Survival, activity patterns, movements, home ranges and resource selection of female mule deer and white-tailed deer in western Kansas

by

Talesha Karish

B.S., Delaware Valley College, 2009
M.S., New Mexico State University, 2020

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Division of Biology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2022

Abstract

White-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*) occur in sympatric populations across the Great Plains in North America. Mule deer abundance and occupied range has been declining during the past three decades while white-tailed deer abundance and occupied range has been increasing. Factors contributing to the dichotomous population growth and distribution patterns across their sympatric range are unknown, but potentially include differential survival, space use, and resource selection, all of which may be contributing to indirect competition that may be negatively affecting mule deer populations. Overlap in resource use or space use between mule deer and white-tailed deer could be evidence of competition or competitive exclusion. Activity patterns could provide insights for temporal segregation or competition. Differential space use could allow these species to spatially segregate and co-occur without competing for the same resources. My objectives were to 1) estimate annual and seasonal survival rates, 2) identify cause-specific mortality of adult female mule deer and white-tailed deer, 3) compare behavior patterns between adult mule deer and white-tailed deer of both sexes at seasonal and fine temporal period scales, 4) evaluate the difference in movements between adult female mule deer and white-tailed deer at seasonal and fine temporal scales, 5) test for differences in home range area and composition of adult female mule deer and white-tailed deer at seasonal and fine temporal scales, and 6) evaluate differences in seasonal multi-scale resource selection by female mule deer and white-tailed deer in western Kansas. I deployed collars on 184 pregnant females (94 mule deer and 90 white-tailed deer) at two different study sites in western Kansas (North, South) over three years, 2018, 2019 and 2020. Each deer received a high-resolution GPS/VHF collar that recorded hourly locations, activity accelerometer data along 3 axes, and used an activity sensor to identify mortality events.

I used a Kaplan-Meier model to estimate cumulative weekly and annual survival and fit a hazard function to each survival model. I tested for relative influence of factors on estimated survival. I categorized activity points into three behavioral states (feeding, resting, and running). I converted activity points into a proportion of total behavior for each deer and tested for differences in the proportion of behavior categories between species and among seasons. I calculated individual hourly and daily movements seasonally and compared them between species and among seasons. I calculated annual and seasonal 95% home ranges and 50% core areas for each individual deer using a Biased Brownian Bridge movement model. Using logistic regression, I modeled resource selection by mule deer and white-tailed deer at the landscape scale, within home range scale, and within the core home range to identify selection for potential habitat variables and cover types. There was no difference in annual survival of adult female deer between species (mule deer [0.78 ± 0.04] and white-tailed deer [0.77 ± 0.05]). Harvest was the leading known cause of female mortality at 14% of the total mortality, but it was low compared to other studies in the Great Plains. Behavior of both species was similar in all seasons except for rut for males. In rut, males doubled their running behavior. Firearm season produced no changes in behavior for either species or sex. However, the greatest movements and home ranges were in the firearm season. There were greater movements and home ranges in the cold seasons than in the warm seasons. Mule deer were found to use steeper slopes than white-tailed deer, and white-tailed deer used riparian and woodland areas more than mule deer. Habitat patches enrolled in the U.S. Department of Agriculture Conservation Reserve Program were strongly selected by both species in every season and scale. Managers should focus on preserving CRP to stabilize the mule deer population. Given harvest rates of females are low, survival of adult females of both species of deer appears to be little affected by harvest, so there is no need to alter harvest rates of either species.

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Major Professor
Dr. David A. Haukos

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I used a Kaplan-Meier model to estimate cumulative weekly and annual survival and fit a hazard function to each survival model. I tested for relative influence of factors on estimated survival. I categorized activity points into three behavioral states (feeding, resting, and running). I converted activity points into a proportion of total behavior for each deer and tested for differences in the proportion of behavior categories between species and among seasons. I calculated individual hourly and daily movements seasonally and compared them between species and among seasons. I calculated annual and seasonal 95% home ranges and 50% core areas for each individual deer using a Biased Brownian Bridge movement model. Using logistic regression, I modeled resource selection by mule deer and white-tailed deer at the landscape scale, within home range scale, and within the core home range to identify selection for potential habitat variables and cover types. There was no difference in annual survival of adult female deer between species (mule deer [0.78 ± 0.04] and white-tailed deer [0.77 ± 0.05]). Harvest was the leading known cause of female mortality at 14% of the total mortality, but it was low compared to other studies in the Great Plains. Behavior of both species was similar in all seasons except for rut for males. In rut, males doubled their running behavior. Firearm season produced no changes in behavior for either species or sex. However, the greatest movements and home ranges were in the firearm season. There were greater movements and home ranges in the cold seasons than in the warm seasons. Mule deer were found to use steeper slopes than white-tailed deer, and white-tailed deer used riparian and woodland areas more than mule deer. Habitat patches enrolled in the U.S. Department of Agriculture Conservation Reserve Program were strongly selected by both species in every season and scale. Managers should focus on preserving CRP to stabilize the mule deer population. Given harvest rates of females are low,

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Acknowledgements

I would first like to acknowledge those that provided funding for the project; the Kansas Department of Wildlife, and Parks, Kansas Bowhunters Association, Kansas State University Division of Biology, and the U.S. Geological Survey Kansas Cooperative Fish and Wildlife Research Unit. I would like to thank Dr. Loyd Fox and Levi Jaster for initiating and supporting the project. I would like to thank the past and current members of the Haukos lab who provided unwavering support and friendship for me. I will always value and look back fondly on the time we had together. I want to thank all the technicians we had throughout the years; the project was successful due to your hard work. I want to thank all the landowners whose support allowed the project to come to fruition in the first place; especially Stacey Hoeme and Larry Brown, without their support the project would not have happened. I would like to thank the other students on the project, Maureen Kinlan and Mitchell Kern. Without all of us working together and helping each other, this project would not have been as successful as it was. I would like to thank Dr. Drew Ricketts who originally proposed the project and was a major part of the project. I would like the thank my committee members, Dr. Dan Sullins and Dr. Andrew Hope who helped me and guided me along this process. Lastly, I would thank my advisor Dr. David Haukos, your knowledge and passion for science in conservation and management changed the way I think about science. Thank you for seeing the potential in me and believing in me even when I doubted myself. Words cannot express how much that means to me.

Dedication

This dissertation is dedicated to my dog, Mille. You are the best friend and writing companion anyone could ask for.

Chapter 1 - Survival and cause-specific mortality of adult female mule deer and white-tailed deer in western Kansas

Introduction

Growth and management of deer herds are strongly related to annual survival of adult females (Eberhardt 2002). Populations can rapidly recover from years of poor fawn and juvenile survival if annual adult female survival is high (Robinson et al. 2014). The most effective way to manage deer populations is manipulation of the female portion of the population. In most areas of the United States, deer populations are managed by adjusting sales of antlerless hunting permits (Brown et al. 2000). When harvest of females is additive to the natural mortality, the population growth rate will decline. When harvest rates of females are low, however, hunter harvest is compensatory and has little effect on population demography of deer (Simard et al. 2013).

Causes of female death other than harvest also affect deer populations by reducing abundance more than expected based on harvest alone. Extrinsic and intrinsic factors such as weather, disease, or predation could affect the survival rate of the population. Usually these factors are compensatory, individually each having little effect on the annual survival rate. However, if non-hunting mortality increases beyond a certain threshold, annual survival may decline. Estimating annual and seasonal survival in association with identifying cause-specific mortality of females are important to inform management strategies for deer.

Populations of mule deer (*Odocoileus hemionus*) in the Great Plains are declining in abundance and undergoing range contraction while populations of white-tailed deer (*O. virginianus*) are increasing in abundance and experiencing range expansion (VerCauteren 2003). Historically, much of the Great Plains was occupied exclusively by mule deer, with white-tailed deer limited to the eastern tall-grass prairie and eastern deciduous forest interface (VerCauteren 2003, MDWG 2020). Both species were nearly extirpated from the Great Plains by the early 1900s due to unregulated harvest and habitat degradation, with many populations recovering to levels supporting sport harvest by the mid-late 1900s (Anderson 1964, Ballard et al. 2001, VerCauteren 2003). White-tailed deer populations have been expanding westward in the Great Plains for the past four decades (VerCauteren 2003, Hanberry and Hanberry 2020). Although abundance and range occupancy of mule deer were stable throughout much of the 1900s, significant population declines have occurred throughout much of the Great Plains since the late 1900s (Ballard et al. 2001, MDWG 2020). Currently, occupied range expansion by white-tailed deer appears to be concurrent with contraction of the occupied range of mule deer in the Great Plains (Ballard et al. 2001, VerCauteren 2003). Lower survival rates of adult female mule deer than female white-tailed deer may contribute to an overall population decline in mule deer.

Harvest is a major cause of mortality for both species of deer in the Great Plains (Wood et al. 1989, Haskell 2007, Frost 2009, Grovenburg et al. 2011, Moratz et al. 2018). Female harvest has been found to vary among states, ranging anywhere from 13% to 89% of the total mortality (Wood et al. 1989, Haskell 2007, Frost 2009, Grovenburg et al. 2011, Moratz et al. 2018). Harvest targeting females is usually used to manage deer populations throughout the Great Plains, because growth or decline of populations is related to the abundance of the female population (Brown et al. 2000). When population abundance or density declines, issuance of antlerless permits are typically restricted in an attempt to recover the population (Brown et al. 2000).

In Kansas, population trends of mule deer and white-tailed deer are diverging in a similar pattern as elsewhere in the Great Plains. In response, Kansas Department of Wildlife and Parks

(KDWP) has limited the number of hunting permits for antlerless mule deer for several years, while an individual can purchase multiple permits for antlerless white-tailed deer. Despite limiting the number of female permits, the decline of the mule deer population continues (Figure 1.1; MDWG 2021). I hypothesize that female white-tailed deer will have a lower rate of annual survival than female mule deer in Kansas; in part, due to a greater harvest rate. Harvest, however, does not account for all causes of death and other factors may be limiting the mule deer population in Kansas.

Causes of death, other than hunting, must be identified for complete consideration of potential population limiting factors. Predation is a major cause of death for adult female deer of both species in many areas including the northern Great Plains (Ballard et al 2001). Mortality from predation can be as high as 35% in some areas of the Great Plains (Moratz et al. 2018). However, predation pressure on adult female deer in Kansas is unknown (Anderson 1963). The potential predator community of adult female deer in Kansas consists primarily of coyotes (*Canis latrans*) and bobcats (*Lynx rufus*), and is lacking larger predators found in other areas (e.g., mountain lions [*Puma concolor*; Cooley et al. 2008], gray wolves [*C. lupus*; Dellinger et al. 2018], and brown bears [*Ursus arctos*; Munro et al. 2006]). Although coyotes are a major cause of mortality for deer fawns in Kansas (Kern 2019), it is unlikely that coyote predation is a factor for healthy adult female deer except during adverse environmental conditions. Coyotes are known to prey on adult deer in deep snow in the northern Great Plains (Lingle 2001, 2002), but snow accumulation in Kansas rarely exceeds 0.3 m and typically remains for only a few days (High Plains Regional Climate Center 2020). Adult deer of both species are known to face and act aggressively toward coyotes, limiting the predation effectiveness of coyotes on healthy females (Garner and Morrison 1980, Mackie et al. 2001, Lingle 2001). I hypothesize that predation is not likely a major cause of death of adult female deer in Kansas, but additional probable causes of mortality need to be considered.

In the Great Plains, mortality factors of adult female deer other than harvest and predation are primarily vehicle collisions and natural causes (i.e., disease; Wood et al. 1989, Whittaker and Lindzey 2001, Haskell 2007, Frost 2009, Grovenburg et al. 2011, Moratz et al. 2018). Mortality rates vary among study sites but have been reported as high as 39% and 16% of the total mortality in other studies on the Great Plains for natural mortality and vehicle collisions, respectively (Whittaker and Lindzey 2001, Haskell 2007). There were >11,000 reported cases of deer-vehicle collisions in Kansas during 2019, many more collisions went unreported (Kansas Department of Transportation 2020). Most collisions occurred during the fall rut period; however, there are no data on the sex/age/species of the deer involved in the crashes (Kansas Department of Transportation 2020). Natural causes such as disease or starvation are potential sources of mortality for both species of deer in the Great Plains (Wood et al. 1989, Haskell 2007, Frost 2009, Grovenburg el al. 2011, Moratz el al 2018). While starvation is not likely a concern in Kansas due to mild winters and abundant available food resources in rangelands, woodlands, and crop fields, diseases are becoming more prevalent. The main disease of concern in Kansas is chronic wasting disease (CWD), which does affect adult females (MDWG 2020). KDWP is monitoring the spread of CWD and suggests that deer be tested before consumption (MDWG 2020). It is likely that if deer die naturally, it would be more frequent during seasons and life stages when they are energetically stressed such as in the fawning or weaning period. I hypothesize that mortality resulting from vehicle collisions and natural causes will peak at different times during the year, with the majority of collisions happening during the fall rut period and majority of the natural deaths happening during the fawning or weaning period when females are stressed.

Knowledge of survival rates, seasonal timing of increased mortality risks, and cause-specific mortality of adult female deer is necessary to inform management strategies for deer populations in Kansas. While harvest is closely monitored and managed, relative contribution of other causes of mortality on survival of adult female deer are unknown in Kansas. To identify potential factors influencing the diverging trends of mule deer and white-tailed deer, my objectives were to 1) estimate annual and seasonal survival rates and 2) identify cause-specific mortality of adult female mule deer and white-tailed deer in western Kansas. Considering the relative influence of female survival on population demography of deer species, survival rates and causes of mortality are needed to understand potential factors involved in the declining mule deer population.

Study Area

My study occurred at 2 contrasting field sites in western Kansas that supported sympatric populations of mule deer and white-tailed deer in landscapes containing habitat features representative of both species (Figure 1.2). These sites were roughly 150 km apart and chosen because of reported declines in mule deer abundance, but with sufficient mule deer densities necessary to obtain appropriate sample sizes (in 2018, 5.43 mule deer/km^2; Levi Jaster KDWP personal communication).

The North field site (~85,000 ha) was in Decatur, Norton, Sheridan, and Graham counties; it consisted of relatively small tracts of landowner properties surrounding a large wooded riparian area. The South field site (~137,000 ha) was in Logan, Scott, Gove, and Lane counties, consisting of relatively larger tracts of landowner properties interspersed with steep ravines and chalk cliffs. Average yearly temperatures from 2006-2020 was 12.43° C in the North site and 11.97° C in the South site (NOAA 2021). Average annual precipitation from 2006-2020 was 57.84 cm in the North site and 51.19 cm in the South site from 2000-2020 (NOAA 2021). The average temperatures (°C) from 2018 to 2020 were 12.10 in the North site and 11.73 in the South site and similar to the long-term averages. Annual precipitation during 2018 (North 92.1 cm, South 66.7 cm) and 2019 (North 74.4 cm, South 52.7cm) was wetter than the long-term average years, but 2020 represented drought conditions (North 36.94 cm, South 36.09 cm).

Common landcover types were cropland, pasture, woodland/riparian, and U.S. Department of Agriculture Conservation Reserve Program (CRP) lands. Agriculture was the dominant land use feature in both study sites, which included livestock grazing of native rangeland and row-crops. Corn (*Zea mays*), wheat (*Triticum aestivum*), and milo (*Sorghum bicolor*) were the most common crops; alfalfa (*Medicago sativa*), soybeans (*Glycine max*), and sunflowers (*Helianthus annuus*) were less common. Grasslands consisted of native short and mixed-grass prairie primarily grazed by cattle. Common grasses included little bluestem (*Schizachyrium scoparium*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*B. gracilis*). Common forbs were broom snakeweed (*Gutierrezia sarothrae*), common mullin (*Verbascum thapsus*), and tall thistle (*Cirsium altissimum*); common succulents were yucca (*Yucca glauca*) and prickly pear cactus (*Opuntia macrorhiza*).

The CRP lands in both study sites were ungrazed and planted with mostly tallgrass prairie grass species including big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). Woodlands were associated with riparian areas along the Solomon River at the North site, and Smoky Hill River and tributaries in the South site. Shelterbelts and dispersed tree clusters (i.e., former homesteads) were scattered throughout both study sites. Common tree species included American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), black cherry (*Prunus serotina*), eastern cottonwood (*Populus deltoides*), honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*), mulberry (*Morus rubra*), and eastern red cedar (*Juniperus virginiana*). Plum thickets (*Prunus angustifolia*) and smooth sumac (*Rhus glabra*) were shrubs commonly found in ravines and valleys in western Kansas.

Study areas were defined annually based on a minimum convex polygon (MCP) estimated from all female locations for both species combined (Mohr 1947). Study areas for 2018, 2019, and 2020, respectively, were 450.84 km^2, 857.40 km^2, and 685.48 km^2 for the North site and 1,387.54 km^2, 664.96 km^2, and 1,041.60 km^2 for the South site. I buffered the landscape MCP by 200 m, which was similar to the average hourly movement of the deer (Chapter 3). I created a landcover map for each year for the landscape MCP by digitally delineating polygons of different landcover patches using ArcGIS (10.6) from a satellite image (ESRI World Imagery) for the entire landscape scale boundary. Only patches 30 m^2 or larger were delineated. The landcover type was ground-truthed for each polygon each year. Delineated landcover types across sites were: native pasture, ravine, crop type, CRP, human structure, woodland, and riparian (Figures 1.3-1.5).

Methods

Capture

At each study site, at least 15 white-tailed deer and 15 mule deer were captured and collared in February 2018 and 2019, and March 2020 for a total of ≥60 collared adult females annually. A commercial helicopter crew (Quicksilver Air Inc, Fairbanks, AK, USA) captured and sedated the deer using 15 mg Butorphanol [50 mg/ml], 15 mg Azaperone [50 mg/ml], and 15 mg Midazolam [50 mg/ml] (Wolfe and Miller 2016). Captured deer were transported to a central processing location where I estimated age by tooth wear and eruption (Severinghaus 1949), recorded morphometric data (total body length, hind foot length, neck girth, chest girth, and body fat measurements using an ultrasound [cm]), body mass (kg), and attached uniquely numbered ear tags to each deer. I also took blood and tissue samples to test for epizootic hemorrhagic disease, blue tongue virus, and CWD during the first year of capture. Pregnancy was confirmed by a licensed veterinarian using an ultrasound (IBEX PRO/r, E.I. Medical Imaging, Loveland, CO, USA). Pregnant females received high-resolution GPS/VHF VERTEX PLUS-2 collars (Vectronic Aerospace GmbH, Berlin, Germany). Collars recorded hourly GPS locations during the entire deployment period and were programed to drop off at 60 weeks from date of capture. Collar fit was specific to species with white-tailed deer and mule deer collars at 38 cm and 43 cm circumference, respectively. Collars had a mortality sensor programmed to send an alert after 6 hours of motionlessness. All animal handling procedures were approved by the Institutional Animal Care and Use Committee at Kansas State University (protocol 3963), and authorized under the state of Kansas scientific, education, or exhibition wildlife permits (SC-024-2018, SC-015-2019, SC-032-2020).

Mortality Investigation

All mortalities were investigated as soon as possible after a mortality alert was received. Mortalities were categorized as anthropogenic (harvest, hunting loss, poached), vehicle collision, predation, suspected natural (disease/old age), or unknown. Hunters reported a harvested deer using contact information provided on ear tags and radio collars. There were 2 major hunting seasons each year, archery and firearm. Dates of the archery seasons were 9/17 to 12/31, 9/16 to 12/31, and 9/13 to 12/31 in 2018, 2019, and 2020, respectively. General 12-day firearm season was from 11/28 to 12/9, 12/4 to 12/15, and 12/2 to 12/13 in 2018, 2019, and 2020, respectively.

The antlerless white-tailed-only extended firearm season began January 1 each year, with the length of the season dependent on hunting unit and year; Unit 1(North Site) and Unit 2 (South site) was 1/1/19-1/6/19, 1/1/20-1/5/20, and 1/1/21-1/17/21, Unit 17 (South site) was 1/1/19, 1/1/20-1/3/20 and 1/1/21-1/10/21.

Complete field necropsies were conducted to investigate the cause of the mortality where the cause of death was not due to hunting. Each deer was skinned to assess potential hemorrhaging or bite wounds. Patterns of hemorrhaging could be used to determine causes of mortality such as vehicle collision or predation. Location of bite wounds could also lead to distinguish between predation events or scavenging. For instance, bite wounds with hemorrhaging on the back legs likely indicates predation by coyotes. I determined death to be from natural causes if a deer carcass was intact with no signs of hemorrhaging.

If a natural (disease, old age) death was suspected, organ samples were sent to the Southeastern Cooperative Wildlife Disease Study at the University of Georgia (SCWDS) to test for diseases, including CWD, epizootic hemorrhagic disease, and blue tongue. Samples included heart, lungs, liver, spleen, kidneys, and any tumors. These samples were thinly sliced (≥1 cm) and stored in a formalin solution. All mule deer heads were sent to SCWDS to test for the presence of meningeal brain worm (*Parelaphostrongylus tenuis*). Retropharyngeal lymph nodes from all mortalities of collared females and opportunistically collected from harvested mule deer were sent to SCWDS to test for CWD. If the cause of death could not be determined from tissue samples, then the mortality was documented as unknown.

Statistical Analyses

I compared morphometric data (body mass, total body length, hind foot length, neck girth, chest girth, and rump fat) at capture among species, sites, and years using a factorial analysis of variance (ANOVA; $\alpha = 0.05$). Year was not significant in the ANOVA test, so I combined data from all years. I grouped captured females based on species and study site: north mule deer, south mule deer, north white-tailed deer, and south white-tailed deer. I tested for morphometric differences among groups using ANOVA. I used a Tukey HSD test to test for difference among groups following a significant ANOVA test ($P < 0.05$).

I estimated annual survival of adult female mule deer and white-tailed deer during 2018, 2019, and 2020 at 2 study sites in western Kansas. Any deer that died within 2 weeks of capture was censored and considered capture myopathy. All remaining deer were entered into the at-risk population at 2 weeks after capture each year. Each week was an encounter occasion for 55 occasions, at which point surviving animals were considered to have survived the entire interval. I monitored fate on a daily basis because each animal was constantly monitored, so there were no missing occasions. Marked animals entered the at-risk population on the same week the first 2 years (March 1) and at the 3rd week (March 22) during the third year. I categorized each individual into 4 groups based on study site and species: north mule deer, north white-tailed deer, south mule deer, and south white-tailed deer.

I used a Kaplan-Meier model to estimate cumulative weekly and annual survival using the survival package in Program R (Kaplan and Meier 1958, Therneau 2012, R Core Team 2019). I then used the hazard function to fit a hazard curve to each survival model (Gu 2014). Relative hazard risk indicates time periods with increased likelihood of mortality for deer among species, sites, and years.

I used the known fate survival model in Program MARK to test for relative influence of factors on estimated survival. I tested for effects of species, sites, year, and week on survival. I tested an *a priori* model suite consisting of 9 models, including a null and global model (Table 1.1).

Results

I captured 217 female deer during 2018 to 2020; 109 mule deer and 108 white-tailed deer (Table 1.2), and deployed collars on 184 pregnant females; 94 mule deer and 90 white-tailed deer. The annual pregnancy rate in 2018 was 91% for mule deer and 86% for white-tailed deer; in 2019 was 86% for mule deer and 94% for white-tailed deer; and in 2020 was 94% for mule deer and 91% for white-tailed deer (Table 1.2). There were 6 capture myopathies for a total of 178 individuals (93 mule deer, 85 white-tailed deer) available for analyses. No cases of epizootic hemorrhagic disease were detected from 63 deer tested during the first year of capture (Table 1.3). However, there were 15 suspected and 4 positive cases of blue tongue virus. Out of 53 deer tested for CWD, 2 cases were suspected. Out of 8 mortalities of tagged female deer tested for disease, 2 tested positive for CWD (1 natural mortality, and 1 hunter kill); there were no positive cases of epizootic hemorrhagic disease or blue tongue.

All captured deer, including individuals that were not collared due to age or not being pregnant, were included in a comparison of morphometric measurements. There were some missing measurements due to human error, as total number of deer measured varied by category from 193 to 210 deer. There were no differences among groups for neck girth, hind foot length, and body condition (Table 1.4). Body mass, chest girth, total body length, and rump fat differed among groups (Table 1.5). South mule deer had the greatest body mass, while south white-tailed deer had the lowest body mass. North white-tailed deer had the longest total body length with south mule deer having the shortest body length. North white-tailed deer had the largest chest girth while south white-tailed deer had the smallest chest girth. North white-tailed deer also had the greatest rump fat while the north mule deer had the lowest.

There were 4 collar failures and 36 total mortalities during the three years of my study. There were 9 mortalities in 2018: 1 hunter harvest (archery), 1 hunter loss (antlerless firearm), and 7 deaths from unknown causes. In 2019, there were 8 mortalities: 1 hunter harvest (firearm), 2 vehicle collisions, 4 unknown causes, and 1 natural death that tested positive for CWD. There were 19 mortalities in 2020: 2 hunter harvest (firearm; one deer tested positive for CWD), 2 vehicle collisions, and 15 unknown causes. Of the 3 deer harvested or considered a hunting loss in 2018 and 2019, all were white-tailed deer (1 archery, 1 firearm, 1 antlerless firearm); whereas, in 2020 the 2 harvested deer were mule deer (firearm). The overall percentages of cause of death were 14% anthropogenic, 11% vehicle collision, 0% predation, 3% suspected natural, and 72% unknown. The largest number of the mortalities were categorized as unknown, for which there was no identifiable disease, evidence of predation, or anthropogenic effects. Mortalities were distributed throughout the year with a slight increase in the fall/winter months for both species (Figure 1.6). Unknown mortalities followed the same pattern with a slight increase in the fall winter months (Figure 1.7).

There was relatively high annual survival of the 178 tagged individuals during the study. Apparent annual survival was 0.81, 0.85, and 0.67 for 2018, 2019, and 2020, respectively. Apparent survival was also calculated by species and site group for each year, with similar results except for white-tailed deer in the south during 2020 (Table 1.6). Results from the Kaplan-Meier model estimated annual survival of all individuals combined across years was 0.78 $\pm$ 0.03 (Figure 1.8). Annual survival for the species was similar for mule deer (0.78 $\pm$ 0.04) and white-tailed deer (0.77 $\pm$ 0.05; Figure 1.9). Survival rates were slightly greater for the North site

(0.82 ± 0.04) than South site (0.72 ± 0.05; Figure 1.10). Annual survival was similar between 2018 (0.81 ± 0.05) and 2019 (0.85 ± 0.05), which were greater than 2020 (0.67 ± 0.06; Figure 1.11). The steepest decline in weekly survival occurred between weeks 30 and 50 (October through January; Figures 1.8-1.11).

The hazard curves showed a slight variation in the hazard rate during each year, albeit with a rather low risk of mortality during any month. Patterns of relative hazard rate were similar between mule deer and white-tailed deer. Mule deer had a relatively high hazard rate during the beginning of the annual time period during February and March, whereas the hazard rate for white-tailed deer peaked at the end of the time period (January and February; Figure 1.12). The hazard rate was almost flat throughout the annual period for the South site, while the North site had a hazard rate that peaked around 30 to 50 weeks (Figure 1.13). The hazard rate briefly peaked >0.02 during 2020 (week 40); otherwise, the hazard rate was quite low across each year (Figure 1.14).

The top-ranked model in the known fate model suite was the time model, indicating that survival was time dependent (i.e., week) across years, species, and sites; there were no other competing models (Table 1.1). The derived annual survival estimate for the entire encounter period was 0.78 ± 0.02 (95% CI 0.74, 0.81). Weekly survival varied from 1.00 ± 0.00 to 0.98 ± 0.01. Weeks most likely affecting the survival rate were between weeks 33 to 46 (October to January), when there were consistently lower weekly survival rates (Figure 1.15).

Discussion

There was no difference in annual survival of adult female deer between species or sites. Usually, female survival is a driver of population growth. Therefore, because of the significant declines in mule deer abundance in western Kansas, I expected lower survival rate for mule deer than white-tailed deer. Because there was no difference in survival rate between the mule deer and white-tailed deer, the mule deer decline in western Kansas is likely not due to differences in adult female survival.

Both species had relatively greater survival rates the first two years; however, both had a slightly lower survival rate during 2020. Causes for differences in mortality among years are uncertain due to the number of unknown mortalities. Survival of male mule deer also experienced a decline in 2020 in the North study area, but no causal factor was identified to explain that pattern (Kinlan 2021). Interestingly male mule deer survival was reduced in the North site (Kinlan 2021) while female white-tailed deer survival was reduced in the South site. It is unknown what caused the difference survival patterns for sexes between sites. However, the female overall survival still corresponds with previous work indicating that survival of adult female deer is relatively high for populations in the Great Plains (Table 1.7)

Female survival (mule deer 0.78, white-tailed deer 0.77) in my study was similar to results from eastern Nebraska (0.74, Frost 2009), Minnesota and South Dakota (0.76, Grovenburg et al. 2011), Montana (0.75, Wood et al. 1989) and Colorado (0.80, Whittaker and Lindzey 2001). Female survival was greater than studies in western Nebraska (0.68, Frost 2009) and South Dakota and Wyoming (2 subpopulations 0.62 and 0.18, Klaver et al. 2008). It was less than survival in Texas (0.89 Haskell 2007), North and South Dakota (0.88, Moratz et al. 2018), and Colorado, Idaho, and Montana (0.85, Unsworth et al. 1999). The causes of death in this study were similar to other studies with hunting and vehicle collisions being common causes of death. In some studies, disease or natural were listed as causes of death as well. Many studies had predation as cause of death, which was dissimilar, because I found no confirmed cases of predation on adult deer in Kansas. All of the studies that listed causes of death had unknown mortalities as well

I was unable to determine a cause for the majority (72%) of adult female deer mortalities in the study, primarily due to the condition of the carcass following scavenging. Scavengers frequently moved collars delaying sensor activation preventing timely detection and investigation of mortalities. Most captured females were in healthy body condition at the time of capture at the end of winter, so it is unlikely that starvation was a cause of death. There was a slight increase in the number of unknown mortalities in the fall/winter that follows along with the overall mortality pattern. For future studies, due to the abundant scavengers in the Great Plains, collars with less sensitive mortality sensors or cameras on the collars could provide more information on cause-specific mortalities. Cameras could be used to provide information on whether it was a natural death or not.

There was only one (3%) confirmed natural death during the study. Natural deaths include disease or starvation. There were likely more natural deaths due to the number of unknown deaths, but the carcasses were too scavenged to collect samples for testing. Other studies had a range of natural mortalities from 1.7% to 38% of total mortalities (Frost 2009, Haskell 2007, Grovenburg et al. 2011, Moratz et.al 2018). While starvation was unlikely due to the abundance of food, there are some diseases that could affect populations of both species. When possible, I tested for EHD, blue tongue virus, and CWD. There were no female mortalities positive for EHD or blue tongue and only 2 mortalities tested positive for CWD. However, prevalence of CWD was greater for males in the same study sites (Kinlan 2021). That could be because a lower sample size of female mortalities were tested than the males. Therefore, the true number of CWD cases could be larger especially with the number of unknown mortalities.

Continued CWD monitoring and encouraging hunters to get more females tested would be beneficial. It is possible that more females died from CWD or other diseases, but scavenging of carcasses prevented sampling for diseases for many mortalities.

There is no indication that more natural or unknown deaths occurred during stressful periods of fawning and weaning for females; instead, timing of most deaths for both categories of mortalities was during fall and winter. Although weekly survival was still high during the fall and winter (0.98 ± 0.01), there were relatively more weekly deaths during that time period, which also included hunting season, than during the remainder of the year. Males of both species also had lower survival in November and December in western Kansas (Kinlan 2021). These months include the major firearm hunting season.

Harvest was the most prevalent known cause of mortality at 14% of the total mortality, but it was low compared to other studies in the Great Plains. In the plains of Montana, harvest was responsible for 83% and 89% of the total mortality for mule deer and white-tailed deer, respectively (Wood et al 1989). In Minnesota and South Dakota, harvest accounted for 69% of the total mortality of white-tailed deer (Grovenburg et al. 2011). In Nebraska, 57% of the total mortality of mule deer and white-tailed deer was due to hunting (Frost 2019). However, another study in South Dakota did not identify harvest as a leading cause of mortality with only 19% of adult female white-tailed deer mortalities caused by hunting (Moratz et al. 2018). Harvest seems to be variable based on site for female mule deer and white-tailed deer in the Great Plains.

There was no difference between species in the relative effect of harvest on annual survival. This result was unexpected considering the large difference of available hunting permits for adult females between white-tailed deer and mule deer. Only 5 females (2 white-tailed deer, 1 hunter loss white-tailed deer, 2 mule deer) were harvested during the entire 3-year study; of the 184 collared deer in the study only 2.7% were harvested. Conversely, harvest accounted for >50% of the mortality of male mule deer and white-tailed deer in the same study areas in Kansas, indicating hunters are targeting males (Kinlan 2021). It could be that culturally in Kansas, hunters do not harvest females due to desire to harvest a mature male instead or fear of lowering the population (York 2000). Kansas landowners, who also hunt, may be more protective of “their” deer herds and have more of an interest in seeing herds grow. Therefore, the number of available antlerless permits does not appear to be related to harvest pressure on adult female deer in western Kansas.

Vehicle collisions were the second greatest known cause of mortality at 11% of total mortality. There was no point in time when collisions were most frequent for the females. However, for males, the majority, 66%, of the collisions occurred during rut or subsequent to rut (Kinlan 2021). Vehicle collisions were common causes of mortality in other studies in the Great Plains, so this result was not unexpected (Wood et al. 1989, Whittaker and Lindzey 2001, Haskell 2007, Frost 2009, Grovenburg et al. 2011, Moratz et al. 2018). Essentially, the top two identified causes of death of adult female mule deer and white-tailed deer in western Kansas are hunting (14%) and vehicle collisions (11%) and have similar effects on the survival. Both hunting and vehicle collisions have little to do with the health or overall condition of an individual.

Most deer were in good body condition when captured. There were few differences in morphometric measurements between species that represent health, such as body mass and chest girth. Any differences were likely not biologically significant between the species. Given individual members of both species were healthy at capture, it is not surprising to report so few confirmed natural deaths. Survival probability was more influenced by time of year than body condition.

If the survival of adult female deer in western Kansas is based more on chance (i.e., hunting, vehicle collisions) than body condition (i.e., natural deaths), similar survival rates between species is not surprising. Apparently, there is no dominant ecological condition driving mortality for either species, so the risk of morality is similar for both species. The survival and health of adult females is likely not driving the decline of the mule deer population in western Kansas.

Management Implications

The population demography of deer herds is based on adult female survival (Eberhardt 2002). Management of deer populations is by manipulating female survival through harvest. However, in Kansas, the decline of mule deer is not due to harvest or mortality rate of females. Both mule deer and white-tailed deer had low harvest rates in Kansas possibly due to aversion of female harvest by hunters. Harvest of female deer in Kansas is likely compensatory rather than additive mortality. There is not a need to change the harvest rate of female mule deer as current harvest rates are not influencing the mule deer population. Overall, adult female mule deer and white-tailed had high survival rates in western Kansas, such that altering harvest levels is unlikely to change population trajectories.

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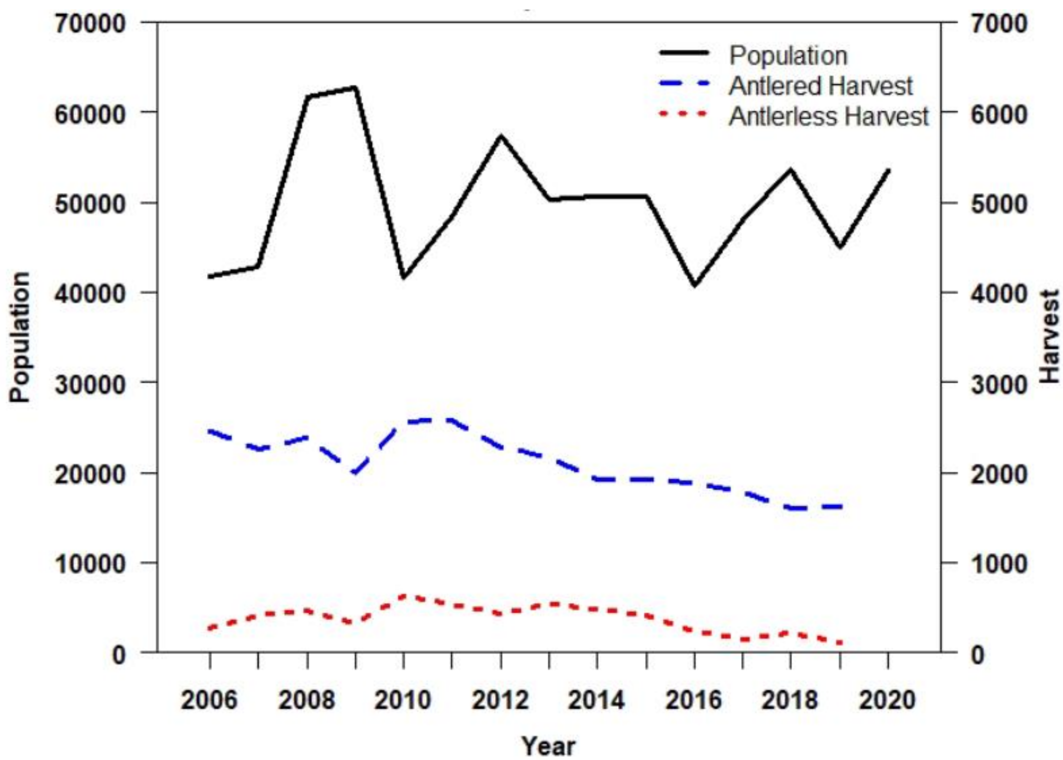

Figure 1.1. Antlered and antlerless harvest and estimated population of mule deer in Kansas USA from 2006 to 2020 (MDWG 2021).

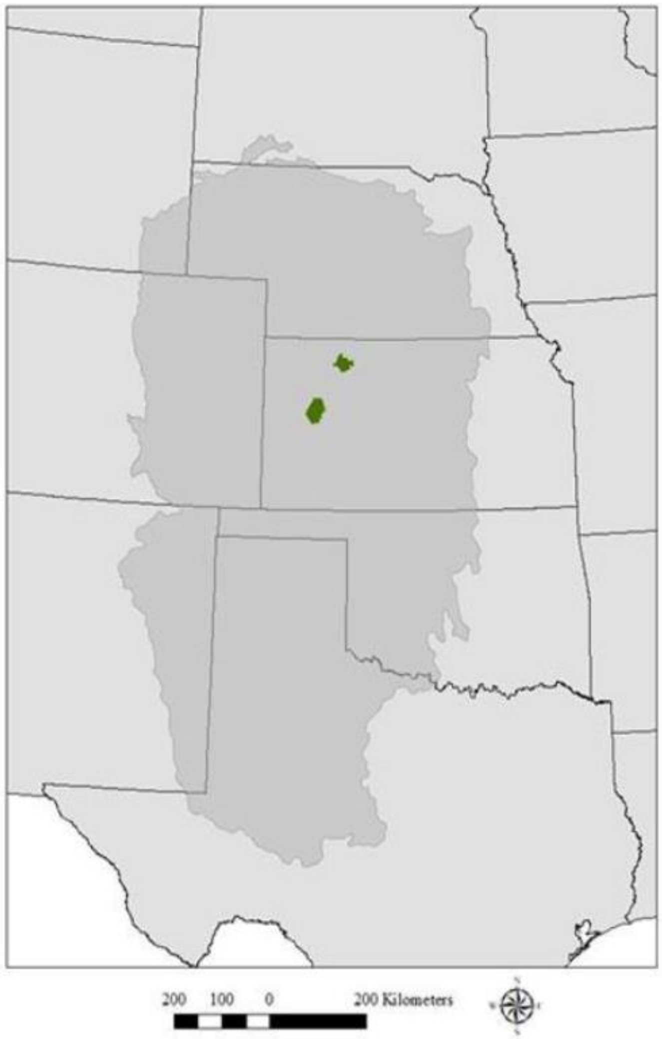

Figure 1.2. Location of 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA. The gray shading is the Central Great Plains and High Plains level III ecoregions (U.S. Environmental Protection Agency 2000).

