

Colorado Parks and Wildlife
July 1, 2016 – June 30, 2017

WILDLIFE RESEARCH REPORT

State of _____	Colorado	: Parks and Wildlife
Cost Center _____	3430	: Mammals Research
Work Package _____	3001	: Deer Conservation
Task No. _____	6	: Population Performance of Piceance Basin Mule Deer in Response to Natural Gas Resource Extraction and Mitigation Efforts to Address Human Activity and Habitat Degradation

Federal Aid Project: _____ W-243-R2 _____ :

Period Covered: July 1, 2016 – June 30, 2017

Author: C. R. Anderson, Jr.

Personnel: E. Bergman, E. Cardenas, D. Collins, B. deVergie, D. Finley, M. Fisher, L. Gepfert, J. Hudson, D. Johnston, T. Knowles, D. Lewis, T. Mullins, J. Pelham, B. Petch, J. Rivale, R. Schilowsky, G. Smith, R. Velarde, T. Verzuh, S. Williams, L. Wolfe, CPW; E. Hollowed, L. Belmonte, BLM; T. Graham, Ranch Advisory Partners; P. Doherty, J. Northrup, M. Peterson, G. Wittmyer, K. Wilson, Colorado State University; R. Swisher, S. Swisher, Quicksilver Air, Inc.; B. Mallow, Kiwi Air, Inc.; L. Coulter, Coulter Aviation. Project support received from Federal Aid in Wildlife Restoration, Colorado Mule Deer Association, Colorado Mule Deer Foundation, Muley Fanatic Foundation, Colorado State Severance Tax Fund, EnCana Corp., ExxonMobil Production Co./XTO Energy, Marathon Oil Corp., Shell Petroleum, and WPX Energy.

All information in this report is preliminary and subject to further evaluation. Information MAY NOT BE PUBLISHED OR QUOTED without permission of the authors. Manipulation of these data beyond that contained in this report is discouraged.

ABSTRACT

We propose to experimentally evaluate winter range habitat treatments and human-activity management alternatives intended to enhance mule deer (*Odocoileus hemionus*) populations exposed to energy-development activities. The Piceance Basin of northwestern Colorado was selected as the project area due to ongoing natural gas development in one of the most extensive and important mule deer winter and transition range areas in Colorado. The data presented here represent the first 9 years of data (5 years of pretreatment, 4 years post treatment) of a long-term study addressing habitat improvements and evaluation of energy development practices intended to improve mule deer fitness in areas exposed to extensive energy development. We monitored deer on 4 winter range study areas representing varying levels of development to serve as treatment (North Magnolia, South Magnolia) and control (North Ridge, Ryan Gulch) sites. We recorded habitat use and movement patterns, estimated neonatal, overwinter fawn and annual adult female survival, estimated early and late winter body condition of adult females, and estimated late winter annual abundance/density. During this research segment, we targeted 240 fawns (60/study area) and 120 does (30/study area) in early December 2016 for VHF and GPS radiocollar attachment, respectively, and adult female body condition assessment. We attempted recapture of 120 does (30/study area) and 40 fawns (20 in 2 study areas) in March 2017 for late winter body condition assessment. Winter range habitat improvements completed spring 2013 resulted in 604 acres of

mechanically treated pinion-juniper/mountain shrub habitats in each of the 2 treatment areas with relatively minor and extensive energy development, respectively. Post-treatment monitoring will continue for another year to provide sufficient time to measure how vegetation and deer respond to these changes. Based on data collected through year 9 of this 10-year project: (1) annual adult female survival was consistent among areas averaging 79-87% annually, but overwinter fawn survival was variable, ranging from 31% to 95% within study areas, with annual and study area differences primarily due to early winter fawn condition, annual weather conditions, and winter conditions potentially enhancing predation success; (2) migratory mule deer selected for areas with increased cover and increased their rate of travel through developed areas, and avoided negative influences through behavioral shifts in timing and rate of migration, but did not avoid development structures; (3) mule deer body condition early and late winter was generally consistent within areas, with higher variability among study areas early winter, primarily due to December lactation rates, and late winter condition related to seasonal moisture and winter severity; (4) mule deer exhibited behavioral plasticity in relation to energy development, where disturbance distance varied relative to diurnal extent and magnitude of development activity, which may provide for several options in future development planning; (5) late winter mule deer densities have consistently increased in 3 of 4 study areas, averaging about +6% annually, with the North Ridge study area exhibiting erratic population changes that may be an artifact of periodic migration behavior prior to survey timing; and (6) post treatment vegetation responses have provided evidence of improved forage conditions, but longer term monitoring will be required to address the full potential of habitat mitigation efforts. Detailed habitat use analyses are still pending for the pre and post-treatment periods. We will continue to collect population and habitat use data across all study sites to evaluate the effectiveness of habitat improvements on winter range. This approach will allow us to determine whether it is possible to effectively mitigate development disturbances in highly developed areas, or whether it is better to allocate mitigation efforts toward less or non-impacted areas. In collaboration with Colorado State University, we monitored neonate survival in relation to energy development on all study areas since 2012. This will allow us to include neonatal and parturition data with other demographic parameters to evaluate mule deer/energy development interactions. This study is slated to continue through 2018 to allow sufficient time for measuring mule deer population responses to landscape level manipulations.

**WILDLIFE RESEARCH
REPORT**

**POPULATION PERFORMANCE OF PICEANCE BASIN MULE DEER IN RESPONSE
TO NATURAL GAS RESOURCE EXTRACTION AND MITIGATION EFFORTS TO
ADDRESS HUMAN ACTIVITY AND HABITAT DEGRADATION**

CHARLES R. ANDERSON, JR

PROJECT NARRATIVE

OBJECTIVES

1. To determine experimentally whether enhancing mule deer habitat conditions on winter range elicits behavioral responses, improves body condition, increases fawn survival, and ultimately, population density on mule deer winter ranges exposed to extensive energy development.
2. To determine experimentally to what extent modification of energy development practices enhance habitat selection, body condition, fawn survival, and winter range mule deer densities.

SEGMENT OBJECTIVES

1. Collect and reattach GPS collars to maintain sample sizes for addressing mule deer habitat use and behavioral patterns in 4 study areas experiencing varying levels of energy development of the Piceance Basin, northwest Colorado.
2. Estimate early and late winter body condition of adult female mule deer in each of the 4 winter herd segments using ultrasound techniques. Estimate early and late winter fawn weights in areas with and without habitat treatments to assess winter fawn condition relative to habitat improvements.
3. Monitor over-winter fawn and annual adult female mule deer survival by daily ground tracking and bi-weekly aerial tracking.
4. Conduct Mark-Resight helicopter surveys to estimate late winter mule deer abundance and density in each study area.
5. Monitor habitat treatment response for assessing efficacy of habitat improvement projects to mitigate energy development disturbances to mule deer.
6. Continue neonate survival and adult female parturition evaluations to complete demographic parameters for assessing mule deer/energy development interactions.

INTRODUCTION

Extraction of natural gas from areas throughout western Colorado has raised concerns among many public stakeholders and Colorado Parks and Wildlife (CPW) that the cumulative impacts associated with this intense industrialization will dramatically and negatively affect the wildlife resources of the region. Concern is especially high for mule deer due to their recreational and economic importance as a principal game species and their ecological importance as one of the

primary herbivores of the Colorado Plateau Ecoregion. Extraction of natural gas will directly affect the potential suitability of the landscape used by mule deer through conversion of native habitat vegetation with drill pads, roads, or introduction of noxious weeds, by fragmenting habitat with drill pads and roads, by increasing noise levels via compressor stations and vehicle traffic, and by increasing the year-round presence of human activities. Extraction will indirectly affect deer by increasing the human work-force population of the region resulting in the need for additional landscape conversion for human housing, supporting businesses, and upgraded road/transportation infrastructure. Additionally, increased traffic on rural roads will raise the potential for vehicle-animal collisions. Thus, research documenting these relationships and evaluating the most effective strategies for minimizing and mitigating these activities will greatly enhance future management efforts to sustain mule deer populations for future recreational and ecological values.

The Piceance Basin in northwest Colorado contains one of the largest migratory mule deer populations in North America and also covers some of the largest natural gas reserves in North America. Projected energy development throughout northwest Colorado within the next 20 years is expected to reach about 15,000 wells, many of which will occur in the Piceance Basin, which currently supports over 250 active gas well pads (<http://cogcc.state.co.us>; Fig. 1). Anderson and Freddy (2008) in their long-term research proposal identified 6 primary study objectives to assess measures to offset impacts of energy extraction on mule deer population performance. During the first 5 years of this study, we gathered baseline habitat utilization and demographic data from radiocollared deer across the Piceance Basin to allow assessment of habitat mitigation approaches that were completed April 2013. We are currently monitoring 2 control areas: 1 with development (0.6 pads & facilities/km²; Ryan Gulch) and 1 without (North Ridge). The control areas will be compared with 2 treatment areas experiencing similar development intensities (South Magnolia, 0.9 well pads & facilities/km² and North Magnolia, 0.1 well pads & facilities/km²), that also received habitat improvements from 2011–2013 (604 acres each). Habitat and mule deer responses to mechanical habitat treatments will be evaluated until 2018 to assess the success of this habitat mitigation strategy to benefit mule deer exposed to energy development disturbance. In addition, mule deer behavioral patterns in relation to energy development activities in the area are being monitored to identify effective Best Management Practices (BMPs) for future energy development planning. This progress report describes the previous 9.5 years (Jan 2008–June 2017) of mule deer population performance during the pretreatment phase on 4 winter range herd segments, which includes monitoring habitat selection and behavior patterns of adult female mule deer; spring/summer neonate, overwinter fawn and annual adult female survival; estimates of adult female body condition and fawn weights during early and late winter; and annual late-winter abundance/density estimates.

STUDY AREAS

The Piceance Basin, located between the cities of Rangely, Meeker, and Rifle in northwest Colorado, was selected as the project area due to its ecological importance as home to one of the largest migratory mule deer populations in North America and because it exhibits one of the highest natural gas reserves in North America (Fig. 1). Historically, mule deer numbers on winter range were estimated between 20,000–30,000 (White and Lubow 2002), and the current number of well pads (Fig.1) and projected number of gas wells in the Piceance Basin over the next 20 years is about 250 and 15,000, respectively. Mule deer winter range in the Piceance Basin is predominantly characterized as a topographically diverse pinion pine (*Pinus edulis*)-Utah juniper (*Juniperus osteosperma*; pinion-juniper) shrubland complex ranging from 1,675 m to 2,285 m in elevation (Bartmann and Steinert 1981). Pinion-juniper are the dominant overstory species and major shrub species include Utah serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), Gamble's oak (*Quercus gambelii*), mountain snowberry (*Symphoricarpos oreophilus*), and rabbitbrush (*Chrysothamnus* spp.; Bartmann et al. 1992). The Piceance Basin is segmented by numerous drainages characterized by stands of big

sagebrush, saltbush (*Atriplex* spp.), and black greasewood (*Sarcobatus vermiculatus*), with the majority of the primary drainages having been converted to mixed-grass hay fields. Grasses and forbs common to the area consist of wheatgrass (*Agropyron* spp.), blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*), Indian rice grass (*Oryzopsis hymenoides*), arrowleaf balsamroot (*Balsamorhiza sagittata*), broom snakeweed (*Gutierrezia sarothrae*), pinnate tansymustard (*Descurainia pinnata*), milkvetch (*Astragalus* spp.), Lewis flax (*Linum lewisii*), evening primrose (*Oenothera* spp.), skyrocket gilia (*Gilia aggregata*), buckwheat (*Erigonum* spp.), Indian paintbrush (*Castilleja* spp.), and penstemon (*Penstemon* spp.; Gibbs 1978). The climate of the Piceance Basin is characterized by warm dry summers and cold winters with most of the annual moisture resulting from spring snow melt and brief summer monsoonal rain storms.

Wintering mule deer population segments we are investigating include: North Ridge (53 km²) just north of the Dry Fork of Piceance Creek including the White River in the northeastern portion of the Basin, Ryan Gulch (141 km²) between Ryan Gulch and Dry Gulch in the southwestern portion of the Basin, North Magnolia (79 km²) between the Dry Fork of Piceance Creek and Lee Gulch in the north-central portion of the Basin, and South Magnolia (83 km²) between Lee Gulch and Piceance Creek in the south-central portion of the Basin (Fig. 1). Each of these wintering population segments has received varying levels of natural gas development: no development in North Ridge, light development in North Magnolia (0.1 pads & facilities/km²), and relatively high development in the Ryan Gulch (0.6 pads & facilities/km²) and South Magnolia (0.9 pads & facilities/km²) segments (Fig. 1). Development activity was high through 2011 and has declined substantially since natural gas prices began to decline in 2012. Among the 4 study areas, North Ridge has served as an unmanipulated control site, Ryan Gulch will serve to address human-activity management alternatives (BMPs) that benefit mule deer exposed to energy development and as a developed control area for comparison to the developed treatment area receiving habitat improvements (South Magnolia), and North and South Magnolia will allow us to assess the utility of habitat treatments intended to enhance mule deer population performance in areas exposed to light (North Magnolia) and relatively heavy (South Magnolia) energy development activities.

METHODS

Tasks addressed this period included mule deer capture and collaring, monitoring neonate, overwinter fawn and annual adult female survival, estimating adult female body condition during early and late winter using ultrasonography and winter fawn condition measuring early and late winter fawn weights, estimating mule deer abundance applying helicopter mark-resight surveys, and monitoring vegetation responses to habitat treatments completed spring 2013. We employed helicopter net-gunning techniques (Barrett et al. 1982, van Reenen 1982) to target 240 fawns and 120 adult females during early December 2016, and 120 adult females and 40 fawns (primarily recaptures) during early March 2017. Once netted, all deer were hobbled and blind folded. Fawns were weighed and radio-collared, and sex was recorded prior to release at the capture site. Adult females were transported to localized handling sites for recording body measurements and fitted with GPS collars (5 fix attempts/day; G2110D, Advanced Telemetry Systems, Isanti, MN, USA) prior to release. To provide direct measures of decline in overwinter body condition, we targeted 30 adult females in each study area that were captured the previous December. During March, 20 fawns were recaptured, weighed and released in South Magnolia (within the habitat treatment areas) and Ryan Gulch (control area) to quantify overwinter declines in fawn body condition. Fawn collars were spliced and fitted with rubber surgical tubing to facilitate collar drop between mid-summer and autumn for winter fawns and during winter for neonates, and GPS collars were supplied with timed drop-off mechanisms scheduled to release early April of the year following deployment. All radio-collars were equipped with mortality sensing options (i.e., increased pulse rate following 8 hrs of inactivity).

