POTENTIAL EFFECTS OF OIL AND GAS ENERGY DEVELOPMENT ON MULE DEER IN WESTERN NORTH DAKOTA

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ABSTRACT

Oil and gas energy development are an integral part of the western North Dakota landscape, and continued development is likely based on abundant oil reserves. Much of the oil reserve boundaries overlap with the primary mule deer (*Odocoileus hemionus*) range in North Dakota. Mule deer are valued in the state for hunting and wildlife viewing; currently, demand for hunting permits exceeds availability. For wildlife managers to sustainably allocate hunting permits or identify appropriate mitigation strategies to address potential effects from energy development, it is necessary to understand the impacts of oil and gas energy development on mule deer demographics and behavior. We investigated the potential impacts of oil and gas energy development on mule deer resource selection, movements, physiological stress, and survival, in western North Dakota, 2013-2016.

We captured 207 female mule deer (101 adults and 106 juveniles) from February 2013, December 2013 and December 2014, and fitted deer with satellite GPS radio collars. We programmed collars to collect locations every 5 hours. We also programmed collars to transmit real-time locations if collars remained still for >6 hours, which allowed us to investigate mortality events. We conducted necropsies on all intact carcasses at the North Dakota Game and Fish Department (NDGF) veterinary laboratory. We collected 431,581 locations from collared mule deer form, February2013 - December 2015.

We used discrete choice models to compare used mule deer GPS locations to random available locations. We used predictor variables from three hypothesis sets: Vegetation (vegetation class, distance from wooded edge, interspersion juxtaposition index, Normalized difference vegetation index [NDVI]), Topography (aspect, percent slope, ruggedness [vector ruggedness measure], and landforms), and Anthropogenic Development (distance to nearest

road, road density, density of active well pads, and presence of drilling rig within 600m or 2500 m). We also included interaction terms for age (juvenile, adult), season (spring, summer, winter, autumn) and period of day (day, night, or crepuscular).

Our top model was the global model which included all variables except distance to nearest road, which was removed due to correlation with road density. The most important predictor of resource selection was the presence of a drilling rig within 600 m. The probability of selection for an area with a drilling rig within 600 m was 22 times less likely than the probability of selection for an area without a drilling rig. Road densities negatively influenced mule deer resource selection, but the relationship was not as strong as drilling rigs. Juveniles showed less avoidance to areas with drilling rigs within 600 m or areas with increased road density than adults. The presence of a drilling rig at 2500 m and the density of active well pads did not significantly affect the relative probability of selection. When a drilling rig was not present, mule deer selected areas closer to wooded edges, and wooded or shrubland vegetation types. Mule deer selected areas with moderate slopes and ruggedness. Ridges, upper draws and slopes were used more than lower slopes, valley bottoms or flat areas.

We calculated straight line movement distances between 5-hour step lengths and used random effects models to predict movement distances with the same variables used in the resource selection models, with the exception of aspect. Again, the global model was the top model. However, none of our predictor variables significantly predicted movement distances. The natural and individual variation in 5-hour movement distances was greater than any impacts from vegetation, topography or anthropogenic development. It is also possible that the straight line between two points, 5 hours apart, shortens the actual movement path, and over-smooths the data, making it difficult to detect any patterns in movement data.

We collected fecal samples during capture events for physiological stress hormone analysis. To bolster our sample size, we also included data from mule deer captured in a parallel study in eastern Montana. We collected 190 fecal samples. All fecal samples were homogenized, frozen, and sent to the University of Missouri Wildlife Physiological Laboratory (Columbia, MO), where concentrations of fecal glucocorticoid metabolites (FGM; physiological stress hormones) were measured. We used generalized linear models to evaluate the relationship between FGM and vegetation, topography, and anthropogenic development metrics calculated around the capture location (1.91 km or 2.91 km buffer depending on the variable). We added temperature and gravel pits to our list of covariates. Our top model was the global model. Deer captured from areas with > 3 gravel pits within 2.91 km or >1 drilling rig within 2.91 km had significantly higher FGM levels. We hypothesized that ruggedness would mitigate any disturbance impacts, but ruggedness only showed a slight, positive relationship. Temperature had a marginal effect, where FGM levels were higher when the temperature was below 0° C.

We analyzed survival data for 203 mule deer using radio-tracking data. We observed 86 mortality events. We calculated bi-weekly utilization distributions (UDs; kernel density estimates) for each deer and classified UDs into survived or mortality categories depending on whether the deer survived that period. We assigned predictor variables to each UD for background variables (age, season, temperature, biological year, snow depth, NDVI, and management unit), oil and gas energy development (distance to nearest rig, distance to nearest active well pad, rig density, well pad density, number of drilling rigs, and number of well pads) and road variables (distance to nearest road, road length and road density). We compared home ranges for periods where deer survived to home ranges where deer died using generalized linear models. The estimated annual adult survival probability was 85.6%, and overwinter juvenile

survival probability (Dec – May) was 67.7%. Survival probabilities were lowest in the winter season for adults and juveniles. The leading cause of mortality for adults was predation (32%) and for juveniles was malnutrition (22%). The most significant factor other than age and season was well pad density, and survival rates decreased by 24% when well pad density went from 0 to 1.93 well pads/km^2 (0 to 5 well pads/mi^2).

Finally, we combined results from the resource selection, physiological stress, and survival chapters with data from long-term survey data on abundance and recruitment, to create risk assessment maps for our study area. We modeled risk as the cumulative habitat quality based on survival, abundance, juvenile production, and physiological stress, predicted by our previous models for current vegetative, topography, and oil and gas development metrics. The value in this tool lies in its utility for identifying areas with high levels of risk imposed on resident deer should an area be proposed for development.

We have identified mule deer avoidance of drilling rigs and areas with high road densities, increased physiological stress in areas with high gravel pit or drilling rig densities, and decreased survival in areas with high well pad density. Our results show that mule deer responded to oil and gas development by modifying behavior, initiating a physiological stress response, and reducing survival. We make the following recommendations for oil and gas energy development occurring in mule deer range in North Dakota:

1) Minimize drilling rig locations (and gravel pits) in primary mule deer habitats during winter and fawning/fawn rearing seasons, and select locations for drilling rigs that are more open (>1.1 km from wooded edge) and have lower slopes (<15%).
2) Maintain new development infrastructure near existing roads to avoid increases in overall road density.

3) In areas where multiple wells will be drilled, consolidate wells on fewer well pads to minimize the overall well pad density (i.e. maintain well pad densities $< 5/\text{mi}^2$).
4) Create a new “primary mule deer range” map updated with information from resource selection models that incorporate: vegetation, topography, current oil and gas infrastructure and road densities.

INTRODUCTION

In North America, the exploration and production of hydrocarbons increased rapidly beginning in the early 2000s (United States Energy Information Administration [USEIA] 2012). Disturbance from such development can have negative effects on wildlife at the landscape-level, including spatial displacement and population declines (Northrup and Wittemyer 2013). Thus, examinations of resource selection patterns of wildlife species can provide a means for quantifying and understanding the spatial effects of oil and gas energy development.

Gas and oil production has become an important part of North Dakota's economy and landscape. Currently, North Dakota is among the top oil producing states and it is expected that development will continue at a great pace. Copeland et al. (2009) identified portions of western North Dakota with extremely high potential for oil and gas development. In a 2008 report, the USGS estimated a mean of 3.65 billion barrels of oil could be recoverable in the Bakken Formation in western North Dakota (http://www.usgs.gov/newsroom/article.asp?ID=1911). In 2013, the USGS raised that estimate to 7.4 billion barrels of oil and 6.7 trillion cubic feet of natural gas (http://pubs.usgs.gov/fs/2013/3013/fs2013-3013.pdf). Given recent technological developments in rock fracturing methods, recent estimates now suggest upwards of 18 billion barrels might be a more accurate estimate (http://www.nd.gov/ndic/ic-press/bakken-form-06.pdf). Such projections have resulted in considerable interest in oil and gas production in western North Dakota.

Current energy development is thus expected to continue to alter western North Dakota landscapes. As of January 2015, there were 11,892 wells producing 1.2 million barrels of oil/day (Helms 2015). Industry projections estimate that another 40,000 wells will be drilled in the next 18 years (North Dakota Industrial Commission [NDIC] presentation,14 February 2014). The average size of a well pad is 3.7 acres, and includes an average of 1.5 acres of access road development. Even larger, multi-well pads (typically 6-8 wells, and as many as 18 wells) are becoming more commonplace with the development of lateral drilling technology (Helms 2015). Multiple, directional wells—which can pump oil up to 4 miles, horizontally, from a well pad—can be positioned on a single well pad or along a narrow corridor, thus increasing the individual well pad size, but decreasing the overall footprint of each well. During the first year of development of each well, it takes roughly 2,000 vehicle visits to the well pad (NDIC Energy Presentation, Bismarck State College, 29 January 2014). In January 2014, 186 oil rigs were actively drilling in western North Dakota (vs. 78 in January of 2010). Also, in January 2015, 166 drilling rigs continued to drill for oil in western North Dakota despite lowest crude oil prices since 2009. Production is likely to remain above one million barrels of oil through 2045 (Oil and Gas Division Presentation). This scale of development has the potential to impact local wildlife resources.

A primary concern with increased oil and gas energy development is the potential loss of important wildlife habitat through direct and indirect effects. Direct effects include direct loss of habitat through development of infrastructure (e.g., well pad, roads, gravel pits, water depots, storage sites, etc.). Indirect effects include factors associated with the infrastructure such as traffic and noise that might reduce suitability of an area. Most studies have identified negative impacts of oil and gas development on the habitat of a diversity of species through either direct loss or through displacement (Sawyer et al. 2006, Walker et al. 2007). Although few studies found no effect from energy development, no study found effects due to all metrics. For example, Lendrum et al. (2012) found an effect of well pad density on 5-hour movement distances during migration, but did not detect avoidance of well pads during migration.

Researchers have documented both direct and indirect impacts of oil and gas energy development on mule deer (*Odocoileus hemionus*) in Wyoming (Sawyer et al. 2017), Colorado (Lendrum et al. 2012, Northrup et al. 2015), Montana (Ihsle 1982), and in North Dakota (Fox 1989, Cuiti et al. 2014), but the responses vary by region and season. Currently, it is projected that about 18% of the primary mule deer range in North Dakota is moderately affected by oil and gas development; another 1.7% is highly impacted (North Dakota Game and Fish Department [NDGF], unpublished report). There are 1,123 active wells in the primary mule deer range, and 6,991 active wells in the primary and secondary mule deer range. Much of this development has occurred in the past 5 years (NDGF, unpublished report). Mule deer are a valuable component of the North Dakota landscape and are prized as a game species in North Dakota. In 2014, 7,667 hunters applied for 1,150 antlered mule deer licenses. Oil and gas energy development overlaps much of the mule deer range in North Dakota, and has the potential to affect (directly or indirectly) mule deer habitat in the state.

The most recent mule deer research in North Dakota by Cuiti et al. (2014) found that juvenile production was significantly affected by the interaction between number of oil wells and an index of coyote density. While the cause of this correlation is not well understood, Cuiti et al. (2014) hypothesized that it may be due to a behavioral response to oil and gas energy development that could reduce available fawning areas and increase predator efficiency. Researchers have studied the impacts of oil and gas energy development on mule deer space use in multiple oil and gas developments. Easterly et al. (1991) reported 29 mule deer fitted with VHF collars in eastern Wyoming used areas farther away from development during the drilling phase only. Sawyer (2009) also observed avoidance of wintering areas near active developments (up to 3.7 km from drilling rigs), but avoidance persisted after drilling phases (Sawyer et al.

2017). Avoidance behavior without acclimatization (i.e. displacement) is particularly significant if mule deer are displaced from important habitats that are limited in availability. Alternatively, Ihsle (1982) did not detect impacts of oil and gas development on mule deer space use in northwestern Montana, but energy development density was low. Northrup et al. (2015) found that mule deer on winter ranges in the Piceance region of northwestern Colorado avoided drilling rigs, producing well pads, and roads, but the avoidance distances (e.g. 600-800 m from drilling rigs) were not as high as in Wyoming. Mule deer in Colorado also showed that avoidance distances decreased after the drilling phase. It was suspected that increased vegetation and ruggedness might have helped to mitigate impacts of oil and gas energy development on mule deer in Colorado. Regional variation in both avoidance distance and avoidance persistence suggests that research from other regions may have limited inference for mule deer resource selection in North Dakota.

Although there are links between oil and gas energy development and mule deer abundance (Sawyer et al. 2017), and juvenile production (Cuiti et al. 2014), there is little available research investigating the relationship between survival and energy development. Over a 15-year period in western Wyoming, Sawyer et al. (2017) noted a difference of 20% between the reduction in mule deer abundance for the population that wintered in a gas development compared to the entire subherd (36% vs. 16% reduction). The source for the decline in abundance (decreased survival, reproduction or emigration) could not be identified, but authors suggested that strong fidelity to seasonal ranges likely precluded emigration. Although hunting success rates can increase with increasing well pad density (Dorning et al. 2016), the population decline in Wyoming occurred despite reductions in hunting permits. Using long-term survey data, Cuiti et al. (2014) found a negative relationship between well pad density and juvenile production (juvenile-to-female adult ratio) in western North Dakota. However, the relationship was only significant when an interaction effect was included for coyote density. More work is still needed to investigate how impacts of oil and gas energy development might affect mule deer population dynamics via changes in survival or recruitment.

If oil and gas development has similar direct and indirect effects on mule deer in North Dakota as in other states, available habitat could be greatly reduced by the ongoing oil and gas energy development in the state. However, the effects in North Dakota could be different due to the rugged topography and woody vegetation of the badlands, non-migratory movement patterns, and a long history (> 30 years) of oil activity in the North Dakota mule deer range. Managers require region-specific information on impacts to mule deer to protect priority areas, and mitigate the potential effects appropriately. Further, mule deer in North Dakota are at the eastern edge of their distribution (Remote Sensing and GIS Laboratory 2005). Species living near the edge of their distribution are often subjected to higher levels of ecological stress (Davies et al. 2013). Because mule deer are a valued species in North Dakota, it is imperative that their habitat is better delineated and protected from effects that detract from the overall suitability.

This research is designed to be a comprehensive assessment of oil and gas development on mule deer populations in western North Dakota. Through study of space use and demographics, we have identified key factors affecting mule deer in areas of development, and recommend potential mitigation strategies to reduce and minimize impacts. The objectives of this research were to: 1) Investigate and quantify effects of oil and gas development to mule deer populations through study of resource selection (Chapter I), movements, (Chapter II), stress hormones (Chapter III), survival (Chapter IV), and 2) to overlay the effects of oil and gas energy development on mule deer in a risk assessment framework (Chapter V). A key component of this objective will be the identification of mitigation measures intended to reduce and avoid impacts to mule deer populations. In addition, this research will be a valuable supplement to the two, previous studies on mule deer biology in North Dakota (Jensen 1988 and Fox 1989). Although this study was not specifically designed to focus on reproduction we were able to estimate female pregnancy rates with opportunistic data.

Objectives

1. Investigate potential effects of oil and gas energy development on mule deer movements, physiological stress, and resource selection.

2. Investigate potential impacts of oil and gas energy development on mule deer demographics: female adult survival, and female juvenile survival.

3. Develop a risk assessment framework to compile results from previous objectives into risk maps which could be used to guide development alternatives and mitigation strategies.

Methods for all Chapters

Study Area

Our study was centered on primary mule deer range western in North Dakota—namely, the highly-eroded, broken topography (badlands) bordering the Little Missouri River (Figure 1). This area coincides largely with the Little Missouri National Grasslands, the largest National Grasslands in the United States (>400,000 ha; Mumma and Lawton 1991). We also included smaller patches of badlands along the south shore of Lake Sakakawea and between the Yellowstone and Little Missouri Rivers. Our study area was 7,906 km^2 and ranges from Latitude 46.48 in the south, west to the North Dakota border (Longitude 104.05), east to the Fort Berthold Indian Reservation (Longitude 47.85), and north to Lake Sakakawea (Latitude 48.11).

In 2014, we added subsequent areas with low levels of oil and gas energy development in similar badlands habitats: 1) to the east of the Yellowstone River in eastern Montana, and 2) south of Culbertson, MT adjacent to the Missouri River (Figure 1). These areas were added to increase sample size for our physiological stress research.

Ecology. The primary vegetation type was mixed-grass prairie with pockets of shrubs and wooded north-facing slopes, draws and floodplains. North-facing, wooded slopes were dominated by Rocky Mountain juniper (*Juniperus scopulorum*), common juniper (*Juniperus communis*), horizontal juniper (*Juniperus horizontalis*), chokecherry (*Prunus virginianus*), skunkbrush (*Rhus trilobata*), and woods rose (*Rosa woodsii*). Wooded draws often contained green ash (*Fraxinus pennsylvanica*) with chokecherry and woods rose understory. The overstory for wooded floodplains of the Little Missouri River was cottonwood (Populus deltoides). Wide, well-drained valley bottoms contained mostly silver sage (*Artemisia cana*) and western wheatgrass (*Agropyron smithii*). Shrub patches included: buffaloberry (*Shepherdia argentea*), buckbrush (*Symphoricarpos occidentalis*), chokecherry and skunkbrush (*Rhus trilobata*). South-facing, eroded clay slopes were typically bare, but did have rabbitbrush (*Chrysothamnus nauseosus*), shadscale saltbush (*Atriplex confertifolia*), and greasewood (*Sarcobatus vermiculatus*). Major grasslands included western wheatgrass, little bluestem (*Andropogon scoparius*), blue grama (*Bouteloua gracilis*), needle-and-thread (Stipa comata), green needlegrass (*Stipa viridula*), and prairie junegrass (*Koeleria cristata*). Introduced grasses included smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), Kentucky bluegrass (Poa pratensis) and cheatgrass (*Bromus tectorum*). A thorough study of vegetative components of the Little Missouri National Grasslands can be found in Godfread (1994).

Other ungulate species included: white-tailed deer (*Odocoileus virginianus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), bighorn sheep (*Ovis Canadensis*), as well as domestic cattle, sheep and horses. Potential predators of mule deer included coyotes (*Canis* *latrans*), mountain lions (*Puma concolor*), bobcats (*Lynx* rufus) and golden eagles (*Aquila chrysaetos*).

Climate. The climate was similar across our study area, except for the winter of 2012-13, when snow accumulated in the northern portion of the study area, but not to the south (mean daily snow accumulation for Watford City: 596 cm vs. Marmarth 495 cm; National Oceanic and Atmospheric Administration [NOAA] 2017). Temperature in our study area from 2013-2015 ranged from -37.2 C to 40 C. The average seasonal high/low daily temperatures were: winter: -0.2/-11.7, spring: 15.6/1.3, summer: 25.7/11.2 and autumn: 9.1/-3.3 (Figure 2). Annual precipitation (biological year) was 53.6 cm, 44.6 cm, and 35.9 cm for 2013, 2014, and 2015 respectively. Seasonal precipitation totals were winter: 12.6 cm, spring: 33.4 cm, summer: 65.6 cm, and autumn: 16.0 cm (data from daily summaries for Grassy Butte, Keene, Watford City, Dickinson, Marmarth, and Medora ND and Sidney, MT; NOAA 2017).

Geology. Topography is generally eroded badlands habitats, and elevation ranges from 550m to 1050m above sea level. Soils are clayey, with sandy loam draws and sandy hilltops. Bedrock layers are primarily sandstone, and in the eroded areas exposed sandstone, coal veins and scoria layers lend to the general appearance of badlands (Mumma and Lawton 1991, Godfread 1994).

Land Use. Land ownership is intermingled with 52% public (USFS, National Park Service, State Trust Lands, Bureau of Land Management) and 48% private. Due to the arid climate and availability of affordable grazing leases on public lands, private lands are typically managed for livestock production. Only 6% of the area was cultivated: 3% row crops (primarily winter and spring wheat, canola, sunflowers and corn), 1% planted alfalfa, and 2% planted hay (NASS 2015). Because 52% of our study area included public land, it was open to public hunting. Due to low deer densities during our study (Figure 3), hunting seasons for antlerless mule deer were closed from 2012-2015. Antlered mule deer seasons were open for archery (September-December) and rifle (first two weeks in November) seasons. Our study area spanned five hunting units, and in those units 601 mule deer bucks were harvested by 800 rifles hunters in 2012 up to 1,144 mule deer bucks by 1,400 hunters in 2015 (North Dakota Game and Fish Department [NDGF], unpublished data. Archery harvest summaries are only available statewide, where harvest ranged from 416 in 2012 to 750 in 2015.

The Bakken and Three Forks Shale Formations largely overlapped with our study area (Figure 4), and oil and gas development, including drilling rigs and actively producing wells, occurred prior to and during our study (Figure 5). The study area encompassed areas with more than 1.93 active well pads/km^2 (5 active well pads/mi^2), which the Western Association of Fish and Wildlife Agencies guidelines (WAFWA; Lutz et al. 2011) considered a high level of development for mule deer habitat.

Field Methods

To guide our capture effort, we identified target locations for adult and juvenile captures based on the level of oil and gas development. We used a coarse grid (4.8 x 4.8 km) to stratify our study area into 3 development levels. We chose 4.8 km as a conservative estimate for an area that would contain an annual home range for a non-migratory, female, adult mule deer, 17.8 km^2 (Hamlin and Mackie 1989), and because the distance (3 miles) allowed us to overlay our grid on legal description lines to correspond with lands where we had permission to capture deer. Hebblewhite et al. (2011) summarized several studies on the impacts of energy development on ungulate resource selection and found that noticeable avoidance occurred when well densities reached 0.1 to 0.4 wells/km^2, or when road densities reached 0.18-1.05 km/km^2. Further, in the

WAFWA habitat guidelines for mule deer, areas with 5-16 wells and 20-80 acres disturbed/mi^2 (1.9-6.2 wells/km^2 and 8.1-32.4 hectares/2.6 km^2; Lutz et al. 2011) were considered high impact to mule deer habitat (Fox et al. 2009). In our study area there were areas with up to 9.0 active wells/km^2; however, that included well pads with multiple producing wells per pad. We therefore examined individual well pads (see also Northrup et al. 2015). Our study area had areas with up to 3.6 active well pads/km^2, and in addition there were other types of oil and gas related infrastructure: gas plants, water depots, gravel pits, etc.

To combine linear and point development features, we used a minimum hypothesized disturbance distance for each development feature, and buffered the feature to estimate the area disturbed. We assumed traffic is the major disturbance in oil and gas energy development (Sawyer et al. 2009), so we buffered lower traffic development features (producing well pads, low grade gravel roads) by 100 m (Freddy et al. 1986, Fox 1989 and Lutz et al. 2003), and higher traffic development features (drilling rigs, high grade and paved roads, gas plants, gravel pits) by 250 m. Our buffers were conservative; mule deer avoided areas 100-400 m from roads (Freddy et al. 1986, Fox 1989 and Lutz et al. 2003) and mule deer selected areas that were 600 m to 3.7 km from active drilling rigs (Sawyer et al. 2009, Northrup et al. 2015). We dissolved all overlapping buffer polygons to create a single oil and gas energy development polygon. We overlaid the development polygon on our gridded study area to calculate the proportion of each 4.8 x 4.8 km grid cell that was overlapped by our development polygon. We used natural breaks in the proportion disturbed to classify grid cells into a low, medium or high development. Finally, we created two systematic random sets of locations (20 for adults, 10 for juveniles) in each development level, which served as target capture locations. To minimize the potential for auto-correlation, we maintained 4.8 km between any two capture target locations (i.e. 1 point per grid cell).

Statewide mule deer abundance was at a 15-year low in 2012, with fewer than 5 deer/mi^2 (15-year range: 4.5 – 10 deer/mi^2; NDGF, unpublished data), so we flew reconnaissance flights prior to capture to search for deer near target locations, beginning December 2012. We recorded waypoints for each deer group (or abundant tracks in snow), and adjusted the random target capture locations to match the nearest waypoint where deer were found. Although we could not find and capture deer at every target location, we maintained our original capture distribution within each treatment level.

We captured mule deer February 2013, December 2013, and December 2014 using helicopter net-gunning (Native Range Capture Services Inc., Elko, Nevada). In each development level, we captured and fitted 20 female adults ($\geq$ 1.5 years old) and 10 female juveniles with satellite GPS collars (G2110E Iridium and G2110L Iridium; Advanced Telemetry Systems Inc. [ATS], Isanti, Minnesota), for a total of 90 GPS-collared deer (i.e., 30 deer at 3 treatment levels). We programmed collars to collect GPS locations every 5 hours to ensure sampling from all times of the day. Data were transmitted via satellite every 4 days; satellite technology allowed us to collect locations without disturbing deer during monitoring activities. Further, satellites attained locations regardless of access to the deer location. We programmed collars to transmit notifications if the collar was inactive for >6 hours, which enabled us to inspect carcasses promptly after mortality events. A built-in VHF transmitter aided in real-time tracking of deer, which was necessary to quickly recover carcasses after mortality events. Battery expectancy for this GPS fix schedule was 3.5 years and 2 years for G2110E and G2110L collars, respectively.

We conducted subsequent captures annually to maintain a radio-marked sample of 60 female adults and 30 female juveniles. We captured new juveniles each winter because juveniles captured the previous year graduated to yearlings on 01 June (the approximate parturition date in North Dakota; Jensen 1988). We captured additional female adults to account for mortalities and collar failures. All animal use activities were reviewed and approved by the University of Missouri Institutional Animal Care and Use Committee (Protocol 7552).

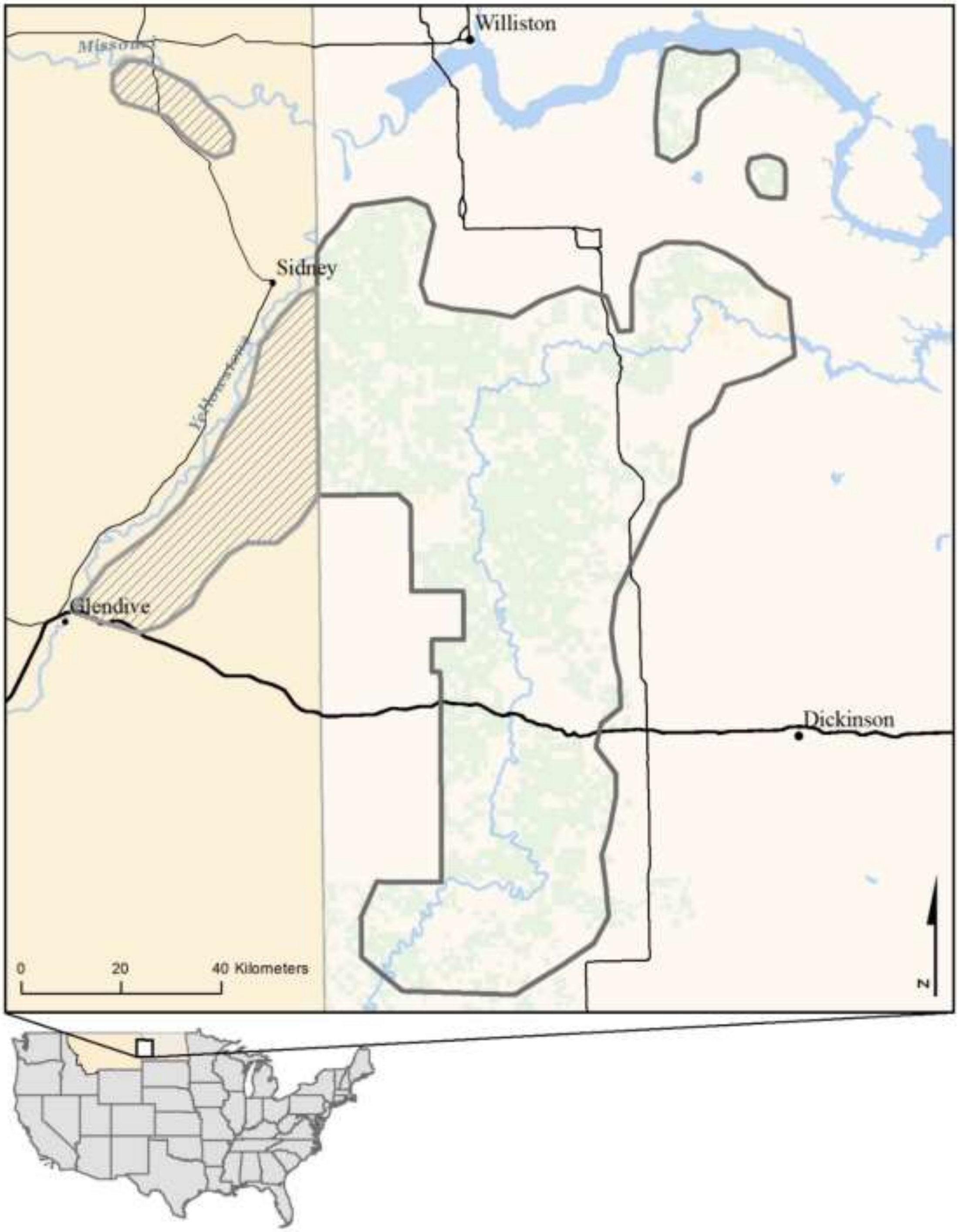

Figure 1. Map of mule deer study area in western North Dakota overlapping the Little Missouri National Grasslands (green). Also shown are boundaries for two Montana study areas (hashed lines) along the Yellowstone River and southeast of Culbertson, MT; the Montana study areas were only used for the physiological stress chapter of this report.

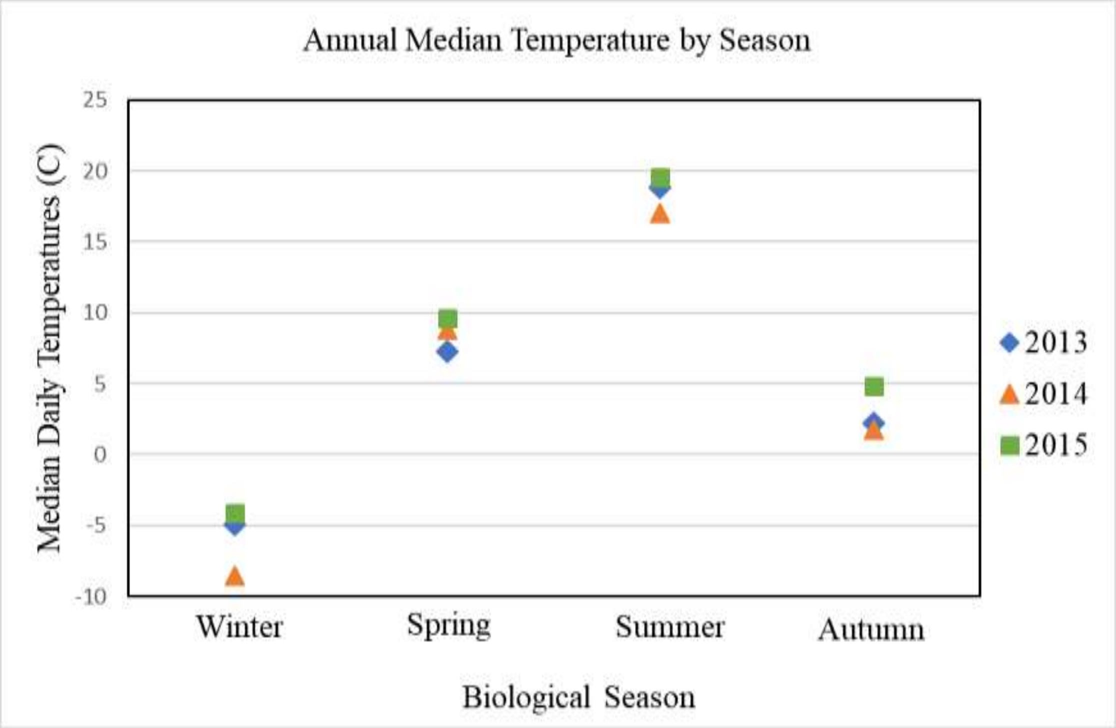

Figure 2. Median of the mean daily minimum and maximum temperatures, by season, for each year of this research, 2013-2015. Data compiled from National Oceanic and Atmospheric Administration, Climate Data Online, Daily Summaries for Grassy Butte, Keene, Watford City, Dickinson, Marmarth, and Medora, ND and Sidney, MT.