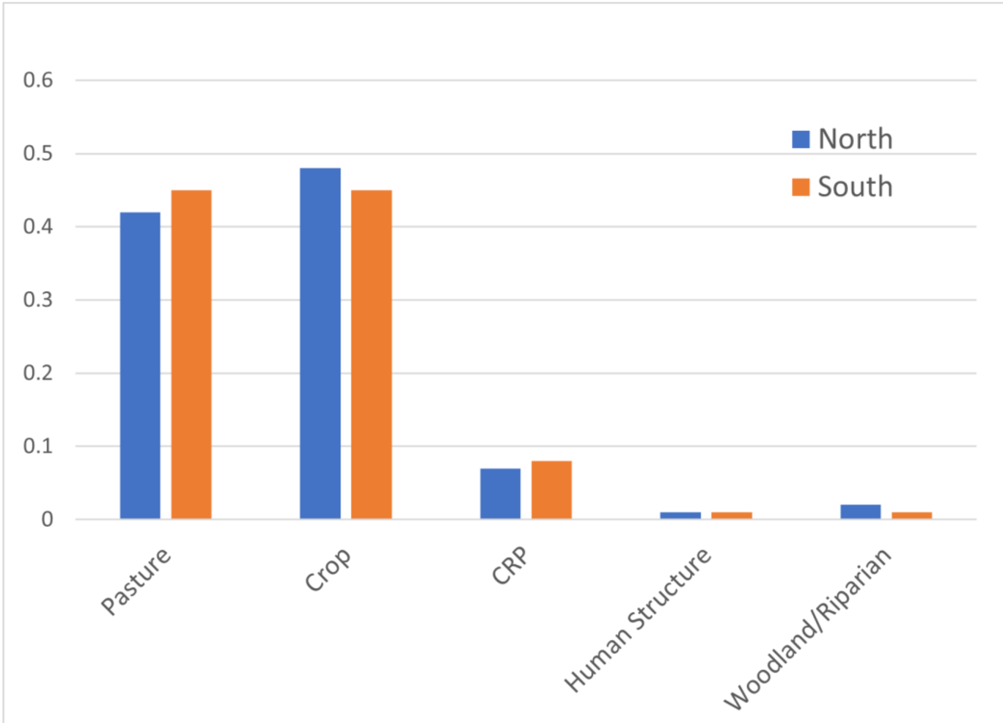

Figure 1.3. The proportion of landcover types in the 2018 landscape boundaries of the 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA.

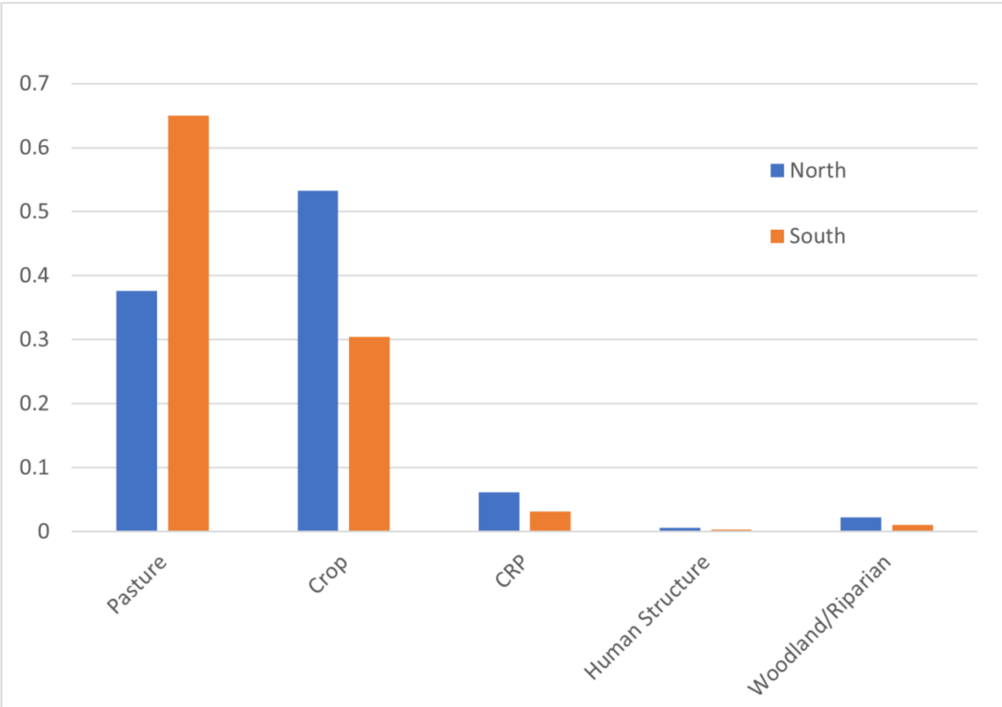

Figure 1.4. The proportion of landcover types in the 2019 landscape boundaries of the 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA.

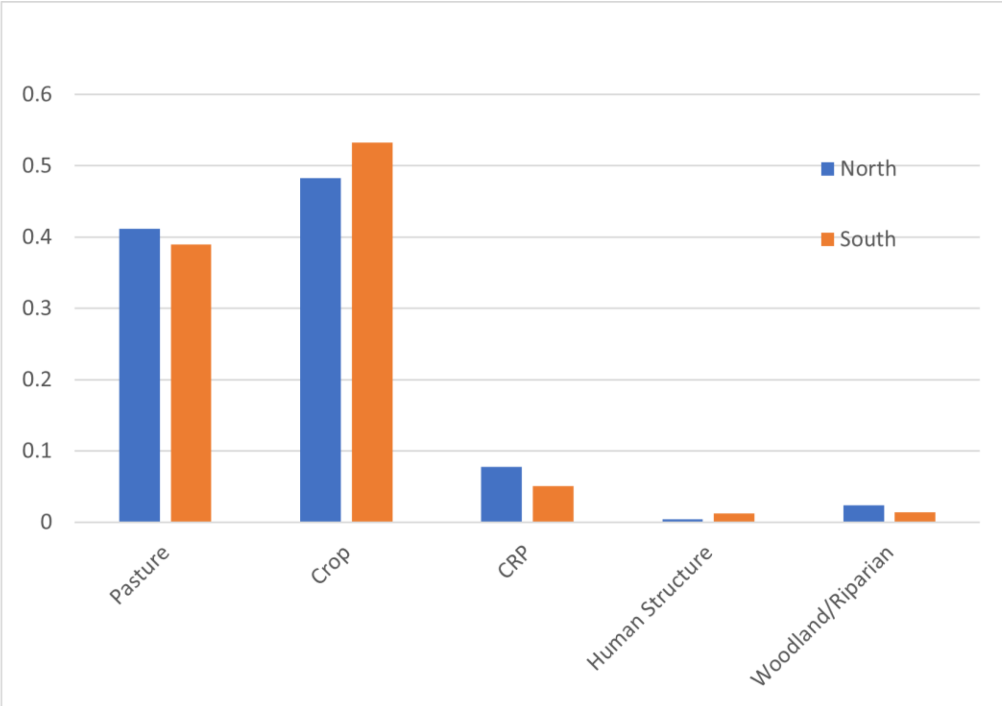

Figure 1.5. The proportion of landcover types in the 2020 landscape boundaries of the 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA.

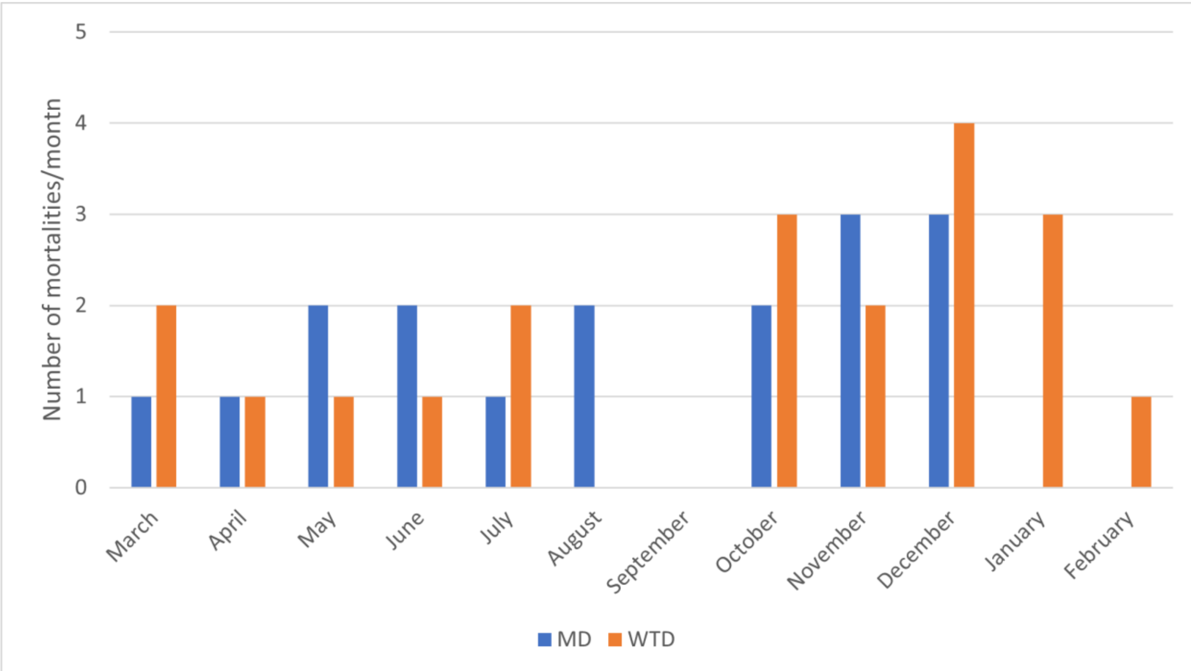

Figure 1.6. Annual distribution of monthly mortalities during 2018-2020 for adult female mule deer (MD) and white-tailed deer (WTD) in western Kansas, USA.

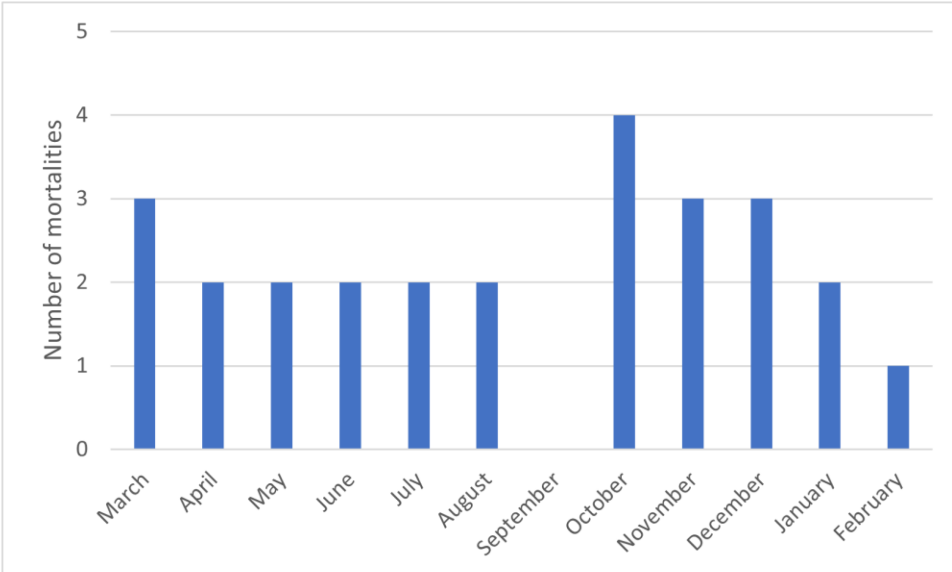

Figure 1.7. Annual distribution of unknown mortalities of adult female mule deer and white-tailed deer during 2018-2020 in western Kansas, USA.

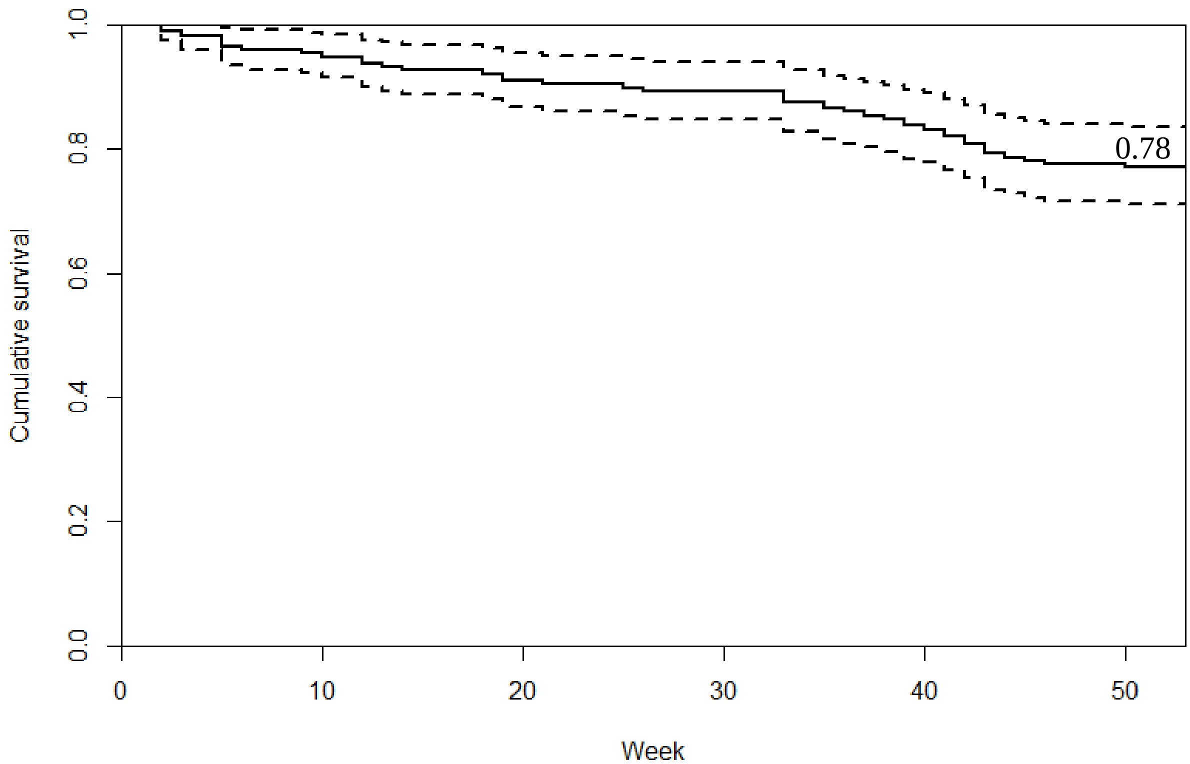

Figure 1.8. Cumulative weekly survival with 95% confidence intervals for adult female mule deer and white-tailed deer in 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019. and 2020. Week 1 began on March 1.

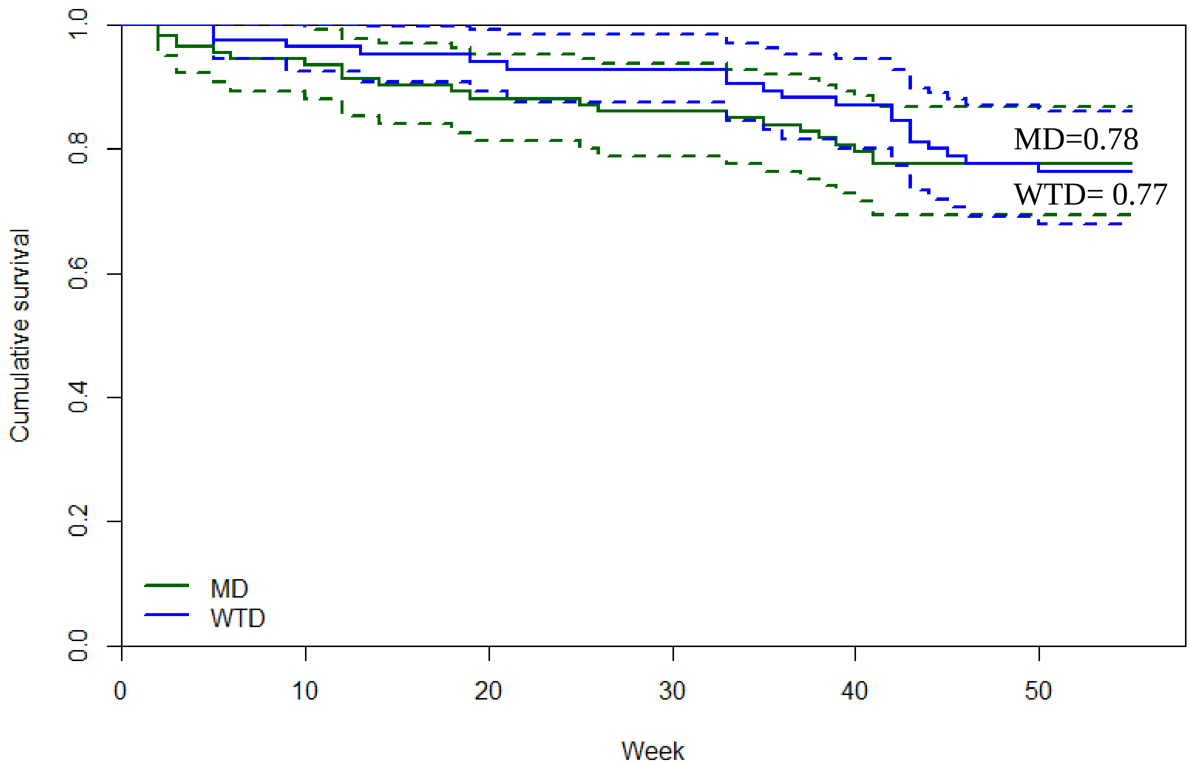

Figure 1.9. Cumulative weekly survival for species with 95% confidence intervals for adult female mule deer (MD) and white-tailed deer (WTD) combined across 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019, and 2020. Week 1 began on March 1.

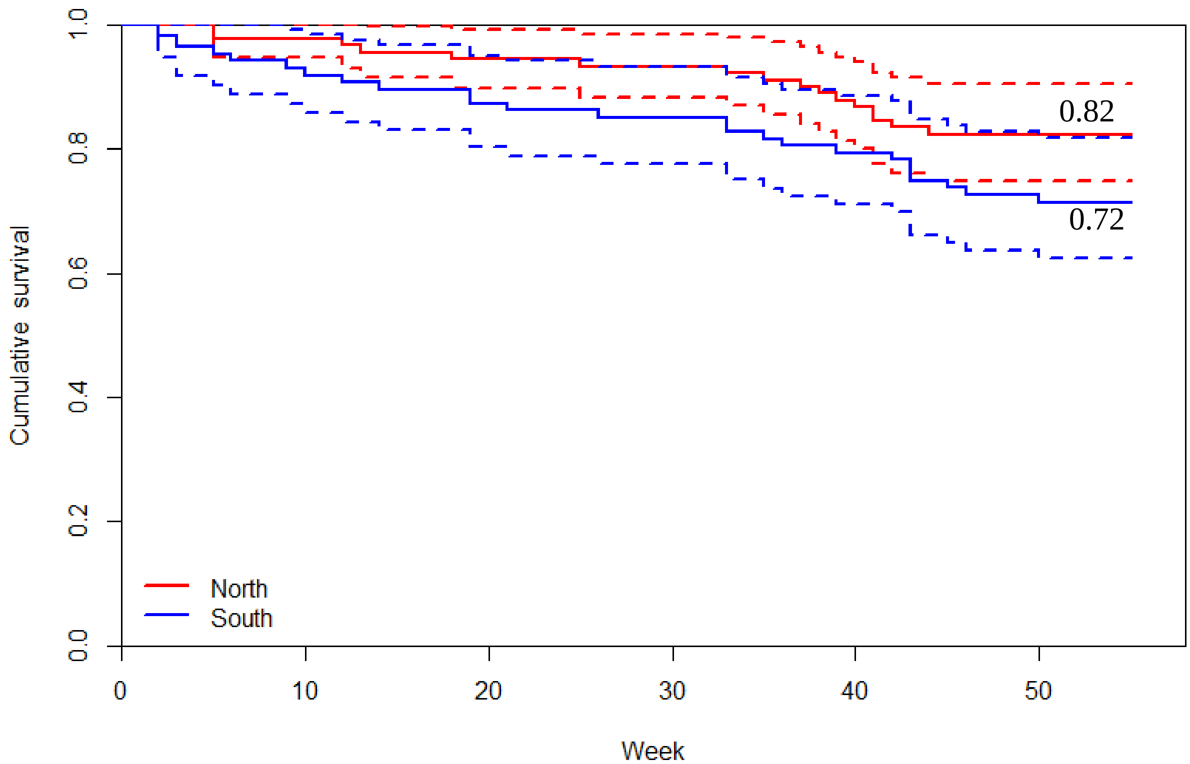

Figure 1.10. Cumulative weekly survival for study sites with 95% confidence intervals for adult female mule deer and white-tailed deer (combined) in 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019, and 2020. Week 1 began on March 1.

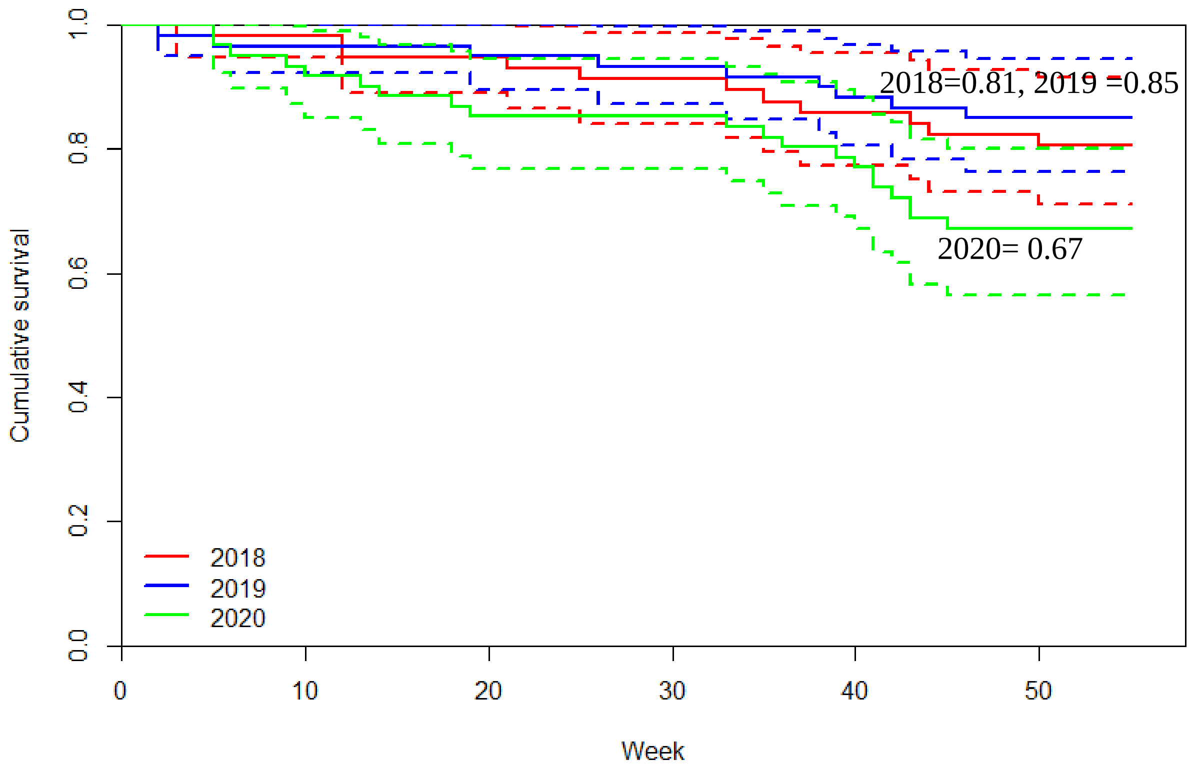

Figure 1.11. Cumulative weekly survival by year with 95% confidence intervals for adult female deer combined across species and study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019, and 2020. Week 1 began on March 1.

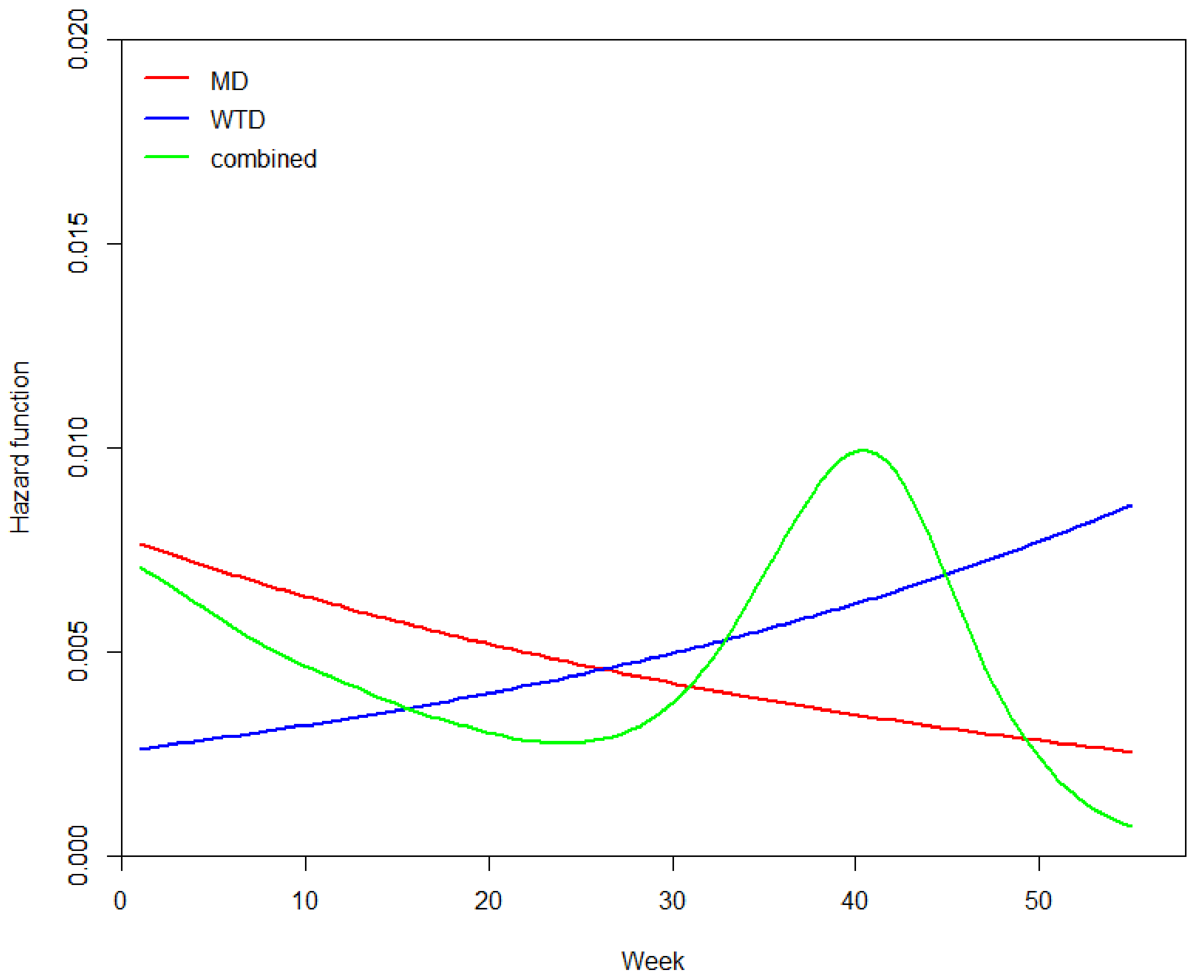

Figure 1.12. Hazard function identifying relative weekly hazard risk for mule deer (MD), white-tailed deer (WTD) and combined species across both study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, and across all years. Week 1 began on March 1.

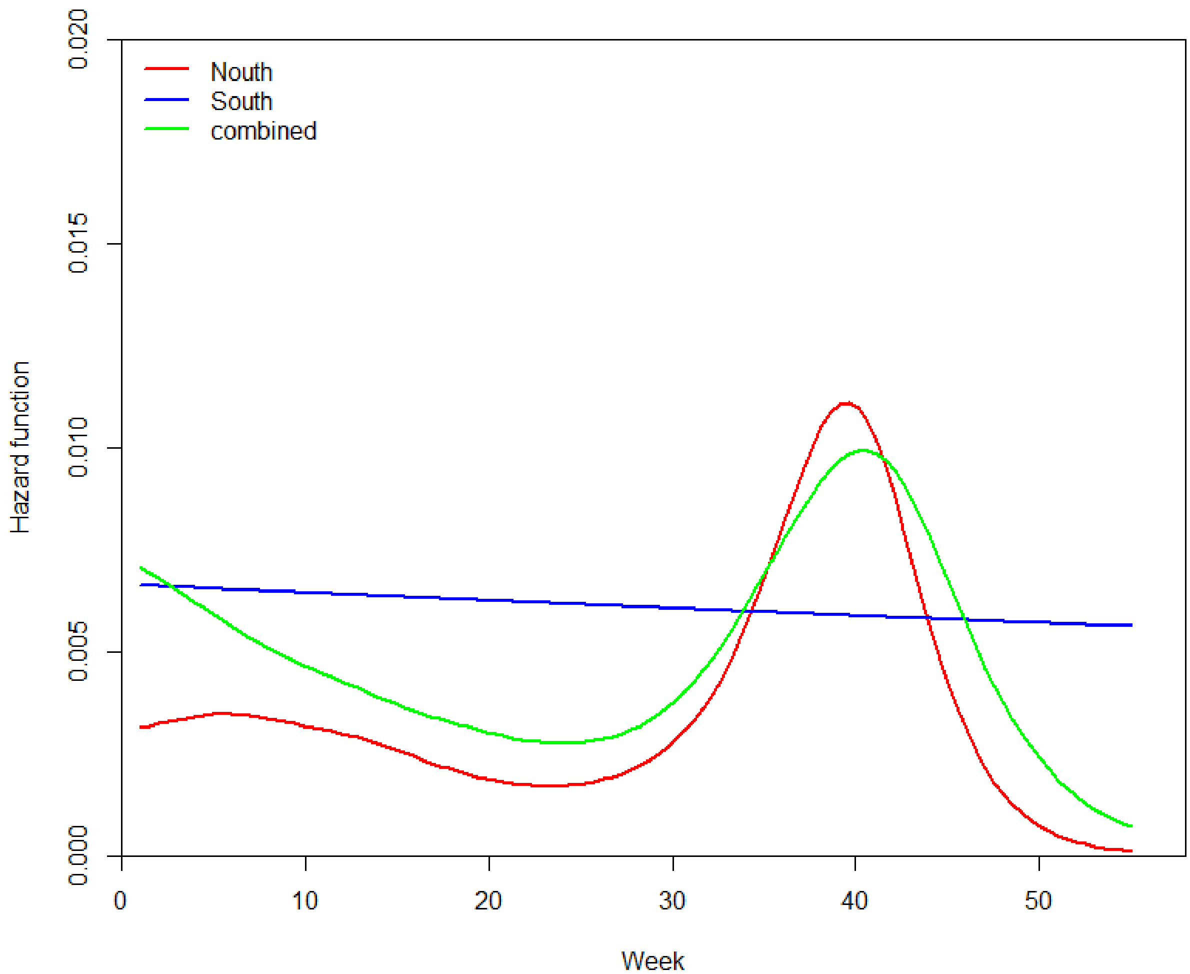

Figure 1.13. Hazard function identifying relative weekly hazard risk of combined mule deer and white-tailed deer in 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019, and 2020. Week 1 began on March 1.

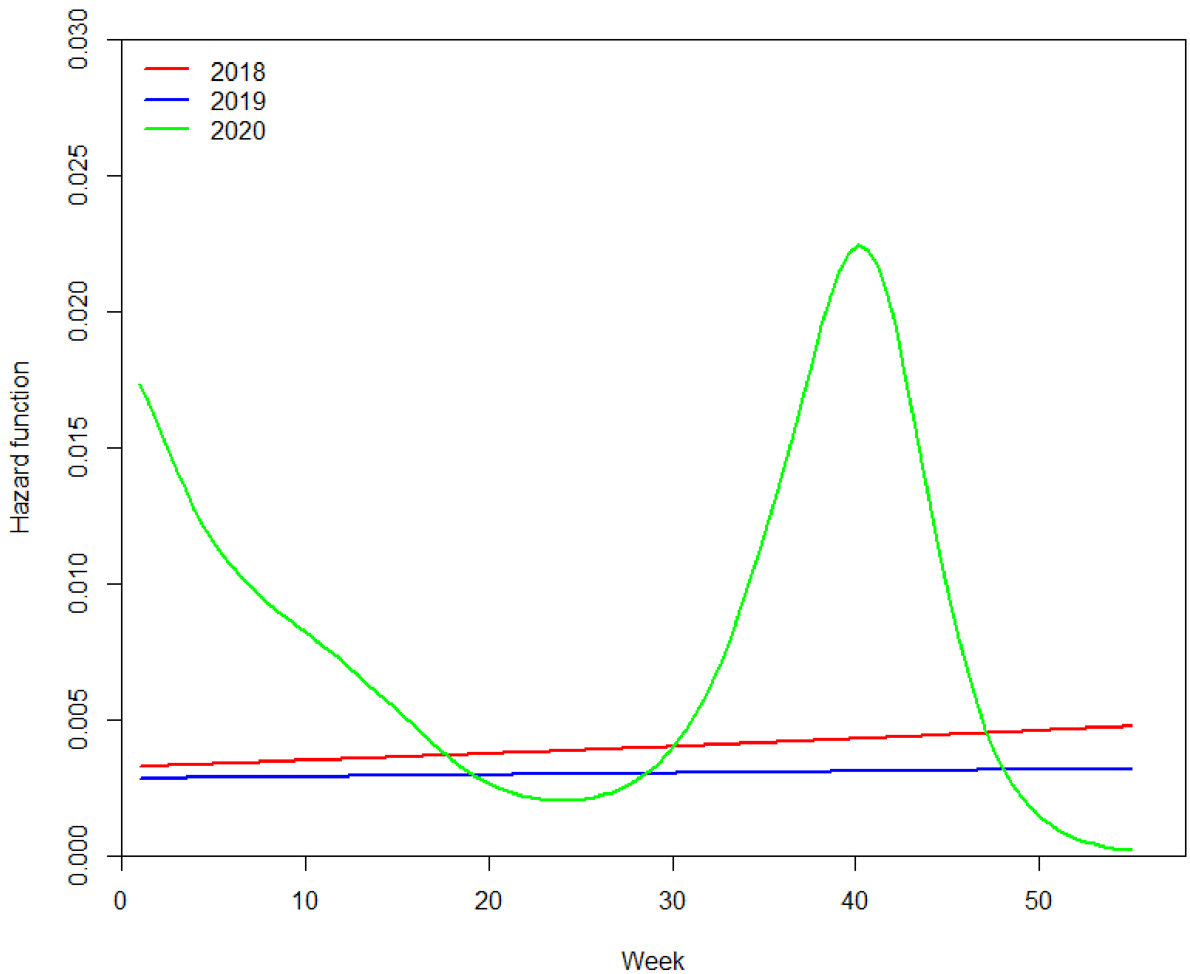

Figure 1.14. Hazard function identifying relative weekly hazard risk for each year considering combined data for both mule deer and white-tailed deer species and both study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, compared between the years of 2018, 2019, and 2020. Week 1 began on March 1.

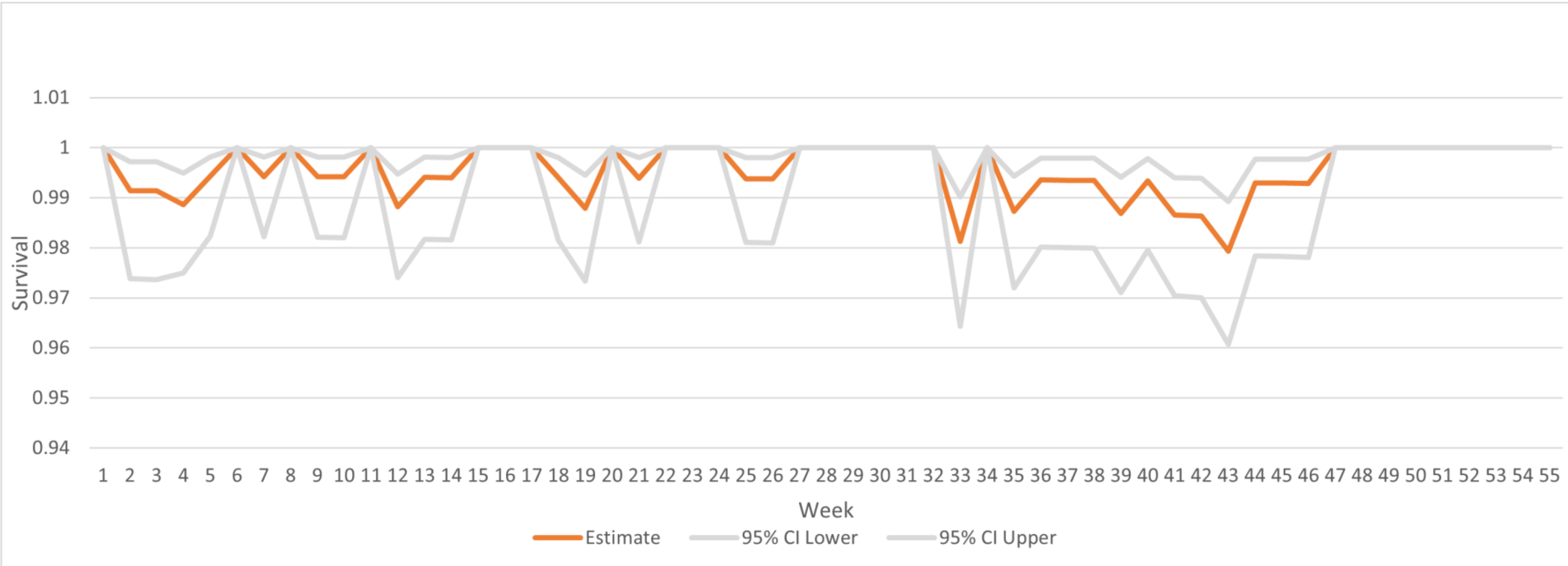

Figure 1.15. Figure 1.15. Known fate weekly survival estimates for 55 weeks, with 95% confidence intervals, of adult female mule deer and white-tailed deer (combined species data) in western Kansas, USA, during 2018, 2019, and 2020. Week 1 began on March 1.

Table 1.1. Ranking of known-fate models estimating survival of adult female mule deer and white-tailed deer in 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, for 2018, 2019, and 2020. The table presents Akaike's Information Criterion (AICc), delta AICc (ΔAICc), AICc weights (w_i), model likelihood, number of parameters (K), and log likelihood (-2log(L))

Model	AICc	ΔAICc	w_i	Model Likelihood	*K*	-2log(L)
{S(time)}	1426.19	0.00	1	1	55	1315.95
{S(mass)}	1493.58	67.39	0	0	2	1489.58
{S (year2020)}	1494.40	68.21	0	0	4	1486.40
{S(.)}	1495.60	69.41	0	0	1	1493.60
{S((year)}	1496.25	70.06	0	0	5	1486.25
{S(species*site*year)}	1498.04	71.85	0	0	7	1484.04
{S((site)}	1499.39	73.20	0	0	4	1491.39
{S(species)}	1501.60	75.41	0	0	4	1493.60
{S(species*site*year*time)}	1951.70	525.51	0	0	382	1176.06

Table 1.2. Number of adult female mule deer (MD) and white-tailed deer (WTD) captured, recaptured, and percent pregnant during February and March at 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019, and 2020

Year/Study Site	Species	# Captured	# Recaptured	Percent Pregnant
2018				
North	WTD	19	-	84%
South	WTD	17	-	88%
North	MD	18	-	94%
South	MD	17	-	94%
2019				
North	WTD	19	0	89%
South	WTD	17	1	100%
North	MD	19	1	89%
South	MD	18	4	83%
2020				
North	WTD	17	3	88%
South	WTD	17	4	94%
North	MD	18	6	94%
South	MD	17	6	94%

Table 1.3 Disease testing of live female mule deer (MD) and white-tailed deer (WTD) captured, February 2018 at 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA. The disease tested for were blue tongue virus, epizootic hemorrhagic disease (EHD), and chronic wasting disease (CWD).

Site	Species	Number tested	Blue tongue suspect	Blue tongue positive	EHD suspect	Number tested	CWD suspected
North	MD	17	2	2	0	16	0
South	MD	17	5	1	0	14	0
North	WTD	15	5	0	0	9	1
South	WTD	14	3	1	0	13	1

Table 1.4. Average (±SE) morphometric measurements (body mass, chest girth, total body length, neck girth, body score, and rump fat) for mule deer (MD) and white-tailed deer (WTD) captured during February (2018, 2019) and March (2020) at 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018, 2019, and 2020.

Site	Species	Body Mass (kg)	Chest Girth (cm)	Total Body (cm)	Neck Girth (cm)	Hind Foot Length (cm)	Body Score	Rump Fat (cm)
2018								
North	WTD	71.27±1.51	102.57±0.75	162.53±1.61	39.27±0.52	47.27±0.43	6.85±0.56	7.40± 0.84
South	WTD	63.76±1.43	98.93±1.08	162.13±1.77	40.02±0.67	46.76±0.35	6.86±0.71	6.29±1.13
North	MD	68.24±1.63	101.46±1.03	159.34±1.84	39.40±0.53	47.68±0.54	6.50±0.63	4.88±0.57
South	MD	69.72±1.47	102.05±1.11	158.26±2.07	41.60±0.78	47.64±0.39	8.00±0.56	5.53±0.53
2019								
North	WTD	64.92±0.98	102.65±1.00	163.34±1.46	43.08±0.80	47.21±0.28	7.63±0.23	8.50±0.77
South	WTD	62.89±1.25	102.31±0.79	160.41±1.73	40.48±0.95	47.19±0.50	7.53±0.19	7.41±0.58
North	MD	65.37±1.41	102.28±0.75	160.16±1.14	42.98±0.74	47.76±0.42	7.32±0.25	4.47±0.45
South	MD	65.54±0.90	102.45±0.58	158.14±1.68	39.48±0.91	47.61±0.25	7.83±0.17	6.39±0.51
2020								
North	WTD	65.08±1.50	103.73±0.78	165.40±2.53	44.00±0.98	47.00±0.58	7.86±0.30	7.07±0.59
South	WTD	64.10±1.44	99.18±1.17	160.12±1.33	45.41±1.25	47.88±0.41	7.41±0.27	5.24±0.62
North	MD	66.26±0.89	104.23±1.23	160.72±0.81	42.08±0.89	47.36±0.32	7.17±0.36	5.18±0.45
South	MD	70.34±1.40	103.12±0.78	161.82±1.79	42.82±1.56	48.88±0.43	7.13±0.46	5.67±0.55

Table 1.5. Comparison of mean (±SE) morphometric data pooled over three years (2018-2020) across adult female mule deer (MD) and white-tailed deer (WTD) captured in February and March at 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA. Capture morphometrics included body mass (kg), total body length (TBL; cm), hind foot length (cm), neck girth (cm), chest girth (cm), body condition index score (BC, 1-9), and rump fat (cm).