Mule Deer Habitat Use and Movements

We downloaded and summarized data from GPS collars deployed and recovered since 2008. GPS collars maintained the same schedule of attempting to collect locations every 5 hours, except for 40 does in Ryan Gulch and 10 control deer from North Ridge where location rates were programmed for every 30-60 minutes to increase resolution of movement data for evaluation of deer behavior patterns in relation to differing development activities. Joe Northrup (CSU PhD Candidate) recently analyzed resource selection data relative to energy development (Northrup 2015) and those results are addressed below. Mule deer resource selection analyses to address success of habitat improvements are pending until vegetation responses are fully realized, which will begin by fall 2018.

Mule Deer Survival

Mule deer mortality monitoring consisted of daily ground-telemetry tracking and aerial monitoring approximately every 2 weeks from fixed-wing aircraft on winter range and weekly aerial monitoring on summer range. Once a mortality signal was detected, deer were located and necropsied to assess cause of death (Stonehouse et al., 2016). We estimated weekly survival using the staggered entry Kaplan-Meier procedure (Kaplan and Meier 1958, Pollock et al. 1989). Capture-related mortalities (any doe/fawn mortalities occurring within 10 days of capture; excluding neonates) and collar failures were censored from survival rate estimates. We estimated survival rates from 1 July 2016 through 30 June 2017 for adult females, from birth to mid December for neonates, and from early December 2016–mid June 2017 for winter fawns.

Adult Female Body Measurements

We applied ultrasonography techniques described by Stephenson et al. (1998, 2002) and Cook et al. (2001) to measure maximum subcutaneous rump fat (mm), loin depth (longissimus dorsi muscle, mm), and to estimate % ingesta-free body fat. We estimated a body condition score (BCS) for each deer by palpating the rump (Cook et al. 2001, 2007, 2009). We examined differences ($P < 0.05$) in nutritional status among study areas and between years evident in non-overlapping 95% confidence intervals. We considered differences in body condition meaningful when mean rump fat or % body fat differed statistically between comparisons. Other body measurements recorded included pregnancy status (pregnant, barren) via blood samples, fetal counts using ultrasonography, weight (kg), chest girth (cm), and hind-foot length (cm).

Abundance Estimates

We conducted 4 helicopter mark-resight surveys (2 observers and the pilot) during late March/early April to estimate deer abundance in all 4 study areas. We delineated each study area from GPS locations collected on winter range during the first 3 years of the study (Jan 2008 through April 2011). Two aerial fixed-wing telemetry surveys/study area were conducted during helicopter mark-resight surveys to determine which marked deer were within each survey area, and we confirmed adult female locations during surveys from GPS data acquired April 2017. We delineated flight paths in ArcGIS 10.0 prior to surveys following topographic contours (e.g., drainages, ridges) and approximating 500–600 m spacing throughout each study area; flight paths during surveys were followed using GPS navigation in the helicopter. Two 12 x 12 cm pieces of Ritchey livestock banding material (Ritchey Livestock ID, Brighton, CO USA) were uniquely marked using color, number, and symbol combinations and attached to each radio-collar to enhance mark-resight estimates. Each deer observed during surveys was recorded as mark ID#, unmarked, or unidentified mark.

We used program MARK (White and Burnham 1999), applying the immigration-emigration mixed logit-normal model (McClintock et al. 2008), to estimate mule deer abundance and confidence intervals. For mark-resight model evaluations, we examined parameter combinations of varying detection rates with survey occasion and whether individual sighting probabilities (i.e., individual heterogeneity) were constant or varied ($\sigma^2 = 0$ or $\neq 0$). Model selection procedures followed the information-theoretic approach of Burnham and Anderson (2002).

RESULTS AND DISCUSSION

Deer Captures and Survival

The helicopter crew captured 242 fawns and 121 does during Dec 2016 and 122 does and 41 fawns during March 2017. Sixteen fawn mortalities (6.6%; proximate cause = 5 capture myopathy, 11 predation) occurred within the 10 day censorship period during December and 2 fawn mortalities (4.9%; 1 capture myopathy, 1 predation) occurred during the March capture. Doe mortalities totaled 2 (1.7%; capture myopathy) and 4 (3.3%; capture myopathy) within 10 days of the December and March capture periods, respectively. Mortality rates 10 days post capture have typically varied between 2.5–3.5% for fawns and does since Jan 2008, except during the 2011–2012 capture season where myopathy rates were higher (3–6%) due to dry, warm conditions (Anderson and Bishop 2012). Excluding December fawn captures, myopathy rates were comparable to expected levels when compared to previous years. The relatively high myopathy rates (including ongoing predation that occurred within the 10-day censorship period) for early winter fawn captures were likely linked to the relatively severe winter conditions evident through January 2017, resulting in crusted snow conditions, and unusually high levels of coyote (*Canis latrans*) predation; crusted snow conditions may have enhanced predation by coyotes by enabling them to stay above the snow while fleeing deer were inhibited by breaking through the crust.

Fawn survival estimates from early December 2016 through mid June 2017 were similar (overlapping 95% CIs) among 3 study areas ranging from 0.51 to 0.67, with a lower survival estimate from South Magnolia fawns (0.31; Table 1, Fig. 1). In comparison to previous years, coyote predation was much more common in all areas this winter and the dominant proximate cause of mortality in South Magnolia. This increase in coyote predation may be related to multiple factors including increasing coyote numbers in response to high rabbit densities the past few years following by a recent drop in the rabbit population in combination with crusted snow conditions enhancing coyote predation success on mule deer fawns. General comparisons to previous years suggest relatively low fawn survival this winter, which was comparable to the lower survival rates observed during 2010-11 (Fig. 2). Both low survival winters coincided with harsher weather conditions with an added influence of predation coupled with crusted snow this past winter. Winter fawn survival (Fig. 2) also appears to correlate with summer forage conditions as suggested from relative December fawn weights (Fig. 3).

Annual adult female survival varied from 0.73 (Ryan Gulch) to 0.91 (North Magnolia; Table 1) during 2016–17, but was comparable among study areas during 2016–17 and to previous years ($P > 0.05$), with the exception of lower survival in North Magnolia during 2011–12 ($\hat{S} = 0.68$, Anderson and Bishop 2012). Relatively low sample sizes per study area for adult female survival do not allow statistical discrimination among years unless large differences are evident (e.g., >15 –20%). Estimates below 80% are biologically concerning if these values represent the respective population, but low statistical power precludes confirmation within study areas. When combined among study areas, annual survival estimates have varied from 79% in 2012-13 to 86% in 2014-15 and was 83% this year, which is comparable to the long term average. Lower combined survival estimates are consistent with extreme environmental conditions consisting of dryer moisture conditions during late winter/spring (2012-13) and/or cold temperatures with heavy snow during early winter (2015-16).

Spring Migration Patterns

Collaboration with Idaho State University to address mule deer migration patterns in developed and undeveloped landscapes (funded from energy company contributions) has been completed. Four manuscripts from this effort have been published (Lendrum et al. 2012, Lendrum et al. 2013, Lendrum et al. 2014, Anderson and Bishop 2014; Appendix A).

In addressing habitat selection during spring migration, Lendrum et al. (2012; Fig. 4) noted that mule deer migrating through the most developed landscapes exhibited longer step lengths (straight line distance between GPS locations) and selected habitats providing greater security cover than deer in undeveloped landscapes that migrated through more open areas that provided increased foraging opportunities. Migrating deer also selected areas closer to well pads, but avoided roads, except in the highest developed areas where road densities were likely too high for avoidance without significant deviations from traditional migration routes.

In the second manuscript Lendrum et al. (2013) addressed biological and environmental factors influencing spring migration and assessed how energy development influenced migratory behavior. Overall, spring migration was influenced by snow depth, temperature, and green-up on winter and summer range; increasing temperatures, snow melt and emerging vegetation dictated timing of winter range departure and summer range arrival. Duration of Piceance Basin mule deer migration was short, with median migration durations of 3–8 days among the 4 areas (straight line distance between seasonal ranges averaged 32–40 km). Deer in poor condition migrated later than deer in good condition, but condition was similar among areas regardless of development status (Table 2). Migrating deer from developed study areas did not avoid development structures, but departed later, arrived earlier and migrated more quickly than deer from undeveloped areas. While large changes in timing of migration could have nutritional consequences and negatively influence reproduction and neonate survival, the relatively minor shift we observed should not result in long-term fitness consequences. Migratory deer in the Piceance Basin appear to avoid negative effects of energy development through behavioral shifts in timing and rate of migration.

In the third publication Lendrum et al. (2014), monitored migratory mule deer in the Piceance Basin to examine the relationship between the Normalized Difference Vegetation Index (NDVI), which is a coarse-scale measure of forage quality using a GIS assessment of vegetation greenness, and fecal nitrogen to assess the assumption that forage quality and deer diets can be reasonably linked to address deer habitat use patterns from remotely sensed data. We found that diet quality evident from fecal nitrogen and coarse measures of vegetation green-up were informative, and that Piceance Basin mule deer exhibited rapid migration (3 to 8 days depending on study area), left winter range following snow melt with lowest fecal N and NDVI values, and progressed to summer range as vegetation green-up and nitrogen levels increased, but ahead of peak vegetation green-up on summer range. It is plausible that this rapid migration strategy is evident for deer in relatively good condition and allows for early arrival on summer range to take advantage of optimal forage conditions prior to parturition.

Anderson and Bishop (2014) summarized results from Lendrum et al. (2012, 2013) and Sawyer et al. (2012) addressing migratory mule deer and energy development in northwest Colorado and south-central Wyoming, respectively. The interactions between migratory mule deer and energy development identified by Lendrum et al. (2012, 2013) and Sawyer et al. (2012) suggest mule deer may benefit from energy development planning by considering thresholds of development that may alter migratory behavior. It appears that migration rate, migration routes, and stopover use, if present, may be altered at high development intensities. In addition, migratory mule deer may benefit by maintaining security cover along migration paths, and improved habitat conditions may facilitate more direct and rapid migration requiring less energy to complete migration. Enhancing permeability along migration routes by applying dispersed development plans (<2 well pads/km²) and minimizing

disturbance to vegetation types by maintaining security cover should reduce impacts to migratory mule deer as well as other migratory ungulates. Where feasible, habitat improvement projects on winter range and possibly stopover sites would also enhance migratory mule deer populations by enhancing energy reserves for long-distance movements and parturition shortly after summer range arrival. Where possible, directional drilling could be used to extract energy resources from underneath migration routes while maintaining no or minimal surface occupancy. Lastly, we emphasize that GPS studies now allow managers to accurately map migration routes for entire populations and identify relatively narrow corridors that are most heavily used thus allowing for the identification of the most important corridors for migrating ungulates. Where available, we encourage agencies to incorporate such migration corridors into land-use plans (e.g., resource management plans) and National Environmental Policy Act documents.

Mule Deer Body Condition

Early-winter body condition measurements of adult female mule deer during December 2016 were similar among study areas ($P < 0.05$, Fig. 5, Table 2). Early winter condition this year was moderate to low compared to previous years with notably high condition exhibited from Ryan Gulch does during December 2011 and 2015 (Fig. 5). Adult female body condition during early winter appears primarily related to the proportion of lactating does identified during December captures, where higher condition correlates with lower lactation rates. Since 2011, excluding Ryan Gulch during 2014, North Ridge during 2016 and North Magnolia this year, late winter body condition initially trended upward and appears to be stabilizing recently (Fig. 5, Table 2). The observed increase was likely related to relatively mild winters from 2012 - 2015 and the generally stabilizing condition may be related to more severe conditions during early winter the past 2 years; temperatures increased during mid-winter resulting in snow-melt, which likely improved late winter condition above what might have resulted if severe winter conditions continued. Adult female body condition thus far appears more related to early winter lactation rates, seasonal moisture conditions, relative deer densities (Fig. 6), and winter severity than observed development intensity thus far.

December 2016 fawn weights were generally lower than observed during previous years (about 3.6 kg below average; Fig. 3). December fawn condition has been correlated with winter fawn survival (Fig. 2), which was consistent with the relatively low winter fawn survival observed this past winter.

Because adult female body condition has been largely uninformative in regards to habitat treatment responses (pending further analyses), we began late winter fawn recaptures in South Magnolia (habitat treatment area) and Ryan Gulch (control area) to assess changes in over-winter body condition the past 2 years. Fawns from both areas exhibited significant weight loss ($P < 0.05$) during 2015-16, with fawns from the treatment area exhibiting significantly less weight loss ($P < 0.001$; -3.1 kg) than fawns from the untreated area (-5.6 kg). Results from winter 2016-17 differed in that fawns from both areas exhibited similarly reduced body condition early winter (about 4 kg lighter on average) and maintained their weights into late winter (negligible weight differences from Dec to Mar). These results are conflicting with respect to habitat treatment effects, but will require more detailed analyses to address other factors that may influence nutritional benefits of habitat improvements on winter range. We will continue monitoring over-winter condition of fawns from the treatment and control areas to evaluate over-winter fawn condition in areas with and without habitat improvements.

Mule Deer Behavioral Response to Energy Development

We recently completed evaluations of deer behavior patterns in relation to energy development activities (Northrup et al. 2015, 2016a, 2016b). We found diurnal responses to development activity, where deer used timbered areas away from development activity while bedded during the day and

moved into more open areas generally closer to developed areas while foraging at night. Disturbance distances from producing pads and roads declined from 600 m to 200 m and about 140 m to 60 m from daytime to nighttime, respectively, but increased from 600 m to 800 m for nighttime drilling pad activity. We suspect deer behaviorally respond to fluctuations in development activity, where road traffic and producing well pad activity decline at night, but drilling pad disturbance may increase from compressors and lights used to facilitate nighttime drilling activity. These evaluations were applied during an active drilling phase in the Piceance Basin and deer use was influenced by development activity in 25% (nighttime) to 50% (day time) of critical winter range during that period. However, deer densities have comparably increased among developed and undeveloped study areas (Fig. 6) suggesting that deer can behaviorally mediate development disturbance under observed development and deer densities by taking advantage of fluctuations in development activity to address their nutritional requirements. Given the plasticity in deer behavior, a number of potential options for future development planning exists including drilling schedule modifications (seasonal and/or diurnal), concentrated/staged development, reducing road traffic, and using light/noise barriers around drill rigs. It will be informative to determine if habitat improvements will further reduce development disturbance and increase management options for future development planning.

