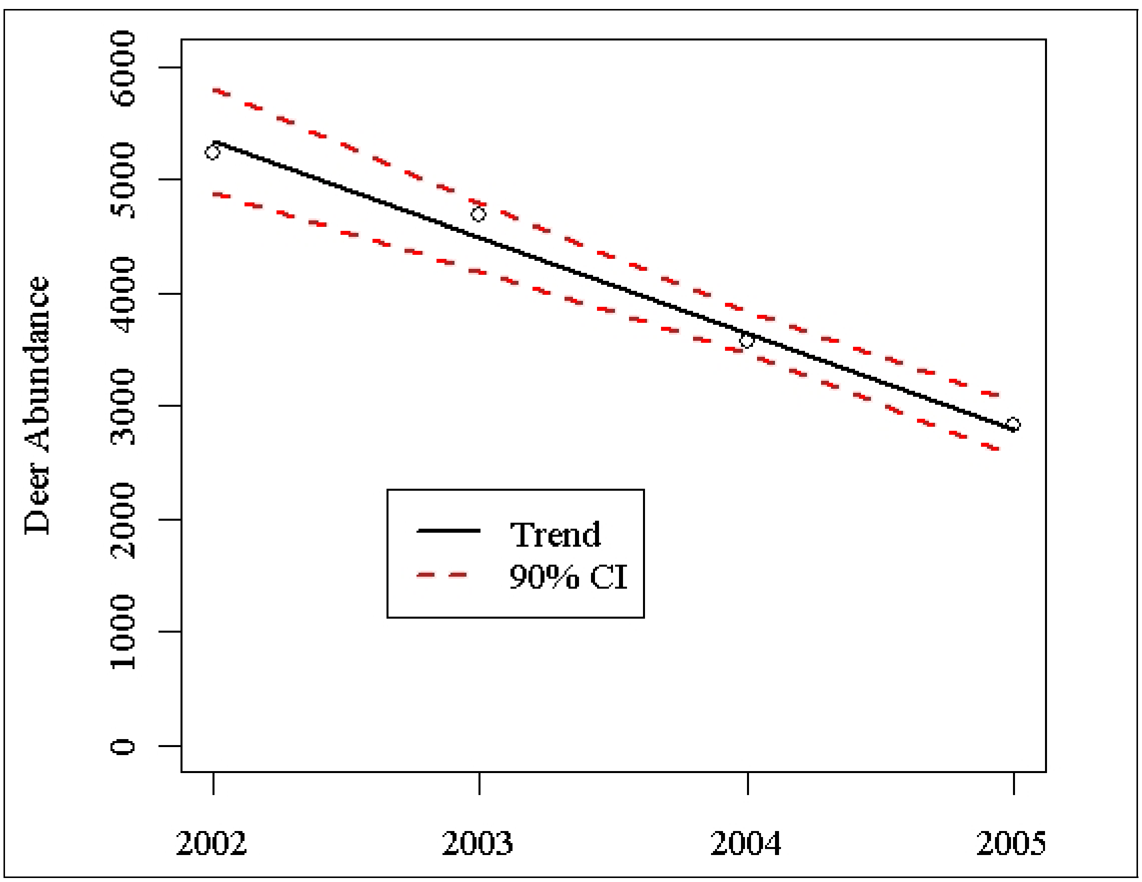

Figure 2.10. Regression plot and 90% confidence intervals of deer abundance in treatment area (Mesa), February 2002 – 2005.

Table 2.3 Summary statistics for abundance and density estimates in the control area, February 2002 - 2005.

Summary Statistics	**Control Area** (Pinedale Front)			
Year	***2002[a]***	***2003[b]***	***2004***	***2005***
Total Quadrats (*U*)	35	38	70	70
Quadrats Sampled (*u*)	7	18	34	33
Deer Counted (*N*)	810	849	1,171	2,018
Density Estimate ($\hat{D}$)	***116***	***47***	***34***	***61***
Variance ($V\hat{a}r(\hat{D})$)	406	64	22	39
Standard Error ($SE(\hat{D})$)	20.14	8.01	4.70	6.28
90% Confidence Interval	(83, 149)	(31, 63)	(26, 42)	(51, 71)
Abundance Estimate($\hat{N}$)	***4,050***	***1,792***	***2,411***	***4,281***
Variance ($V\hat{a}r(\hat{N})$)	496,752	92,661	108,347	193,294
Standard Error ($SE(\hat{N})$)	705	304	329	440
90% Confidence Interval	(2,891 - 5,209)	(1,291 - 2,293)	(1,870 - 2,952)	(3,558 - 5,004)
Coefficient of Variation ($CV(\hat{N})$)	17%	17%	14%	10%

[a] Abundance and density estimates expected to be high.
[b] Abundance and density estimates expected to be low.

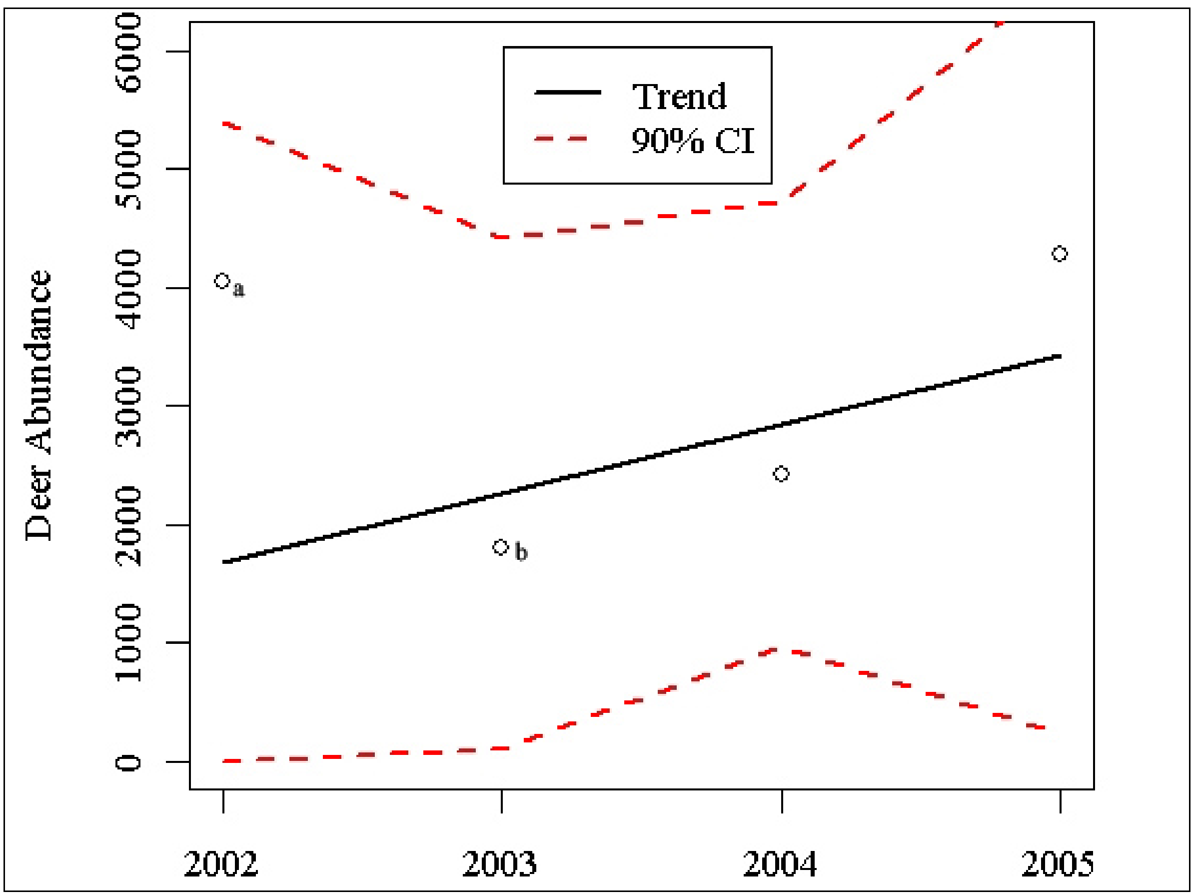

Figure 2.11. Regression plot and 90% confidence intervals of deer abundance in control area (Pinedale Front), February 2002 – 2005.

2.4.4.2 Reproduction

Year	Treatment fawn:doe December	Control fawn:doe December
Pre-Development Phase		
1992-93	62	61
1993-94	47	51
1994-95	61	72
1995-96	56	63
1996-97	73	75
1997-98	92	81
1998-99	67	76
1999-00	85	76
Average	**68**	**69**
Development Phase		
2000-01	85	81
2001-02	69	71
2002-03	64	65
2003-04	78	78
2004-05	68	69
Average	**73**	**73**

The WGFD conducted helicopter composition (buck:doe:fawn) surveys to collect pre-winter (December) information on the sex (i.e., buck or doe) and age (i.e., fawn or adult) structure of the population. A total of 8,622 deer were classified in December of 2004, including 3,345 on the Mesa Winter Range Complex and 5,277 on the Pinedale Front Winter Range Complex (S. Smith, WGFD, unpublished data). Estimated fawn:doe ratios were 68:100 for the Mesa and 69:100 in the Pinedale Front (Table 2.4). Both areas have displayed similar trends in reproduction (fawn:doe ratios) prior to and since the PAPA ROD in 2000 (Figure 2.12).

Table 2.4 (Left)
Mule deer fawn:doe ratios measured for treatment (Mesa) and control (Pinedale Front) areas by Wyoming Game and Fish Department, 1992-2005.

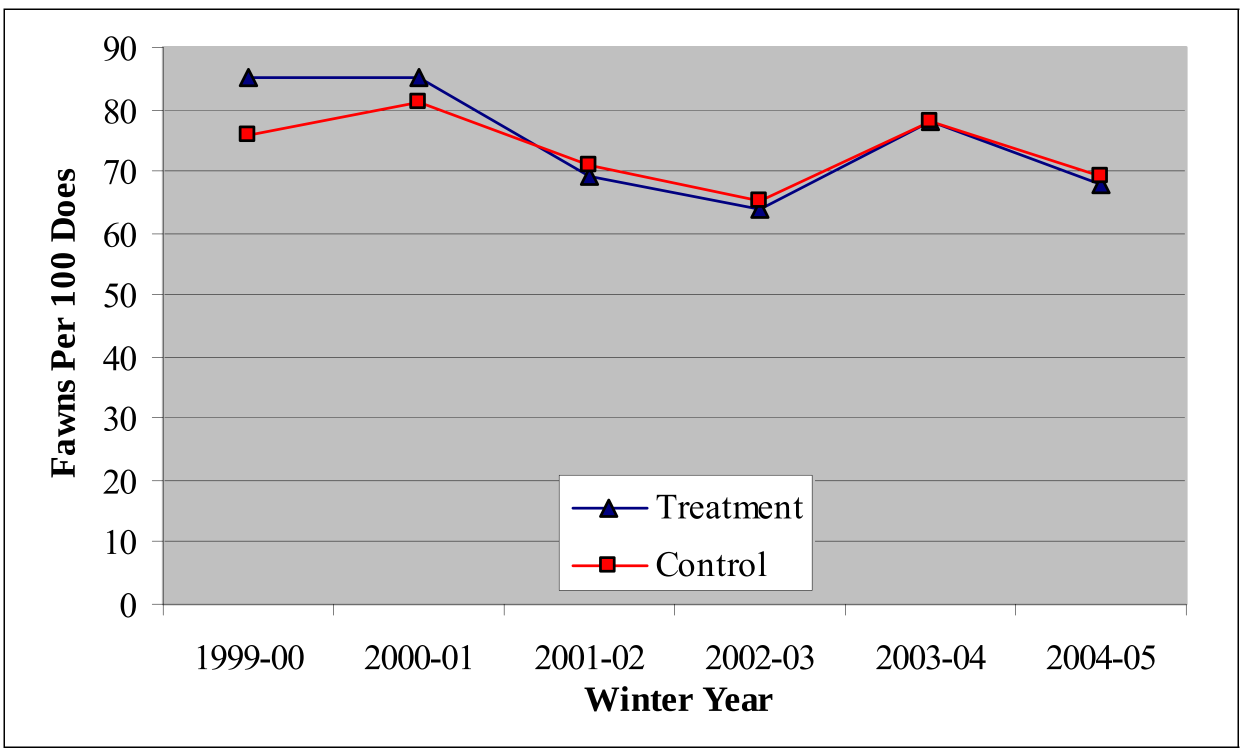

Figure 2.12 December fawn:doe ratios in treatment and control areas, 1999-2005.