	North MD	South MD	North WTD	South WTD	*F*	DF	*P*
Mass	66.60±0.78^{a,b}	68.48±0.78^{a}	65.02±0.76^{bc}	63.53±0.78^{c}	7.21	3, 210	<0.001
TBL	160.10±0.73^{b}	159.38±1.07^{b}	163.70±1.06^{a}	160.86±0.92^{a,b}	3.82	3, 201	0.01
Hind Foot	47.60±0.24^{a}	48.01±0.22^{a}	47.17±0.24^{a}	47.28±0.25^{a}	2.65	3, 202	0.05
Neck	41.57±0.47^{a}	41.27±0.67^{a}	42.06±0.53^{a}	41.97± 0.66^{a}	0.40	3, 204	0.75
Chest	102.70±0.60^{a}	102.54±0.48^{a}	102.96±0.51^{a}	100.19±0.62^{b}	5.19	3, 199	0.002
BC	7.02±0.24^{a}	7.65±0.23^{a}	7.48±0.21^{a}	7.29±0.24^{a}	1.38	3, 191	0.25
Rump	4.83±0.28^{c}	5.90±0.31^{b,c}	7.73±0.42^{a}	6.31±0.45^{b}	10.74	3, 193	<0.001

^{abc} Means followed by the same superscript did not differ among the species/site groups

Table 1.6. Apparent survival of adult female mule deer and white-tailed deer over 3 years (2018-2020), at 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA.

	2018	2019	2020
North mule deer	0.73	0.93	0.76
South mule deer	0.87	0.67	0.75
North white-tailed deer	0.87	0.87	0.79
South white-tailed deer	0.75	0.93	0.36

Table 1.7. Estimates of annual survival and mortality factors of female mule deer and white-tailed deer in previous studies in the Great Plains region.

State	Species	Survival Rate($\hat{\boldsymbol{S}}$)	Mortality Factors	Author
Kansas	MD WTD	MD=0.78 ± 0.04 WTD =0.77 ± 0.05	Hunting, Vehicle, Natural, Unknown	This study
Nebraska	MD WTD combined	**Eastern** = 0.74 CI = 0.74-0.75 **Western** = 0.68 CI = 0.67-0.69	Hunting, Vehicle, Boat, Train, Predation, Poaching, Disease, Unknown	Frost 2009
Texas	MD WTD combined	Entire study ≈0.89	Hunting, Vehicle, Predation, Unknown, Starvation	Haskell 2007
Minnesota and South Dakota	WTD	Annual = 0.76 CI = 0.70- 0.80 Summer = 0.97 CI = 0.96-0.98 Fall = 0.80 CI = 0.76-0.83 Winter = 0.97 CI = 0.96-0.98	Hunting Vehicle, Predation, Disease, Unknown, Poaching, Wounding loss	Grovenburg et al. 2011
South Dakota and Wyoming	WTD	2 subpopulations annual survival =0.62 annual survival =0.18	_	Klaver et al. 2008
North and South Dakota	WTD	Entire study = 0.88 CI = 0.83–0.91 Pre-hunt = 0.98 CI = 0.96-0.99 Hunt = 0.93 CI = 0.90–0.96	Hunting, Vehicle, Predation, Disease, Unknown, Starvation	Moratz et al. 2018
Montana	MD	Annual = 0.75	Hunting, Vehicle, Predation, Unknown, Starvation	Wood et al. 1989
Colorado, Idaho and Montana	MD	Mean survival across all states = 0.853 ± 0.011 SE	-	Unsworth et al. 1999
Colorado	MD	Entire study = 0.80	Vehicle, Predation, Unknown,	Whittaker and Lindzey 2001

Chapter 2 - Activity patterns of adult mule deer and white-tailed deer in western Kansas

Introduction

For sympatric species temporal segregation or variation in behaviors may minimize competition, allowing species to co-exist (Carothers and Jaksic 1984). If resources are shared and limited, species can avoid direct competition by different activity patterns or timing of activity patterns. Activity patterns represent relative intensity of behaviors among certain time periods. Differing levels of activity through time could allow for niche partitioning allowing 2 species to occupy almost the exact same niche only segregated temporally. However, when activity patterns are similar between sympatric species, temporal partitioning cannot occur; therefore, likelihood of interspecific competition for limited resources increases. It is important to identify potential areas of competition between similar species particularly when populations of one or both species are declining.

Population abundance and occupied range of mule deer (*Odocoileus hemionus*) in the Great Plains are declining while white-tailed deer (*O. virginianus*) populations have been expanding in abundance and range. Historically, white-tailed deer were limited to the eastern tallgrass prairie and eastern deciduous forest interface with most regions of the Great Plains occupied solely by mule deer (VerCauteren 2003). Both populations were nearly extirpated from the Great Plains by the early 1900s followed by recovery throughout the mid-late 1900s (Anderson 1964, Ballard et al. 2001, VerCauteren 2003). White-tailed deer populations have been expanding westward in the Great Plains during the past 3 decades (VerCauteren 2003, Hanberry and Hanberry 2020). Currently, the expanding range of white-tailed deer appears to be concurrent with contraction of the occupied range of mule deer populations (Ballard et al. 2001, VerCauteren 2003). This trend is present in Kansas, USA, with mule deer populations declining in abundance and occupied range while white-tailed deer populations are increasing (Fox 2016, KDWP 2022). Direct competition between these species is potentially occurring because of their similarities in resource selection, space use, and, potentially, activity patterns. If any resource is limited, evidence of direct competition may indicate a potential factor contributing to recent declining population trends of mule deer.

Activity patterns are determined using accelerometers contained in collars deployed on individual animals. Accelerometers measure the acceleration along an axis of a collared animal (Gaylord et al. 2016). Data from multiple axes on a collar paired with visual observations can link behavior to patterns of axis acceleration (Gaylord et al. 2016). Behaviors most often chosen to represent activity are active behaviors such as feeding and running and inactive behavior such as resting (Gaylord et al. 2016). When active behaviors increase, inactive behavior will decrease and vice versa.

Mule deer and white-tailed deer have similar feeding and resting patterns across diel periods (Kufeld et al. 1988, Webb et al. 2010). Both species are crepuscular with relatively larger movements at dawn and dusk (Kufeld et al. 1988, Webb et al. 2010). Both species typically exhibit increased nocturnal active behaviors in areas or during periods of increased human disturbance such as farming, hunting, or urban areas. However, differences in behavior, resource selection, and habitat use across biological seasons could lead to differences in activity patterns between species.

Differences in resource selection might lead to different patterns of activity between species and sexes (Butler et al. 2009). Mule deer are known to select for high elevation, rough terrains, and open canopies while white-tailed deer select lower elevations and closed canopies (Mackie et al. 1998, Brunjes et al. 2006). Behavioral responses differ between species when confronted by predators or what is considered a predator such as human disturbance. White-tailed deer run at the first sign of a predator, whereas mule deer will seek higher ground, turn, and confront the predator (Lingle 2001, 2002). This constant difference in behavior in response to perceived threats could lead to major differences in activity patterns, potentially providing a fitness advantage for white-tailed deer over mule deer.

While anti-predator behavior and resource selection are constant differences, there are periods during the year when activity patterns temporarily change. It is likely that activity patterns of males and females change during the diel period in response to disturbance during hunting seasons (Little et al. 2016). In much of the Great Plains, males are heavily harvested, but hunting culture promotes not shooting females, assuming that populations will increase in the absence of female harvest (York 2020). Male mule deer and white-tailed deer were found to have lower movements and increased time in core use areas during the 12-day firearm period in Kansas (Kinlan 2021). However, even if female deer harvest is low, human presence and associated disturbance during hunting seasons remains, likely influencing female activity patterns. For example, female white-tailed deer subjected to 9-day muzzleloader hunting period increase their total use area in Nebraska, USA (Hygnstrom et al. 2011). I predict that adult female deer will show more active behavior during the 12-day firearm season in Kansas than during other time periods, but adult male deer will have lower active behavior during the firearm season than other periods.

The Kansas firearm season directly follows the rut period for both species (Kinlan 2021), so post-rut recovery may also affect and lower male activity. Rut is the most energetically stressful time of year and will greatly affect behavior patterns of male deer. Males can lose up to 30% of their body mass during rut increasing the risk for natural mortality in addition to the potential of being harvested (DeYoung 1989, Ditchkoff et al. 2001 Harrison et al. 2011). In western Kansas, there is an increase in non-hunting related mortalities in the post-rut period for male deer (Kinlan 2021).

Active behavior is assumed to increase during rut for both species of deer. However, patterns of behavior changes during rut may differ between species or sexes. For example, movements of adult male mule deer and white-tailed deer increased in western Kansas during rut when compared to annual movements, but male mule deer had lower bi-hourly and daily movements than male white-tailed deer (Kinlan 2021). Mule deer increased use of their core area without expanding their home range area during rut (Kinlan 2021). Because mule deer have mixed-sex groups during winter, males do not have to expand their range to find a mate (Lingle 2003). Conversely, white-tailed deer males are more solitary and have to search for a mate outside of their core use area (Lingle 2003). I hypothesize that because mule deer are in mixed-sex groups, their active behavior will be lower than white-tailed deer males that have to actively search out and find mates during rut. While I predict that active behavior of male deer will increase during rut for both species, I predict that male mule deer will have lower active behavior patterns than white-tailed deer.

Because rut influences male activity patterns, female activity patterns likely change as well during rut, causing rut to be a stressful time period for both males and females. The behavioral response by females to rut is unknown because there is no published information on female activity patterns during this period for deer populations in the Great Plains. It is assumed that female activity increases during rut due to males seeking, herding, and chasing females. However, activity by females during rut may be affected by the density of males. In an area of high male density, female white-tailed deer decreased their movements during rut compared to pre-rut (Holzenbein and Schwede 1989); however, in an area of low male density, female white-tailed deer increased their mobility during rut (Labisky and Fritzen 1998). I hypothesize that female mule deer will have more active behavior than female white-tailed deer during rut due to lower density of male mule deer in western Kansas.

Because of the lack of information on activity patterns for either deer species in the Great Plains, comparison of behavior patterns will provide insights into factors contributing to competition or co-existence between these species. Differences in behavior patterns between species could be indicative of interference competition between white-tailed deer and mule deer, contributing to population trends in the Great Plains. Conversely, differences in activity patterns may allow these species to co-occur. My objective was to compare behavior patterns between adult mule deer and white-tailed deer of both sexes at seasonal and fine temporal period scales in western Kansas. I focused on changes in behavior during rut and firearm seasons. Activity patterns of both sexes were analyzed simultaneously because other than rut when male activity will likely influence behavior of females, behavior of both sexes will likely be similar (Webb et al. 2010).

Study Area

My study occurred at 2 contrasting field sites in western Kansas that supported sympatric populations of mule deer and white-tailed deer in landscapes containing habitat features representative of both species (Figure 1.2). These sites were roughly 150 km apart and chosen because of reported declines in mule deer abundance, but with sufficient mule deer densities necessary to obtain appropriate sample sizes (in 2018, 5.43 mule deer/km^2; Levi Jaster KDWP personal communication).

The North field site (~85,000 ha) was in Decatur, Norton, Sheridan, and Graham counties; it consisted of relatively small tracts of landowner properties surrounding a large wooded riparian area. The South field site (~137,000 ha) was in Logan, Scott, Gove, and Lane counties, consisting of relatively larger tracts of landowner properties interspersed with steep ravines and chalk cliffs. Average yearly temperatures from 2006-2020 was 12.43° C in the North site and 11.97° C in the South site (NOAA 2021). Average annual precipitation from 2006-2020 was 57.84 cm in the North site and 51.19 cm in the South site from 2000-2020 (NOAA 2021). The average temperatures (°C) from 2018 to 2020 were 12.10 in the North site and 11.73 in the South site and similar to the long-term averages. Annual precipitation during 2018 (North 92.1 cm, South 66.7 cm) and 2019 (North 74.4 cm, South 52.7cm) was wetter than the long-term average years, but 2020 represented drought conditions (North 36.94 cm, South 36.09 cm).

Common landcover types were cropland, pasture, woodland/riparian, and U.S. Department of Agriculture Conservation Reserve Program (CRP) lands. Agriculture was the dominant land use feature in both study sites, which included livestock grazing of native rangeland and row-crops. Corn (*Zea mays*), wheat (*Triticum aestivum*), and milo (*Sorghum bicolor*) were the most common crops; alfalfa (*Medicago sativa*), soybeans (*Glycine max*), and sunflowers (*Helianthus annuus*) were less common. Grasslands consisted of native short and mixed-grass prairie primarily grazed by cattle. Common grasses included little bluestem (*Schizachyrium scoparium*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*B. gracilis*). Common forbs were broom snakeweed (*Gutierrezia sarothrae*), common mullin (*Verbascum* *thapsus*), and tall thistle (*Cirsium altissimum*); common succulents were yucca (*Yucca glauca*) and prickly pear cactus (*Opuntia macrorhiza*).

The CRP lands in both study sites were ungrazed and planted with mostly tallgrass prairie grass species including big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). Woodlands were associated with riparian areas along the Solomon River at the North site, and Smoky Hill River and tributaries in the South site. Shelterbelts and dispersed tree clusters (i.e., former homesteads) were scattered throughout both study sites. Common tree species included American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), black cherry (*Prunus serotina*), eastern cottonwood (*Populus deltoides*), honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*), mulberry (*Morus rubra*), and eastern red cedar (*Juniperus virginiana*). Plum thickets (*Prunus angustifolia*) and smooth sumac (*Rhus glabra*) were shrubs commonly found in ravines and valleys in western Kansas.

Study areas were defined annually based on a minimum convex polygon (MCP) estimated from all female locations for both species combined (Mohr 1947). Study areas for 2018, 2019, and 2020, respectively, were 450.84 km^2, 857.40 km^2, and 685.48 km^2 for the North site and 1,387.54 km^2, 664.96 km^2, and 1,041.60 km^2 for the South site. I buffered the landscape MCP by 200 m, which was similar to the average hourly movement of the deer (Chapter 3). I created a landcover map for each year for the landscape MCP by digitally delineating polygons of different landcover patches using ArcGIS (10.6) from a satellite image (ESRI World Imagery) for the entire landscape scale boundary. Only patches 30 m^2 or larger were delineated. The landcover type was ground-truthed for each polygon each year. Delineated landcover types across sites were: native pasture, ravine, crop type, CRP, human structure, woodland, and riparian (Figures 1.3-1.5).

Methods

Capture

A commercial helicopter capture crew (Quicksilver Air Inc, Fairbanks, AK) captured deer via aerial net gun in February during 2018 and 2019 and March in 2020. Captured deer were sedated (15 mg Butorphanol [50 mg/ml], 15 mg Azaperone [50 mg/ml], and 15 mg Midazolam [50 mg/ml]; Wolfe and Miller 2016) and transported to a central processing location where I estimated age by tooth wear and eruption (Severinghaus 1949), collected morphometric data (total body length, hind foot length, nest girth, and chest girth [cm]), recorded body mass (kg), and attached numbered ear tags to each deer. Pregnancy was confirmed using an ultrasound (IBEX PRO/r, E.I. Medical Imaging, Loveland, CO) by a licensed veterinarian. Each pregnant collared deer received a vaginal implant transmitter (VIT) that was digitally linked with the collar. When a doe gave birth, the VIT was expelled and the collar sent a GPS location at the time of expulsion. Fawn birth date was used to create biological seasons for females.

All male deer and pregnant females received a high-resolution GPS/VHF VERTEX PLUS-2 collar with a 3-axis activity sensor (Vectronics, Berlin, Germany). Female collars recorded hourly GPS locations during the entire deployment period and programed to drop off at 60 weeks from date of capture. Collar fit was specific to species with white-tailed deer and mule deer collars at 38 cm and 43 cm circumference, respectively. Male collars had an expandable elastic insert to account for neck swelling during rut and programed to drop off 180 weeks from capture. Male collars recorded locations every two hours except for the 12-day firearm period when locations were recorded every 30 minutes.

Activity sensors on deployed collars continuously measured acceleration 8 times per second along 3 axes and averaged these data every 5 minutes. Acceleration was measured on a scale of 0 to 255. Store-on-board activity data were manually retrieved and downloaded when the collars fell off at 60 and 180 weeks from capture for surviving females and males, respectively, or following a confirmed mortality. The data file consisted of an Excel csv file of 3 columns of acceleration data along with the temperature for every 5 minutes for the entire recording period.

A total of 60 males and 60 females were captured during 2018 of the study split evenly between species and site. To maintain a sample size of 60 at the start of the field season during 2019 and 2020, males were captured and collared to replace the number of male deer that died during the previous year. During all 3 years of capture, ≥60 females were captured and collared annually. All animal handling procedures are approved by the Institutional Animal Care and Use Committee at Kansas State University (protocol 3963), and authorized under the state of Kansas scientific, education, or exhibition wildlife permits (SC-024-2018, SC-015-2019, SC-032-2020).

Life Stages/Seasons

I categorized annual temporal periods based on life stages and hunting seasons. For females, the pregnant season started March 1 following capture and continued until the mean fawn birth date each year. The fawn season was from the mean birth date until the wean date, which was defined as 70 days from birth. Weaned lasted from the mean weaned or fawn death date until archery season. For males, spring and summer were combined into one category from March 1 until the start of archery season. The following seasons were the same for both sexes. Fall/archery season was from the start of archery (9/17/18, 9/16/19, 9/13/20) to the start of rut. Rut was from the beginning of rut (10/31 all years) until the end of rut (11/24/18, 11/21/19, 11/23/20, Kinlan 2021). Firearm season was 11/28/18-12/9/18, 12/4/19-12/15/19, and 12/2/20-12/13/20. Winter season was from the end of firearm season to February 28.

Analysis

The 3-axis activity data were recorded as x (forward/backward), y (side-to-side), and z (up and down) and in arbitrary units from 0-255. These units represent acceleration between 2 consecutive points. Each activity point was assigned an active behavioral state based on definitive function models developed by Gaylord et al. (2016) to classify behavior states of ungulates based on acceleration activity. The model uses information from the x and y axes and categorizes the activity point into a behavioral state. I used the 3-category model (feeding [walking], resting, running) due to 3 categories being the most accurate for determining mule deer activity (Gaylord 2013). The model cannot determine the difference between feeding and walking as both are usually concurrent in ungulates (Gaylord et al. 2016).

I converted activity points into a proportion of total behavior for each deer for each season. I was most interested in differences in behavior among seasons because within-day activity can be represented by movement data (Chapter 3). I used a 2-way multivariate analysis of variance (MANOVA) to test for differences in the proportion of behavior categories (feeding, resting, and running) between species and among seasons. Following a significant MANOVA test for the interaction ($P < 0.05$), I used a univariate one-way analysis of variance (ANOVA) to test for differences in behavior among seasons by species. I used a Tukey HSD test as a post-hoc test to separate seasons following a significant ANOVA test ($P < 0.05$). I also used a *t*-test to test for significant difference between species for each behavior for each season.

Results

Females

Activity data from 171 individual females were downloaded during the three years. Greater than 116,000 activity points were collected per collar for individuals that survived an entire year. Based on activity data, there was an interaction for proportion of behaviors between species and among seasons ($F_{6, 4334} = 11.45$, $P < 0.001$) for females. Due to the presence of an interaction, I compared proportion of behaviors among seasons by species. Behaviors differed among seasons for mule deer ($F_{6, 2265} = 18.83$, $P < 0.001$) and white-tailed deer ($F_{6, 2069} = 15.38$, $P < 0.001$; Table 2.1).

For female mule deer, there was a statistical difference among seasons for each behavior category (Table 2.1). Average proportion of feeding was greatest during fawn season with feeding during rut and firearm season similar to the wean, fall, and winter seasons. Proportion of feeding during pregnancy was similar to wean, fall, rut, and fawn seasons. Conversely, the average proportion of resting was greatest during the fawn season, which was similar to rut, firearm, and winter seasons. The average proportion of running behavior was greatest during the firearm season, but statistically similar to rut.

For female white-tailed deer, average proportion of behaviors statistically differed among seasons for each behavior category (Table 2.1). The proportion of feeding was lowest during the firearm season, but similar to rut and winter seasons. The average proportion of resting was lowest during fawn. The average proportion of time running was greatest during the fawn season, which differed from all other seasons (Table 2.1).

For both species, rut and firearm seasons did not cause an ecologically significant change in proportion of any behavior. Activity means during rut and firearm seasons were always similar to other seasons. The largest changes were during the fawn season with the lowest proportion of rest for both species, greatest proportion of feeding for mule deer, and greatest proportion of running for white-tailed deer (Table 2.1).

There were statistical differences in the average proportion of behaviors between species within seasons (Table 2.2). Running behavior was always greater for white-tailed deer than mule deer. However, because the greatest difference between means was only 0.07 units, it is unlikely that any statistical differences in proportion of behaviors between species within seasons are ecologically relevant and likely the result of a large sample size.

Males

Activity data from 69 individual males were downloaded during the three years. Like the females, greater than 116,000 activity points were collected per collar for individuals that survived an entire year. There was an interaction for proportion of behaviors between species and seasons ($F_{4,\ 1846} = 9.26$, $P < 0.001$). Subsequently, I tested for differences in behavior among seasons by species. Proportion of behavior statistically differed among seasons for both mule deer ($F_{4,\ 1131} = 101.85$, $P < 0.001$) and white-tailed deer ($F_{4,\ 715} = 71.53$, $P < 0.001$).

Male mule deer had statistical differences among seasons in every behavior category (Table 2.3). In the feeding category, behavior proportions were similar among seasons except for fall, which had the lowest value. Rut had the lowest proportion of resting behavior, which was not similar to any other season. Fall had the highest resting proportion and was not similar to any other season. The proportion of resting behavior during the firearm season was similar to winter. The proportion of running behavior during rut was double the next largest proportion of running during firearm and winter seasons. Running during firearm and winter seasons was similar to fall. The lowest proportion of running behavior was in the spring/summer season.

Proportion of behavior differed among seasons for male white-tailed deer (Table 2.3). The proportion of time feeding during spring/summer was similar to firearm and winter; feeding during rut was similar to firearm, winter, and fall. The proportion of time resting was lowest during rut, but similar to spring/summer; resting during the firearm season was similar to fall and winter periods. Running behavior had the largest proportion during rut by more than double the next largest proportion during fall, which was similar to spring/summer and firearm periods. The proportion of time running was lowest during winter, but it was similar to firearm season.

There were some statistically different values in the proportion of behavior of the species within seasons (Table 2.4). The rut season effected behavior for both species. While feeding was similar to other seasons the most significant changes were in the run and resting categories. The resting category during rut was the lowest out of all the seasons. The run category was the greatest during the rut and it was double the other seasons for both species. Another stressful season for the males was firearm season, but firearm season behavior was always similar to other seasons so it is unknown if firearm affected male behavior. While there was statistical differences between the species behavior, the greatest difference between the means of the behaviors was 0.06. It is unlikely that there is biological significant difference in behavior between species.

Discussion

Because mule deer and white-tailed deer are ecologically similar, they usually segregate spatiallybased on elevation when they co-occur (Antony and Smith 1977, Mackie et al. 1998, Brunjes et al. 2006). However, western Kansas lacks a relevant elevation gradient, so unable to segregate, mule deer and white-tailed deer are interacting for the first time in recent history in Kansas. Two similar species can survive overlap in space and resource use if there are adequate resources or differences in behavior that allows partitioning of resources. Behavior of animals changes because of physiological stress, whether it is biological like the rut or due to outside influence such as lack of food or hunting and other disturbance. In my results, there were few relevant differences in behavior between mule deer and white-tailed deer within seasons or among seasons for both sexes within species indicating that either (1) species co-occurrence has not been long enough for behavior differences to develop, (2) sufficient resources are available to support co-occurring deer populations, or (3) population densities are not at levels for competitive exclusion to develop relative to available habitat.

Behavior of male deer only changed during rut. Males increased running behavior (mule deer from 7 to 14%, white-tailed deer 7-17%) and reduced resting behavior during rut (mule deer from 47 to 40%, white-tailed deer 46-41%). Males of both species also increase their movements during the rut (Webb 2010, Kinlan 2021). However, I did not find evidence for a change in female behavior during rut. While there is a prevailing assumption that male behavior during rut will affect female behavior, it appears that males actually do not chase females enough to alter their overall behavior patterns. In Kansas, the firearm hunting season immediately follows rut, creating a different type of stress on both sexes of deer.

The firearm season surprisingly produced very little change in behavior for either sex or species. While males in the study were heavily hunted (Kinlan 2021), few females in the study were harvested (Chapter 1). Other studies have shown that firearm seasons affects movements of sexes of both species (Hygnstrom 2011, Kinlan 2021). Apparently, activity behavior patterns change very little in western Kansas even during a supposedly stressful season. This could be due to the lack of intensive hunting pressure or other disturbance on the mostly private land. However, there was a statistical difference in the run behavior between sexes for both species during all seasons except hunting when mule deer increased their running behavior to no statistical differences between species. Differential response to predators and disturbance between deer species for both sexes may contribute to the differences in running behavior as white-tailed deer will run away and mule deer will run to a high point and then turn and look at the predator (Lingle 2001, 2002).

There was little difference between the species for the spring/summer season for males and pregnancy, fawn, and wean seasons for females. There was also little difference between sexes. Different behavior between sexes occurred during spring and summer when females had almost double the running behavior during pregnancy, fawn, and wean seasons than their male counterparts throughout spring and summer. It is unknown what caused the difference in behavior as females did not have fawns to tend during the pregnancy season.

Deer in western Kansas are subject to relatively little stress during non-drought years. Densities of both species of deer are low in western Kansas; therefore, competition between species for space, food, or other resources is likely not occurring. Typically, extreme or intense weather events are short in duration, food is plentiful, and predation is minimal to potentially non-existent. There are no limiting resources and few disturbances due to the lack of public land. Thus, there are no major temporal changes in stressors causing either deer species to change their behavior. Because these species have similar behavior patterns, they could potentially be occupying the same niche without risk of competition due to the lack of limiting resources. Furthermore, there is similarity in the hourly diel movements between species and overlap in resource use especially at the larger scales (Chapters 3, 4; Kinlan 2021), which may develop into competition should resources become limiting. While there are abundant resources currently in western Kansas, if the white-tailed deer population increases to a high enough density to limit resources, it could eventually out compete the mule deer population.

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Table 2.1. Average (±SE) proportion of 3 behaviors (feeding, resting, run) among 7 defined seasons for female mule deer and white-tailed deer in 2 study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018 to 2021.

		Season									
Species	Behavior	Pregnancy	Fawn	Wean	Fall	Rut	Firearm	Winter	*F*	DF	*P*
MD	Feeding	0.41 ± 0.01^{ab}	0.43 ± 0.01^{a}	0.39 ± 0.01^{bc}	0.40 ± 0.01^{bc}	0.39 ± 0.01^{bc}	0.37 ± 0.01^{c}	0.40 ± 0.01^{c}	7.21	6, 2265	<0.001
MD	Resting	0.51 ± 0.01^{a}	0.47 ± 0.01^{b}	0.51 ± 0.01^{a}	0.51 ± 0.01^{a}	0.49 ± 0.01^{ab}	0.50 ± 0.01^{ab}	0.49 ± 0.01^{ab}	3.04	6, 2265	<0.001
MD	Run	0.08 ± 0.002^{d}	0.10 ± 0.003^{bc}	0.10 ± 0.004^{c}	0.09 ± 0.003^{c}	0.12 ± 0.004^{ab}	0.13 ± 0.01^{a}	0.10 ± 0.004^{bc}	18.83	6, 2265	<0.001
WTD	Feeding	0.40 ± 0.01^{ab}	0.40 ± 0.01^{ab}	0.41 ± 0.01^{a}	0.40 ± 0.01^{ab}	0.37 ± 0.01^{bc}	0.36 ± 0.01^{c}	0.39 ± 0.01^{abc}	4.91	6, 2069	<0.001
WTD	Resting	0.48 ± 0.01^{a}	0.43 ± 0.01^{b}	0.49 ± 0.01^{a}	0.46 ± 0.01^{a}	0.51 ± 0.01^{a}	0.50 ± 0.01^{a}	0.48 ± 0.01^{a}	5.36	6, 2069	<0.001
WTD	Run	0.12 ± 0.004^{bc}	0.17 ± 0.01^{a}	0.11 ± 0.01^{c}	0.13 ± 0.004^{bc}	0.12 ± 0.01^{bc}	0.14 ± 0.01^{b}	0.13 ± 0.01^{bc}	15.38	6, 2069	<0.001

[abcd] Means followed by the same superscript did not differ among the seasons

Table 2.2. Average (±SE) proportion of 3 behaviors in 7 seasons for adult female mule deer (MD) and white-tailed deer (WTD) in two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Season	Behavior	$\bar{x}$ MD	$\bar{x}$ WTD	*t*	DF	*P*
Pregnancy	Feeding	0.41 ± 0.01	0.40 ± 0.01	0.97	629.16	0.33
Pregnancy	Lay	0.51 ± 0.01	0.48 ± 0.01	2.55	611.49	0.01
Pregnancy	Run	0.08 ± 0.002	0.12 ± 0.004	-7.86	515.56	<0.001
Fawn	Feeding	0.43 ± 0.01	0.40 ± 0.01	3.79	647.73	<0.001
Fawn	Lay	0.47 ± 0.01	0.43 ± 0.01	3.27	618.27	<0.001
Fawn	Run	0.10 ± 0.003	0.17 ± 0.01	-10.73	540.34	< 0.001
Wean	Feeding	0.39 ± 0.01	0.41 ± 0.01	-1.96	609.57	0.05
Wean	Lay	0.51 ± 0.01	0.46 ± 0.01	3.80	591.19	<0.001
wean	Run	0.10 ± 0.004	0.13 ± 0.01	-5.08	566.64	<0.001
Fall	Feeding	0.40 ± 0.01	0.40 ± 0.01	-0.13	579.75	0.90
Fall	Lay	0.51 ± 0.01	0.49 ± 0.01	1.31	579.38	0.19
Fall	Run	0.09 ± 0.003	0.11 ± 0.004	-3.10	565.58	<0.001
Rut	Feeding	0.39 ± 0.01	0.37 ± 0.01	1.49	592.69	0.14
Rut	Lay	0.49 ± 0.01	0.51 ± 0.01	-0.96	596.34	0.34
Rut	Run	0.12 ± 0.004	0.12 ± 0.01	-0.21	593.29	0.83
Firearm	Feeding	0.37 ± 0.01	0.36 ± 0.01	0.99	578.34	0.32
Firearm	Lay	0.50 ± 0.01	0.50 ± 0.01	0.20	576.45	0.84
Firearm	Run	0.13 ± 0.01	0.14 ± 0.01	-1.99	549.98	0.05
Winter	Feeding	0.40 ± 0.01	0.39 ± 0.01	0.52	561.50	0.60
Winter	Lay	0.49 ± 0.01	0.48 ± 0.01	0.90	557.98	0.37
Winter	Run	0.10 ± 0.004	0.13 ± 0.01	-3.36	497.44	<0.001

Table 2.3. Average (±SE) proportion of 3 behaviors (feeding, resting, run) among 5 defined seasons for adult male mule deer (MD) and white-tailed deer (WTD) in two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018 to 2021

		Season							
Species	Behavior	Spring-Summer	Fall	Rut	Firearm	Winter	*F*	DF	*P*
MD	Feeding	0.45 ± 0.01[a]	0.37 ± 0.01[b]	0.45 ± 0.01[a]	0.47 ± 0.01[a]	0.46 ± 0.01[a]	14.61	4,131	<0.001
MD	Resting	0.52 ± 0.01[b]	0.58 ± 0.01[a]	0.40 ± 0.01[d]	0.47 ± 0.01[c]	0.47 ± 0.02[bc]	30.58	4,1131	<0.001
MD	Run	0.04± 0.002[c]	0.05± 0.003[bc]	0.14± 0.01[a]	0.07± 0.005[b]	0.07± 0.004[b]	101.8	4,1131	<0.001
WTD	Feeding	0.48 ± 0.01[a]	0.38 ± 0.01[c]	0.41 ± 0.01[bc]	0.43 ± 0.02[abc]	0.46 ± 0.02[ab]	8.659	4,715	<0.001
WTD	Resting	0.46 ± 0.01[bc]	0.55± 0.02[a]	0.41 ± 0.02[c]	0.51 ± 0.02[ab]	0.50 ± 0.02[ab]	9.479	4,715	<0.001
WTD	Run	0.06± 0.004[bc]	0.07± 0.01[b]	0.17± 0.01[a]	0.06± 0.01[bc]	0.04± 0.004[c]	71.51	4,715	<0.001

[abcd] Means followed by the same superscript did not differ among the seasons.

Table 2.4. Average (±SE) proportion of 3 behaviors in 5 seasons for adult male mule deer (MD) and white-tailed deer (WTD) in two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Season	Behavior	$\bar{x}$ MD	$\bar{x}$ WTD	*t*	DF	*P*
Spsumm*	Feeding	0.45 ± 0.01	0.48 ± 0.01	-2.60	362.97	0.01
Spsumm	Lay	0.52 ± 0.01	0.46 ± 0.01	4.10	349.67	<0.001
Spsumm	Run	0.04 ± 0.002	0.06 ± 0.004	-6.22	291.06	<0.001
Fall	Feeding	0.37 ± 0.01	0.38 ± 0.01	-0.37	310.34	0.71
Fall	Lay	0.58 ± 0.01	0.55 ± 0.02	1.50	297.39	0.14
Fall	Run	0.05 ± 0.003	0.07 ± 0.01	-3.58	233.61	<0.001
Rut	Feeding	0.45 ± 0.01	0.41 ± 0.01	2.69	302.82	0.01
Rut	Lay	0.40 ± 0.01	0.41 ± 0.02	-0.53	283.22	0.60
Rut	Run	0.14 ± 0.01	0.17 ± 0.01	-2.62	263.17	0.01
Firearm	Feeding	0.47 ± 0.01	0.43 ± 0.02	1.64	228.46	0.10
Firearm	Lay	0.47 ± 0.01	0.51 ± 0.02	-1.85	230.21	0.07
Firearm	Run	0.07 ± 0.01	0.06 ± 0.01	1.42	291.38	0.16
Winter	Feeding	0.46 ± 0.01	0.46 ± 0.02	0.30	217.22	0.77
Winter	Lay	0.47 ± 0.02	0.50 ± 0.02	-0.98	222.51	0.33
Winter	Run	0.07 ± 0.004	0.04 ± 0.004	3.52	253.70	<0.001

*Spring-Summer

Chapter 3 - Movement and home ranges of adult female mule deer and white-tailed deer in western Kansas

Introduction

Home ranges and movements are an important component of deer ecology. They can provide information about potential competition, within species interactions, and resource selection (Moorcraft and Barnett 2008, Brunjes et al. 2009a). Home ranges and movements are affected by many factors including weather (Webb et al. 2010), time of year, hunting seasons (Hygnstrom and VerCauteren 2000), predation risk (Gehr et al. 2020), physiological demands (Bertrand et al. 1996), landscape composition and configuration (Dechen Quinn et al. 2013), and biological processes such as rut and fawning (Labisky and Fritzen 1998, D'Angelo et al. 2004). Studying movements and home ranges will provide insight into species' activity patterns and their response to seasonal disturbance.

Describing home range area and composition and movement patterns is particularly informative when managing sympatric species using similar habitat types. Patterns in home range and core-use areas could be evidence of competition between populations of sympatric white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*). For example, if white-tailed deer had significantly larger home ranges than mule deer, it could be evidence for indirect competitive dominance. Differences in movements during a diel cycle could allow these species to temporally segregate to avoid or minimize potential competition. Differences in landcover composition of home ranges could indicate spatial segregation of the species. It is currently unknown if there is any competition between deer species in western Kansas, due to only recently having the potential for interspecific competition in this region of the Great Plains.

By the early 1900s, both species were nearly extirpated from Kansas and much of the Great Plains due to overharvest and habitat degradation. Many populations recovered to levels sufficient to support sport harvest by the mid-1900s (Anderson 1964, Ballard et al. 2001, VerCauteren 2003). White-tailed deer populations have been expanding westward in the Great Plains since the latter 1900s into what historically was principally mule deer range (VerCauteren 2003, Hanberry and Hanberry 2020). Significant population declines and reduction in occupied range have occurred for mule deer since the late 1900s (Ballard et al. 2001, MDWG 2020). Factors contributing to the population reduction in abundance and occupied area are unclear, but range contraction of mule deer appears to be concurrent with range expansion of white-tailed deer.

It is unknown if competition between mule deer and white-tailed deer is contributing to the mule deer decline because these sympatric populations usually spatially segregate along an elevation gradient. In Kansas, absent a significant elevation gradient, they are seemingly occupying the same niche. Additionally, in western Kansas, the two species have similar behavior patterns (Chapter 2) and overlapping resource selection (Chapter 4). However, two species can occupy the same niche if there is temporal or spatial segregation (Carothers and Jaksic 1984). Spatial and temporal differences in movements and home range could allow the two species to occupy similar niches.

Mule deer and white-tailed deer have similar resting and activity patterns across diel periods (Kufeld et al. 1988, Webb et al. 2010). Both species are crepuscular with their greatest movements during dawn and dusk. I expect that timing of movements in Kansas will be no different and predict that the hourly movements will be greater for both species during dawn and dusk time periods, compared to diurnal and nocturnal periods. However, there are many factors affecting deer movement, both intrinsic such as breeding state and extrinsic such as weather.

Weather can be a major factor influencing deer movements and home ranges. When it is cold, deer have greater energy requirements. Deer can alter their movements to conserve energy during winter, including reducing food intake (Mautz 1978). Deer are also known to utilize thermal cover for protection against the snow and cold; therefore, reducing their movements in response to the cold (Coe et al 2018). Deer are also known to utilize thermal cover for protection against periods of increased temperature (Sargeant et al. 1994, Bello et al. 2001). Deer will also expand and contract their home ranges in relation to resource availability (e.g., food, mates). Deer with smaller home ranges usually have higher quality resources available than deer with larger home ranges (Marchinton and Hirth 1984). I predict that during fawn and wean seasons (the warmest seasons), adult females will move most at night and least during the daytime due to deer avoiding movements during warmer daily periods. I predict that home range and core-use areas of deer will be smaller during the resource-rich summer season than during the resource-poor winter season.

Home range area of mule deer and white-tailed deer is highly variable across the Great Plains. Mule deer seasonal home range area varied from 2.10 km^2 to 29.23 km^2, while annual area ranged from 6.30 km^2 to 24.95 km^2 (Wood et al. 1989, Webb et al. 2013). White-tailed deer seasonal home range area varied from 2.08 km^2 to 10.20 km^2, with the annual area ranging from 2.75 km^2 to 33.48 km^2 (Wood et al. 1989, Brunjes et al. 2009, Grovenburg et al. 2009, Hygnstrom et al. 2011). Because home range area estimates are so variable and based on many factors (e.g., collar technology, home range estimator), it is likely that application of estimated home range area will be study-specific. Home ranges of both species in the Great Plains have a very wide range in the literature so there was no comfortable way to approximate home ranges in western Kansas without calculating them. Estimation of home range and core-use areas is necessary to inform deer management strategies in western Kansas.

Disturbances such as predators, hunters, or even other deer during rut may affect movements and home ranges. Deer species have different patterns for dealing with disturbances, based on their response to predators. White-tailed deer usually run to the nearest thick, usually woody cover, while mule deer will run to higher elevation and then turn and confront the predator (Lingle 2001, 2002). White-tailed deer may have larger movements due to their running from all disturbances and therefore, larger home ranges than mule deer. Prolonged disturbances, such as hunters afield during a short hunting season, will affect movements and home ranges more than singular disturbances.

In other areas in the Great Plains, adult female white-tailed deer are known to expand their home range during a low intensity hunt (i.e., muzzleloader; Hygnstrom et al. 2011). In a suburban area in Nebraska, female white-tailed deer had high fidelity to home ranges even during an archery and muzzleloader hunting season (Hygnstrom and VerCauteren 2000). In Oregon, Brown et al. (2020) found that female mule deer increased their movements, but not their home ranges during a male hunting season. However, no other information about the effect of hunting on female deer movements and home range is available for populations in the Great Plains. Although harvest of adult females is low for both species (Chapter 1), disturbance by hunters targeting adult males remains and may influence movements and home range area of adult females. I predict that adult females of both species will increase their movements and home range area during the 12-day firearm period, with white-tailed deer having greater movements than mule deer.