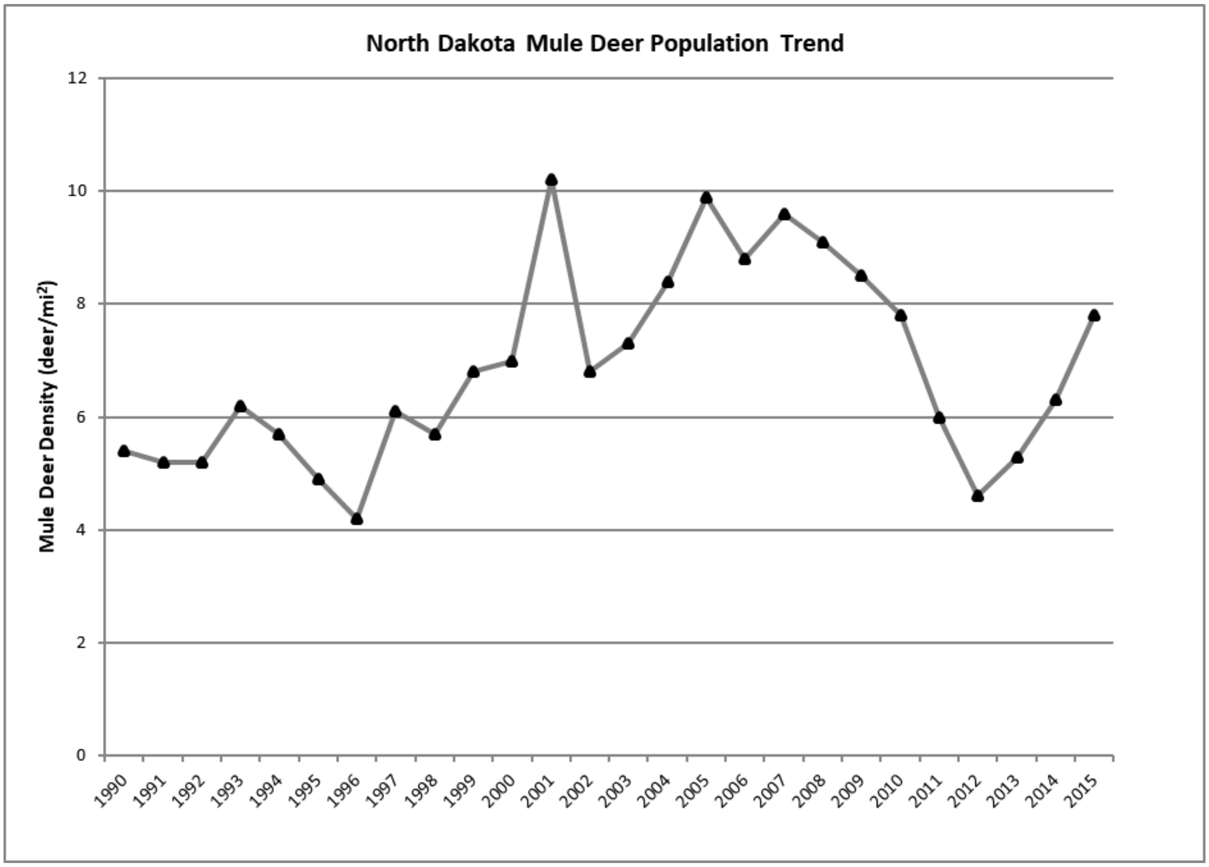

Figure 3. Chart of the long-term mule deer density in western North Dakota from 1990-2015, determined by aerial, block counts. The density in 2012, prior to our initial capture, was the lowest since 1996.

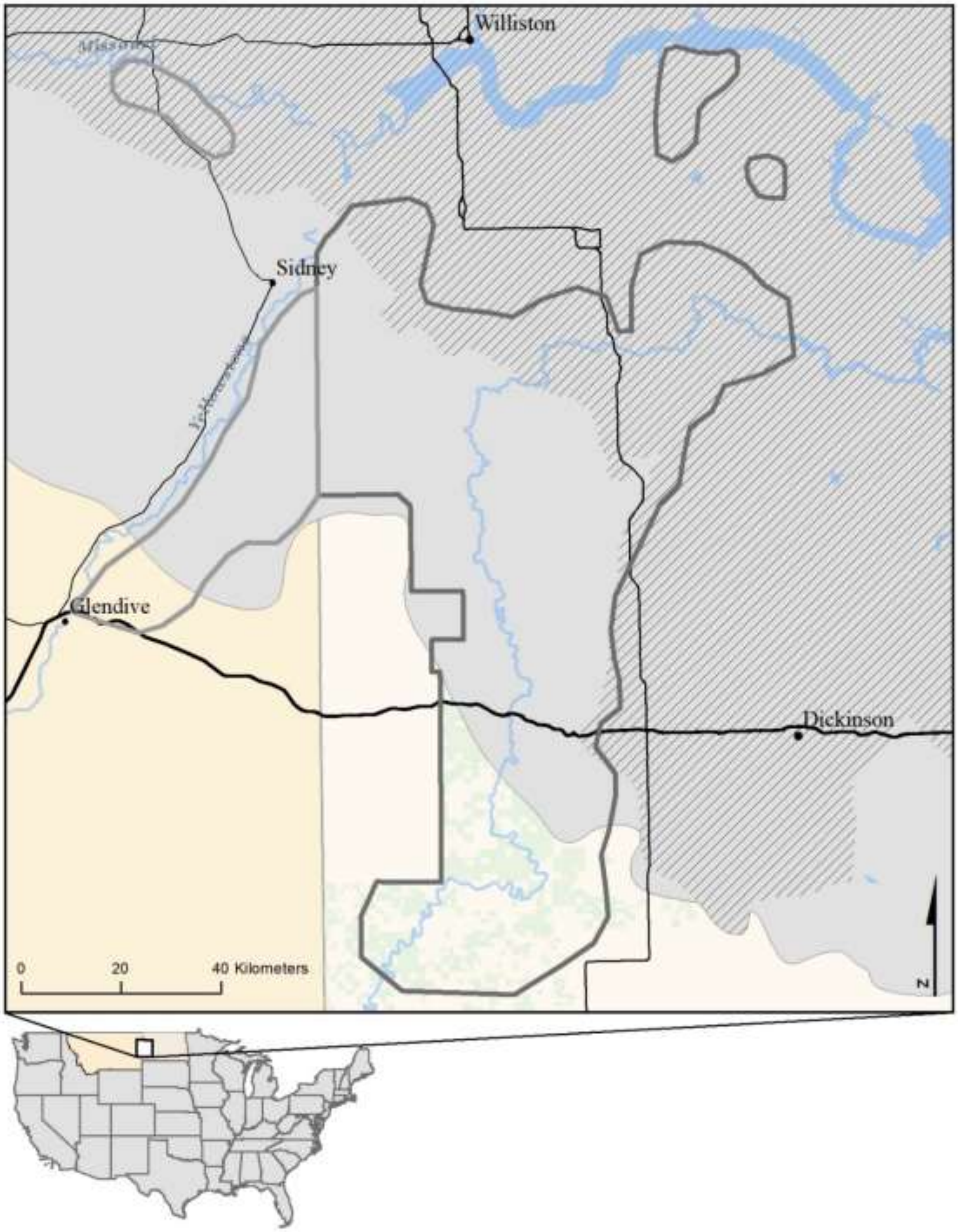

Figure 4. Map of mule deer study area and the overlapping Bakken (hashed lines) and Three Forks oil formations (gray) in western North Dakota and eastern Montana.

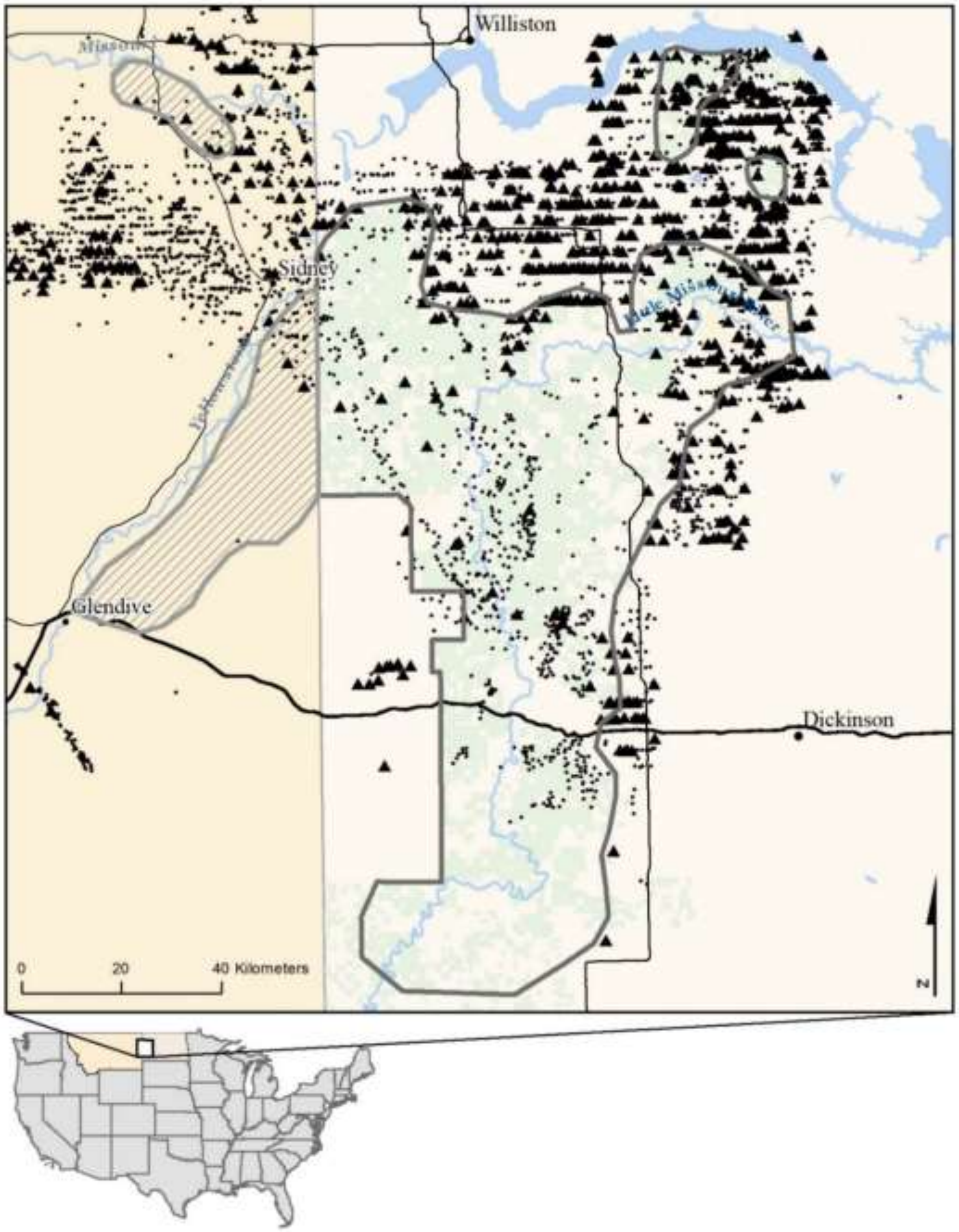

Figure 5. Map showing distribution of active drilling rigs (black triangles) and producing well pads (black dots) in western North Dakota and eastern Montana from 2013-2016.

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CHAPTER I. RESOURCE SELECTION OF MULE DEER IN WESTERN NORTH DAKOTA

Introduction

Animals distribute themselves across the landscape which is a fundamental ecological process that serves to maximize fitness (Fretwell and Lucas 1969). Understanding habitat selection can provide insight into numerous, individual-level ecological processes (e.g., site fidelity [Creel et al. 2005], foraging and predation risk [Switzer 1997]), as well as landscape-scale processes that affect population distribution and abundance (e.g., population dynamics [Pulliam and Danielson 1991], speciation [Rice 1987], dispersal [Shafer et al. 2012]). As noted by Sawyer et al. (2006), human development can change habitat selection patterns; however, different species may be affected in different and complex ways. Human activity may directly convert habitat into unusable area, but some activities may also lead to functional habitat loss in a disproportionately larger area that that which was developed directly (e.g., Sawyer et al. 2006). Animal responses to human activities also can be more nuanced, whereupon humans can be perceived as predators, prompting behavioral shifts that stem from tradeoffs between security and foraging or reproduction (Frid and Dill 2002, Hebblewhite and Merrill 2008). In contrast, animals can be attracted to areas of human development if vegetation disturbance stimulates new plant growth (Lutz et al. 2011) or through protection against predation (i.e., “human shield” [Berger 2007]). Such responses to anthropogenic changes can yield positive results for animals, though they can also lead to greater potential for negative encounters via human-wildlife conflict (Johnson et al. 2004) and the formation of evolutionary traps (e.g., Northrup et al. 2012, Chitwood et al. 2017). Given the myriad and complex responses of animals to human development, quantifying the mechanisms driving changes in wildlife behavior continue to be critical for developing appropriate management and mitigation strategies.

Throughout the western United States, energy development has occurred on mule deer (*Odocoileus hemionus*) winter range, which can result in decreased access to high quality forage (Parker et al. 1984). Moreover, across much of their range, mule deer have experienced major population declines (Unsworth et al. 1999), and recent studies indicate that mule deer have been displaced by and altered their habitat selection patterns in response to oil and gas energy development (Sawyer et al. 2006, 2009). Given that energy extraction is projected to continue to increase over the next several decades (USEIA 2014), assessing the effects of energy development on mule deer resource selection continues to be a major management priority. Thus, our objective was to identify the anthropogenic, vegetative, and topographic drivers of mule deer resource selection in a landscape that was undergoing rapid development due to energy extraction.

Methods

We analyzed mule deer landscape-scale selection (Johnson et al. 1980) in western North Dakota from Feb 2013 to Sept 2016 by employing a used vs. paired-available, discrete choice design (Cooper and Millspaugh 1999). We designated each mule deer location as a used site and selected 5 paired-available locations for each used site, without replacement, from a pool of random locations we created throughout the study area. To create the pool of random locations, we first defined the study area extent as a composite of buffers around capture locations with radii representing the mean of the maximum distances mule deer traveled from their capture site. Thus, we buffered 119 capture locations with a radius of 11 km to define available space (Figure 6). Then, because mule deer use was not uniform across the study area, we stratified the study area extent into 22 km x 22 km grid cells and placed 5 times the number of random locations as used locations within each grid cell. At each used and paired-available mule deer location, we identified vegetation, topographic, and anthropogenic development variables (Table 1) that may influence mule deer selection and hypothesized how each variable may be related to selection (e.g., linear, quadratic, or pseudo-threshold relationship; Franklin et al. 2000).

We used the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) 30-m United States Cropland layer (USDA NASS 2013-2016) in ArcInfo 10.5 (Environmental Research Systems Institute, Redlands, CA) to identify vegetation types across the study area. To reduce the number of vegetation classes, we grouped NASS vegetation types into 7 dominant categories including “wood” (deciduous and evergreen forest and woody wetlands—we grouped deciduous and evergreen because remote sensing data did not appear to accurately differentiate juniper from deciduous trees), “shrub” (shrublands), “grass” (grasslands), “hay” (hay fields and fallow/idle croplands), “legume” (alfalfa, peas, and other legume crops), “crop” (non-legume crops), and “barren” (areas devoid of vegetation). We dissolved pixels identified as “disturbance” into the majority vegetation category within a 0.09 km^2 square neighborhood around the pixel because disturbance categories, primarily consisting of unpaved roads, were relatively rare throughout our study area (<2% of pixels) and we already included road density as a variable in our model. If “disturbance” was the majority category in the 0.09 km^2 neighborhood, we reclassified the pixel as “barren.” Also, we acquired monthly normalized difference vegetation index (NDVI) layers with 250-m resolution from eMODIS (Jenkerson et al. 2010) to quantify vegetation greenness because NDVI can be used as an indicator of forage availability for ungulates in open habitats (Borowik et al. 2013).

We included two vegetation-based variables that characterized landscape patterns: distance to the nearest wooded edge (Northrup et al. 2015, like maximum structural contrast: Kie et al. 2002) and interspersion and juxtaposition index (IJI; McGarigal et al. 2012). To calculate distance to wooded edge, we first “smoothed” the wood category from our vegetation layer. Occasionally, pixels classified as something other than “wood” occurred within contiguous wooded areas. We reclassified pixels as “wood” if ≥ 75% of the surrounding pixels were classified as “wood” to ensure pixels surrounded by contiguous forest were not classified as wooded edge. Next, we designated a pixel as “wooded edge” if the pixel had at least one neighboring “wood” pixel, but was not completely surrounded by “wood” pixels. Last, we calculated the Euclidean distance from each pixel across the study area to the nearest “wooded edge” pixel to create a spatial map of distances to wooded edge. We used the moving window option in FRAGSTATS (McGarigal et al. 2012) to calculate the IJI within a 2-km buffer around each pixel of the 30-m 2011 National Land Cover Database layer (Homer et al. 2015). The IJI values ranged from 0 to 100, with higher values representing a vegetation patch type being equally adjacent to all other patch types. We hypothesized mule deer would select for moderate IJI levels, so we included the quadratic form of this variable in our model.

We used a 30-m digital elevation model (DEM) raster layer to calculate slope, northness, ruggedness index, and landforms based on the topographic position index (landform TPI). We created slope and aspect layers from the DEM layer using the Spatial Analyst toolbox in ArcInfo 10.5 and calculated topographic northness by taking the cosine of the aspect in radians, which results in values ranging from -1 (sloping directly south) to 1 (sloping directly north). We calculated the ruggedness index using equations provided in Sappington et al. (2007), who determined that a 3 x 3 pixel neighborhood (8,100 m^2) captured the complexity of the landscape without over-smoothing it. Ruggedness values ranged from 0 to 1, with greater values representing greater ruggedness. We calculated landform TPI using the Topography Toolbox for ArcGIS 10.1 and Earlier (Dilts 2015), and classified landform TPI values developed at 180-m and 2000-m scales into 4 landforms: ridges and heads of draws; mid to upper slopes; flat, lower slopes; and valleys. We hypothesized mule deer would select moderate values for slope and ruggedness (moderate slopes: Sawyer et al. 2009; mule deer selected lower slopes: Lendrum et al. 2012, Horncastle et al. 2013; greater slopes: Northrup et al. 2015), so we included the quadratic form for these variables.

We created line shapefiles for all roads by using City and County Roads and State and Federal Roads (ND Department of Transportation 2016), combined with a road shapefile digitized manually from 2015 NAIP aerial imagery, at a 1:5,000 scale. We used this roads layer to estimate distance to primary or secondary roads and road densities by dividing the total length of roads within 2 km by 12.57 (area within 2 km). We determined the number of drilling rigs and active wells each month using spatial data from the Oil and Gas Division, North Dakota Department of Mineral Resources (downloaded monthly 2013-2016). We consolidated multiple wells if they occurred on the same well pad (Northrup et al. 2015), so we used active well pads in our models. If a drilling rig and well were present on the same active well pad, we consolidated them as a drilling rig (Northrup et al. 2015) to avoid duplication of development points at a single well pad. The effects of drilling rigs and active well pads on selection may be scale-dependent, so we included the presence/absence of drilling rigs within 2.5 km (Sawyer et al. 2009) and 600 m (Northrup et al. 2015), as well as the number of active well pads within 2 km (Sawyer et al. 2009), 900 m (Fox et al. 2009), 400 m (Northrup et al. 2015), and 100 m (Fox 1989).

We hypothesized the influence of variables on selection would be dependent on season (summer [Jun. 1 – Sep. 31], autumn [Oct. 1 – Nov. 30], winter [Dec. 1 – Mar. 31], spring [Apr. 1 – May 31]), time of day (day, night, crepuscular [within 2 hours of sunrise or sunset]), and age (adult [≥1 year old], juvenile [<1 year old]). Thus, we included interactions between each variable and season, time of day, and age in our analysis. We checked for multicollinearity between variables by calculating Pearson's correlation coefficient (*r*) using the cor() function in R (R Core Team 2016). If $r > 0.65$, we removed the correlated variable that explained the least variation in selection. Distance to road and number of active well pads within 2 km were correlated with other variables so we removed them from the model analysis.

We fit conditional logistic models using the "clogit" package in R with unique mule deer identification as a "cluster" variable, which accounts for potential dependence among locations when calculating variance (Therneau 2015). First, we ran single-parameter models that included only active well pad variables at each scale (2,000 m, 900 m, 400 m, 100 m). We used only the most supported scale for the active well pad variable (i.e., number of active well pads within 900 m) in future modeling to reduce the number of parameters in our final model. Next, we ran a vegetation model that included vegetation and IJI covariates; a topographic model with slope, northness, ruggedness, and landform TPI covariates; a development model that included road, rig, and active well pad covariates; and a full global model with all covariates. We compared Akaike's Information Criterion values (Akaike 1973) among models and assumed the model with the lowest AIC value was the most supported (Burnham and Anderson 2002). Due to the large size of the dataset, we used the Lewis high-performance computing cluster at the University of Missouri, which consists of 1,808 cores and 13TB of RAM, to fit conditional logistic resource selection models.

We demonstrated the effect of variables on mule deer selection by using model results to calculate and plot the changes in relative probability of selection across the range of values of the variable of interest while keeping all other variables in the model at their average value. We used the facet grid option in the “ggplot2” package in R (Wickham 2009) to facilitate the identification of differences among seasons, times of day, and ages. We also created a predictive map of mule deer selection across the study area using Raster Calculator in ArcMap 10.5.

We evaluated the predictive ability of our top model by using a modified 5-fold cross-validation design (Boyce et al. 2002). We withheld 20% of choice sets (1 used and 5 paired-available locations; “test” data) and refit the most-supported model using the remaining data ("training" data). We used the new parameter estimates from the training data model to calculate relative selection probabilities for locations in each choice set of the "test" data. Finally, we ranked locations within each choice set by their relative probabilities of selection. We repeated these procedures 5 times, without replacement, so the relative probability of selection was estimated for each location from the dataset using pseudo-independent “training” data. We assessed model performance by examining the proportion of choice sets where the location selected by the mule deer had the highest predicted relative probability of selection, compared to the paired available locations. Given the choice set consisted of 6 options, we would expect predictive success of 16.67% due to random chance alone. We expected a good predictive model to show a large proportion of used sites with higher relative probabilities of selection than random sites.

Results

We captured 207 mule deer (101 adults and 106 juveniles) in North Dakota during 3 captures: February 2013, December 2013, and December 2014 (Table 2). We used 431,581 used mule deer locations and 2,157,905 random locations of 157 adults and 103 juveniles (Table 3). The full global selection model had a lower AIC value (AIC = 1,267,613) than the vegetation model (AIC = 1,352,782), topographic model (AIC = 1,370,499), and anthropogenic development model (AIC = 1,487,884). Thus, we used the global model to predict mule deer selection.

The presence of a drilling rig within 600 m had the greatest impact on mule deer selection; sites without drilling rigs within 600 m were approximately 22 times more likely to be selected than sites with drilling rigs (Table 4, Figure 7, Figure 8). However, the presence of drilling rigs within 2,500 m and the number of active well pads within 900 m had no significant influence on mule deer resource selection. Road densities also influenced adult mule deer selection, with greater relative probabilities of selection at lower road densities (Figure 9), but the effect was less pronounced in juveniles. Drilling rigs were relatively scarce across the study area, with only 0.22% of available sites having drilling rigs within 600 m. Thus, while drilling rigs drove selection within 600 m when they occurred, vegetation and topographic features were the main drivers of mule deer selection across most of the study area (Table 4, Figure 10).

Mule deer were more likely to use wooded and shrubby areas close to wooded edges and less likely to use crops during the day across seasons (Figures 11 and 12). However, they were more likely to use more open vegetation types such as hay and legumes during the night and crepuscular hours (Figure 11). Mule deer selected ridges/heads of draws and slopes more often than flat areas and valleys during the day, but differences among topographic positions were less pronounced at night (Figure 13). Mule deer generally selected areas with higher ruggedness, but the effect plateaued at ruggedness values >0.75 and mule deer used less rugged areas at night and crepuscular hours (Figure 14). Similarly, probability of mule deer selection peaked at intermediate slopes, ranging from 15% to 20%, with steeper slopes selected more often during the day and in winter (Figure 15).

Our model predicted mule deer selection reasonably well, with 37.84% of used locations predicted to have the highest relative probability of selection and 80% of used locations ranked in the top 3 of the 6 available choices. The used location was only predicted to be the least probable of selection out of the available choices 2.7% of the time, providing further support for the utility of our model.

Discussion

Mule deer resource selection in response to energy-related development, topography, and vegetative cover has been mixed across studies. Like Northrup et al. (2015) in the Piceance Basin of northwestern Colorado, we determined the strongest negative predictor of mule deer use to be the density of drilling rigs within 600 m across all seasons. Sawyer et al. (2009) documented avoidance of drilling rigs on winter range, but in our study, avoidance was even stronger in other seasons, particularly in summer and autumn. Although winter habitat can be crucial for mule deer and ungulate population growth in general (Forrester and Wittmer 2013), ungulates might be using areas of increased development in winter when the need for foraging outweighs the cost of vigilance. Compared to the Pinedale Anticline (Sawyer et al. 2009), both the Piceance Basin (Northrup et al. 2015) and the Little Missouri Badlands (this study) had greater topographical relief and vegetative cover. Moreover, we did not find significant relationships between deer use and active well pad densities at 100 m, 400 m, 900 m, or 2000 m, contrary to results reported elsewhere (Sawyer et al. 2009, Northrup et al. 2015). During migration in the Piceance Basin, Lendrum et al. (2012) did not detect mule deer avoiding areas closer to well pads; rather, deer selected areas closer to well pads in their developed sites. Lendrum et al. (2012) hypothesized that increased topography and vegetative cover might have mitigated the influence of indirect effects of drilling rigs on mule deer resource selection. Indeed, ungulates have shown suppressed responses to anthropogenic development in areas with decreased visual distance (Webb et al. 2011, Montgomery et al. 2012).

Lendrum et al. (2012) also hypothesized that deer potentially were acclimated to the presence of the well pads on developed sites, which is consistent with the idea that ungulates may become accustomed to predictable, low levels of unthreatening traffic (Freddy et al. 1986, Lutz et al. 2003). However, Sawyer et al. (2006, 2017; Pinedale Anticline) did not observe deer becoming accustomed to oil and gas development, even after 3 years. Fox (1989) studied mule deer in a portion of our study area during early development phases and documented lower relative use of areas around well pads. Thus, it is possible that in our study area, a combination of topographical and vegetative cover, as well as a long-term acclimatization to anthropogenic disturbance, resulted in shorter avoidance distances from drilling rigs (600 m) and no significant avoidance of well pads.

Age of deer affected resource selection relative to road density and presence of drilling rigs. Mule deer had greater relative probabilities of selection at lower road densities, though the effect was less pronounced in juveniles. Similarly, adult deer avoided drilling rigs more than juveniles did. Though we did not connect resource selection to reproductive success in this study, age-related differences in selection could have profound effects on population dynamics if mature females choose to move away from anthropogenic disturbances and suffer negative nutritional consequences of using inferior habitat conditions. For example, Lendrum et al. (2013) determined that rates of travel during migration and timing of arrival to parturition areas were affected by oil and gas energy development, which could have population-level implications if deer do not adapt to disturbances accordingly. Given that drilling rigs were relatively scarce across the study area, with only 0.22% of available sites having drilling rigs within 600 m, it is more likely that road density (and, by extension, traffic) is a more important driver of age-related resource selection patterns. Sawyer et al. (2009) determined that high levels of traffic near well pads helped drive winter habitat selection patterns at their site, and Northrup et al. (2015) suggested that reduced vehicle traffic is likely one of the best mitigation strategies to benefit mule deer in energy landscapes.

While drilling rigs drove selection within 600 m where they occurred, vegetation and topographic features were the most important drivers of mule deer selection across most of the study area. Mule deer selected for areas with moderate slopes, on ridges or upper draws, and closer to wooded edges. Thus, at a landscape-scale, our predictive map shows a higher probability of use consistent with the delineation of primary mule deer range (North Dakota Game and Fish Department [NDGF], species range map, unpublished). Also, deer selected for moderate levels of ruggedness, but the relationship was not as strong as the relationship with slope. It is possible that ruggedness was not as useful for predicting habitat use because it was measured at a larger scale (90 x 90 m grid cell) than slope (30 x 30 m grid cell). Some areas in the badlands appear to have very low relative probability of selection but are known to harbor high densities of deer (e.g., Little Missouri River basin, Buckhorn Road., Lower 30 Road, KT Road, parts of the HT Ranch aerial survey block, and Davis Creek). These areas were all relatively flat areas with topographic relief that might have been over-smoothed by 30 m DEM data and small patches of buffaloberry or other shrubs that would not have been classified by 30 m NASS vegetation data. Thus, we must acknowledge that it is likely that some selection is occurring at scales smaller than the scale of our vegetation or elevation data.

Management Implications

The two most crucial periods for mule deer population growth and persistence are: 1) juvenile recruitment (Jun - Sep) and 2) winter survival (Dec - Mar; Forrester and Wittmer 2013). Hebblewhite (2008) recommended minimizing human disturbance during the winter on mule deer winter range, but because deer in our study avoided drilling rigs and areas with increased road density in all seasons, it also appears managers might consider negative effects during the summer fawning and fawn rearing season. Well spacing that minimizes the development of new roads (and increased traffic) will have fewer negative effects on mule deer habitat. Although it is not realistic that drilling be restricted in summer and winter, it could benefit deer to consider spacing of drilling rigs during these crucial periods. Additionally, because deer selected ridges and heads of draws more than any other landform, we suggest that anthropogenic infrastructure should be placed in flatter (< 15% slope), open areas (>1.1 km from wooded edges) when possible.

Finally, we provide data that could be used to improve the primary mule deer range maps currently used by the NDGF. Two areas are currently excluded from “primary” range on the current species map appear to have suitable habitat for mule deer: 1) the badlands and hills between the towns of Trotters and Cartwright and 2) the Missouri River breaks on the south side of Lake Sakakawea from Tobacco Gardens State Park to Antelope Creek Wildlife Management Area. The resource selection models we have developed could be applied to western North Dakota to improve the delineation of primary and secondary mule deer range.

Table 1. Organization of variables in respective hypothesis sets used to model resource selection of mule deer in North Dakota from 2013 to 2015.

Hypothesis	Models
Vegetation	Vegetation Class[a]
	Wooded edge (distance to nearest wooded edge)
	Interspersion Juxtaposition Index (IJI)[b]
	NDVI[c]
Topography	Northness (sine of aspect)
	Slope (%)
	Ruggedness (vector ruggedness measure, 0 to 1)
	Landform[d]
Anthropogenic Development	Distance to nearest road
	Road density (within 2,000 m buffer)
	Density of active well pads (within 900 m)
	Presence of drilling rig (calculated within 600 m and 2500 m)
(Interactions)	Age[e]
	Season[f]
	Time of Day[g]

[a] Vegetation Class from National Agriculture Statistics Survey data (wooded, shrubland, grassland, legume crops, row crops, fallow/planted hay, barren)

[b] IJI = a measure of landscape homogeneity

[c] NDVI = Normalized Difference Vegetation Index, a measure of vegetation greenness

[d] Landform = topographic concavity calculated using the Topographic Position Index (ridge or head of draw, mid to upper slope, lower slope, valley, flat)

[e] Age = mule deer age assuming 01 June fawning date (<1 = fawn, >1 = adult)

[f] Season: summer (01 Jun – 30 Sep), fall (01 Oct – 31 Dec), winter (01 Jan – 31 Mar), spring (01 Apr – 31 May)

[g] Time of Day = day, night or crepuscular (+/- 2 hours from sunrise or sunset).

Table 2. Summary of mule deer captured during three capture events in North Dakota and two capture events in Montana, December 2012[a] – 2014.