2.4.4.3 Over-winter Fawn Survival

The WGFD conducted ground-based composition (adult:fawn) surveys to estimate post-winter fawn:adult ratios during April of 2005 (S. Smith, WGFD, unpublished data). A total of 2,252 and 2,024 deer were counted in the Pinedale Front and Mesa winter ranges, respectively (Tables 2.5-2.6). Estimates of over-winter fawn survival were 0.79 and 0.64 in the Pinedale Front and Mesa, respectively (Tables 2.5-2.6). Except for the relatively severe 2003-04 winter (Photo 2.1), over-winter fawn survival has generally been lower in the treatment area (Mesa) compared to the control (Pinedale Front), since the PAPA ROD in 2000 (Figure 2.13).

Table 2.5 Mule deer count data and calculations for over-winter fawn survival in the control (Pinedale Front), 1999-2005.

Year	December Adults	December Fawns	April Adults	April Fawns	*A**	*B***	$\hat{S}_a$	$\hat{S}_f$
1999-00	2,698	1,517	959	494	0.56	0.52	0.83	0.76
2000-01	2,853	1,769	955	478	0.62	0.50	0.85	0.69
2001-02	4,593	2,455	790	300	0.53	0.38	0.85	0.60
2002-03	3,565	1,813	704	254	0.51	0.36	0.96	0.68
2003-04	3,977	2,463	1771	441	0.62	0.25	0.82	0.33
2004-05	3,394	1,883	1565	687	0.55	0.44	1.0	0.79

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

Table 2.6 Mule deer count data and calculations for over-winter fawn survival in the treatment (Mesa), 1999-2005.

Year	December Adults	December Fawns	April Adults	April Fawns	*A*	*B*	$\hat{S}_a$	$\hat{S}_f$
1999-00	2,550	1,547	1,390	764	0.61	0.55	0.82	0.74
2000-01	2,420	1,458	1,685	707	0.60	0.42	0.85	0.59
2001-02	2,546	1,275	1,366	460	0.50	0.34	0.85	0.57
2002-03	1,864	914	1,489	470	0.49	0.32	0.88	0.57
2003-04	2,063	1,201	1,215	319	0.58	0.26	0.79	0.36
2004-05	2,162	1,183	1,477	547	0.55	0.37	0.95	0.64

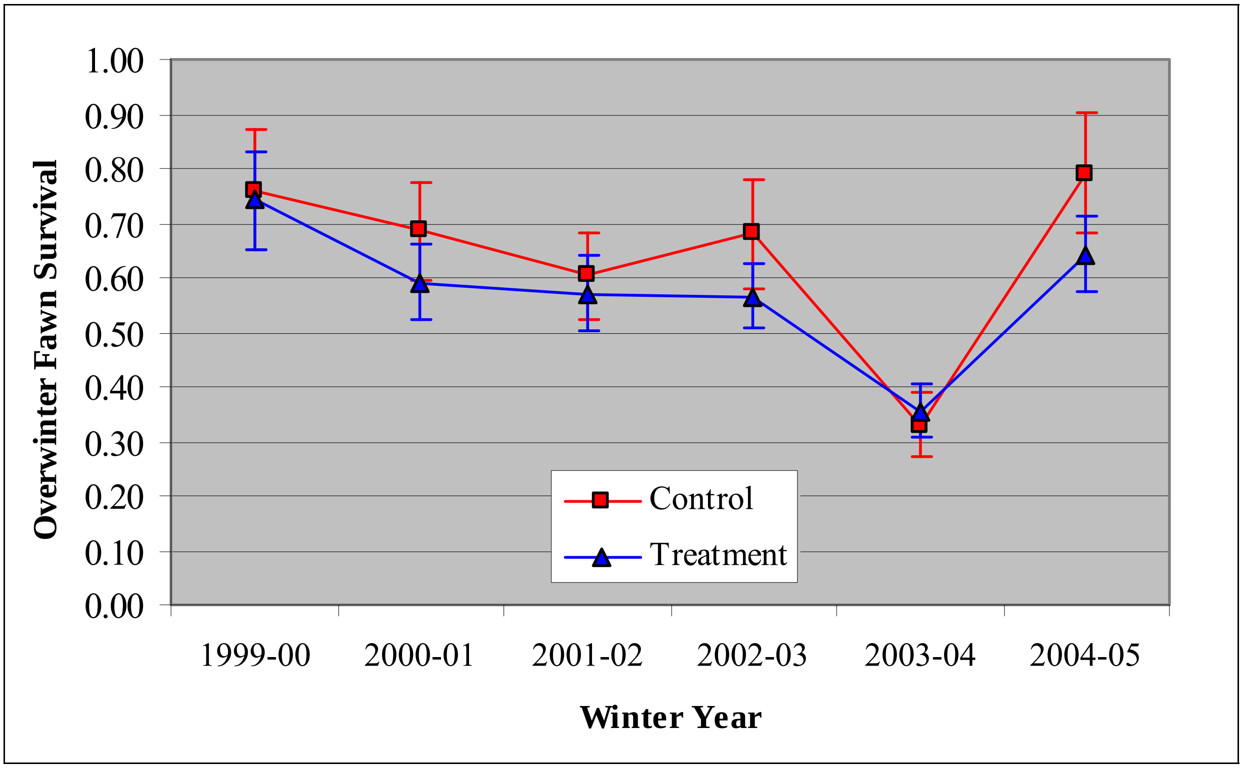

Figure 2.13 Estimated over-winter fawn survival and associated 90% confidence bands for treatment and control areas, 1999-2005.

2.4.4.4 Adult Winter Survival

Winter (December 15 – April 15) survival rates were estimated using the telemetry records of 67 radio-collared adult female deer, including 45 in the treatment and 22 in the control area. Two radiocollared deer (#874, #505) died in the treatment and none in the control. Both deer that died in the treatment were in poor body condition and starvation appeared to be the cause of death. Winter survival rates were 0.95 and 1.00 for the treatment and control areas, respectively (Table 2.7, Figure 2.14). It is worth noting that one deer (#804) from the control died in early November 2004, however she was not included in this survival analysis because her death occurred outside the December 15 – April 15 period that we used to estimate winter survival. Because standard methods cannot be used to compute a standard error or confidence interval for a proportion equal to 1.0, we used a one-sided binomial hypothesis test (Lehmann 1986:93) to estimate the standard error in Table 2.5. The estimated standard error (0.07) is larger than estimates from previous years and should be considered conservative. The high adult survival rates corresponded with a relatively mild winter, compared with 2003-04 (Photos 2.1 and 2.2).

Table 2.7 Winter (2004-05) survival rates and summary statistics for adult female radio-collared deer in treatment and control areas.

Study Area	Time Period	N_1	N_2	$\hat{S}$	90% CI	SE
Pinedale Anticline (Treatment)	December 15, 2004 - April 15, 2005	45	2	0.95	0.91 to 0.99	0.03
Pinedale Front (Control)	December 15, 2004 - April 15, 2005	22	0	1.0	0.91 to 1.0	0.07

N_1=number of available collars, N_2=number of deaths, $\hat{S}$ =survival estimate, CI=confidence interval

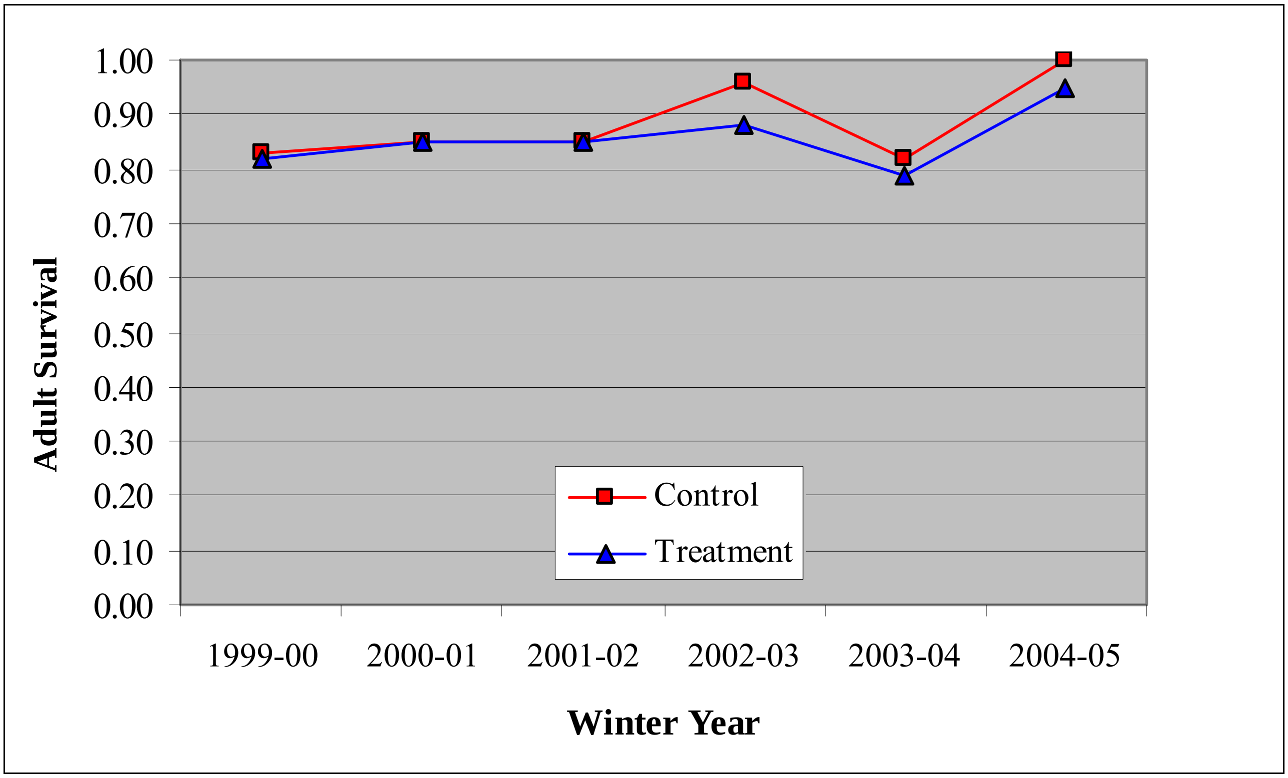

Figure 2.14 Winter survival rates of adult female radio-collared deer in treatment and control areas, 1999-2005.

Photo 2.1 Snow conditions on Mesa during February 2004 (view south towards Two Buttes).

Photo 2.2. Snow conditions on Mesa during February 2005 (view south towards Two Buttes).

2.4.5 Direct Habitat Loss

2.4.5.1 Pre-Development

Prior to development, The Mesa portion of the PAPA was relatively undisturbed, with very few improved roads and approximately a dozen existing well pads (Figure 2.15).