Rut is known to be the most energetically stressful time of year for males, increasing movements and decreasing their mass by 30% (DeYoung and Miller 2011). In low density populations, females increased their movement and home range during rut (Labisky and Fritzen 1998). In South Carolina, in a population with a near equal sex ratio, females still expanded their home range during rut (D'Angelo et al. 2004). However, there is no published information on female movement patterns during rut for deer populations in the Great Plains. Female responses to rut in the Great Plains are unknown, but it is assumed that movements and home range area will increase due to harassment by males. I predict that females of both species will increase their hourly and daily movements and home range area during rut, with white-tailed deer exhibiting greater movements and home range area.

Because home range area and composition are specific to individuals in a defined site, knowledge of home range area and composition will inform management strategies targeting availability of resources (e.g., cover types). Differences in movements between species could indicate that the species are temporally segregated, potentially reducing competition for resources. Similar movement patterns and overlapping home ranges could indicate the potential for competition between the species. Additional evidence for potential competition occurs when landcover composition of home range and core-use area are similar between species. My objectives were to 1) evaluate differences in movements between adult female mule deer and white-tailed deer at seasonal and fine temporal scales in western Kansas, and 2) test for differences in area and composition of adult female mule deer and white-tailed deer home ranges at seasonal and fine temporal scales in western Kansas.

Study Area

My study occurred at 2 contrasting field sites in western Kansas that supported sympatric populations of mule deer and white-tailed deer in landscapes containing habitat features representative of both species (Figure 1.2). These sites were roughly 150 km apart and chosen because of reported declines in mule deer abundance, but with sufficient mule deer densities necessary to obtain appropriate sample sizes (in 2018, 5.43 mule deer/km^2; Levi Jaster KDWP personal communication).

The North field site (~85,000 ha) was in Decatur, Norton, Sheridan, and Graham counties; it consisted of relatively small tracts of landowner properties surrounding a large wooded riparian area. The South field site (~137,000 ha) was in Logan, Scott, Gove, and Lane counties, consisting of relatively larger tracts of landowner properties interspersed with steep ravines and chalk cliffs. Average yearly temperatures from 2006-2020 was 12.43° C in the North site and 11.97° C in the South site (NOAA 2021). Average annual precipitation from 2006-2020 was 57.84 cm in the North site and 51.19 cm in the South site from 2000-2020 (NOAA 2021). The average temperatures (°C) from 2018 to 2020 were 12.10 in the North site and 11.73 in the South site and similar to the long-term averages. Annual precipitation during 2018 (North 92.1 cm, South 66.7 cm) and 2019 (North 74.4 cm, South 52.7cm) was wetter than the long-term average years, but 2020 represented drought conditions (North 36.94 cm, South 36.09 cm).

Common landcover types were cropland, pasture, woodland/riparian, and U.S. Department of Agriculture Conservation Reserve Program (CRP) lands. Agriculture was the dominant land use feature in both study sites, which included livestock grazing of native rangeland and row-crops. Corn (*Zea mays*), wheat (*Triticum aestivum*), and milo (*Sorghum bicolor*) were the most common crops; alfalfa (*Medicago sativa*), soybeans (*Glycine max*), and sunflowers (*Helianthus annuus*) were less common. Grasslands consisted of native short and mixed-grass prairie primarily grazed by cattle. Common grasses included little bluestem (*Schizachyrium scoparium*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*B. gracilis*). Common forbs were broom snakeweed (*Gutierrezia sarothrae*), common mullin (*Verbascum thapsus*), and tall thistle (*Cirsium altissimum*); common succulents were yucca (*Yucca glauca*) and prickly pear cactus (*Opuntia macrorhiza*).

The CRP lands in both study sites were ungrazed and planted with mostly tallgrass prairie grass species including big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). Woodlands were associated with riparian areas along the Solomon River at the North site, and Smoky Hill River and tributaries in the South site. Shelterbelts and dispersed tree clusters (i.e., former homesteads) were scattered throughout both study sites. Common tree species included American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), black cherry (*Prunus serotina*), eastern cottonwood (*Populus deltoides*), honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*), mulberry (*Morus rubra*), and eastern red cedar (*Juniperus virginiana*). Plum thickets (*Prunus angustifolia*) and smooth sumac (*Rhus glabra*) were shrubs commonly found in ravines and valleys in western Kansas.

Study areas were defined annually based on a minimum convex polygon (MCP) estimated from all female locations for both species combined (Mohr 1947). Study areas for 2018, 2019, and 2020, respectively, were 450.84 km^2, 857.40 km^2, and 685.48 km^2 for the North site and 1,387.54 km^2, 664.96 km^2, and 1,041.60 km^2 for the South site. I buffered the landscape MCP by 200 m, which was similar to the average hourly movement of the deer. I created a landcover map for each year for the landscape MCP by digitally delineating polygons of different landcover patches using ArcGIS (10.6) from a satellite image (ESRI World Imagery) for the entire landscape scale boundary. Only patches 30 m^2 or larger were delineated. The landcover type was ground-truthed for each polygon each year. Delineated landcover types across sites were: native pasture, ravine, crop type, CRP, human structure, woodland, and riparian (Figures 1.3-1.5).

Methods

Capture

At each study site, at least 15 white-tailed deer and 15 mule deer were captured and collared in February 2018 and 2019 and March 2020 for a total of ≥60 collared adult females annually. A commercial helicopter crew (Quicksilver Air Inc, Fairbanks, AK, USA) captured and sedated the deer using 15 mg Butorphanol [50 mg/ml], 15 mg Azaperone [50 mg/ml], and 15 mg Midazolam [50 mg/ml] (Wolfe and Miller 2016). Captured deer were transported to a central processing location where pregnancy was confirmed by a licensed veterinarian using an ultrasound (IBEX PRO/r, E.I. Medical Imaging, Loveland, CO, USA). Pregnant females received high-resolution GPS/VHF VERTEX PLUS-2 collars (Vectronic Aerospace GmbH, Berlin, Germany). Collars recorded hourly GPS locations during the entire deployment period and were programed to drop off at 60 weeks from date of capture. Collar fit was specific to species with white-tailed deer and mule deer collars at 38 cm and 43 cm circumference, respectively. Collars had a mortality sensor programmed to send an alert after six hours of motionlessness. All animal handling procedures are approved by the Institutional Animal Care and Use Committee at Kansas State University (protocol 3963), and authorized under the state of Kansas scientific, education, or exhibition wildlife permits (SC-024-2018, SC-015-2019, SC-032-2020).

Life Stages/Seasons and Diel Periods

I categorized annual temporal periods based on life stages and hunting seasons. The pregnant season started March 1 following capture and continued until the mean fawn birth date each year. The fawn season was from the mean birth date until the mean wean date, which was defined as 70 days from birth. Weaned lasted from the mean weaned or death date until archery season. Fall/archery season was from the start of archery (9/17/18, 9/16/19, 9/13/20) to the start of rut. Rut was from the beginning of rut (10/31 all years) until the end of rut (11/24/18, 11/21/19, 11/23/20, Kinlan 2021). Firearm season was a 12-day period primarily in early December (11/28/18 -12/9/18, 12/4/19-12/15/19, 12/2/20-12/13/20). Winter season was from the end of firearm season to February 28. There was an antlerless white-tailed hunting season during the winter season; however, due to low harvest and hunter participation it was not delineated out of the winter season.

Diel periods were classified using civil twilight time into four time periods; dawn, day, dusk, and night. The dawn time period commenced 15 minutes before civil twilight and ended 2 hours later. The daytime period ran from the end of the dawn period until the start of the dusk period, and dusk period started 2 hours before and ended 15 minutes after civil twilight. The night period began at the end of the dusk time period and ended at the beginning of the dawn time period. Civil twilight times were averaged and adjusted biweekly, and times were estimated to the nearest quarter hour (USNO 2018).

Movements

I derived minimum hourly movements as the Euclidean distance between successive locations for each individual deer. I calculated minimum daily movements as the sum of distance between successive hourly locations for 24 hours. I grouped species and site (i.e., four total groups) and used an analysis of variance (ANOVA) to test for differences in average minimum hourly and daily movements among groups by season. I compared average hourly movements among daily time periods by season using ANOVA. I compared average hourly movement among landcover types using ANOVA to test for effects of landcover on movement rate. I set $\alpha = 0.05$.

Home Range

I estimated home ranges and core-use areas using Biased Random Bridge movement models by season and annually using the adehabitatHR package in Program R (Calenge 2006). I estimated the home range area of adult female deer using the 95% isopleth and core-use area using the 50% isopleth (Brunjes et al. 2009). I used an ANOVA to test for differences in average home range and core-use areas among species and site groups by season.

It was important to test for space overlap between species to assess the degree of shared area for cumulative home range of all marked individuals for each species. MCPs were used to obtain a continuous home range for analysis. I estimated overlap of core areas of total MCP per species and site using 50% isopleth MCPs for each species and site group for each year. I then used the intersect tool in ArcGIS 10.2.2 to derive the area of the overlap between species in each site for each year and calculated the percent overlap per the total home range of the species and site.

I estimated annual differences in proportion of landcover composition between home ranges and core-use areas. Landcover types consisted of Crop, CRP, Pasture, Riparian, Urban, and Woodland in the North study site, and Crop, CRP, Pasture, Ravine, Riparian, Urban, and Woodland in the South study site. I estimated the proportion of each landcover type in each seasonal home range and core-use area using ArcGIS 10.8.1.

Results

Movements

Average hourly movement varied among species/site groups by season; differences among season and species/site groups ranged from 120 m to 283 m (Table 3.1). Annual average minimum hourly movement distances varied seasonally from 120.46 ± 1.08 [SE] m to 233.40 ± 3.65 m for mule deer in the North site, 142.54 ± 0.96 m to 249.97 ± 3.97 m for mule deer in the South site, 134.91 ± 1.18 m to 217.62 ± 3.65 m for white-tailed deer in the North site, and 163.92±1.48 m to 283.3 0± 4.61 m for white-tailed deer in the South site. South white-tailed deer had the greatest hourly movements in each season. South mule deer had greater movements than North mule deer in each season except for pregnancy (Table 3.1).

Across all species, sites, and seasons, hourly distance moved during the diurnal period was lower than during dawn, dusk, and nocturnal periods (Figure 3.1). Nocturnal movements were slightly larger than diurnal movements and similar to dawn and dusk for the warm seasons of fawn, wean, and fall. Movements during dawn and dusk were similar and greater than movements during rut, firearm, winter, and pregnancy seasons (Figure 3.1). Rank order of average movements for daily periods were similar among species and site groups among seasons. Hourly movements during firearm season were the greatest among seasons for each group (Table 3.1). Movements were greater in the rut, firearm, and winter seasons than in the warmer seasons (Table 3.1). Hourly movements were lowest during fawn and wean seasons (Table 3.1). Hourly movements followed a crepuscular pattern as expected with little variation across seasons.

Average hourly distance was similar between fawn and weaning seasons for North mule deer. North white-tailed deer had similar average hourly distance between pregnancy and fall and between rut and winter (Table 3.1). There were no similar average hourly movement distances among seasons for deer species in the South study site (Table 3.1). However, the largest difference of hourly movements among the species-site groups in a single season was 75.95 m.

Total average daily movement distance also varied among species and site groups; 2877.51 ± 35.47 m to 5586.34 ± 122.85 m for mule deer in the North site, 3342.78 ± 36.03 m to 5978.42 ± 123.78 m for mule deer in the South site, 3220.60 ± 39.18 m to 5203.37 ± 126.73 m for white-tailed deer in the North site, and 3915.51 ± 45.14 m to 6793.79 ± 152.38 m for white-tailed deer in the South site. By season, daily average movement distances varied between 2877 to 6793 m (Table 3.2). South white-tailed deer had the largest daily movement in all seasons, nearly 1 km longer than other species and site groups. South mule deer had larger movements than North mule deer in every season except pregnancy and firearm seasons. Daily movement distance was greatest during the firearm season for all species/site groups. Rut had similar daily average movement distance as the winter season. The difference in the season between the species/site groups ranged from the smallest in the rut season 617.60 m to the greatest difference 1836.56 m in the winter seasons. Daily movements were likely biologically different between the species/site groups.

The number of points in the landcover types ranged from 30 to 67,086 for all years combined (Table 3.3). The most used landcover types over the seasons, based on telemetry points, for mule deer were native pasture (28%), crop (32%), CRP (17%), and ravine (23%) during the three years. Mule deer rarely used riparian (1%), urban (0.2%), and woodland (1%) cover types. White-tailed deer used crop (0.26%) and CRP (0.26%) most often. White-tailed deer also used native pasture (0.15%), ravine (0.14%), and riparian (0.16%) cover types at similar levels. Woodland (3%) use was low, but was greater than urban (1%) use. Similar trends are evident by site and year (Tables 3.4-3.9). Mule deer used pasture, crop, CRP, and ravine, when available, and rarely used riparian, urban, and woodland. White-tailed deer used riparian and woodland in both sites over the years but used these cover types more in the North site. Use of CRP landcover was always used but level of use was dependent on site as mule deer used it more in the North and white-tailed deer used it more in the South.

Average minimum hourly movements within frequently used landcover types were approximately 200 m, which was close to the average for overall minimum hourly movements (Figures 3.2-3.7). Landcover types tended to be used more frequently in relation to their availability were crop, CRP, and ravine for mule deer, and crop, CRP, ravine, and riparian and woodland for the white-tailed deer (Figures 3.8-3.10). Those landcover types tended to have movements ≤200 m; indicating that deer were residing and spending time in those landcover types where they felt safe. The other landcover types such as urban, and riparian and woodland for mule deer had larger associated movements, indicating deer were just moving through those landcover types and not residing there. Landcover type composition and use of landcover for white-tailed deer varied based on site. North white-tailed deer tended to use woodland and riparian areas often, but did not in the South, most likely because the North had considerably more large riparian and woodland areas compared to the relative smaller and isolated patches in the South.

Home Range

A total of 1097 (558 mule deer. 539 white-tailed deer) seasonal and 174 annual home ranges were estimated for 174 deer (90 mule deer, 84 white-tailed deer), over the three-year period. I estimated the home range (95% isopleths) and core-use (50% isopleths) areas of the home range in each season and each year (Figures 3.11-3.12). Average home range areas ranged between 1.70 to 11.32 km^2 among seasons. Average seasonal core-use areas ranged from 0.27 to

1.99 km^2. Annual home ranges ranged from 5.36 to 14.53 km^2 and annual core-use areas ranged from 0.66 to 2.36 km^2 (Table 3.10). Seasonal home ranges were consistently lowest during fawn and wean seasons (Table 3.11). Average home range values during rut season were larger than the fall in every species-site group. Core-use areas were largest during the firearm season (Table 3.12). Winter core-use area were also larger than the rut core-use area. Core-use areas during the cooler seasons of rut, firearm, winter, and pregnancy were larger than during the warmer seasons of fawn, wean, and fall seasons.

Average home range area differed among seasons (Table 3.11). There were no differences in home range area between North mule deer and North white-tailed deer for any season except pregnancy when North mule deer home range was larger (8.14 ± 0.48 km^2- 4.36 ± 0.48 km^2). Similarly, there were no differences in home range area between South mule deer and South white-tailed deer except for winter when South white-tailed deer home range area was larger (11.32 ± 0.94 km^2 - 6.68 ± 0.41 km^2). Average home range area did not differ between North and South mule deer during pregnancy (South mule deer-North mule deer, 6.90 ± 0.46 km^2 - 8.14 ± 0.48 km^2), firearm (7.36 ± 0.46 km^2 - 5.73 ± 0.45 km^2), and winter seasons (6.68 ± 0.41 km^2 - 5.65 ± 0.38 km^2). Home range area did differ between species during fawning (4.26 ± 0.53 km^2 - 2.40 ± 0.21 km^2), wean (3.59 ± 0.32 km^2 - 1.70 ± 0.13 km^2), fall (5.41 ± 0.41 km^2 - 3.24 ± 0.21 km^2), and rut (6.38 ± 0.55 km^2 - 3.91 ± 0.25 km^2) with South mule deer home range always larger than North mule deer. Average home range area between North and South white-tailed deer did not differ during wean (3.01 ± 0.29 km^2 - 2.03 ± 0.49 km^2) season. However, the average home range size did differ in the seasons of pregnancy (7.75 ± 0.53 km^2 - 4.36 ± 0.48 km^2), fawn (4.24 ± 0.36 km^2 - 1.92 ± 0.24 km^2), fall (5.03 ± 0.47 km^2 - 2.91 ± 0.35 km^2), rut (7.24 ± 0.71 km^2 - 3.61 ± 0.39 km^2), firearm (8.88 ± 0.66 km^2 - 5.20 ± 0.61 km^2), and winter

(11.32 ± 0.94 km^2 - 5.43 ± 0.52 km^2) with South white-tailed deer always having a larger home range than North white-tailed deer.

Comparisons of core-use areas resulted in similar patterns of differences between sites than between species. There were no differences in core-use area between North mule deer and North white-tailed deer in each season except for pregnancy (North mule deer, North white-tailed deer, 1.56 ± 0.08 km^2 - 0.65 ± 0.09 km^2; Table 3.12). There were no differences in core-use area between South mule deer and South white-tailed deer except for winter (South mule deer -South white-tailed deer, 1.30 ± 0.08 km^2 - 1.99 ± 0.14 km^2; Table 3.12). Again, similar to the home range results, North and South mule deer had similar core-use areas during pregnancy (North mule deer-South mule deer,1.56 ± 0.08 km^2 - 1.37 ± 0.10 km^2), firearm (1.10 ± 0.10 km^2 - 1.35 ± 0.07 km^2), and winter seasons (1.12 ± 0.07 km^2 - 1.30 ± 0.08 km^2). Mule deer had different core-use areas between North and South sites in the seasons of fawn (0.37 ± 0.03 km^2 - 0.69 ± 0.08 km^2), wean (0.27 ± 0.02 km^2 - 0.59 ± 0.06 km^2), fall (0.58 ± 0.04 km^2 - 0.88 ± 0.07 km^2), and rut (0.74 ± 0.05 km^2 - 1.16 ± 0.12 km^2), with South mule deer core-use area always larger than North mule deer. Core-use area differed between sites for all seasons (pregnancy 0.65 ± 0.09 km^2 - 1.32 ± 0.11 km^2; fawn 0.36 ± 0.06 km^2 - 0.76 ± 0.08 km^2; wean 0.30 ± 0.04 km^2 - 0.53 ± 0.05 km^2; fall 0.44 ± 0.04 km^2 - 0.86 ± 0.07 km^2; rut 0.59 ± 0.06 km^2 - 1.25 ± 0.12 km^2; firearm 0.89 ± 0.10 km^2 - 1.61 ± 0.12 km^2; winter 0.83 ± 0.08 km^2 - 1.99 ± 0.14 km^2) for white-tailed deer, with South white-tailed deer core-use area always being larger than North white-tailed deer.

I estimated annual 50% isopleth MCPs for all marked individuals combined for each species and site group to assess potential overlap in space use between species. In each year and site combination, the 50% MCP for white-tailed deer was larger than mule deer (Table 3.13).

The percent overlap in space use in the South study site was similar between 2019 and 2020. However, overlap was larger for both species in the South study site in 2018. Overlap in space use between species varied greatly in the North study site. In 2018, it was similar between species with mule deer being 30.96% km^2 and white-tailed deer being 28.89% km^2. In 2019, there was no overlap between the species, but in 2020 there 73.17% overlap of the mule deer MCP by the white-tailed deer MCP.

Proportion of landcover (mean, range) in home ranges differed between species (Figures 3.13-3.14). White-tailed deer had a greater proportion of riparian (16%, 9-33%) and woodland (2%, 1-3%) in their home ranges and core areas than mule deer (riparian 1%, 0-2%, and woodland 1%, 0-2%). The most common landcover types (mean, range) within the North study sites for both deer species in their home range and core use areas were crop (36%, 18-48%;), CRP (20%, 8-28%), and native pasture (34%, 9-65%). The most common landcover types in home range and core use areas for the South study site were crop (37%, 14-75%), CRP (16%, 6-38%), pasture (14% 4-31%), and ravine (32% 10-72%). Mule deer home ranges contained greater proportion of ravine (38%, 14-72%) than white-tailed deer (26%, 10-37%). North mule deer and south white-tailed deer had proportionally more CRP in their core areas than home ranges. Urban use was negligible for both species in all seasons (0-1%).

Discussion

Area and composition of home ranges along with movements are important aspects of deer ecology. Because of the potential effects that each species could have on the other, simultaneously quantifying home ranges and movements for both species provides insights into species interaction, resource selection, and potential competition. My results indicate that mule deer and white-tailed deer had similar movement patterns and home range areas within study sites across seasons, but there was some variation in movements and home range areas among seasons for each species within study sites and, in particular, between study sites.

Minimum hourly movements were statistically different among species/site groups in each season. However, some of the differences were small and likely not biologically relevant for these populations. Daily movements among the remainder of species/site groups were similar; differences were likely not biologically relevant. The one species/site group that stood out was South white-tailed deer. Statistically, South white-tailed deer had the greatest hourly movement and highest daily movement distances. It could be because the woody areas or "safe" areas were so patchy in the south that white-tailed deer had to keep moving to find a place of refuge.

There were differences in hourly and daily movements among seasons. Both daily and hourly movements were greatest during the firearm season. Hourly movement varied from 29.37 m to 44.11 m to the next greatest season across the species-site groups. Daily movement varied from 763.03 to 1121.22 to the next greatest season across the species-site groups. Root et al. (1988) found that female daily movement increased during a firearm season compared to pre and post-firearm seasons. Even though female harvest is low, the presence of hunters on the landscape still may evoke a response by females to disturbance, as evident from their increased movement.

Both deer species had nearly identical diel movement patterns, following a crepuscular pattern with greatest movements during dusk and dawn. Distance moved during the dawn and dusk periods was greater during rut, firearm, and winter seasons than the warm seasons. During rut, it is likely the deer were moving more during crepuscular periods to avoid predators or find a mate. During firearm season, deer were likely moving more during the crepuscular period to avoid the hunters. Movements during winter were likely a carryover effect from the hunting season, deer kept moving primarily during the crepuscular period to avoid disturbance. The crepuscular pattern was expected and followed that reported in the literature (Kufeld et al. 1988, Webb et al. 2010). The crepuscular pattern is likely an evolutionary response to mitigate predator risk during the day (Bartel and Orrock 2021).

Movements in commonly used landcover types were similar to the overall average hourly movement. For example, crop and native pasture had relatively low movements and were the primary used landcover types. Movement distances were greater in landcover types of relatively low use. Deer likely reside longer in landcover types that are used most often. Whereas deer are likely just passing through relatively lightly used landcover types (i.e. mule deer passing through riparian patches) Level of movements correlates to relative use of landcover types.

Home range and core-use areas varied seasonally for both species. Seasonal home ranges and core areas were smallest during fawn and wean season, likely due to giving birth and tending fawns. Deer also tend to have smaller home ranges with access to high quality resources (Marchinton and Hirth 1984). As predicted, home ranges were smaller during the resource rich summer when compared to the cooler seasons. When home range areas were calculated seasonally, mule deer and white-tailed deer had larger home ranges in winter than in summer in other studies (Table 3.14). When food and cover resources are abundant during summer, deer should have smaller home ranges than during cool seasons such as rut, firearm, and winter. Home ranges and core-use areas of both deer species in the rut season were larger than the fall season, but smaller than firearm and winter.

Rut surprisingly did not affect movements or home ranges for either species. This is the first reported study of female response to rut in the Great Plains. Outside of the Great Plains, in other studies, there was a response to rut by females. In a low-density population in Florida, female white-tailed deer increased both their daily movements and home range area during rut (Labisky and Fritzen 1998). Hölzenbein and Schwede (1989) reported that female white-tailed deer decreased their daily distance from pre-rut to post rut in Virginia, whereas home ranges were largest during rut. In Kansas, movements of both species during rut were similar to the winter season, but home ranges were smaller during rut. This indicates a lack of response by females to rut as movements and home ranges did not increase similar to other studies, indicates that rut had very little effect on the movements and home ranges. Likely the low density of both males and females of both species affected the movements and home range of the females during rut.

It is important to understand the overlap in area between the populations of the mule deer and white-tailed deer. Core-use area overlap of the species could indicate a potential for competition between the species. White-tailed deer had on average a 14.01±3.49 km^2 larger 50% isopleth MCP than mule deer. Overlap of the 50% isopleth MCPs between species was more consistent in the South site than the North site. The mule deer MCP was always overlapped more by the white-tailed deer MCP than the white-tailed deer was overlapped by the mule deer. That could be an indication of white-tailed encroaching onto mule deer space. Overlap between species should continue to be monitored to measure the potential for white-tailed deer encroaching further into mule deer space.

There was a difference in the proportion of landcover types within home ranges and core-use areas between species. The most common landcover types were crop, CRP, ravine, and native pasture in both home range and core-use areas. Despite lack of evidence for selection of native pasture (Chapter 4), this landcover type is an important part of both home ranges and core-use areas in all seasons. Pasture was a part of all species/site groups home range and core area in all seasons ranging up to 70% of the composition in a season. Mule deer home ranges were comprised of more ravine than white-tailed deer, which follows mule deer predilection for selecting steeper slopes (Chapter 4; Wood et al. 1989, Avery et al. 2003, Leonhart 2003, Brunjes et al. 2006). White-tailed deer home ranges and core areas contained more woodland and riparian areas, which again follows along with their resource selection and previous studies (Chapter 4; Wood et al. 1989, Avery et al. 2003, Leonhart 2003, Brunjes et al. 2006). Tracts of CRP were a very important part of the composition for both species considering the relatively low occurrence on the landscape in the two study sites (Figures 1.2-1.4). There were differences in the composition between the home ranges and core-use areas of the species that indicates mule deer and white-tailed deer were selecting specifically for different core areas than the home ranges.

In summary, mule deer and white-tailed deer movements were similar among seasons for species-site groups except for South white-tailed deer. Diel movement patterns were similar for both species throughout the year. These findings indicate that mule deer and white-tailed deer do not temporally segregate. However, it appears they somewhat spatially segregate due to their difference in home range and core-use area composition, which may limit potential competition between the species. Mule deer used more ravines, while white-tailed deer used riparian and woody areas. It is unknown if the deer species are avoiding each other, or their home range composition reflects differences in habitat use between these species. Despite similar movement patterns, it is unlikely that competition is occurring because of the lack of evidence for limiting resources in western Kansas during the study.

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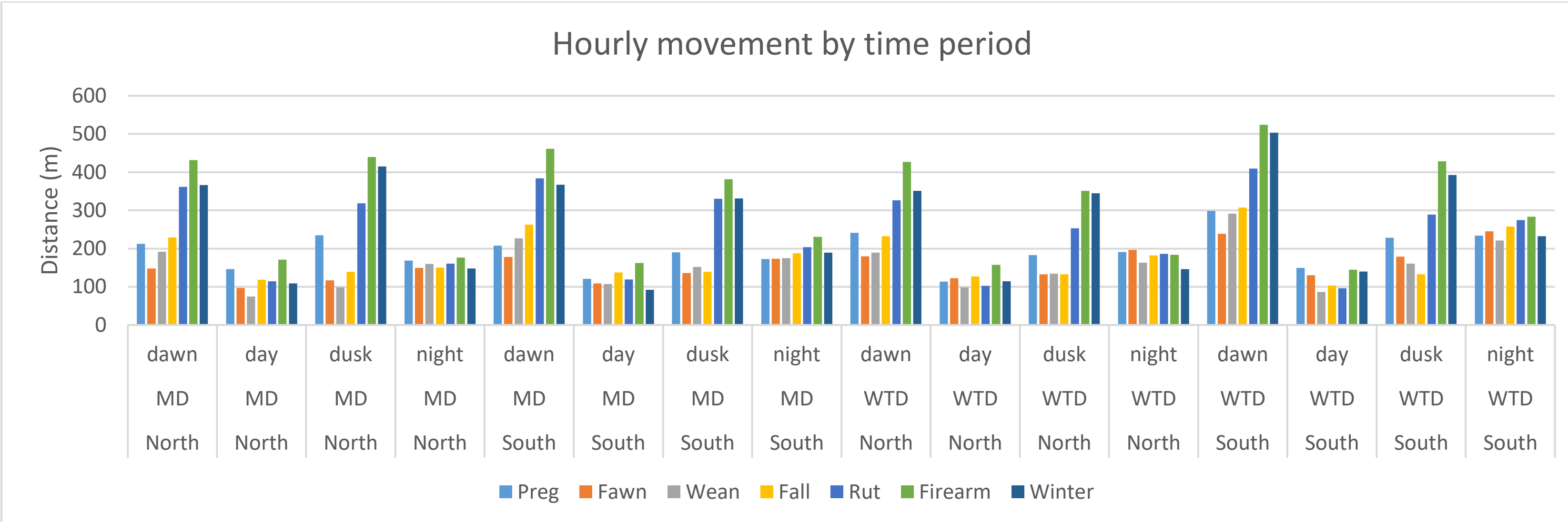

Figure 3.1. Average hourly movement (m) of mule deer (MD) and white-tailed deer (WTD) in four time periods (dawn, day dusk, night) among by seven seasons in two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

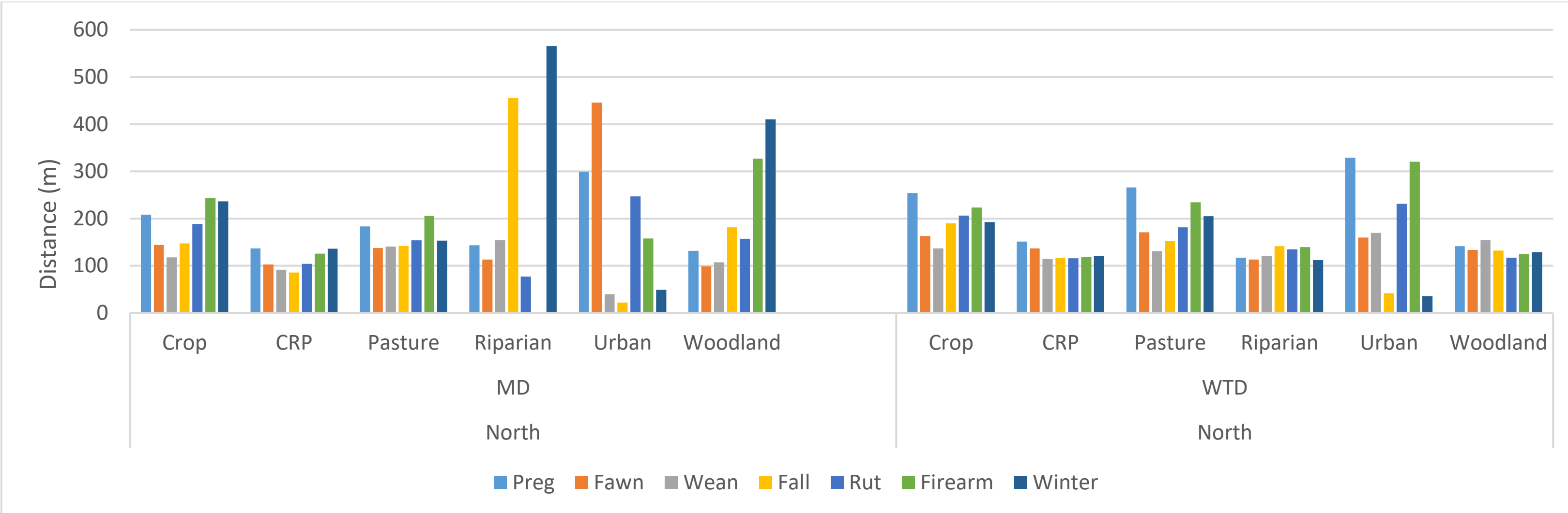

Figure 3.2. Average hourly movement of mule deer (MD) and white-tailed deer (WTD) in landcover types in the seasons throughout 2018 in the North site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA.

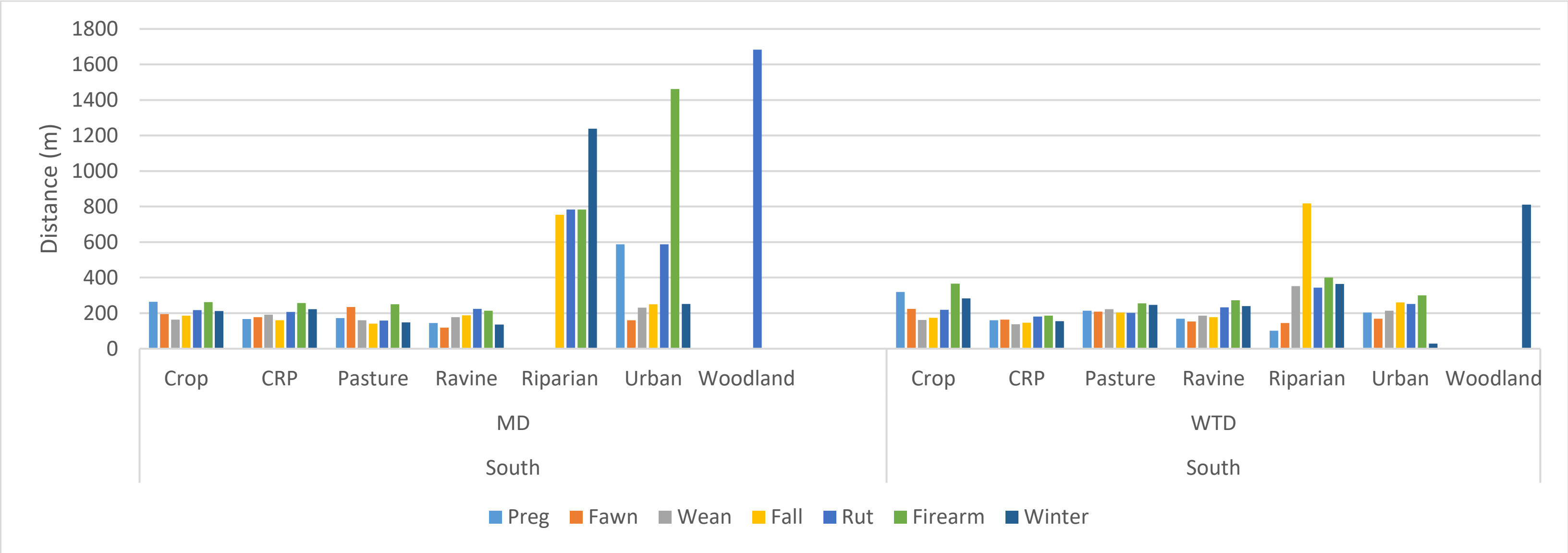

Figure 3.3. Average hourly movement of mule deer (MD) and white-tailed deer (WTD) in landcover types in the seasons throughout 2018 in the South site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

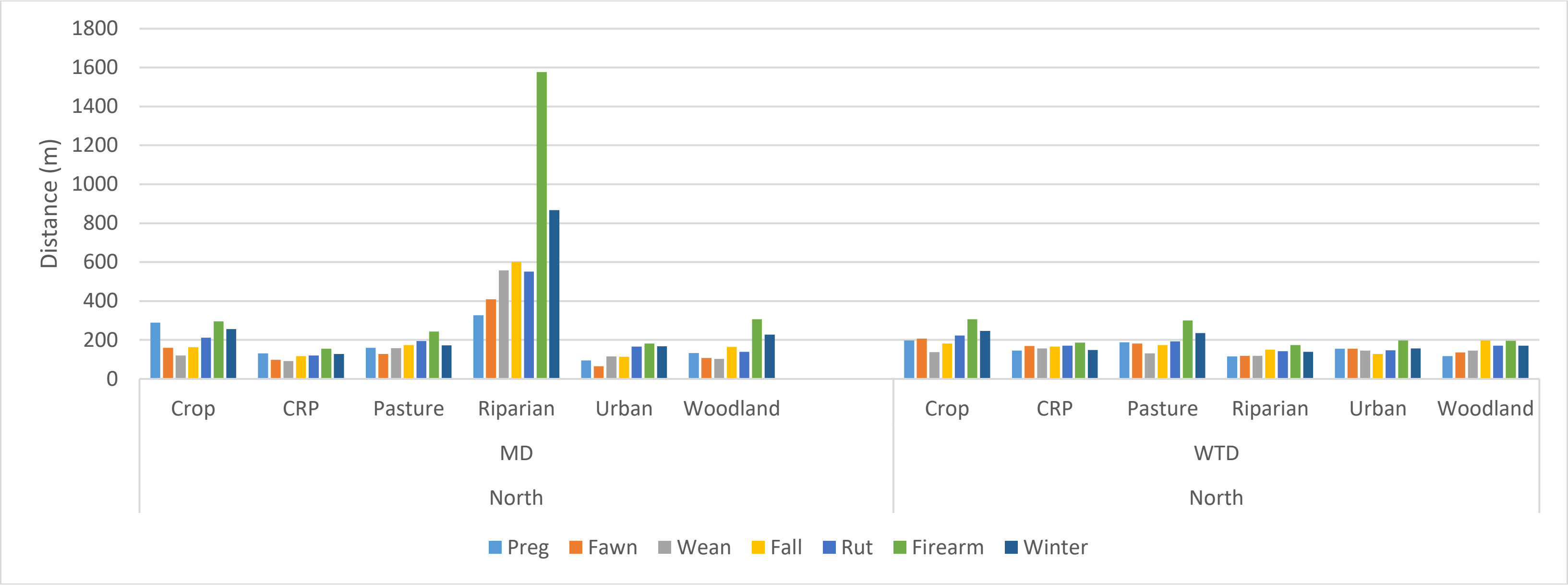

Figure 3.4. Average hourly movement of mule deer (MD) and white-tailed deer (WTD) in landcover types in the seasons in the North site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA.

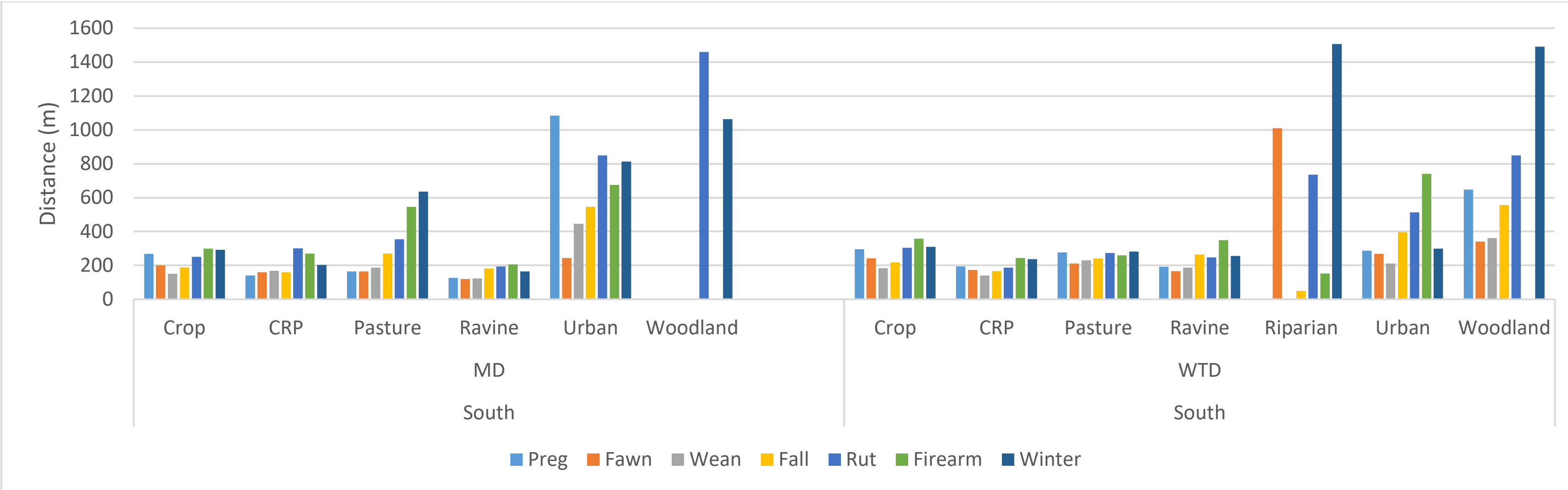

Figure 3.5. Average hourly movement of mule deer (MD) and white-tailed deer (WTD) in landcover types in the seasons throughout 2019 in the South site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

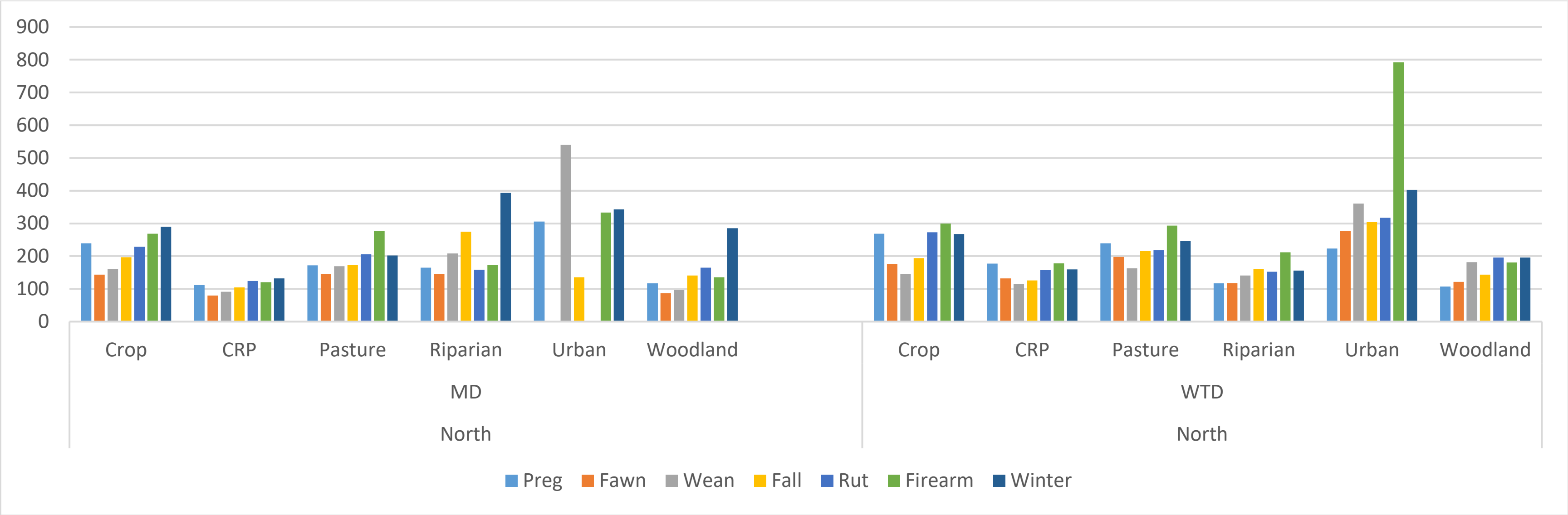

Figure 3.6. Average hourly movement of mule deer (MD) and white-tailed deer (WTD) in landcover types in the seasons throughout 2020 in the North site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA.