	North Dakota			Montana		
Year	Does	Fawns	Total	Does	Fawns	Total
2012[a]	60	30	90	-	-	-
2013[b]	16	30	46	20	20	40
2014	25	46	71	10	23	33
Total	**101**	**106**	**207**	30	43	73

[a] The initial capture in North Dakota was postponed until February 2013

[b] The initial capture in Montana was postponed until February 2014

Table 3. Number of mule deer (n) and used/random mule deer locations from 2013-2016 in western North Dakota that we used for discrete choice analyses.

Age	Time of Day[a]	Season[b]	*n*	Used	Random
Adult	Day	Summer	145	58,801	294,005
Adult	Day	Autumn	128	15,830	79,150
Adult	Day	Winter	140	30,570	152,850
Adult	Day	Spring	131	26,560	132,800
Adult	Crepuscular	Summer	145	45,679	228,395
Adult	Crepuscular	Autumn	128	20,808	104,040
Adult	Crepuscular	Winter	140	39,285	196,425
Adult	Crepuscular	Spring	131	20,903	104,515
Adult	Night	Summer	145	31,610	158,050
Adult	Night	Autumn	128	25,018	125,090
Adult	Night	Winter	140	49,691	248,455
Adult	Night	Spring	131	14,898	74,490
Juvenile	Day	Winter	103	9,123	45,615
Juvenile	Day	Spring	67	7,055	35,275
Juvenile	Crepuscular	Winter	103	11,614	58,070
Juvenile	Crepuscular	Spring	67	5,531	27,655
Juvenile	Night	Winter	103	14,679	73,395
Juvenile	Night	Spring	68	3,926	19,630
Total				431,581	2,157,905

[a] Day = 2 hours after sunrise - 2 hours before sunset; Crepuscular = within 2 hours of sunrise or sunset; Night = 2 hours after sunset - 2 hours before sunrise

[b] Summer = Jun. 1 - Sep. 31; Autumn = Oct. 1 - Nov. 30; Winter = Dec. 1 - Mar. 31; Spring = Apr. 1 - May 31

Table 4. Estimates, robust standard errors of estimates (SE), odds ratios (OR), odds ratio 95% confidence limits (OR L95, OR U95), and significance levels (SL) for variables in the global model predicting mule deer selection in western North Dakota from 2013-2016. Colons represent interactions between variables. The reference state (variables without interactions) represents adults in summer during the day.

Variable[a]	Estimate	SE	OR	OR L95	OR U95	SL[c]
Road Density	-0.3700	0.1095	0.691	0.557	0.856	***
NDVI	-0.1266	0.1078	0.881	0.713	1.088	
Rugged	0.3719	0.1443	1.451	1.093	1.925	**
Rugged_sq[b]	-0.2446	0.1162	0.783	0.624	0.983	*
Slope	0.7514	0.0838	2.120	1.799	2.498	***
Slope_sq	-0.4486	0.0675	0.638	0.559	0.729	***
Northness	-0.0012	0.0284	0.999	0.945	1.056	
TPI_Ridge	0.8696	0.1403	2.386	1.812	3.141	***
TPI_Upper Slope	0.4308	0.1553	1.539	1.135	2.086	**
TPI_Lower Slope	0.4716	0.1342	1.603	1.232	2.085	***
TPI_Valley	0.2672	0.1520	1.306	0.970	1.760	
NASS_Barren	-0.2133	0.0740	0.808	0.699	0.934	**
NASS_Crop	-1.7936	0.5436	0.166	0.057	0.483	***
NASS_Hay	-0.6054	0.1487	0.546	0.408	0.731	***
NASS_Legume	-0.6217	0.2787	0.537	0.311	0.927	*
NASS_Shrub	0.4864	0.0494	1.626	1.476	1.792	***
NASS_Wood	0.8397	0.0683	2.316	2.025	2.648	***
IJI	0.5953	0.4707	1.814	0.721	4.563	
IJI_sq	-0.9797	0.4608	0.375	0.152	0.926	*
WoodEdge	-0.8887	0.1216	0.411	0.324	0.522	***
Well900	-0.0086	0.0841	0.991	0.841	1.169	
Rig600	-3.1038	1.0231	0.045	0.006	0.333	**
Rig2500	0.0269	0.3285	1.027	0.540	1.956	
Road Density:AUTUMN	0.0364	0.0316	1.037	0.975	1.103	
Road Density:SPRING	0.0041	0.0333	1.004	0.941	1.072	
Road Density:WINTER	0.0609	0.0405	1.063	0.982	1.151	
Road Density:Juvenile	0.2725	0.1245	1.313	1.029	1.676	*
Road Density:Crepuscular	0.0011	0.0072	1.001	0.987	1.015	
Road Density:Night	0.0045	0.0142	1.004	0.977	1.033	
NDVI:AUTUMN	0.2461	0.0871	1.279	1.078	1.517	**
NDVI:SPRING	0.2153	0.1248	1.240	0.971	1.584	
NDVI:WINTER	0.1210	0.1056	1.129	0.918	1.388	
NDVI:Juvenile	-0.0170	0.0470	0.983	0.897	1.078	
NDVI:Crepuscular	0.0389	0.0080	1.040	1.023	1.056	***

NDVI:Night	0.0557	0.0123	1.057	1.032	1.083	***
Rugged:AUTUMN	-0.0289	0.0741	0.971	0.840	1.123	
Rugged:SPRING	0.1189	0.1168	1.126	0.896	1.416	
Rugged:WINTER	0.2398	0.0972	1.271	1.050	1.538	*
Rugged:Juvenile	0.0780	0.0982	1.081	0.892	1.311	
Rugged:Crepuscular	-0.1965	0.0519	0.822	0.742	0.910	***
Rugged:Night	-0.2214	0.0673	0.801	0.702	0.914	***
Rugged_sq:AUTUMN	0.0096	0.0658	1.010	0.887	1.149	
Rugged_sq:SPRING	-0.0934	0.0957	0.911	0.755	1.099	
Rugged_sq:WINTER	-0.1773	0.0791	0.838	0.717	0.978	*
Rugged_sq:Juvenile	-0.0565	0.0800	0.945	0.808	1.106	
Rugged_sq:Crepuscular	0.1367	0.0425	1.146	1.055	1.246	**
Rugged_sq:Night	0.1464	0.0547	1.158	1.040	1.289	**
Slope:AUTUMN	-0.3522	0.0558	0.703	0.630	0.784	***
Slope:SPRING	0.1175	0.0554	1.125	1.009	1.254	*
Slope:WINTER	0.4006	0.0585	1.493	1.331	1.674	***
Slope:Juvenile	0.0504	0.0943	1.052	0.874	1.265	
Slope:Crepuscular	-0.1742	0.0297	0.840	0.793	0.890	***
Slope:Night	-0.3190	0.0458	0.727	0.664	0.795	***
Slope_sq:AUTUMN	0.1825	0.0536	1.200	1.081	1.333	***
Slope_sq:SPRING	-0.1243	0.0459	0.883	0.807	0.966	**
Slope_sq:WINTER	-0.2469	0.0494	0.781	0.709	0.861	***
Slope_sq:Juvenile	0.0062	0.0791	1.006	0.862	1.175	
Slope_sq:Crepuscular	0.0496	0.0242	1.051	1.002	1.102	*
Slope_sq:Night	0.0874	0.0393	1.091	1.010	1.179	*
Northness:AUTUMN	-0.0772	0.0167	0.926	0.896	0.957	***
Northness:SPRING	-0.0830	0.0194	0.920	0.886	0.956	***
Northness:WINTER	-0.0377	0.0201	0.963	0.926	1.002	
Northness:Juvenile	-0.0489	0.0316	0.952	0.895	1.013	
Northness:Crepuscular	0.0097	0.0087	1.010	0.993	1.027	
Northness:Night	0.0556	0.0141	1.057	1.028	1.087	***
TPI_Ridge:AUTUMN	0.1694	0.0802	1.185	1.012	1.386	*
TPI_Upper Slope:AUTUMN	0.0957	0.0838	1.100	0.934	1.297	
TPI_Lower Slope:AUTUMN	-0.1629	0.0769	0.850	0.731	0.988	*
TPI_Valley:AUTUMN	-0.1693	0.0980	0.844	0.697	1.023	
TPI_Ridge:SPRING	-0.2709	0.0968	0.763	0.631	0.922	**
TPI_Upper Slope:SPRING	-0.1584	0.1028	0.854	0.698	1.044	
TPI_Lower Slope:SPRING	-0.0246	0.0948	0.976	0.810	1.175	
TPI_Valley:SPRING	0.1977	0.1017	1.219	0.998	1.488	
TPI_Ridge:WINTER	-0.1448	0.0913	0.865	0.723	1.035	
TPI_Upper Slope:WINTER	-0.0374	0.1048	0.963	0.784	1.183	

TPI_Lower Slope:WINTER	0.1309	0.0836	1.140	0.968	1.343	
TPI_Valley:WINTER	0.3120	0.0955	1.366	1.133	1.647	**
TPI_Ridge:Juvenile	0.2492	0.1563	1.283	0.944	1.743	
TPI_Upper Slope:Juvenile	0.2461	0.1725	1.279	0.912	1.794	
TPI_Lower Slope:Juvenile	0.2704	0.1448	1.310	0.987	1.740	
TPI_Valley:Juvenile	0.1685	0.1752	1.183	0.840	1.668	
TPI_Ridge:Crepuscular	-0.3531	0.0604	0.702	0.624	0.791	***
TPI_Upper Slope:Crepuscular	-0.1671	0.0619	0.846	0.749	0.955	**
TPI_Lower Slope:Crepuscular	-0.0960	0.0552	0.908	0.815	1.012	
TPI_Valley:Crepuscular	0.0432	0.0664	1.044	0.917	1.189	
TPI_Ridge:Night	-0.4603	0.0772	0.631	0.543	0.734	***
TPI_Upper Slope:Night	-0.1678	0.0830	0.846	0.719	0.995	*
TPI_Lower Slope:Night	-0.1256	0.0713	0.882	0.767	1.014	
TPI_Valley:Night	0.0005	0.0846	1.001	0.848	1.181	
NASS_Barren:AUTUMN	-0.0184	0.0826	0.982	0.835	1.154	
NASS_Crop:AUTUMN	0.9937	0.3468	2.701	1.369	5.331	**
NASS_Hay:AUTUMN	0.0497	0.1221	1.051	0.827	1.335	
NASS_Legume:AUTUMN	0.2966	0.2005	1.345	0.908	1.993	
NASS_Shrub:AUTUMN	-0.0481	0.0345	0.953	0.891	1.020	
NASS_Wood:AUTUMN	-0.0775	0.0505	0.925	0.838	1.022	
NASS_Barren:SPRING	0.0163	0.0677	1.016	0.890	1.161	
NASS_Crop:SPRING	-0.4383	0.4807	0.645	0.251	1.655	
NASS_Hay:SPRING	0.1461	0.1914	1.157	0.795	1.684	
NASS_Legume:SPRING	0.4972	0.1918	1.644	1.129	2.394	**
NASS_Shrub:SPRING	-0.1194	0.0290	0.887	0.838	0.940	***
NASS_Wood:SPRING	-0.1416	0.0431	0.868	0.798	0.944	**
NASS_Barren:WINTER	0.3778	0.0709	1.459	1.270	1.676	***
NASS_Crop:WINTER	0.4734	0.5253	1.605	0.573	4.495	
NASS_Hay:WINTER	-0.6032	0.2409	0.547	0.341	0.877	*
NASS_Legume:WINTER	-0.1028	0.2506	0.902	0.552	1.475	
NASS_Shrub:WINTER	-0.0745	0.0318	0.928	0.872	0.988	*
NASS_Wood:WINTER	-0.1449	0.0505	0.865	0.784	0.955	**
NASS_Barren:Juvenile	0.1417	0.1399	1.152	0.876	1.516	
NASS_Crop:Juvenile	-0.7212	0.7309	0.486	0.116	2.037	
NASS_Hay:Juvenile	-0.4963	0.3375	0.609	0.314	1.180	
NASS_Legume:Juvenile	-0.7812	0.4461	0.458	0.191	1.098	
NASS_Shrub:Juvenile	-0.0397	0.0572	0.961	0.859	1.075	
NASS_Wood:Juvenile	-0.1314	0.0775	0.877	0.753	1.021	
NASS_Barren:Crepuscular	-0.2539	0.0351	0.776	0.724	0.831	***
NASS_Crop:Crepuscular	0.4356	0.2394	1.546	0.967	2.472	
NASS_Hay:Crepuscular	1.0031	0.1017	2.727	2.234	3.328	***

NASS_Legume:Crepuscular	0.7817	0.1076	2.185	1.770	2.699	***
NASS_Shrub:Crepuscular	-0.1695	0.0228	0.844	0.807	0.883	***
NASS_Wood:Crepuscular	-0.3590	0.0266	0.698	0.663	0.736	***
NASS_Barren:Night	-0.5043	0.0454	0.604	0.553	0.660	***
NASS_Crop:Night	0.6043	0.2927	1.830	1.031	3.248	*
NASS_Hay:Night	1.0388	0.1091	2.826	2.282	3.499	***
NASS_Legume:Night	0.8820	0.1246	2.416	1.892	3.084	***
NASS_Shrub:Night	-0.2419	0.0323	0.785	0.737	0.837	***
NASS_Wood:Night	-0.6340	0.0431	0.530	0.488	0.577	***
IJI:AUTUMN	-0.2639	0.1368	0.768	0.587	1.004	
IJI:SPRING	-0.2838	0.1493	0.753	0.562	1.009	
IJI:WINTER	-0.4593	0.1604	0.632	0.461	0.865	**
IJI:Juvenile	0.0332	0.6429	1.034	0.293	3.645	
IJI:Crepuscular	-0.0050	0.0384	0.995	0.923	1.073	
IJI:Night	-0.0383	0.0578	0.962	0.859	1.078	
IJI_sq:AUTUMN	0.2714	0.1362	1.312	1.004	1.713	*
IJI_sq:SPRING	0.3535	0.1475	1.424	1.066	1.902	*
IJI_sq:WINTER	0.5532	0.1598	1.739	1.271	2.378	***
IJI_sq:Juvenile	-0.2071	0.6322	0.813	0.235	2.807	
IJI_sq:Crepuscular	0.0913	0.0381	1.096	1.017	1.181	*
IJI_sq:Night	0.1895	0.0578	1.209	1.079	1.354	**
WoodEdge:AUTUMN	0.1350	0.0664	1.145	1.005	1.304	*
WoodEdge:SPRING	-0.0136	0.0822	0.987	0.840	1.159	
WoodEdge:WINTER	0.0833	0.0814	1.087	0.927	1.275	
WoodEdge:Juvenile	0.1076	0.1201	1.114	0.880	1.409	
WoodEdge:Crepuscular	0.1439	0.0481	1.155	1.051	1.269	**
WoodEdge:Night	0.2693	0.0701	1.309	1.141	1.502	***
Well900:AUTUMN	-0.0409	0.0392	0.960	0.889	1.037	
Well900:SPRING	-0.0022	0.0429	0.998	0.917	1.085	
Well900:WINTER	0.0742	0.0470	1.077	0.982	1.181	
Well900:Juvenile	0.1327	0.0758	1.142	0.984	1.325	
Well900:Crepuscular	0.0223	0.0131	1.023	0.997	1.049	
Well900:Night	0.0407	0.0232	1.042	0.995	1.090	
Rig600:AUTUMN	-0.1346	1.1040	0.874	0.100	7.608	
Rig600:SPRING	0.9293	1.1906	2.533	0.246	26.126	
Rig600:WINTER	1.0098	1.1128	2.745	0.310	24.309	
Rig600:Juvenile	0.6389	0.8498	1.894	0.358	10.020	
Rig600:Crepuscular	0.6925	0.2657	1.999	1.187	3.365	**
Rig600:Night	0.5411	0.4457	1.718	0.717	4.115	
Rig2500:AUTUMN	0.0238	0.3382	1.024	0.528	1.987	
Rig2500:SPRING	-0.1190	0.3327	0.888	0.463	1.704	

Rig2500:WINTER	-0.0475	0.2725	0.954	0.559	1.627
Rig2500:Juvenile	-0.1698	0.6021	0.844	0.259	2.746
Rig2500:Crepuscular	-0.0002	0.0252	1.000	0.952	1.051
Rig2500:Night	-0.0308	0.0466	0.970	0.885	1.062

[a] Road Density = road density (km/km^2) of primary and secondary roads; NDVI = normalized difference vegetation index; Rugged = ruggedness index; Slope = percent slope; Northness = quantity describing how north-facing the slope is; TPI = landform topographic position index; NASS = national agricultural statistics service vegetation; IJI = interspersion and juxtaposition index; WoodEdge = distance to wooded edge; Well900 = number of well pads within 900 m; Rig600/2500 = presence/absence of drilling rigs within 600/2500 m.

[b] "_sq" = quadratic form of the variable.

[c] Significance Level: "***" = p-value < 0.001; "**" = p-value < 0.01; "*" = p-value < 0.05

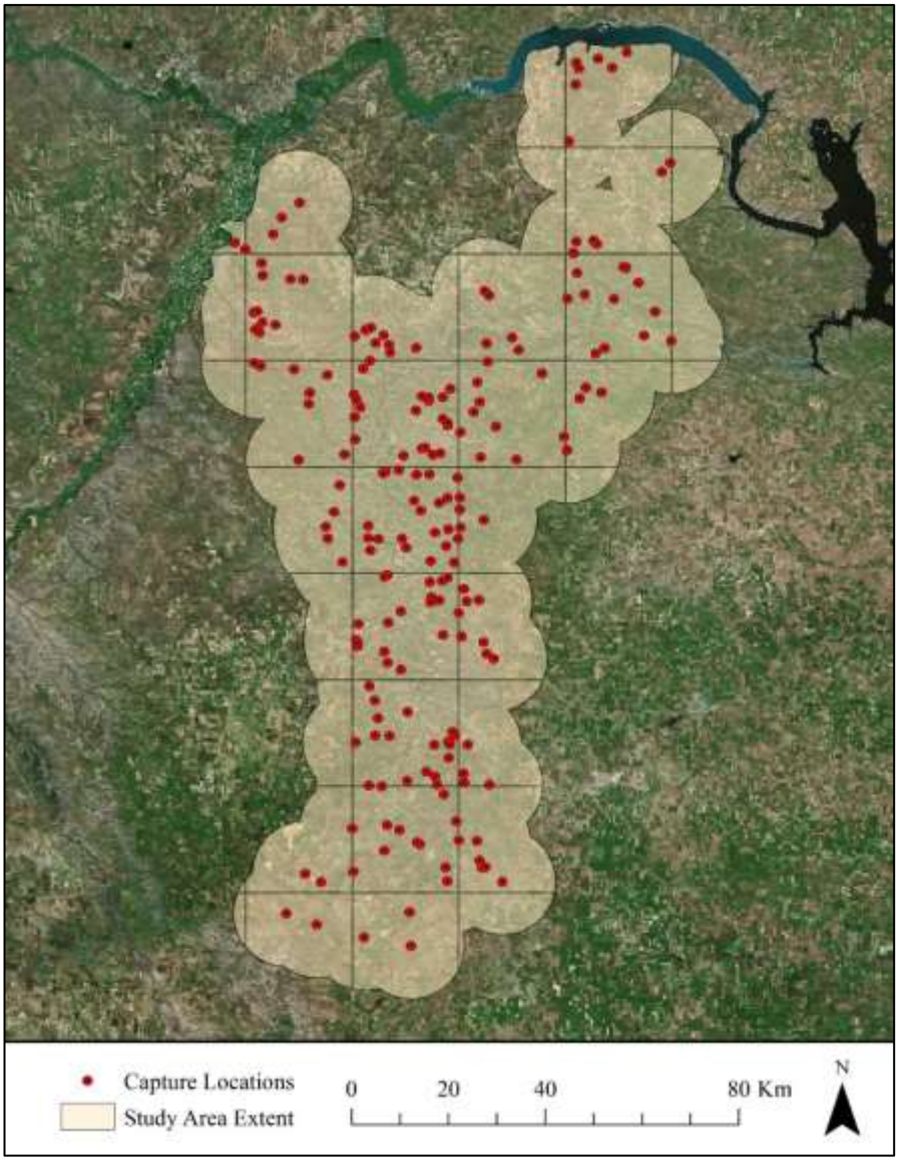

Figure 6. Mule deer capture locations in western North Dakota from 2013 –2016 and study area extent, defined as the composite area of each capture location buffered by the mean of maximum distances mule deer moved from capture sites (11 km). We randomly placed locations equal to 5 times the number of used locations within each grid cell shown.

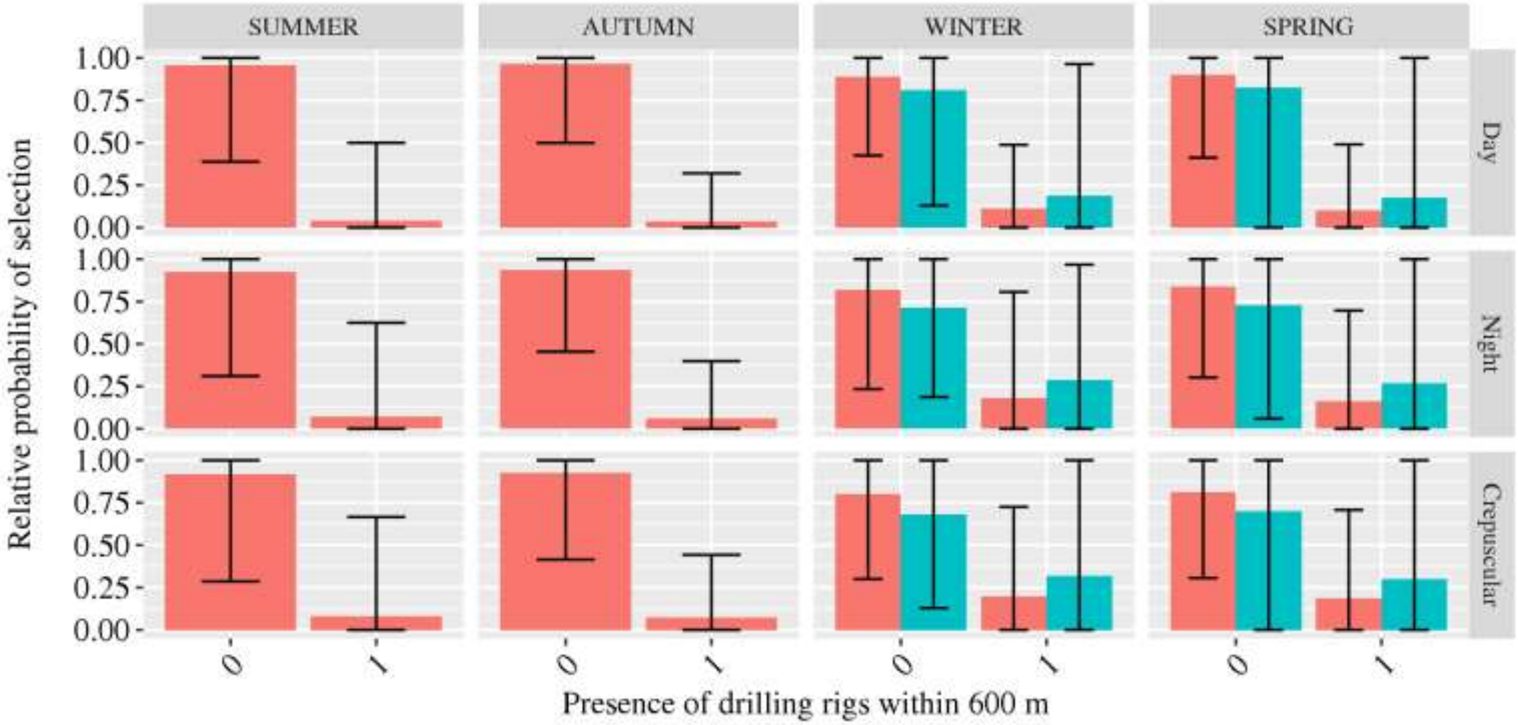

Figure 7. Effect of the presence of drilling rigs within 600 m on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Red represents adults, blue represents juveniles (no juveniles were tagged during summer and autumn seasons), and error bars represent 95% confidence intervals. Probabilities shown are relative, not absolute.

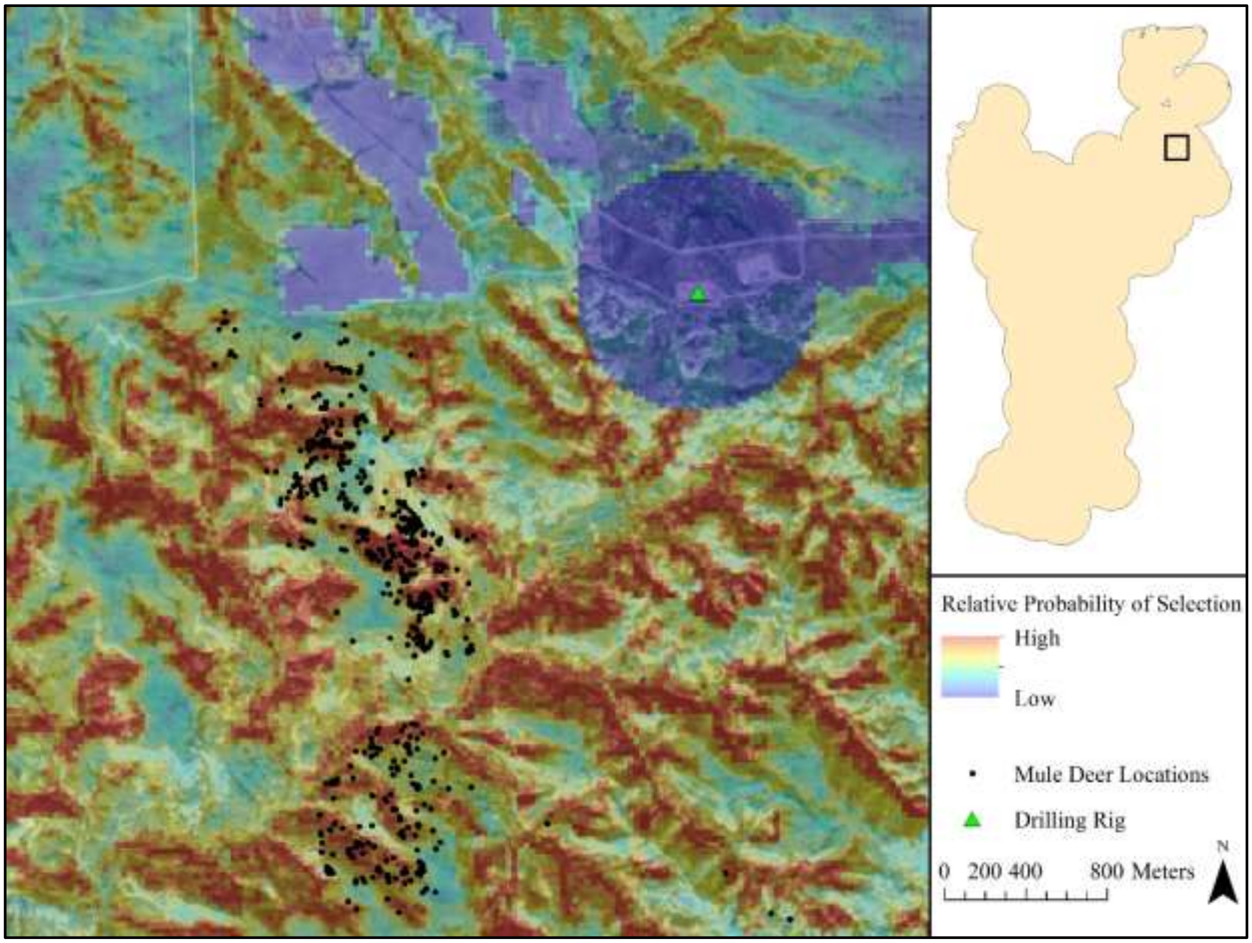

Figure 8. Predictive map of adult mule deer selection during the day in summer in western North Dakota, zoomed in to show detail. Black dots represent actual mule deer locations and warmer colors represent higher relative probabilities of selection, estimated from our global model. The dark blue circle in the northeast section of the map demonstrates the effect a drilling rig had on the relative probability of selection.

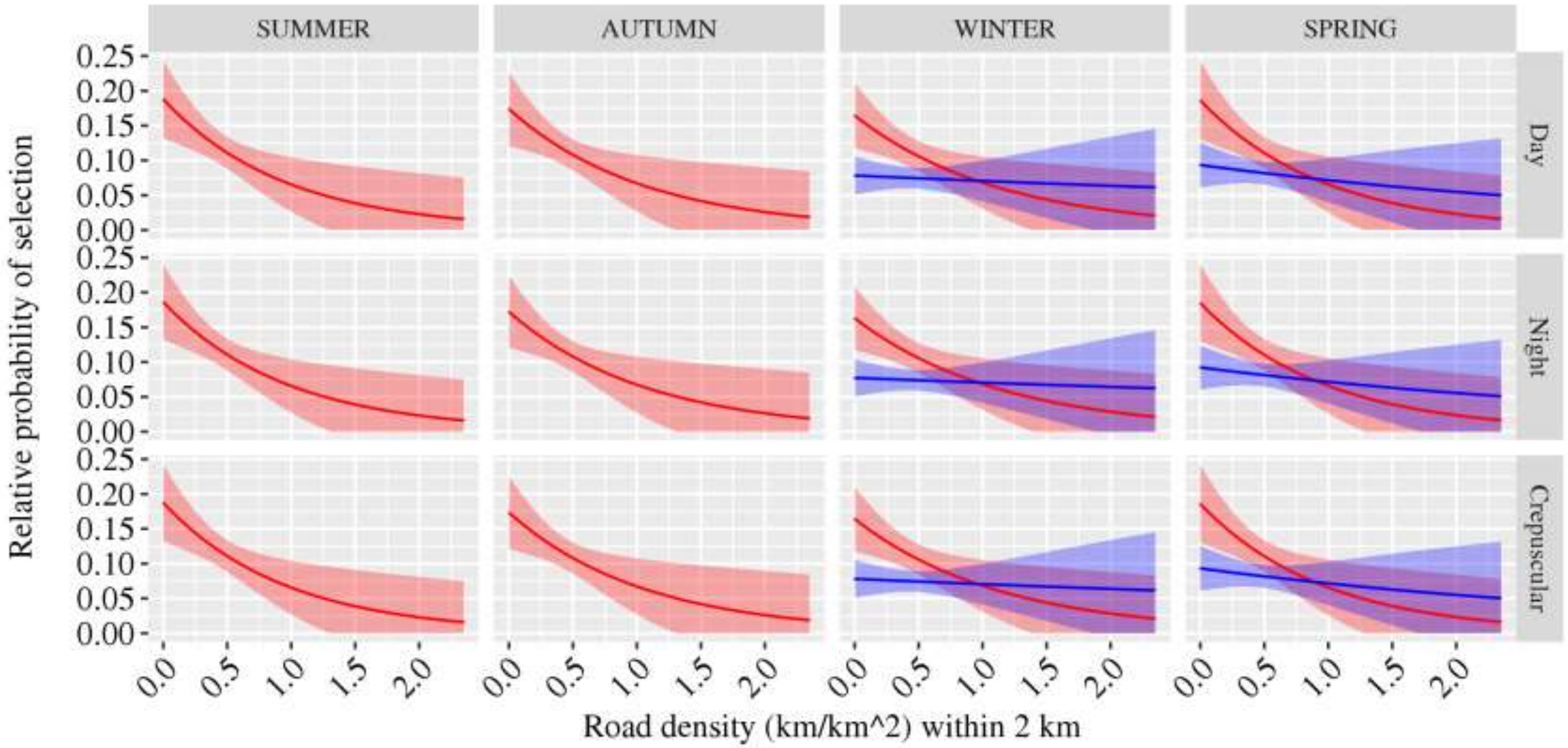

Figure 9. Effect of primary and secondary road density on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Red represents adults, blue represents juveniles (no juveniles were tagged during summer and autumn seasons), and ribbons represent 95% confidence intervals. Probabilities shown are relative, not absolute.