Neonate Survival

To complete demographic parameters addressing mule deer–energy development interactions, CPW, Colorado State University, and ExxonMobil Production entered into a collaborative agreement to investigate neonate survival and adult female parturition in developed and undeveloped landscapes (funded by ExxonMobil Production Co.) beginning spring 2012. Mark Peterson (Graduate Research Assistant) and Paul Doherty (CSU professor) assisted with this research, which was completed December 2014, and continued by CPW during 2015 and 2016. Neonate capture and collaring efforts totaled 85 during spring 2012, 67 during spring 2013, 54 during spring 2014, 59 during spring 2015, and 58 during spring 2016. Overall, estimated neonate survival through mid-December was 0.39 (95% CI = 0.28–0.50) during 2012, 0.37 (95% CI = 0.25–0.48) during 2013, 0.57 (95% CI = 0.44 – 0.70) during 2014, 0.36 (95% CI = 0.23–0.49) during 2015, and 0.32 (95% CI = 0.19–0.44) during 2016. Through December 2016, predation was the highest proximate mortality factor (averaging about 50% annually), with relatively low incidents of starvation/disease directly influencing spring/summer fawn survival (mean < 4%). Manuscripts addressing neonate fawn survival and adult female parturition in relation to energy development are currently in preparation and review for publication.

Mule Deer Population Estimates

Mark-resight models that best predicted abundance estimates (lowest AIC_c; Burnham and Anderson 2002) exhibited variable sightability across surveys (P_i) for all study areas, and variable individual sightability ($\sigma^2 = 0$) for North Magnolia deer and homogenous sightability ($\sigma^2 \neq 0$) for the other 3 areas. North Ridge exhibited the highest deer density (15.8/km²), with comparable but lower deer densities in the other 3 areas (10.3–11.9/km²; Table 3, Fig. 6). Densities similarly increased over the 9 year monitoring period in 3 of the 4 study areas averaging about 6% annual increases from North Magnolia, South Magnolia and Ryan Gulch. Mule deer density estimates from North Ridge have been erratic with a significant decline this past year (Fig. 6). Biological support for the recent decline is lacking based on similar demographic parameter estimates when compared to the other study areas showing population growth (Tables 1 and 2, Figs. 2, 3 and 5). Reasons for the recent decline in North Ridge are unclear, but lack of closure partially due to early migration has been an issue in the past and may have artificially reduced the population estimate this year. Active GPS collars addressing last year's movement patterns will be collected April 2018 and movement data will be assessed to address the potential closure issue.

Abundance estimates from 2017 were similarly precise from all 4 study areas, but error of estimates was greater (mean CICVs ranged from 0.19 – 0.22) than past surveys (typically ~0.15). Increased error was likely associated with reduced sightability from a different helicopter (Hughes MD 500) used than during previous years (Bell 47). We shifted to the Hughes MD 500 helicopter to increase power and consistently allow for 3 people in the helicopter to assist with deer surveys. The Bell 47 is less powerful and, depending on weather conditions, may only provide for 2 people in the helicopter, but provides for increased visibility. Based on estimate comparisons using the 2 different helicopters, the Bell 47 provides improved population estimates even with the potential limitation of survey personnel and will be used for future surveys.

Magnolia Habitat Treatments

We completed 116 acres of pilot habitat treatments in January 2011 (Anderson and Bishop 2011; Environmental Assessment: DOI-BLM-CO-110-2011-004-EA), 54 acres of mechanical treatment method comparison treatments (hydro-ax, roller-chop, chaining) in January 2012 (Stephens 2014), and 1,038 acres of hydro-ax treatments in April 2013 (Determination of NEPA Adequacy: DOI-BLM-CO-110-2012-0134- DNA), totaling 604 treated acres in each study area (Fig. 7). Vegetation response in the pilot treatment sites was visually evident by fall 2011 (Fig. 7), and resulted in statistically significant ($P < 0.05$) increases in native grass and forb cover by the 2014 growing season. 2016 results are still pending, but shrub responses appear promising from data collected last fall. Stephens (2014) reported that all 3 mechanical treatment methods compared resulted in roughly a 3 fold increase in grasses, forbs, and shrubs combined after 2 growing seasons (versus control sites), but cautioned that rollerchop treatments may be more vulnerable to invasive species response. Vegetative responses from 2013 hydro-ax treatments were visually evident following 1 growing season and shrub responses have been notable since the 4th growing season, but statistical comparisons are still pending. As anticipated, grass and forb responses were evident 2 to 3 years post-treatment, with longer term response expected (3-5 years) for palatable shrubs.

Of note, relatively high moisture conditions experienced during spring 2014 and 2015 resulted in higher than normal prevalence of cheatgrass (*Bromus tectorum*); cheatgrass invasion has previously been minor to non-existent. Cheatgrass invasion, however, does not appear directly related to treatment sites because occurrence is evident in both treatment and control areas. We anticipate this outbreak will subside based on past competitive advantage of native species to dominate, but will continue to monitor species composition and address cheatgrass persistence in treatment and control sites.

GPS data addressing deer use of treatment sites is becoming available and will be analyzed as additional data are collected and vegetation responses progress. We observed improved fawn condition ($P < 0.001$) in South Magnolia following the 4th growing season of habitat treatments when compared to fawn condition in the Ryan Gulch control area. Vegetation and mule deer responses will continue to be documented for the next year to assess the utility of this mitigation approach in benefiting mule deer exposed to energy development disturbance.

SUMMARY AND COLLABORATIONS

The long-term goal of this study is to investigate habitat treatments and energy development practices that enhance mule deer populations exposed to extensive energy development activity. The information presented here summarizes mule deer population parameters from the 4-year pre-treatment period and 5 years post-treatment. The pretreatment period was completed by spring 2013, providing baseline data for comparison with intended improvements in habitat conditions and response to varying degrees in human development activity. Winter range habitat improvements resulting in 604 acres of mechanically treated pinion-juniper/mountain shrub habitats in each of 2

study areas were completed by April of 2013, and subsequent vegetation responses have met or exceeded expectations. Post-treatment monitoring will continue for another year to provide sufficient time to measure how deer respond to these changes. Based on data collected through year 9 of this 10-year project: (1) annual adult female survival was consistent among areas averaging 79-87% annually, but overwinter fawn survival was variable, ranging from 31% to 95% within study areas, with annual and study area differences primarily due to early winter fawn condition, annual weather conditions, and winter conditions potentially enhancing predation success; (2) migratory mule deer selected for areas with increased cover and increased their rate of travel through developed areas, and avoided negative influences through behavioral shifts in timing and rate of migration, but did not avoid development structures; (3) mule deer body condition early and late winter was generally consistent within areas, with higher variability among study areas early winter, primarily due to December lactation rates, and late winter condition related to seasonal moisture and winter severity; (4) mule deer exhibited behavioral plasticity in relation to energy development, where disturbance distance varied relative to diurnal extent and magnitude of development activity, which may provide for several options in future development planning; and (5) late winter mule deer densities have consistently increased in 3 of 4 study areas, averaging about +6% annually, with the North Ridge study area exhibiting erratic population changes that may be an artifact of periodic migration behavior prior to survey timing. Detailed habitat use analyses are pending for the pre and post-habitat treatment periods. We will continue to collect the various population and habitat use data across study sites to evaluate the effectiveness of habitat improvements on winter range. This approach will allow us to determine whether it is possible to effectively mitigate development impacts in highly developed areas, or whether it is better to allocate mitigation dollars toward less or non-impacted areas. In a previous project conducted on the Uncomphahgre Plateau, Colorado, Bergman et al. (2014) found that habitat treatments implemented in pinion-juniper habitat in undeveloped areas increased overwinter survival of fawns by a magnitude of 1.15.

Hay field improvements have been completed in the North Magnolia study area by WPX Energy to fulfill a Wildlife Management Plan (WMP) agreement with CPW; elk (*Cervus elaphus*) response has been evident, but mule deer response has thus far been minor. A similar WMP agreement between ExxonMobil/XTO Energy and CPW allowed completion and continued monitoring of mechanical habitat improvements in the Magnolia study areas. Collaborative research with agency biologists, graduate students, and university professors has produced 15 scientific publications addressing improved monitoring techniques for neonate mule deer captures (Bishop et al. 2011), approaches to address proximate mortality factors from field necropsies of mule deer (Stonehouse et al. 2016), mule deer migration (Lendrum et al. 2012, 2013, 2014; Anderson and Bishop 2014), improved approaches to address animal habitat use patterns (Northrup et al. 2013), mule deer response to helicopter capture and handling (Northrup et al. 2014a), potential effects of male-biased harvest on mule deer productivity (Freeman et al. 2014), mule deer genetics in relation to body condition and migration (Northrup et al. 2014b), spatial and temporal factors influencing auditory vigilance in mule deer (Lynch et al. 2014), the relationship of plant phenology with mule deer body condition (Seral et al. 2015), and mule deer responses to differing energy development activities to inform future development planning (Northrup et al. 2015, Northrup et al. 2016a, Northrup et al. 2016b); these publications are summarized in Appendix A. Ongoing cooperative agreements will be necessary to sustain this project to completion (through 2018). We anticipate the opportunity to work cooperatively toward developing solutions for allowing the nation's energy reserves to be developed in a manner that benefits wildlife and the people who value both the wildlife and energy resources of Colorado.

LITERATURE CITED

- Anderson, C. R., Jr., and D. J. Freddy. 2008. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Final Study Plan, Colorado Division of Wildlife, Ft. Collins, CO, USA.
- Anderson, C. R., Jr., and C. J. Bishop. 2011. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Job Progress Report, Colorado Division of Wildlife, Ft. Collins, CO, USA.
- Anderson, C. R., Jr., and C. J. Bishop. 2012. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Job Progress Report, Colorado Parks and Wildlife, Ft. Collins, CO, USA.
- Anderson, C. R., Jr., and C. J. Bishop. 2014. Migration patterns of adult female mule deer in response to energy development. Pages 47-50 in *Transactions of the 79th North American Wildlife & Natural Resources Conference* (R. A. Coon & M. C. Dunfee, eds.). Wildlife Management Institute, Gardners, PA, USA. ISSN 0078-1355.
- Bartmann, R. M. 1975. Piceance deer study—population density and structure. Job Progress Report, Colorado Division of Wildlife, Fort Collins, Colorado, USA.
- Bartmann, R. B., and S. F. Steinert. 1981. Distribution and movements of mule deer in the White River Drainage, Colorado. Special Report No. 51, Colorado Division of Wildlife, Fort Collins, Colorado, USA.
- Bartmann, R. M., G. C. White, and L. H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. *Wildlife Monograph* No. 121.
- Barrett, M. W., J. W. Nolan, and L. D. Roy. 1982. Evaluation of a hand-held net-gun to capture large mammals. *Wildlife Society Bulletin* 10:108-114.
- Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty, Jr. 2014. Habitat management influences over-winter survival of mule deer fawns in Colorado. *Journal of Wildlife Management* 78(3):448–455; DOI: 10.1002/jwmg.683
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.
- Cook, R. C., J. G. Cook, D. L. Murray, P. Zager, B. K. Johnson, and M. W. Gratson. 2001. Development of predictive models of nutritional condition for rocky mountain elk. *Journal of Wildlife Management* 65:973-987.
- Cook, R. C., T. R. Stephenson, W. L. Meyers, J. G. Cook, and L. A. Shipley. 2007. Validating predictive models of nutritional condition for mule deer. *Journal of Wildlife Management* 71:1934-1943.
- Cook, R. C., J. G. Cook, T. R. Stephenson, W. L. Meyers, S. M. McCorquodale, D. J. Vales, L. L. Irwin, P. Briggs Hall, R. D. Spencer, S. L. Murphie, K. A. Schoenecker, P. J. Miller. 2009. Revisions of rump fat and body scoring indices for deer, elk, and moose. *Journal of Wildlife Management* 74:880-896.
- Freeman, E. D., R. T. Larsen, M. E. Peterson, C. R. Anderson, Jr., K. R. Hersey, and B. R. McMillan. 2014. Effects of male-biased harvest on mule deer: implications for rates of pregnancy, synchrony, and timing of parturition. *Wildlife Society Bulletin*; DOI: 10.1002/wsb.450
- Gibbs, H. D. 1978. Nutritional quality of mule deer foods, Piceance Basin, Colorado. Thesis, Colorado State University, Fort Collins, Colorado, USA.
- Kaplan, E. L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. *Journal of the American Statistical Association* 52:457-481.