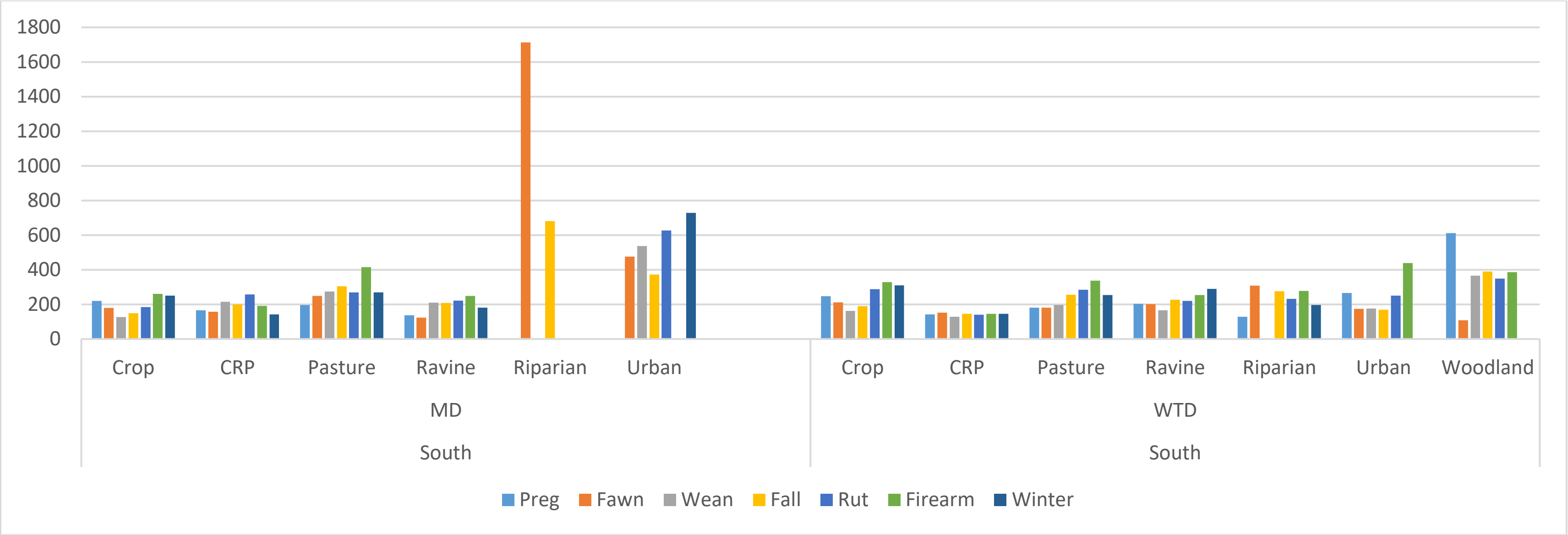

Figure 3.7. Average hourly movement of mule deer (MD) and white-tailed deer (WTD) in landcover types in the seasons throughout 2020 in the South site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

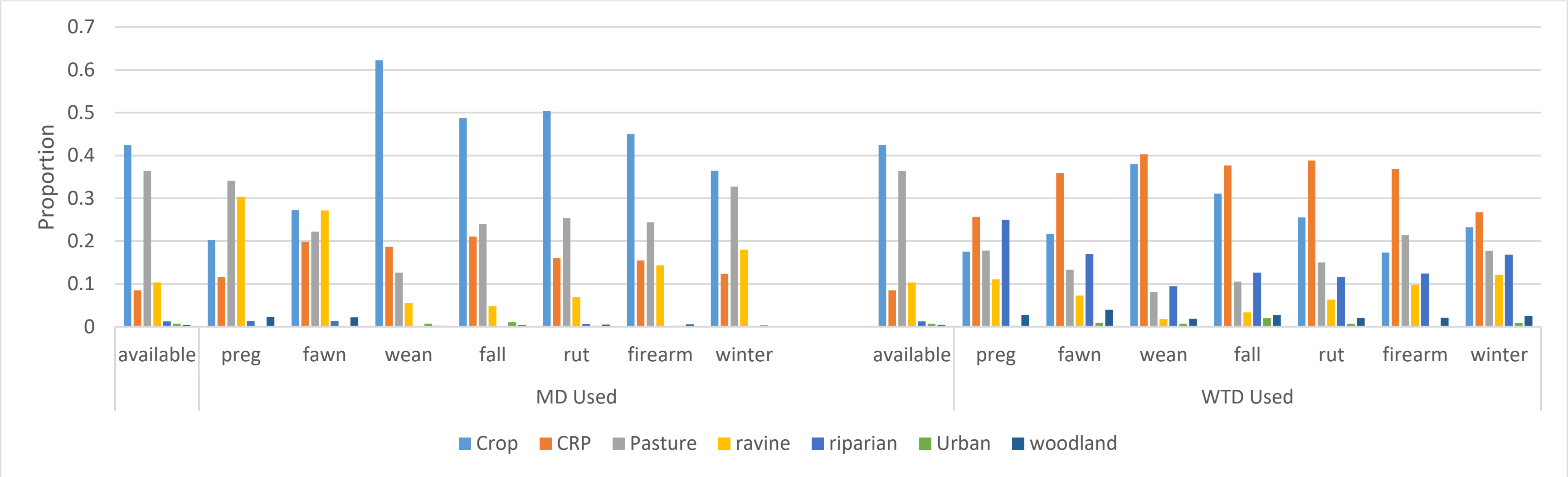

Figure 3.8. Proportion of available landcover types and used locations of mule deer (MD) and white-tailed deer (WTD) in landcover types split up by season in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018.

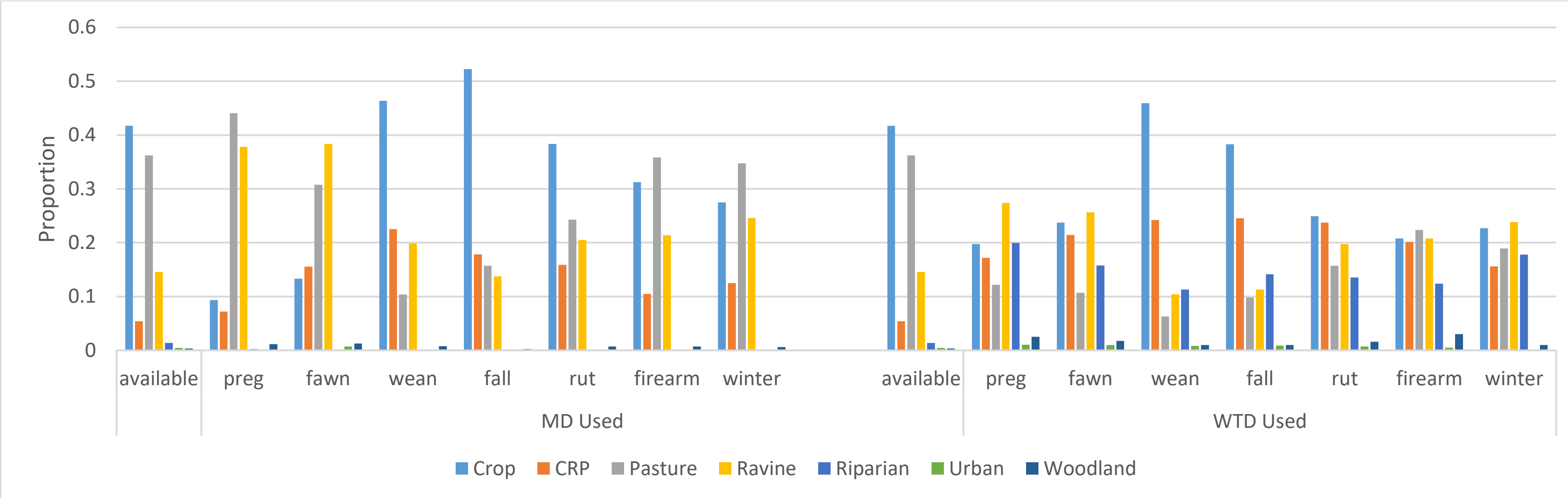

Figure 3.9. Proportion of available landcover types of used locations of mule deer (MD) and white-tailed deer (WTD) in landcover types split up by season in in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2019.

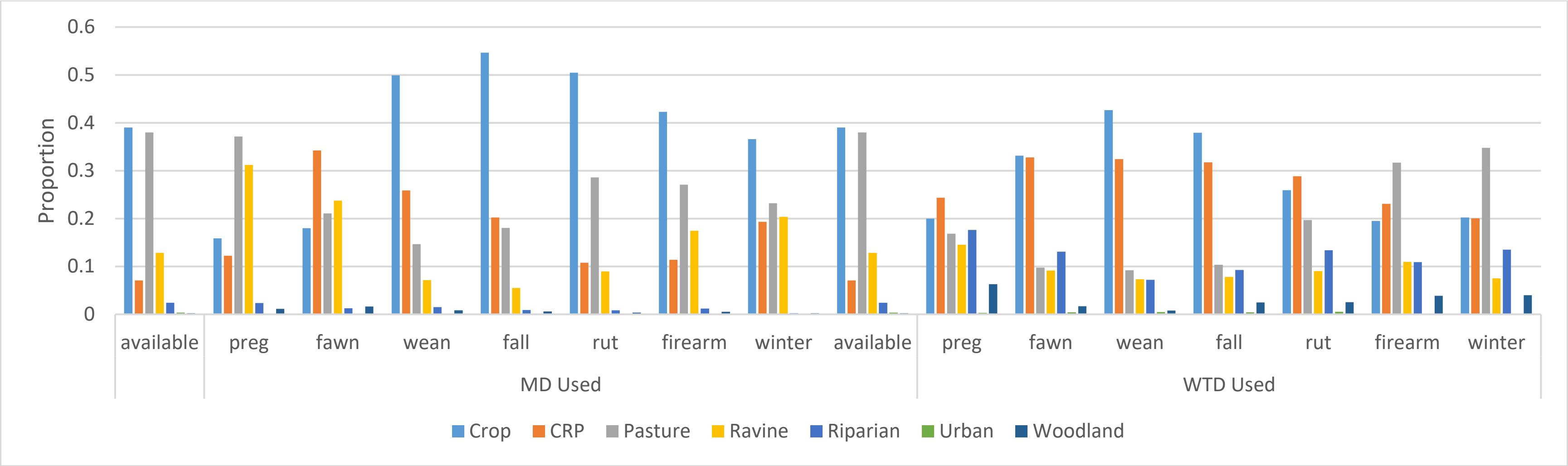

Figure 3.10. Proportion of available landcover types and used locations of mule deer (MD) and white-tailed deer (WTD) in landcover types split up by season in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2020.

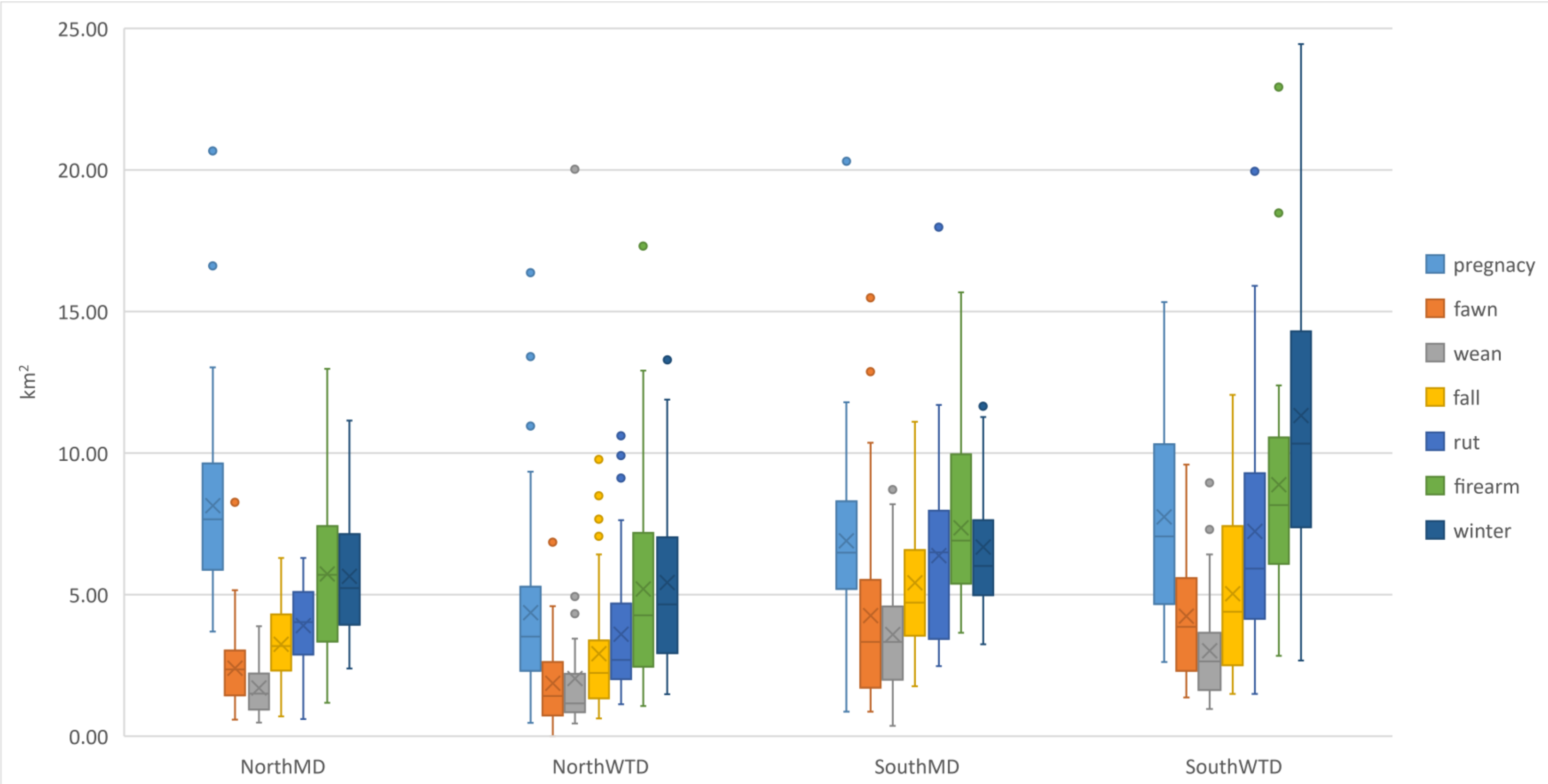

Figure 3.11. Estimated 95% Biased Random Bridge isopleths of mule deer (MD) and white-tailed deer (WTD) extents of home ranges split by season in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018-2021. The box plots are quartiles with the mean being a X inside the boxplots, the median being the line across the box, the whiskers are the minimum and maximum values inside the range and the dots are outliers from the boxplots.

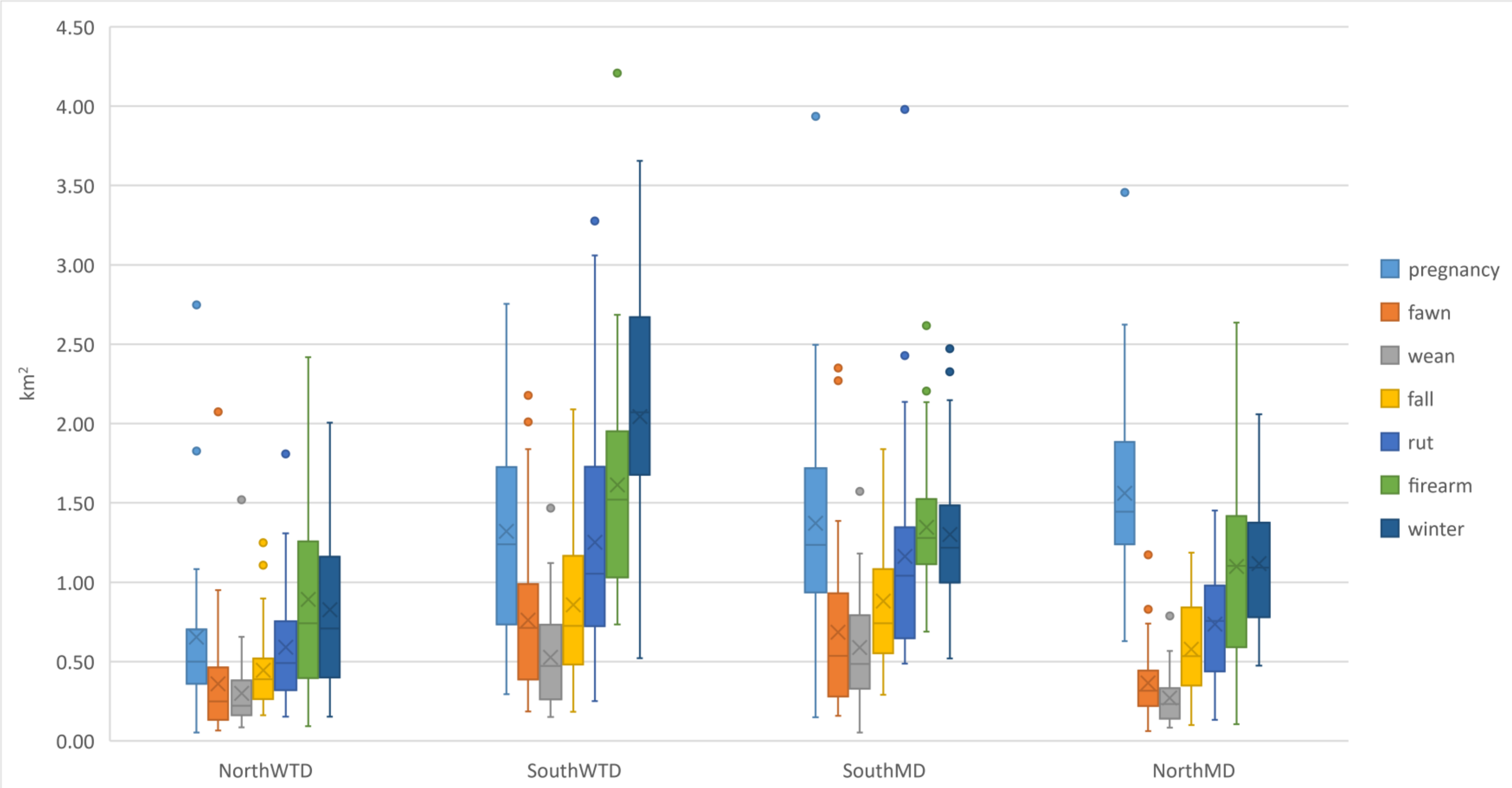

Figure 3.12. Estimated 50% Biased Random Bridge isopleths of mule deer (MD) and white-tailed deer (WTD) core areas split by season in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018-2021. The box plots are quartiles with the mean being a X inside the boxplots, the median being the line across the box, the whiskers are the minimum and maximum values inside the range and the dots are outliers from the boxplots.

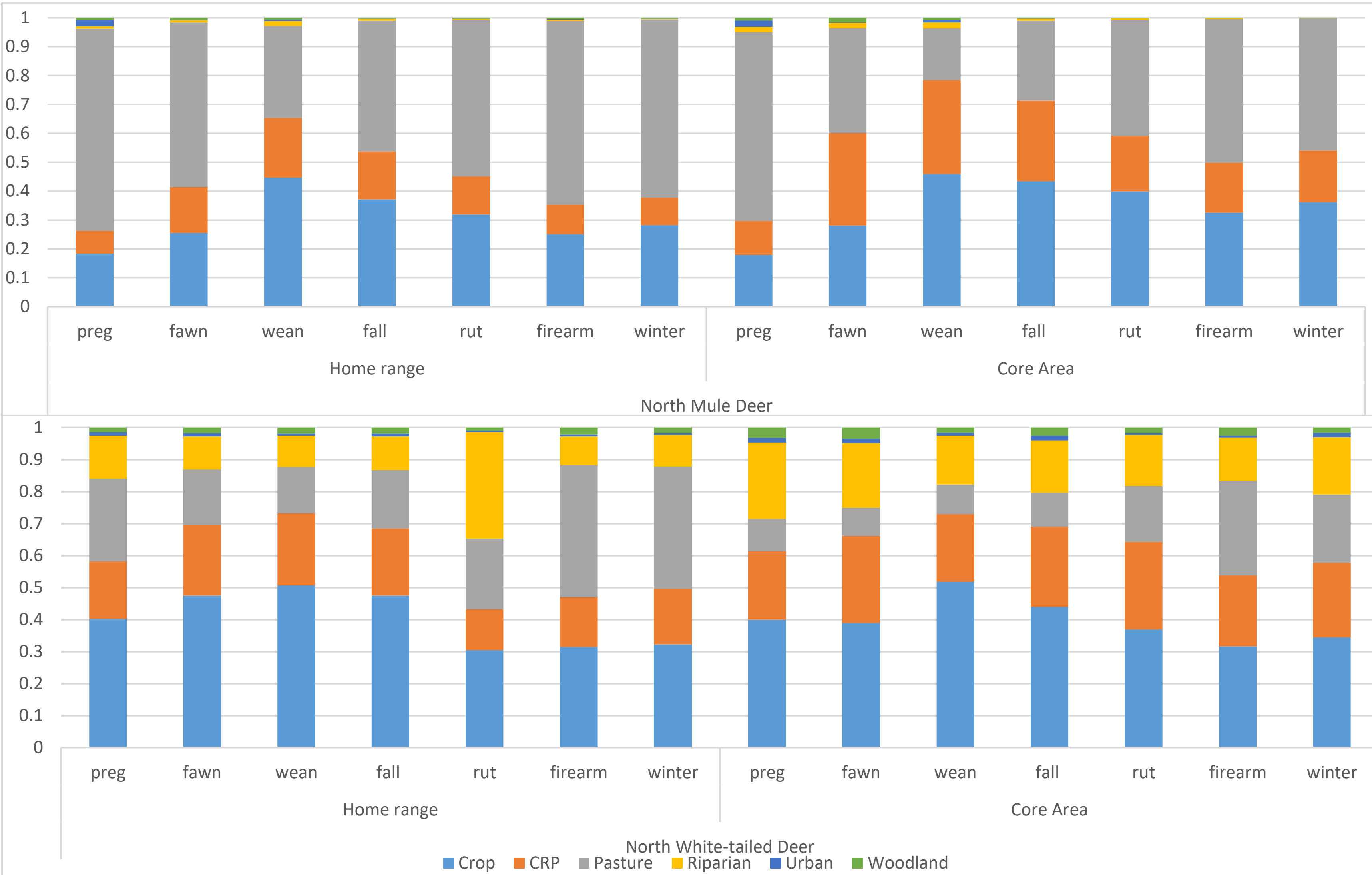

Figure 3.13. Proportion of landcover types in the home ranges (95% isopleth) and core-use (50% isopleth) areas of mule deer and white-tailed deer in the North field site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA, during 2018-2021.

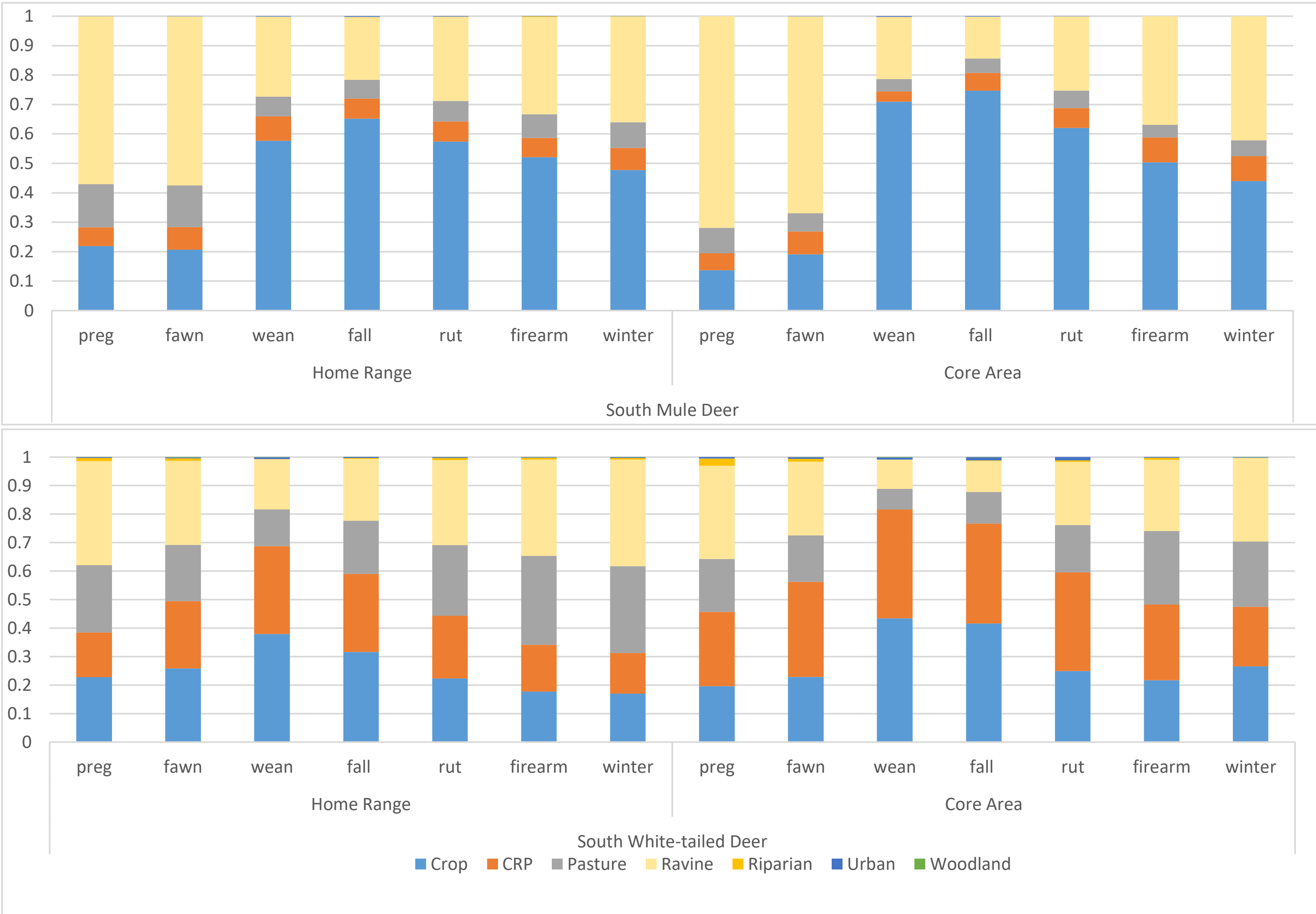

Figure 3.14. Proportion of landcover types in the home ranges (95% isopleth) and core-use (50% isopleth) areas of mule deer and white-tailed deer in the South field site (Logan, Scott, Gove and Lane counties) in western Kansas, USA, during 2018-2021.

Table 3.1. Average hourly movement (m) and standard error of adult female mule deer (MD) and white-tailed deer (WTD) by defined season in two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Season	North MD	South MD	North WTD	South WTD	*F*	DF	*P*
Pregnant	171.80±0.89^{Db}	157.53±0.87^{Ed}	164.51±1.00^{Cc}	202.52±1.18^{Da}	388.5	3, 337663	<0.001
Fawn	120.55±0.73^{Fd}	142.54±0.96^{Gc}	152.30±0.92^{Db}	182.87±1.11^{Fa}	786.9	3, 271791	<0.001
Wean	120.46±1.08^{Fd}	151.88±1.41^{Fb}	134.91±1.18^{Ec}	163.92±1.48^{Ga}	224.7	3, 147145	<0.001
Fall	147.22±1.12^{Ed}	172.92±1.51^{Db}	162.08±1.35^{Cc}	195.58±1.65^{Ea}	213.4	3, 171215	<0.001
Rut	180.55±1.95^{Cc}	207.82±2.44^{Bb}	178.72±2.01^{Bc}	233.46±2.77^{Ca}	126.6	3, 85573	<0.001
Firearm	233.40±3.65^{Ad}	249.97±3.97^{Ab}	217.62±3.65^{Ac}	283.30±4.61^{Aa}	49.92	3, 41476	<0.001
Winter	189.29±1.18^{Bd}	196.67±1.29^{Cb}	177.98±1.20^{Bc}	253.93±1.80^{Ba}	579.2	3, 250938	<0.001
F	788.9	429.5	189.1	426.4			
DF	6, 354306	6, 313509	6, 330887	6, 307099			
P	<0.001	<0.001	<0.001	<0.001			

^{ABCDEFG}Means followed by the same superscript uppercase letter did not differ among seasons within site/species group.
^{abcd}Means followed by the same superscript lowercase letter did not differ among site/species groups within season.

Table 3.2. The average daily movement (m) and standard error of mule deer (MD) and white-tailed deer (WTD), by defined season in two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Season	North MD	South MD	North WTD	South WTD	*F*	DF	*P*
Pregnant	4091.42±27.40^{Cb}	3749.03±27.29^{Ed}	3921.95±33.48^{Cc}	4834.75±38.02^{Da}	219.5	3, 14165	<0.001
Fawn	2877.67±26.51^{Ed}	3342.78±36.03^{Fc}	3628.67±37.27^{Db}	4364.30±36.40^{Ea}	339.8	3, 11436	<0.001
Wean	2877.51±35.47^{Ed}	3615.72±46.09^{Eb}	3220.60±39.18^{Ec}	3915.51±45.14^{Fa}	122.4	3, 6162	<0.001
Fall	3519.62±36.75^{Dc}	4133.28±48.07^{Db}	3876.55±52.55^{Cb}	4673.95±55.90^{Da}	69.37	3, 4908	<0.001
Rut	4328.66±60.01^{Bc}	4985.74±85.54^{Bb}	4284.53±65.54^{Bc}	5603.34±96.70^{Ca}	64.98	3, 3564	<0.001
Firearm	5586.34±122.85^{Abc}	5978.42±123.78^{Ab}	5203.37±126.73^{Ac}	6793.79±152.38^{Aa}	26.51	3, 1729	<0.001
Winter	4465.12±35.54^{Bc}	4626.82±36.48^{Cb}	4194.20±38.77^{Bd}	6030.76±56.18^{Ba}	361.6	3, 10628	<0.001
F	429.6	240.6	84.47	228.7			
DF	6, 14869	6, 13220	6, 13892	6, 12861			
P	<0.001	<0.001	<0.001	<0.001			

^{ABCDEF}Means followed by the same superscript uppercase letter did not differ among seasons within site/species group.
^{abcd}Means followed by the same superscript lowercase letter did not differ among site/species groups within season.

Table 3.3. The number (within season and by landcover type) and proportion of points (within season) for all years (2018-2020) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season in the North site (Decatur, Norton, Sheridan, and Graham counties) and in the south site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

	Landcover							Total points
	Crop	CRP	Pasture	Ravine	Riparian	Urban	Woodland	
MD								
Pregnancy	26465 (0.15)	17880 (0.10)	67086 (0.38)	57893 (0.33)	2156 (0.01)	193 (0.001)	2720 (0.02)	174393
Fawn	27045 (0.19)	32049 (0.23)	34308 (0.25)	41344 (0.30)	1183 (0.01)	425 (0.003)	2342 (0.02)	138696
Wean	40408 (0.53)	16805 (0.22)	9462 (0.12)	8270 (0.11)	371 (0.005)	221 (0.003)	452 (0.01)	75989
Fall	45817 (0.52)	17398 (0.20)	16941 (0.19)	7012 (0.08)	344 (0.004)	340 (0.004)	352 (0.004)	88204
Rut	18877 (0.46)	5443 (0.13)	10683 (0.26)	5234 (0.13)	151 (0.004)	60 (0.001)	191 (0.005)	40639
Firearm	10221 (0.41)	3469 (0.14)	7063 (0.28)	3724 (0.15)	187 (0.01)	30 (0.001)	160 (0.01)	24854
Winter	44080 (0.34)	19253 (0.15)	39765 (0.30)	27478 (0.21)	132 (0.001)	169 (0.001)	403 (0.003)	131280
Total points	211890	111676	183829	150955	4524	1427	3870	668171
WTD								
Pregnancy	31612 (0.19)	36775 (0.22)	25673 (0.15)	30164 (0.18)	35124 (0.21)	909 (0.01)	5975 (0.04)	166232
Fawn	34395 (0.26)	39457 (0.30)	14986 (0.11)	19076 (0.14)	20361 (0.15)	1024 (0.01)	3260 (0.02)	132559
Wean	30040 (0.42)	22928 (0.32)	5514 (0.08)	4626 (0.06)	6760 (0.09)	489 (0.01)	879 (0.01)	71236
Fall	29859 (0.36)	25955 (0.31)	8519 (0.1)	6332 (0.08)	10060 (0.12)	912 (0.01)	1694 (0.02)	83331
Rut	10305 (0.25)	12439 (0.31)	6724 (0.17)	4776 (0.12)	5175 (0.13)	269 (0.01)	818 (0.02)	40506
Firearm	3846 (0.19)	5312 (0.27)	4908 (0.25)	2876 (0.14)	2392 (0.12)	54 (0.003)	587 (0.03)	19975
Winter	25923 (0.22)	23879 (0.21)	25847 (0.22)	18422 (0.16)	19115 (0.16)	425 (0.004)	2592 (0.02)	116203
Total points	165980	166745	92171	86272	98987	4082	15805	630042

Table 3.4. The number (within season and by landcover type) and proportion of points (within season) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season for the 2018 season in the North site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA.

	Landcover						
	Crop	CRP	Pasture	Riparian	Urban	Woodland	Total points
North MD							
Pregnancy	7008 (0.22)	4597 (0.15)	17692 (0.56)	821 (0.03)	69 (0.002)	1422 (0.04)	31609
Fawn	6418 (0.27)	6977 (0.30)	8413 (0.36)	592 (0.03)	10 (0.000)	1002 (0.04)	23412
Wean	6981 (0.53)	3974 (0.30)	1996 (0.15)	22 (0.002)	108 (0.01)	59 (0.004)	13140
Fall	5389 (0.39)	3851 (0.28)	4295 (0.31)	32 (0.002)	213 (0.02)	105 (0.01)	13885
Rut	2886 (0.42)	1465 (0.21)	2431 (0.35)	91 (0.01)	9 (0.001)	71 (0.01)	6953
Firearm	1023 (0.32)	621 (0.20)	1479 (0.47)	0 (0)	11 (0.003)	39 (0.01)	3173
Winter	5863 (0.28)	3626 (0.17)	11384 (0.54)	8 (0.000)	135 (0.01)	52 (0.002)	21068
Total points	34545	24490	46211	1566	544	2711	107356
North WTD							
Pregnancy	6648 (0.21)	6837 (0.21)	4052 (0.13)	12852 (0.40)	46 (0.01)	1610 (0.05)	32045
Fawn	7304 (0.29)	6762 (0.27)	2174 (0.09)	6893 (0.28)	154 (0.01)	1745 (0.07)	25032
Wean	6422 (0.44)	4152 (0.28)	1241 (0.08)	2365 (0.16)	72 (0.001)	465 (0.03)	14717
Fall	5322 (0.34)	4759 (0.30)	1224 (0.08)	3411 (0.22)	321 (0.02)	734 (0.05)	15771
Rut	2631 (0.32)	2693 (0.33)	947 (0.11)	1688 (0.20)	11 (0.001)	301 (0.04)	8271
Firearm	773 (0.21)	1400 (0.37)	608 (0.16)	812 (0.22)	3 (0.001)	143 (0.04)	3739
Winter	5903 (0.26)	6161 (0.27)	2560 (0.11)	6763 (0.3)	323 (0.01)	1031 (0.05)	22741
Total points	35003	32764	12806	34784	930	6029	122316

Table 3.5. The number (within season and by landcover type) and proportion of points (within season) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season for the 2018 season in the south site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

	Landcover							
	Crop	CRP	Pasture	Ravine	Riparian	Urban	Woodland	Total points
South MD								
Pregnancy	5798 (18.36)	2764 (8.75)	3850 (12.19)	19167 (60.69)	0 (0)	5 (0.02)	0 (0)	31584
Fawn	6192 (27.07)	2192 (9.58)	1867 (8.16)	12563 (54.92)	4 (0.02)	57 (0.25)	0 (0)	22875
Wean	10174 (70.56)	1172 (8.13)	1486 (10.31)	1514 (10.50)	0 (0)	73 (0.51)	0 (0)	14419
Fall	8535 (58.08)	2164 (14.73)	2551 (17.36)	1360 (9.26)	5 (0.03)	79 (0.54)	0 (0)	14694
Rut	4778 (57.77)	979 (11.84)	1438 (17.39)	1048 (12.67)	2 (0.02)	25 (0.30)	1 (0.01)	8271
Firearm	2145 (55.60)	466 (12.08)	236 (6.12)	1007 (26.10)	0 (0)	4 (0.10)	0 (0)	3858
Winter	10771 (43.90)	2020 (8.23)	3528 (14.38)	8199 (33.42)	4 (0.02)	11 (0.04)	0 (0)	24533
Total points	48393	11757	14956	44858	15	254	1	120234
South WTD								
Pregnancy	3721 (13.69)	8366 (30.77)	6502 (23.91)	6573 (24.18)	1942 (7.14)	85 (0.31)	0 (0)	27189
Fawn	2322 (12.00)	9163 (47.37)	3744 (19.35)	3222 (16.66)	654 (3.38)	239 (1.24)	0 (0)	19344
Wean	3121 (29.87)	5978 (57.21)	786 (7.52)	440 (4.21)	16 (0.15)	108 (1.03)	0 (0)	10449
Fall	3115 (27.43)	5463 (48.11)	1634 (14.39)	910 (8.01)	10 (0.09)	224 (1.97)	0 (0)	11356
Rut	1152 (17.62)	3054 (46.70)	1274 (19.48)	937 (14.33)	28 (0.43)	94 (1.44)	0 (0)	6539
Firearm	398 (13.17)	1093 (36.16)	838 (27.72)	662 (21.90)	27 (0.89)	5 (0.17)	0 (0)	3023
Winter	3562 (19.82)	4731 (26.32)	4652 (25.88)	4911 (27.32)	83 (0.46)	33 (0.18)	3 (0.02)	17975
Total points	17391	37848	19430	17655	2760	788	3	95875

Table 3.6. The number (within season and by landcover type) and proportion of points (within season) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season for the 2019 season in the North site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA.