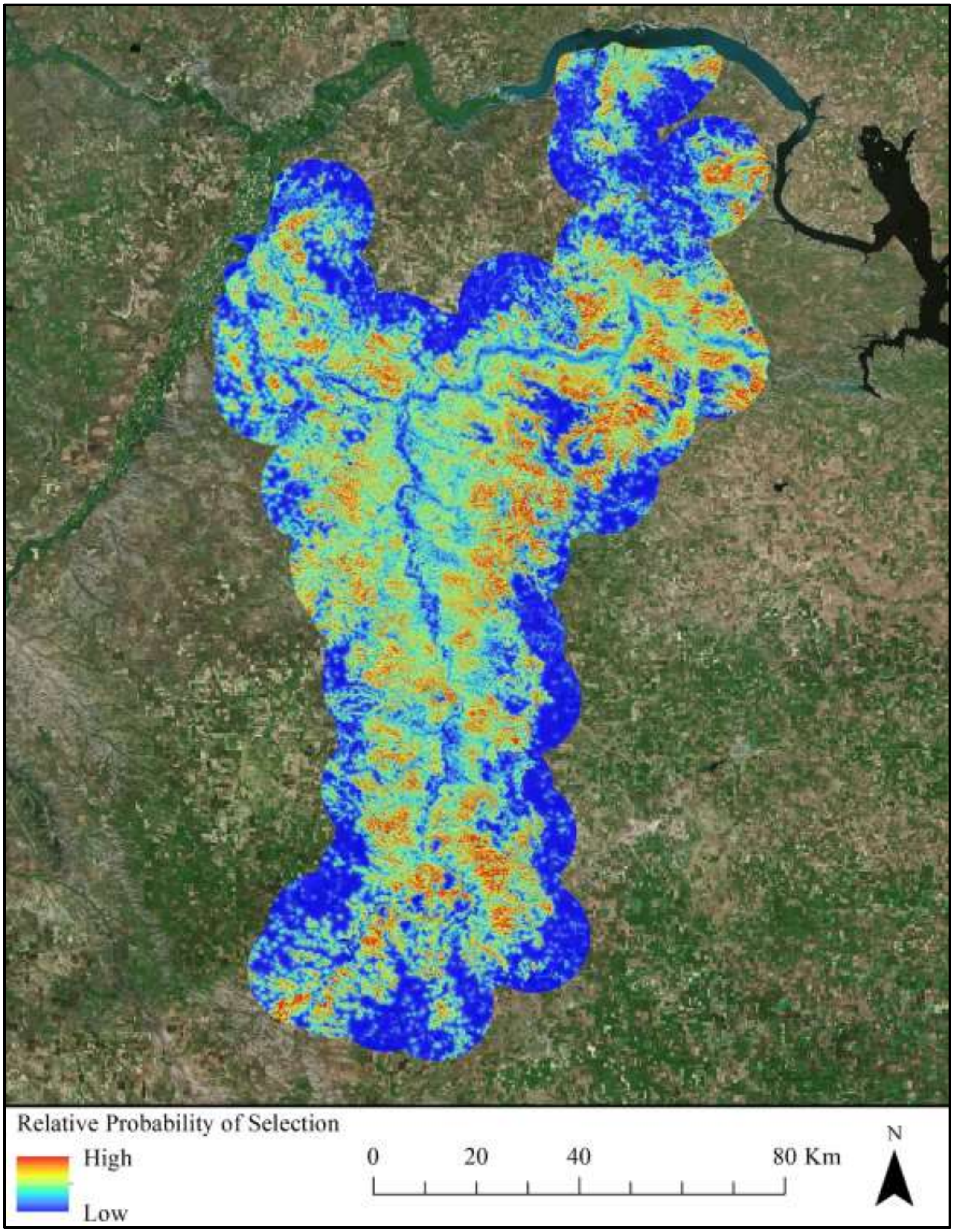

Figure 10. Predictive map of adult mule deer selection during the day in summer across the study area in western North Dakota. Warmer colors represent higher relative probabilities of selection.

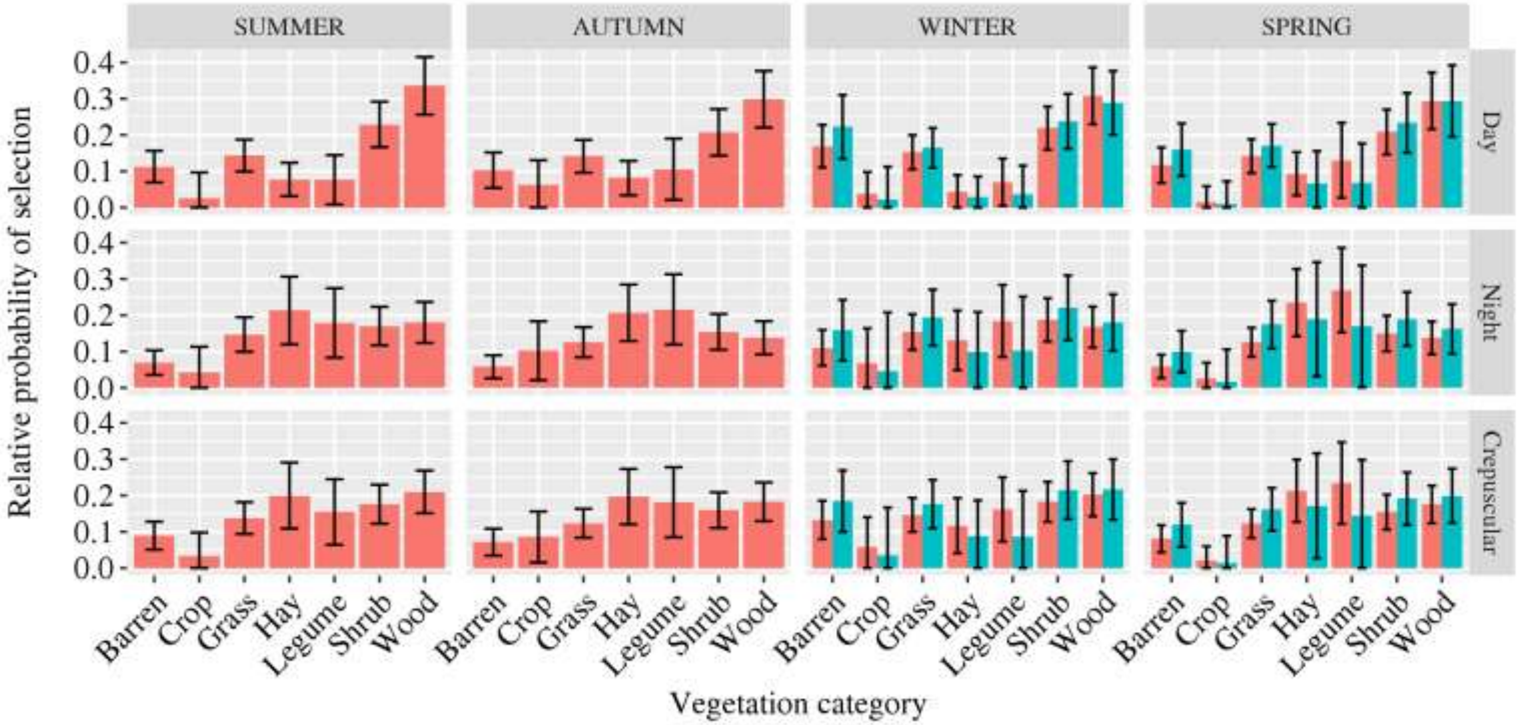

Figure 11. Effect of vegetation type on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Red bars represent adults and blue bars represent juveniles; no juveniles were tagged during summer and autumn seasons. Error bars represent 95% confidence intervals. Probabilities shown are relative, not absolute.

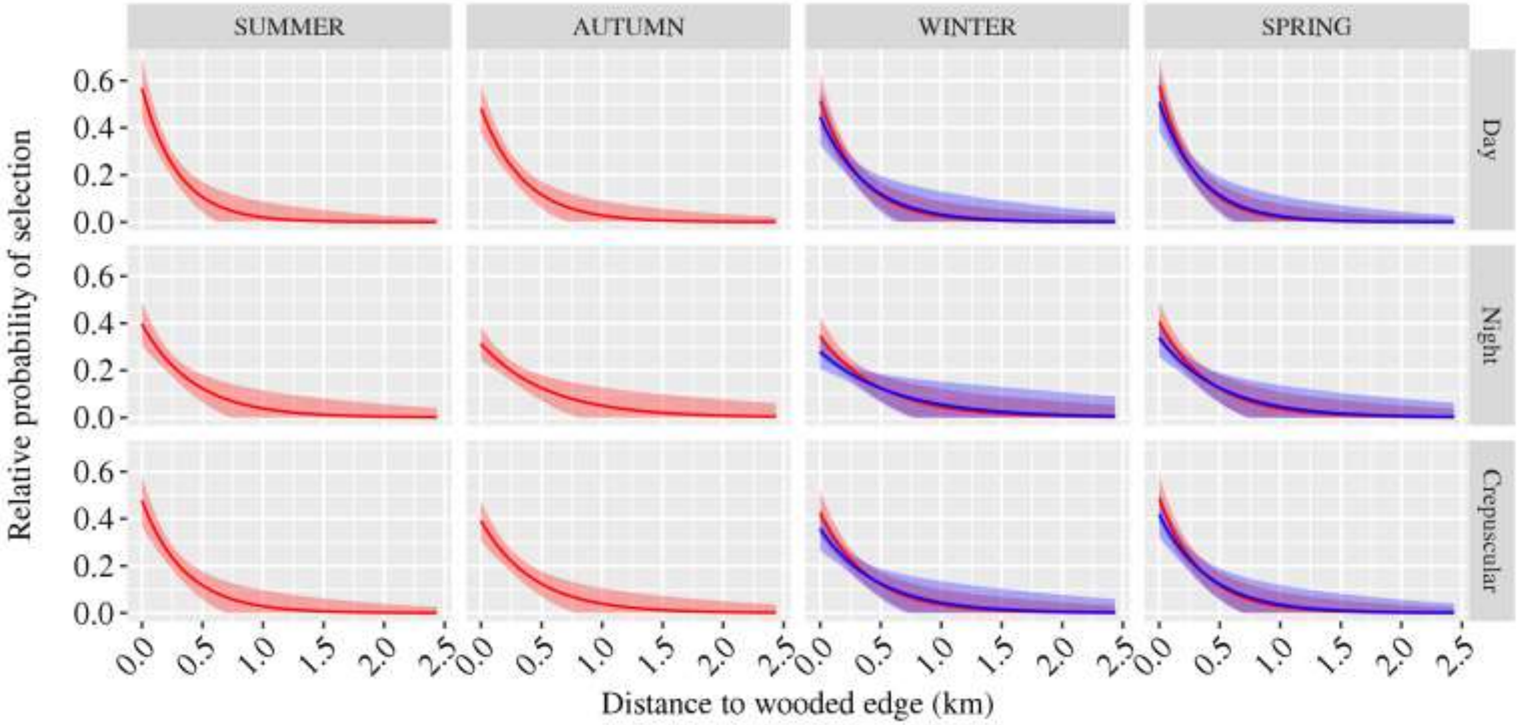

Figure 12. Effect of distance to wooded edge on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Red represents adults, blue represents juveniles, and ribbons represent 95% confidence intervals; no juveniles were tagged during summer and autumn seasons. Probabilities shown are relative, not absolute.

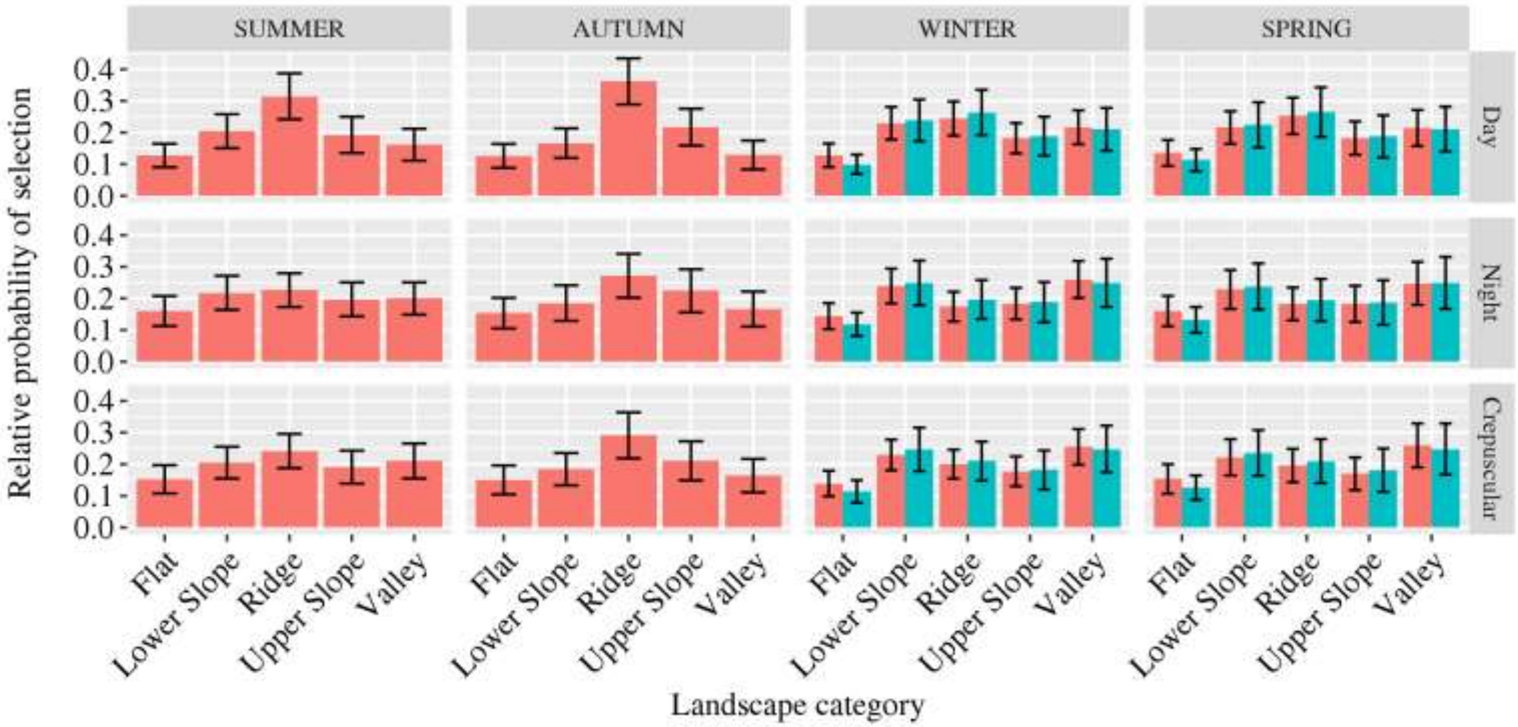

Figure 13. Effect of landscape type on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Red bars represent adults and blue bars represent juveniles; no juveniles were tagged during summer and autumn seasons. Error bars represent 95% confidence intervals. Probabilities shown are relative, not absolute.

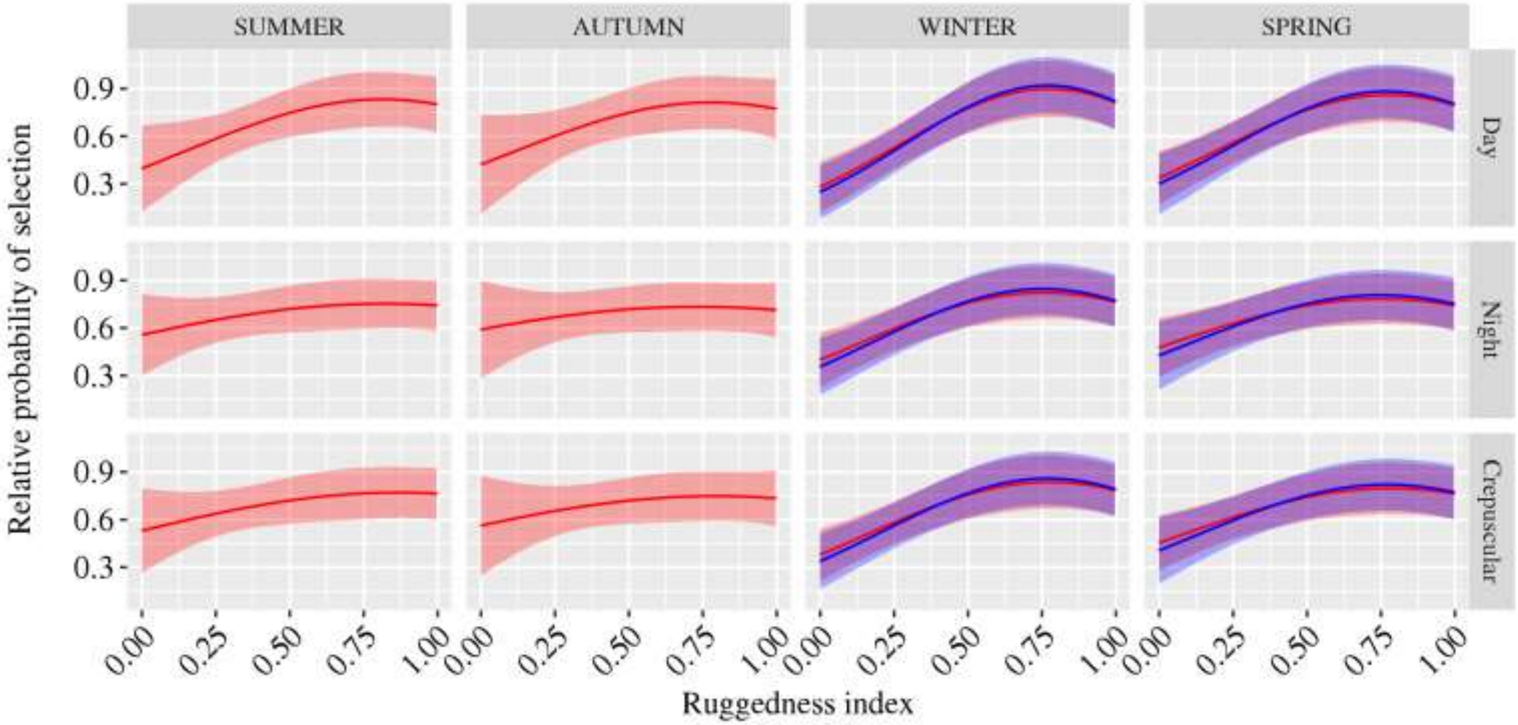

Figure 14. Effect of ruggedness on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Higher ruggedness index values represent more rugged terrain. Red represents adults, blue represents juveniles, and ribbons represent 95% confidence intervals; no juveniles were tagged during summer and autumn seasons. Probabilities shown are relative, not absolute.

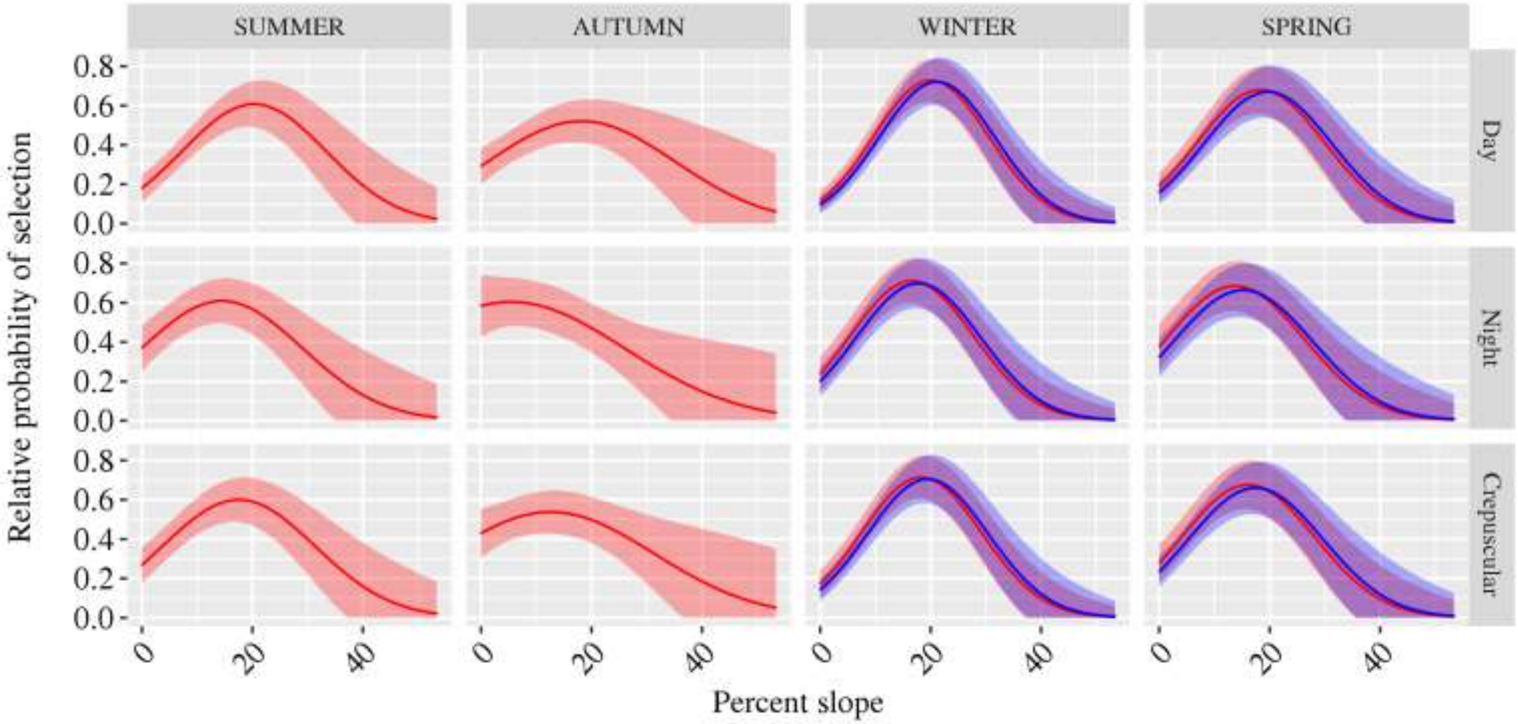

Figure 15. Effect of percent slope on the relative probability of mule deer selecting locations in western North Dakota from 2013-2016. Red represents adults, blue represents juveniles, and ribbons represent 95% confidence intervals; no juveniles were tagged during summer and autumn seasons. Probabilities shown are relative, not absolute.

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CHAPTER II. MOVEMENTS OF MULE DEER IN WESTERN NORTH DAKOTA

Introduction

“Movement is the glue that connects local population dynamics in space” (Turchin 1996, p. 2086), and increased movement distances to meet daily requirements requires more energy (Parker et al. 1984, Morales et al. 2010). Anthropogenic development has the potential to affect wildlife movements by fragmenting landscapes or by increasing risk aversion. Recent research in the Piceance Basin of Colorado documented longer step lengths for migrating mule deer in areas with high well pad densities (Lendrum et al. 2012). Additional studies have found differences in resource use around development features such as: roads, well pads, and drilling rigs (Sawyer et al. 2006, Northrup et al. 2015; see also Chapter I of this study). It is also possible that ungulates can acclimate to predictable disturbances (Stankowich 2008), and in some instances, show less responsiveness to risk in areas with increased traffic (Brown et al. 2012).

Movements are typically studied in migratory species, and although researchers have studied the effects of oil and gas energy development on wildlife resource use, few have studied the relationship between oil and gas energy development and movements of a non-migratory ungulate. We examined the relationship between movement distances (step lengths; Lendrum et al. 2012) and natural and anthropogenic development features.

Analytical methods

We calculated movement distances with Euclidean distance between successive, 5-hour GPS locations (i.e. 5-hour step lengths). We censored locations if time between successive GPS fixes was ≤ 4.5 hours or ≥ 5.5 hours.

We modelled mule deer movement distances using resource attributes from three hypothesis sets: vegetation, topographic, and anthropogenic development. We used a multi-state (e.g., Washburn et al. 2004) information-theoretic modeling approach (Burnham and Anderson

2002) to determine first, which variables to keep in each hypothesis set (Table 5), and second, to compare models of all combinations of hypothesis sets. We included interaction effects for age, season, and time of day when comparing models.

We calculated movement distances using Euclidian distance between successive 5-hour GPS fixes. We removed any movements with GPS fix time > 5.25 h or < 4.75 h. We also examined locations that were > 5 km from previous locations and removed any that appeared to be erroneous GPS locations: horizontal depth of precision > 5; unlikely locations (lakes or towns); or two-successive fixes > 5 km apart (e.g. significant departures from seasonal range with return in < 10 hours).

We included vegetation attributes because daily movement rates in ungulates are partly dependent on vegetation requirements to meet cover and forage needs (Hebblewhite et al. 2008, Sawyer and Kauffman 2011, Lendrum et al. 2012). We used the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) 30-m United States Cropland layer (USDA NASS 2013-2016) in ArcInfo 10.5 (Environmental Research Systems Institute, Redlands, CA) to identify vegetation types across the study area and we acquired monthly normalized difference vegetation index (NDVI) layers with 250-m resolution from eMODIS (Jenkerson et al. 2010) to quantify vegetation greenness. NDVI can be used as an indicator of forage availability for ungulates in open habitats (Borowik et al. 2013), and ungulates move to areas with increased forage quality (Hebblewhite et al. 2008, Sawyer and Kauffman 2011). To reduce the number of vegetation classes, we grouped NASS vegetation types into 7 dominant categories including “wood” (deciduous and evergreen forest and woody wetlands—we grouped deciduous and evergreen because remote sensing data did not appear to accurately differentiate juniper from deciduous trees), “shrub” (shrublands), “grass” (grasslands), "hay" (hay fields and fallow/idle croplands), "legume" (alfalfa, peas, and other legume crops), "crop" (non-legume crops), and "barren" (areas devoid of vegetation). We dissolved pixels identified as "disturbance" into the majority vegetation category within a 0.09 km^2 square neighborhood around the pixel because pixels classified as the disturbance category by NASS were relatively rare throughout our study area (<2% of pixels). Disturbance pixels were typically along roads, and we already included road density as a disturbance variable in our model. If "disturbance" was the majority category in the 0.09 km^2 neighborhood, we reclassified the pixel as "barren". We predicted that mule deer would move more in areas with lower NDVI values to meet foraging needs. We also predicted that movement distances would be shorter in wooded and shrub habitats where mule deer are likely to bed (Jensen 1988) than in grassland, hay, legume or crop habitats, which deer occupy during foraging (Jensen 1988).

We also examined the landscape patterns of vegetation data by looking at homogeneity of habitat patches, or interspersion and juxtaposition index (IJI; McGarigal et al. 2012) and distance to the nearest wooded edge (Northrup et al. 2015; similar to maximum structural contrast: Kie et al. 2002). To calculate distance to wooded edge, we first "smoothed" the wood category from our vegetation layer. Occasionally, pixels classified as something other than "wood" occurred within contiguous wooded areas. We reclassified pixels as "wood" if ≥ 75% of the surrounding pixels were classified as "wood" to ensure pixels surrounded by contiguous forest were not classified as wooded edge. Next, we designated a pixel as "wooded edge" if the pixel had at least one neighboring "wood" pixel, but was not completely surrounded by "wood" pixels. Last, we calculated the Euclidean distance from each pixel across the study area to the nearest "wooded edge" pixel to create a spatial map of distances to wooded edge. We used the moving window option in FRAGSTATS (McGarigal et al. 2012) to calculate the IJI within a 2 km buffer around each pixel of the 30-m 2011 National Land Cover Database layer (Homer et al. 2015). IJI values ranged from 0 to 100, with higher values representing a vegetation patch type being equally adjacent to all other patch types. We hypothesized that deer step lengths would increase in more homogenized habitats (i.e. higher IJI values) where all resources are closer together, and increase as the distance to wooded edge increased, as deer would be further from bedding areas.

We included a topography hypothesis set of resource attributes because ungulate movements might be affected by slope (Lendrum et al. 2012) and ruggedness. We used a 30-m digital elevation model (DEM) raster layer to calculate slope and ruggedness index. We created slope layers from the DEM layer using the Spatial Analyst toolbox in ArcInfo 10.5. We calculated the ruggedness index using equations provided in Sappington et al. (2007) within a 3 x 3 pixel neighborhood (8,100 m^2) because Sappington et al. (2007) found that scale captured the complexity of the landscape without over-smoothing it. Ruggedness values ranged from 0 to 1, with higher values representing higher ruggedness. We hypothesized mule deer movements would be impeded by increased slope and ruggedness.

We included the following variables in our anthropogenic disturbance models: road density, distance to nearest road, density of active well pads, and density of active drilling rigs. We created line shapefiles for all roads by using City and County Roads and State and Federal Roads (ND Department of Transportation 2016), combined with a road shapefile digitized manually from 2015 NAIP aerial imagery, at a 1:5,000 scale. We used this roads layer to estimate distance to road and road densities by dividing the total length of roads within 2 km by 12.57 (area within 2 km). We determined the number of drilling rigs and active wells each month using spatial data from the Oil and Gas Division, North Dakota Department of Mineral Resources (downloaded monthly 2013-2016). We consolidated multiple wells if they occurred on the same well pad (Northrup et al. 2015). If a drilling rig and well were present on the same well pad, we consolidated them as a drilling rig (Northrup et al. 2015) to avoid duplication of development points at a single well pad. The effects of drilling rigs and well pads on selection may be scale-dependent, so we included the number of drilling rigs within 2.5 km (Sawyer et al. 2009) and 600 m (Northrup et al. 2015), and the number of well pads within 2 km (Sawyer et al. 2009), 900 m (Fox et al. 2009), 400 m (Northrup et al. 2015), and 100 m (Fox 1989). We predicted that anthropogenic development would result in increased disturbance, and increased mule deer movement distances.

We hypothesized the influence of variables on selection would be dependent on season (summer [Jun. 1 – Sep. 31], autumn [Oct. 1 – Nov. 30], winter [Dec. 1 – Mar. 31], spring [Apr. 1 – May 31]), time of day (day, night, crepuscular [within 2 hours of sunrise or sunset]), and age (adult [≥1 year old], juvenile [<1 year old]). Thus, we included interactions between each variable and season, time of day, and age in our analysis. We checked for multicollinearity between variables by calculating Pearson's correlation coefficient (r) using the cor() function in R (R Core Team 2016). If r > 0.65, we removed the correlated variable that had the highest AIC value.

Next, we determined which form of each continuous vegetation variable, including linear, quadratic, and pseudo-threshold (e.g., Franklin et al. 2000) was most supported at each scale by comparing Akaike's information criterion (AIC; Akaike 1973) values across variable forms. We used the non-linear form of the variable if it was >2 AIC units better than the linear form; otherwise, we used the linear form. Finally, we established which biological, temperature, landscape, and anthropogenic disturbance model was most supported and combined top models to determine which hypothesis or combination of hypotheses explained the most variation in mule deer movement distances. For all model stages, we used the lmer() linear mixed-effects models with random effects to account for potential auto-correlation among locations from the same deer (R Core Team 2016). We used 5,000 draws from the multivariate normal distribution of the fixed and random coefficients to calculate predictor slopes for model parameters.

Results

We analyzed 423,813 deer movements (373,770 adult, 50,043 juvenile) from 201 mule deer (98 female adults and 103 juveniles), in western North Dakota from February 2013 to June 2016. Movement distances ranged from 0.0 m to 12.8 km (mean = 355.6 m, SD = 419.1 m).

Distance to the nearest road and road density were auto-correlated (r = 0.73), and because distance to nearest road predicted movement distance better than road density, we removed road density from all models. Likewise, well density calculated at 900 m and well density calculated at 2000 m were correlated (r = 0.75); the 2000 m scale was most supported, so well density at 900 m was removed. Global models were the top models for all hypothesis sets. The top model when combining all combinations of vegetation, topography and anthropogenic development hypothesis sets was also the global model (with interactions included; see Table 6).