- Lendrum, P. E., C. R. Anderson, Jr., R. A. Long, J. K. Kie, and R. T. Bowyer. 2012. Habitat selection by mule deer during migration: effects of landscape structure and natural gas development. *Ecosphere* 3(9):82. <http://dx.doi.org/10.1890/1053-0703-2012-00000>.
- Lendrum, P. E., C. R. Anderson, Jr., K. L. Monteith, J. A. Jenks, and R. T. Bowyer. 2013. Migrating Mule Deer: Effects of Anthropogenically Altered Landscapes. *PLoS ONE* 8(5): e64548. doi:10.1371/journal.pone.0064548
- Lendrum, P. E., C. R. Anderson, Jr., K. L. Monteith, J. A. Jenks, and R. T. Bowyer. 2014. Relating the movement of a rapidly migrating ungulate to spatiotemporal patterns of forage quality. *Mammalian Biology*: <http://dx.doi.org/10.1016/j.mambio.2014.05.005>
- Lynch, E., J. M. Northrup, M. F. McKenna, C. R. Anderson Jr., L. Angeloni, and G. Wittemyer. 2014. Landscape and anthropogenic features influence the use of auditory vigilance by mule deer. *Behavioral Ecology*; doi:10.1093/beheco/aru158.
- McClintock, B. T., G. C. White, K. P. Burnham, and M. A. Pride. 2008. A generalized mixed effects model of abundance for mark—resight data when sampling is without replacement. Pages 271- 289 in D. L. Thompson, E. G. Cooch, and M. J. Conroy, editors, *Modeling demographic processes in marked populations*. Springer, New York, New York, USA.
- Northrup, J. M. 2015. Behavioral response of mule deer to natural gas development in the Piceance Basin. Dissertation, Colorado State University, Fort Collins, USA.
- Northrup, J. M., M. B. Hooten, C. R. Anderson, Jr., and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use–availability design. *Ecology* 94(7):1456-1463.
- Northrup, J. M., C. R. Anderson, Jr., and G. Wittemyer. 2014a. Effects of helicopter capture and handling on movement behavior of mule deer. *Journal of Wildlife Management* 78(4):731-738; DOI: 10.1002/jwmg.705
- Northrup, J. M., A. B. Shafer, C. R. Anderson Jr., D. W. Coltman, and G. Wittemyer. 2014b. Fine-scale genetic correlates to condition and migration in a wild cervid. *Evolutionary Applications* ISSN 1752-4571; doi: 10.1111/eva.12189
- Northrup, J. M., C. R. Anderson, Jr., and G. Wittemyer. 2015. Quantifying spatial habitat loss from hydrocarbon development through assessing habitat selection patterns of mule deer. *Global Change Biology*, doi: 10.1111/gcb.13037.
- Northrup, J. M., C. R. Anderson, Jr., M. B. Hooten, and G. Wittemyer. 2016a. Movement reveals scale dependence in habitat selection of a large ungulate. *Ecological Applications* 26:2746-2757
- Northrup, J. M., C. R. Anderson, Jr., and G. Wittemyer. 2016b. Environmental dynamics and anthropogenic development alter philopatry and space-use in a North American cervid. *Diversity and Distributions* 22: 547-557, DOI: 10.1111/ddi.12417
- Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. C. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53:7-15.
- Sawyer, H., M. J. Kauffman, A. D. Middleton, T. A. Morrison, R. M. Nielson, and T. B. Wycoff. 2012. A framework for understanding semi-permeable barrier effects on migratory ungulates. *Journal of Applied Ecology* 50:68-78.
- Searle, K. R., M. B. Rice, C. R. Anderson, C. Bishop and N. T. Hobbs. 2015. Asynchronous vegetation phenology enhances winter body condition of a large mobile herbivore. *Oecologia* ISSN 0029- 8549; DOI 10.1007/s00442-015-3348-9
- Stephens, G. J. 2014. Understorey responses to mechanical removal of pinyon-juniper overstorey. MS Thesis, Colorado State University, Ft. Collins USA.
- Stephenson, T. R., V. C. Bleich, B. M. Pierce, and G. P. Mulcahy. 2002. Validation of mule deer body composition using in vivo and post-mortem indices of nutritional condition. *Wildlife Society Bulletin* 30:557-564.
- Stephenson, T. R., K. J. Hundertmark, C. C. Swartz, and V. Van Ballenberghe. 1998. Predicting body fat and mass in moose with ultrasonography. *Canadian Journal of Zoology* 76:717-722.

- Stonehouse, K. F., C. R. Anderson Jr., M. E. Peterson, and D. R. Collins. 2016. Approaches to field investigations of cause-specific mortality in mule deer (*Odocoileus hemionus*). Colorado Parks and Wildlife Technical Report No. 48, First Edition, 317 W. Prospect Rd., Ft. Collins, CO USA. DOW-R-T-48-16, ISSN 0084-8883.
- Unsworth, J. W., D. F. Pack, G. C. White, and R. M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. *Journal of Wildlife Management* 63:315-326.
- Van Reenen, G. 1982. Field experience in the capture of red deer by helicopter in New Zealand with reference to post-capture sequela and management. Pages 408-421 *in* L. Nielsen, J. C. Haigh, and M. E. Fowler, editors. *Chemical immobilization of North American wildlife*. Wisconsin Humane Society, Milwaukee, USA.
- White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked individuals. *Bird Study* 46:120-139.
- White, G. C., and B. C. Lubow. 2002. Fitting population models to multiple sources of observed data. *Journal of Wildlife Management* 66:300-309.

Prepared by _____
Charles R. Anderson, Jr., Mammals Research Leader

Table 1. Survival rate estimates (\hat{S}) of fawn (1 Dec. 2016–15 June 2017) and adult female (1 July 2016–30 June 2017) mule deer from 4 winter range study areas of the Piceance Basin in northwest Colorado.

Cohort			
Study area	Initial sample size (n)	March doe sample ^a (n)	\hat{S} (95% CI)
Fawns			
Ryan Gulch	61		0.506 (0.381–0.632)
South Magnolia	53		0.312 (0.183–0.441)
North Magnolia	54		0.655 (0.525–0.785)
North Ridge	60		0.665 (0.546–0.785)
Adult females			
Ryan Gulch	28	50	0.726 (0.570–0.882)
South Magnolia	23	46	0.849 (0.720–0.997)
North Magnolia	29	57	0.914 (0.829–0.999)
North Ridge	19	47	0.845 (0.721–0.968)

^aAdult female sample sizes following capture and radio-collaring efforts March, 2017.

Table 2. Mean rump fat (mm), Body Condition Score (BCS^a), and % ingesta-free body fat (% fat) of adult female mule deer from 4 study areas in the Piceance Basin of northwest Colorado, March and December, 2009–2017. Values in parentheses = SD.

Study Area	March 2009			December 2009			March 2010		
	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	1.73 (1.78)	2.66 (0.55)	7.08 (1.27)	8.35 (6.36)	4.06 (1.13)	10.54 (3.72)	2.31 (1.44)	2.35 (0.48)	6.37 (1.41)
South Magnolia	1.29 (0.47)	2.51 (0.66)	6.74 (2.27)	10.05 (6.19)	4.07 (1.21)	11.44 (3.50)	3.12 (2.20)	2.64 (0.59)	7.11 (1.69)
North Magnolia	1.31 (1.01)	2.66 (0.68)	7.15 (1.63)	10.67 (5.76)	4.25 (0.96)	11.94 (3.39)	3.15 (2.34)	2.85 (0.53)	7.54 (1.53)
North Ridge	1.57 (1.22)	2.60 (0.56)	6.81 (1.68)	5.25 (5.65)	3.63 (1.11)	9.37 (3.08)	1.77 (1.11)	2.42 (0.49)	6.39 (1.45)

Table 2. Continued.

Study Area	December 2010			March 2011			December 2011		
	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	7.26 (6.36)	3.24 (0.96)	9.69 (3.56)	1.55 (0.60)	2.53 (0.42)	6.72 (1.37)	13.41 (6.39)	4.21 (1.17)	13.17 (3.64)
South Magnolia	9.85 (6.78)	3.30 (0.61)	11.27 (3.75)	1.65 (0.75)	2.35 (0.50)	6.15 (1.75)	8.18 (5.45)	3.41 (0.82)	10.34 (3.28)
North Magnolia	9.55 (6.49)	3.46 (1.16)	10.79 (4.26)	1.65 (0.67)	2.53 (0.49)	6.79 (1.47)	8.76 (5.77)	3.74 (0.91)	10.73 (3.14)
North Ridge	7.25 (5.41)	3.47 (0.86)	9.85 (3.02)	1.45 (0.76)	2.24 (0.49)	6.30 (1.65)	8.86 (5.37)	3.51 (0.99)	10.77 (3.33)

Table 2. Continued.

Study Area	March 2012			December 2012			March 2013		
	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	2.15 (1.44)	2.74 (0.44)	7.22 (1.16)	6.34 (4.35)	3.30 (0.77)	9.34 (2.43)	1.87 (0.90)	2.65 (0.37)	7.14 (0.89)
South Magnolia	1.66 (0.77)	2.59 (0.36)	7.03 (1.13)	8.30 (5.71)	3.46 (1.07)	10.32 (3.23)	2.06 (0.77)	2.65 (0.26)	7.19 (0.66)
North Magnolia	1.90 (0.76)	2.84 (0.34)	7.61 (0.96)	9.66 (6.41)	3.84 (1.16)	11.18 (3.64)	1.76 (0.91)	2.59 (0.41)	6.87 (1.11)
North Ridge	2.24 (1.58)	2.70 (0.35)	7.26 (1.05)	5.76 (4.10)	3.32 (0.82)	9.06 (2.31)	1.87 (0.73)	2.48 (0.34)	6.70 (1.12)

Table 2. Continued.

Study Area	December 2013			March 2014			December 2014		
	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	9.27 (6.29)	3.47 (0.87)	10.61 (3.76)	1.69 (0.85)	2.68 (0.39)	7.03 (0.99)	8.50 (6.76)	3.69 (1.03)	10.56 (3.70)
South Magnolia	11.27 (8.40)	3.99 (1.04)	11.40 (4.16)	2.57 (1.61)	2.96 (0.30)	7.75 (0.68)	10.96 (6.82)	4.08 (1.06)	11.98 (3.81)
North Magnolia	9.00 (6.15)	3.44 (0.78)	10.48 (3.25)	2.33 (2.12)	2.80 (0.49)	7.31 (1.43)	9.52 (5.83)	3.83 (1.04)	11.18 (3.32)
North Ridge	11.17 (5.28)	3.85 (0.72)	11.66 (2.69)	2.38 (1.52)	2.68 (0.39)	7.16 (1.14)	7.93 (5.50)	3.74 (0.76)	10.20 (3.01)

Table 2. Continued.

Study Area	March 2015			December 2015			March 2016		
	Rump fat	BCS	% fat	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	2.62 (0.95)	2.89 (0.40)	7.44 (0.53)	12.80 (6.83)	4.24 (0.88)	12.89 (3.72)	2.29 (0.64)	2.81 (0.37)	7.29 (0.52)
South Magnolia	2.66 (1.36)	2.97 (0.55)	7.62 (0.74)	6.93 (4.83)	3.83 (0.89)	9.83 (2.69)	2.07 (1.39)	2.78 (0.39)	7.46 (0.93)
North Magnolia	2.25 (0.97)	2.90 (0.42)	7.49 (0.90)	8.79 (6.01)	3.79 (0.85)	10.81 (3.54)	2.43 (1.01)	2.71 (0.39)	7.17 (0.87)
North Ridge	2.28 (1.37)	2.92 (0.46)	7.43 (1.05)	5.47 (5.49)	3.25 (0.66)	9.35 (2.75)	1.58 (0.70)	2.51 (0.41)	6.73 (1.26)

Table 2. Continued.

Study Area	December 2016			March 2017		
	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	8.20 (4.90)	3.94 (0.97)	10.46 (2.70)	2.39 (0.74)	2.49 (0.38)	6.78 (0.97)
South Magnolia	6.27 (4.62)	3.54 (0.88)	9.37 (2.53)	2.48 (0.77)	2.57 (0.35)	7.09 (0.63)
North Magnolia	7.90 (5.52)	3.86 (1.01)	10.34 (3.14)	1.82 (0.72)	2.53 (0.27)	7.05 (0.58)
North Ridge	7.74 (5.48)	3.85 (0.95)	10.01 (3.09)	2.30 (1.61)	2.74 (0.45)	7.23 (1.21)

^aBody condition score taken from palpations of the rump following Cook et al. (2009).

Table 3. Mark-resight abundance (N) and density estimates of mule deer from 4 winter range herd segments in the Piceance Basin, northwest Colorado, 27 March–4 April 2017. Data represent 4 helicopter resight surveys from all 4 study areas.

Study area	Mean No. sighted	Mean No. marked	N (95% CI)	Density (deer/km ²)
Ryan Gulch	284	16	1,446 (1,184–1,792)	10.3
South Magnolia	171	14	991 (803–1,246)	11.9
North Magnolia	188	18	904 (757–1,098)	11.4
North Ridge	182	15	840 (695–1,040)	15.8

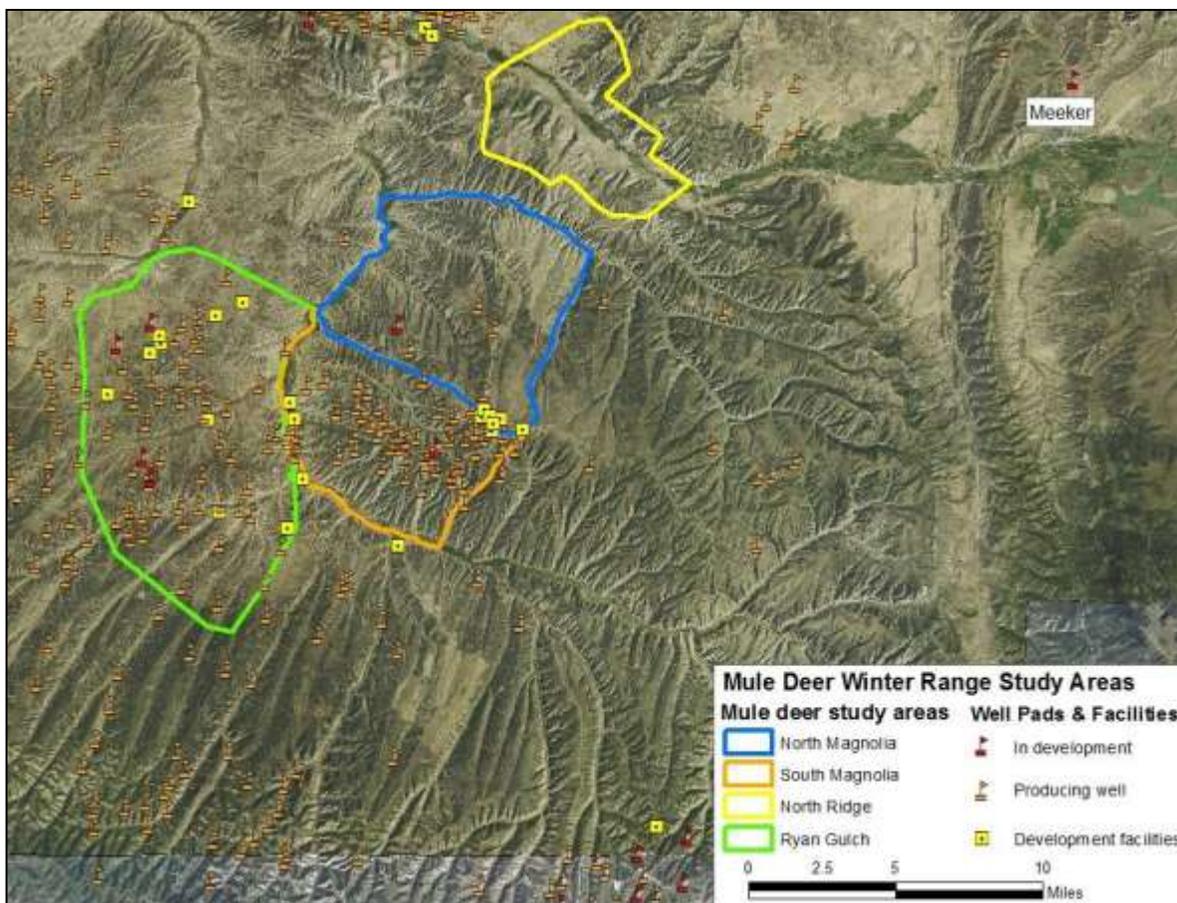


Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, winter 2013/14 (Accessed <http://cogcc.state.co.us/> Dec. 31, 2013). Development activity has subsided with no additional drilling since 2013.