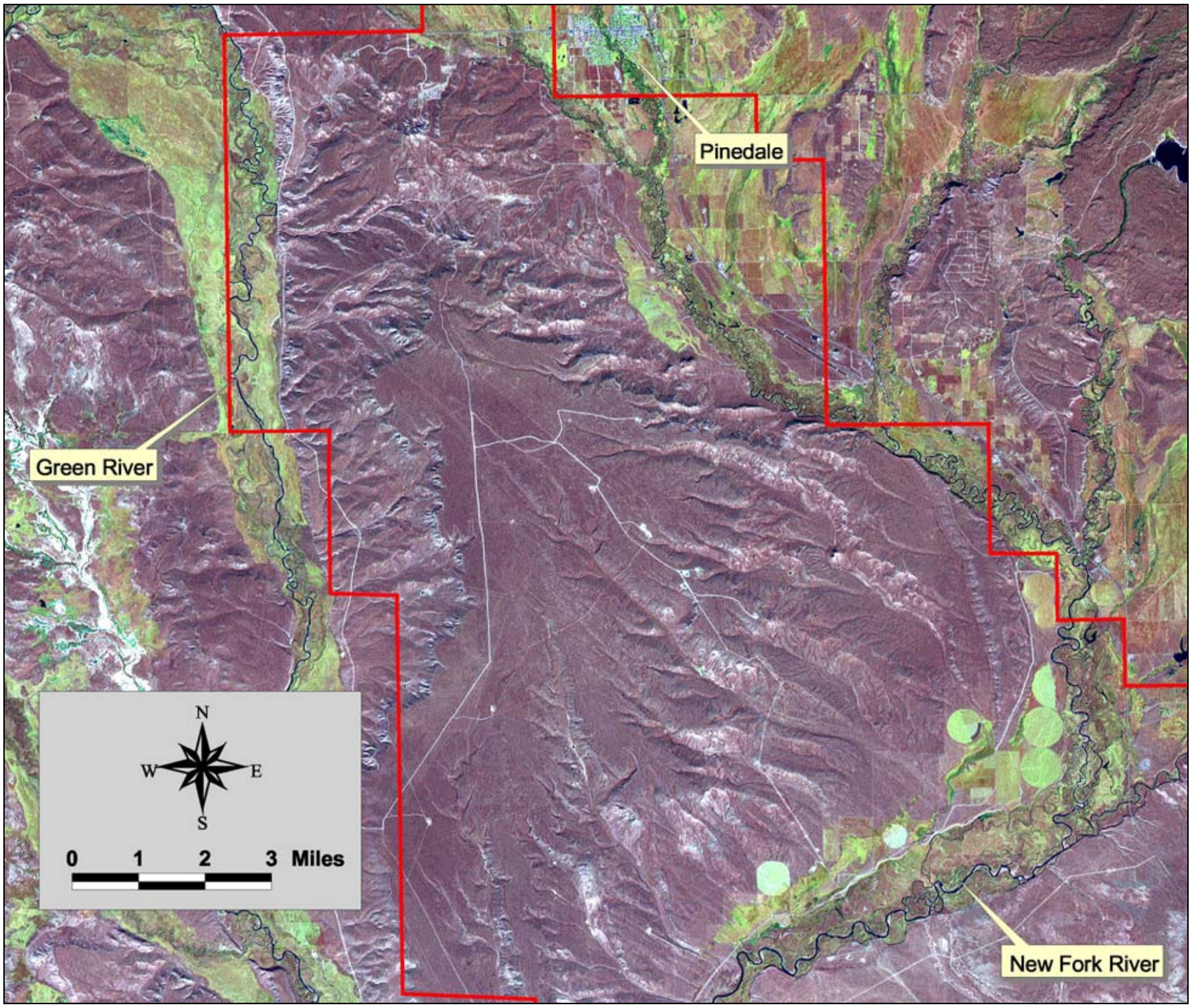

Figure 2.15 Satellite image of the Mesa on October 1999, prior to development of the Pinedale Anticline Project Area (PAPA).

2.4.5.2 Year 1 of Development

The BLM's ROD for the PAPA was released in July, 2000. Accordingly, natural gas development was minimal during this year. Approximately 11 miles of new roads and 39 acres of well pads were constructed on the Mesa during 2000 (Table 2.8). Approximately 51% of total surface disturbance was associated with road building, while the other 49% was attributed to well pad construction (Table 2.8).

2.4.5.3 Year 2 of Development

2001 marked the first full calendar year of gas field development in the PAPA. Most development occurred along the central portion of the Mesa, adjacent to Lovatt Draw (Figure 2.16). Based on satellite imagery, approximately 13 miles of new roads and 113 acres of well pads were constructed on the Mesa during the first nine months 2001 (Table 2.8). Approximately 30% of total surface disturbance was associated with road building, while the other 70% was attributed to well pad construction (Table 2.8).

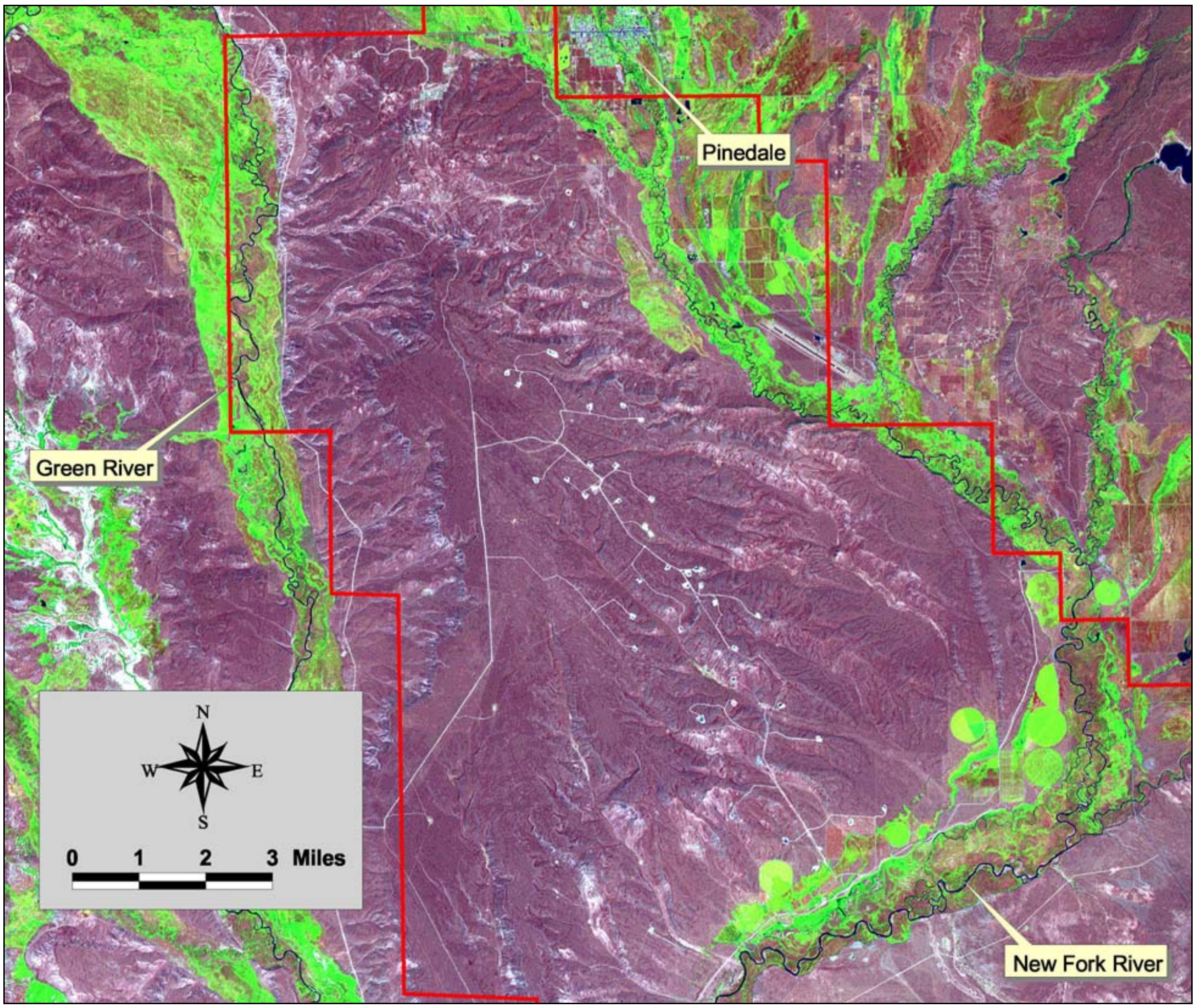

Figure 2.16 Satellite image taken in August 2001 during Year 2 of gas development in the Pinedale Anticline Project Area (PAPA).

2.4.5.4 Year 3 of Development

Similar to 2001, most development in 2002 occurred along the central portion of the Mesa, adjacent to Lovatt Draw, from the Paradise Road northwest to Stewart Point (Figure 2.17). Drilling activity was also evident on the northern Mesa, east of Stewart Point. Based on satellite imagery, approximately 18 miles of new roads and 201 acres of well pads were constructed on the Mesa between August 2001 and October 2002 (Table 2.8). Approximately 25% of total surface disturbance was associated with road building, while the other 75% was attributed to well pad construction (Table 2.8).

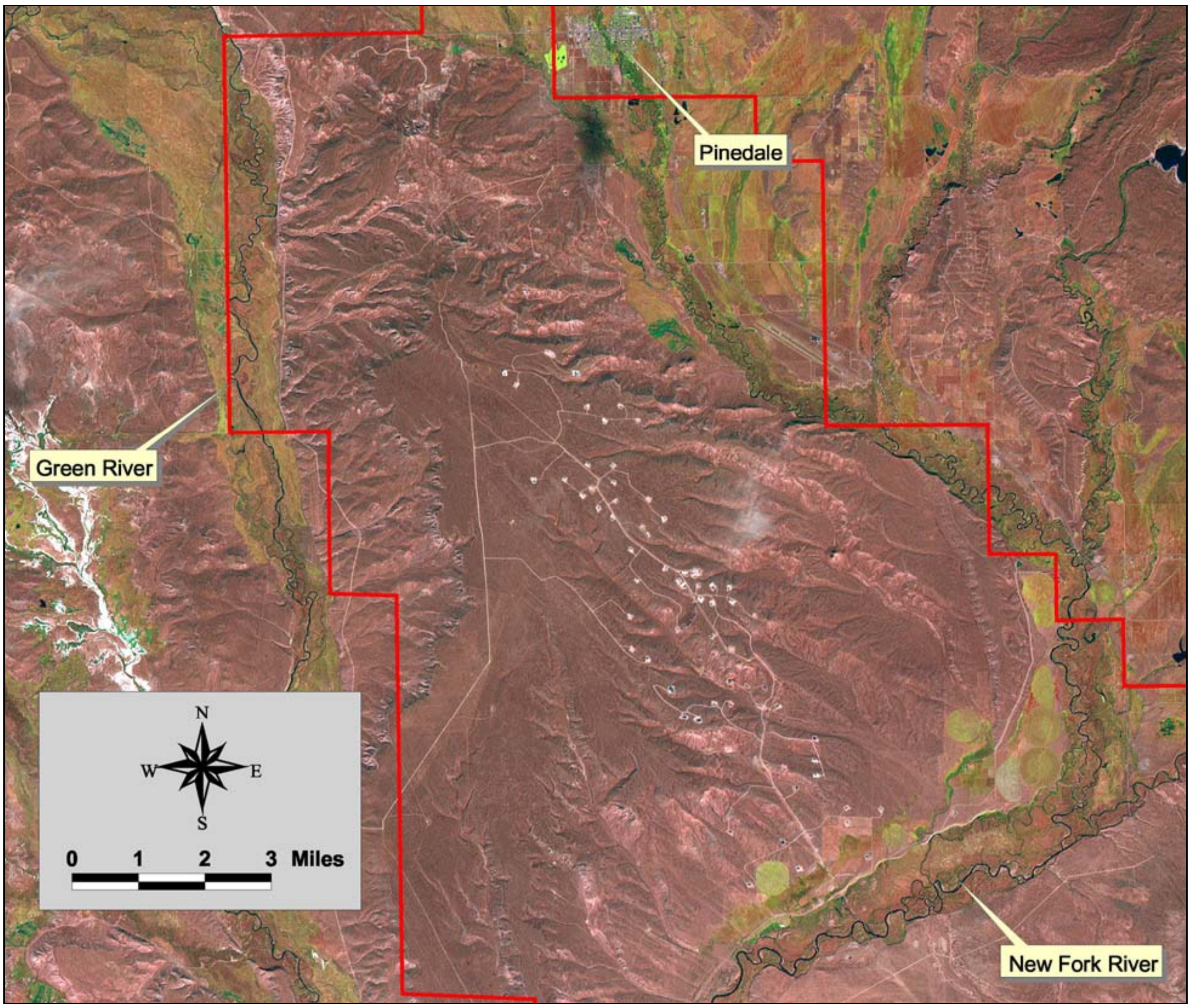

Figure 2.17 Satellite image taken in October 2002 during Year 3 of gas development in the Pinedale Anticline Project Area (PAPA).