Plots of the influence of vegetation, topography, and development covariates with interactions reveal too much variation around 5-hour movement distances across the range of covariate values to be used in modelling the influence of our covariates on movement distances (Figures 16 – 26).

Discussion

Movement distances for mule deer in our study area showed much variation and were not significantly predicted by season, time of day, natural features, or oil and gas development metrics. Our findings differ from findings for migrating mule deer in Colorado, where high well pad density and nighttime locations were correlated with higher movement distances (Lendrum et al. 2012). However, they only documented a significant increase in movement distances in a migration corridor with high density of well pads (1.99 well pads/km^2), not at medium high densities (1.54 well pads/km^2). The maximum well pad density (calculated by 2000 m buffer from starting location) for our data was 1.91 well pads/km^2 (χ = 1.47 well pads/km^2), so a movement distance response to oil and gas energy development might not occur in areas with lower well pad densities. Finally, we examined movement distances over all seasons because mule deer in North Dakota did not show strong migratory patterns. It is possible that mule deer movements in Colorado were more sensitive to predictor variables during migration.

It is also possible that 5-hour step lengths over-smoothed movement paths, because movement path distance depends on the temporal scale used (Turchin et al. 1996), and using Euclidian distance to measure the distance travelled between two points will underestimate the actual movement distance (i.e. smooth the movement path; Rowcliffe et al. 2012). Bryne et al. (2014) used motion variances obtained from dynamic Brownian bridge movement models to model habitat selection during diurnal and nocturnal time periods for white-tailed deer. However, they used a much higher sampling rate (30-minute fix rates) to calculate motion variances for capturing daily activity patterns. We likely sampled multiple activity states (foraging, bedding, relocating, etc.) within individual 5-hour steps. However, further modelling is needed to see whether computing movement distances over multiple step lengths (e.g. dBBMM) could have minimized variation around movement distance measurements.

Management Implications

We did not find evidence of any effect on movement distances due to oil and gas energy development metrics, but we also did not find a relationship between movement distance and season or time of day. Because circadian rhythms in deer activity patterns are well documented

(Wallmo 1981, Lendrum et al. 2012, Byrne et al. 2014), it is possible that our data over-smoothed movement distances. We recommend further exploration of the relationship between 5-hour movement distances, and suggest that 5-hour movement distances may be more appropriate for modelling environmental impacts during migration than for non-migratory ungulates.

Table 5. Organization of variables in respective hypothesis sets used to explain movement distances of mule deer in North Dakota from 2013 to 2015.

Hypothesis	Models[a]
Vegetation	
	Null
	Vegetation Class
	Wooded Edge
	Interspersion Juxtaposition Index (IJI)
	NDVI
Topography	
	Null
	Slope
	Ruggedness
Anthropogenic Development	
	Null
	Distance to nearest road
	Road density
	Density of active well pads (calculated at 100m, 400m 900m and 2000m)
	Density of drilling rigs (calculated at 600m and 2500m)
(Interactions)	
	Age
	Season
	Time of Day

[a] Null = intercept-only model; Vegetation Class from National Agriculture Statistics Survey data (wooded, shrubland, grassland, legume crops, row crops, fallow/planted hay, barren), Wooded edge = distance to the nearest wooded edge; IJI = a measure of landscape homogeneity; NDVI = landscape greenness; ruggedness = vector ruggedness measure (0 to 1); Road density = density of roads calculated within 2000m buffer from location; age = mule deer age assuming 01 June parturition date (<1 = juvenile, >1 = adult); Season: summer (01 Jun – 30 Sep), fall (01 Oct – 31 Dec), winter (01 Jan – 31 Mar), spring (01 Apr – 31 May); and Time of Day = day, night or crepuscular (+/- 2 hours from sunrise or sunset).

Table 6. Ranking of models of all hypothesis set combinations, sorted by AIC scores, used to predict movement distances for mule deer in western North Dakota, 2013 - 2016.

	K	AIC	Delta_AIC	AICWt	Res.LL
Global	209	6264503	0	1	-3132042
Dist + Veg	176	6265753	1250.57	0	-3132701
Topo + Veg	145	6266235	1732.35	0	-3132973
Vegetation	112	6267659	3155.79	0	-3133717
Dist + Topo	110	6273850	9346.87	0	-3136815
Topography	46	6276284	11781.09	0	-3138096
Disturbance	77	6277619	13115.96	0	-3138732
Interactions	13	6280879	16375.94	0	-3140426
Null	3	6298220	33717.51	0	-3149107

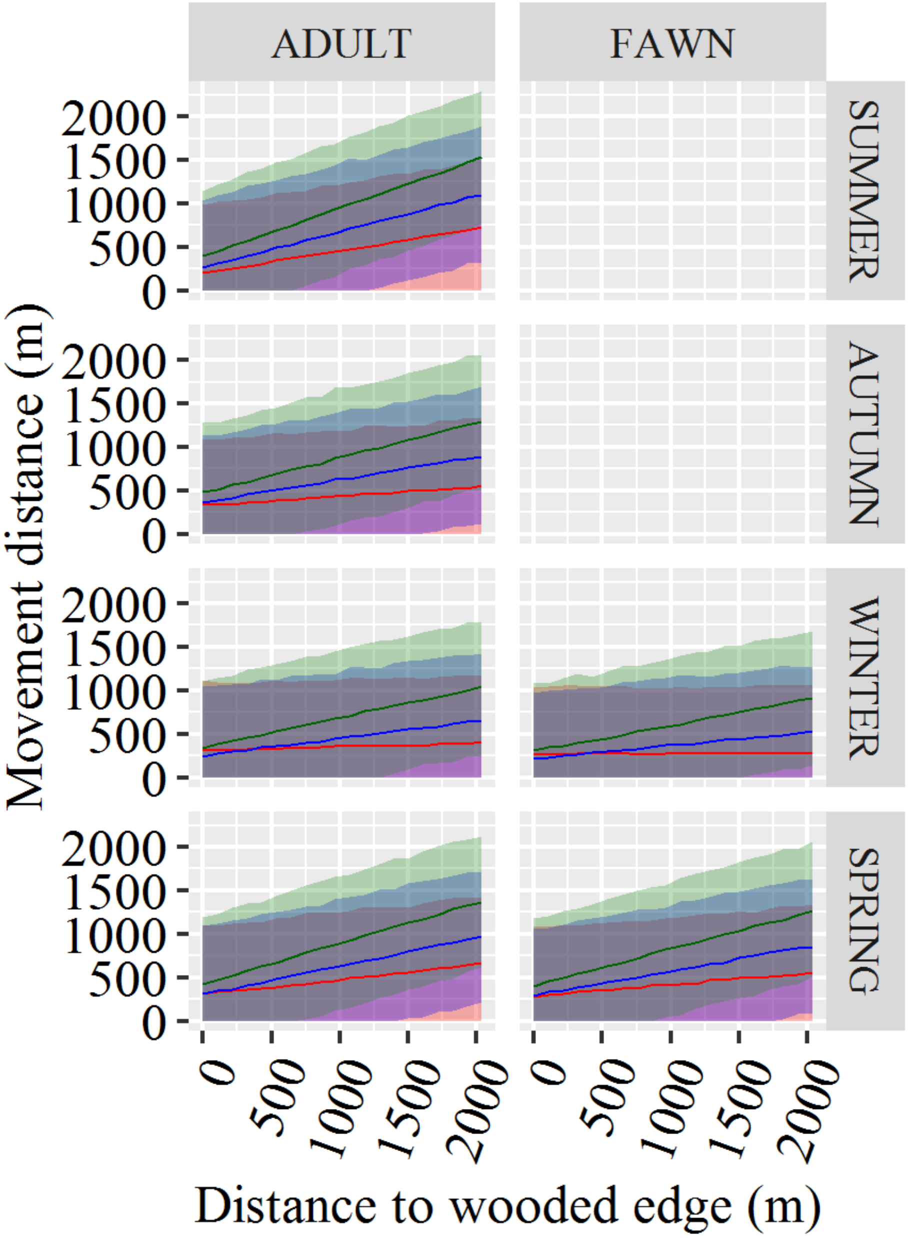

Figure 16. Plots movement distance predicted by distance to wooded edge for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

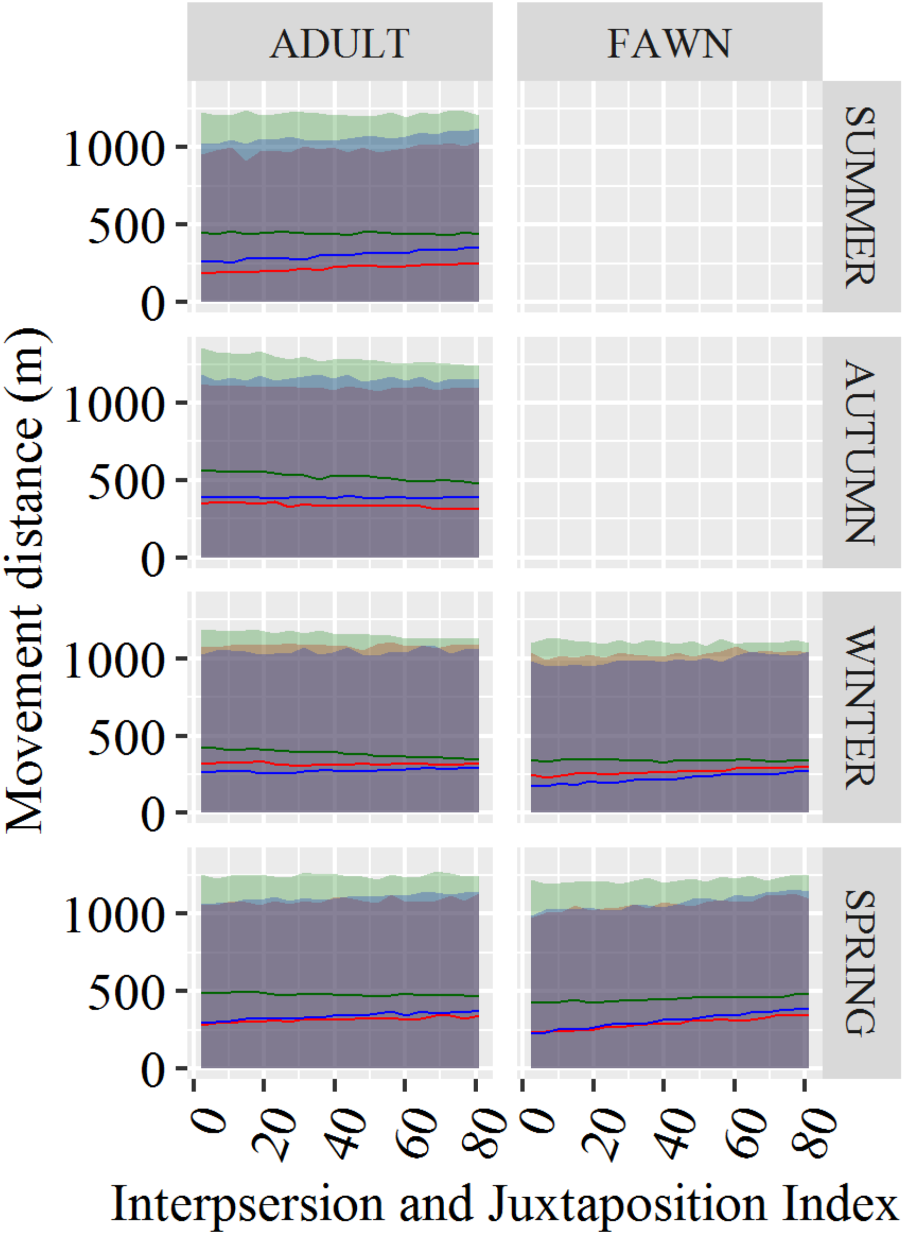

Figure 17. Plots of movement distance predicted by IJI for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

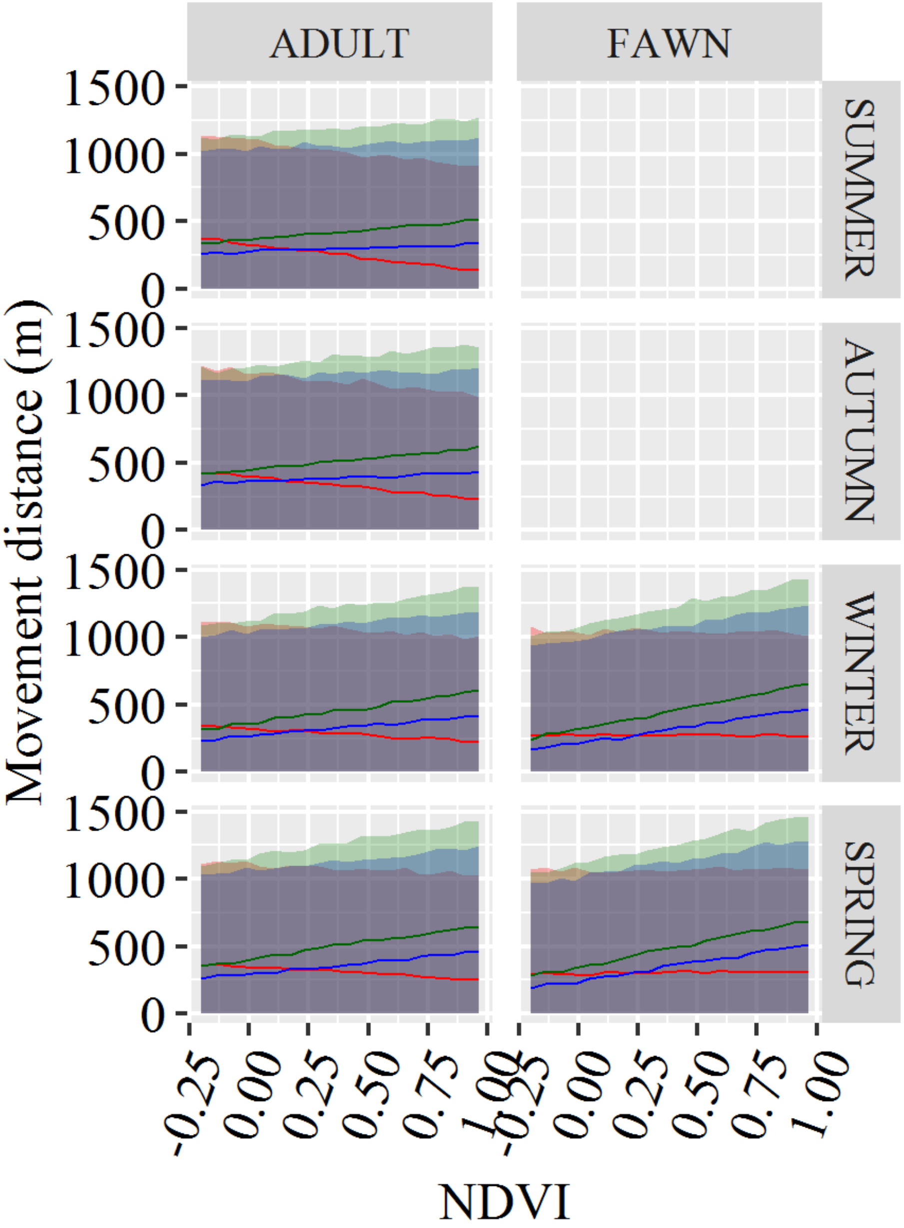

Figure 18. Plots of movement distance predicted by NDVI for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

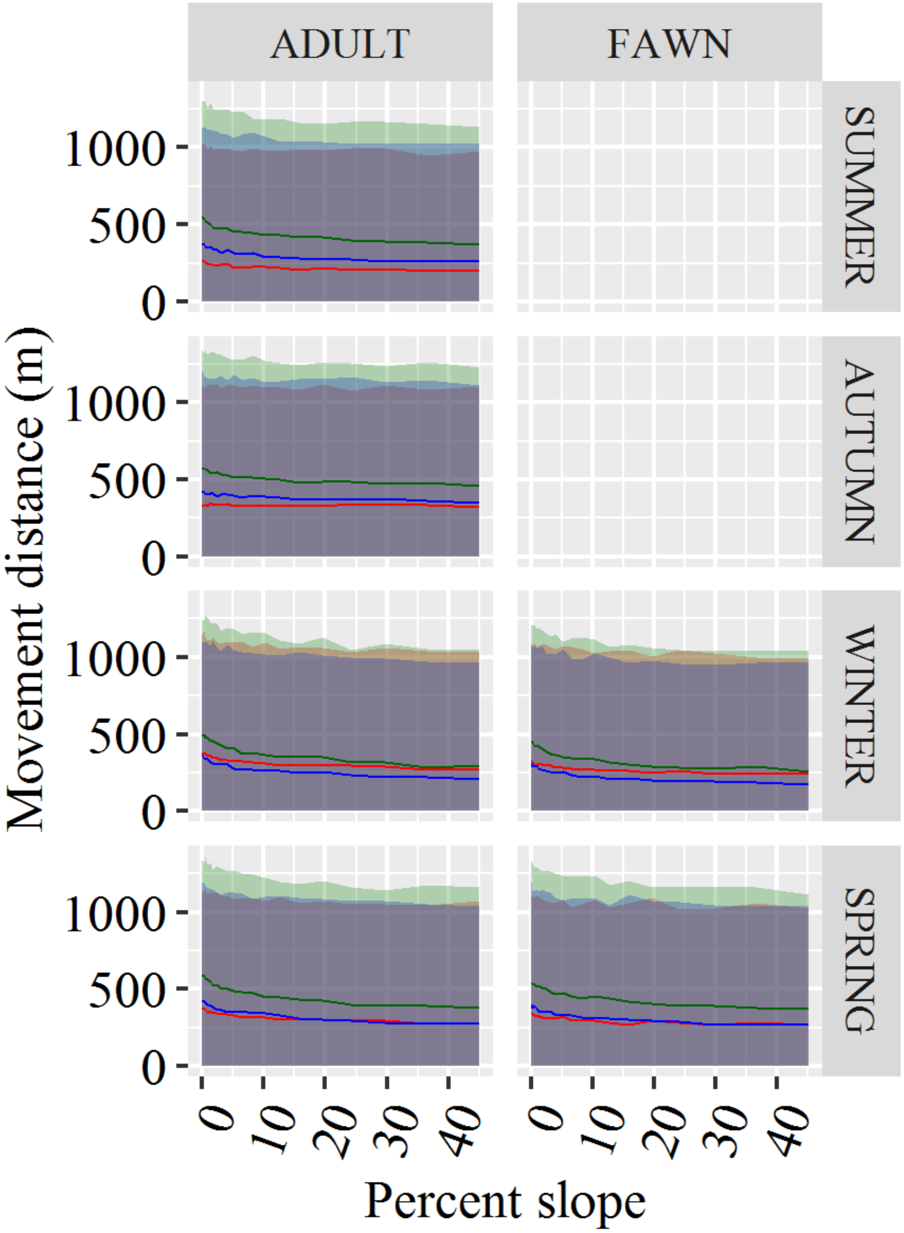

Figure 19. Plots of movement distance predicted by percent slope for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

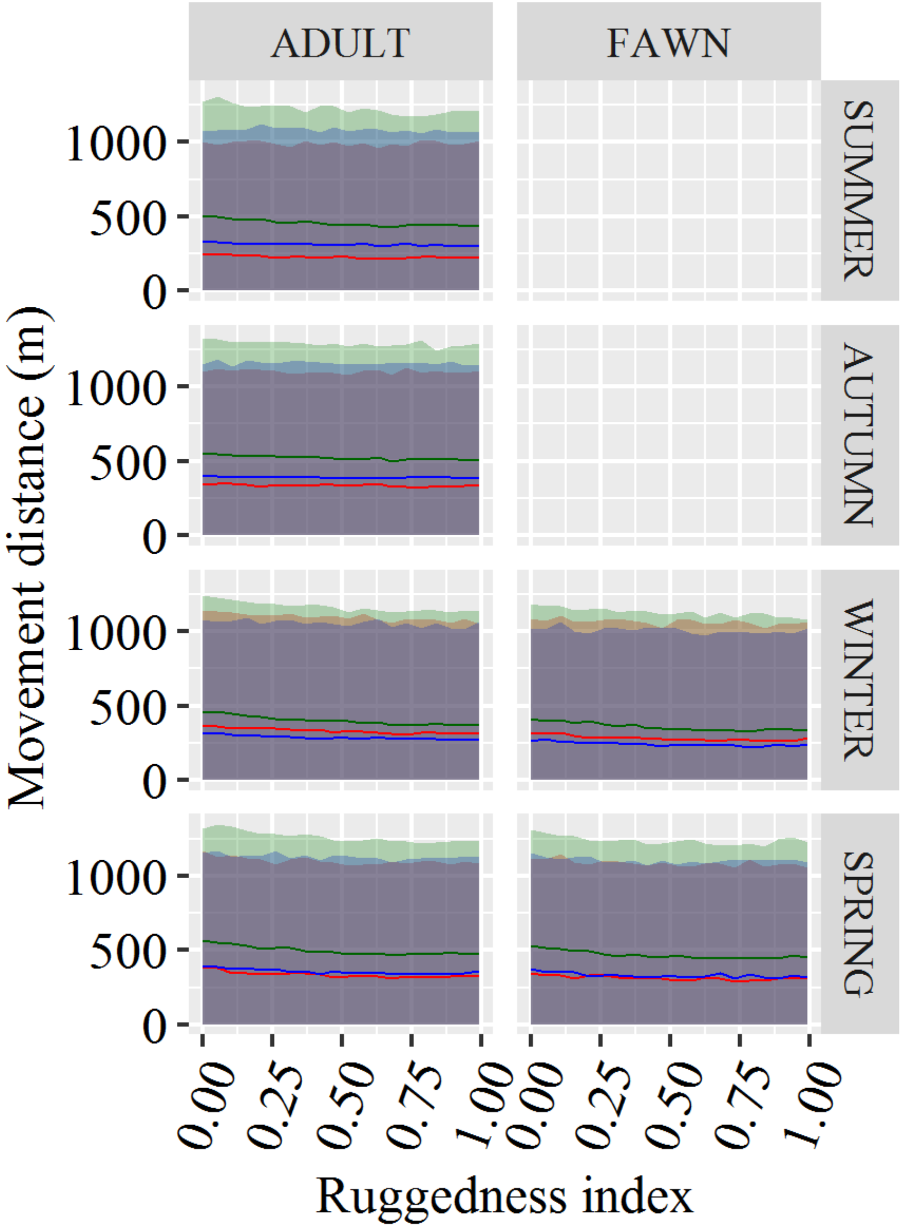

Figure 20. Plots of movement distance predicted by ruggedness for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

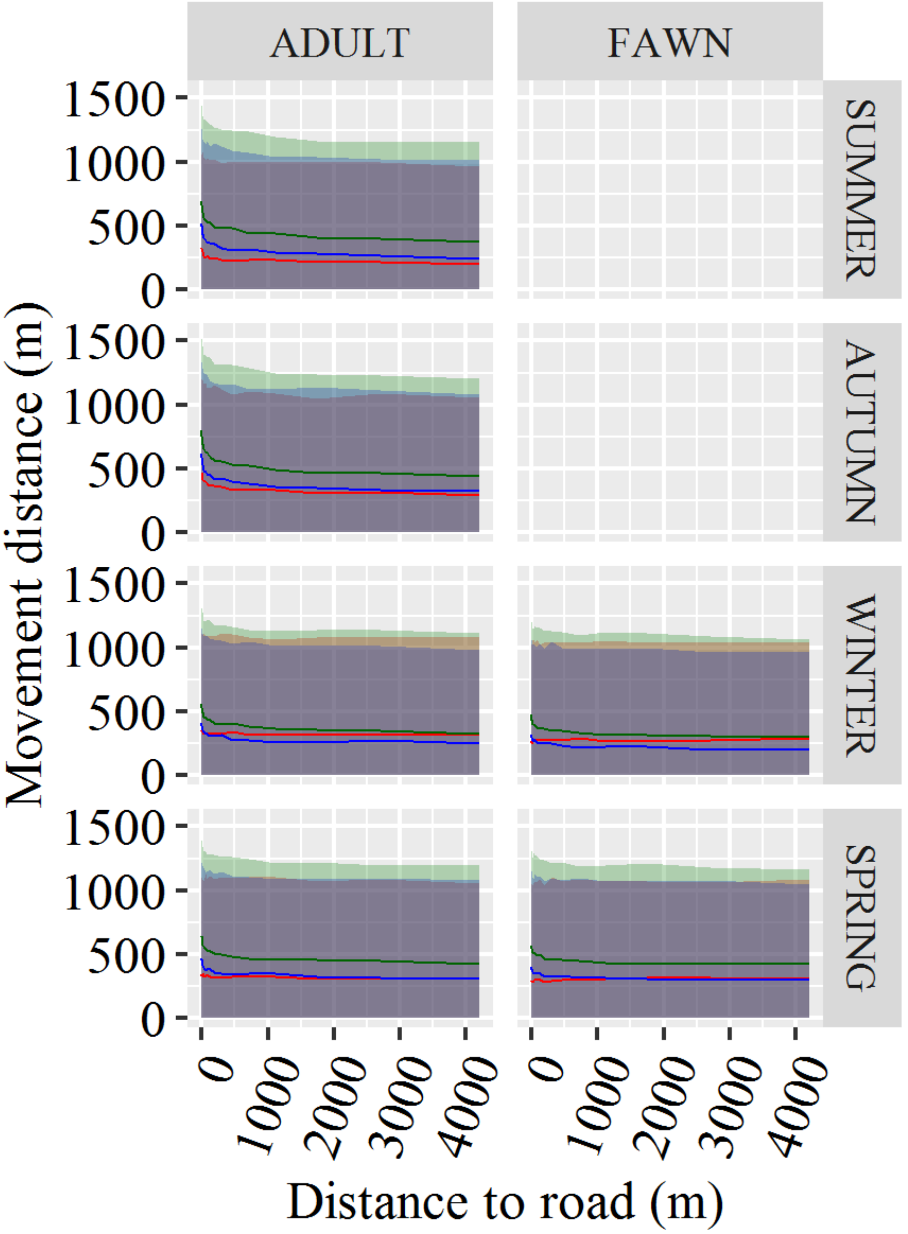

Figure 21. Plots of movement distance predicted by distance to nearest road for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

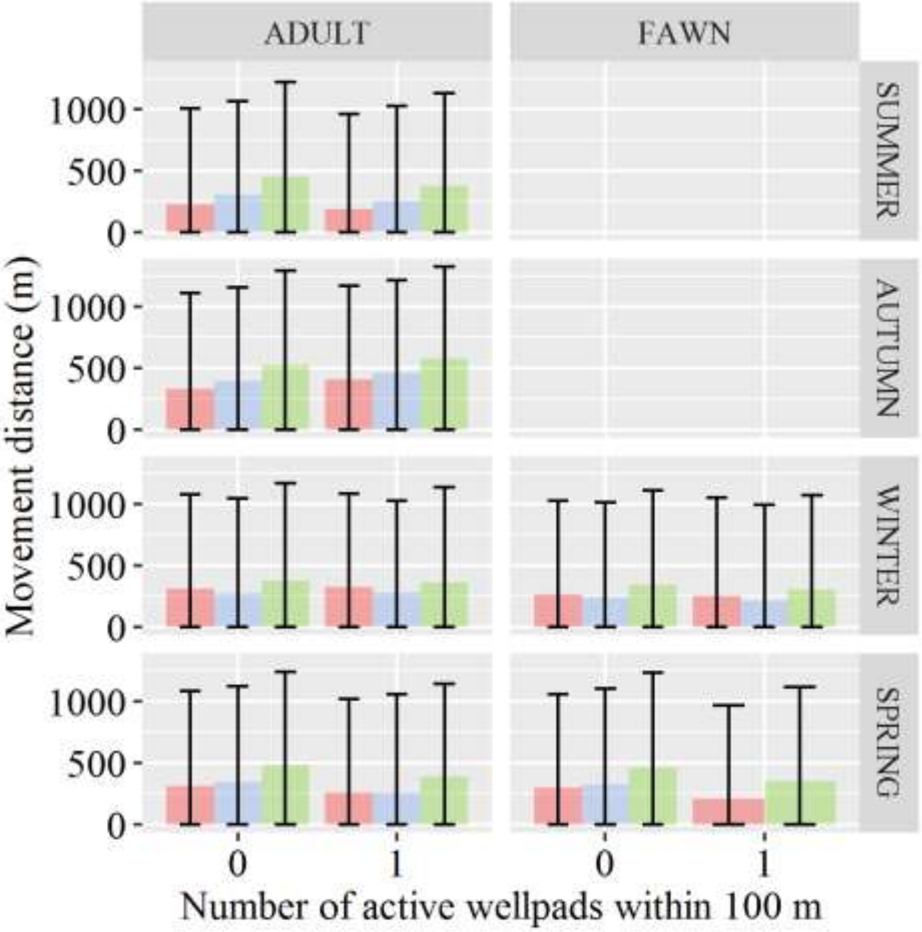

Figure 22. Plots of movement distance predicted by well density calculated in 100m buffer for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

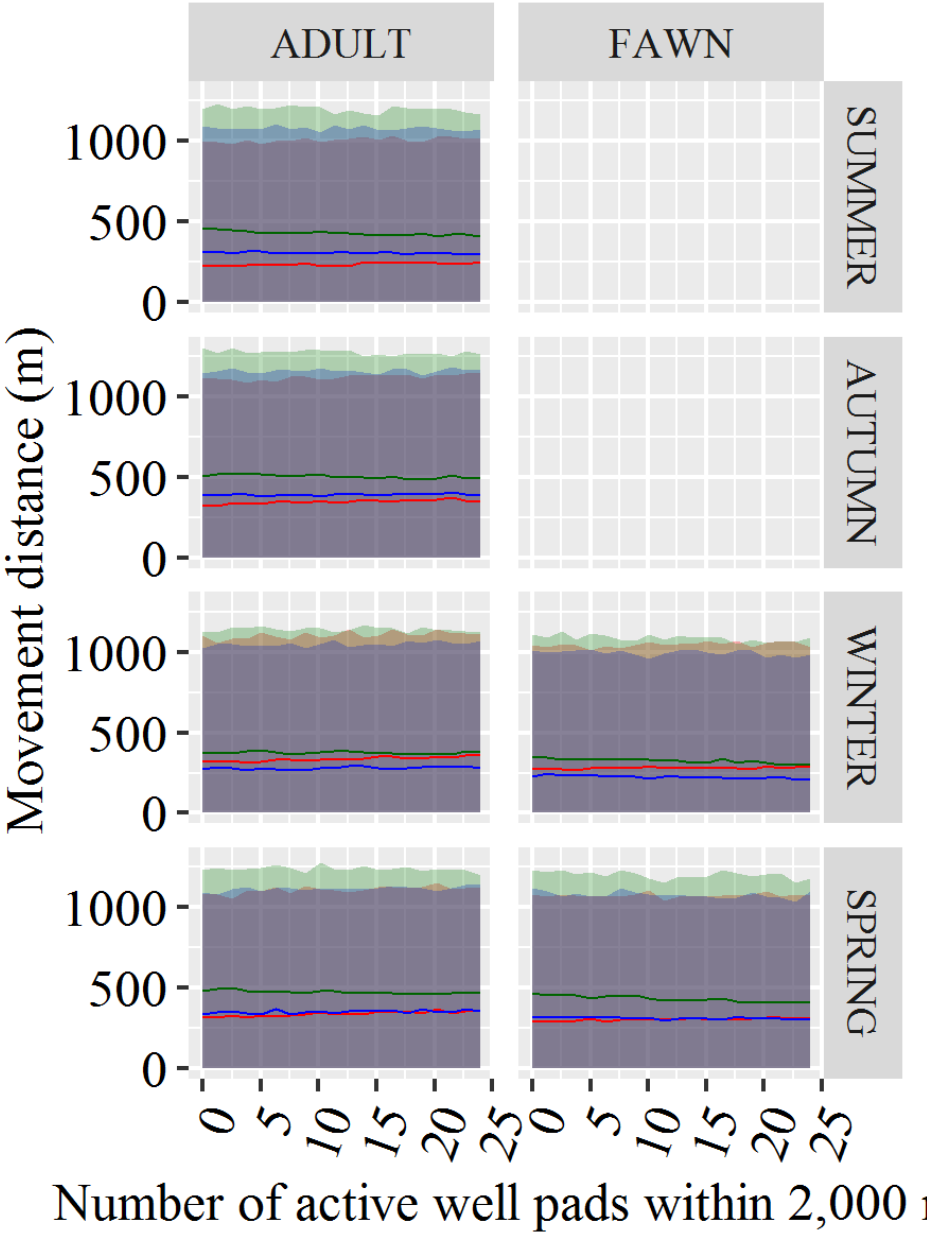

Figure 23. Plots of movement distance predicted by active well pad density calculated using a 2000 m buffer, for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