	Landcover						
	Crop	CRP	Pasture	Riparian	Urban	Woodland	Total points
North MD							
Pregnancy	3121 (9.78)	3231 (10.13)	24562 (77.01)	147 (0.46)	112 (0.35)	723 (2.27)	31896
Fawn	4755 (18.96)	6614 (26.37)	12779 (50.94)	1 (0.00)	348 (1.39)	588 (2.34)	25085
Wean	6362 (44.1)	5356 (37.12)	2477 (17.17)	7 (0.05)	28 (0.19)	197 (1.37)	14427
Fall	7034 (43.39)	4688 (28.92)	4386 (27.05)	18 (0.11)	18 (0.11)	68 (0.42)	16212
Rut	2686 (33.95)	1802 (22.78)	3290 (41.58)	18 (0.23)	17 (0.21)	99 (1.25)	7912
Firearm	1009 (25.02)	555 (13.76)	2402 (59.56)	10 (0.25)	7 (0.17)	50 (1.24)	4033
Winter	6194 (24.23)	4227 (16.54)	14862 (58.14)	13 (0.05)	10 (0.04)	256 (1.00)	25562
Total points	31161	26473	64758	214	540	1981	125127
North WTD							0
Pregnancy	7574 (24.72)	4983 (16.26)	3495 (11.41)	12393 (40.44)	635 (2.07)	1564 (5.1)	30644
Fawn	7087 (31.72)	4312 (19.30)	2375 (10.63)	7327 (32.79)	457 (2.05)	785 (3.51)	22343
Wean	5758 (49.9)	1452 (12.58)	995 (8.62)	2939 (25.47)	173 (1.50)	222 (1.92)	11539
Fall	4712 (36.65)	2115 (16.45)	1377 (10.71)	4149 (32.27)	226 (1.76)	278 (2.16)	12857
Rut	1580 (24.92)	1222 (19.27)	1312 (20.69)	1908 (30.09)	99 (1.56)	220 (3.47)	6341
Firearm	665 (19.26)	538 (15.59)	1014 (29.37)	960 (27.81)	40 (1.16)	235 (6.81)	3452
Winter	4434 (20.30)	3758 (17.20)	4554 (20.85)	8566 (39.21)	63 (0.29)	469 (2.15)	21844
Total points	31810	18380	15122	38242	1693	3773	109020

Table 3.7. The number (within season and by landcover type) and proportion of points (within season) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season for the 2019 season in the south site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

	Landcover							
	Crop	CRP	Pasture	Ravine	Riparian	Urban	Woodland	Total points
South MD								
Pregnancy	2606 (8.89)	1168 (3.99)	2405 (8.21)	23128 (78.91)	0 (0)	1 (0.003)	0 (0)	29308
Fawn	1486 (6.83)	675 (3.10)	1641 (7.54)	17954 (82.52)	0 (0)	1 (0.005)	0 (0)	21757
Wean	5627 (49.14)	473 (4.13)	204 (1.78)	5144 (44.92)	0 (0)	4 (0.03)	0 (0)	11452
Fall	7912 (63.78)	417 (3.36)	119 (0.96)	3938 (31.75)	0 (0)	19 (0.15)	0 (0)	12405
Rut	2545 (44.38)	364 (6.35)	26 (0.45)	2796 (48.76)	0 (0)	2 (0.03)	1 (0.02)	5734
Firearm	1109 (40.40)	156 (5.68)	27 (0.98)	1448 (52.75)	0 (0)	5 (0.18)	0 (0)	2745
Winter	5627 (32.26)	1138 (6.53)	86 (0.49)	10583 (60.68)	0 (0)	3 (0.02)	3 (0.02)	17440
Total points	26912	4391	4508	64991	0	35	4	100841
South WTD								
Pregnancy	4795 (14.97)	5782 (18.06)	4151 (12.96)	17145 (53.54)	134 (0.42)	12 (0.04)	4 (0.01)	32023
Fawn	4138 (16.56)	5828 (23.33)	2698 (10.80)	12122 (48.52)	148 (0.59)	10 (0.04)	41 (0.16)	24985
Wean	6186 (42.76)	4847 (33.51)	645 (4.46)	2711 (18.74)	0 (0)	38 (0.26)	39 (0.27)	14466
Fall	6528 (39.59)	5093 (30.89)	1506 (9.13)	3318 (20.12)	0 (0)	31 (0.19)	11 (0.07)	16487
Rut	1939 (24.91)	2130 (27.37)	911 (11.7)	2792 (35.87)	3 (0.04)	6 (0.08)	2 (0.03)	7783
Firearm	953 (21.99)	1028 (23.72)	729 (16.82)	1620 (37.38)	3 (0.07)	1 (0.02)	0 (0)	4334
Winter	6495 (24.72)	3750 (14.27)	4565 (17.37)	11461 (43.62)	2 (0.01)	2 (0.01)	2 (0.01)	26277
Total points	31034	28458	15205	51169	290	100	99	126355

Table 3.8. The number (within season and by landcover type) and proportion of points (within season) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season for the 2020 season in the North site (Decatur, Norton, Sheridan, and Graham counties) in western Kansas, USA.

	Landcover						
	Crop	CRP	Pasture	Riparian	Urban	Woodland	Total points
North MD							
Pregnancy	2814 (10.52)	5297 (19.81)	16858 (63.05)	1187 (4.44)	6 (0.02)	575 (2.15)	26737
Fawn	3078 (11.93)	12845 (49.80)	8534 (33.09)	584 (2.26)	0 (0)	752 (2.92)	25793
Wean	3591 (28.63)	5334 (42.53)	3078 (24.54)	342 (2.73)	1 (0.01)	196 (1.56)	12542
Fall	5376 (31.20)	5989 (34.76)	5401 (31.35)	284 (1.65)	1 (0.01)	179 (1.04)	17230
Rut	2609 (30.19)	1592 (18.42)	4258 (49.28)	131 (1.52)	0 (0)	51 (0.59)	8641
Firearm	1118 (29.15)	692 (18.04)	1895 (49.41)	86 (2.24)	5 (0.13)	39 (1.02)	3835
Winter	5908 (27.68)	5725 (26.82)	9504 (44.53)	107 (0.50)	9 (0.04)	92 (0.43)	21345
Total points	24494	37474	49528	2721	22	1884	116123
North WTD							
Pregnancy	3439 (15.82)	4915 (22.61)	3080 (14.17)	7454 (34.29)	61 (0.28)	2789 (12.83)	21738
Fawn	6105 (30.59)	6795 (34.05)	1157 (5.80)	5205 (26.08)	19 (0.10)	674 (3.38)	19955
Wean	4141 (41.36)	3471 (34.66)	818 (8.17)	1435 (14.33)	6 (0.06)	142 (1.42)	10013
Fall	4701 (34.12)	4734 (34.36)	1291 (9.37)	2378 (17.26)	17 (0.12)	655 (4.75)	13776
Rut	1761 (25.60)	2127 (30.92)	1357 (19.73)	1315 (19.12)	23 (0.33)	295 (4.29)	6878
Firearm	638 (20.29)	751 (23.88)	1078 (34.28)	470 (14.94)	2 (0.06)	206 (6.55)	3145
Winter	4207 (21.47)	4119 (21.02)	6602 (33.69)	3601 (18.38)	4 (0.02)	1064 (5.43)	19597
Total points	24992	26912	15383	21858	132	5825	95102

Table 3.9. The number (within season and by landcover type) and proportion of points (within season) for mule deer (MD) and white-tailed deer (WTD) in each landcover type by season for the 2020 season in the south site (Logan, Scott, Gove and Lane counties) in western Kansas, USA.

	Landcover							
	Crop	CRP	Pasture	Ravine	Riparian	Urban	Woodland	Total points
South MD								
Pregnancy	5118 (22.00)	823 (3.54)	1719 (7.39)	15598 (67.06)	1 (0.004)	0 (0)	0 (0)	23259
Fawn	5116 (25.87)	2746 (13.89)	1074 (5.43)	10827 (54.75)	2 (0.01)	9 (0.05)	0 (0)	19774
Wean	7673 (76.66)	496 (4.96)	221 (2.21)	1612 (16.11)	0 (0)	7 (0.07)	0 (0)	10009
Fall	11571 (83.98)	289 (2.10)	189 (1.37)	1714 (12.44)	5 (0.04)	10 (0.07)	0 (0)	13778
Rut	5236 (75.80)	85 (1.23)	192 (2.78)	1390 (20.12)	0 (0)	5 (0.07)	0 (0)	6908
Firearm	1954 (56.97)	135 (3.94)	72 (2.10)	1269 (37.00)	0 (0)	0 (0)	0 (0)	3430
Winter	9717 (45.55)	2517 (11.8)	401 (1.88)	8696 (40.77)	0 (0)	1 (0.005)	0 (0)	21332
Total points	46385	7091	3868	41106	8	32	0	98490
South WTD								0
Pregnancy	5435 (24.06)	5892 (26.08)	4393 (19.44)	6446 (28.53)	349 (1.54)	70 (0.31)	8 (0.04)	22593
Fawn	7439 (35.59)	6597 (31.56)	2838 (13.58)	3732 (17.86)	134 (0.64)	145 (0.69)	15 (0.07)	20900
Wean	4412 (43.89)	3028 (30.12)	1029 (10.24)	1475 (14.67)	5 (0.05)	92 (0.92)	11 (0.11)	10052
Fall	5481 (41.89)	3791 (28.97)	1487 (11.37)	2104 (16.08)	112 (0.86)	93 (0.71)	16 (0.12)	13084
Rut	1242 (26.46)	1213 (25.84)	923 (19.66)	1047 (22.31)	233 (4.96)	36 (0.77)	0 (0)	4694
Firearm	419 (18.36)	502 (22.00)	641 (28.09)	594 (26.03)	120 (5.26)	3 (0.13)	3 (0.13)	2282
Winter	1322 (17.02)	1360 (17.51)	2914 (37.51)	2050 (26.39)	100 (1.29)	0 (0)	23 (0.30)	7769
Total points	25750	22383	14225	17448	1053	439	76	81374

Table 3.10. Annual average (±SE) of mule deer (MD) and white-tailed deer (WTD) 95% Biased Random Bridge (BRB) home ranges and 50% Biased Random Bridge home ranges in the two study sites (North [N; Decatur, Norton, Sheridan, and Graham counties] and South [S; Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

	NMD (km^2)	SMD (km^2)	NWTD (km^2)	SWTD (km^2)
95% BRB				
2018	8.19 ± 0.83	12.70 ± 1.78	5.36 ± 1.08	14.53 ± 1.73
2019	9.13 ± 0.67	9.50 ± 1.27	9.45 ± 2.97	12.67 ± 1.20
2020	7.03 ± 0.64	10.72 ± 1.09	9.00 ± 1.31	9.88 ± 1.47
50% BRB				
2018	1.26 ± 0.14	2.36 ± 0.32	0.66 ± 0.14	2.05 ± 0.32
2019	1.36 ± 0.11	1.75 ± 0.19	0.99 ± 0.25	2.18 ± 0.22
2020	1.14 ± 0.12	2.02 ± 0.20	1.04 ± 0.18	1.37 ± 0.25

Table 3.11. Seasonal averages (±SE) of mule deer (MD) and white-tailed deer (WTD) 95% Biased Random Bridge home ranges in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Season	North MD (km^2)	South MD (km^2)	North WTD (km^2)	South WTD (km^2)	*F*	DF	*P*
Pregnancy	8.14±0.48[a]	6.90±0.46[a]	4.36±0.48[b]	7.75±0.53[a]	12.10	3, 171	<0.001
Fawn	2.40±0.21[b]	4.26±0.53[a]	1.92±0.24[b]	4.24±0.36[a]	11.89	3, 160	<0.001
Wean	1.70±0.13[c]	3.59±0.32[a]	2.03±0.49[bc]	3.01±0.29[ab]	7.09	3, 156	<0.001
Fall	3.24±0.21[b]	5.41±0.41[a]	2.91±0.35[b]	5.03±0.47[a]	11.87	3, 153	<0.001
Rut	3.91±0.25[b]	6.38±0.55[a]	3.61±0.39[b]	7.24±0.71[a]	13.63	3, 148	<0.001
Firearm	5.73±0.45[bc]	7.36±0.46[ab]	5.20±0.61[c]	8.88±0.66[a]	9.16	3, 142	<0.001
Winter	5.65±0.38[b]	6.68±0.41[b]	5.43±0.52[b]	11.32±0.94[a]	20.96	3, 138	<0.001

[abc] Means followed by same superscript letter did not differ across groups within season.

Table 3.12. Seasonal averages (±SE) of mule deer (MD) and white-tailed deer (WTD) 50% Biased random bridges home range core areas in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Season	North MD (km^2)	South MD (km^2)	North WTD (km^2)	South WTD (km^2)	*F*	DF	*P*
Pregnancy	1.56±0.08[a]	1.37±0.10[a]	0.65±0.09[b]	1.32±0.11[a]	17.07	3, 171	<0.001
Fawn	0.37±0.03[b]	0.69±0.08[a]	0.36±0.06[b]	0.76±0.08[a]	11.10	3, 161	<0.001
Wean	0.27±0.02[b]	0.59±0.06[a]	0.30±0.04[b]	0.53±0.05[a]	13.95	3, 156	<0.001
Fall	0.58±0.04[b]	0.88±0.07[a]	0.44±0.04[b]	0.86±0.07[a]	13.92	3, 153	<0.001
Rut	0.74±0.05[b]	1.16±0.12[a]	0.59±0.06[b]	1.25±0.12[a]	13.25	3, 148	<0.001
Firearm	1.10±0.10[bc]	1.35±0.07[ab]	0.89±0.10[c]	1.61±0.12[a]	9.38	3, 142	<0.001
Winter	1.12±0.07[bc]	1.30±0.08[b]	0.83±0.08[c]	1.99±0.14[a]	24.87	3, 138	<0.001

Table 3.13. Annual 50% minimum convex polygons (MCP; km^2) of mule deer (MD) and white-tailed deer (WTD) core areas, size of overlap between the core areas, and percent of overlap in the two study sites (North (N) [Decatur, Norton, Sheridan, and Graham counties] and South (S) [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Year	NMD MCP	NWTD MCP	km^2 of overlap	% of overlap North MD	% of overlap North WTD
2018	27.71	29.70	8.58	30.96	28.89
2019	16.10	23.39	0.00	0.00	0.00
2020	17.11	33.78	12.52	73.17	37.06

Year	SMD MCP	SWTD MCP	km^2 of overlap	% of overlap South MD	% of overlap South WTD
2018	57.17	68.72	48.39	84.64	70.42
2019	18.90	36.53	6.67	35.29	18.26
2020	48.05	76.97	23.06	47.99	30.00

Table 3.14. Estimates of seasonal home range areas of mule deer and white-tailed deer across the Great Plains.

Deer	Area	Home range method	Transmitter type	Seasonal (km^2)	Author
MD	Montana prairie badlands	MCP	VHF	summer = 2.1- 2.9 winter = 2.3-3.4	Wood et al. 1989
MD	Nebraska	kernel density	VHF	summer ≈15 winter ≈25	Walter et al. 2011
MD	Wyoming	kernel density	GPS	summer1 = 15.92 winter 1 = 24.11 winter 2 = 29.23	Webb et al. 2013
MD	Colorado Southeast	kernel density	GPS	summer1 = 6.23 summer2 = 5.51 winter 1 = 7.68 winter 2 = 9.88	Carrollo et al. 2017
WTD	Montana prairie badlands	MCP	VHF	summer = 3.36 winter = 6.34	Wood et al. 1989
WTD	South Dakota	MCP	VHF	summer = 9.2 winter = 10.2	Grovenburg et al. 2009
WTD	Nebraska	kernel density	VHF	summer ≈ 4 winter ≈ 7	Walter et al. 2011

Chapter 4 - Resource selection by female mule deer and white-tailed deer in western Kansas

Introduction

Resource selection is a behavioral process whereby animals assess relative habitat quality across a landscape. It is assumed that selection of resources at levels greater than their availability will maximize individual fitness (Thomas and Tayler 2006). Results based on resource selection are then used by managers to determine potential factors limiting population growth. Managing for limiting resources may help increase declining or low populations. It is especially important to consider resource selection for animals whose populations are declining or in competition with another species (Manly et al. 2002).

Competition may be occurring between mule deer (*Odocoileus hemionus*) and white-tailed deer (*O. virginianus*) populations in the western Great Plains. Mule deer and white-tailed deer are similar species with analogous body types, herd structures, breeding seasons, diets, diel movement, and foraging activity patterns (Antony and Smith 1977). Thus, these species have similar resource needs for much of their life cycle. Previous studies suggest that sympatric mule deer and white-tailed deer populations spatially segregate by elevation, resulting in differential availability and use of resources between species (Mackie et al. 1998, Brunjes et al. 2006). However, in the western Great Plains, these species may be forced to occupy the same niche due to lack of elevational gradients, which according to the competitive exclusion principle means one species will eventually outcompete the other if both are actively selecting the same resources and some resources are limited (Hardin 1960).

However, the potential for competition between these species is relatively recent. Historically, much of the Great Plains was occupied exclusively by mule deer, with white-tailed deer limited to the eastern tall-grass prairie and eastern deciduous forest interface (VerCauteren 2003, MDWG 2020). Both species were nearly extirpated from Kansas and much of the Great Plains by the early 1900s due to overharvest and habitat degradation; however, many populations recovered to levels supporting sport harvest by the mid-late 1900s (Anderson 1964, Ballard et al. 2001, VerCauteren 2003). White-tailed deer populations have been expanding westward in the Great Plains for the past several decades, likely in response to changing land cover (VerCauteren 2003, Hanberry and Hanberry 2020). Mule deer populations were stable throughout much of the Great Plains for most of the 1900s; however, significant population declines have occurred since the late 1900s (Ballard et al. 2001, MDWG 2020). Currently, occupied range expansion by white-tailed deer appears to be concurrent with contraction of the occupied range of mule deer in the Great Plains (Ballard et al. 2001, VerCauteren 2003).

Population trends of mule deer and white-tailed deer in Kansas are similar to other areas of the Great Plains. In western Kansas, due to the lack of a significant elevational gradient to spatially segregate populations, deer species are possibly competing for the same resources, such as foraging areas, bed sites, and fawning sites, for the first time in history. Evidence for potential competition could include both species selecting the same resources at the same time at the same scale. While similar in many respects, there may be differences between species identified by their resource selection in the Great Plains that provide insights into potential factors allowing co-existence. The most likely difference is greater use of relatively steeper slopes and rougher terrain by mule deer than white-tailed deer, similar to other findings for sympatric populations (Wood et al. 1989, Avery et al. 2003, Leonhart 2003, Brunjes et al. 2006). Mule deer typically select for areas with less vegetation cover than white-tailed deer (Lingle 2002, Avery et al. 2003, Leonhart 2003). White-tailed deer typically select for less rough topography and greater vegetation obstruction and canopy cover (Wood et al. 1989, Avery et al. 2003, Leonhart 2003, Brunjes et al. 2006).

In western Nebraska, both species select for areas closer to forest cover; however, the effect was 2 to 3 times stronger for white-tailed deer for all seasons except post-parturition (Jun 21-Sep 30) when mule deer had greater selection for forest cover (Baasch 2008). A subsequent study in the same area found the same effect with both species selecting for forested, riparian landcover types over open grassland (Walter et al. 2011). In both studies, both species of deer utilized crop fields in most seasons (Baasch 2008, Walter et al. 2011). In eastern Montana, mule deer select sagebrush grasslands, bunchgrass prairies, badlands, mesic shrublands, and hardwood draws over the less topographically variable mixed-grass prairie and grain fields (Wood et al. 1989). Conversely, white-tailed deer select hardwood draws throughout the year and mesic shrublands every season but winter. In autumn, white-tailed deer select for grain crop fields, even shifting their home ranges for easier access to the crop fields (Wood et al. 1989). In Kansas it is unknown if the two species are selecting different landcover types, which could lead to potential competition if they are selecting the same landcover type.

To test for mechanisms of potential competition, my objective was to test for differences in seasonal multi-scale resource selection between adult female mule deer and white-tailed deer in western Kansas. I hypothesized that selection of resources varies among seasons and life stages of female deer due to changing energy requirements. I predicted that when physiologically stressed (i.e., during fawning and lactation), the two species will show more differences in resource selection than during the rest of the annual cycle (Volk et al. 2007, Butler et al. 2009, Long et al. 2009). Energy demand is relatively greater during fawning and lactation season than other seasons, requiring females to search for additional resources, possibly competing for high quality resources (Volk et al. 2007, Long et al. 2009).

Due to similarity in resource needs between species, I predicted that there will be differences in resource selection between species at smaller rather than larger spatial scales. Terrain roughness, elevation, aspect, and slope are likely important factors for resource selection and space use by both species (Avery et al. 2003, Coe et. al 2018). If there is no segregation at larger landscape level scales as expected, then segregation will likely occur at the finer scales of selection. If mule deer and white-tailed deer are competing primarily for vegetation-related resources, comparison of point-scale habitat variables such as vegetation obstruction, percent cover of functional groups, and canopy cover can be used to test for evidence of potential competition. If species do not use or select for the same levels of micro-habitat variables, it is unlikely that direct competition is occurring.

Study Area

My study occurred at 2 contrasting field sites in western Kansas that supported sympatric populations of mule deer and white-tailed deer in landscapes containing habitat features representative of both species (Figure 1.2). These sites were roughly 150 km apart and chosen because of reported declines in mule deer abundance, but with sufficient mule deer densities necessary to obtain appropriate sample sizes (in 2018, 5.43 mule deer/km^2; Levi Jaster KDWP personal communication).

The North field site (~85,000 ha) was in Decatur, Norton, Sheridan, and Graham counties; it consisted of relatively small tracts of landowner properties surrounding a large wooded riparian area. The South field site (~137,000 ha) was in Logan, Scott, Gove, and Lane counties, consisting of relatively larger tracts of landowner properties interspersed with steep ravines and chalk cliffs. Average yearly temperatures from 2006-2020 was 12.43° C in the North site and 11.97° C in the South site (NOAA 2021). Average annual precipitation from 2006-2020 was 57.84 cm in the North site and 51.19 cm in the South site from 2000-2020 (NOAA 2021). The average temperatures (°C) from 2018 to 2020 were 12.10 in the North site and 11.73 in the South site and similar to the long-term averages. Annual precipitation during 2018 (North 92.1 cm, South 66.7 cm) and 2019 (North 74.4 cm, South 52.7cm) was wetter than the long-term average years, but 2020 represented drought conditions (North 36.94 cm, South 36.09 cm).

Common landcover types were cropland, pasture, woodland/riparian, and U.S. Department of Agriculture Conservation Reserve Program (CRP) lands. Agriculture was the dominant land use feature in both study sites, which included livestock grazing of native rangeland and row-crops. Corn (*Zea mays*), wheat (*Triticum aestivum*), and milo (*Sorghum bicolor*) were the most common crops; alfalfa (*Medicago sativa*), soybeans (*Glycine max*), and sunflowers (*Helianthus annuus*) were less common. Grasslands consisted of native short and mixed-grass prairie primarily grazed by cattle. Common grasses included little bluestem (*Schizachyrium scoparium*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*B. gracilis*). Common forbs were broom snakeweed (*Gutierrezia sarothrae*), common mullin (*Verbascum thapsus*), and tall thistle (*Cirsium altissimum*); common succulents were yucca (*Yucca glauca*) and prickly pear cactus (*Opuntia macrorhiza*).

The CRP lands in both study sites were ungrazed and planted with mostly tallgrass prairie grass species including big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). Woodlands were associated with riparian areas along the Solomon River at the North site, and Smoky Hill River and tributaries in the South site.

Shelterbelts and dispersed tree clusters (i.e., former homesteads) were scattered throughout both study sites. Common tree species included American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), black cherry (*Prunus serotina*), eastern cottonwood (*Populus deltoides*), honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*), mulberry (*Morus rubra*), and eastern red cedar (*Juniperus virginiana*). Plum thickets (*Prunus angustifolia*) and smooth sumac (*Rhus glabra*) were shrubs commonly found in ravines and valleys in western Kansas.

Study areas were defined annually based on a minimum convex polygon (MCP) estimated from all female locations for both species combined (Mohr 1947). Study areas for 2018, 2019, and 2020, respectively, were 450.84 km^2, 857.40 km^2, and 685.48 km^2 for the North site and 1,387.54 km^2, 664.96 km^2, and 1,041.60 km^2 for the South site. I buffered the landscape MCP by 200 m, which was similar to the average hourly movement of the deer (Chapter 3). I created a landcover map for each year for the landscape MCP by digitally delineating polygons of different landcover patches using ArcGIS (10.6) from a satellite image (ESRI World Imagery) for the entire landscape scale boundary. Only patches 30 m^2 or larger were delineated. The landcover type was ground-truthed for each polygon each year. Delineated landcover types across sites were: native pasture, ravine, crop type, CRP, human structure, woodland, and riparian (Figures 1.3-1.5).

Methods

Capture

At each study site, at least 15 white-tailed deer and 15 mule deer were captured and collared in February 2018 and 2019 and March 2020 for a total of ≥60 collared adult females annually. A commercial helicopter crew (Quicksilver Air Inc, Fairbanks, AK, USA) captured and sedated the deer using 15 mg Butorphanol [50 mg/ml], 15 mg Azaperone [50 mg/ml], and 15 mg Midazolam [50 mg/ml] (Wolfe and Miller 2016). Captured deer were transported to a central processing location where I estimated age by tooth wear and eruption (Severinghaus 1949), recorded morphometric data (total body length, hind foot length, nest girth, chest girth, and body fat measurements using an ultrasound [cm]), body mass (kg), and attached uniquely numbered ear tags to each deer. Pregnancy was confirmed by a licensed veterinarian using an ultrasound (IBEX PRO/r, E.I. Medical Imaging, Loveland, CO, USA). Pregnant females received high-resolution GPS/VHF VERTEX PLUS-2 collars (Vectronic Aerospace GmbH, Berlin, Germany). Collars recorded hourly GPS locations during the entire deployment period and were programed to drop off at 60 weeks from date of capture. Collar fit was specific to species with white-tailed deer and mule deer collars at 38 cm and 43 cm circumference, respectively. Collars had a mortality sensor programmed to send an alert after 6 hours of motionlessness. All animal handling procedures are approved by the Institutional Animal Care and Use Committee at Kansas State University (protocol 3963), and authorized under the state of Kansas scientific, education, or exhibition wildlife permits (SC-024-2018, SC-015-2019, SC-032-2020).

Life Stages/Seasons

I categorized seasonal temporal periods based on life stages and hunting seasons. The pregnant season started March 1 following capture and continued until the mean fawn birth date each year. The fawn season was from the mean birth date until the wean date, which was defined as 70 days from birth. Weaned lasted from the mean weaned or death date until archery season. Fall/archery season was from the start of archery (9/17/18, 9/16/19, 9/13/20) to the start of rut. Rut was from the beginning of rut (10/31 all years) until the end of rut (11/24/18, 11/21/19, 11/23/20). Firearm season was a 12-day period primarily in early December (11/28/18-12/9/18, 12/4/19-12/15/19, 12/2/20-12/13/20). Winter season was from the end of firearm season to

February 28. During winter season, there is an antlerless white-tailed hunting season; however, due to low harvest and hunting pressure, it was not delineated separately from the winter season.

Vegetation Surveys

Because both species have similar resource requirements, I predicted a greater difference in selection using 4th order selection compared to higher orders of selection (Johnson 1980). To measure 4th order resource selection on deer, I conducted weekly vegetation surveys of micro-habitat variables. Vegetation surveys consisted of an actual location randomly chosen from the set of weekly individual location points for each deer and a paired point 300 m in a random direction from the actual location in the same landcover patch. One pair of points was done each week for each tagged deer. At each point, I measured visual vegetation obstruction, vegetation functional group composition, vegetation height, litter depth, and canopy cover (Lemmon 1957, Daubenmire 1959, Robel 1970). Visual vegetation obstruction was measured using a Robel pole 4 m away from the center point and 1 m high in each cardinal direction. The level of obstruction (0%, 25%, 50%, 75%, 100%) was measured at the highest decimeter of the pole (Robel 1970). I estimated horizontal cover of vegetation using 8 25 x 50-cm Daubenmire frames at each point, 4 frames were measured at the point in each cardinal direction and 4 frames were measured at 4 m away from the point in each cardinal direction. In each fame, I estimated the percent cover of each vegetation functional group, measured height of the tallest vegetation (cm), and recorded litter depth (cm; Daubenmire 1959). Data from all the frames were averaged at each point. Functional groups were groups of vegetation structure types that may affect deer selection: grass, forbs, shrub, litter, and succulent. Percent bare ground was also recorded. When there was tree canopy cover, I used a spherical densiometer to measure the canopy coverage at each cardinal direction 4 m away from the point, averaging all measurements for each point (Lemmon 1957).

Resource Selection

I modeled resource selection by mule deer and white-tailed deer at the landscape scale (2nd order selection), within home range scale (95% isopleth; 3rd order selection), and within the core home range (50% isopleth; 3rd order selection) to identify selection for potential habitat variables and cover types. I defined the available landscape annually based on a MCP estimated from all female locations collected for both species combined (Mohr 1948). For each location, a paired random point was generated within the landscape scale to assess availability of resources to measure 2nd order selection. In each season, I generated 95% and 50% MCPs for each female to assess 3rd order resource selection at the home-range and core-use scales, respectively. All points from the vegetation surveys were used to assess availability. I selected the paired random points from the vegetation surveys that were within the 95% and 50% MCPs of each individual deer to estimate availability. I used MCPs to define home ranges instead of other methods of home range calculation such as Biased Brownian Bridge Movement models (Chapter 3) because I needed a continuous defined landscape for resource selection analyses (Zeale et al 2012).

I used macro-habitat variables, gathered from remote sensing data, and micro-habitat variables from vegetation surveys to assess resource selection within defined seasons at different spatial scales. I used a digital elevation model (DEM) from U.S. Geological Survey (USGS) with 10-m resolution to estimate aspect, slope, and elevation at each used and available point (https://earthexplorer.usgs.gov/). I extracted elevation and percent slope values for used and available points from the DEM and derived slope layer, respectively, using ArcGIS 10.8.1. After calculating aspect from the DEM, I used the cosine function (e.g., cos [aspect × π/180]) to convert aspect to a noncircular, continuous variable representing northness with values closer to -

1 representing south-facing aspects and values closer to 1 representing north-facing aspects (Nussear 2009); northness values were extracted for used and available locations.

Landcover type was determined using the landcover map described in the Study Area section. The landcover types across sites were: native pasture, ravine, crop, CRP, urban, woodland, and riparian (Figures 1.3-1.5). These categorical variables were extracted for each used and random point. Microhabitat variables were from the vegetation surveys.

I used logistic regression based on used and random available paired points to model habitat selection using the function glm in Program R (Keating and Cherry 2004, R Core Team 2021). I used Akaike's Information Criterion corrected for small sample size (AIC_c) to rank models based on delta AIC_c and assessed model support using model weights (Burnham and Anderson 2002). There were two model suites consisting of single variable models, the first model suite only included macro-habitat variables that were tested at the landscape scale for each season (Table 4.1). The second model suite included both macro and micro-habitat variables that were tested at the home range and core-use area scale for each season (Table 4.1). The reference level (model intercept) was grass/pasture for landcover type, mule deer for species, and North study site for study site.

For 4^{th} order selection, I used a multivariate analysis of variance (MANOVA) to test for vegetation differences between used and paired-random points. I also used MANOVA to compare vegetation at used points between species. I tested obstruction variables and vegetation functional group variables in separate analyses. When the MANOVA was significant ($P < 0.05$), I used paired *t*-tests to test for differences for each variable, with $\alpha = 0.05$.

Results

Mule Deer Resource Selection

At the landscape scale (2nd order selection), top-ranked models among seasons for female mule deer were either slope or landcover, with no competing models (Table 4.2). Slope was the top-ranked model for pregnancy, firearm, and winter seasons with mule deer selecting for greater slopes in each season (Figure 4.1). Landcover was the top-ranked model for fawn, wean, fall, and rut seasons. In the four seasons, mule deer consistently selected CRP; fawn β = 1.72 (95% CI = 1.70–1.74), wean β = 2.02 (95% CI = 1.99–2.06), fall β = 1.59 (95% CI = 1.56–1.63), and rut β = 0.98 (95% CI = 0.93–1.03). Mule deer had slightly greater selection strength for woodland than CRP in the fawn season, β = 2.02 (95% CI = 1.94–2.11) but strength of selection was less than CRP in wean β = 0.85 (95% CI = 0.70–1.00), fall β = 0.59 (95% CI = 0.45–0.73), and rut β = 0.31 (95% CI = 0.11–0.50) seasons. Strength of selection for cropland varied greatly, but cropland was selected for each season. The seasonal strength of selection for cropland from lowest to highest was fawn β = 0.13 (95% CI = 0.11–0.15), rut β = 0.67 (95% CI = 0.64–0.70), fall β = 0.87 (95% CI = 0.85–0.90), and wean β = 1.50 (95% CI = 1.47–1.52). Female mule deer did not select for ravines in the fall β = 0.03 (95% CI = -0.01–0.07). Strength of selection for ravine varied among the other three seasons, rut β = 0.23 (95% CI = 0.18–0.28), wean β = 0.68 (95% CI = 0.63–0.72), and fawn β = 1.68 (95% CI = 1.65–1.70). Selection for riparian landcover varied from being selected in the fawn season β = 0.32 (95% CI = 0.25–0.38), used similar to available in the wean season β = -0.08 (95% CI = -0.20–0.04), but avoided during fall β = -0.76 (95% CI = -0.87– -0.64) and rut β = -0.35 (95% CI = -0.48– -0.21) seasons. Urban was selected during the wean β = 1.15 (95% CI = 1.00–1.30) and fall β = 1.02 (95% CI = 0.89–1.15) seasons, but avoided during fawn β = -0.88 (95% CI = -1.06– -0.69) and rut β = -0.62 (95% CI =

-0.89– -0.35) seasons. In each season, native pasture was used less than available; fawn β = -0.61 (95% CI = -0.62– -0.59), wean β = -1.07 (95% CI = -1.09– -1.04), fall β = -0.58 (95% CI = -0.60– -0.57), and rut β = -0.39 (95% CI = -0.37– -0.41).

At the home range scale (3rd order selection), mule deer selected for increasing slope during pregnancy and firearm seasons (Figure 4.3, Table 4.3). The top-ranked model for selection during fawn and wean seasons was landcover. In both fawn β = 1.18 (95% CI = 0.85–1.50) and wean β = 1.19 (95% CI = 74–1.63) seasons, CRP was strongly selected. Riparian β = 1.73 (95% CI = 0.15–3.32) and woodland β = 1.95 (95% CI = 0.67–3.22) landcovers were only available during the fawn season and had stronger strength of selection than CRP. Selection for ravine in fawn β = 0.72 (95% CI = 0.42–1.01) and wean β = 0.56 (95% CI = 0.02–1.10) seasons was stronger than crop, but considerably less than CRP. Crop was not selected in the fawn season β = 0.19 (95% CI = -0.12–0.50) but was selected in the wean season β = 0.39 (95% CI = 0.01–0.76). Native pasture was used less than available during both fawn β = -0.48 (95% CI= -0.68– -0.28) and wean β = -0.48 (95% CI= -0.17– -0.80). The top-ranked model for fall and rut seasons was visual obstruction, with mule deer selecting for greater obstruction in both seasons (Figure 4.5). Selection during the winter season had competing top models of slope and landcover. In the competing landcover model in winter, mule deer selected for CRP β = 1.01 (95% CI =0.31– 1.71). Pasture β = -0.02 (95% CI = -0.30– 0.26), crop β = -0.40 (95% CI = -0.81–0.01) and ravine β = 0.23 (95% CI = -0.23– 0.70) were used in proportion to available.

In the core-use area (3rd order selection), mule deer selected for greater slope in the pregnancy season (Figure 4.7, Table 4.4). Landcover was the top-ranked model for fawn, wean, fall, and winter seasons. The landcover type with the most consistently strong strength of selection was CRP, which was selected in fawn β = 1.12 (95% CI= 0.66–1.59), wean β = 1.70

(95% CI= 1.04–2.37), fall β = 0.97 (95% CI= 0.40– 1.54), and winter β = 1.06 (95% CI= 0.06-2.06) seasons. In the fawn season, woodland β = 2.01 (95% CI = 0.46–3.57) was selected, but that was the only season woodland was available. Riparian was only available in the fawn season, but was used in proportion to availability β = 1.90 (95% CI = -0.31–4.11). Ravine was selected in the fawn β = 0.81 (95% CI = 0.38–1.25) and wean β = 0.91 (95% CI = 0.12–1.71) seasons, but not in the fall β = 0.68 (95% CI = -0.08–1.43) or winter β = 0.26 (95% CI = -0.43–0.96) seasons. Crop was only selected in the wean season β = 0.56 (95% CI= 0.0003–1.12), and use in proportion to availability in fawn β = 0.28 (95% CI = -0.17–0.72), fall β = 0.38 (95% CI = -0.07–0.83) or winter β = -0.56 (95% CI = -1.13–0.02) seasons. Native pasture was used less than available in the fawn β = -0.51 (95% CI = -0.80– -0.22), wean β = -0.71 (95% CI = -0.23– -1.20) and fall β = -0.41 (95% CI = -0.02– -0.79) seasons. Pasture was used in proportion to availability in the winter season β = 0.04 (95% CI = -0.35–0.42). In the rut season, the two competing top models were obstruction and slope, with mule deer selecting for greater obstruction and slope (Figure 4.9). The top-ranked model was not significant in the firearm season.

White-Tailed Deer Resource Selection

At the landscape scale (2nd order selection), landcover was the top-ranked model each season for white-tailed deer (Table 4.5). Riparian, woodland, and CRP had consistently strong selection in each season. Selection for riparian was greatest in each season: pregnancy β = 3.37 (95% CI = 3.32–3.41), fawn β = 3.53 (95% CI = 3.48–3.58), wean β = 3.23 (95% CI = 3.17–3.30), fall β = 3.32 (95% CI = 3.26–3.38), rut β = 2.93 (95% CI = 2.84–3.02), firearm β = 2.40 (95% CI = 2.28–2.52), and winter β = 2.91 (95% CI = 2.86–2.96). Selection for woodland and CRP alternated between second and third greatest strength of selection. Selection for woodland was pregnancy β = 2.76 (95% CI = 2.69–2.83), fawn β = 2.94 (95% CI = 2.86–3.02), wean β = 2.56 (95% CI = 2.44–2.67), fall β = 2.85 (95% CI = 2.75–2.95), rut β = 2.30 (95% CI = 2.15–2.45), firearm β = 1.90 (95% CI = 1.70–2.10), and winter β = 2.18 (95% CI = 2.10–2.26). Selection for CRP was pregnancy β = 1.95 (95% CI = 1.92–1.97), fawn β = 2.66 (95% CI = 2.64–2.69), wean β = 3.12 (95% CI = 3.08–3.16), fall β = 2.84 (95% CI = 2.80–2.87), rut β = 2.32 (95% CI = 2.27–2.37), firearm β = 1.91 (95% CI = 1.85–1.98), and winter β = 1.75 (95% CI = 1.72–1.78). Selection for ravine was greater than crop except for fall, but was less than woodland and CRP. Strength of selection for ravine by season was pregnancy β = 1.13 (95% CI = 1.10–1.15), fawn β = 1.07 (95% CI = 1.03–1.10), wean β = 0.64 (95% CI = 0.58–0.69), fall β = 0.77 (95% CI = 0.72–0.81), rut β = 0.75 (95% CI = 0.69–0.80), firearm β = 0.71 (95% CI = 0.64–0.79), and winter β = 1.00 (95% CI = 0.97–1.03). Crop was selected during pregnancy β = 0.02 (95% CI = 0.002–0.04), fawn β = 0.73 (95% CI = 0.71–0.75), wean β = 1.52 (95% CI = 1.49–1.56), fall β = 1.16 (95% CI = 1.13–1.19), rut β = 0.44 (95% CI = 0.40–0.47), and winter β = 0.04 (95% CI = 0.02–0.07) but avoided during firearm β = -0.32 (95% CI= -0.38– -0.27). Urban was selected for during pregnancy β = 0.15 (95% CI = 0.02–0.28), fawn β = 1.77 (95% CI = 1.67–1.88), wean β = 1.83 (95% CI = 1.68–1.97), fall β = 2.46 (95% CI = 2.34–2.58), rut β = 1.19 (95% CI = 1.00–1.38), and winter β = 0.84 (95% CI = 0.73–0.96) but avoided during firearm β = -1.00 (95% CI = -1.47– -0.52). Native pasture was used less than available in all seasons, pregnancy β = -0.78 (95% CI = -80– -0.77), fawn β = -1.18 (95% CI = -1.20– -1.16), wean β = -1.55 (95% CI = -1.58– -1.52), fall β = -1.33 (95% CI = -1.36– -1.31), rut β = -0.87 (95% CI = -0.90– -0.85), firearm β = -0.49 (95% CI = -0.53– -0.45), and winter β = -0.65 (95% CI = -0.66– -0.63).

At the home range scale (3rd order selection), landcover was the top-ranked model for pregnancy, fawn, wean, and fall seasons (Figure 4.11). Canopy cover was the top-ranked model in winter. The top model variables were not significant in the rut and firearm seasons (Table 4.6). Riparian and woodland were the top two ranked landcover types in pregnancy, fawn, and wean seasons. Seasonal ranking of selection for riparian was pregnancy β = 1.51 (95% CI = 1.05–1.96), fawn β = 2.09 (95% CI = 1.25–2.63), wean β = 2.07 (95% CI = 1.29–2.84), and fall β = 1.71 (95% CI = 1.08–2.33). Selection for woodland was pregnancy β =1.86 (95% CI = 0.84–2.88), fawn β = 2.14 (95% CI = 0.85–3.44), and wean β = 1.40 (95% CI= 0.04–2.75), but used in proportion to availability in fall β = 0.91 (95% CI = -0.29–2.11). Ravine and CRP had similar strength of selection throughout the pregnancy, fawn, and wean seasons, but ravine was not selected for the fall season. Selection for ravine was pregnancy β = 0.49 (95% CI = 0.03–0.95) fawn β = 0.95 (95% CI = 0.51–1.39), wean β = 1.33 (95% CI = 0.58–2.08), and fall β = 0.46 (95% CI = -0.13–1.05). Selection for CRP was pregnancy β = 0.58 (95% CI = 0.20–0.96), fawn β = 0.90 (95% CI = 0.52–1.29), wean β = 1.21 (95% CI = 0.66–1.77), and fall β = 0.75 (95% CI = 0.32–1.19). There was no selection for crop in pregnancy β = -0.17 (95% CI = -0.55–0.21) and fawn seasons β = 0.20 (95% CI= -0.17–0.58); however, there was selection for crop in the wean β = 0.87 (95% CI= 0.34–1.39) and fall β = 0.45 (95% CI= 0.04–0.85) seasons. Native pasture was used than available in pregnancy β = -0.42 (95% CI = -0.71– -0.13) fawn β = -0.68 (95% CI = -0.99– -0.36), wean β = -0.99 (95% CI = -1.47– -0.51), and fall β = -0.57 (95% CI = -0.92– -0.22) seasons. In the winter season, white-tailed deer selected for greater canopy cover (Figure 4.12).