2.4.5.5 Year 4 of Development

Similar to 2001 and 2002, most gas development in 2003 occurred along the central portion of the Mesa, adjacent to Lovatt Draw, from the Paradise Road northwest to Stewart Point (Figure 2.18). Drilling activity was also evident on the northern Mesa, east of Stewart Point. Based on satellite imagery, approximately 14 miles of new roads and 237 acres of well pads were constructed on the Mesa between October 2002 and September 2003 (Table 2.8). Approximately 18% of total surface disturbance was associated with road building, while the other 82% was attributed to well pad construction (Table 2.8).

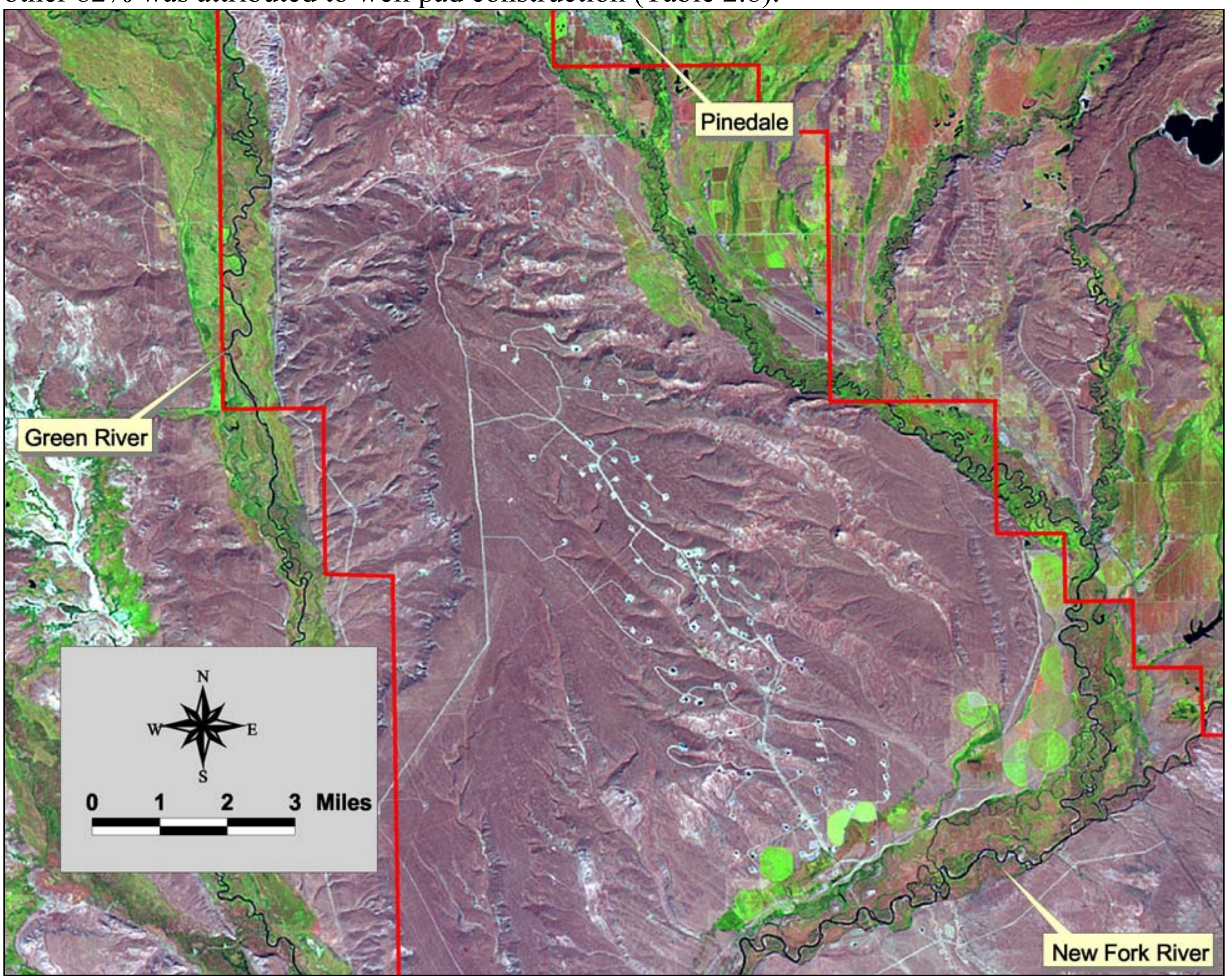

Figure 2.18 Satellite image taken in September 2003 during Year 4 of gas development in the Pinedale Anticline Project Area (PAPA).

2.4.5.5 Year 5 of Development

Similar to 2001-2003, most gas development in 2004 occurred along the central portion of the Mesa, adjacent to Lovatt Draw, from the Paradise Road northwest to Stewart Point (Figure 2.19). Drilling activity was also evident on the northern Mesa, east of Stewart Point. Based on satellite imagery, approximately 3 miles of new roads and 221 acres of well pads were constructed on the Mesa between September 2003 and August 2004 (Table 2.8). Approximately 5% of total surface disturbance was associated with road building, while the other 95% was attributed to well pad construction (Table 2.8).

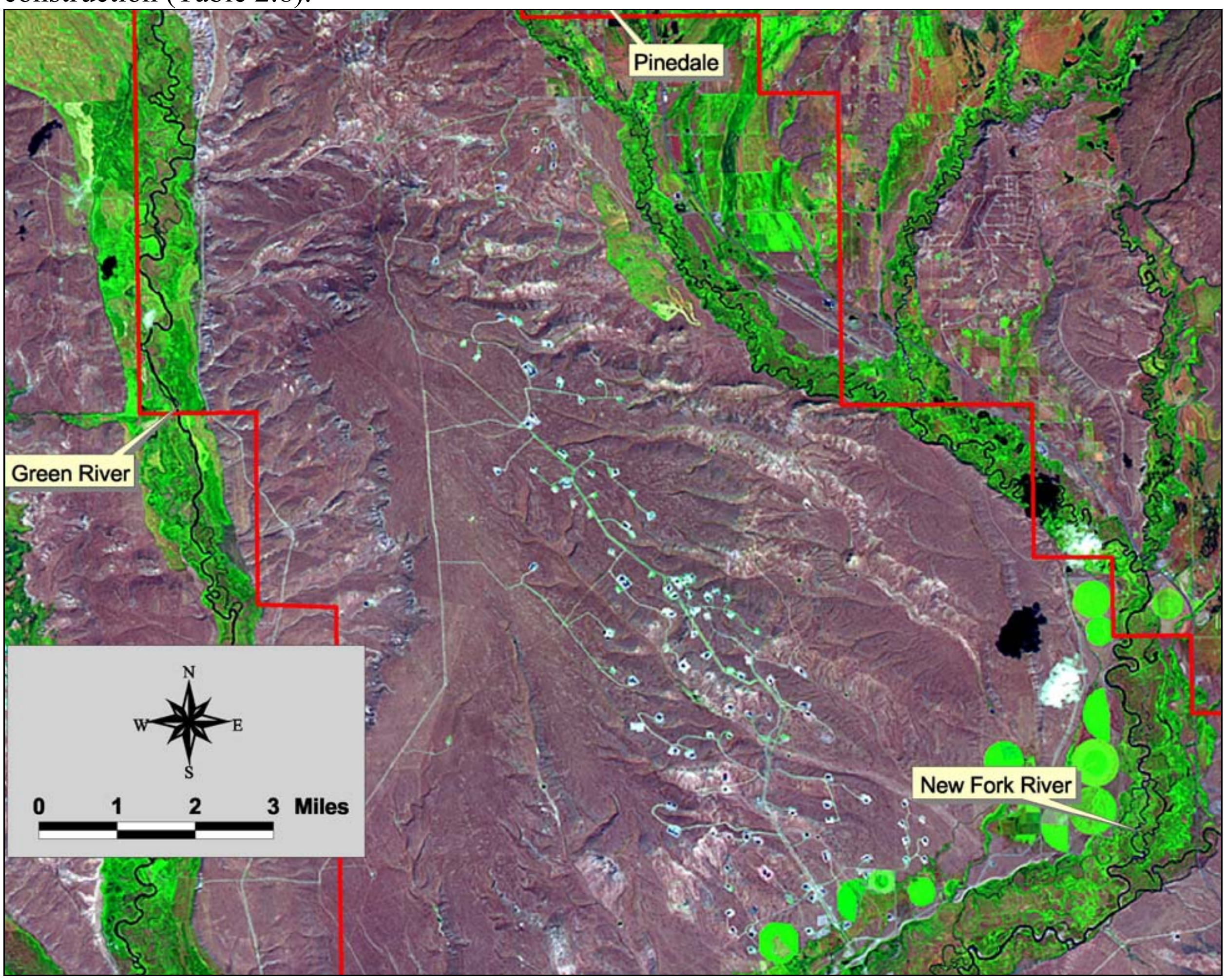

Figure 2.19 Satellite image taken in August 2004 during Year 5 of gas development in the Pinedale Anticline Project Area (PAPA).

Table 2.8 Summary of annual and cumulative direct habitat loss (i.e., surface disturbance) associated with road networks and well pads on the Mesa, 2000-2004.

Year	Roads (mi)	Roads (acres)[a]	Well Pads (acres)	Total (acres)	% Roads	% Well Pads
2000	11.4	41	39	80	51%	49%
2001	13.1	48	113	161	30%	70%
2002	18.1	66	201	267	25%	75%
2003	13.9	51	237	288	18%	82%
2004	3.2	12	221	233	5%	95%
Total	59.7	218	811	1,029	21%	79%

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

2.4.6 Resource Selection

Population-level models (Table 2.9) and predictive maps (Figures 2.20-2.24) were estimated for five winter periods: Pre-Development (Winters 1998-99 and 1999-00), Year 1 of Development (Winter 2000-01), Year 2 of Development (Winter 2001-02), Year 3 of Development (Winter 2002-03), and Year 4 of Development (Winter 2003-04).

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

The population–level RSPF 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 2.9). Units with the highest probability of use (Figure 2.20) had an average elevation of 2,275 m, an average slope of 5 degrees, and an average road density of 0.14 km/km^2. Aspects with the highest probability of use were northwest and southwest.