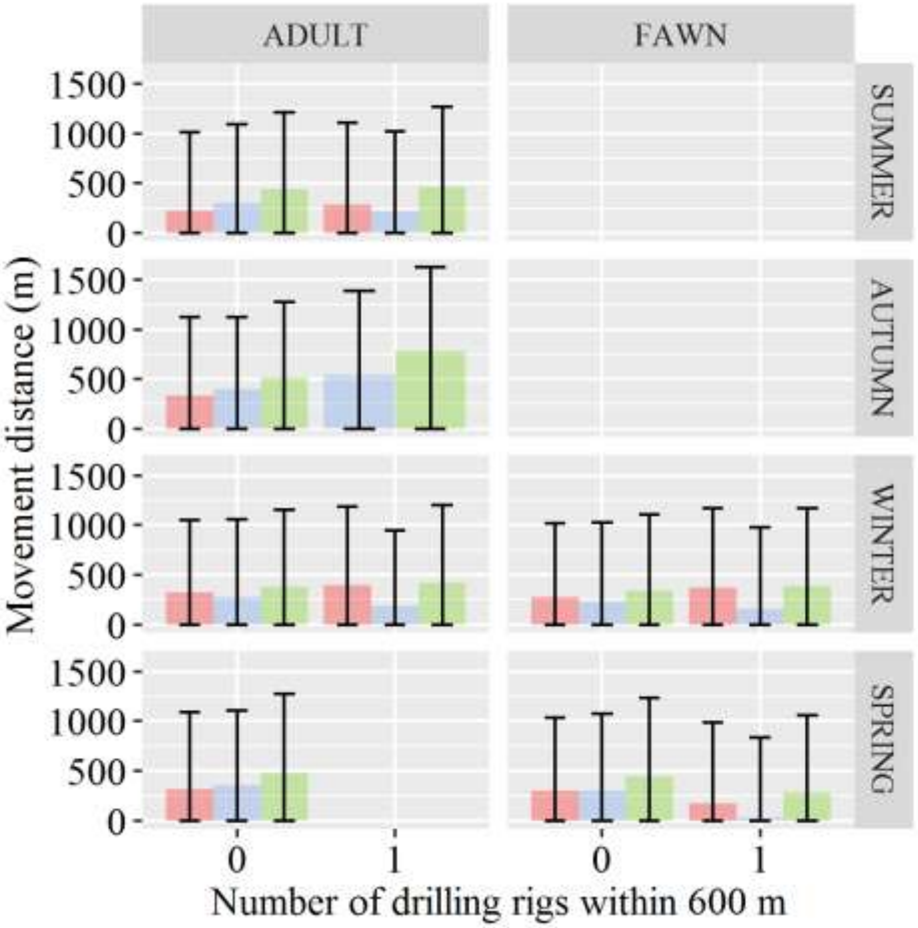

Figure 24. Plots of movement distance predicted by presence of a drilling rig within 600 m for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

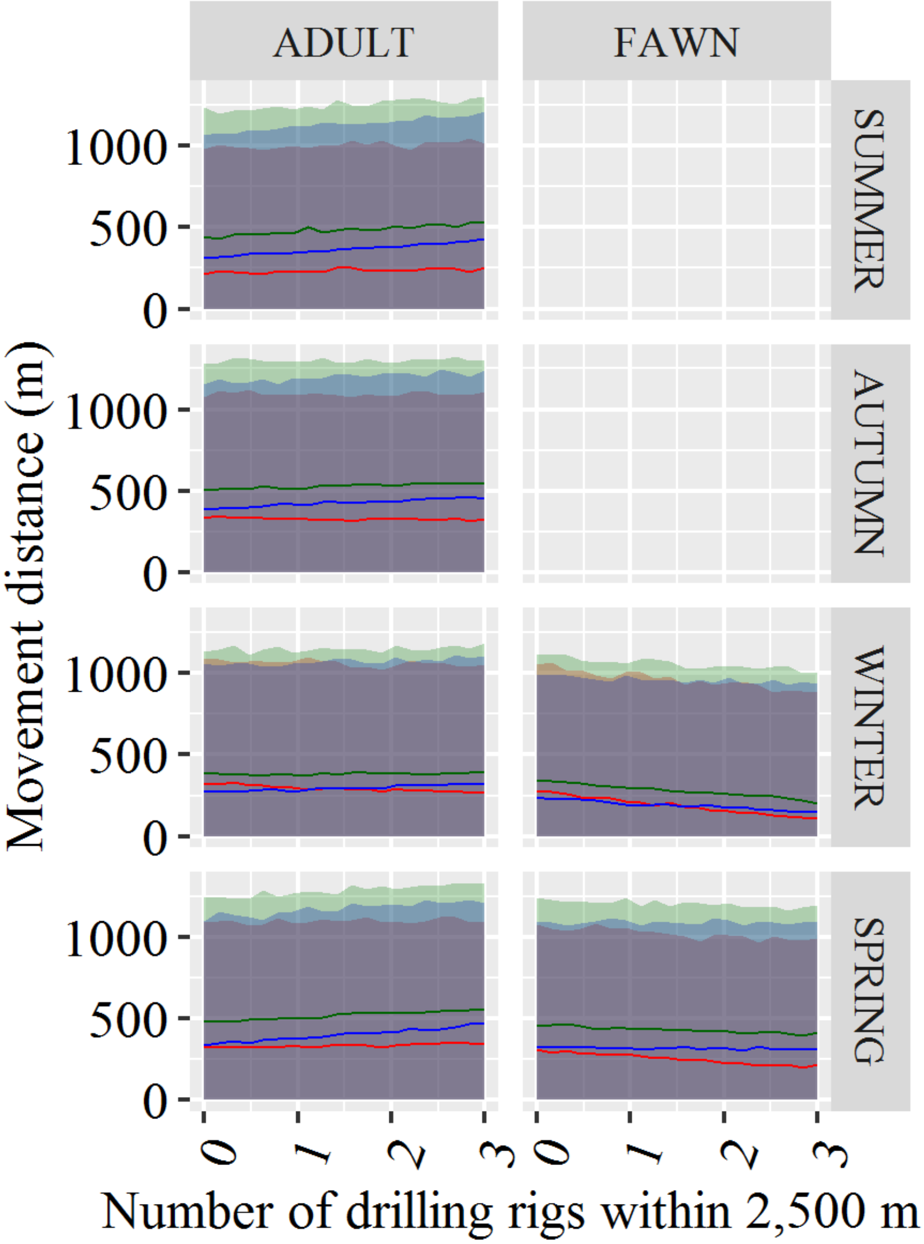

Figure 25. Plots of movement distance predicted by presence of a drilling rig within 2500 m for adults and juveniles during each season and each time of day (day: red, night: blue, crepuscular: green).

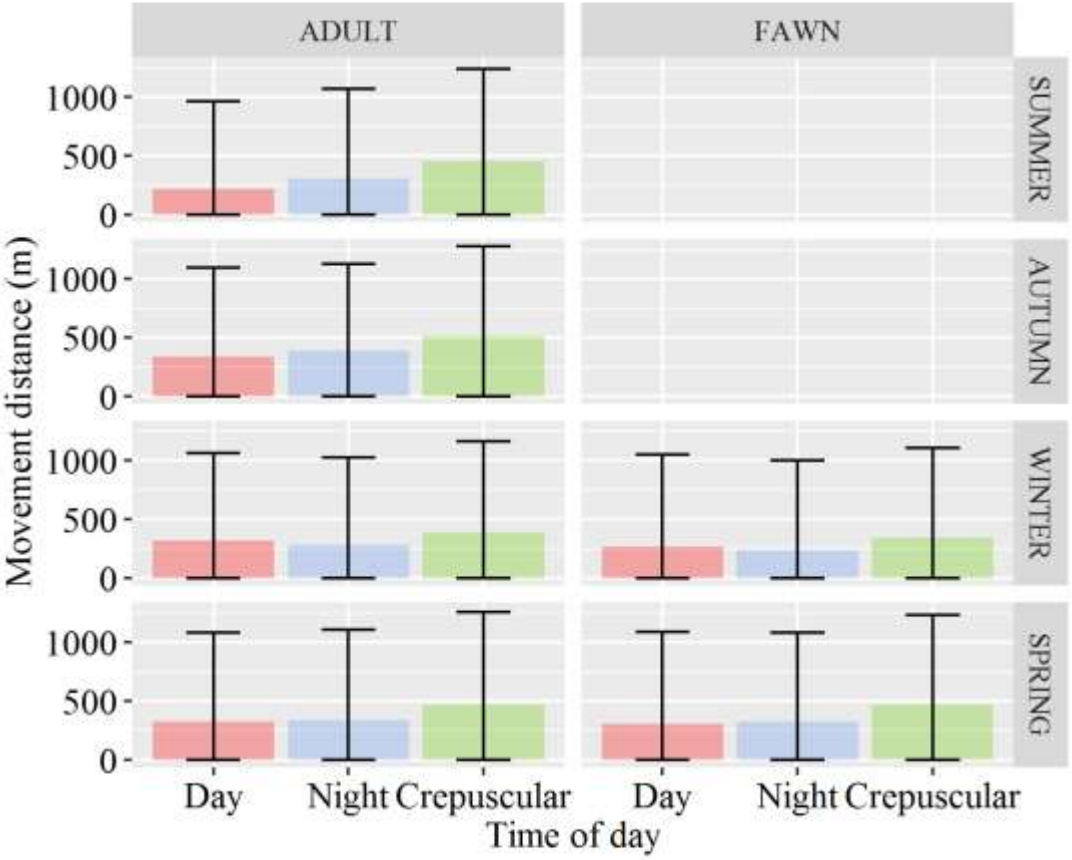

Figure 26. Plots of movement distance predicted by time of day for adults and juveniles during each season.

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CHAPTER III. PHYSIOLOGICAL STRESS RESPONSE OF MULE DEER TO OIL AND GAS ENERGY DEVELOPMENT AND ENVIRONMENTAL CONDITIONS IN WESTERN NORTH DAKOTA

Introduction

Animals respond to external stimuli behaviorally and physiologically and stress hormones are commonly used to measure adrenocortical activity (Millspaugh et al. 2001, Sheriff et al. 2011). Stress hormones can be detected in blood, urine, and feces (Harvey et al. 1984, Wingfield et al. 1994, Wasser et al. 2000). However, with free-ranging animals the response to capture, handling, and blood collection might induce a physiological stress response and complicate data interpretation (Le Maho et al. 1992). Procedures have been developed to quantify adrenal activity non-invasively, through measurement of fecal glucocorticoid metabolite (FGM) levels (Graham and Brown 1996, Wasser et al. 2000, Millspaugh et al. 2002, Keay et al. 2006, Rothschild et al. 2008, Sheriff et al. 2011). In many studies use of fecal material has the added benefit of showing cumulative effects of stressors as they contain metabolites of stress hormones produced over a period of time (Harper and Austad 2000, Wasser et al. 2000, Millspaugh and Washburn 2004).

Physiological stress has many potentially deleterious effects (Sapolsky et al. 2000). Wildlife managers care about physiological stress in wildlife because it is a sensitive measure of wildlife response and can often foreworn of population level effects such as reduced survival (Millspaugh and Washburn 2004). Further, managers might use such information about the physiological stress response of wildlife to help mitigate human-induced disturbances. Ungulates in particular are sensitive to such disturbances, which can affect their behavior, physiology, and demographics (Cassirer et al. 1992, Phillips and Alldredge 2000, Creel et al. 2002, Stankowich 2008). Thus, measurements of the wildlife physiological stress measurements can offer additional insight into wildlife response to human activities, particularly when partnered with other metrics such as behavior and demographics. Many researchers use physiological stress measures as an indicator of general animal well-being (Sheriff et al. 2011). We used fecal hormone assays to evaluate mule deer (*Odocoileus hemionus*) response to human disturbance (i.e., energy development) and biological factors such as age and environmental conditions.

Methods

Field Methods

We collected fecal samples opportunistically from female adult and juvenile mule deer, after they were captured to be fit with radio collars for a research project in western North Dakota and eastern Montana. Captures occurred during the winter from 2013-2015. We homogenized and froze all fecal samples until assays were completed; fresh samples avoided complications of microbial breakdown of hormone metabolites (Millspaugh and Washburn 2004). We confirmed information about the animal such as sex and age which provides useful context for hormone measurements.

Laboratory Methods

We placed frozen fecal samples in a lyophilizer (Freeze-dry Specialties, Inc., Osseo, Minnesota) for 24 hr. Once freeze-dried, we ground samples, sifted them through a stainless steel mesh to remove large particles, and mixed them thoroughly. We placed dried feces (~0.2 g) in a test tube with 2.0 mL of 90% methanol and vortexed at high speed in a multi-tube vortexer for 30 min. Samples were then centrifuged at ~1900*g* for 20 min, and the supernatant was saved and stored at –20 °C until assayed.

We measured corticosterone metabolites in deer feces (FGM) using a commercially available corticosterone I^{125} double-antibody RIA kit (Cat. #07120103, MP Biomedicals, Solon, Ohio). We followed the manufacturer's method for the corticosterone I^{125} RIA, except that we halved the volume of all reagents (Wasser et al. 2000). These procedures were previously validated by Millspaugh et al. (2002) for white-tailed deer. We conducted a standard assay validation including assessment of parallelism, recovery of exogenous analyte, intra- and interassay precision, and assay sensitivity (Jeffcoate 1981, Grotjan and Keel 1996, O'Fegan 2000) to confirm the assay accurately and precisely measured testosterone metabolites in white-tailed deer feces. We conducted parallelism and recovery of exogenous testosterone validation assays on two pooled fecal extract samples (expected low and high levels; each pool consisted of feces from three samples). Parallelism ensures the assay maintains linearity under dilution, and recovery of exogenous corticosterone verifies accurate measurement throughout the working range of the assay (Jeffcoate 1981). We added exogenous corticosterone to the low and high pooled fecal extracts to obtain testosterone values under higher dilution levels. We used tests for equal slopes (parallelism) to determine if log-transformed curves of serially diluted pooled fecal extracts were parallel to log-transformed corticosterone standard curves. We selected two mule deer fecal samples and analyzed them in the two assays; interassay variation was calculated from these two samples. We calculated intra-assay variation by averaging the coefficient of variation (CVs) of replicate tubes from 20 randomly chosen samples. Inter-assay variation 4.1% and average intra-assay variation for 20 random samples was 1.6%.

Data Analysis

We evaluated the association of FGM levels in mule deer with natural and anthropogenic factors using a multi-stage (e.g., Washburn et al. 2004) information-theoretic modeling approach (Burnham and Anderson 2002). We divided potentially influential variables into 4 hypothesis sets, including biological, temperature, landscape, and anthropogenic disturbance (Table 7). In biological models we included biological year of capture (01 June – 31 May: 2012-13, 2013-14, 2014-15); season of capture (fall or winter) because cortisol levels vary seasonally in white-tailed deer (Bubenik et al. 1977); and mule deer age (adult, >1.5 years old; and juveniles, < 1 year old) because FGM levels were affected by age in elk (Creel et al. 2002). We included minimum temperature from the nearest weather station (Amidon, Watford City, Grassy Butte, Medora, Culbertson, Sidney, Glendive; National Oceanic and Atmospheric Administration, 2013-2015) within the previous 24 and 48 hours of mule deer capture in temperature models. FGM levels are an index of plasma corticosteroid levels 12-24 hours prior to sampling (Millspaugh et al. 2002), and a physiological stress response may occur up to 36 hours after a significant drop in temperature (Moll et al. 2009), thus we considered this potential lag effect.

To determine the potential effects of landscape features on FGM levels in mule deer, we included a ruggedness index and proportion of forest/shrub cover in landscape models, both of which might mitigate the effects of anthropogenic disturbance on physiological stress (Easterly et al. 1991, Lendrum et al. 2012; in elk, Montgomery et al. 2012). We used the 30-m 2011 National Land Cover Database (NLCD; Homer et al. 2015) in ArcInfo 10.5 (Environmental Research Systems Institute, Redlands, CA) to calculate the proportion of forest or shrub cover by dividing the number of pixels identified as forest or shrub cover by the total number of pixels within 2 km of the capture site (scale based on Kie et al. 2002). We used a 30-m Digital Elevation Model layer to calculate the ruggedness index (Sappington et al. 2007) for each pixel using a 3 x 3 pixel neighborhood (8,100 m^2), which captures the complexity of the landscape without over-smoothing it (Sappington et al. 2007). We then calculated the mean ruggedness index within 2 km of the capture site.

Anthropogenic disturbance may decrease time spent foraging by ungulates (in white-tailed deer, Lagory 1986; elk, Laundre et al. 2001) and has been correlated with increased FGM levels in elk (Millspaugh et al. 2001, Creel et al. 2002), thus we included the following variables in our anthropogenic disturbance models: road density and number of active well pads, drilling rigs, and gravel pits. We used a combination of available and digitized line shapefiles for roads. We used ND Department of Transportation State and Federal Highways and County and City Roads (ND GIS Hub 2016, online), and digitized missing roads at a 1:5,000 scale. We estimated road densities by dividing the total length of roads by the area within 1.91 km of the capture site. We determined the number of active well pads within 1.91 km, drilling rigs within 2.91 km, and gravel pits within 2.91 km of mule deer capture locations using spatial data from the ND Oil and Gas Division (ND Department of Mineral Resources). We used 1.91 km and 2.91 km buffers to quantify anthropogenic disturbance variables because 0.91 km is the approximate radius of a 2.4 km^2 winter home range, which was the upper range of home ranges for non-migratory, female, adult mule deer in the Missouri River Breaks of Montana (Hamlin and Mackie 1990), and indirect impacts on mule deer have been identified up to 1 km and beyond 2 km by well pads and drilling rigs, respectively (Fox et al. 2009, Sawyer et al. 2009).

Next, we determined which form of each continuous vegetation variable, including linear, quadratic, and pseudo-threshold (e.g., Franklin et al. 2000) was most supported at each scale by comparing Akaike's information criterion (Akaike 1973) adjusted for small sample size (AICc) values across variable forms. We used the non-linear form of the variable if it was >2 AICc units better than the linear form; otherwise, we used the linear form. We checked for multicollinearity between variables by calculating Pearson’s correlation coefficient (r) using the cor() function in R (R Core Team 2016). If $r > 0.65$, we removed the correlated variable with the highest AICc value. Finally, we established which biological, temperature, landscape, and anthropogenic disturbance model was most supported and combined top models to determine which hypothesis or combination of hypotheses explained the most variation in mule deer FGM levels. For all model stages, we used the glm() linear regression function with a Gaussian family and Identity link in R (R Core Team 2016) to estimate AICc values and model parameters

Results

We collected 190 fecal samples from 62 adults and 128 juveniles (Table 8). FGM levels ranged from 40.24 – 247.29 (mean = 118.47, SD = 44.83). The global model was most supported (Table 9). The winter of 2014-15 had higher FGM levels than the previous two winters (Figure 27). When temperatures were below 0^{o}C, FGM values were higher than when the temperature was above 0^{o}C (Figure 27C), but the effect was marginal. Contrary to our hypothesis that ruggedness might mitigate the impacts of development, FGM increased with increasing ruggedness (Figure 27D), although the result was not significant.

Beyond annual differences, the most significant effect we observed related to energy development. FGM increased with increasing density of gravel pits, but not until the density of gravel pits was above 3 within 2.91 km of the capture location (Figure 27A). The trend was observed in all years of study. Similarly, FGM values doubled when there were >1 drilling rigs within 2.91 km of the capture location (Figure 27B).

Discussion

Disturbance in the form of density of gravel pits and drilling rigs were the most important factor correlated with mule deer FGMs in this study, while road density and active well pad density were not significantly correlated with mule deer FGMs. This result supports previous research indicating that ungulates might grow accustomed to consistent, low levels of predictable traffic and disturbance (Stankowich 2008, Malo et al. 2011, Brown et al. 2012, Shannon et al.

2014). Gravel pits and drilling rigs have higher levels of traffic, and because drilling rigs are on the landscape for a short time, the traffic is less predictable. This result is also supported by other stress physiology research (Millspaugh et al. 2001, Creel et al. 2002, Crino et al. 2011, Hayward et al. 2011) which indicates that unpredictable disturbances can elicit a physiological stress response in a diversity of wildlife species. For example, Millspaugh et al. (2001) noted higher FGMs of elk in the Black Hills, South Dakota as human activity levels increased in the summer. Similarly, Creel et al. (2002) noted increased FGMs as snowmobile activity increased in Yellowstone National Park. The lack of mule deer specific data, and our results, indicate that physiological stress metrics might be similarly sensitive and useful indicator of animal response to environmental and human-induced disturbances.

These results also indicate that human disturbance was correlated with elevated physiological stress and overrode climate factors, such as temperature. Temperature was a factor affecting mule deer physiological response. Numerous studies have documented a correlation between ungulate FGMs and temperature. For example, Moll et al. (2009) observed an inverse relationship between temperature and FGM in white-tailed deer (Moll et al. 2009). FGM was positively correlated with temperature in elk in Custer State Park, South Dakota (Millspaugh et al. 2001). In many other ungulates, the pattern of FGM secretion throughout the year is not consistent (e.g., caribou, Bubenik et al. 1998; moose, Franzman et al. 1975). We suspect that the FGM secretion we observed is owed to the predominant stressors of the environment at the time of capture. In studies such as ours, it is difficult to tease out the factors affecting FGMs because it is possible human activities and temperature exhibit similar seasonal trends. However, each of these factors explained a different portion of the variation in FGMs, so both might offer insight into how mule deer response to human-induced and environmental disturbances.

These findings are consistent with recent resource selection studies that have shown stronger avoidance of actively drilling rigs than roads or well pads (Sawyer et al. 2009, Northrup et al. 2015) and Chapter I of this study, which indicates mule deer respond spatially to energy development. Thus, we hypothesize that several metrics of response by mule deer point a similar direction and indicate that mule deer are responsive to energy development and the associated activity. It is possible that other potential stressors, many of which could co-vary with human development and temperature, such as food shortages or drought could affect the patterns we observed. However, there is no evidence that deer were malnourished or that other unmeasured environmental conditions overrode what we considered as covariates. We suspect that the degree of human activity in this environment is perceived to be stressful. The elevated FGMs that we observed are not necessarily bad, rather they indicated that the animal has initiated a coping mechanism, through the physiological stress response. In fact, elevated FGMs are an important part of the vertebrate stress response which is stimulated in response to a diversity of stressors, whether they are real or perceived (Selye 1937). Secretion of FGMs helps the animal deal with a stressor and redirects behavior and other coping mechanisms to avoid the stressor. It only becomes deleterious to the animal when these coping mechanisms fail and the animal is unable to eliminate the stressor in the environment. This inability to cope leads to chronic stress which can have multiple negative effects (Sapolsky et al. 2000). We are unable to determine whether these FGM levels were chronic for several reasons including the one-time nature of our sample collection in winter only, the lack of repeated sample collection from the same individuals, and the lack of an experimental design that allows us to assign cause and effect responses.

Age was not a significant predictor of physiological stress levels in our study, but we noted year effects. We detected higher physiological stress levels in 2014-2015 which could be owed to drier environmental conditions that summer, which could have affected forage quality and potentially mule deer condition before winter. For ungulates, seasonal availability of water and forage abundance and quality can vary greatly by year, resulting in seasonal differences in basal fecal glucocorticoid metabolite concentrations (Huber et al. 2003, Dalmou et al. 2007, Chinnadurai et al. 2009, Corlatti et al. 2011). For a number of reasons we might expect age to be influential. For example, juveniles might have less body fat and more likely to be stressed by nutritional limitations in winter. Further, juveniles might be less accustomed to human activities than adults. However, age was not important indicating that deer of all ages responded similarly from a physiological stress perspective to human-induced and environmental disturbances.

Management Implications

Although we observed increased physiological stress, as measured by FGMs, correlated with energy development metrics including the density of gravel pits and number of drilling rigs, it is important to keep these results in context. We did not correlate physiological stress with demographic parameters, thus we are unable to ascertain whether these observed increased values in FGMs have any deleterious effects on demographics. These findings could be causal, or they could be surrogates for another stressor that we did not include in our analysis. Our study is correlative and it is difficult to tease apart the implications of these results. However, we do hypothesize that mule deer are initiating a physiological stress response, a coping mechanism, in response to these metrics of energy development. Instead of relying solely on FGMs, we encourage managers to use these results in conjunction with other metrics of mule deer response, such as survival, movements, and resource selection to more fully assess whether energy development has a negative impact on mule deer populations. Experimental manipulations, in conjunction with year-round sampling, particularly of the same individuals would more fully allow cause and effect relationships to be determined.

There has been a great deal of research investigating the response of wildlife to energy development. We believe that FGMs could be one important measure, when combined with traditional metrics of spatial ecology and population demographics to elucidate the potential impacts. Our results indicate that FGMs could be a useful method for passively examining physiological stress levels of wildlife in areas with anthropogenic development. We advocate for the application of this technique to complement other measurements of disturbance and to partner multiple metrics.

Table 7. Models included in broad hypotheses related to the influence of natural and anthropogenic factors on FGM levels in mule deer in North Dakota and Montana in 2013 and 2014.

Hypothesis	Models[a]
Biological	
	Null
	Age
	Year
	Season
	Year + Season
	Age + Year
	Age + Season
	Age + Year + Season
Landscape	
	Null
	Wood/Shrub
	Rugged
	Wood/Shrub + Rugged
Temperature	
	Null
	Temp<24h
	Temp<48h
Anthropogenic Disturbance	
	Null
	Active well pads
	Drilling rigs
	Gravel
	Roads
	Active well pads + Drilling rigs + Gravel
	Active well pads + Drilling rigs + Gravel + Roads

[a] Null = intercept-only model; Age = mule deer age (adult or juvenile); Year = biological year (2012-13, 2013-14, 2014-15); Season = fall or winter; Wood/Shrub = proportion of area dominated by forest or shrub cover within 2 km of mule deer capture site; Rugged = mean ruggedness index within 2 km of capture site; Temp<24 = minimum temperature in the 24 hours leading up to mule deer capture; Temp<48 = minimum temperature in the 48 hours leading up to mule deer capture; Active well pads = number of active well pads within 1.91 km of capture site; Drilling rigs = number of active drilling rigs within 2.91 km of capture site; Gravel = number of active gravel pits within 2.91 km of capture site; Roads = road density (km/km^2) within 1.91 km of capture site.

Table 8. Summary of mule deer fecal samples collected during 3 consecutive winters in western North Dakota, summarized by age and state.

	2012-13		2013-14		2014-15		Total		
	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Total
ND	7	12	25	27	0	46	32	85	117
MT	NA	NA	20	20	10	23	30	43	73
Total	7	12	45	47	10	69	62	128	190

Table 9. Summary of top model results for physiological stress response of mule deer. Those marked with “*” are significant at the P < 0.05 level and those marked with “.” are between P 0.05 and 0.10.

Parameter	Estimate	SE	t value	Pr(>|t|)	Significance
(Intercept)	30.2859	50.18557	0.603	0.547	
BioYear13-14	3.2077	15.23614	0.211	0.8335	
BioYear14-15	23.22126	10.94491	2.122	0.0352	*
rugged	121.7659	74.18563	1.641	0.1025	
temp24	-0.62561	0.33753	-1.854	0.0654	.
temp24_sq	-0.0263	0.01981	-1.327	0.1861	
rig	-75.2101	46.65048	-1.612	0.1087	
rig_sq	66.30546	29.37873	2.257	0.0252	*
gravel	-7.08733	5.05097	-1.403	0.1623	
gravel_sq	1.69643	0.65265	2.599	0.0101	*

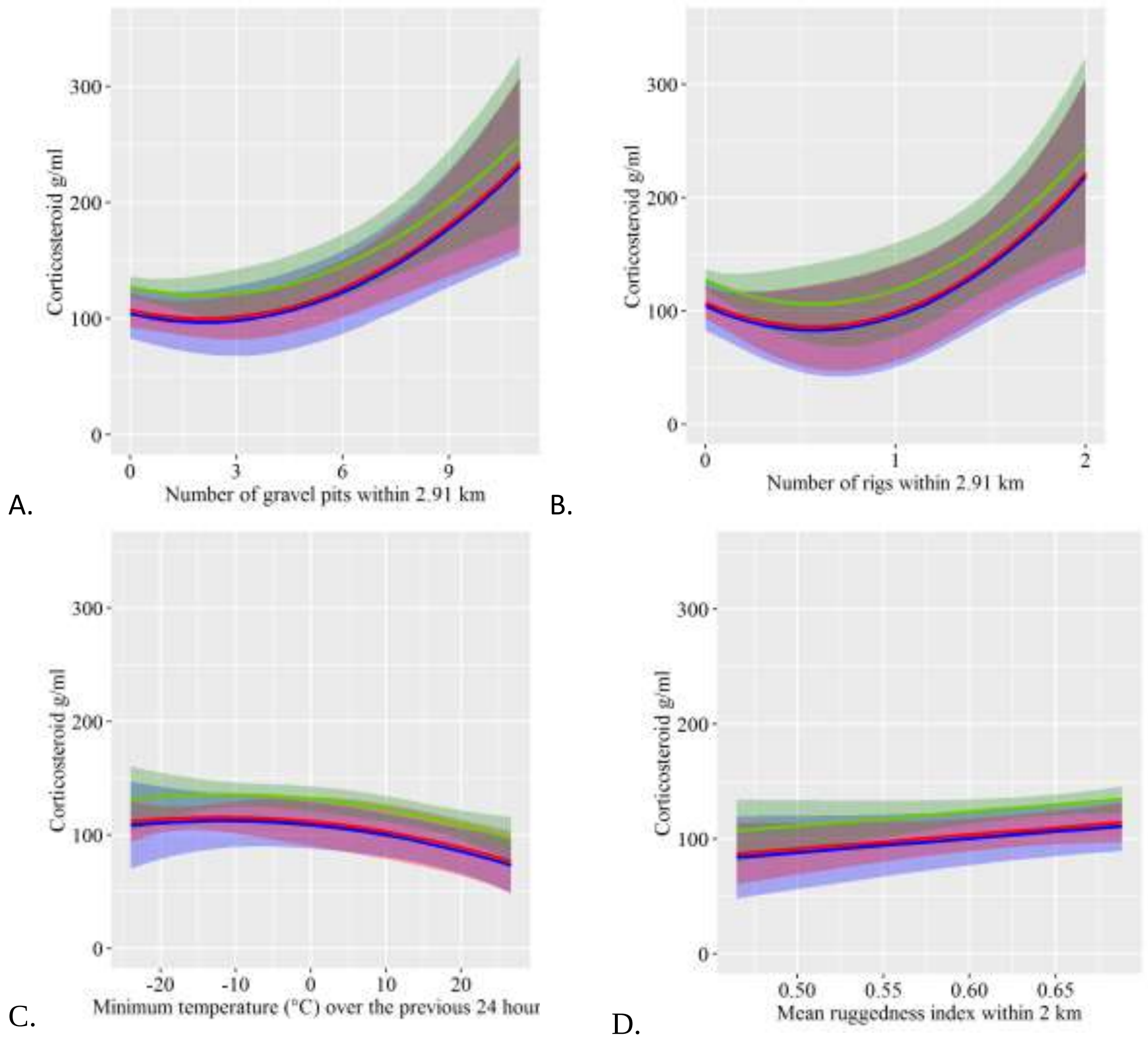

Figure 27 (A-D). Physiological stress response of mule deer to disturbance and environmental conditions in western North Dakota. Blue = 2012-2013, Red = 2013-2014, and Green = 2014-2015. Ribbons represent 95% confidence intervals.