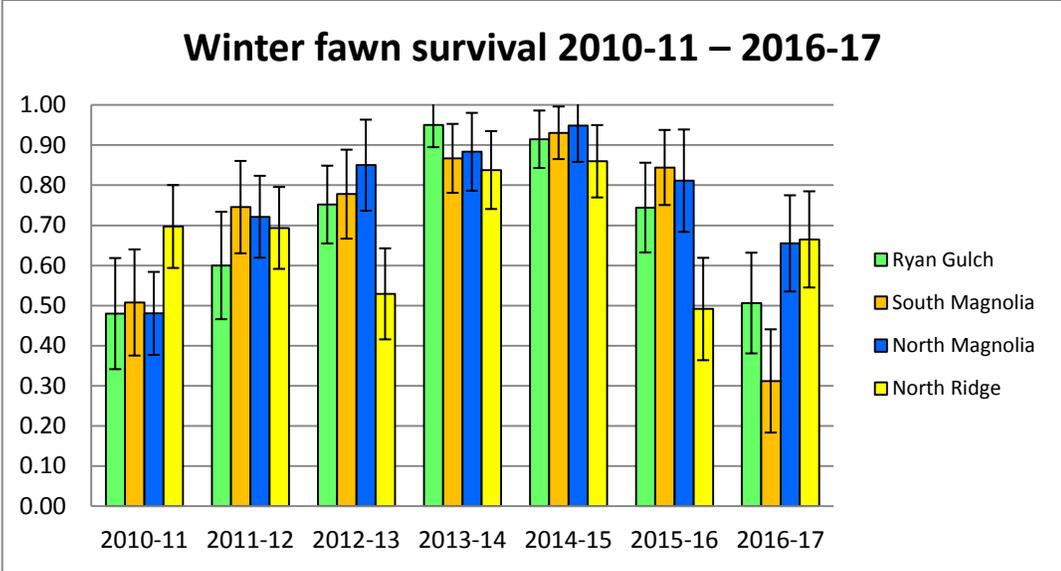


Figure 2. Over-winter (Dec–June) mule deer fawn survival (\hat{S}) from 4 study areas in the Piceance Basin, northwest Colorado. Error bars = 95% CI. Winter survival rates from 2009-10 and 2010-11 are unavailable due to pre-mature collar drop, but 2009-10 and 2010-11 survival mirrored rates observed during 2011-12 and 2012-13 (excluding North Ridge), respectively, until collars began dropping during mid – late March of those years.

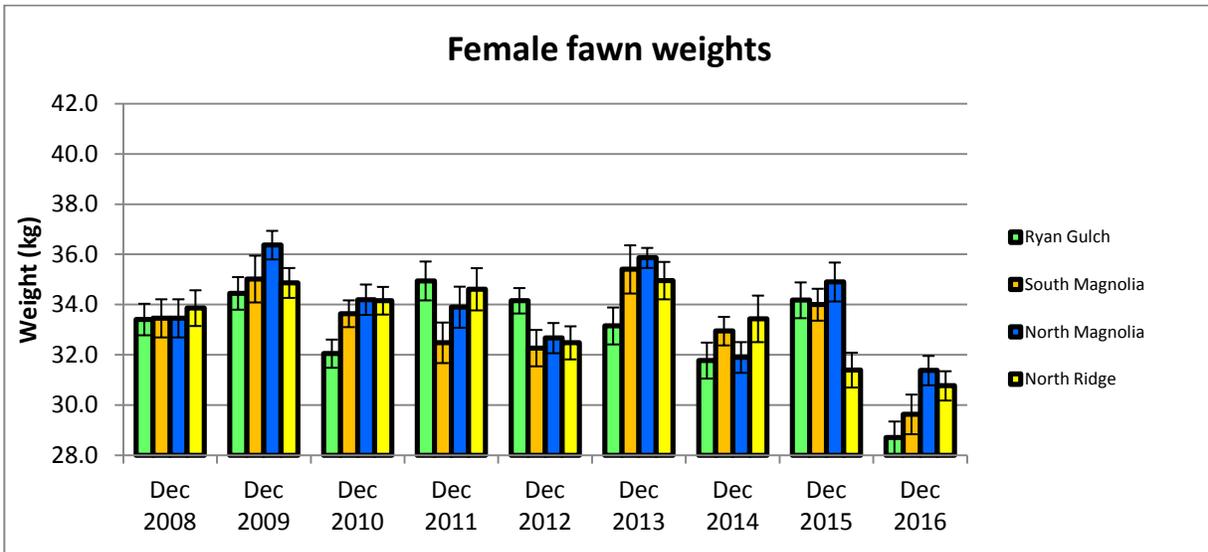
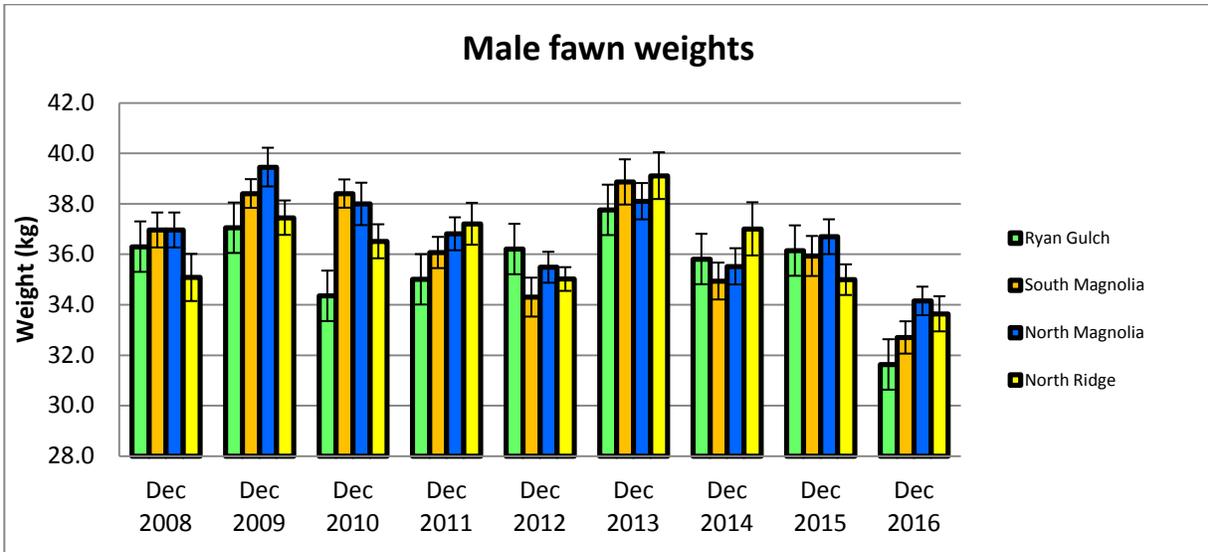


Figure 3. Mean male and female fawn weights and 95% CI (error bars) from 4 mule deer study areas in the Piceance Basin, northwest Colorado, December 2008–2016.

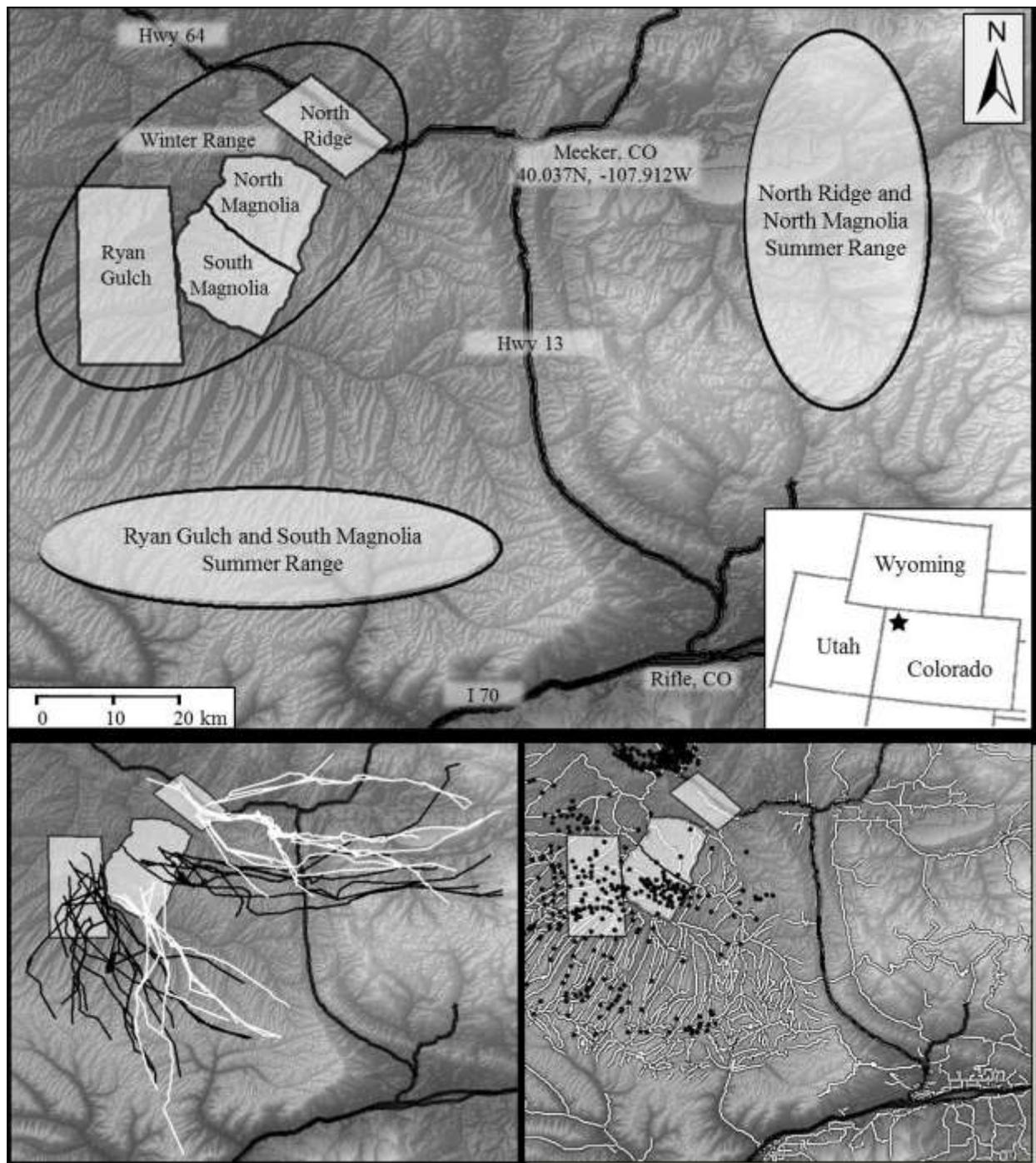


Figure 4. Mule deer study areas in the Piceance Basin of northwestern Colorado, USA (Top), spring 2009 migration routes of adult female mule deer ($n = 52$; Lower left), and active natural-gas well pads (black dots) and roads (state, county, and natural-gas; white lines) from May 2009 (Lower right; from Lendrum et al. 2012).