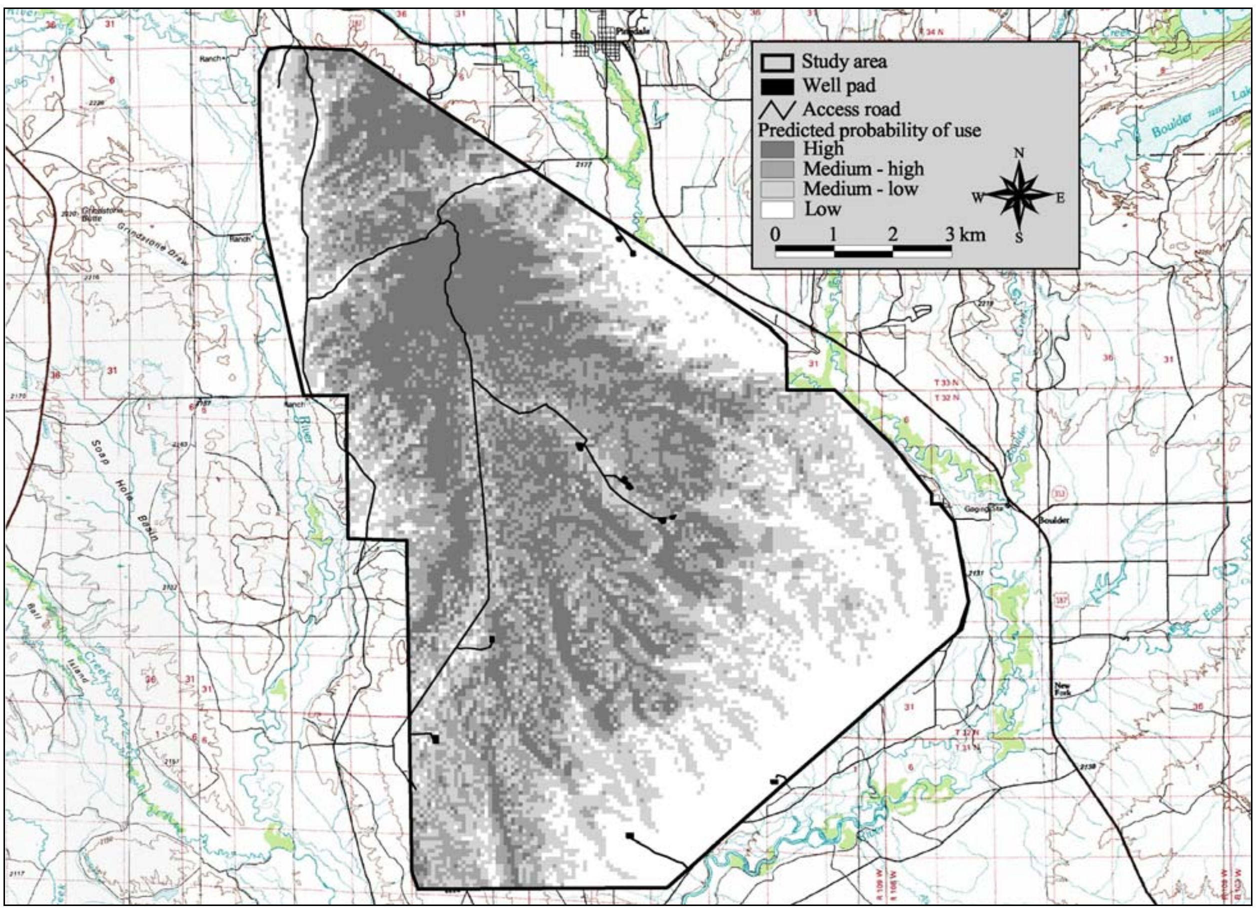

Figure 2.20. Predicted probabilities and associated categories of mule deer habitat use during 1998-99 and 1999-2000 winters, prior to natural gas field development in western Wyoming.

Table 2.9. Habitat variables and coefficients for population-level winter mule deer resource selection probability functions (RSPF) before and during 4 years of natural gas development in western Wyoming, 1998-2004.

Variable	Pre-Development[a]			Year 1			Year 2			Year 3			Year 4		
	β	SE	P	β	SE	P[b]	β	SE	P[c]	β	SE	P[d]	β	SE	P[d]
Intercept	-29.649	6.637	<0.001	-84.56	21.124	0.003	-75.712	12.93	<0.001	-104.295	11.316	<0.001	-60.949	13.117	<0.001
Elevation	0.009	0.001	<0.001	0.031	0.008	0.005	0.027	0.005	<0.001	0.036	0.004	<0.001	0.022	0.006	0.003
Slope	0.098	0.010	<0.001	0.391	0.073	<0.001	0.258	0.046	<0.001	0.342	0.128	0.036	0.472	0.078	<0.001
$Slope^2$	-0.004	0.001	<0.001	-0.022	0.004	<0.001	-0.017	0.003	<0.001	-0.019	0.007	0.042	-0.025	0.005	<0.001
Well distance	na			3.129	1.899	0.134	3.375	1.264	0.018	6.712	2.394	0.031	na		
Well $distance^2$	na			-0.465	0.229	0.073	-0.416	0.156	0.019	-0.719	0.289	0.047	na		
Road density	-0.249	0.027	<0.001	-0.827	0.387	0.061	ns			ns[e]			0.675	0.615	0.299
Road $density^2$	ns			ns			ns			ns			-0.624	0.128	<0.001
Aspect = NE	0.012	0.051	0.818	ns			ns			ns			na		
Aspect = NW	0.399	0.025	<0.001	ns			ns			ns			na		
Aspect = SE	-0.301	0.222	<0.001	ns			ns			ns			na		
Aspect = SW	0.194	0.028	<0.001	ns			ns			ns			na		

2.4.6.2 Year 1 of Development: Winter 2000-01

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

The population–level RSPF was estimated from 18,706 GPS locations collected from 10 radiocollared deer during the winter of 2000–01 (Table 2.9). The RSPF included elevation, slope, road density, and distance to well pad (Table 2.9). Deer selected for areas with higher elevations, moderate slopes, low road densities, and away from well pads. Habitat units with the highest probability of use (Figure 2.21) had an average elevation of 2,266 m, slope of 5 degrees, road density of 0.16 km/km^2, and were 2.7 km away from the nearest well pad. Predictive maps indicate probability of deer use was lowest in areas close to well pads and access roads (Figure 2.21). Shifts in deer distribution between pre-development and Year 1 of development were evident through the changes in the 4 deer use categories (Table 2.10). 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.

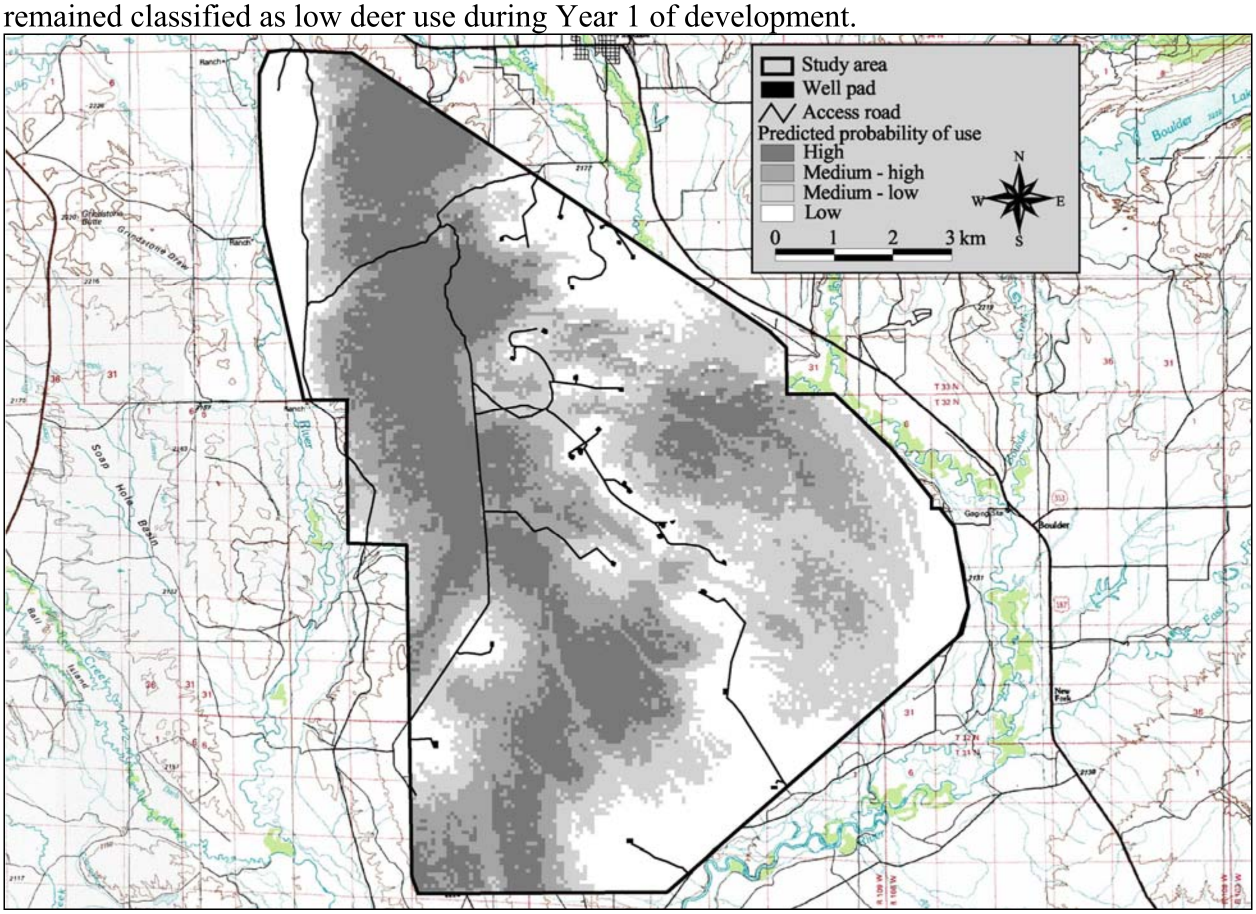

Figure 2.21. Predicted probabilities and associated categories of mule deer habitat use during Year 1 (winter of 2000-01) of natural gas development in western Wyoming.

2.4.6.3 Year 2 of Development: Winter 2001-02

Individual models were developed for 15 radiocollared deer during the winter (4 January to 15 April) of 2001–02. Fourteen of the 15 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, all 15 deer selected for moderate slopes and 12 of 15 deer selected areas away from well pads.

The population–level RSPF was estimated from 14,851 GPS locations collected from 15 radiocollared deer during the winter of 2001–02 (Table 2.9). The RSPF included elevation, slope, and distance to well pad (Table 2.9). Deer selected for areas with higher elevations, moderate slopes, and away from well pads. Habitat units with the highest probability of use (Figure 2.22) had an average elevation of 2,255 m, slope of 5 degrees, and were 3.1 km away from the nearest well pad. Predictive maps indicate probability of deer use was lowest in areas close to well pads (Figure 2.22). 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 2.10). 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.