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CHAPTER IV. POTENTIAL EFFECTS OF OIL AND GAS ENERGY DEVELOPMENT ON SURVIVAL OF MULE DEER IN WESTERN NORTH DAKOTA

Introduction

Reproduction and survival are the principal elements of wildlife population growth, and unsurprisingly, female adult survival and juvenile recruitment are the most significant demographic parameters affecting population growth rates in mule deer (Wallmo 1981, White and Bartmann 1998, Bishop et al. 2009, Forrester and Wittmer 2013). Managers have little information on female adult mule deer survival in North Dakota, but female adult mule deer survival rates across their distribution tend to be high and stable (Forrester and Wittmer 2013). Currently, North Dakota Game and Fish Department (NDGF) biologists collect information on juvenile production (juvenile-to-adult female ratios) during October aerial surveys, but little is known about the survival of juveniles during winter and spring. Juvenile overwinter survival rates tend to vary in mule deer (Pac et al. 1991, Gaillard et al. 1998, Unsworth et al. 1999, Forrester and Wittmer 2013), so high fecundity rates and high, steady survival rates in adults may be necessary to account for low juvenile survival (Pac et al. 1991, Forrester and Wittmer 2013).

Although there are few published studies linking oil and gas energy development metrics with mule deer survival, Sawyer et al. (2002) concluded that long-term avoidance of energy development could result in decreased fitness, including decreased survival. Sawyer et al. (2017) documented decreases in abundance of mule deer in an oil and gas developed area, but the demographic parameter causing declines was unknown. Decreases in abundance may be due to emigration, reduced fecundity, or reduced survival, but additional research is needed to identify the mechanisms that could link mule deer abundance to oil and gas energy development.

Several ungulate studies suggest that human developments and disturbance could indirectly affect survival via: decreased foraging time (Freddy et al. 1986) or increased energy expenditure (Parker and Robbins 1984). However, Freddy et al. (1986) found that despite increased energetic costs near snowmobile trails, disturbances did not affect survival. The leading causes of mortality in unhunted mule deer populations are predation and malnutrition/disease (Forrester and Wittmer 2013), and oil and gas developments could increase survival by reducing predation rates (Hebblewhite et al. 2005, Hebblewhite et al. 2009) or improving forage quality by disturbing senescent vegetation (Lutz et al. 2011). In Colorado and New Mexico, Webb et al. (2011) documented no strong associations between the survival of Rocky Mountain elk and anthropogenic development, but there was a weak negative relationship noted for elk that used a core gas field. Additional information on the relationship between ungulate survival and oil and gas energy development is needed to understand how energy development could affect ungulate populations.

Methods

Survival Analysis

We evaluated mule deer survival with GPS collar data. We programmed the GPS collars to activate a 'mortality mode' if the onboard activity sensor did not detect movement for > 6 hours; in mortality mode, collars would transmit a real-time mortality notification and hourly coordinates until activity was detected or collar was retrieved. We attempted to retrieve all mortalities promptly after receiving mortality notifications to investigate carcasses prior to rotting or scavenging. We examined evidence in the field (tracks, weather conditions, risks) and transported carcasses or remains to the NDGF veterinary lab to conduct formal necropsies. We used information from the field investigation and GPS location data to determine actual mortality times. We determined proximate causes of mortality, but in some instances multiple sources may have contributed to the ultimate fate (e.g. if malnutrition led to increased vulnerability to predation, the ultimate cause was likely poor forage quality).

We evaluated survival status using a biweekly temporal scale to aid in determining the environmental conditions the deer encountered before a mortality event occurred. We coded survival as either 1 (alive) or 0 (dead). We coded rows after collar failures or after a mortality event as ‘NA’ until the end of the study period. We evaluated survival probability using logistic regression with the glm function in program R (R Core Team 2016), which is equivalent to known-fate analysis in program MARK.

We used survival covariate data that corresponded with the survival status time period, and summarized covariates at the biweekly UD scale. We organized covariates into 3 major categories: background (e.g. temperature, season, etc.), gas and oil development metrics, and road metrics (Table 10). We summarized home ranges every 2 weeks with a kernel density estimator (KDE). We used the KDE to create a utilization distribution (UD) for each deer on the same temporal scale using package 'ks' in program R (Duong 2017). If a deer died during the 2-week interval, we only used locations up to the first mortality signal for UD construction, as long as there was a minimum of 3 locations. If a deer died with only 1 or 2 locations within an interval, we merged those points into the previous interval (n = 2). We created 99% home range contours for each UD to evaluate spatial covariates. We calculated a centroid for each 99% home range contour for measuring distance to nearest feature (e.g. road, well pad, etc...).

We categorized covariates unrelated to oil and gas development (e.g., weather, age, etc.) as “background” covariates. We aged deer as either adults (> 6 months) or juveniles (< 6 months) at capture. We graduated all juveniles to the adult cohort if they survived to the next biological year (01 June; thus we only have data for juveniles from December captures through 01 June). We used the following seasons: spring (1 April - 31 May), summer (1 June - 30 September), autumn (1 October - 30 November), and winter (1 December - 31 March). Collars were equipped with an onboard thermometer, and temperature was recorded with each successful GPS fix. We averaged the onboard temperature data over the biweekly temporal interval. We assigned harvest unit for each deer as either North or South based on North Dakota Game and Fish Department (NDGF) management units. We considered any deer north of US interstate 94 in the northern badlands management unit (north), and all other deer in the southern badlands (south). We included management unit to account for variation in deer density (study period, 2013- 2015, average: northern badlands: 2.27 deer/km^2 and southern badlands 3.41 deer/km^2) and variations in predator densities (mountain lion core habitat is mainly in the northern badlands).

We used the Normalized Difference Vegetation Index (NDVI) as a proxy for mule deer forage quality (Hurley et al. 2014). We calculated NDVI for each GPS location using Movebank's Env-DATA interface (Dodge et al. 2013). Band 1 (red) and band 2 (near infrared) are collected daily at a 250-meter resolution (https://lpdaac.usgs.gov/). We calculated NDVI with the formula: $NDVI = (band2 - band1)/(band2 + band1)$ (Jackson and Huete 1991). We assigned surface snow depth values for each GPS location using Movebank's Env-DATA interface. Env-DATA uses daily, 250-meter resolution snow depth data interpolated from the National Center for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR) model (http://rda.ucar.edu/datasets/ds608.0/index.html#sfol-wl-/data/ds608.0?g=3). We averaged snow depth values for each location used for home range construction.

We collected gas and oil development covariates from the North Dakota Industrial omission, Oil and Gas Division, ArcIMS viewer (online, 2017). We first obtained locations of oil and gas extraction, which we further categorized temporally into drilling rigs and well pads. We classified a well pad as a drilling rig for any period when a well was being drilled on the well pad. We re-categorized well pads as active well pads after the drilling infrastructure had been removed from the site, if there was at least one producing well on the well pad. We calculated the distance to nearest drilling rig and active well pad (hereafter, well pad) from the centroid of the 99% home range contour. We determined the number of drilling rigs and well pads by counting the number of drilling rigs and well pads that occurred within a 99% contour during the same time period. We calculated drilling rig and well pad density by dividing the count of drilling rigs and well pads by the area of the 99% contour (km^2). We did not find high levels of correlation between rig density and rig number ($r^2 = 0.29$) or well pad density and number of well pads ($r^2 = 0.28$). The low correlation between the number of well pads or drilling rigs and density can be attributed to the variation in biweekly UD size (mean = 4.78, SD = 13.10).

We used line shapefiles for roads from the North Dakota Department of Transportation and manually digitized missing roads from 2015 aerial imagery at a 1:5,000 scale. We calculated Euclidean distance to nearest road using the 99% contour centroid as the starting point. We calculated road length as the total length of road within the 99% contour. We then calculated road density within the 99% contour by dividing road length by the 99% contour area. Road density and road length were not highly correlated ($r^2 = 0.10$). We centered all continuous variables and scaled them using the scale() function in R.

Model Selection

We determined the covariates that best described mule deer survival probabilities by first finding parsimonious "background", "oil and gas", and "road" models. First, we fit models that contained all covariates (full models) within each covariate group (Table 10). After fitting full models, we removed slope coefficients with a Wald Test *p*-value > 0.1 from the model (reduced model). We then conducted a likelihood ratio test to compare the full and reduced model. We used covariates from the three covariate groups with the most support from the likelihood ratio test in the next step, where we fit 8 models with different combinations of background, gas and oil, and road covariates (Table 10). We used Akaike information criteria (AIC; Akaike 1973) to compare the 8 different model combinations. Any model within 2 AIC units of the top model were considered for predicting mule deer survival probabilities.

Results

From 2013-2016, we collared and collected GPS locations on 203 mule deer in North Dakota and observed 86 mortality events over the course of the study period. Two juveniles died within two weeks of capture and were removed from analysis. We were not able to determine the cause of mortality for 22% of adults or 39% of juveniles. The leading cause of mortality we determined in adult female mule deer was predation (coyote and mountain lion; 32%), followed by malnutrition (16%), illegal harvest (10%), disease/injury (10%), vehicle collisions (6%) and parturition (4%). The leading cause of mortality we identified for juveniles was malnutrition (22%), followed by predation (coyote only, 19%), disease/injury (14%), and vehicle collisions (6%; Figure 28). We observed high quantities of nasal bots (>30, max = 55) in the guttural pouches and/or nasal passages of 8 deer. There is little literature suggesting that nasal bots contribute to mortality in mule deer, but we attributed mortalities to “disease/injury” when there were > 30 nasal bots encountered during necropsies and we could not detect other causes for mortality.

We found intact jaws on 34 of the 40 adult mortalities that were captured as unknown age adults. We estimated age by tooth wear (age categories: 1, 2, 3, 4, 5, 6+; n =10) or cementum annuli (n = 24 ; Matson's Laboratory LLC, Manhattan, MT). Of the deceased adults we were able to age, 70.5% were ≥ 6 years old. Further, of the cementum-aged deer (n=24) we found a mean mortality age of 6.8, and 9 of the 24 were ≥ 8 years old. The maximum age for any deer aged by cementum aging was 11 years old (n=2). The youngest adult deer at time of capture was 1.5 years old (n=1).

Our top reduced model for background covariates contained only age, season, temperature, and harvest unit (likelihood ratio test statistic = 9.40, degrees of freedom = 8, *p*-value = 0.15; Table 11). In the oil and gas covariate group, the full model was selected over the reduced model (likelihood ratio test statistic = 18.35, degrees of freedom = 9, *p*-value = < 0.01). In the road covariate group, the reduced model that contained only road density was selected (likelihood ratio test statistic = 0.30, degrees of freedom = 2, *p*-value = 0.86)

Our AIC model selection results demonstrated both background and oil and gas covariates predict mule deer survival probability (Table 12). Although a model including road covariates was within 2 AIC units as the top model, slope coefficients for road covariates was close to 0, so we considered these to be "pretender variables" (Anderson 2008). No other models were competitive (i.e., ΔAIC > 60 for all other models), so we used the top model for inference. The top model consisted of background and oil and gas covariates, including: age, season, temperature, unit, study area, well pad distance, well pad density, well pad number, rig distance, rig density, rig number, and a study area rig distance interaction (Table 12).

Annual adult survival probability was 85.9% (upper 95% CI =93.0%, lower 95% CI = 75.5%, Table 13). Overwinter (01 December – 01 June) juvenile survival probability was 67.7%

(upper 95% CI = 81.8%, lower 95% CI = 49.3%, Table 13). Adult survival probabilities were significantly higher than juvenile survival probabilities (Wald Test statistic = 8.327, p-value = < 0.01, Figure 29). Mule deer survival was lowest in winter and significantly higher in autumn (Winter, Test Statistic = -2.44, *p*-value = 0.01, Autumn, Test Statistic = 8.36, *p*-value = <0.01, Figure 29). Winter adult survival was 93.0% (upper 95% CI =96.7%, lower 95% CI = 86.9%, Table 13) and Winter juvenile survival was 75.9% (upper 95% CI =86.6%, lower 95% CI = 61.3%, Table 13). Survival probability was inversely related to distance to nearest well pad (Figure 30B). However, the distance to nearest well pad was a weak relationship at meaningful distances (< 5 km); mule deer had approximately equal survival probabilities 0 to 5 km from a well pad. Survival probability decreased as well pad density increased (Figure 30A). An increase in well pad density from 0 to 1.93/km^2 (0 to 5 well pads/mi^2) resulted in a 24% decrease in survival (Table 14). We did not detect any effects in survival related to proximity of drilling rigs, drilling rig density, or drilling rig number.

Discussion

In addition to natural phenomenon, we found that mule deer survival probability was negatively related to well pad density. This result lends evidence to the hypothesis described by Sawyer et al. (2006) that reduced resource availability due to avoidance of well pads could negatively affect survival rates; however, we did not observe spatial avoidance of well pads in our study area. It is possible that chronic physiological stress, increased vigilance, decreased forage availability or increased risk flight energy expenditures contributed to decreased survival in areas with higher densities of well pads. If there are benefits in forage quality when vegetation is disturbed around well pads (Lutz et al. 2011), they are not sufficient enough to overcome the costs of the disturbance.

Mule deer survival was most negatively affected by the winter season, similar to other studies on mule deer in northern latitudes (White et al. 1987, Bishop et al. 2005, Lomas and Bender 2007, Carnes 2009, Hurley et al. 2011, Brodie et al. 2013, Monteith et al. 2013) as well as previous population models on mule deer in North Dakota (Ciuti et al. 2015). Low winter survival can be a factor of poor nutrition, competition for resources (density dependence), increased predator efficiency, or restricted movements. The mule deer population in North Dakota is non-migratory and mule deer densities were rebounding during our study, so it is unlikely that low winter survival was due to restricted movements or competition for resources. We observed moderate rates of predation, but many of the carcasses we investigated that were killed by predators also had low levels of body fat. Low levels of body fat are normal in mule deer during winter and spring, but Bishop et al. (2005) found that predation rates were higher when nutrition was poorer. Finally, lower survival probabilities in winter have been attributed to low temperatures and increase snow depths. We found that survival decreased more with lower temperatures than with increased snow depths, which is consistent with previous models on North Dakota deer survey data (Ciuti et al. 2015), although neither relationship was significant. It is possible that snow depths and temperature were not more strongly correlated with survival because we examined bi-weekly survival, and the effects of snow depth and temperature may take longer than two weeks to produce a response. Also, the combination of wind, rugged terrain and patchy vegetation typically often result in a mosaic of snow depths during an average winter, so it’s possible that deer can avoid areas with deep snow. This relationship might not be true during severe winters if extensive snow depths (exceeding 35 cm; Brinkman et al. 2005), which did not occur during our study period.

We documented an annual female adult survival probability (0.86) that is similar to survival rates found in literature reviews of multiple survival studies (0.85, Unsworth et al. 1999; 0.84, Forrester and Wittmer 2013). The literature reviews did not describe whether survival rates were affected by hunter harvest; there were no hunting seasons for antlerless mule deer during our study, and the study area experienced average winters (winter severity index was low; NDGF unpublished data). Hunting can be the main source of mortality in adult mule deer (83%, Wood et al. 1989; 22.6%, Carnes 2009), and hunter success increases with increased road density (Dorning et al. 2016). It is possible that during years with open hunting seasons, a negative relationship between survival and road density would be more pronounced (Fox 1989).

Survival rates we observed may have been lower than expected due to an aging adult population. Following two winters, 2009-10 and 2010-11, with higher than average severity (severity defined by number of days with > 35 cm snow depths and low temperatures below -7° C; Brinkman et al. 2005), and low juvenile production, it is likely that the mule deer population we studied was skewed toward older age-classes. White et al. (1987) studied a mule deer population in Colorado, which also had limited female adult hunting permits and found deer harvest consisted of age structure similar to ours (60% ≥ 8 years old, and 15% ≤ 4 years old). An interaction effect between older age structure and winter severity was documented to compound mortality sources in mule deer in Montana after two, successive severe winters (Pac et al. 1991). Nonetheless, it is likely that additional mortality from antlerless hunting seasons would have resulted in lower adult survival probability during our study.

Although we did not have information on juvenile neonatal survival, we may be able to use juvenile recruitment (survival through 1 year of age) to put our overwinter and spring survival rates in context. Biologists in Colorado have used population models to determine a minimum of 50-60 juveniles per 100 does to maintain positive population growth rates (Gill 1999). Unsworth et al. provide a Leslie Matrix model, which shows, with our observed 85.9% adult survival and 67.7% juvenile overwinter survival, a December fawn-to-doe ratio of 0.5 would be required to maintain populations size. NDGF estimates juvenile production annually with aerial census block surveys, flown in October. From 1991-2016, the mean fawn-to-doe ratio was 90 fawns per 100 does (89/100 during our study). If we assume high survival during November (Carnes 2009), we could calculate an approximate 01 June recruitment rate by extrapolating the fawn-to-doe ratio with the respective overwinter and spring survival rates to the numerator and denominator of the ratio (0.68 for juveniles and 0.90 for adults). This results in a recruitment rate of 67 fawns per 100 does, which is above the threshold of 50-60 juveniles per 100 adults, recommended by Gill (1999). Even though we observed high rates of predation on juveniles during our study, juvenile recruitment rates observed during our study are within an acceptable range that would allow healthy population growth. High rates of juvenile mortality in mule deer are often offset by high rates of pregnancy and fecundity (Forrester and Wittmer 2013). In fact, mule deer densities increased in our study area from 2.43 deer/km^2 in 2013 to 3.42 deer/km^2 in 2015 (NDGF survey data, excluding Bowman survey blocks). It should be noted, these densities are near the long-term average 2.7 deer/km^2 (1991-2016). Juvenile recruitment may be even higher when density is lower (Bartmann et al. 1992, Ciuti et al. 2015).

Predation (coyote and mountain lion) was the leading cause of mortality on adult females in our study, and the second leading cause of mortality in juveniles. Predation is typically the leading cause of mortality across the western range (Forrester and Wittmer 2013), particularly in Colorado (Bartmann et al. 1992, Whittaker and Lindzey 1999, Bishop et al. 2009). We did not detect any predation by bobcats (*Lynx rufus*), perhaps due to low bobcat densities during our study (NDGF, unpublished data). We also did not observe any instances of mountain lion predation on juveniles during our study during the overwinter period (Dec - Jun), which coincides with research in our study area that documented mountain lions were less likely to predate on juvenile ungulates during the winter season (Wilckens et al. 2015). Anecdotal evidence suggests alternative prey species (lagomorph, *peromyscus spp.*, *microtus spp.*, etc.) abundance was low following severe winters, which might affect predation rates (Hamlin et al. 1984, Hurley et al. 2011).

Although we report cause-specific mortality, we did not investigate whether effects are additive or compensatory. If forage quality is limited and inversely related to mule deer density, then any mortality factors that are correlated with poor nutrition may be partially compensatory mortality (Bergman et al. 2015). For example, predation rates may be higher when nutrition is poorer (Bishop et al. 2009). We observed high adult survival that was consistent across seasons while juvenile winter, spring, and post winter (01 December – 01 June) survival was low and variable (Table 13). Mule deer population growth is conditional on high and consistent adult female survival and fecundity rates (Forrester and Wittmer 2013). Mule deer population growth is inhibited by both juvenile predation and nutritional effects on fecundity (Forrester and Wittmer 2013). Mule deer populations overcome low juvenile survival rates by increasing fecundity rates. Fecundity rates can be suppressed by adult females that have poor body condition due to low quality forage on the landscape which can limit population growth (Forrester and Wittmer 2013).

We observed poor to fair body condition during necropsies (gelatinous bone marrow and low amounts of fat in back, muscles or organs) in 30% of the mortalities attributed to predation. Majority (74%) of predator-caused mortalities (n=23) occurred during the overwinter period, when poor body condition might be expected (Shallow et al. 2015). Predation rates were correlated with forage quality in Colorado during a forage improvement experiment (Bishop et al. 2009), and it is likely that some degree of predation on mule deer may be compensatory. However, during the summer season, when resources were not limited, mountain lion predation contributed to 35.7% of adult deer mortality (n =5), whereas only one predation event was attributed to coyote predation during summer. Coyote predation rates may be underestimated in our study because we could not discern scavenging from predation for 21% of the unknown mortalities ("Unknown (coyote?)" category, Figure 28). Although predation rates were the greatest cause of mortality in our population (26.7%), it should be noted that we observed survival rates that are consistent with average to high survival rates reported in the literature, albeit during a period without hunting permits for antlerless deer. Last, the inverse relationship between survival and higher well pad density suggests that mule deer are not finding refugia from predators in developed areas (sensu Hebblewhite et al. 2009), even though research that overlapped our study showed mountain lions selected areas further from anthropogenic disturbance (Johnson 2017).

We did not detect high rates of vehicle collisions or illegal harvest, but even small increases in female adult mortality could have significant effects on mule deer populations because positive population growth rates depend on high, stable female adult survival (Forrester and Wittmer 2013). Vehicle collision rates in our study may be low because we avoided major highways while capturing. However, road density was not in our top model for predicting survival rates.

Management Implications

We estimate a 24% decline in survival probability when well pad density increases from 0 to 1.93 well pads/km^2, which coincides with high development levels in the guidelines established by the Western Association of Fish and Wildlife Agencies (Lutz et al. 2011). Our findings that mule deer survival decreased with increasing well pad density confirm the benefit of consolidating wells to fewer well pads. This aligns with best management practices outlined by the NDGF and North Dakota Petroleum Council (NDGF & NDPC 2013).

Because 16% of adult mortalities and 22% of juvenile mortalities were attributed to malnutrition, and survival was lowest during winter, it is possible that treatments to improve forage nutrition could mitigate decreases in survival (sensu Bishop et al. 2009). Bishop et al. (2009) also found that experiments to increase forage nutrition led to decreases in predation rates (45% of all mortalities were due to predation or malnutrition), so forage improvement projects could have compounded benefits. It should be noted, habitat mitigation is species specific, and actions that benefit one species might not benefit all wildlife (Gallo et al. 2017).

Table 10. Major grouping of mule deer survival covariates with parameters in each group. Background covariates are any covariate not directly related to gas/oil development. Gas and Oil development are related only to drilling rigs and well pad development on the landscape. Road covariates are related to primary and secondary roads within the study area.

Covariate Group	Parameter	Retained
Background	Age	Yes
	Season	Yes
	Temperature	No
	Biological year	No
	Snow depth	No
	NDVI	No
	Unit	Yes
Gas and Oil Development	Distance to nearest rig	Yes
	Distance to nearest well pad	Yes
	Rig density	Yes
	Well pad density	Yes
	Number of drilling rigs	Yes
	Number of well pads	Yes
	Study area	Yes
Road	Distance to nearest road	No
	Road length	No
	Road density	Yes

Table 11. Top mule deer survival models ranked by lowest AIC. Background covariates are age, season, temperature and unit. Oil and Gas development covariates are distance to nearest drilling rig and well pad, drilling rig and well pad density, and number of drilling rig and well pad within the 99% UD contour. Road covariates is road density. Which is the length of road divided by the 99% UD contour area (km^2).

Model Parameters	**K**	**ΔAIC**	**AIC**
Background + Oil and Gas Development	15	0.00	1029.50
Background + Oil and Gas Development + Road	16	1.70	1031.19
Oil and Gas Development	9	64.93	1094.42
Gas and Oil Development + Road	10	66.32	1095.82
Background	8	84.73	1114.23
Background + Road	7	86.67	1116.16
Road	2	153.42	1182.92
Intercept only	1	158.44	1187.93

Table 12. Estimates, standard error, z-value, and significance levels (SL) for variables in the top model predicting mule deer survival in western North Dakota from 2013-2016. Colons represent interactions between variables. Fall is the reference variable for season interactions.

Deviance Residuals	Min	1Q	Median	3Q	Max
	-3.6147	0.0835	0.1104	0.1595	0.869

Coefficients:	Estimate	Std. Error	z value	SL[a]	
(Intercept)	5.0303	0.6031	8.341	<2.00e-16	***
Age	1.3766	0.2262	6.086	1.16E-09	***
SeasonSpring	-1.1083	0.5539	-2.001	0.0454	*
SeasonSummer	-0.6181	0.5927	-1.043	0.297	
SeasonWinter	-1.2892	0.5305	-2.430	0.0151	*
Temperature	0.2189	0.1342	1.631	0.1028	
Unit	-0.6367	0.3929	-1.621	0.1051	
Well_Pad_Dist	-0.2786	0.1334	-2.088	0.0368	*
Well_Pad_Density	-0.2030	0.0805	-2.521	0.0117	*
Well_Pad_Number	0.5186	0.3126	1.659	0.0971	
Study_AreaND	0.1120	0.4173	0.268	0.7884	
RigDist	0.0964	0.2416	0.399	0.6898	
Rig_Density	-0.0379	0.0556	-0.681	0.4956	
Rig_Number	-0.0411	0.1229	-0.335	0.7378	
Study_AreaND:RigDist	0.3919	0.3276	1.197	0.2315	

[a] Significance Level: "***" = p-value < 0.001; "**" = p-value < 0.01; "*" = p-value < 0.05

Table 13. Seasonal survival rates with 95% upper and lower confidence intervals. Estimates obtained by bootstrapping (n = 5000) results from the top model. Each season and age was estimated for annual adult survival all seasons were multiplied together, and winter and spring were multiplied for post-winter juvenile survival.

	Survival Rate	**Upper 95% CI**	**Lower 95% CI**
Adult			
Annual	85.9%	92.8%	75.3%
Overwinter (Dec - May)	90.3%	95.3%	81.9%
Winter	93.0%	96.8%	86.6%
Spring	97.0%	98.7%	94.0%
Summer	96.3%	98.5%	92.3%
Autumn	98.9%	99.7%	97.0%
Juvenile			
Overwinter (Dec - May)	67.7%	81.8%	49.3%
Winter	75.9%	87.1%	60.5%
Spring	88.9%	94.7%	79.7%

Table 14. Estimated survival probabilities with the 95% upper and lower confidence intervals for mule deer, calculated at the upper limits of well pad density levels established by WAWFWA energy development guidelines for mule deer (Lutz et al. 2011). Densities correlate to 0, 1, 4, and 5 well pads/mile^2, respectively. Note: well pad density was calculated within a biweekly UD, so the max well pad density in our data (un-scaled) was 3.84 well pad / km^2 might be higher than the well pad density calculated at larger scales.

WAWFWA levels of oil and gas energy development	Density (Well pads/km^2)	Survival Probability	Upper 95% CI	Lower 95% CI
Baseline	0.00	0.91	0.95	0.84
Low (0-1 well pad/mi^2)	0.39	0.88	0.94	0.79
Medium (2-4 well pads/mi^2)	1.54	0.74	0.90	0.47
High (>5 well pads/mi^2)	1.93	0.67	0.89	0.32

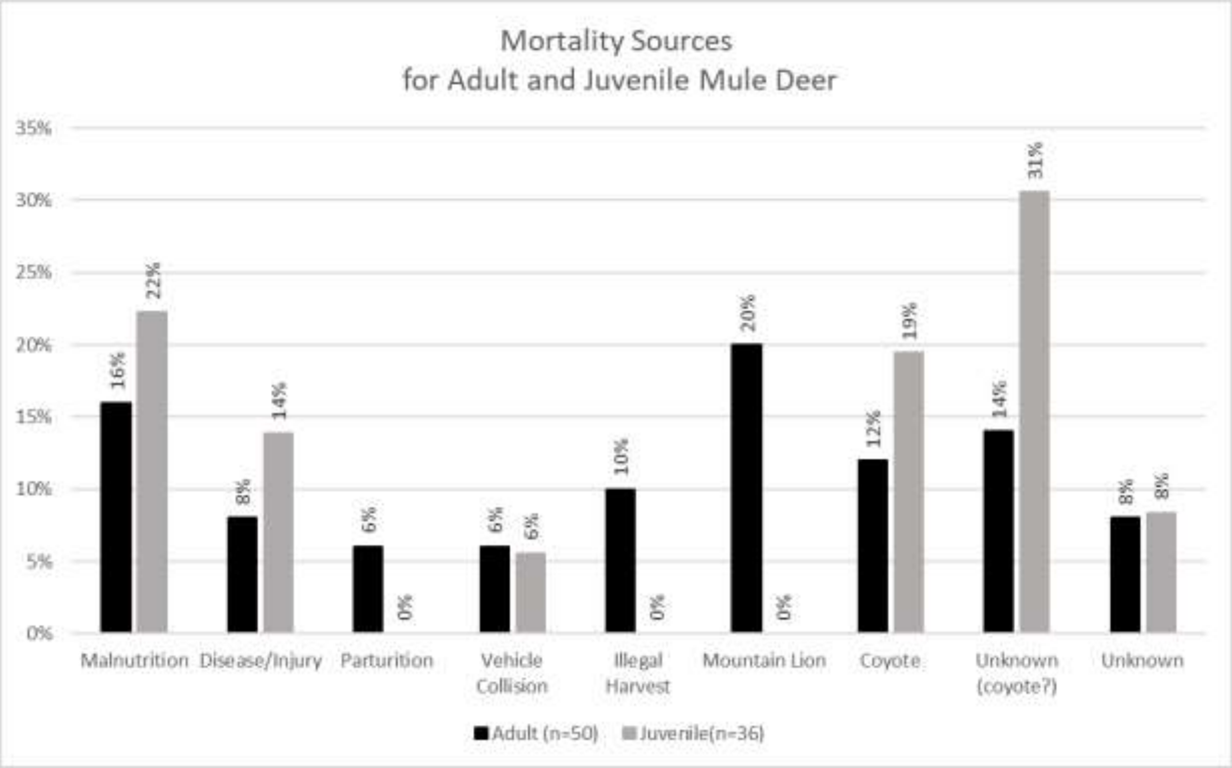

Figure 28. Mortality sources for radio-collared female, adult and juvenile mule deer in western North Dakota, 2013-2016. We summarized proximate causes of mortality, but it is possible that multiple factors contribute to mortality. “Unknown (coyote?)” represents unknown mortalities that were heavily scavenged with no further evidence to discern scavenging from predation; we included this category for reference to show a range of potential predation from the “Unknown” cause of mortality.