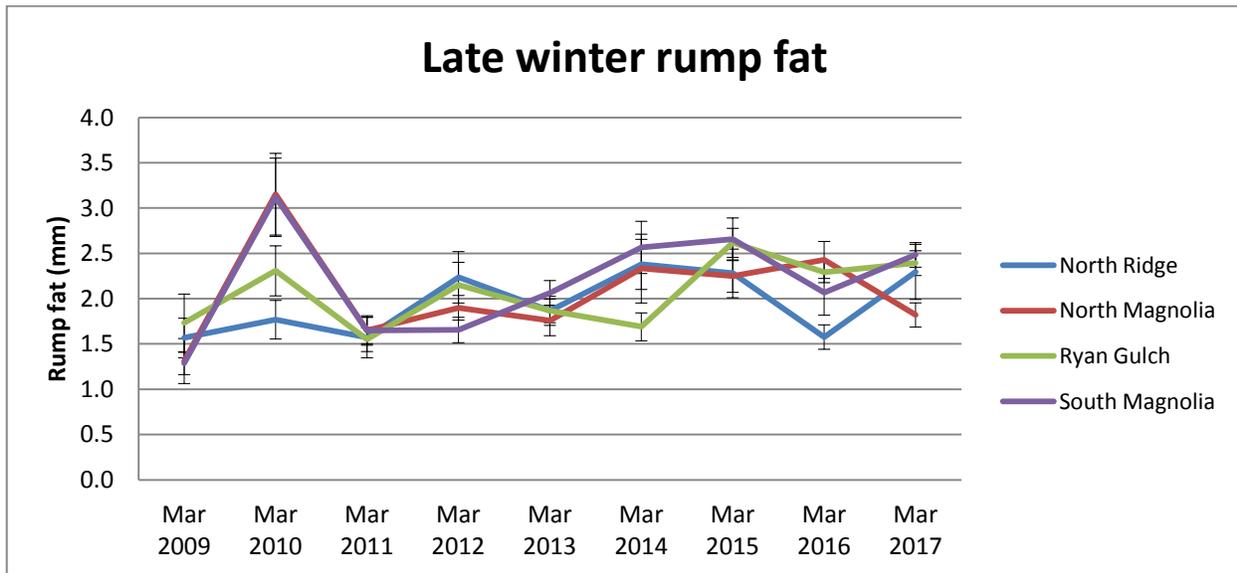
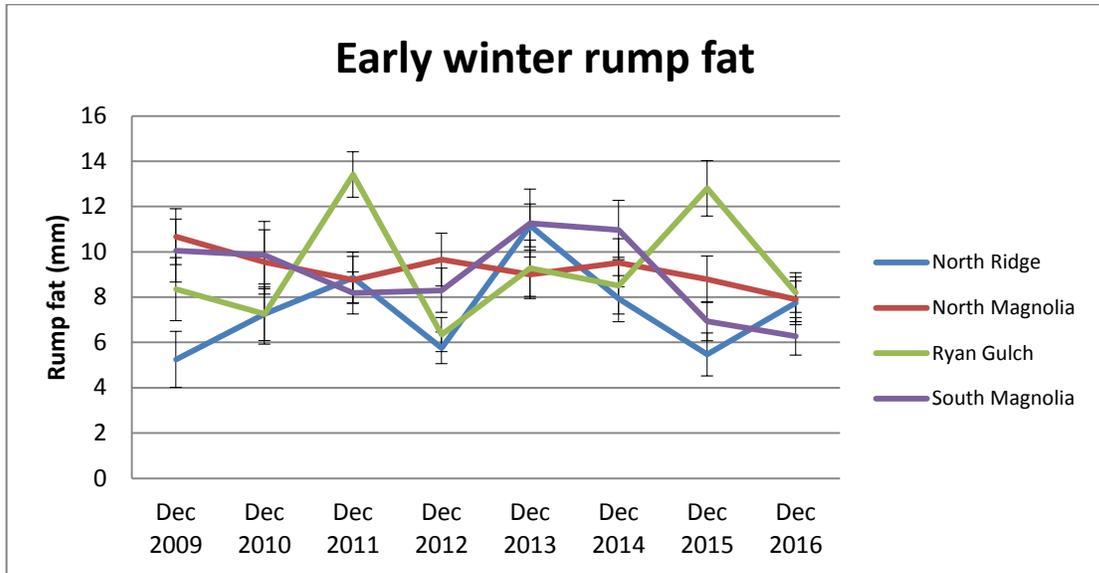


Figure 5. Mean early (early Dec., Top) and late winter (early Mar., Bottom) body condition (mm rump fat) of adult female mule deer from 4 winter range study areas in the Piceance Basin of northwest Colorado, March 2009–March 2017. Error bars = 95% CI.

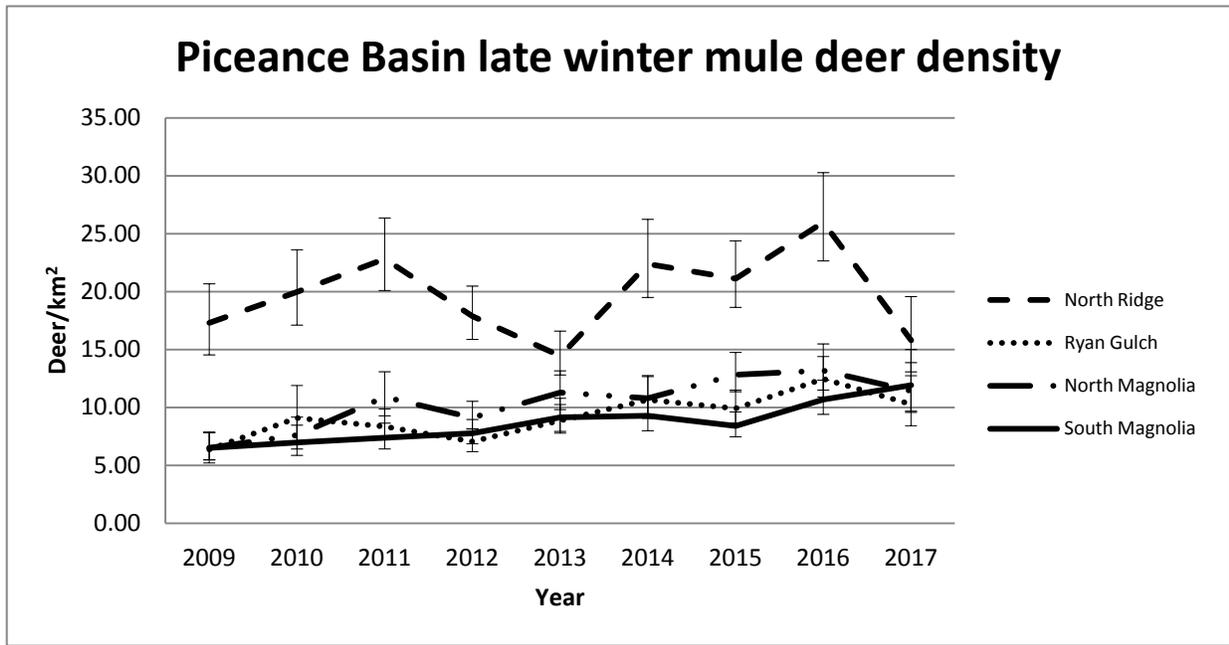


Figure 6. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009–2017. Estimates for North Ridge 2014 and 2015 and for North Magnolia 2015 were adjusted upward (using GPS migration data) to account for early migration from winter range prior to and during surveys.

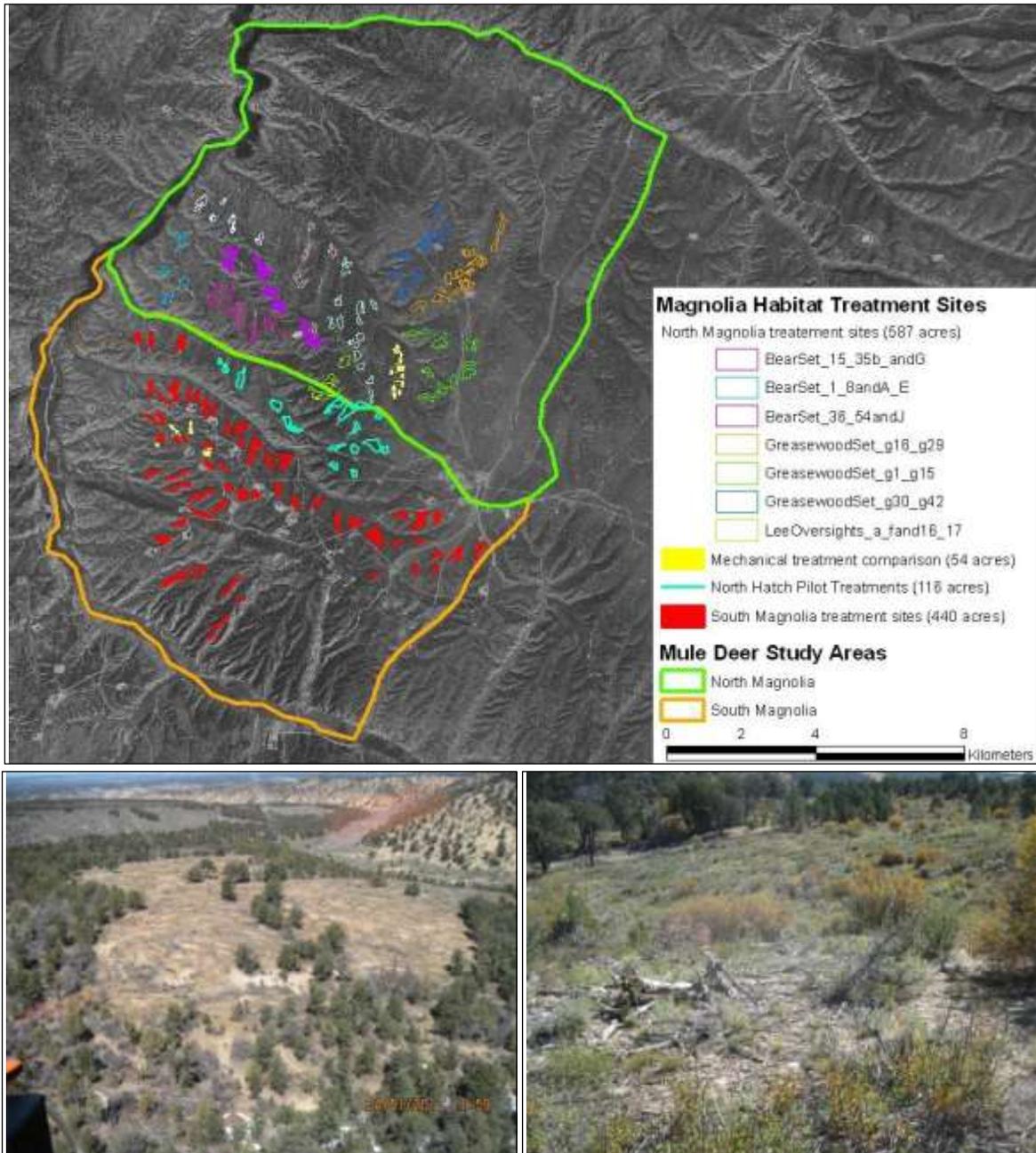


Figure 7. Habitat treatment site delineations in 2 mule deer study areas (604 acres each) of the Piceance Basin, northwest Colorado (Top; cyan polygons completed Jan. 2011 using hydro-axe; yellow polygons completed Jan. 2012 using hydro-axe, roller-chop, and chaining; and remaining polygons completed April 2013 using hydro-axe). January 2011 hydro-axe treatment-site photos from North Hatch Gulch during April (Lower left, aerial view) and October, 2011 (Lower right, ground view).

Appendix A. Abstracts of published manuscripts resulting from Piceance Basin mule deer/energy development interaction research collaborations. Abstract format specific to the respective journal requirements.

Effectiveness of a redesigned vaginal implant transmitter in mule deer

CHAD J. BISHOP¹, CHARLES R. ANDERSON JR.¹, DANIEL P. WALSH¹, ERIC J. BERGMAN¹, PETER KUECHLE², and JOHN ROTH²

¹Colorado Parks and Wildlife, Fort Collins, Colorado 80526 USA

²Advanced Telemetry Systems, Isanti, Minnesota 55040 USA

Citation: Bishop, C. J., C. R. Anderson Jr., D. P. Walsh, E. J. Bergman, P. Kuechle, and J. Roth. 2011. Effectiveness of a redesigned vaginal implant transmitter in mule deer. *Journal of Wildlife Management* 75(8):1797-1806; DOI: 10.1002/jwmg.229

ABSTRACT Our understanding of factors that limit mule deer (*Odocoileus hemionus*) populations may be improved by evaluating neonatal survival as a function of dam characteristics under free-ranging conditions, which generally requires that both neonates and dams are radiocollared. The most viable technique facilitating capture of neonates from radiocollared adult females is use of vaginal implant transmitters (VITs). To date, VITs have allowed research opportunities that were not previously possible; however, VITs are often expelled from adult females prepartum, which limits their effectiveness. We redesigned an existing VIT manufactured by Advanced Telemetry Systems (ATS; Isanti, MN) by lengthening and widening wings used to retain the VIT in an adult female. Our objective was to increase VIT retention rates and thereby increase the likelihood of locating birth sites and newborn fawns. We placed the newly designed VITs in 59 adult female mule deer and evaluated the probability of retention to parturition and the probability of detecting newborn fawns. We also developed an equation for determining VIT sample size necessary to achieve a specified sample size of neonates. The probability of a VIT being retained until parturition was 0.766 (SE = 0.0605) and the probability of a VIT being retained to within 3 days of parturition was 0.894 (SE = 0.0441). In a similar study using the original VIT wings (Bishop et al. 2007), the probability of a VIT being retained until parturition was 0.447 (SE = 0.0468) and the probability of retention to within 3 days of parturition was 0.623 (SE = 0.0456). Thus, our design modification increased VIT retention to parturition by 0.319 (SE = 0.0765) and VIT retention to within 3 days of parturition by 0.271 (SE = 0.0634). Considering dams that retained VITs to within 3 days of parturition, the probability of detecting at least 1 neonate was 0.952 (SE = 0.0334) and the probability of detecting both fawns from twin litters was 0.588 (SE = 0.0827). We expended approximately 12 person-hours per detected neonate. As a guide for researchers planning future studies, we found that VIT sample size should approximately equal the targeted neonate sample size. Our study expands opportunities for conducting research that links adult female attributes to productivity and offspring survival in mule deer. © 2014 The Wildlife Society.

Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development

PATRICK E. LENDRUM¹, CHARLES R. ANDERSON JR.², RYAN A. LONG¹, JOHN G. KIE¹, AND R. TERRY BOWYER¹

¹Department of Biological Sciences, Idaho State University, Pocatello, Idaho 83209 USA

²Colorado Parks and Wildlife, Grand Junction, Colorado 81505 USA

Citation: Lendrum, P. E., C. R. Anderson Jr., R. A. Long, J. G. Kie, and R. T. Bowyer. 2012. Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. *Ecosphere* 3(9):82 <http://dx.doi.org/10.1890/ES12-00165.1>

Abstract. The disruption of traditional migratory routes by anthropogenic disturbances has shifted patterns of resource selection by many species, and in some instances has caused populations to decline. Moreover, in recent decades populations of mule deer (*Odocoileus hemionus*) have declined throughout much of their historic range in the western United States. We used resource-selection functions to determine if the presence of natural-gas development altered patterns of resource selection by migrating mule deer. We compared spring migration routes of adult female mule deer fitted with GPS collars ($n = 167$) among four study areas that had varying degrees of natural-gas development from 2008 to 2010 in the Piceance Basin of northwest Colorado, USA. Mule deer migrating through the most developed area had longer step lengths (straight-line distance between successive GPS locations) compared with deer in less developed areas. Additionally, deer migrating through the most developed study areas tended to select for habitat types that provided greater amounts of concealment cover, whereas deer from the least developed areas tended to select habitats that increased access to forage and cover. Deer selected habitats closer to well pads and avoided roads in all instances except along the most highly developed migratory routes, where road densities may have been too high for deer to avoid roads without deviating substantially from established migration routes. These results indicate that behavioral tendencies toward avoidance of anthropogenic disturbance can be overridden during migration by the strong fidelity ungulates demonstrate towards migration routes. If avoidance is feasible, then deer may select areas further from development, whereas in highly developed areas, deer may simply increase their rate of travel along established migration routes.