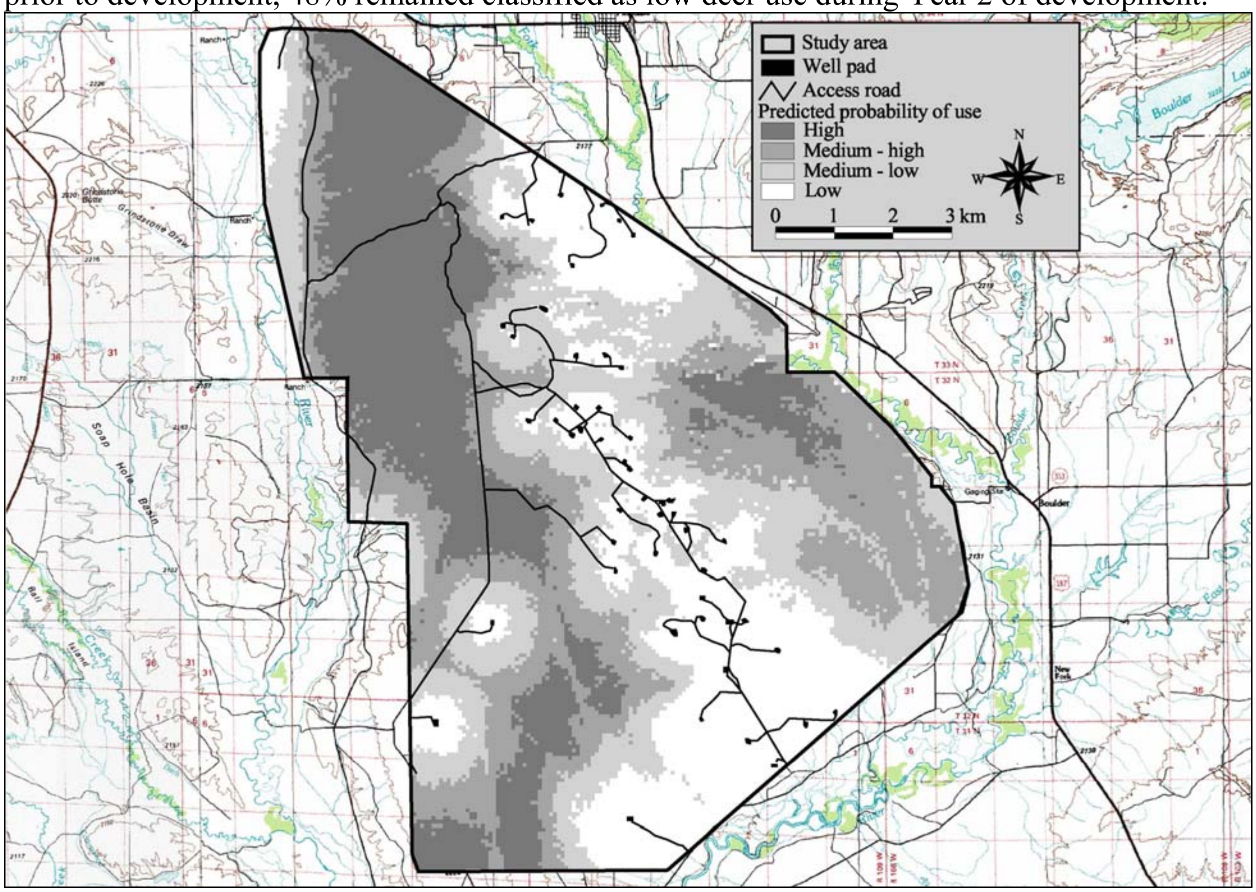

Figure 2.22. Predicted probabilities and associated categories of mule deer habitat use during Year 2 (winter of 2001-02) of natural gas development in western Wyoming.

2.4.6.4 Year 3 of Development: Winter 2002-03

Individual models were developed for 7 radiocollared deer during the winter (20 December to 15 April) of 2002–03. 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 RSPF was estimated from 5,131 GPS locations collected from 7 radiocollared deer during the winter of 2002–03 (Table 2.9). Our target sample of 10 marked animals was not met because 3 deer died early in the season. The RSPF included elevation, slope, and distance to well pad (Table 2.9). Deer selected areas with high elevations, moderate slopes, and away from well pads. Habitat units with the highest probability of use (Figure 2.23) had an average elevation of 2,233 m, slope of 5 degrees, and were 3.7 km away from the nearest well pad. Predictive maps indicate probability of deer use was lowest in areas close to well pads (Figure 2.23). 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 2.10). 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.

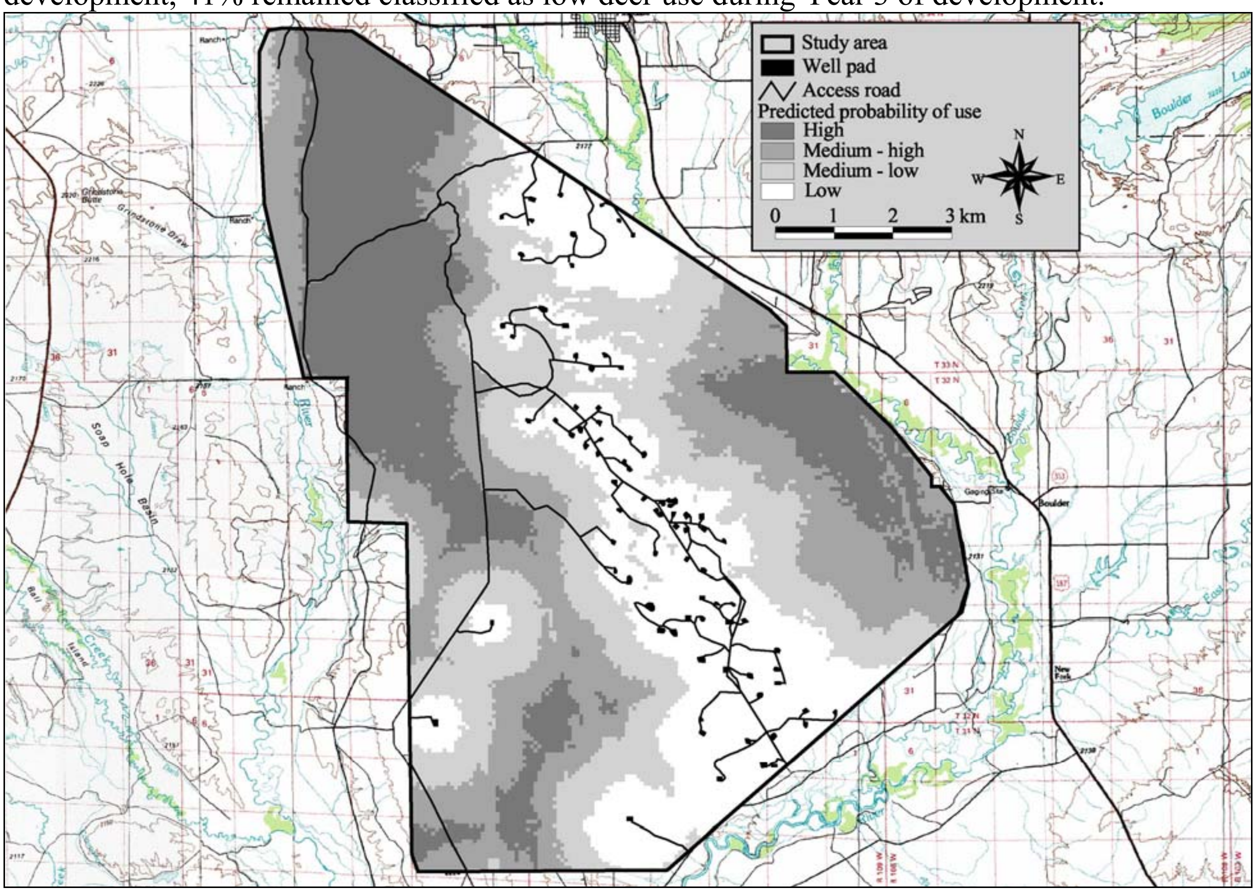

Figure 2.23. Predicted probabilities and associated categories of mule deer habitat use during Year 3 (winter of 2002-03) of natural gas development in western Wyoming.

2.4.6.5 Year 4 of Development: Winter 2003-04

Individual models were estimated for 11 radiocollared deer during the winter (20 December to 15 April) of 2003–04. Nine of eleven deer had positive coefficients for elevation, indicating selection for higher elevations. Based on the relationship between the linear and quadratic terms for slope and road density variables, 10 deer selected for moderate slopes and all 11 deer selected areas with low road density.

The population–level RSPF was estimated from 12,207 GPS locations collected from 11 radiocollared deer during the winter of 2003–04 (Table 2.9). The RSPF included elevation, slope, and road density (Table 2.9). Deer selected for areas with higher elevations, moderate slopes, and low road densities. Habitat units with the highest probability of use (Figure 2.24) had an average elevation of 2,276 m, slope of 8 degrees, and road density < 1.2 km/km^2. Predictive maps indicate probability of deer use was lowest in areas with high road densities and areas along the peripheral of the study area (Figure 2.24). Aside from the areas with high road densities, the probability of deer use between pre-development and Year 4 of development was more similar than during Years 1-3 of development, as evidenced through the changes in the 4 deer use categories (Table 2.10). Of the habitat units classified as high deer use prior to development, 71% were classified as high deer use during Year 4 of development. And, of the areas classified as low deer use prior to development, 77% remained classified as low deer use during Year 4 of development.

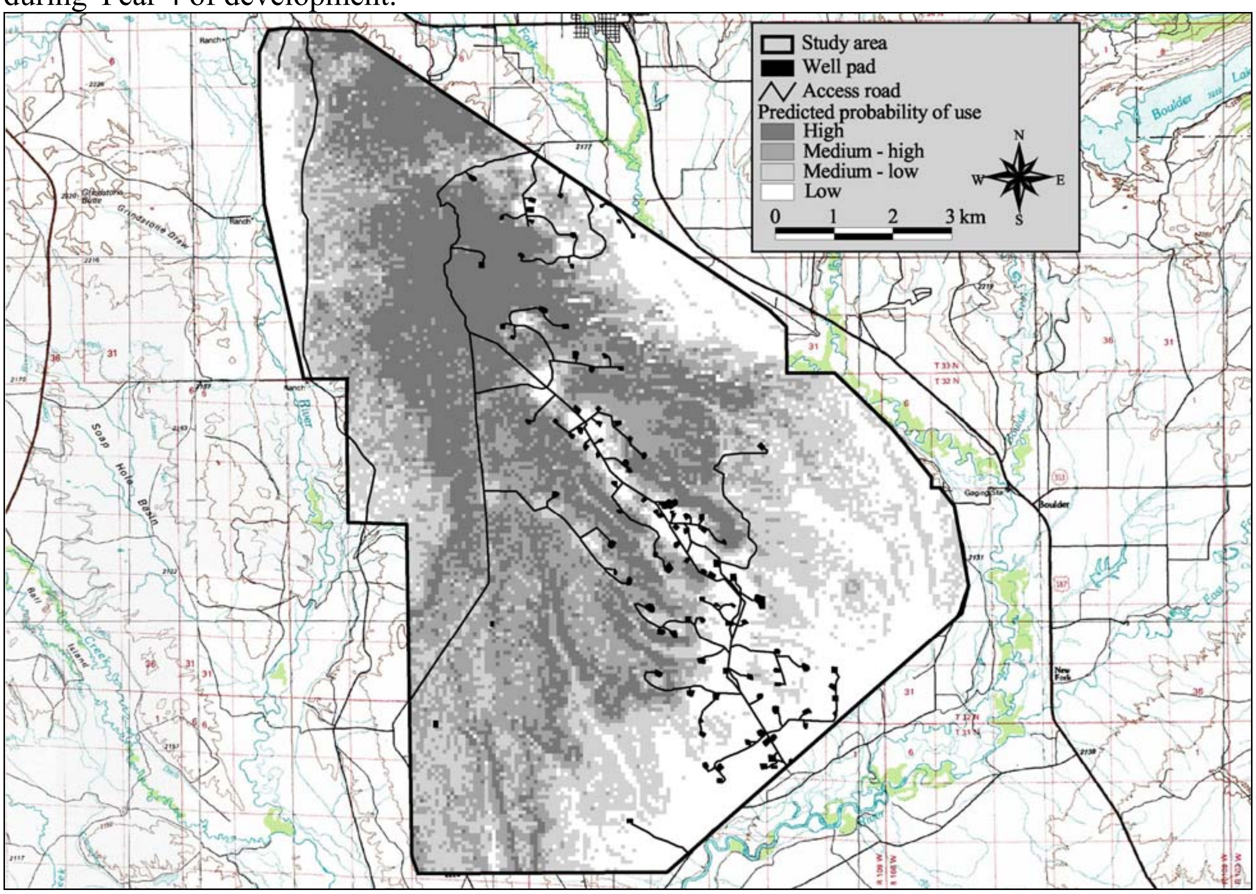

Figure 2.24. Predicted probabilities and associated categories of mule deer habitat use during Year 4 (winter of 2003-04) of natural gas development in western Wyoming.