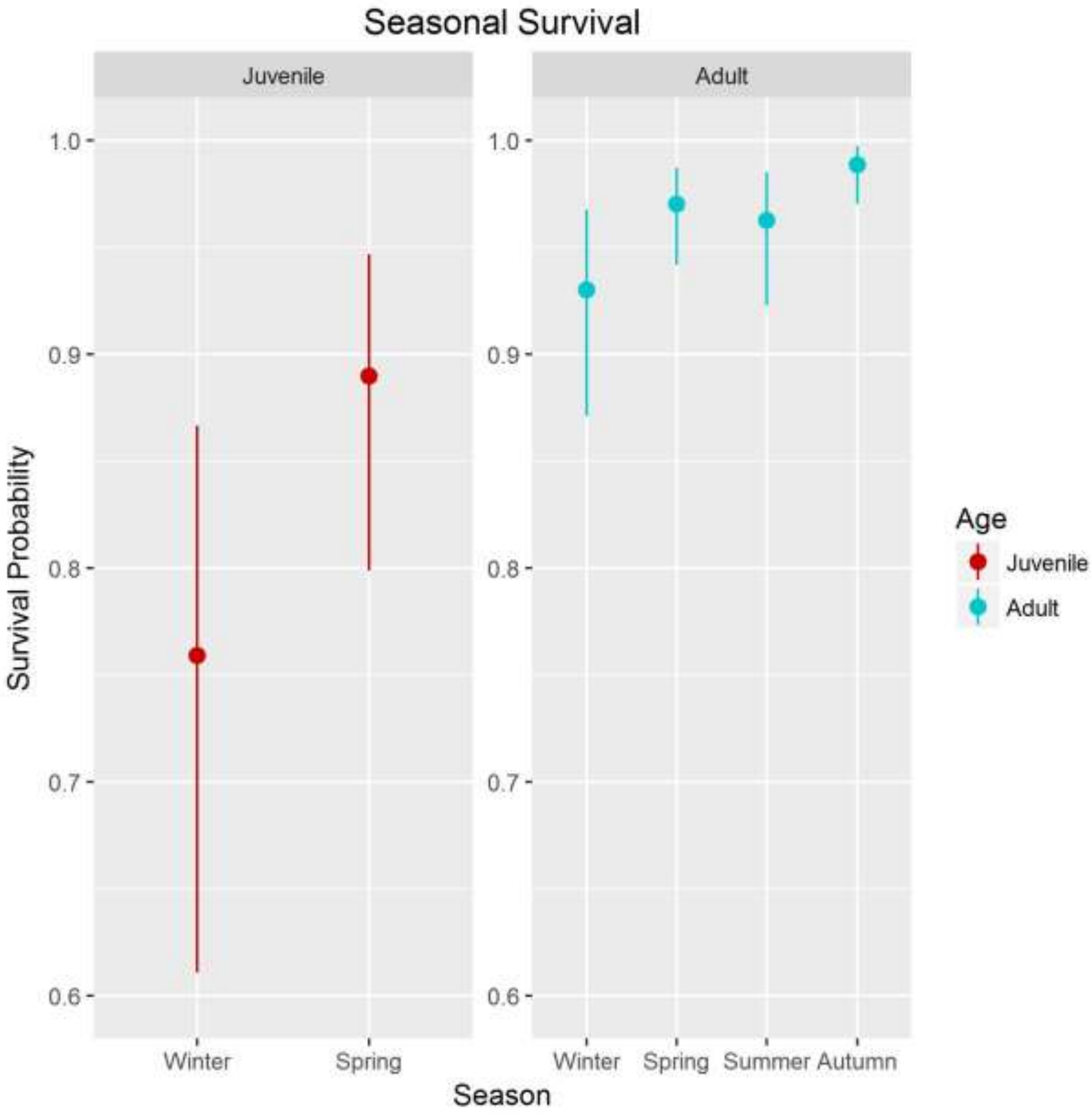

Figure 29. Seasonal survival probability and 95% confidence intervals for juvenile (< 1 year) and adult (> 1 year) mule deer in western North Dakota. The seasonal survival probabilities for juveniles only shows winter and spring, because no fawns were captured prior to winter (Dec. – Feb.). The seasons varied in length: summer = 8.7 biweekly intervals, winter = 8.6 biweekly intervals, autumn 4.4 biweekly intervals, and spring = 4.3 biweekly intervals.

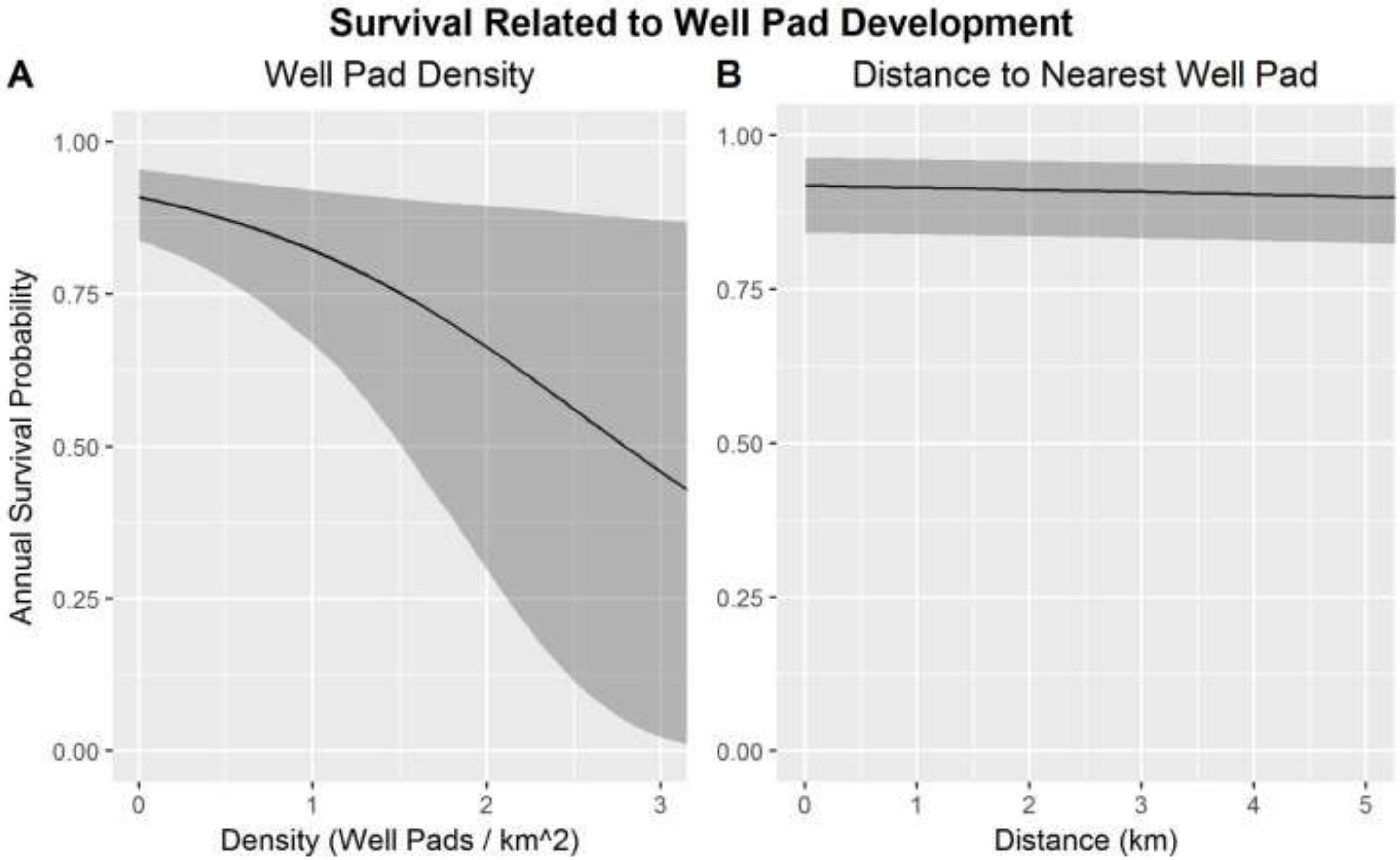

Figure 30. Mule deer survival probability in western North Dakota related to significant well pad covariates modelled with biweekly, 99% home range contours (kernel density estimator). **A**: Survival probability decreased as well pad density increased. Density was calculated as the number of well pads within each 99% contour (km^2). **B**: As distance from well pad increased, the survival probability decreased; however, noticeable declines did not occur until distance exceeded 7 km. Distance was measured from the centroid of the 99% contour to the nearest well pad.

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CHAPTER V. CUMULATIVE RISK ASSESSMENT MAPS AS A TOOL TO EVALUATE RELATIVE RISK FOR MULE DEER POPULATIONS IN WESTERN NORTH DAKOTA

Introduction

Abundant wildlife research has focused on population dynamics (reproduction, survival), movements (immigration and emigration), and distribution patterns relative to available habitat (resource use and selection). Recent work has attempted to link wildlife spatial responses with wildlife population responses (McDonald and McDonald 2002, Aldridge and Boyce 2007, Aldridge and Boyce 2008, Matthiopoulos et al.2015). Population sinks (areas with high probability of selection, but low survival or reproduction; *sensu* Pulliam 1988, Aldridge and Boyce 2007) show the need for examining the combined effects of resource selection and demographic response. Because resource metrics may include positive and/or negative effects on occurrence and fitness, it is important to consider the cumulative effects unique resource combinations may have on multiple components of wildlife behavior and fitness.

In addition to identifying factors that influence mule deer resource selection, physiological stress and survival, it is important to understand how these measures interact over the landscape. We identified predictor variables that affected resource selection, physiological stress, and movements uniquely, and in this chapter we combine maps for resource selection, physiological stress, and survival to map the relative cumulative value of unique combinations of resources across our study area. Identifying areas of highest value, will help to identify areas with the greatest risk to mule deer populations if they were developed for oil and gas energy extraction. The spatial layers we developed could be used as a tool to model potential effects of multiple alternatives for proposed oil and gas development; this tool could be used to inform management decisions and mitigate potential impacts on mule deer.

Methods

We used the raster calculator in ArcMap 10.5 (Environmental Research Systems Institute, Redlands, CA) to combine the most supported mule deer resource selection, physiological stress, and survival models (see Chapters I, III, and IV, respectively) with long-term abundance and juvenile production data to calculate predictive maps across the study area for adults during the day in winter. We chose this combination of spatial layers so that we could incorporate all project results that might influence the suitability and utility of areas for mule deer populations; we only modelled physiological stress in winter, during capture events. Also, survival rates were lowest during winter (Chapter IV). We used oil and gas development data from December 2015 to create all maps (Figure 31). To avoid conclusions based on insignificant predictor variables in our top survival model (i.e., the effect of the predictor variable was not significantly different than 0), we used the smallest absolute value within the 95% confidence interval for each coefficient that was not significant when calculating predicted survival across the study area.

We created an abundance map of the study area using existing, long-term, aerial survey data from the North Dakota Game and Fish Department (NDGF) to assign juvenile production and abundance levels within our study area. NDGF conducted aerial census counts twice annually on 23 survey blocks from 1991-2016 to measure abundance (April-May; deer per mile^2) and juvenile production (October; ratio of juveniles per female adult). We calculated the long-term average abundance and juvenile production for each survey block for all years of available data 1991-2016.

We divided primary and secondary mule deer range (NDGF mule deer range map, unpublished) by the NDGF sub-management unit boundaries to produce 5 sub-management regions: southern badlands, northern badlands, Mondak oil field, Lake Sakakawea, and Killdeer. And we extrapolated the average long-term average abundance and juvenile production levels from survey blocks contained by the sub-management regions. Long-term averages were not available for the Mondak Oil field or Lake Sakakawea sub-management regions, so we used data from survey blocks that were established in 2013 to extrapolate abundance and juvenile production rates to those regions.

We classified abundance and juvenile production into 4 classes (tertiary range, low, med, high) to rank sub-management units. We classified abundance into low (0-5 deer/mile^2), medium (>5-10 deer/mile^2), and high (>10 deer/mile^2), and juvenile production into low (0-0.50 juveniles per female adult), medium (0.51- 0.75 juveniles per female adult), and high (>0.75 juveniles per female adult). We used a matrix to combine abundance and juvenile production levels (low juvenile production and low abundance = low; low juvenile production and high abundance = med, etc.).

To estimate areas at risk of negative effects from development (i.e., areas that currently have high value to mule deer), we first re-scaled all maps described above to a 0 – 1 scale. For physiological stress, we scaled the map so areas of predicted high physiological stress received values closer to 0, while areas of low physiological stress received values closer to 1. For resource selection and survival, we scaled the map so values of 0 represented the lowest relative probability of selection and values of 1 represented the highest value (i.e., the minimum predicted survival value received a "0" and maximum predicted survival value received a "1"). Next, we weighted the survival map by 3x so this layer would be a larger driver of predicted risk. We used categorical abundance maps (non-habitat, low, medium and high) with values of 0, 0.1, 0.2, and 0.3, which approximated the standard deviation of scaled, weighted survival models.

Because demographic consequences, such as survival, abundance and recruitment are the most important metric affecting population growth, these models were weighted greater than other measures. Finally, we added all maps together (Figure 32) to achieve a predicted risk map with values ranging from 0-5.3 (maximum of 1 for resource selection and physiological stress, 3 for survival, and 0.3 for the abundance and juvenile production layer), with higher values representing the highest quality areas which would equate to higher risk of potential negative effects from oil and gas development in the future (i.e., higher value to mule deer; Figure 33A).

To further demonstrate how risk could be affected by oil and gas development, we provided a finer scale map that also shows the locations of drilling rigs, active well pads, and gravel pits used to create the risk map (Figure 33B). The fine scale map also helps to visualize the scale that active well pads and drilling rigs influence risk to mule deer.

Results

Cumulative risk was lower in areas with existing development, because the negative effects of well pad density on survival and presence of drilling rigs within 600 on resource selection have decreased the overall value of those areas. Risk to mule deer increased surrounding drilling rigs, largely due to lower mule deer survival rates and increased physiological stress levels near drilling rigs. Overall, risk to mule deer juveniles was greater than adults, again largely due to lower juvenile survival.

Discussion

We used a landscape-scale risk assessment to generate a visual representation of combined model results on risk to mule deer in North Dakota due to potential development. The maps are useful to identify the areas in western North Dakota that have the highest quality habitat based on survival, abundance, juvenile production, and physiological stress. One of the areas with the highest values (warmest shades, Figure 33A) is the Killdeer sub-management unit, which had high long-term averages for juvenile production and abundance combined with high probability of use. However, the existing oil and gas development occurs at densities that have negative impacts in part of this area. The areas where development poses the least risk to mule deer populations are the dark blue areas on the maps, which are areas with existing oil and gas development features, low long-term abundance and juvenile production, further from the wooded draws and moderate slopes found in the badlands.

Another factor affecting our maps is the negative relationship between survival and distance from the nearest well pad. We believe the distances where this relationship is significant (>7 km) are artifacts of sampling (maximum distances from nearest well pads were very high, > 30 km, in some areas; Chapter IV), but nonetheless it was a significant variable in our models that affected cumulative risk (note blue areas in the southern portion of our map that are > 30 km from the nearest well pad). In the future, we will further examine the consequences of including distance to the nearest well pad as a continuous variable. This response, which was more evident visually, proves another benefit of calculating cumulative risk assessment maps as a tool to evaluate assumptions in modelled results.

One benefit of using actual landscape data for calculating risk assessment maps is that it helps to visualize the potential impacts of variables based on realistic spatial arrangement on the landscape. For instance, well pad density was negatively associated with survival, and since we weighted survival highest among our input models, the resulting map was driven by survival probabilities. Further, drilling rig density, even though not significantly correlated with survival, strongly affected our initial maps because there was a large, but insignificant difference between survival probabilities in areas with higher and lower drilling rig densities. The addition of one drilling rig in an area the size of an average mule deer biweekly UD (6.07 km2), results in a drilling rig density of 0.16 rigs/km^2, which is 23 standard deviations above the mean drilling rig density in the study area (mean = 0.0002, SD = 0.007). Although drilling rig density is theoretically a continuous variable, actual landscape-scale values in our study area were very low because drilling rigs were only on the landscape for a short time, and in relatively low densities. We addressed this issue in our resource selection chapter by converting rig density to a categorical, presence or absence variable. In the future, we will consider the effect of modelling rigs as continuous variables to further examine the support for the effect of rigs on survival.

Management Implications

Our map illustrates the utility of a risk assessment framework, but the main utility will be in the future for comparing multiple oil and gas development alternatives. We recommend developing this method into a tool that could be used on a case-by-case basis to model potential effects of proposed oil and gas developments, particularly when multiple alternatives are available.

In the fine-scale map of cumulative risk (Figure 1B), there are areas around drilling rigs that still have high risk, despite existing negative effect of a drilling rig on mule deer probability of use. We gave higher weight to demographic components in our risk assessment maps (survival and abundance and juvenile production), so the negative effect on probability of use around a drilling rig was diminished. We recommend managers apply this risk assessment tool with careful consideration of inputs. Because survival rates did not appear to limit population growth in our study area, managers may benefit from examining multiple maps (e.g. resource selection map in Figure 8; Chapter I).

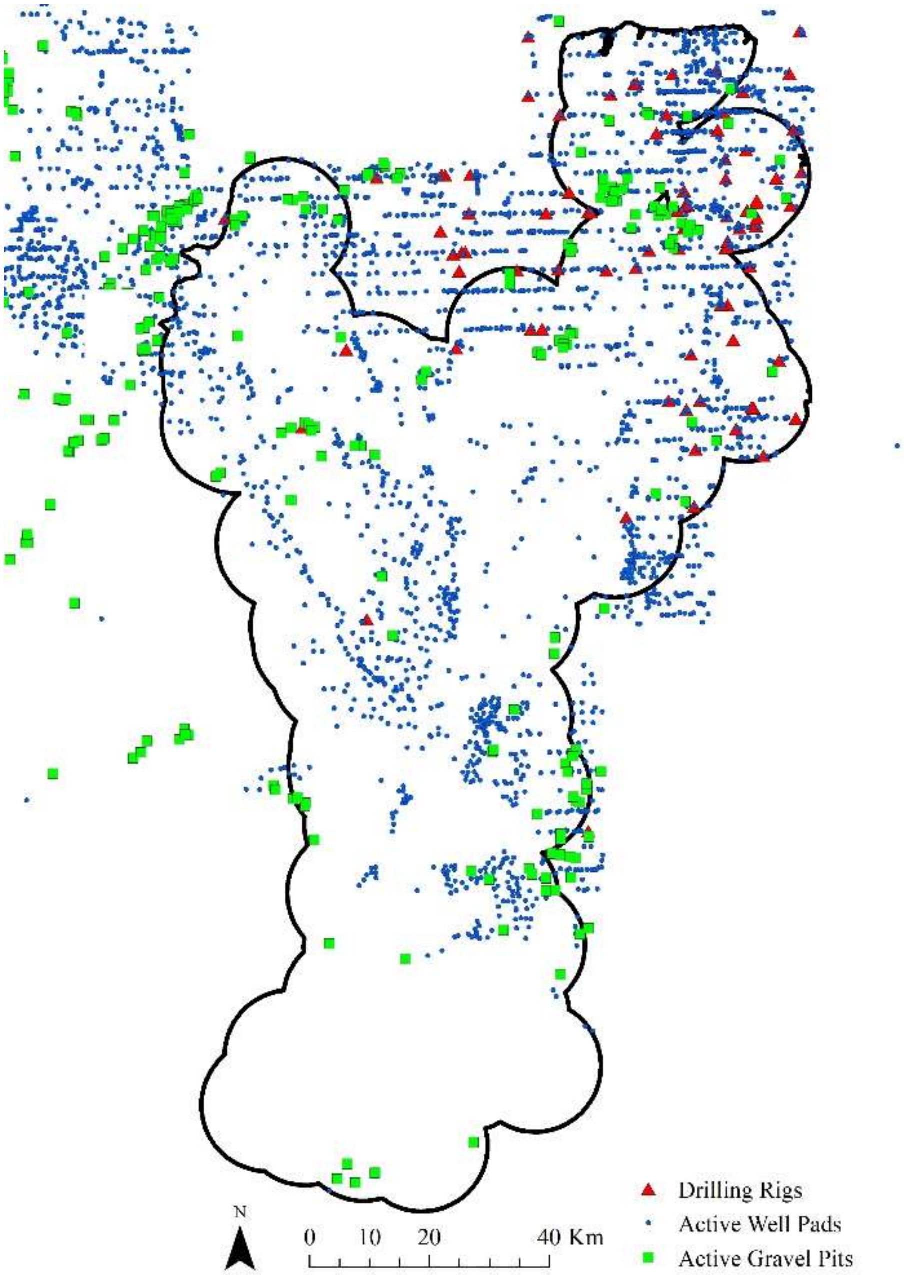

Figure 31. Anthropogenic development data (Dec 2015) for western North Dakota included in mule deer risk maps. We used data from the North Dakota Oil and Gas Division ArcIMS server (online).

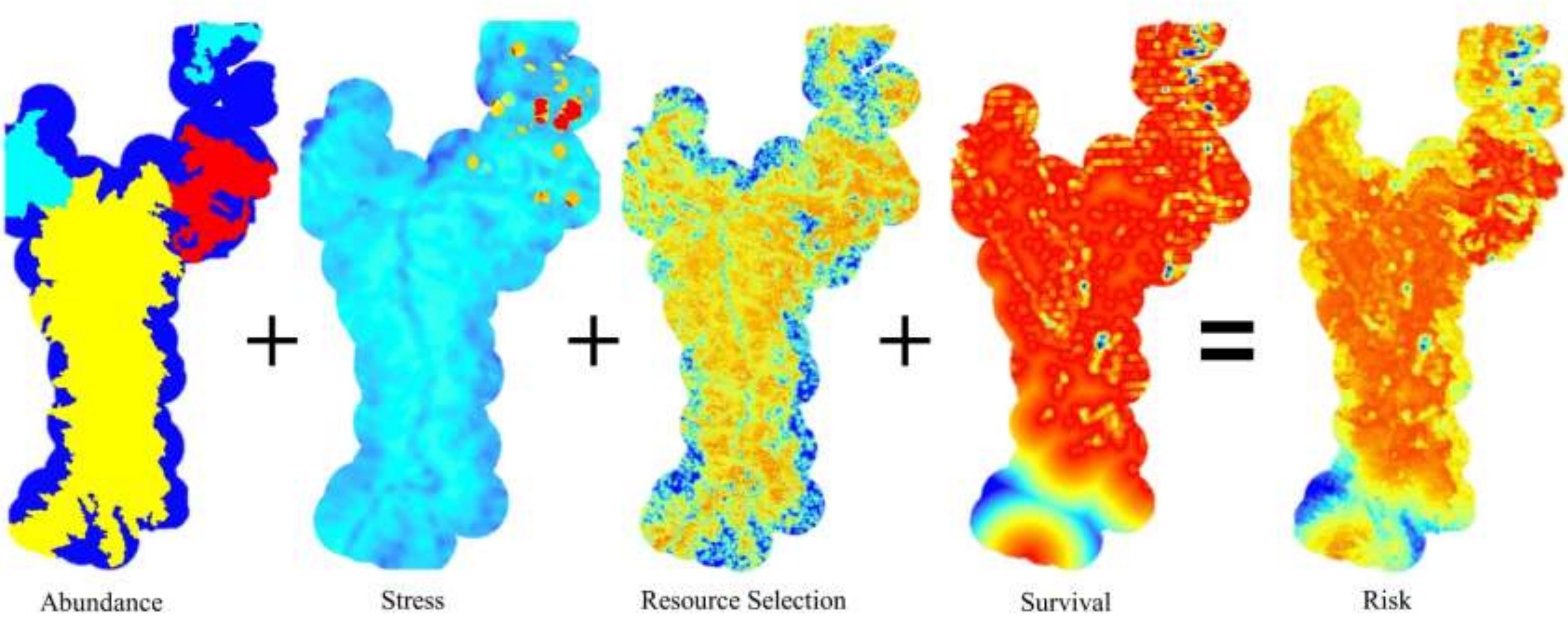

Figure 32. Example of how mule deer abundance, physiological stress, resource selection, and survival predictive maps in western North Dakota in 2015 are summed to create the final risk map.

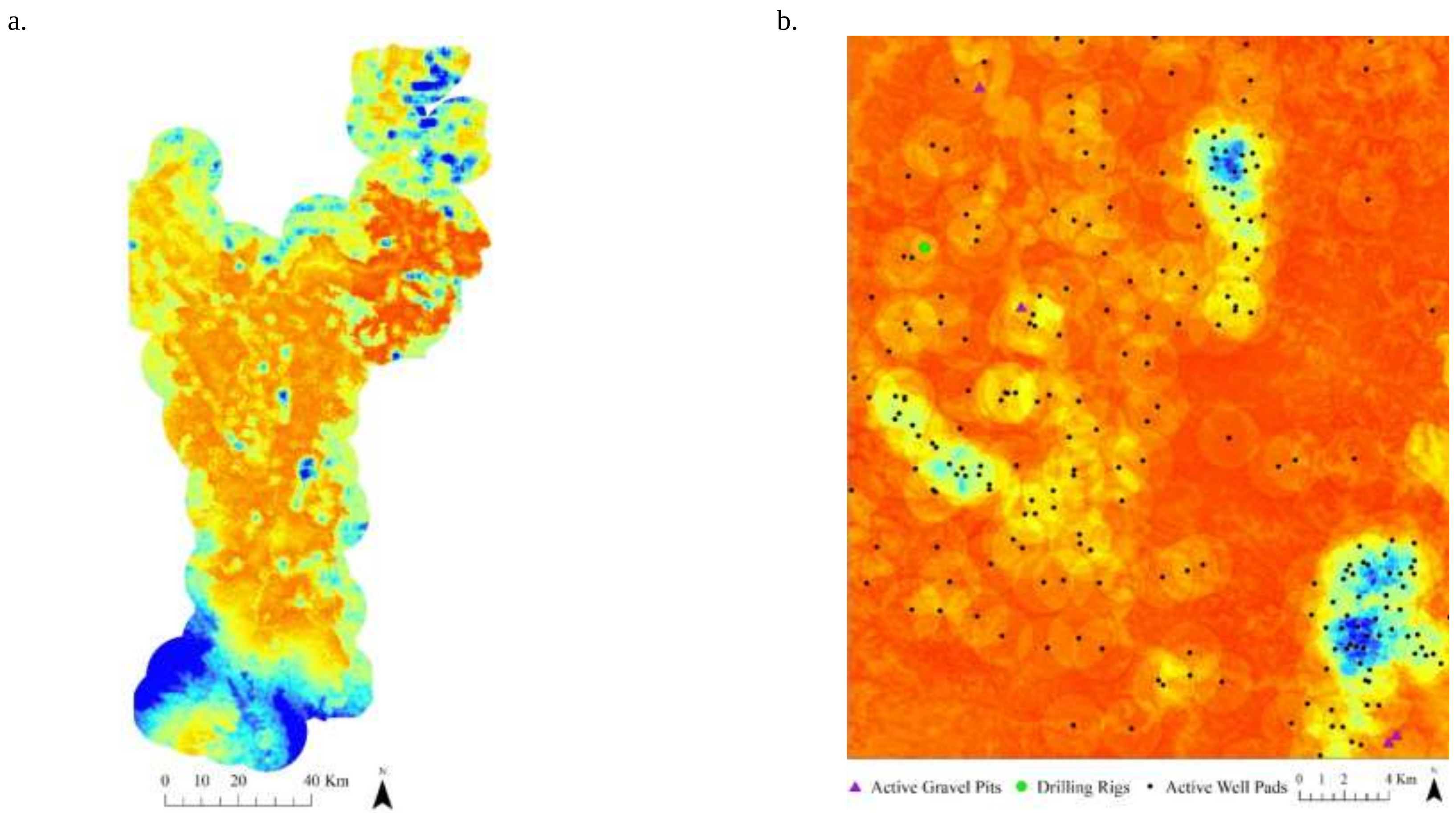

Figure 33. Example of landscape risk map for adult mule deer in western North Dakota during winter, 2015 (a.). Warmer colors represent areas with higher resource value to mule deer, thereby making them more risky for development. Effects of development from active gravel pits, drilling rigs, and active well pads on landscape value for mule deer are shown in detail in b. Development reduces the value of the landscape to mule deer; thus, making it less risky for future development.

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APPENDIX

Support for the North Dakota Game and Fish Department & North Dakota Petroleum Council's Recommended Management Practices for Reducing Oil/Gas Impacts to Wildlife

The results in this report lend further support to several of the existing recommended management practices for reducing oil/gas impacts to wildlife identified by the North Dakota Game and Fish Department and North Dakota Petroleum Council (NDGF 2013). We now summarize recommended management practices that were supported by our research (only numbered points supported by our research are shown).

Concerning section 1: "Direct Habitat Loss (e.g. as a result of well pad and O/G road development)"

The current recommendations on direct habitat loss include,

> 1. Locate well pads, facilities and roads in clustered configurations within the least sensitive habitats. Drill multiple wells from the same pad where feasible. Site wells, tank batteries, compressor stations and other facilities near existing roads whenever possible. Minimize road construction by coordinating location and use among companies operating in the same oil and gas field, as practical and feasible given State permitting requirements. Following drilling, complete interim reclamation of well pads to the minimum size necessary to safely and efficiently conduct operations. (NDGF & NDPC 2013)

Our survival results show that mule deer survival is negatively affected by areas with high densities of well pads, and confirm the benefit of "clustered configurations" and "multiple wells from the same pad." Resource selection models for mule deer also showed lower probability for use of areas with high road density, which is achieved by siting infrastructure locations near existing roads.

Although our research does not address "least sensitive habitats" for wildlife, our models used to model mule deer resource selection identified habitat combinations that are most likely to be used by mule deer: areas within 0.5 km of wooded or shrub edges, areas with slopes between 15% and 25%, areas with moderate ruggedness, and areas with lower road densities (< 1 km/km^2). We recommend that well pads, facilities and roads be clustered in areas with lower probabilities of selection for mule deer. We have provided resource selection models that can be used as a tool to compute resource selection probabilities for current resource levels, and to predict resource selection probabilities of the same area considering multiple proposed development options. This tool could be used to highlight recommended options for mule deer and to predict the effects of proposed development on mule deer resource selection.

We did not investigate the effects of reclamation on mule deer, but we found indirect support for the existing recommendation,

> 3. Prompt reclamation of pipelines, expired pads, and roads. Assess degraded roads and well pads on public lands that preceded reclamation requirements when the leases were sold to determine potential reclamation action (NDGF & NDPC 2013).

We found mule deer were less likely to use areas that had higher road densities. We provide further support for potential benefits of road reclamation to increase an area's probability of use by mule deer.

Concerning section 2: Indirect Habitat Loss (e.g. disturbance, loud noise, increased truck traffic, dust and tailpipe emissions, habitat fragmentation)

We have shown how resource combinations could be used for maps to model probability of use (Figure 10, Chapter 1) and cumulative risk (Figure ##, Chapter V) for mule deer in western North Dakota. These tools could be used to clarify "primary range" for mule deer in the following recommendation:

> 1. As operationally and economically feasible, design centralized production facilities for oil and gas outside of primary range whenever possible, and locate them closer to major highways and pipelines. Drill multiple wells from the same well pads, as feasible, to lessen disturbance in more sensitive areas. Work collaboratively with operators and wildlife agencies to place new pads and roads in areas with less wildlife disturbance; encourage operators to share existing roads and utility corridors when feasible (NDGF & NDPC, 2013).

In addition to delineating an improved primary range map, results from various chapters confirm the benefit of drilling multiple wells per well. This recommendation would reduce well pad density (negatively associated with mule deer survival) and minimize construction of new roads (mule deer were less likely to use areas with higher road density).

We identified significant season interactions in our models for resource selection, survival and stress. For the recommendation:

> 5. Work with federal and state land managers on public lands to consider potential timing restrictions as appropriate. Mitigating some impacts of physiological stress on mule deer due to disturbance, timing restrictions (particularly during the winter and in late May and June parturition season) on drilling could be implemented… (NDGF & NDPC 2013),

We found lowest survival rates for female adult mule deer during winter, and slightly elevated physiological stress levels when temperatures were < 0° C. Because high, constant female adult survival is important for population growth in mule deer, we support the recommendation to consider timing restrictions during winter months. We also found greater avoidance of drilling rigs in summer and autumn than in the winter or spring seasons. Because it is unfeasible to restrict development for such broad seasons, we re-emphasize locating oil and gas development infrastructure in areas less likely to be used by mule deer (< 15% slopes, > 1.1 km from wooded edges, etc. from Chapter 1).

Concerning section 3: Loss of Important Limited Habitat Types (e.g. woody draws, native prairie)

We found mule deer were more likely to use areas closer to wooded edges (up to 0.5 km), and moderate slopes 15-25%, i.e. "woody draws," and our findings are consistent that woody draws are an important habitat type for mule deer.

> 1. Travel plans should direct haul and feeder roads to well pads away from these areas prior to construction where feasible, as private landowners or surface management agency allows (NDGF & NDPC 2013).

In addition to identifying the importance of areas within 0.5 km of wooded edges, we found that mule deer were less likely to use areas within 0.6 km of a drilling rig. We therefore recommend siting development > 1.1 km from woody draws, where feasible, would minimize negative effects on mule deer space use.

Concerning section 4: Direct Mortality

We only identified two anthropogenic sources of direct mortality on mule deer: poaching and vehicle collision. Neither of these can be attributed to oil and gas energy development, but both occurred near roads. Speed restrictions on roads that transect primary mule deer range may help mitigate direct mortality impacts to mule deer. (Our resource selection models could be used to identify areas along roads that are most likely to be used by mule deer).

We identified well pad density as an oil and gas energy development metric that negatively affected mule deer survival, but did not identify the mechanism. We previously addressed negative impacts of well pad density on mule deer survival, by consolidating wells and infrastructure, in the section above on Direct Habitat Loss.