Migrating Mule Deer: Effects of Anthropogenically Altered Landscapes

Patrick E. Lendrum¹, Charles R. Anderson Jr.², Kevin L. Monteith^{1,3}, Jonathan A. Jenks⁴, R. Terry Bowyer¹

¹ Department of Biological Sciences, Idaho State University, Pocatello, Idaho, USA, ² Colorado Division of Parks and Wildlife, Grand Junction, Colorado, USA, ³ Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, Wyoming, USA, ⁴ Department of Natural Resource Management, South Dakota State University, Brookings, South Dakota, USA

Citation: Lendrum, P. E., C. R. Anderson Jr., K. L. Monteith, J. A. Jenks, R. T. Bowyer. 2013. Migrating Mule Deer: Effects of anthropogenically Altered Landscapes. PLoS ONE 8(5): e64548. DOI: 10.1371/journal.pone.0064548

Abstract

Background: Migration is an adaptive strategy that enables animals to enhance resource availability and reduce risk of predation at a broad geographic scale. Ungulate migrations generally occur along traditional routes, many of which have been disrupted by anthropogenic disturbances. Spring migration in ungulates is of particular importance for conservation planning, because it is closely coupled with timing of parturition. The degree to which oil and gas development affects migratory patterns, and whether ungulate migration is sufficiently plastic to compensate for such changes, warrants additional study to better understand this critical conservation issue.

Methodology/Principal Findings: We studied timing and synchrony of departure from winter range and arrival to summer range of female mule deer (*Odocoileus hemionus*) in northwestern Colorado, USA, which has one of the largest natural-gas reserves currently under development in North America. We hypothesized that in addition to local weather, plant phenology, and individual life-history characteristics, patterns of spring migration would be modified by disturbances associated with natural-gas extraction. We captured 205 adult female mule deer, equipped them with GPS collars, and observed patterns of spring migration during 2008–2010.

Conclusions/Significance: Timing of spring migration was related to winter weather (particularly snow depth) and access to emerging vegetation, which varied among years, but was highly synchronous across study areas within years. Additionally, timing of migration was influenced by the collective effects of anthropogenic disturbance, rate of travel, distance traveled, and body condition of adult females. Rates of travel were more rapid over shorter migration distances in areas of high natural-gas development resulting in the delayed departure, but early arrival for females migrating in areas with high development compared with less-developed areas. Such shifts in behavior could have consequences for timing of arrival on birthing areas, especially where mule deer migrate over longer distances or for greater durations.

Practical guidance on characterizing availability in resource selection functions under a use–availability design

JOSEPH M. NORTHRUP¹, MEVIN B. HOOTEN^{1,2,3}, CHARLES R. ANDERSON JR.⁴, AND GEORGE WITTEMYER¹

¹Department of Fish, Wildlife, and Conservation Biology, Colorado State University, 1474 Campus Delivery, Fort Collins, Colorado 80523 USA

²U.S. Geological Survey, Colorado Cooperative Fish and Wildlife Research Unit, 1474 Campus Delivery, Fort Collins, Colorado 80523 USA

³Colorado State University, Department of Statistics, Colorado State University, 1474 Campus Delivery, Fort Collins, Colorado 80523 USA

⁴Mammals Research Section Colorado Parks and Wildlife, 711 Independent Avenue, Grand Junction, Colorado 81505 USA

Citation: Northrup, J. M., M. B. Hooten, C. R. Anderson Jr., and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use–availability design. Ecology 94(7):1456–1463. <http://dx.doi.org/10.1890/12-1688.1>

Abstract. Habitat selection is a fundamental aspect of animal ecology, the understanding of which is critical to management and conservation. Global positioning system data from animals allow fine-scale assessments of habitat selection and typically are analyzed in a use–availability framework, whereby animal locations are contrasted with random locations (the availability sample). Although most use–availability methods are in fact spatial point process models, they often are fit using logistic regression. This framework offers numerous methodological challenges, for which the literature provides little guidance. Specifically, the size and spatial extent of the availability sample influences coefficient estimates potentially causing interpretational bias. We examined the influence of availability on statistical inference through simulations and analysis of serially correlated mule deer GPS data. Bias in estimates arose from incorrectly assessing and sampling the spatial extent of availability. Spatial autocorrelation in covariates, which is common for landscape characteristics, exacerbated the error in availability sampling leading to increased bias. These results have strong implications for habitat selection analyses using GPS data, which are increasingly prevalent in the literature. We recommend that researchers assess the sensitivity of their results to their availability sample and, where bias is likely, take care with interpretations and use cross validation to assess robustness.

Effects of Helicopter Capture and Handling on Movement Behavior of Mule Deer

JOSEPH M. NORTHRUP¹, CHARLES R. ANDERSON JR.², AND GEORGE WITTEMYER¹

¹Department of Fish, Wildlife, and Conservation Biology, Colorado State University, 1474 Campus Delivery, Fort Collins, Colorado 80523 USA

²Mammals Research Section Colorado Parks and Wildlife, 711 Independent Avenue, Grand Junction, Colorado 81505 USA

Citation: Northrup, J. M., C. R. Anderson Jr., and G. Wittemyer. 2014. Effects of helicopter capture and handling on movement behavior of mule deer. *Journal of Wildlife Management* 78(4):731-738; DOI: 10.1002/jwmg.705

ABSTRACT Research on wildlife movement, physiology, and reproductive biology often requires capture and handling of animals. Such invasive treatment can alter behavior, which may bias results or invalidate assumptions regarding representative behaviors. To assess the impacts of handling on mule deer (*Odocoileus hemionus*), a focal species for research in North America, we investigated pre- and post-recapture movements of collared individuals, and compared them to deer that were not recaptured (controls). We compared pre- and post-recapture movement rates (m/hr) and 24-hour straight-line displacement among recaptured and control deer. In addition, we examined the time it took recaptured deer to return to their pre-recapture home range. Both daily straight-line displacement and movement rate were marginally elevated relative to monthly averages for 24 hours following recapture, with non-significant elevation continuing for up to 7 days. Comparing movements averaged over 30 days before and after recapture, we found no differences in displacement, but movement rates demonstrated seasonal effects, with faster movements post- relative to pre-recapture in March and slower movements post- relative to pre-recapture in December. Relative to control deer movements, recaptured deer movement rates in March were higher immediately after recapture and lower in the second and third weeks following recapture. The median time to return to the pre-recapture home range was 13 hours, with 71% of deer returning in the first day, and 91% returning within 4 days. These results indicate a short period of elevated movements following recaptures, likely due to the deer returning to their home ranges, followed by weaker but non-significant depression of movements for up to 3 weeks. Censoring of the first day of data post capture from analyses is strongly supported, and removing additional days until the individual returns to its home range will control for the majority of impacts from capture. © 2014 The Wildlife Society.

Relating the movement of a rapidly migrating ungulate to spatiotemporal patterns of forage quality

Patrick E. Lendrum^a, Charles R. Anderson Jr.^b, Kevin L. Monteith^c, Jonathan A. Jenks^d, R. Terry Bowyer^a

^a Department of Biological Sciences, Idaho State University, 921 South 8th Avenue, Stop 8007, Pocatello 83209, USA

^b Mammals Research Section Colorado Parks and Wildlife, 711 Independent Avenue, Grand Junction 81505, USA

^c Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming, 3166, 1000 East University Avenue, Laramie 82071, USA

^d Department of Natural Resource Management, South Dakota State University, Box 2140B, Brookings 57007, USA

Citation: Lendrum, P. E., C. R. Anderson Jr., K. L. Monteith, J. A. Jenks, and R. T. Bowyer. 2014. Relating the movement of a rapidly migrating ungulate to spatiotemporal patterns of forage quality. *Mammalian Biology*: <http://dx.doi.org/10.1016/j.mambio.2014.05.005>

ABSTRACT: Migratory ungulates exhibit recurring movements, often along traditional routes between seasonal ranges each spring and autumn, which allow them to track resources as they become available on the landscape. We examined the relationship between spring migration of mule deer (*Odocoileus hemionus*) and forage quality, as indexed by spatiotemporal patterns of fecal nitrogen and remotely sensed greenness of vegetation (Normalized Difference Vegetation Index; NDVI) in spring 2010 in the Piceance Basin of northwestern Colorado, USA. NDVI increased throughout spring, and was affected primarily by snow depth when snow was present, and temperature when snow was absent. Fecal nitrogen was lowest when deer were on winter range before migration, increased rapidly to an asymptote during migration, and remained relatively high when deer reached summer range. Values of fecal nitrogen corresponded with increasing NDVI during migration. Spring migration for mule deer provided a way for these large mammals to increase access to a high-quality diet, which was evident in patterns of NDVI and fecal nitrogen. Moreover, these deer “jumped” rather than “surfed” the green wave by arriving on summer range well before peak productivity of forage occurred. This rapid migration may aid in securing resources and seclusion from others on summer range in preparation for parturition, and to minimize detrimental factors such as predation, and malnutrition during migration.

Effects of Male-Biased Harvest on Mule Deer: Implications for Rates of Pregnancy, Synchrony, and Timing of Parturition

ERIC D. FREEMAN¹, RANDY T. LARSEN¹, MARK E. PETERSON², CHARLES R. ANDERSON JR.³, KENT R. HERSEY⁴, AND BROCK R. McMILLAN¹

¹ Department of Plant and Wildlife Sciences, Brigham Young University, 275 WIDB, Provo, UT 84602, USA

² Department of Fish, Wildlife, and Conservation Biology, Colorado State University, 1474 Campus Delivery, Fort Collins, CO 80523, USA

³ Colorado Parks and Wildlife, 711 Independent Avenue, Grand Junction, CO 81505, USA

⁴ Utah Division of Wildlife Resources, 1594 W North Temple, Salt Lake City, UT 84114, USA

Citation: Freeman, E. D., R. T. Larsen, M. E. Peterson, C. R. Anderson Jr., K. R. Hersey, and B. R. McMillan. 2014. Effects of male-biased harvest on mule deer: implications for rates of pregnancy, synchrony, and timing of parturition. *Wildlife Society Bulletin*; DOI: 10.1002/wsb.450

ABSTRACT Evaluating how management practices influence the population dynamics of ungulates may enhance future management of these species. For example, in mule deer (*Odocoileus hemionus*), changes in male/female ratio due to male-biased harvest may alter rates of pregnancy, timing of parturition, and synchrony of parturition if inadequate numbers of males are present to fertilize females during their first estrous cycle. If rates of pregnancy or parturition are influenced by decreased male/female ratios, recruitment may be reduced (e.g., fewer births, later parturition resulting in lower survival of fawns, and a less synchronous parturition that potentially increases susceptibility of neonates to predation). Our objectives were to compare rates of pregnancy, synchrony of parturition, and timing of parturition between exploited mule deer populations with a relatively high (Piceance, CO, USA; 26 males/100 females) and a relatively low (Monroe, UT, USA; 14 males/100 females) male/female ratio. We determined rates of pregnancy via ultrasonography and timing of parturition via vaginal implant transmitters. We found no differences in rates of pregnancy (98.6% and 96.6%; $z = 0.821$; $P = 0.794$), timing of parturition (estimate = 1.258; SE = 1.672; $t = 0.752$; $P = 0.454$), or synchrony of parturition ($F = 1.073$; $P = 0.859$) between Monroe Mountain and Piceance Basin, respectively. The relatively low male/female ratio on Monroe Mountain was not associated with a protracted period of parturition. This finding suggests that relatively low male/female ratios typical of heavily harvested populations do not influence population dynamics because recruitment remains unaffected. © 2014 The Wildlife Society.

Fine-scale genetic correlates to condition and migration in a wild cervid

Joseph M. Northrup,¹ Aaron B. A. Shafer,² Charles R. Anderson Jr.,³ David W. Coltman⁴ and George Wittemyer¹

¹ Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, CO, USA

² Department of Evolutionary Biology, Evolutionary Biology Centre, Uppsala University, Uppsala, Sweden

³ Mammals Research Section, Colorado Parks and Wildlife, Grand Junction, CO, USA

⁴ Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada.

Citation: Northrup, J. M., A. B. Shafer, C. R. Anderson Jr., D. W. Coltman, and G. Wittemyer. 2014. Fine-scale genetic correlates to condition and migration in a wild cervid. *Evolutionary Applications* ISSN 1752-4571; doi: 10.1111/eva.12189

Abstract

The relationship between genetic variation and phenotypic traits is fundamental to the study and management of natural populations. Such relationships often are investigated by assessing correlations between phenotypic traits and heterozygosity or genetic differentiation. Using an extensive data set compiled from free ranging mule deer (*Odocoileus hemionus*), we combined genetic and ecological data to (i) examine correlations between genetic differentiation and migration timing, (ii) screen for mitochondrial haplotypes associated with migration timing, and (iii) test whether nuclear heterozygosity was associated with condition. Migration was related to genetic differentiation (more closely related individuals migrated closer in time) and mitochondrial haplogroup. Body fat was related to heterozygosity at two nuclear loci (with antagonistic patterns), one of which is situated near a known fat metabolism gene in mammals. Despite being focused on a widespread panmictic species, these findings revealed a link between genetic variation and important phenotypes at a fine scale. We hypothesize that these correlations are either the result of mixing refugial lineages or differential mitochondrial haplotypes influencing energetics. The maintenance of phenotypic diversity will be critical to enable the potential tracking of changing climatic conditions, and these correlates highlight the need to consider evolutionary mechanisms in management, even in widely distributed panmictic species.