Table 2.10 Percent change in the 4 pre-development deer use categories through 4 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	71%	23%	3%	2%
Medium-High	Year 1	31%	36%	22%	11%
	Year 2	34%	23%	25%	18%
	Year 3	27%	22%	28%	22%
	Year 4	25%	49%	22%	4%
Medium-Low	Year 1	9%	34%	31%	26%
	Year 2	16%	35%	25%	25%
	Year 3	25%	27%	25%	23%
	Year 4	4%	26%	53%	17%
Low	Year 1	0%	7%	34%	58%
	Year 2	1%	23%	27%	48%
	Year 3	11%	29%	20%	41%
	Year 4	0%	2%	22%	77%

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

2.5 DISCUSSION

Currently, we collect 25,000 to 30,000 locations per year from 20 GPS-collared deer and approximately 400 locations from 40 VHF radio-collared deer. In previous years, the GPS collection schedule has been restricted to the winter (1 November – 15 April) however, beginning in 2005 we deployed new collars that will collect GPS locations on a year-around basis. These data will add to our knowledge of migration routes and seasonal distribution patterns of the Sublette mule deer herd. We plan to continue equipping deer with GPS collars for consecutive years. Although data analysis is delayed a full year when GPS collars operate on the same deer for two consecutive years, acquiring movement and distribution information from the same animal over a period of years provides useful year-to-year comparisons. For example, during the 2002-03 winter we were able to demonstrate that deer on the Mesa wintered farther north than in previous years. And, during the harsh 2003-04 winter we were able to document weather-related shifts in distribution. And, for the last several years we were able to illustrate the strong annual fidelity that deer have for the 50-mile migration route along the Pinedale Front. Additionally, as levels of development continue to increase in the PAPA, it will be important to monitor the same deer for consecutive years to determine whether emigration to other winter ranges is occurring.

Basic distribution maps generated from GPS data illustrated winter distribution patterns of deer in the control (Pinedale Front) and treatment (Mesa) areas, demonstrated the importance of BLM lands, and continued to refine information on migration routes and seasonal ranges. Deer in the treatment area continued to utilize the TPB as a migratory route between winter and spring/fall transition ranges. Deer movements through the TPB were quick (< 2 hours), as evident by the distance between locations, but the TPB continued to function effectively during 2004 and 2005. Agencies, industry, NGO's, and the public recognize the value of maintaining this movement corridor for the Sublette deer herd. Land-use decisions in and adjacent to the TPB should consider the migration routes and seasonal ranges of the Sublette deer herd.

Consistent with previous years, deer distribution and movement patterns in the control area were variable during the 2004-05 winter. The core winter range around Buckskin Crossing was heavily used, but deer shifted areas of use (10–15 miles) in all directions; south to Elk Mountain, southeast along the Big Sandy, easterly to the Little Sandy and Prospects, and northerly to Muddy Mountain. The ability to alter their rates of movements, to change their pathways, and occupy a variety of winter habitats as needed are behaviors that likely allow these deer to best exploit winter ranges. However, the unpredictable movement patterns made calculation of abundance and density estimates difficult, as the size of the sampling frame progressively increased from 2002 through 2004 to encompass the range of our marked deer. Because the sampling frame did not reflect the area utilized by our marked population prior to 2004, abundance and density estimates are expected to be biased high during 2002, and biased low during 2003.

Although winter distribution patterns varied among deer in the control area, the migration route to northerly transition and summer ranges was surprisingly consistent. All GPS-collared deer captured in the Pinedale Front migrated along a distinct movement corridor located at the base of the Wind River Range. Deer followed 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. GPS data collected from individual deer for consecutive winters showed a strong affinity for this migration corridor during both spring and fall migrations. Deer that winter in 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 direction towards the Hoback Basin and adjacent mountain ranges (Sawyer and Lindzey 2001). However, details of this migration route, in terms of size, width, specific location, and deer fidelity were unknown prior to GPS data collected over the last three years. Although these deer may migrate 100 miles between winter and summer ranges (Sawyer and Lindzey 2001), our GPS collars have not previously collected locations May through October, and therefore did not record the entire migration route(s). Deer management in the Sublette DAU is complicated by the long-distance migrations that occur through a variety of habitats and across a mix of land ownership. Knowledge of this migration route should provide agencies with the necessary information to maintain deer movements through the Pinedale Front, adjust harvest strategies accordingly, and prioritize habitat enhancement projects. Because several thousand mule deer rely on this migration corridor to access their seasonal ranges, maintenance of the corridor should be a priority for agencies, industry, and conservation groups.

In addition to basic distribution and movement maps, GPS data can be used to conduct more rigorous scientific analyses, such as estimation of resource selection models (Manly et al. 2002). Resource selection, as described by Manly et al. (2002), is a rapidly advancing methodology for analyzing, modeling, and interpreting wildlife field studies. Resource selection analyses have broad applications, and in the case of this study, were used to determine how mule deer use their habitats in relation to various habitat features, including well pads and road networks associated with energy development. Our basic approach to resource selection treats the GPS-collared deer as the experimental unit and estimates a population-level model (i.e., resource selection probability function [RSPF]), so inference can be made to the entire population of mule deer on the Mesa.

Sample size, in this case the number of collared mule deer, is an important consideration for statistical procedures that rely on simple random sampling to obtain population-level inference. We recognize the number of marked animals in our analysis may appear low, but we believe our sample adequately represents the Mesa deer population because of our *a priori* knowledge of deer movement and distribution patterns. Sawyer and Lindzey (2001) studied the movement and distribution patterns of this mule deer population for three years (1998-2000) prior to gas field development. Their results indicated that most deer congregate in the northern portion of the study area during early winter, before moving on to their respective winter ranges. Our sampling design incorporated this knowledge by obtaining a random sample of deer for collaring while they were congregated on the northern portion of the study area. Thus, while our sample sizes may be less than preferred, we believe our sampling strategy and model-building process adequately represents the PAPA deer population. We believe larger sample sizes should reveal the same relationships between the probability of mule deer habitat use and environmental conditions, but with higher precision.

Prior to this study, descriptions of how mule deer respond to gas development were generally 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, and, 2) animals may move to other areas when not being observed. Our resource selection analysis accounts for the first shortcoming by obtaining a random sample of mule deer and treating the animal as the experimental unit. The random sample results in each animal having the same probability of capture and 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.

We view our resource selection analysis as an objective means to document mule deer behavioral response to natural gas development and quantify indirect habitat losses through time. Although indirect impacts associated with human activity or development have been documented in elk (Lyon 1983, Morrison et al. 1995, Rowland et al. 2000), data that suggest similar behavior in mule deer (Rost and Bailey 1979, Freddy et al. 1986, Yarmaloy et al. 1988, Merrill et al. 1994, Taylor and Knight 2003) are limited and largely observational in nature. Specific knowledge of how, or if mule deer respond to natural gas development does not exist in the literature. The resource selection analysis presented in this report is the only multi-year study that examines the effects of natural gas development on mule deer. Although this study is proposed to run several more years, results to date suggest that winter habitat selection and distribution patterns of mule deer have been affected by well pad development. Changes in habitat selection by mule deer appeared to be immediate (i.e., Year 1 of development) and through 3 years of development, we found no evidence they acclimated or habituated to well pads. Rather, mule deer had progressively higher probability of use in areas farther away from well pads as development progressed; preferring areas 2.7, 3.1, and 3.7 km away from well pads in Years 1, 2, and 3, respectively.

Population–level models and associated predictive maps were useful tools for illustrating changes in habitat selection patterns through time. We recognize the 4 levels of habitat use were subjectively defined and could vary depending on study objectives. Nonetheless, we believe models and associated predictive maps provide a useful framework for quantifying indirect habitat losses 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 by Year 3 of development, 41% of those areas classified as high use before development had changed to medium–low or low use. Conversely, by Year 3 of development, 40% of low use areas had changed to medium–high or high use areas. Assuming habitats with high probability of use prior to development were more suitable than habitats with lower probability of use, these results suggest natural gas development on the Mesa displaced mule deer to less suitable habitats.

Interestingly, the model from Year 4 did not contain the distance to well pad variable and mule deer habitat selection was not influenced by proximity of well pads. Without the influence of well pads, the predictive map looked remarkably similar to pre-development distribution patterns. This distribution pattern probably reflects the heavy snow conditions during Year 4 (2003-04); the most severe winter since this study began in 1998. The heavy snow conditions likely reduced the options and available habitat to deer such that they reverted to their traditional (i.e., pre-development) or available habitats, which were located in areas now covered by or in close proximity to well pads. Given the mild winter in Year 5 (i.e., winter 2004-05), we expect the Year 5 model to include the distance to well pad variable and the predictive map should look similar to those from Years 1 through 3. The analysis from Year 5 is expected to be complete in the summer of 2006.

A single well pad typically disturbs 3 to 4 acres of habitat; however, areas with the highest probability of deer use were 2.7, 3.1, and 3.7 km away from well pads during the first 3 years of development respectively. There are two potential concerns with the apparent avoidance of well pads by mule deer during Years 1 through 3 of development. First, the avoidance or lower probability of use of areas near wells creates indirect habitat losses of winter range that are substantially larger in size than the direct habitat losses incurred when native vegetation is removed during construction of the well pad. Habitat losses, whether direct or indirect, have the potential to reduce carrying capacity of the range and result in population–level effects (i.e., reduced survival, reduced reproduction, or emigration). Second, if deer do not respond by vacating winter ranges, distribution shifts will result in increased density in remaining portions of the winter range, exposing the population to greater risks of density–dependent effects. Consistent with Bartmann et al. (1992), we would expect fawn mortality to be the primary density–dependent population regulation process because of their high susceptibility to over-winter mortality (White et al. 1987, Hobbs 1989).

We continue to monitor four population parameters to detect changes in the treatment and control areas, including: 1) recruitment, 2) adult doe survival, 3) over-winter fawn survival, and 4) abundance. Recruitment (i.e., doe:fawn ratios) in the treatment and control areas has been essentially the same since development began. Estimates of over-winter adult survival have been lower in the treatment area for 3 of the 5 years since development began, and over-winter fawn survival has been lower 4 of 5 years. The only year over-winter fawn survival was not lower in the treatment was in the harsh winter of 2003-04, when we would expect high fawn mortality in both treatment and control areas. While these individual point estimates of over-winter adult and fawn survival were not statistically different between treatment and control areas, the long-term trends suggest deer in the treatment may not be performing as well as deer in the control.

Of particular concern is the decreasing abundance estimates in the treatment area, dropping from 5,228 in 2002 to 2,818 in 2005. This 4-year, 46% reduction in deer abundance is disconcerting because there is no concurrent evidence of a population decline in the control area. At this point in time we cannot detect any positive or negative trends in the control area, but abundance in the treatment area has significantly declined since 2002. Following the severe winter and associated high mortality rates in 2003-04, we expected deer abundance to increase the following year in both treatment and control areas, given the exceptionally mild 2004-05 winter. While an increase was evident in the control area, abundance continued to decline in the treatment area.

Population change is generally a function of four components, including; births, deaths, immigration, and emigration. Ideally, we could explain how each of these components has contributed to the population decline in the treatment area. However, our population monitoring was designed to make comparisons between treatment and control areas, rather than model population dynamics (White 2000). But, based on the population parameters we have measured, we believe reduced over-winter fawn survival, lower adult survival, and emigration are likely responsible for the population changes on the Mesa. The first GPS-collared deer to emigrate from the Mesa and occupy a new, distinct winter range was documented during the 2003-04 winter (see Section 2.4.3). While this behavior was only documented in one of eleven GPS-collared deer that winter, it may have represented 9% of the population, or approximately 320 deer (i.e., 9% of 3,564).