At the core area scale (3rd order selection), white-tailed deer selected for greater canopy cover during the pregnancy season (Figure 4.13, Table 4.7). Top-ranked models for the fawn, fall, rut, and winter seasons included landcover (Figure 4.14). Riparian was strongly selected in four seasons: fawn β = 1.83 (95% CI = 1.13–2.54), fall β = 1.38 (95% CI = 0.50–2.26), rut β = 1.96 (95% CI = 0.36–3.56), and winter β = 2.07 (95% CI = 0.98–3.16). Woodland was only selected in the fawn season β = 2.73 (95% CI= 0.59–4.88), but not in the fall season β = 1.45 (95% CI = -0.23–3.13). Woodland was not available in rut and winter seasons. Ravine was only selected in the fawn season β = 1.16 (95% CI = 0.52–1.81), but used in proportion to availability in fall β = -0.21 (95% CI = -1.21–0.80), rut β = 0.09 (95% CI = -0.88–1.06), and winter β = 0.68 (95% CI= -0.10–1.46) seasons. Similarly, CRP was only selected for the fawn season β = 1.08 (95% CI = 0.52–1.64) and used in proportion to availability in fall β = 0.57 (95% CI= -0.04–1.17), rut β = 0.43 (95% CI = -0.37–1.24), and winter β = 0.35 (95% CI = -0.46–1.17) seasons. Crop was used in proportion to availability in all seasons; fawn β = 0.34 (95% CI = -0.21–0.90), fall β = 0.19 (95% CI = -0.39–0.76), rut β = -0.60 (95% CI = -1.43–0.23), and winter β = 0.28 (95% CI = -0.42–0.98). Native pasture was used less than available in the fawn season β = -0.79 (95% CI = -1.26– -0.32), but used in proportion to availability during fall β = -0.35 (95% CI = -0.85–0.15), rut β = -0.09 (95% CI = -0.68–0.50), and winter β = -0.46 (95% CI = -0.97–0.05) seasons. The wean season had competing top models of canopy cover and landcover (Figure 4.15). White-tailed deer selected for greater canopy cover. Riparian β = 2.08 (95% CI = 1.10–3.06), ravine β = 1.58 (95% CI = 0.52–2.65), CRP β = 1.27 (95% CI = 0.57–1.98) and crop β = 1.05 (95% CI = 0.37–1.73) were all selected while native pasture β = -1.10 (95% CI = -1.70– -0.49) was avoided. The top-ranked model was not significant in the firearm period.

4th Order Selection

I tested vegetation at used points (5,321 points) between mule deer and white-tailed deer and found differences between species for obstruction variables ($F_{5, 5314} = 8.00$, $P < 0.001$) and vegetation functional groups ($F_{6, 5314}$ = 20.91, P < 0.001). Univariately, only percent grass (mule deer vs. white-tailed deer 43.33, 42.63%), percent succulent (3.25, 3.19%), and litter depth (2.39, 2.63 cm) did not differ between mule deer and white-tailed deer (Table 4.8). White-tailed deer consistently used higher visual obstruction than mule deer (0% obstruction 5.71, 6.27 dm; 25% obstruction 4.54, 5.04 dm; 50% obstruction 3.96, 4.42 dm; 75% obstruction 3.56, 3.98 dm; 100% obstruction 2.31, 2.75 dm). White-tailed deer also used a greater percentage of forbs (11.63, 13.94%) and less percentage of bare ground (16.52, 11.51%) than mule deer. Mule deer had greater elevation use (810.71, 795.66 m) and slope use (5.59, 3.77°) than white-tailed deer. However, differences between species were slight, so it is unlikely that meaningful biological differences exist in vegetation and topography at points used by mule deer and white-tailed deer.

Obstruction variables ($F_{5, 5572}$ = 19.14, P < 0.001), and vegetation functional groups ($F_{6, 5571}$ = 12.59, P < 0.001) differed between used and random paired points (n = 5,579) for mule deer. Univariately, average percent grass (actual-random 43.33, 44.66), percent litter (28.82, 28.12), percent succulent (3.24, 3.21%), elevation (810.71, 812.95 m), and aspect (0.14, 0.12) did not differ between used and random points (Table 4.9). Mule deer selected for greater visual obstruction than available for each level of obstruction (used vs. random 0% obstruction 5.71, 4.81 dm; 25% obstruction 4.54, 3.63 dm; 50% obstruction 3.96, 3.08 dm; 75% obstruction 3.56, 2.74 dm; 100% obstruction 2.31, 1.71 dm). Mule deer also selected for greater percent forbs (used vs. random 11.63, 10.27%) and shrubs (3.67, 2.80%) while selecting for less bare ground (16.52, 18.00%) than then available. Mule deer selected for greater vegetation height (47.04, 40.59 cm), greater litter depth (2.39, 2.04 cm), and steeper slope (5.59, 4.01°) than available. However, despite being statistically significant, differences between used and random points were slight, and thus unlikely to be of biological importance.

Visual obstruction ($F_{5, 5060}$ =23.40, $P < 0.001$) and vegetation functional group ($F_{6, 5059}$ = 25.55, $P < 0.001$) differed between used and random paired points (n = 5,067) for white-tailed deer. Only percent succulent (actual-random 3.19, 3.17%), elevation (795.66, 798.35 m), and aspect (0.06-0.07) did not differ between used and random points (Table 4.10). All other variables differed between used and random paired points. White-tailed deer used greater visual obstruction (used vs. random 0% obstruction 6.27, 5.16 dm; 25% obstruction 5.04, 3.95 dm; 50% obstruction 4.42, 3.44 dm; 75% obstruction 3.98, 3.09 dm; 100% obstruction 2.75, 2.08 dm) than available at each level of obstruction. White-tailed deer selected for greater percent forbs (13.94, 10.39%), percent shrubs (3.30, 2.74), percent litter (32.45, 29.50), vegetation height (55.29, 47.65 cm), and litter depth (2.63, 2.07 cm) while selecting for less percent bare ground (11.51, 16.39%) than available. White-tailed deer selected for greater percent canopy cover (0.19, 0.07%) and steeper slopes (3.77, 3.04^{o}) than available. However, despite being statistically significant, differences between used and random points were slight, and thus unlikely to be of biological importance.

Discussion

Resource selection can provide evidence for potential competition between sympatric species. If patterns of resource selection are similar between species, then there is potential for the presence of competition, provided that one or more resources are limiting. However, if patterns of resource selection differ between species, the likelihood of competition for resources is minimized and species likely occupy different niches. Mule deer and white-tailed deer did vary in their patterns of selection for cover types and vegetation structure. Mule deer usually selected for greater slope and visual obstruction; whereas, white-tailed deer usually selected for greater canopy cover. There was a difference in landcover selection, with white-tailed deer selecting for riparian and woodland cover types more often than mule deer in most seasons except fawning, when mule deer selected for riparian and woodland. Differences in resource selection between species at the home range and core-use area scales might be enough to spatially separate mule deer and white-tailed deer such that competitive exclusion is not occurring. For competitive exclusion to occur there has to be limited resources; however, food, cover and space are abundant in western Kansas at current deer population densities, so it is unlikely that competition for resources is occurring despite some overlapping patterns of resource selection.

The major difference at the landscape scale was selection by mule deer for steeper slopes than white-tailed deer in western Kansas. Mule deer are known to use steep slopes and rough terrains more than white-tailed deer in other areas of sympatry (Avery et al. 2003, Leonhart 2003, Brunjes et al. 2006). Despite the relatively minor differences in elevation in western Kansas compared to other areas of sympatry, mule deer and white-tailed deer will still spatially segregate base on topography. At home range and core-use area scales, when landcover was not the top-ranked model, white-tailed deer selected for canopy cover and mule deer selected for visual obstruction. When landcover was the top-ranked model, the major difference at all scales was white-tailed deer selection for wooded areas (e.g., woodland and riparian), while mule deer rarely used areas with overhead cover.

Woody areas provide important habitat for white-tailed deer. When landcover was the top-ranked model, white-tailed deer selected for riparian and woodland land cover types more often and at greater strength than mule deer. When landcover type was the top model for mule deer, riparian and woodland cover types were only available for the fawn season. Mule deer also selected for woody areas after giving birth in Nebraska (Baasch 2008). In Kansas, mule deer fawn bed-site selection had greater woody canopy cover than available at random and it was found that mule deer fawn survival was greater in North site than in South site (Kern 2019). The difference in survival might be due to the North having a large woody riparian area that female mule deer used to hide their fawns. Bed sites of white-tailed deer fawns were also selected for greater canopy cover in both study sites (Kern 2019). When white-tailed deer selected for canopy cover, they were also selecting for woody areas. These findings are similar to findings in other areas where white-tailed deer exhibit greater selection for woody areas than mule deer (Wood et. al 1998, Avery et al. 2003, Brunjes et al. 2006).

Most similarities in resource selection between species were at the landscape scale. Landcover type was the top-ranked model in the fawn, wean, fall, and rut seasons for mule deer; whereas, landcover type was the top-ranked model in all seasons for white-tailed deer. Both species consistently selected for CRP. Selection for crop and ravine was variable for both species among seasons. While woodland was selected for by both species, white-tailed deer had the more frequent and greater strength of selection.

More differences in selection appeared at the home range and core-use area scales. At these spatial scales, woodland and riparian landcover types were not considered available for mule deer selection. Conversely, white-tailed deer strongly selected for woodland and riparian landcover types. Additionally, mule deer selected for obstruction and slope at the home range and core-use area scales compared to selection for canopy cover by white-tailed deer. Mule deer and white-tailed deer selected similar resources at landscape scales due to the overall similarity and overlapping occupied range of these species, but differences in resource selection were apparent at smaller spatial scales between the species contributing to some segregation in the topographically limited landscape of western Kansas.

Some landcover types (crop, CRP, riparian, and woodland) were more strongly selected for by both species than native pasture in all seasons. This pattern was consistent across scales as both deer species selected other landcover types relative to availability more than pasture. However, selection of pasture is relative to availability and pasture comprised about 45% of the landscape. Thus, although native pasture was used by both species (Chapter 3), it was frequently used less than it was available. Native pasture is an important part of deer habitat in western Kansas (Chapter 3). Deer use pasture in all seasons including stressful seasons (e.g., fawning and firearm). Adult female deer used several landcover types during their life cycle (Chapter 3). Native pasture was often used but not considered limiting due to availability across the landscape.

Several landcover types were consistently used at levels greater than availability, indicating potential to be a limiting landcover. Woodland, riparian, and CRP landcover types were relatively rare on the landscape. Selection of these landcover types varied throughout the seasons and thus, their importance varied among seasons. However, selection of a landcover type for certain seasons indicates that the landcover contributes to the overall life cycle of female deer in western Kansas; therefore, managers should consider these landcover patches important for deer populations. In addition to native pasture, these relatively rare landcover types are important to both species of deer resource selection and should be included in management strategies.

Limited research has investigated CRP use by deer in the Great Plains region (Grovenburg et al. 2018). Both species consistently selected for CRP for all season and spatial scale combinations where landcover was the top-ranked selection model. While strength of selection varied among seasons for other landcover types, CRP was consistently strongly selected at every scale for each season. The presence of CRP greatly influences resource selection by deer in western Kansas especially considering the relatively low availability of CRP across the landscape (i.e., 6% of total landscape). Tall, thick, grasses of multiple species characteristic of CRP are rarely found outside of CRP fields in western Kansas. These fields provide a refuge from human activities (e.g., harvest, farming, and ranching) and thermal cover from heat and cold throughout the year. Males of both species in western Kansas also select CRP, especially during the firearm season (Kinlan 2021). Deer in other areas also selected for CRP when it was available (Kamler et al. 2001; Grovenburg et al. 2010, 2018; Nagy-Reis et al. 2019). Vegetation composition and structure of CRP provides refuge for deer found nowhere else on the landscape.

Selection of cropland at the landscape scale varied among seasons where landcover was the top model for both species. At the landscape scale, crop was selected more frequently than native pasture but less than CRP for both species in every season. However, crop was selected less than ravine for mule deer and alternated in relative importance of selection with ravine for white-tailed deer among seasons. Both species selected and used cropland more during seasons where there was standing crop.

Conversely, at home range and core-use area scales, except for the wean season, there was no evidence of selection for cropland, as use was similar to availability. Deer selected for cropland during the wean season (late summer/early fall) when standing crops were present. Selection for cropland was lower in late fall (i.e., rut and firearm seasons) and winter than prior to crop harvest. Deer only selected for cropland when crops had achieved sufficient growth to provide forage and cover. Farmers in western Kansas tend not to leave standing corn or waste grain following harvest, effectively removing food resources or cover for most cropland other than dormant winter wheat.

Slope was an important variable for selection by mule deer at all scales. In all seasons and scales where slope was the top model, mule deer selected for steeper slopes. Slope did not appear to be influential in habitat selection by white-tailed deer because slope was not in any of the top models for any season. White-tailed deer selected for less steep slope in other sympatric studies, but mule deer commonly selected for steeper slopes (Avery et al. 2003, Leonhart 2003, Brunjes et al. 2006). Slope seems to be a vital variable for mule deer selection in western Kansas, but white-tailed deer did not select slope.

Within habitat patches, at 4th order selection, both white-tailed deer and mule deer selected for visual obstruction at greater heights than available. White-tailed deer used visual obstruction at greater heights than mule deer. Mule deer and white-tailed deer selected for steeper slopes within the patch, but mule deer used steeper slopes than white-tailed deer. While both species used canopy cover greater than available, use by white-tailed deer was three times greater than mule deer. While there are statistical differences between habitat metrics between used and available sites, the effect sizes for differences between used and available sites were small; thus, there likely is not a biological effect, as both deer species appear to use resources similar to availability within patches.

For competition to exist between species, there must be a limiting resource, which appears unlikely for deer at their current densities in western Kansas. Body condition for all but a few of the captured deer indicated healthy populations for both species (Chapter 1). Although I found similarities in resource selection between mule deer and white-tailed deer, I did not find any evidence of resource competition between these species. There appears to be sufficient resources (e.g., food, water, and space) available for both deer species even in stressful seasons in western Kansas, to support current population densities, limiting the likelihood of direct competition. However, if population trajectories for both species continues, there may be a change in resource selection by both species. The situation must be monitored to ensure that white-tailed deer populations do not increase to levels capable of outcompeting mule deer. It is currently unknown what is limiting the mule deer population in western Kansas. Potentially, landcover and agricultural practices were changed by humans and current available resources do not support past resource selection patterns when mule deer were plentiful.

Management Implications

Patches of CRP were important in mule deer resource selection. These patches provide vegetation cover and structure found nowhere else on the landscape. When CRP contracts expire and CRP is converted back to cropland or subjected to unmanaged grazing, an important resource for the decreasing mule deer population is removed from the landscape. If all CRP patches cannot be maintained, additional investigation is needed to determine configuration of CRP patches of greatest benefit to deer. Deer likely select CRP tracts based on the surrounding landscape and that information can be extrapolated to other CRP sites and surrounding landscapes occupied by mule deer. Sustaining CRP and choosing to re-enroll important patches of CRP may contribute to the persistence of the mule deer population given the lack of an apparent limiting factor related to resource selection.

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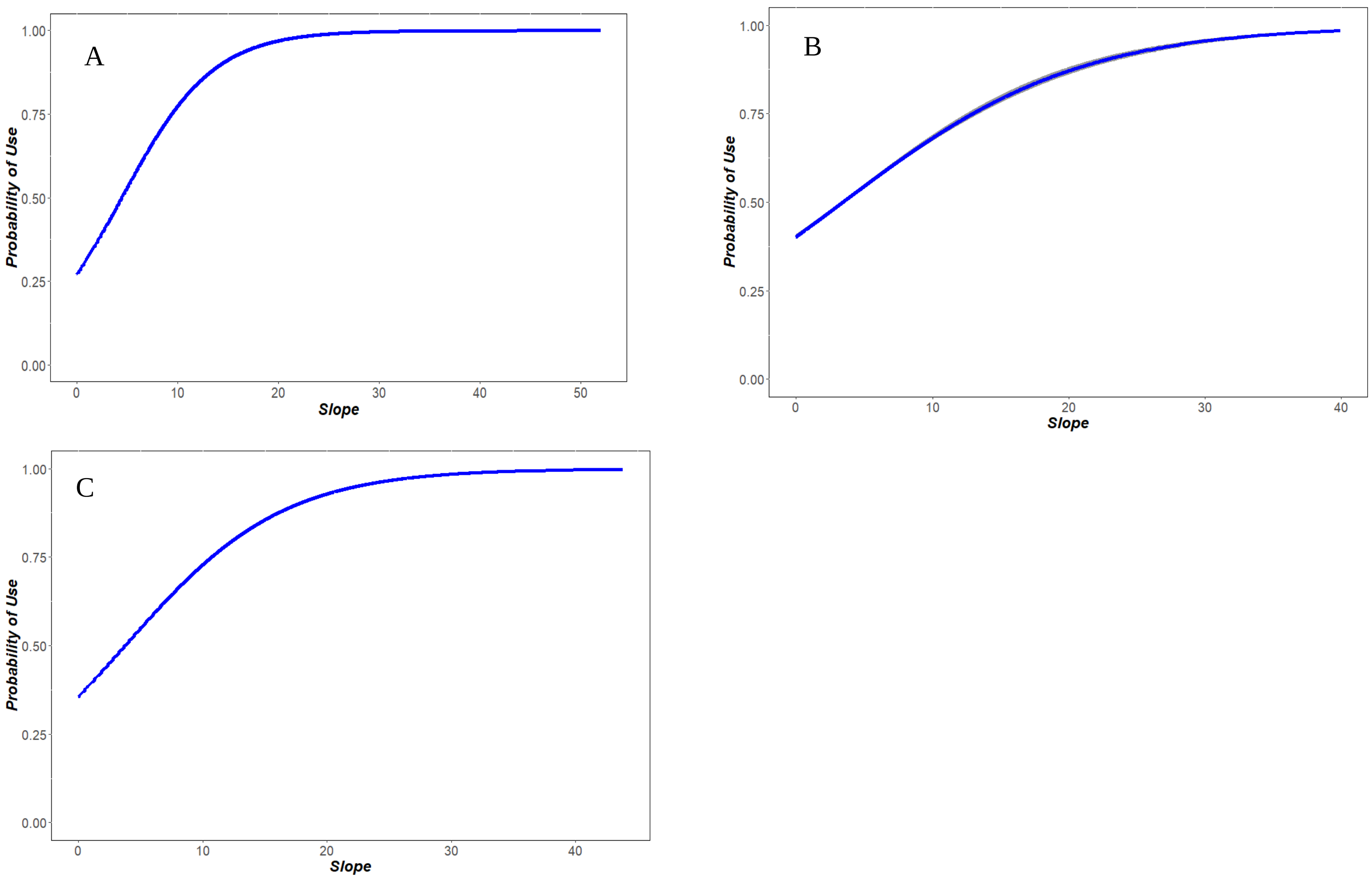

Figure 4.1 The predicted probability of use of degree of slope for adult female mule deer in the pregnancy season (A), firearm season (B), and winter season (C) at the landscape scale in western Kansas, USA, during 2018 to 2021.

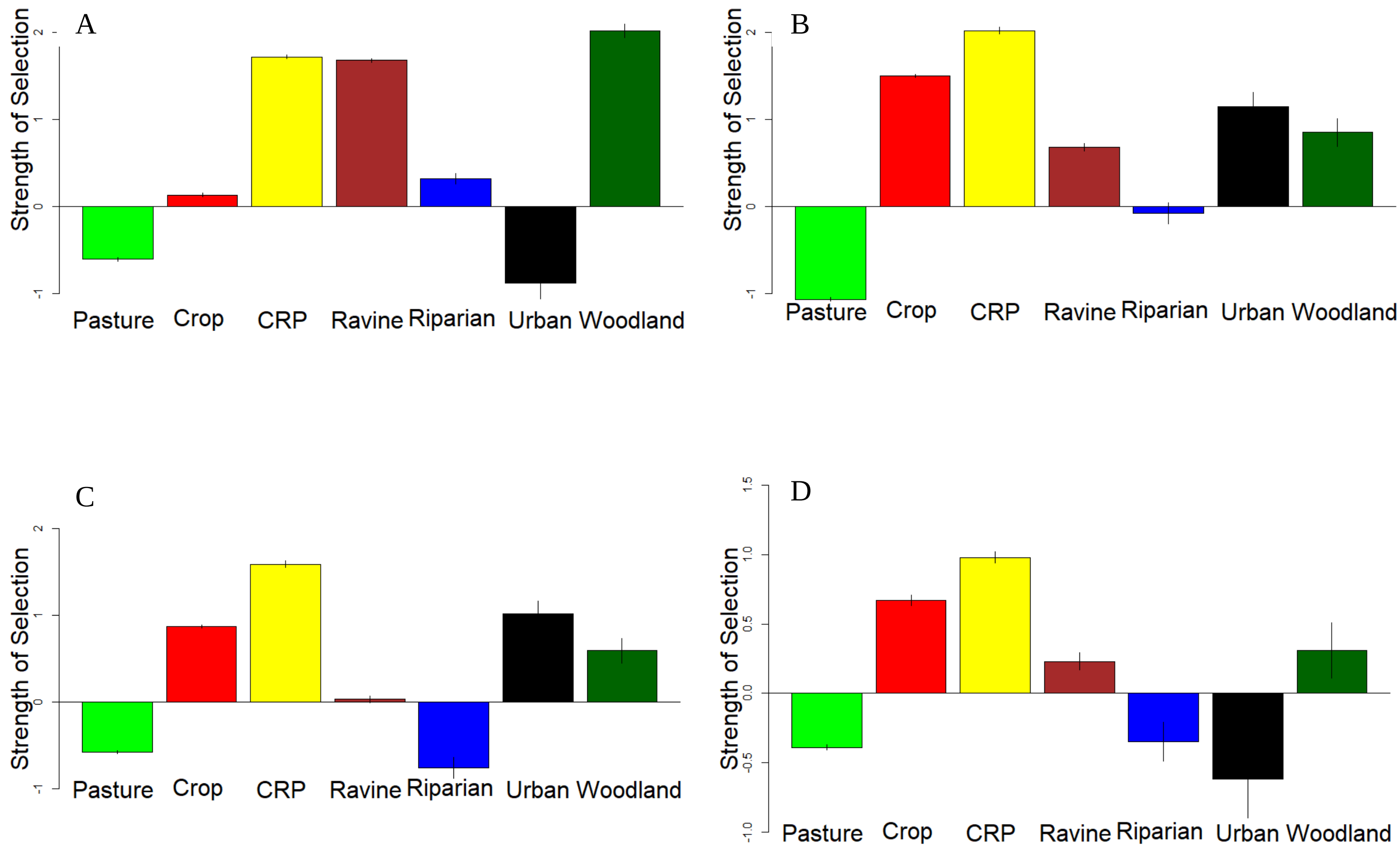

Figure 4.2. The strength of selection for adult female mule deer for landcover type for the fawn season (A), wean season (B), fall season (C), and rut season (D) at the landscape scale in western Kansas, USA, during 2018 to 2021

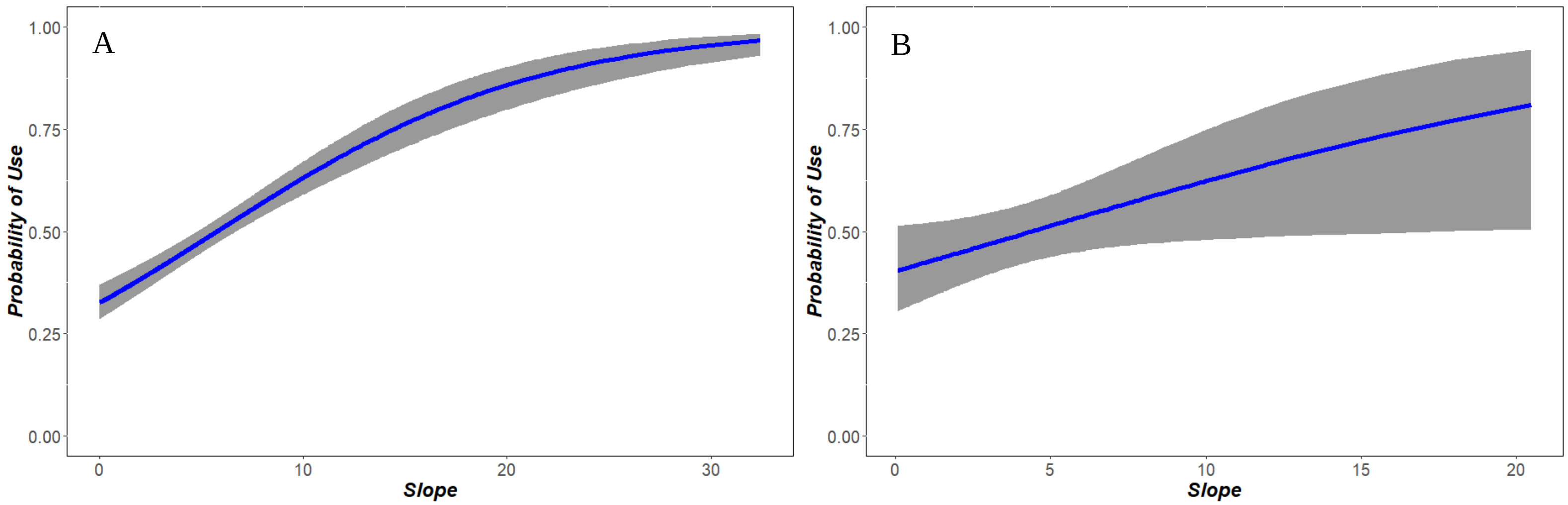

Figure 4.3. The predicted probability of use of degree of slope for adult female mule deer in the pregnancy season (A) and firearm season (B) at the home range scale in western Kansas, USA, during 2018 to 2021.

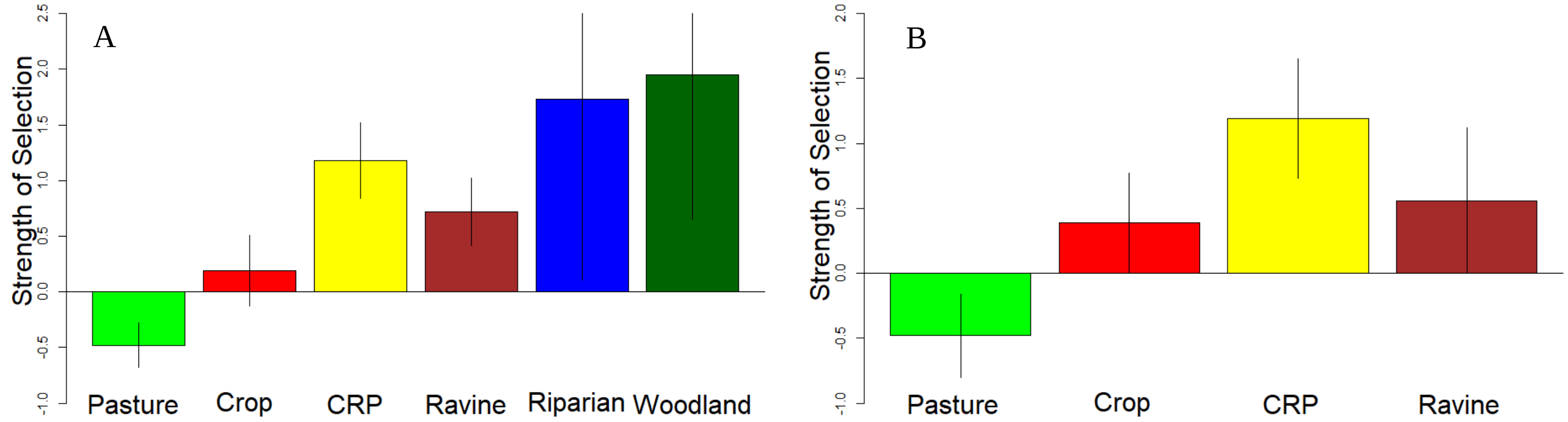

Figure 4.4. The strength of selection for adult female mule deer for landcover type for the fawn season (A) and wean season (B), at the home range scale in western Kansas, USA, during 2018 to 2021.

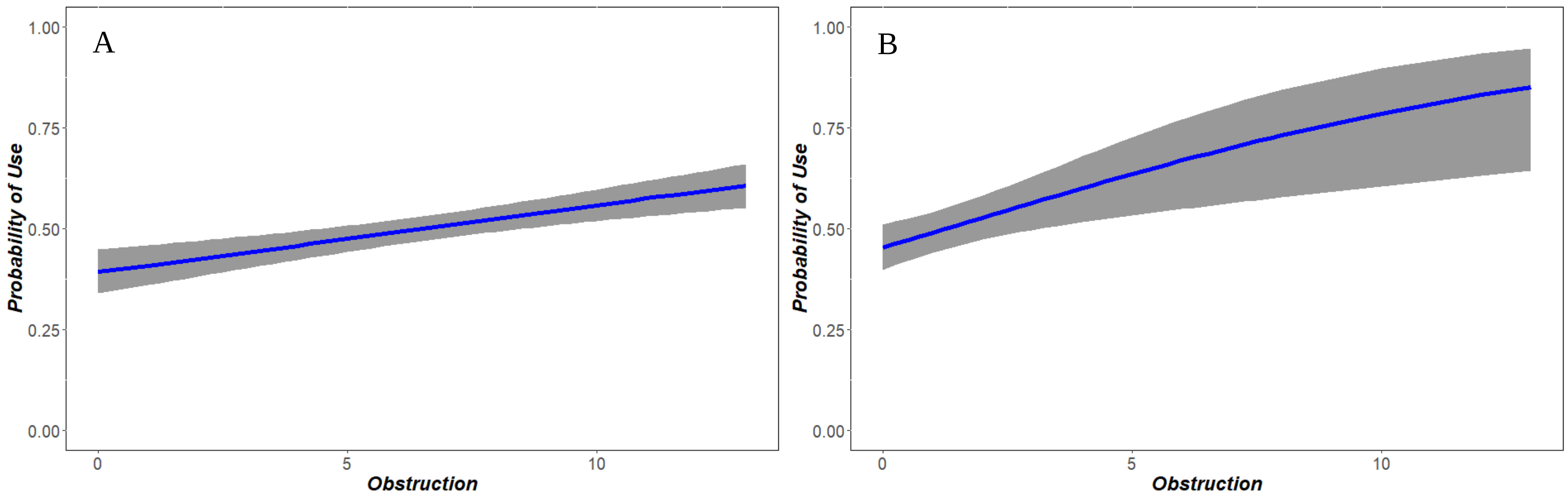

Figure 4.5. The predicted probability of use of 0% visual obstruction in decimeters (dm) for adult female mule deer in the fall season (A) and 100% visual obstruction in the rut season (B) at the home range scale in western Kansas, USA, during 2018 to 2021.

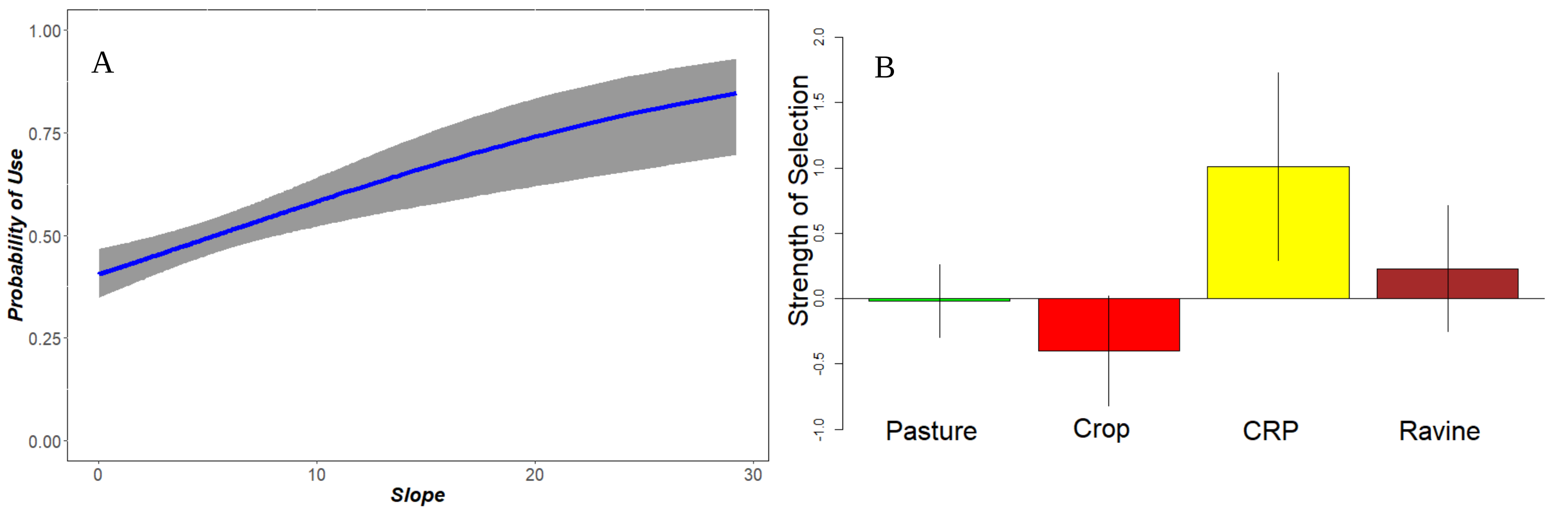

Figure 4.6 The competing top models for adult female mule deer in the winter season, the predicted probability of use of slope and the strength of selection for landcover type at the home range scale in western Kansas, USA during 2018 to 2021.

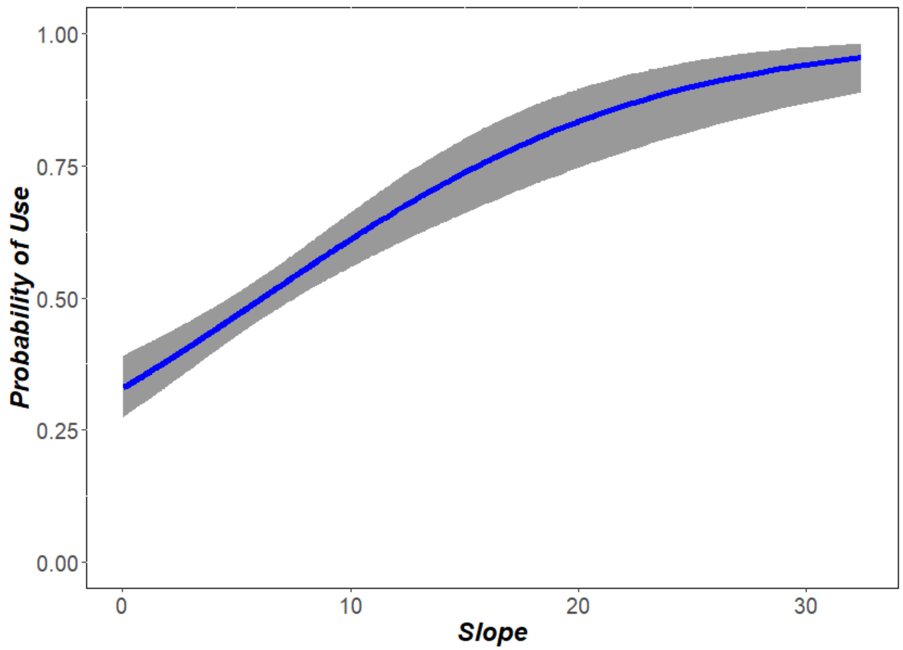

Figure 4.7. The predicted probability of use of slope for adult female mule deer in the pregnancy season at the core-use area scale in western Kansas, USA, during 2018 to 2021.

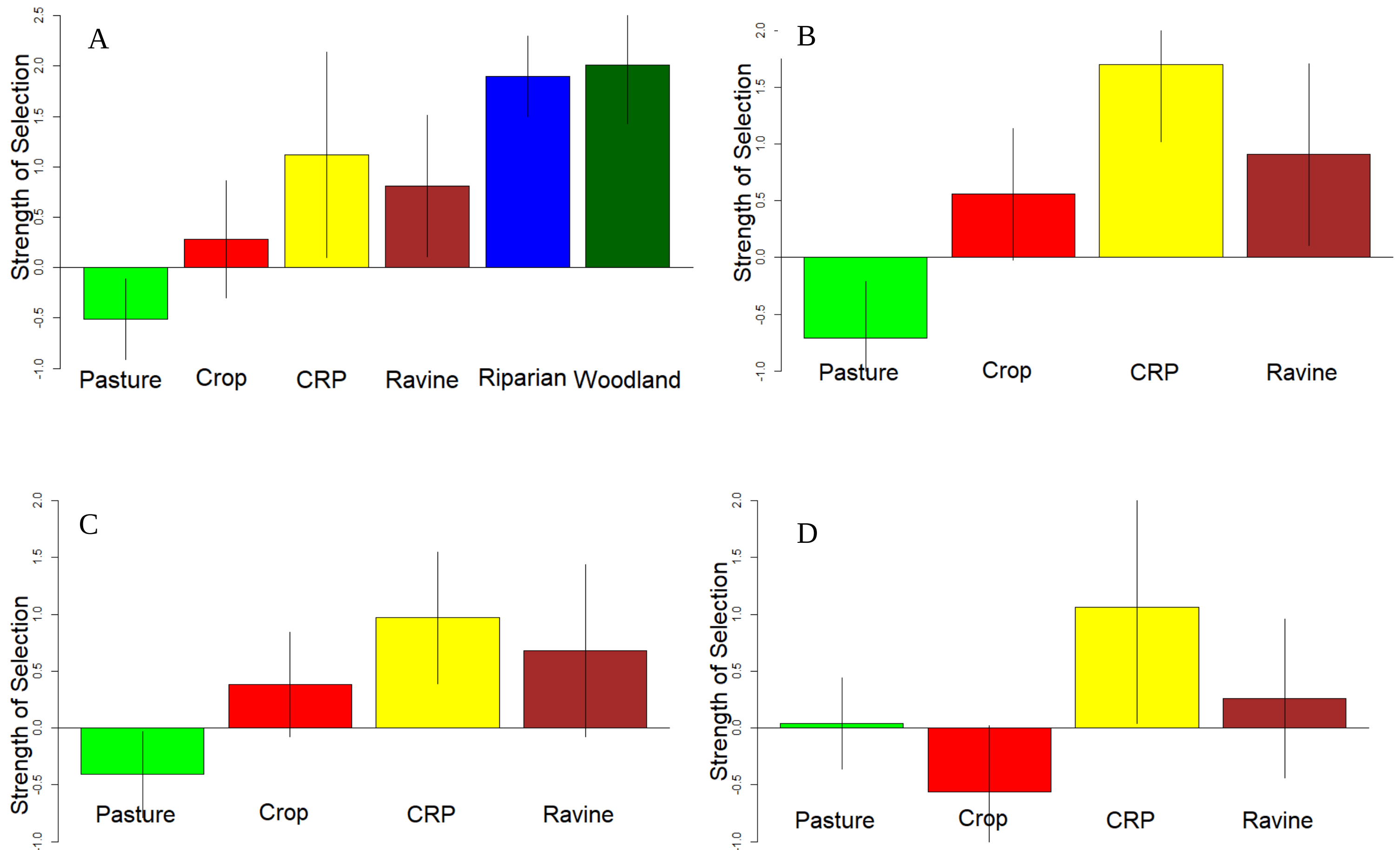

Figure 4.8. The strength of selection for adult female mule deer for landcover type for the fawn season (A), wean season (B), fall season (C), and winter season (D) at the core-use area scale in western Kansas, USA, during 2018 to 2021.