Landscape and anthropogenic features influence the use of auditory vigilance by mule deer

Emma Lynch,^a Joseph M. Northrup,^b Megan F. McKenna,^c Charles R. Anderson Jr.,^d Lisa Angeloni,^{a,e} and George Wittemyer^{a,b}

^aGraduate Degree Program in Ecology, Colorado State University, 1474 Campus Delivery, Fort Collins, CO 80523, USA

^bDepartment of Fish, Wildlife and Conservation Biology, Colorado State University, 1474 Campus Delivery, Fort Collins, CO 80523, USA

^cNatural Sounds and Night Skies Division, National Park Service, 1201 Oakridge Drive, Fort Collins, CO 80525, USA,

^dMammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

^eDepartment of Biology, Colorado State University, 1878 Campus Delivery, Fort Collins, CO 80523, USA

Citation: Lynch, E., J. M. Northrup, M. F. McKenna, C. R. Anderson Jr., L. Angeloni, and G. Wittemyer. 2014. Landscape and anthropogenic features influence the use of auditory vigilance by mule deer. *Behavioral Ecology*; doi:10.1093/beheco/aru158.

While visual forms of vigilance behavior and their relationship with predation risk have been broadly examined, animals also employ other vigilance modalities such as auditory vigilance by listening for the acoustic cues of predators. Similar to the tradeoffs associated with visual vigilance, auditory behavior potentially structures the energy budgets and behavior of animals. The cryptic nature of auditory vigilance makes it difficult to study, but on-animal acoustical monitoring has rapidly advanced our ability to investigate behaviors and conditions related to sound. We utilized this technique to investigate the ways external stimuli in an active natural gas development field affect periodic pausing by mule deer (*Odocoileus hemionus*) within bouts of rumination-based mastication. To better understand the ecological properties that structure this behavior, we investigate spatial and temporal factors related to these pauses to determine if results are consistent with our hypothesis that pausing is used for auditory vigilance. We found that deer paused more when in forested cover and at night, where visual vigilance was likely to be less effective. Additionally, deer paused more in areas of moderate background sound levels, though responses to anthropogenic features were less clear. Our results suggest that pauses during rumination represent a form of auditory vigilance that is responsive to landscape variables. Further exploration of this behavior can facilitate a more holistic understanding of risk perception and the costs associated with vigilance behavior.

Migration Patterns of Adult Female Mule Deer in Response to Energy Development

Charles R. Anderson Jr. and Chad J. Bishop

Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

Citation: Anderson, C. R., Jr., and C. J. Bishop. 2014. Migration patterns of adult female mule deer in response to energy development. Pages 47-50 in *Transactions of the 79th North American Wildlife & Natural Resources Conference* (R. A. Coon & M. C. Dunfee, eds.). Wildlife Management Institute, Gardners, PA, USA. ISSN 0078-1355.

Migration is an adaptive strategy that enables animals to enhance resource availability and reduce risk of predation at a broad geographic scale. Ungulate migrations generally occur along traditional routes, many of which have been disrupted by anthropogenic disturbances. Spring migration in ungulates is of particular importance for conservation planning because it is closely coupled with timing of parturition. The degree to which oil and gas development affects migratory patterns, and whether ungulate migration is sufficiently prepared to compensate for such changes, has recently been investigated in Colorado and Wyoming (Lendrum et al. 2012, 2013; Sawyer et al. 2012).

Lendrum et al. (2012, 2013) and Sawyer et al. (2012) address mule deer (*Odocoileus hemionus*) migration patterns in relation to energy development from northwest Colorado and south-central Wyoming, respectively. We address results from the Colorado and Wyoming studies and then compare similarities and differences.

The interactions between migratory mule deer and energy development identified by Lendrum et al. (2012, 2013) and Sawyer et al. (2012) suggest mule deer may benefit from energy development planning by considering thresholds of development that may alter migratory behavior. It appears that migration rate, migration routes, and stopover use, if present, may be altered at high development intensities. In addition, migratory mule deer may benefit by maintaining security cover along migration paths, and improved habitat conditions may facilitate more direct and rapid migration requiring less energy to complete migration. Enhancing permeability along migration routes by applying dispersed development plans (<2 well pads/km²) and minimizing disturbance to vegetation types by maintaining security cover should reduce impacts to migratory mule deer as well as other migratory ungulates. Where feasible, habitat improvement projects on winter range and possibly stopover sites would also enhance migratory mule deer populations by enhancing energy reserves for long-distance movements and parturition shortly after summer range arrival. Where possible, directional drilling could be used to extract energy resources from underneath migration routes while maintaining no surface occupancy. Lastly, we emphasize that GPS studies now allow managers to accurately map migration routes for entire populations and identify relatively narrow corridors that are most heavily used thus allowing for the identification of the most important corridors for migrating ungulates. Where available, we encourage agencies to incorporate such migration corridors into land-use plans (e.g., resource management plans) and National Environmental Policy Act documents.

Asynchronous vegetation phenology enhances winter body condition of a large mobile herbivore

Kate R. Searle¹ · Mindy B. Rice² · Charles R. Anderson² · Chad Bishop² · N. T. Hobbs³

¹NERC Centre for Ecology and Hydrology, Bush Estate, Penicuik EH26 0QB, UK

²Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

³Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins 80524, CO, USA

Citation: Searle, K. R., M. B. Rice, C. R. Anderson, C. Bishop and N. T. Hobbs. 2015. Asynchronous vegetation phenology enhances winter body condition of a large mobile herbivore. *Oecologia* ISSN 0029-8549; DOI 10.1007/s00442-015-3348-9

Abstract Understanding how spatial and temporal heterogeneity influence ecological processes forms a central challenge in ecology. Individual responses to heterogeneity shape population dynamics, therefore understanding these responses is central to sustainable population management. Emerging evidence has shown that herbivores track heterogeneity in nutritional quality of vegetation by responding to phenological differences in plants. We quantified the benefits mule deer (*Odocoileus hemionus*) accrue from accessing habitats with asynchronous plant phenology in northwest Colorado over 3 years. Our analysis examined both the direct physiological and indirect environmental effects of weather and vegetation phenology on mule deer winter body condition. We identified several important effects of annual weather patterns and topographical variables on vegetation phenology in the home ranges of mule deer. Crucially, temporal patterns of vegetation phenology were linked with differences in body condition, with deer tending to show poorer body condition in areas with less asynchronous vegetation green-up and later vegetation onset. The direct physiological effect of previous winter precipitation on mule deer body condition was much less important than the indirect effect mediated by vegetation phenology.

Quantifying spatial habitat loss from hydrocarbon development through assessing habitat selection patterns of mule deer

JOSEPH M. NORTHRUP¹, CHARLES R. ANDERSON JR.² and GEORGE WITTEMYER^{1,3}

¹Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO, USA

²Mammals Research Section, Colorado Parks and Wildlife, Fort Collins, CO, USA

³Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO, USA

Citation: Northrup, J. M., C. R. Anderson, Jr., and G. Wittemyer. 2015. Quantifying spatial habitat loss from hydrocarbon development through assessing habitat selection patterns of mule deer. *Global Change Biology*, doi: 10.1111/gcb.13037

Abstract

Extraction of oil and natural gas (hydrocarbons) from shale is increasing rapidly in North America, with documented impacts to native species and ecosystems. With shale oil and gas resources on nearly every continent, this development is set to become a major driver of global land-use change. It is increasingly critical to quantify spatial habitat loss driven by this development to implement effective mitigation strategies and develop habitat offsets. Habitat selection is a fundamental ecological process, influencing both individual fitness and population-level distribution on the landscape. Examinations of habitat selection provide a natural means for understanding spatial impacts. We examined the impact of natural gas development on habitat selection patterns of mule deer on their winter range in Colorado. We fit resource selection functions in a Bayesian hierarchical framework, with habitat availability defined using a movement-based modeling approach. Energy development drove considerable alterations to deer habitat selection patterns, with the most substantial impacts manifested as avoidance of well pads with active drilling to a distance of at least 800 m. Deer displayed more nuanced responses to other infrastructure, avoiding pads with active production and roads to a greater degree during the day than night. In aggregate, these responses equate to alteration of behavior by human development in over 50% of the critical winter range in our study area during the day and over 25% at night. Compared to other regions, the topographic and vegetative diversity in the study area appear to provide refugia that allow deer to behaviorally mediate some of the impacts of development. This study, and the methods we employed, provides a template for quantifying spatial take by industrial activities in natural areas and the results offer guidance for policy makers, managers, and industry when attempting to mitigate habitat loss due to energy development.

Environmental dynamics and anthropogenic development alter philopatry and space-use in a North American cervid

Joseph M. Northrup¹, Charles R. Anderson Jr.² and George Wittemyer^{1,3}

¹Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO, USA

²Mammals Research Section, Colorado Parks and Wildlife, Fort Collins, CO, USA

³Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO, USA

Citation: Northrup, J. M., C. R. Anderson, Jr., and G. Wittemyer. 2016. Environmental dynamics and anthropogenic development alter philopatry and space-use in a North American cervid. *Diversity and Distributions* 22: 547-557, DOI: 10.1111/ddi.12417

ABSTRACT

Aim The space an animal uses over a given time period must provide the resources required for meeting energetic needs, reproducing and avoiding predation. Anthropogenic landscape change in concert with environmental dynamics can strongly structure space-use. Investigating these dynamics can provide critical insight into animal ecology, conservation and management.

Location The Piceance Basin, Colorado, USA.

Methods We applied a novel utilization distribution estimation technique based on a continuous-time correlated random walk model to characterize range dynamics of mule deer during winter and summer seasons across multiple years. This approach leverages second-order properties of movement to provide a probabilistic estimate of space-use. We assessed the influence of environmental (cover and forage), individual and anthropogenic factors on interannual variation in range use of individual deer using a hierarchical Bayesian regression framework.

Results Mule deer demonstrated remarkable spatial philopatry, with a median of 50% overlap (range: 8–78%) in year-to-year utilization distributions. Environmental conditions were the primary driver of both philopatry and range size, with anthropogenic disturbance playing a secondary role.

Main conclusions Philopatry in mule deer is suspected to reflect the importance of spatial familiarity (memory) to this species and, therefore, factors driving spatial displacement are of conservation concern. The interaction between range behaviour and dynamics in development disturbance and environmental conditions highlights mechanisms by which anthropogenic environmental change may displace deer from familiar areas and alter their foraging and survival strategies.

Movement reveals scale dependence in habitat selection of a large ungulate

Joseph M. Northrup,¹ Charles R. Anderson Jr.,² Mevin B. Hooten,³ and George Wittemyer⁴

¹Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, Colorado 80523 USA

²Mammals Research Section, Colorado Parks and Wildlife, Fort Collins, Colorado 80523 USA

³U.S. Geological Survey, Colorado Cooperative Fish and Wildlife Research Unit, Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, Colorado 80523 USA

⁴Department of Fish, Wildlife and Conservation Biology and Graduate Degree Program in Ecology, Colorado State University, Fort Collins, Colorado 80523 USA

Citation: Northrup, J. M., C. R. Anderson, Jr., M. B. Hooten, and G. Wittemyer. 2016. Movement reveals scale dependence in habitat selection of a large ungulate. *Ecological Applications* 26:2746-2757

Abstract. Ecological processes operate across temporal and spatial scales. Anthropogenic disturbances impact these processes, but examinations of scale dependence in impacts are infrequent. Such examinations can provide important insight to wildlife–human interactions and guide management efforts to reduce impacts. We assessed spatiotemporal scale dependence in habitat selection of mule deer (*Odocoileus hemionus*) in the Piceance Basin of Colorado, USA, an area of ongoing natural gas development. We employed a newly developed animal movement method to assess habitat selection across scales defined using animal-centric spatiotemporal definitions ranging from the local (defined from five hour movements) to the broad (defined from weekly movements). We extended our analysis to examine variation in scale dependence between night and day and assess functional responses in habitat selection patterns relative to the density of anthropogenic features. Mule deer displayed scale invariance in the direction of their response to energy development features, avoiding well pads and the areas closest to roads at all scales, though with increasing strength of avoidance at coarser scales. Deer displayed scale-dependent responses to most other habitat features, including land cover type and habitat edges. Selection differed between night and day at the finest scales, but homogenized as scale increased. Deer displayed functional responses to development, with deer inhabiting the least developed ranges more strongly avoiding development relative to those with more development in their ranges. Energy development was a primary driver of habitat selection patterns in mule deer, structuring their behaviors across all scales examined. Stronger avoidance at coarser scales suggests that deer behaviorally mediated their interaction with development, but only to a degree. At higher development densities than seen in this area, such mediation may not be possible and thus maintenance of sufficient habitat with lower development densities will be a critical best management practice as development expands globally.

Approaches to field investigations of cause-specific mortality in mule deer (*Odocoileus hemionus*)

Kourtney F. Stonehouse,^{1,2} Charles R. Anderson Jr.,¹ Mark E. Peterson,^{1,2} and David R. Collins¹

¹Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 90526 USA

²Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, Colorado 80523 USA

Citation: Stonehouse, K. F., C. R. Anderson Jr., M. E. Peterson, and D. R. Collins. 2016. Approaches to field investigations of cause-specific mortality in mule deer (*Odocoileus hemionus*). Colorado Parks and Wildlife Technical Report No. 48, First Edition, 317 W. Prospect Rd., Ft. Collins, CO USA. DOW-R-T-48-16, ISSN 0084-8883.

This technical report provides general guidelines for conducting mortality site investigations to help investigators distinguish predation from scavenging and other causes of death. General health indices are also provided to assess whether or not deer may have died from malnutrition or disease or if these factors may have predisposed deer to predation. Lastly, these guidelines will assist investigators in identifying predatory species or scavengers involved through the examination of physical evidence at deer mortality sites. The information presented here is based primarily on field experience gained from a long term research effort in northwest Colorado investigating mule deer mortality sites over several years (<http://cpw.state.co.us/learn/Pages/ResearchMammalsRP-04.aspx>) and literature review where referenced. We acknowledge that proximate and ultimate cause of death can be difficult or impossible to detect from field necropsy alone and examples presented here largely represent proximate causes of mortality; efforts discerning ultimate cause will require specific tissue sample collections, where possible, submitted to a veterinary diagnostic laboratory.

Within this technical report are numerous photographs documenting characteristics of predator attacks on mule deer and signs left by predatory and scavenging species. Additional pictures illustrate differences between healthy and unhealthy tissues and organs. While reading this document, be aware that each mortality investigation is unique and observations in the field may differ from illustrations provided here. Appendix I provides a sample necropsy form to assist in conducting mortality investigations.