Long-term monitoring programs will continue to provide the best opportunities for detecting changes in population parameters and to verify the magnitude of these apparent impacts of development on mule deer performance. As we continue to measure population parameters and examine habitat selection in treatment and control areas, comparisons can be made, and over time, the impacts of energy development on mule deer will be better understood. For this study, the number of captured deer or counted deer may refine the precision of the measurement (e.g., survival, reproduction), but the strength of this monitoring plan and robustness of the conclusions will be determined by the number of years it is implemented. Future monitoring should be modified to incorporate any changes in development plans, such as winter drilling. Assuming winter drilling occurs on federal lands beginning in the 2005-06 winter, we plan to evaluate how different levels of human activity (e.g., traffic) at developing and producing well pads influence mule deer distribution. Understanding mule deer response to different levels of human activity and types of well pads would allow mitigation measures to be evaluated and improved.

2.6 SUMMARY AND MANAGEMENT IMPLICATIONS

The objective of this monitoring effort is to evaluate potential impacts of natural gas development on mule deer in terms of: 1) direct habitat loss, 2) changes in habitat selection, and 3) population performance.

- **Direct Habitat Losses:** Satellite imagery was used to estimate direct habitat losses (i.e., surface disturbance) for the Mesa portion of the PAPA. Through August 2004, approximately 1,029 acres had been disturbed, of which 79% was due to well pad construction and 21% to access roads. Each year development has progressed, well pads account for relatively more direct habitat loss than access roads. Pipelines and seismic tracks *were not* included in the estimates of direct habitat loss.

- **Habitat Selection Patterns:** During Years 1 through 3 of gas development, habitat selection models and predictive maps suggested mule deer were less likely to occupy habitats in close proximity to well pads than those farther away. Changes in habitat selection appeared to be immediate (i.e., Year 1 of development) and no evidence of well pad acclimation occurred through the first 3 years of development, rather deer selected areas farther from well pads as development progressed. The lower levels of deer use within 2.7 to 3.7 km of well pads suggested indirect habitat losses may be substantially larger than direct habitat losses. Additionally, some areas classified as high deer use prior to development changed to areas of low use following development. If areas classified as high use before development were those preferred by deer, then observed shifts in their distribution were towards less preferred and presumably less suitable habitats. During Year 4 of development and following a substantial reduction in deer abundance, habitat selection patterns of deer were influenced by road density, but not proximity of well pads. This may be an artifact of the unusually severe winter during Year 4, where movement options and available habitat for deer were limited. Results from Year 5 should help clarify trends in habitat selection.

- **Population Performance:** We monitored four population characteristics to compare population performance in the treatment (Mesa) and control (Pinedale Front) areas, including: 1) recruitment, 2) over-winter adult doe survival, 3) over-winter fawn survival, and 4) abundance. Recruitment (i.e., doe:fawn ratios) in the treatment and control areas has been essentially the same since development began. Point estimates of over-winter adult survival have been slightly lower in the treatment area for 3 of the 5 years since development began, and over-winter fawn survival has been slightly lower 4 of 5 years. The only year over-winter fawn survival was not lower in the treatment was in the harsh winter of 2003-04, when we would expect high fawn mortality in both treatment and control areas. While these point estimates of over-winter adult and fawn survival were not statistically different between treatment and control areas, the long-term trends in these vital rates suggest deer in the treatment area may not be performing demographically as well as deer in the control area. Additionally, a portion of the deer normally wintering on the Mesa emigrated to a new, distinct winter range during the 2003-04 winter. The combination of changes in births, deaths, and emigration resulted in an estimated 46% reduction in deer abundance over four years, although we are unable to estimate the relative contribution of these factors to the decline. There is no evidence of a similar decline in abundance in the control area.

Possible management implications include:

- Monitoring shifts in distribution, or habitat use, or population parameters allows mitigation measures aimed at reducing impacts to be evaluated and timely, site-specific strategies to be developed. The current mitigation measure is focused on seasonal timing restrictions, where drilling activity is 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 15 November to 30 April. Major shifts in the distribution of mule deer on the Mesa occurred during Years 1 through 3 of development even though drilling on federal lands was largely restricted to non-winter months. Estimates of deer abundance on the Mesa have significantly declined since development began. To date, our findings suggest seasonal timing restrictions may not be achieving desired results.

- In deep-gas fields like the PAPA where well densities range from 4 to 16 pads per section, the number of producing well pads and associated human activity may negate the potential effectiveness of timing restrictions on drilling activities as a means to reduce disturbance to wintering deer. Reducing disturbance to wintering mule deer may require restrictions or approaches that minimize the level of human activity during both production and development phases of wells. Directional drilling technology offers promising new methods for reducing surface disturbance and human activity. Limiting public access and road management strategies may also be a necessary part of mitigation plans.

3.0 LITERATURE CITED

Bartmann, R.M., G.C. White, and L.H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monographs 121.

Bureau of Land Management. 2000. Record of Decision: Environmental impact statement for the Pinedale Anticline natural gas field exploration and development project prepared for Pinedale Field Office, Wyoming.

Bureau of Land Management. 2002. Oil and Gas Activity on Public Lands in the United States and Wyoming. USDI-BLM, Wyoming State Office, Cheyenne.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference. Springer, New York, New York, USA.

Czaplewski, R.L., D.M. Crowe, and L.L. McDonald. 1983. Sample sizes and confidence intervals for wildlife population ratios. Wildlife Society Bulletin 11:121-128.

Di Orio, A. P., R. Callas, and R.J. Schaefer. 2003. Performance of two GPS telemetry collars under different habitat conditions. Wildlife Society Bulletin 31:372-379.

Erickson, W.P., T.L. McDonald, K.G. Gerow, S. Howlin, and J.W. Kern. 2001. Statistical Issues in Resource Selection Studies with Radio-Marked Animals. Pages 209-242 in Millspaugh, J.J. and J.M. Marzluff, eds. Radio Tracking and Animal Populations, Academic Press, San Diego.

Freddy, D.J., W.M. Bronaugh, and M.C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14:63-68.

Glenn, E. M., M. C. Hansen, and R. G. Anthony. 2004. Spotted owl home-range and habitat use in young forests of western Oregon. Journal of Wildlife Management 68:33-50.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, New York.

Hobbs, N.T. 1989. Linking energy balance to survival in mule deer: development and test of a simulation model. Wildlife Monographs 101:1-39.

Hosmer, D.W. and S. Lemeshow. 2000. Applied Logistic Regression. Second edition. New York, John Wiley & Sons. USA.

Johnson, B.K., J.W. Kern, M.J. Wisdom, S.L. Findholt, and J.G. Kie. 2000. Resource selection and spatial separation of mule deer and elk during spring. Journal of Wildlife Management 64:685-697.

Kaplan, E.L. and P. Meier. 1985. Nonparametric estimation from incomplete observations.

Journal of American Statistical Association 53:457-581.

Lehmann EL. 1986. Testing Statistical Hypotheses. Second edition. New York: John Wiley & Sons. USA.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS system for mixed models. SAS Institute Inc., Cary, North Carolina, USA.

Lyon, J.L. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81:592-594.

Mackie, R.J., D.F. Pac, K.L. Hamlin, and G.L. Dusek. 1998. Ecology and management of mule deer and white-tailed deer in Montana. Montana Fish Wildlife and Parks. Helena, MT.

Manly, B.F. 2001. Statistics for environmental science and management. Chapman & Hall, Boca Raton, Florida, USA.

Manly, B.F., L. McDonald, D. Thomas, T. McDonald, and W. Erickson. 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies. Second Edition. Kluwer Academic Publishers, Boston, USA.

Marzluff, J. M., J. J. Millspaugh, P. Hurvitz, and M. S. Handcock. 2004. Relating resources to a probabilistic measure of space use: forest fragments and steller's jays. Ecology 85:1411-1427.

McClean, S.A., M.A. Rumble, R.M. King, and W.L. Baker. 1998. Evaluation of resource selection methods with different definitions of availability. Journal of Wildlife Management 62:793-801.

McCullagh, P. and J. A. Nelder. 1989. Generalized linear models. Second edition. Chapman and Hall, Boca Raton, Florida, USA.

Merrill, E.H., T.P. Hemker, K.P. Woodruff, and L.Kuck. 1994. Impacts of mining facilities on fall migration of mule deer. Wildlife Society Bulletin 22:68-73.

Morrison, J.R., W.J. deVergie, A.W. Alldredge, A.E. Byrne, and W.W. Andree. 1995. The effects of ski area expansion on elk. Wildlife Society Bulletin 23:481-489.

Morrison, M.L., W.M. Block, M.D. Strickland, and W.L. Kendall. 2001. Wildlife Study Design. Springer, New York, USA.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. Fourth edition. McGraw-Hill, Boston, Massachusetts, USA.

Otis, D.L. and G.C. White. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. Journal of Wildlife Management 63:1039-1044.

Rost, G.R. and J.A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43:634-641.

Rowland, M.M., M.J. Wisdom, B.K. Johnson, and J.G. Kie. 2000. Elk distribution and modeling in relation to roads. Journal of Wildlife Management 64:672-684.

Samuel, M.D., E.O. Garton, M.W. Schlegel, and R.G. Carson. 1987. Visibility bias during aerial surveys of elk in northcentral Idaho. Journal of Wildlife Management 51:622-630.

SAS Institute, Inc. 2000. SAS/STAT Users Guide, Cary, N.C.: SAS Institute.

Sawyer, H. and F. Lindzey. 2001. The Sublette Mule Deer Study. Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY.

Sawyer, H., R. Nielson, L. McDonald, and D. Strickland. 2004. 2004 Annual Report. Sublette Mule Deer Study (Phase II): Long-term monitoring plan to assess potential impacts of energy development on mule deer in the Pinedale Anticline Project Area. Western Ecosystems Technology, Inc. Cheyenne, WY.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. Second edition. Charles Griffin & Co. Ltd. London, U.K.

Seber, G.A.F. 1984. Multivariate observations. John Wiley and Sons, New York, New York, USA.

Taylor, A.R. and R. L. Knight. 2003. Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13:951-963.

Thomas, T. and L. Irby. 1990. Habitat use and movement patterns by migrating mule deer in southeastern Idaho. Northwest Science 64:19-27.

Thompson, S. K. 1992. Sampling. John Wiley and Sons, New York, New York, USA.

Thompson, W.L., G.C. White, and C. Gowan. 1998. Monitoring Vertebrate Populations. Academic Press, San Diego, California, USA.

Unsworth, J.W., D.F. Pac, G.C. White, R.M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63(1):315-326.

USGS. 1999. 30 meter National Elevation Dataset (tiled for Wyoming): U.S. Geological Survey EROS Data Center, Sioux Falls, SD.

White, G.C., R.A. Garrott, R.M. Bartmann, L.H. Carpenter, and A.W. Alldredge. 1987. Survival of mule deer in northwest Colorado. Journal of Wildlife Management 51:852-859.

White, G.C, A.F. Reeve, F.G. Lindzey, and K.P. Burnham. 1996. Estimation of mule deer winter mortality from age ratios. Journal of Wildlife Management 60:37-44.

White, G.C, and R. E. Bennetts. 1996. Analysis of frequency count data using the negative binomial distribution. Ecology 77:2549–2557.

White, G.C. 2000. Modeling Population Dynamics. Pages 84-107 in S. Demarais and P.R. Krausman, editors. Ecology and Management of Large Mammals in North America. Prentice Hall, Upper Saddle River, New Jersey.

Wyoming Game and Fish Department. 2002. Annual Big Game Herd Unit Report. Jackson/Pinedale Region. Wyoming Game and Fish Department, Cheyenne, WY.

Yarmaloy, C., M. Bayer, and V. Geist. 1988. Behavior responses and reproduction of mule deer does following experimental harassment with all-terrain vehicle. Canadian Field Naturalist 102:425-429.