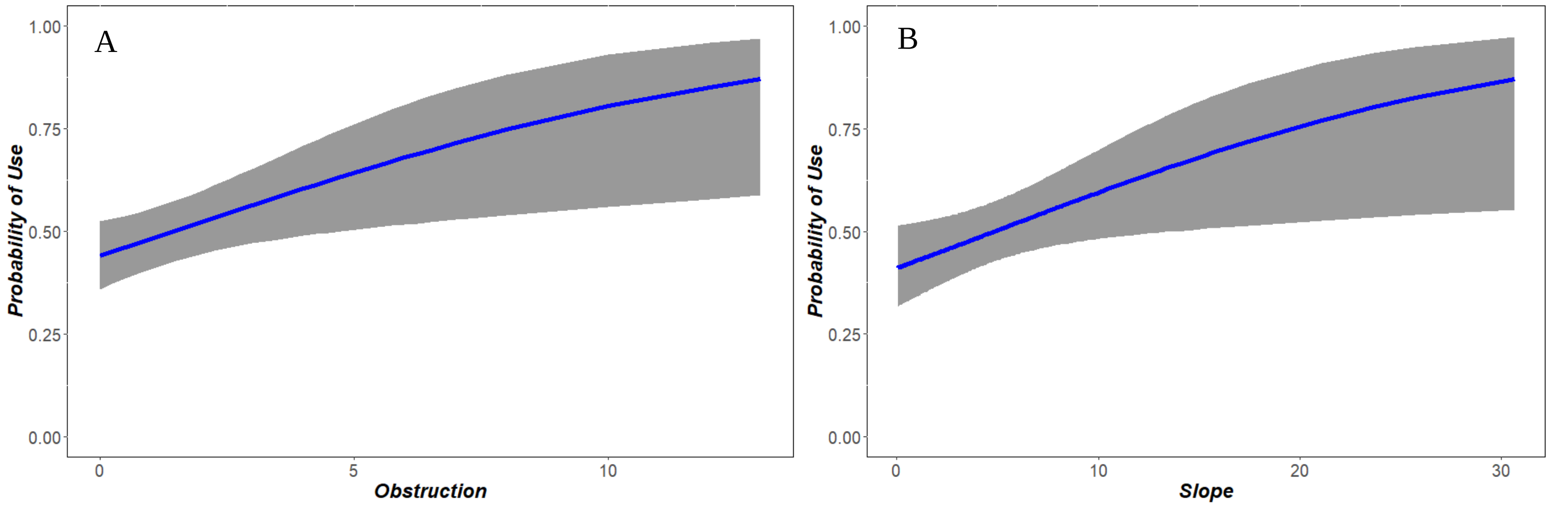

Figure 4.9. The competing top models for adult female mule deer in the rut season the predicted probability of use of 100% visual obstruction (A) in decimeters (dm) and the predicted probability of use of slope (B) at the core-use area scale in western Kansas, USA, during 2018 to 2021.

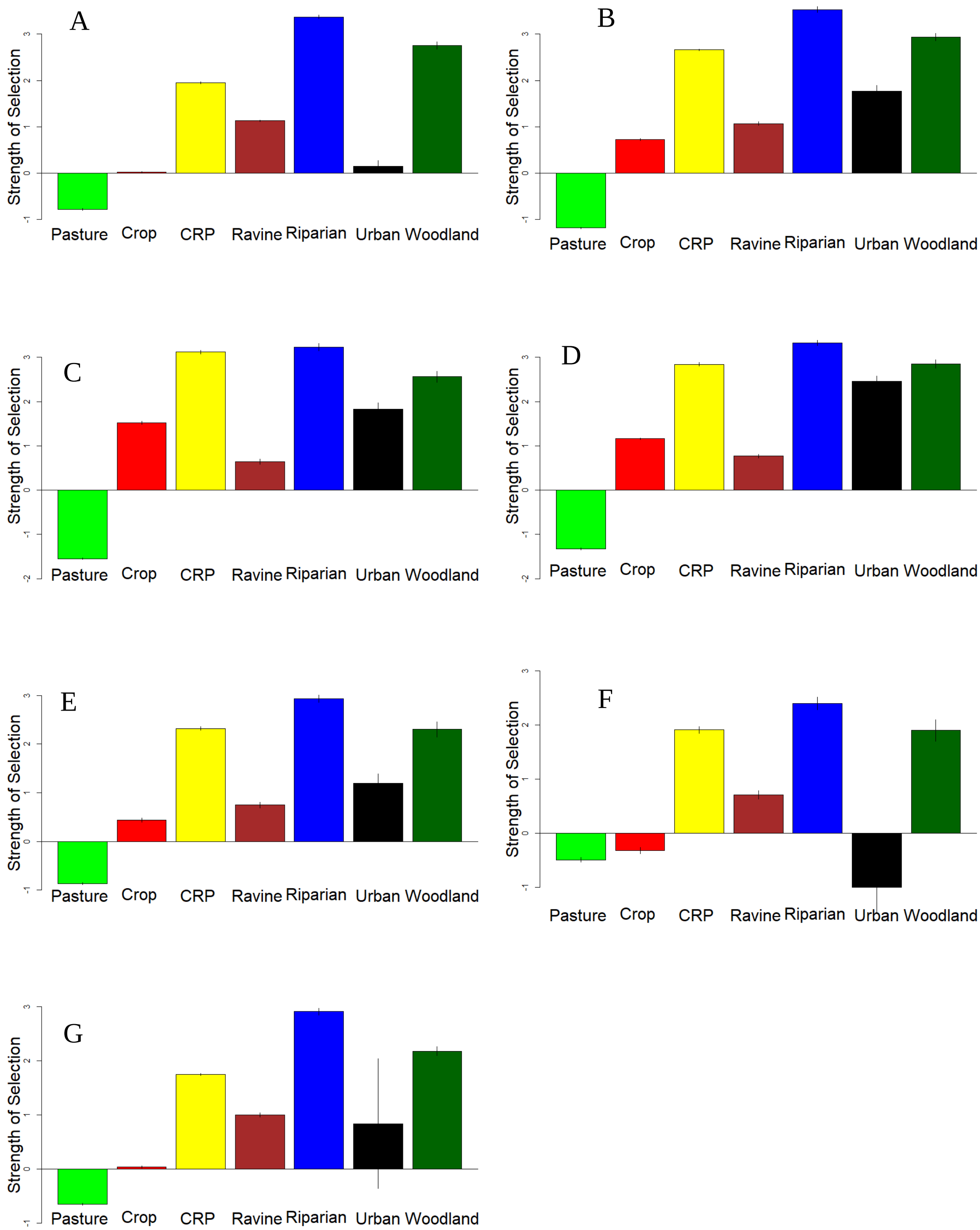

Figure 4.10 The strength of selection of adult female white-tailed deer for landcover type for the pregnancy season (A), fawn season (B), wean season (C), fall season (D), rut season (E), firearm season (F), and winter season (G) at the landscape scale in western Kansas, USA, during 2018 to 2021.

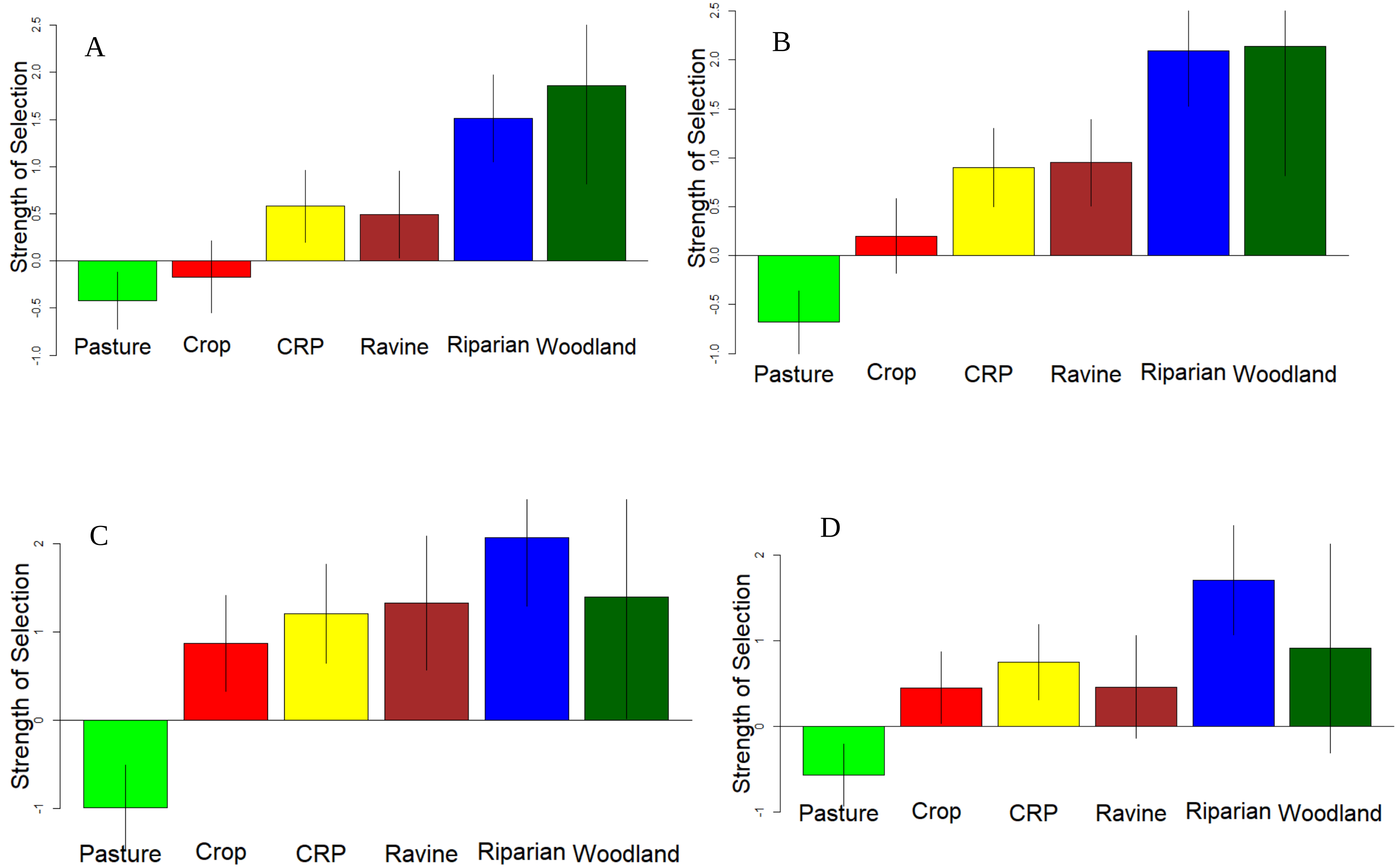

Figure 4.11. The strength of selection for landcover type for the pregnancy season (A), fawn season (B), wean season (C), and fall season (D), at the home range scale by adult female white-tailed deer in western Kansas, USA, during 2018 to 2021.

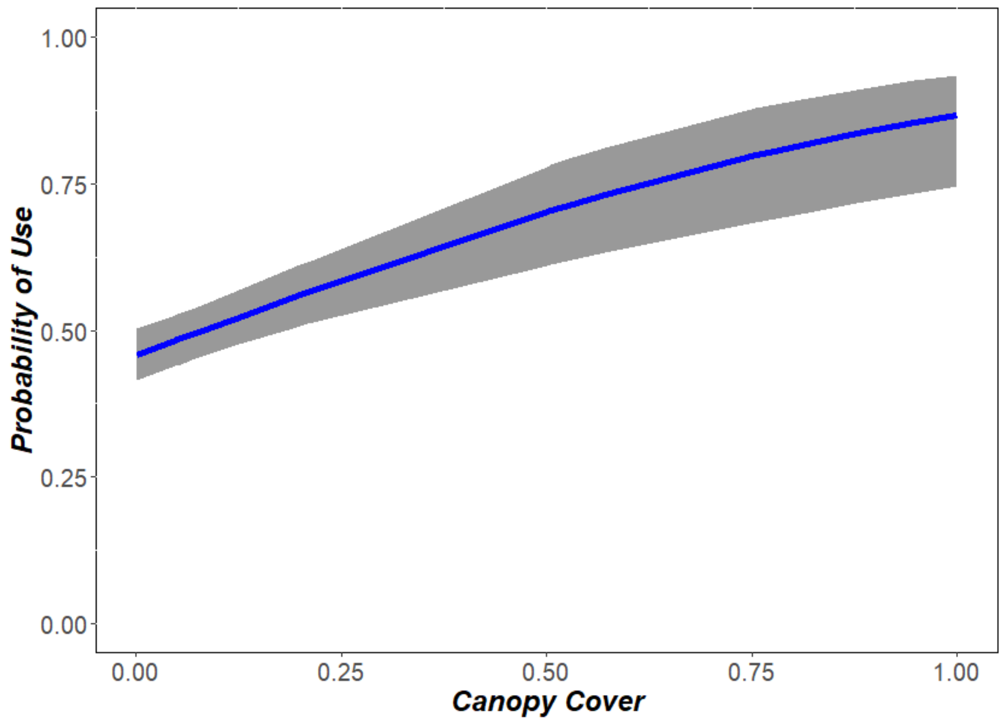

Figure 4.12. The predicted probability of use of percent of canopy cover for adult female white-tailed deer in the winter season at the home range scale in western Kansas, USA, during 2018 to 2021.

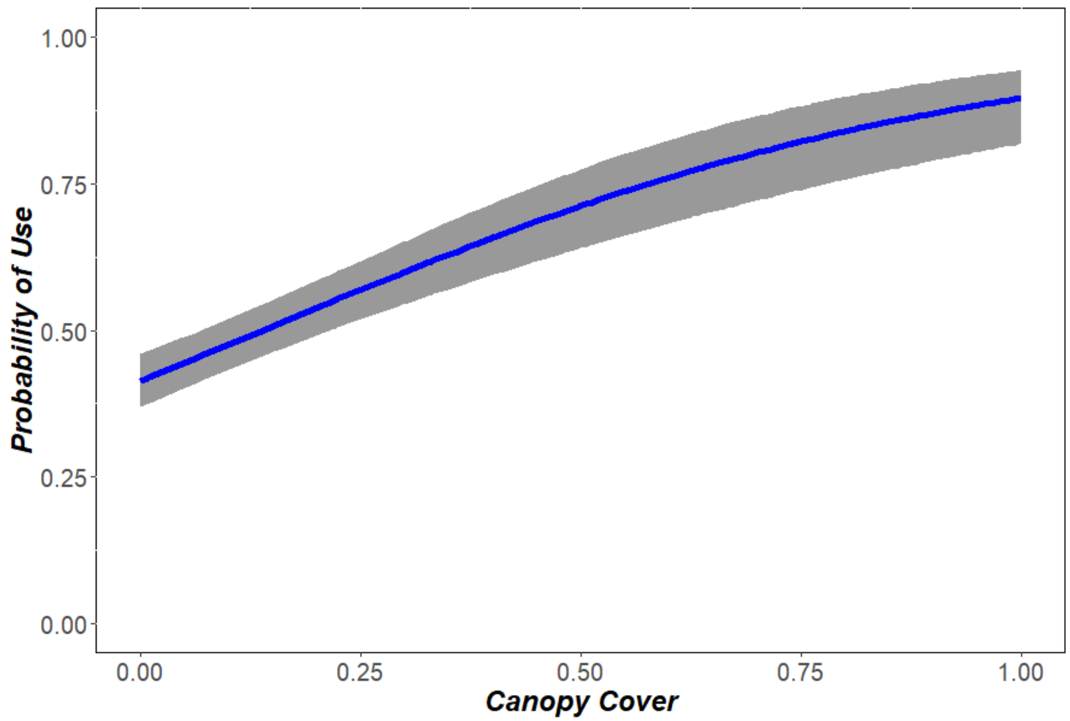

Figure 4.13. The predicted probability of use of percent of canopy cover for adult female white-tailed deer in the pregnancy season at the core-use area scale in western Kansas, USA, during 2018 to 2021.

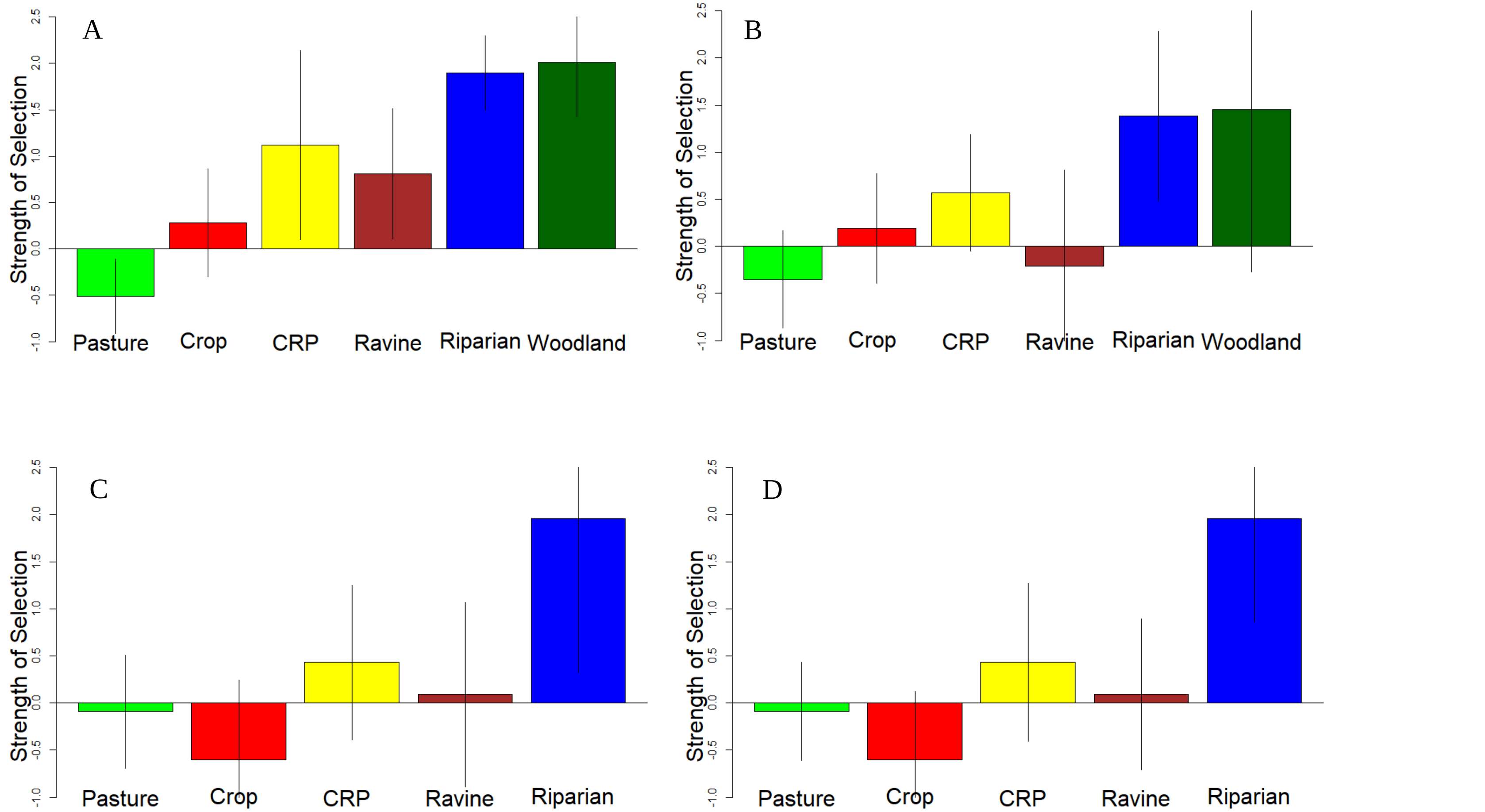

Figure 4.14. The strength of selection for landcover type for the fawn season (A), fall season (B), rut season (C), and winter season (D) at the core-use area scale by adult female white-tailed deer in western Kansas, USA, during 2018 to 2021.

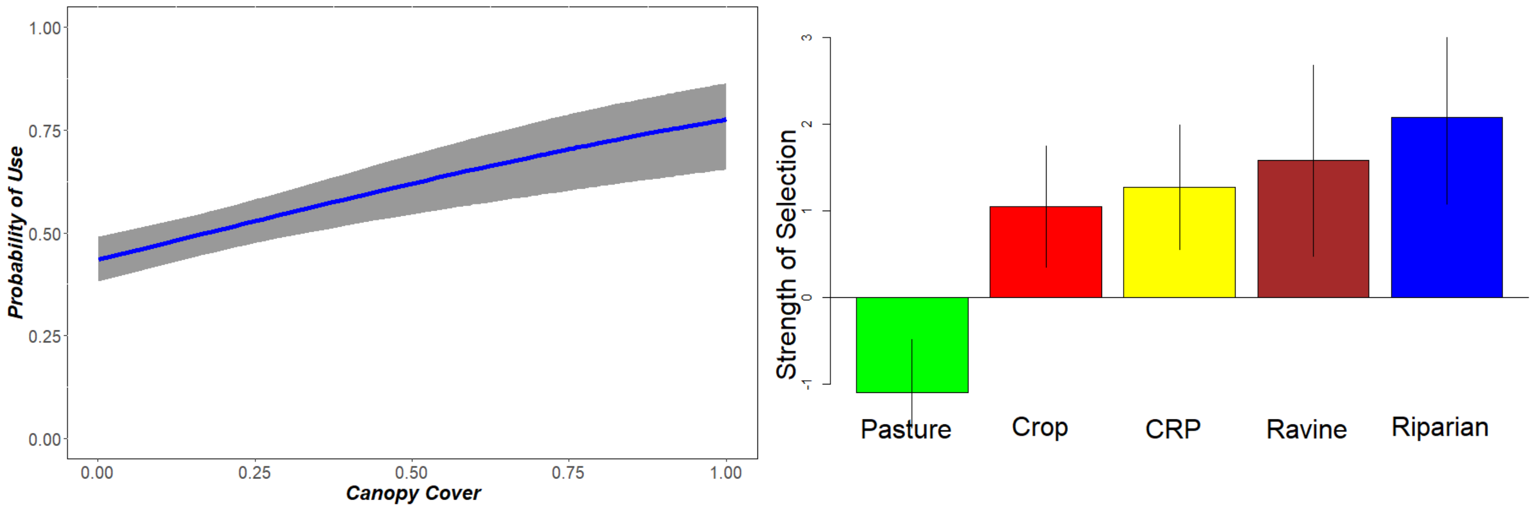

Figure 4.15. The competing top models for adult female white-tailed deer in the wean season, the predicted probability of use of percent of canopy cover (A) and strength of selection for landcover type (B) at the core area scale in western Kansas, USA, during 2018 to 2021.

Table 4.1. Variables comprising model suites for resource selection analysis for mule deer and white-tailed deer in three spatial scales (landscape, home range and core area) in deer for two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

Scale	Variables
Landscape model suite	Landcover type
	Elevation
	Slope
	Aspect
Home range and core area model suite	Landcover types
	Elevation
	Slope
	Aspect
	Obstruction 0%
	Obstruction 25%
	Obstruction 50%
	Obstruction 75%
	Obstruction 100%
	Grass
	Forb
	Shrub
	Bare ground
	Litter
	Succulent
	Vegetation height
	Litter depth
	Canopy cover

Table 4.2. Four highest ranking *a priori* models for seasonal landscape scale resource selection by female mule deer for two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021. I present Akaike's Information Criterion adjusted for small sample size (AIC_c), ΔAIC_c, Akaike weights (w_i), parameters (K), and log likelihood**.**

	AIC_c	ΔAIC_c	w_i	K	logLik
Pregnancy					
Slope	420749	0	1	2	-210372
Landcover	448755	28006.1	0	7	-224370
Aspect	486676	65927.4	0	2	-243336
Elevation	486901	66152	0	2	-243448
Fawn					
Landcover	342445	0	1	7	-171216
Slope	345513	3067.28	0	2	-172754
Aspect	380914	38469	0	2	-190455
Elevation	380915	38470.1	0	2	-190456
Wean					
Landcover	192051	0	1	7	-96019
Elevation	208881	16829.9	0	2	-104439
Aspect	210789	18738.1	0	2	-105393
Slope	210822	18770.5	0	2	-105409
Fall					
Landcover	226490	0	1	7	-113238
Elevation	238062	11571.9	0	2	-119029
Slope	239329	12839.1	0	2	-119663
Aspect	239433	12943.1	0	2	-119715
Rut					
Landcover	122202	0	1	7	-61094
Slope	124282	2080.53	0	2	-62139
Elevation	124345	2143.48	0	2	-62171
Aspect	124771	2569.43	0	2	-62384
Firearm					
Slope	56376.7	0	1	2	-28186
Landcover	56770.4	393.75	0	7	-28378
Elevation	57935.4	1558.75	0	2	-28966
Aspect	58245	1868.29	0	2	-29121
Winter					
Slope	343513	0	1	2	-171755
Landcover	354629	11115.8	0	7	-177308
Elevation	363337	19823.3	0	2	-181666

Aspect	365495	21981.8	0	2	-182746

Table 4.3. Five highest ranking *a priori* models for seasonal home range scale resource selection by female mule deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018-2022. I present the Akaike's Information Criterion adjusted for small sample size (AIC_c), ΔAIC_c, Akaike weights (w_i), parameters (K), and log likelihood.

	AIC_c	ΔAIC_c	w_i	K	logLik
Pregnancy					
Slope	1588	0	1	2	-791.99
Canopy Cover	1653.5	65.5	0	2	-824.74
Shrub	1662.7	74.72	0	2	-829.35
Obstruction	1671.2	83.23	0	2	-833.60
Landcover	1679.8	91.81	0	6	-833.86
Fawn					
Landcover	1737.4	0	1	6	-862.66
Obstruction	1767.4	30	0	2	-881.69
Shrub	1769.3	31.97	0	2	-882.67
Slope	1779.4	42.01	0	2	-887.69
Veg Height	1790.4	52.99	0	2	-893.18
Wean					
Landcover	1103	0	1	4	-547.45
Obstruction	1125.6	22.6	0	2	-560.77
Veg Height	1133.3	30.35	0	2	-564.64
Slope	1135.4	32.4	0	2	-565.67
Shrub	1139.8	36.85	0	2	-567.89
Fall					
Obstruction	1425.8	0	0.797	2	-710.90
Landcover	1428.6	2.78	0.198	6	-708.26
Slope	1438.2	12.38	0.002	2	-717.09
Litter Depth	1439.1	13.34	0.001	2	-717.57
Forb	1439.2	13.37	0.001	2	-717.59
Rut					
Obstruction	518.6	0	0.703	2	-257.29
Slope	522.1	3.5	0.122	2	-259.04
Landcover	523.4	4.81	0.063	5	-256.63
Canopy Cover	523.9	5.33	0.049	2	-259.95
Veg Height	526	7.43	0.017	2	-261.00
Firearm					
Slope	253.1	0	0.357	2	-124.50
Grass	256.7	3.61	0.059	2	-126.31
Forb	256.9	3.81	0.053	2	-126.41
Veg Height	257.2	4.15	0.045	2	-126.58

Obstruction	257.2	4.18	0.044	2	-126.59
Winter					
Landcover	737	0	0.68	4	-364.47
Slope	738.6	1.54	0.315	2	-367.26
Veg Height	749.4	12.34	0.001	2	-372.67
Succulent	750.2	13.17	0.001	2	-373.08
Shrub	751.6	14.57	0	2	-373.78

Table 4.4. Five highest ranking *a priori* models for seasonal core area scale resource selection by female mule deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA. I present the Akaike's Information Criterion adjusted for small sample size (AIC_c), ΔAIC_c, Akaike weights (w_i), parameters (K), and log likelihood.

	AIC_c	ΔAIC_c	w_i	K	logLik
Pregnancy					
Slope	846.7	0	0.999	2	-421.36
Canopy Cover	861.7	15	0.001	2	-428.86
Shrub	872.7	25.99	0	2	-434.36
Obstruction	884.9	38.18	0	2	-440.45
Landcover	886.9	40.2	0	5	-438.43
Fawn					
Landcover	849.5	0	0.909	6	-418.69
Obstruction	854.4	4.89	0.079	2	-425.19
Shrub	858.1	8.56	0.013	2	-427.02
Slope	866.5	16.97	0	2	-431.23
Veg Height	868.9	19.43	0	2	-432.46
Wean					
Landcover	554.9	0	1	4	-273.39
Obstruction	572.3	17.39	0	2	-284.12
Forb	576.8	21.9	0	2	-286.37
Veg Height	581.3	26.45	0	2	-288.65
Bare Ground	584.3	29.39	0	2	-290.12
Fall					
Landcover	701.6	0	0.798	4	-346.76
Obstruction	706.7	5.14	0.061	2	-351.36
Litter Depth	707.0	5.38	0.054	2	-351.48
Veg Height	709.0	7.38	0.02	2	-352.48
Forb	709.5	7.92	0.015	2	-352.75
Rut					
Obstruction	250.1	0	0.553	2	-123.04
Slope	252.0	1.82	0.223	2	-123.95
Bare Ground	255.2	5.09	0.043	2	-125.58
Veg Height	255.4	5.3	0.039	2	-125.69
Shrub	256.0	5.87	0.029	2	-125.97
Winter					
Landcover	363.7	0	0.543	4	-177.76
Slope	366.7	3.03	0.119	2	-181.33
Canopy Cover	367.1	3.45	0.097	2	-181.54
Forb	369.0	5.32	0.038	2	-182.47

Bare Ground	369.2	5.49	0.035	2	-182.56

Table 4.5. Four highest ranking *a priori* models for seasonal landscape scale resource selection by female white-tailed deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018-2022. I present the Akaike's Information Criterion adjusted for small sample size (AIC_c), ΔAIC_c, Akaike weights (w_i), parameters (K), and log likelihood.

	AIC_c	ΔAIC_c	w_i	K	logLik
Pregnancy					
Landcover	358339	0	1	7	-179162
Slope	425671	67331.8	0	2	-212833
Elevation	433006	74667.5	0	2	-216501
Aspect	436838	78498.9	0	2	-218417
Fawn					
Landcover	288656	0	1	7	-144321
Slope	355942	67285.6	0	2	-177969
Elevation	356245	67588.5	0	2	-178120
Aspect	356880	68223.8	0	2	-178438
Wean					
Landcover	158015	0	1	7	-79001
Aspect	193562	35547.2	0	2	-96779
Slope	193753	35737.6	0	2	-96874
Elevation	194041	36025.4	0	2	-97018
Fall					
Landcover	183328	0	1	7	-91657
Elevation	222672	39344.5	0	2	-111334
Aspect	222961	39633.6	0	2	-111479
Slope	223310	39982	0	2	-111653
Rut					
Landcover	96045.3	0	1	7	-48016
Elevation	112571	16526.1	0	2	-56284
Slope	112651	16605.4	0	2	-56323
Aspect	112798	16753.2	0	2	-56397
Firearm					
Landcover	44901.4	0	1	7	-22444
Slope	51558	6656.67	0	2	-25777
Elevation	51737.9	6836.54	0	2	-25867
Aspect	52198.3	7296.94	0	2	-26097
Winter					
Landcover	265285	0	1	7	-132636
Elevation	301576	36290.1	0	2	-150786
Slope	305054	39768.5	0	2	-152525
Aspect	308901	43616	0	2	-154449

Table 4.6. Five highest ranking *a priori* models for seasonal homerange scale resource selection by female white-tailed deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018-2022. I present the Akaike's Information Criterion adjusted for small sample size (AIC_c), ΔAIC_c, Akaike weights (w_i), parameters (K), and log likelihood.

	AIC_c	ΔAIC_c	w_i	K	logLik
Pregnancy					
Landcover	1361.2	0	0.76	6	-674.57
Canopy Cover	1363.5	2.3	0.24	2	-679.76
Obstruction	1402.1	40.85	0	2	-699.03
Bare Ground	1406.1	44.84	0	2	-701.03
Veg Height	1429.2	67.94	0	2	-712.57
Fawn					
Landcover	1571.3	0	1	6	-779.6
Canopy Cover	1608.2	36.94	0	2	-802.10
Obstruction	1628.5	57.26	0	2	-812.26
Bare Ground	1659.6	88.29	0	2	-827.78
Litter Depth	1661.6	90.3	0	2	-828.78
Wean					
Landcover	1008.3	0	1	6	-498.08
Canopy Cover	1042.1	33.83	0	2	-519.04
Litter Depth	1044.5	36.22	0	2	-520.24
Forb	1048.7	40.42	0	2	-522.34
Obstruction	1049.5	41.23	0	2	-522.74
Fall					
Landcover	1245.6	0	1	6	-616.74
Obstruction	1272.0	26.47	0	2	-634.01
Canopy Cover	1278.4	32.84	0	2	-637.20
Litter Depth	1283.8	38.18	0	2	-639.87
Veg Height	1286.0	40.4	0	2	-640.98
Rut					
Landcover	444.8	0	0.966	5	-217.32
Slope	452.0	7.2	0.026	2	-224.00
Obstruction	455.4	10.6	0.005	2	-225.70
Canopy Cover	457.8	12.95	0.001	2	-226.87
Veg Height	461.2	16.36	0	2	-228.58
Firearm					
Landcover	234.8	0	0.77	5	-112.22
Canopy Cover	239.8	4.98	0.064	2	-117.86

Obstruction	240.9	6.1	0.037	2	-118.42
Litter	241.5	6.66	0.028	2	-118.70
Litter Depth	241.9	7.06	0.023	2	-118.90
Winter					
Canopy Cover	707.5	0	0.85	2	-351.74
Landcover	711.0	3.47	0.15	6	-349.40
Slope	730.8	23.33	0	2	-363.40
Litter	735.4	27.93	0	2	-365.70
Bare Ground	736.8	29.34	0	2	-366.41

Table 4.7. Five highest ranking *a priori* models for seasonal core area scale resource selection by female white-tailed deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA. I present the Akaike's Information Criterion adjusted for small sample size (AIC_c), ΔAIC_c, Akaike weights (w_i), parameters (K), and log likelihood.

	AIC_c	ΔAIC_c	w_i	K	logLik
Pregnancy					
Canopy Cover	723	0	0.989	2	-359.47
Landcover	732	9.06	0.011	7	-358.90
Bare Ground	751.4	28.45	0	2	-373.69
Obstruction	752.5	29.5	0	2	-374.22
Veg Height	766.4	43.43	0	2	-381.18
Fawn					
Landcover	820.1	0	0.962	6	-404.00
Obstruction	826.7	6.6	0.035	2	-411.36
Canopy Cover	832.1	11.92	0.002	2	-414.02
Litter Depth	854.9	34.72	0	2	-425.42
Forb	855.3	35.13	0	2	-425.63
Wean					
Landcover	527.2	0	0.654	6	-257.51
Canopy Cover	528.7	1.42	0.321	2	-262.32
Litter Depth	534.6	7.34	0.017	2	-265.28
Obstruction	536.3	9.06	0.007	2	-266.14
Litter	540.7	13.46	0.001	2	-268.34
Fall					
Landcover	628.4	0	0.792	6	-308.09
Obstruction	632	3.6	0.131	2	-313.96
Veg Height	634.2	5.8	0.044	2	-315.07
Bare Ground	635.4	7.06	0.023	2	-315.70
Forb	638	9.69	0.006	2	-317.01
Rut					
Landcover	255.9	0	0.983	5	-122.80
Slope	265.7	9.74	0.008	2	-130.80
Obstruction	266.5	10.54	0.005	2	-131.20
Veg Height	269.7	13.78	0.001	2	-132.82
Forb	270.2	14.3	0.001	2	-133.08
Winter					
Landcover	328.2	0	0.728	5	-158.97
Canopy Cover	330.2	2.03	0.264	2	-163.08
Slope	338.8	10.65	0.004	2	-167.39
Bare Ground	340.3	12.13	0.002	2	-168.13

Litter Depth	342.5	14.33	0.001	2	-169.24

Table 4.8. Comparison of mean (±SE) variables for used locations adult female mule deer (MD) and white-tailed deer (WTD) in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove and Lane counties]) in western Kansas, USA, during 2018 to 2021.

	$\bar{x}$ MD	$\bar{x}$ WTD	*t*	DF	*P*
0% obstruction (dm)	5.71 ± 0.07	6.27 ± 0.08	-5.49	5198.1	<0.001
25% obstruction (dm)	4.54 ± 0.07	5.04 ± 0.08	-4.62	5222.1	<0.001
50% obstruction (dm)	3.96 ± 0.07	4.42 ± 0.08	-4.34	5223.7	<0.001
75% obstruction (dm)	3.56 ± 0.07	3.98 ± 0.08	-4.11	5223.6	<0.001
100% obstruction (dm)	2.31 ± 0.07	2.75 ± 0.07	-4.45	5205.7	<0.001
grass %	43.33 ± 0.55	42.63 ± 0.6	0.86	5211.1	0.39
forb %	11.63 ± 0.29	13.94 ± 0.42	-4.52	4606.4	<0.001
shrub %	3.67 ± 0.11	3.30 ± 0.10	2.52	5317.9	0.01
bare ground %	16.52 ± 0.41	11.51 ± 0.35	9.28	5233.0	<0.001
litter %	28.82 ± 0.49	32.45 ± 0.55	-4.96	5179.6	<0.001
succulent %	3.24 ± 0.07	3.19 ± 0.07	0.51	5167.9	0.61
vegetation height (cm)	47.04 ± 0.71	55.29 ± 0.87	-7.36	5007.0	<0.001
litter depth (cm)	2.39 ± 0.08	2.63 ± 0.09	-1.89	5190.3	0.06
canopy cover %	0.06 ± 0.004	0.19 ± 0.01	-17.9	3775.7	<0.001
elevation (m)	810.71 ± 1.11	795.66 ± 1.39	8.40	4960.9	<0.001
slope (degree)	5.59 ± 0.10	3.77 ± 0.08	13.54	5117.6	<0.001
Aspect	0.14 ± 0.01	0.06 ± 0.01	4.35	5187.4	<0.001

Table 4.9. Comparison of mean (±SE) variables for actual used locations and random points within patches of adult female mule deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018 to 2021.

	$\bar{x}$ actual	$\bar{x}$ random	*t*	DF	*P*
0% obstruction (dm)	5.71 ± 0.07	4.81 ± 0.06	9.62	5543.4	<0.001
25% obstruction (dm)	4.54 ± 0.07	3.63 ± 0.07	9.33	5533.6	<0.001
50% obstruction (dm)	3.96 ± 0.07	3.08 ± 0.06	9.32	5511.9	<0.001
75% obstruction (dm)	3.56 ± 0.07	2.74 ± 0.06	8.08	5510.6	<0.001
100% obstruction (dm)	2.31 ± 0.07	1.71 ± 0.06	6.68	5446.6	<0.001
grass %	43.33 ± 0.55	44.66 ± 0.56	-1.69	5572.3	0.09
forb %	11.63 ± 0.29	10.27 ± 0.27	3.41	5543.3	>0.001
shrub %	3.67 ± 0.11	2.80 ± 0.04	7.58	3487.9	>0.001
bare ground %	16.52 ± 0.41	18.00 ± 0.44	-2.43	5554	0.01
litter %	28.82 ± 0.49	28.12 ± 0.49	1.00	5575.7	0.32
succulent %	3.24 ± 0.07	3.21 ± 0.07	0.38	5575.7	0.71
vegetation height (cm)	47.04 ± 0.71	40.59 ± 0.66	6.68	5545.6	<0.001
litter depth (cm)	2.39 ± 0.08	2.04 ± 0.07	3.25	5453.3	0.001
canopy cover %	0.06 ± 0.004	0.03 ± 0.003	5.26	5227.8	<0.001
elevation (m)	810.71 ± 1.11	812.95 ± 1.11	-1.43	5576.0	0.15
slope (degree)	5.59 ± 0.11	4.01 ± 0.08	12.03	5102.0	<0.001
aspect	0.14 ± 0.01	0.12 ± 0.01	1.04	5573.1	0.30

Table 4.10. Comparison of mean (±SE) variables for actual used locations and random points within patches of adult female white-tailed deer in the two study sites (North [Decatur, Norton, Sheridan, and Graham counties] and South [Logan, Scott, Gove, and Lane counties]) in western Kansas, USA, during 2018 to 2021**.**

	$\bar{x}$ actual	$\bar{x}$ random	*t*	DF	*P*
0% obstruction (dm)	6.27 ± 0.08	5.16 ± 0.07	10.70	5045.1	<0.001
25% obstruction (dm)	5.04 ± 0.08	3.95 ± 0.07	10.10	5039.6	<0.001
50% obstruction (dm)	4.42 ± 0.08	3.44 ± 0.07	9.35	5030.6	<0.001
75% obstruction (dm)	3.98 ± 0.08	3.09 ± 0.07	8.70	5019.8	<0.001
100% obstruction (dm)	2.75 ± 0.07	2.08 ± 0.07	6.77	4982.1	<0.001
grass %	42.63 ± 0.60	44.72 ± 0.61	-2.45	5063.7	0.01
forb %	13.94 ± 0.42	10.39 ± 0.31	6.83	4648.5	<0.001
shrub %	3.30 ± 0.10	2.74 ± 0.05	4.76	3837.2	<0.001
bare ground %	11.51 ± 0.35	16.39 ± 0.44	-8.74	4815.4	<0.001
litter %	32.45 ± 0.55	29.50 ± 0.52	3.91	5050.4	<0.001
succulent %	3.19 ± 0.07	3.17 ± 0.07	0.25	5032.2	0.80
vegetation height (cm)	55.29 ± 0.87	47.65 ± 0.83	6.36	5053.4	<0.001
litter depth (cm)	2.63 ± 0.09	2.07 ± 0.08	4.65	4916.5	<0.001
canopy cover %	0.19 ± 0.01	0.07 ± 0.004	14.99	4314.6	<0.001
elevation (m)	795.66 ± 1.39	798.35 ± 1.38	-1.37	5063.9	0.17
slope (degree)	3.77 ± 0.08	3.04 ± 0.06	6.99	4742.4	<0.001
aspect	0.06 ± 0.01	0.07 ± 0.01	-0.62	5059.5	0.53