Effects of working grassland management on lesser prairie-chicken resource selection within home ranges and during dispersal events

by

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Abstract

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a grassland obligate whose decline has been associated with anthropogenic fragmentation and land use change. Historical habitat drivers (i.e., natural fires and free roaming grazers) created vegetation heterogeneity across the species' range, providing resources for each of their life stages. Currently, most of the lesser prairie-chicken's eastern range consists of rangelands managed with confined continuous livestock grazing without fire as a disturbance. Lesser prairie-chicken habitat is also fragmented at larger scales, limiting dispersals and threatening genetic connectivity. A need exists to determine optimum landscape management that provides seasonal habitat at small scales, and allows for dispersal and metapopulation connectivity at large scales. My first objective was to determine the relationship between cattle distributions and lesser prairie-chicken habitat among patch-burn and rotationally grazed rangelands. My second objective was to determine differences in seasonal selection by female lesser prairie-chickens, relative to fine-scale cattle distributions on these two rangelands. My final objective was to determine movement patterns and resource selection of lesser prairie-chickens during dispersal. I tracked cattle (*Bos taurus*) and lesser prairie-chickens via satellite telemetry in patch-burn and rotationally grazed pastures to model their space use at fine scales. I estimated vegetation change along the resulting gradient of cattle distributions. I determined seasonal selection of lesser prairie-chickens relative to cattle distributions within each management treatment. I tracked GPS-tagged lesser prairie-chickens in the Mixed-Grass Prairie and Short-Grass Prairie/CRP Mosaic ecoregions and delineated dispersals. I used step selection analysis to determine differences in resource selection along each dispersal route. Year-of-fire patches drove cattle site-selection on patch-burn grazed rangelands, which created greater vegetation heterogeneity within pastures. Lesser prairie-chickens selected for different cattle densities during different life stages. On rotationally grazed pastures, lesser prairie-chickens selected for moderate cattle densities during breeding, moderate-to-high densities during post-breeding, and selected for the greatest fine-scale cattle densities during nonbreeding. Within the patch-burn grazed treatment, females avoided moderate cattle densities during breeding and post-breeding, and selected for the lowest cattle densities during nonbreeding. Patch-burn grazed pastures were more heterogeneous and contained greater forb abundance in areas with low cattle densities, which could create better brooding and post-breeding habitat near nesting habitat. In the Mixed-Grass Prairie Ecoregion, lesser prairie-chickens selected for lower tree densities and increased grassland cover at the landscape scale during dispersal. On the Short-Grass Prairie Ecoregion, lesser prairie-chickens avoided areas containing electrical transmission lines. During dispersal, young females traveled further and took longer movement steps. Successful dispersals were also shorter distances than failed dispersals. Drivers of dispersal may be innate and could occur regardless of annual variation in local habitat; however, there is likely a fitness cost associated with increased dispersal length. Land-use alterations influenced habitat within home ranges and affected population connectivity by altering dispersals. Managers can benefit lesser prairie-chickens by altering grazing management to mimic historical drivers of habitat. Population connectivity could be increased by limiting electrical transmission line establishment along corridors in the Short-Grass Prairie Ecoregion and by removing trees and increasing grassland within the Mixed Grass-Prairie Ecoregion.

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Chapter 1 - Fine-scale drivers of lesser prairie-chicken habitat among differently managed landscapes

Introduction

Historically, three dynamic forces shaped vegetation communities in the mixed-grass prairie region of the Great Plains: climate, fire, and grazing (Fuhlendorf and Smeins 1999, McGranahan et al. 2012). Climate created environmental variation across large spatial and temporal scales, while the latter two factors interacted synergistically at small scales, through a relationship known as pyric herbivory (Fuhlendorf and Engle 2001, Fuhlendorf et al. 2009). Within this relationship, patchy wildfires would remove excess dead vegetation and dormant plant matter from prairie landscapes. The resulting regrowth after these fires would be palatable, nutrient-dense plants with reduced defenses against herbivory (Allred et al. 2011*a*, Raynor et al. 2015). Large herbivores of that period, such as American bison (*Bison bison*), would target burned areas, and selectively graze on the resulting vegetation. This created variable grazing pressure across a broad landscape; continuous heavy grazing occurred in recently burned patches, while nonburned patches received little grazing, allowing them to accumulate fuel loads and become more susceptible to fire in subsequent years. Across a continuous prairie landscape, pyric herbivory created a shifting network of landscape patches experiencing or recovering from compounded disturbance (Fuhlendorf et al. 2009).

Native grasslands have been altered, diminished, and extensively fragmented since the expansion of European settlement across the Great Plains (Sampson and Knopf 1994). Primary culprits range from grassland conversion to row-crop agriculture to increased human infrastructure due to energy exploration (Samson et al. 2004, Pruett et al. 2009). These changes have transformed a once-continuous prairie landscape into a matrix of partially isolated patches of native rangeland of various size. Most remaining grasslands have been fenced and free-roaming bison have been replaced with domestic cattle (*Bos taurus*), which are managed to exhibit different grazing patterns than bison relative to forage selection and differ with respect to use of water and trees (Allred et al. 2011*b)*. Natural fires have been suppressed, leading to prairie homogeneity and encroachment of shrubs such as the eastern redcedar (*Juniperus virginiana*) into upland landscapes (Brockway et al. 2002, Engle et al. 2008). Currently, mixed-grass prairie in south-central Kansas is usually managed with cattle in absence of fire, typically in a fashion to maintain roughly equal distribution of grazers throughout management units or pastures (Fuhlendorf and Engle 2001). These practices have altered prairie plant communities and could negatively affect prairie-obligate species.

One such species of concern is the lesser prairie-chicken (*Tympanuchus pallidicinctus*). This grassland obligate requires large contiguous grassland landscapes (between 4,900 ha and 20,234 ha) to sustain populations and individuals possesses a particularly large home range as well; breeding and nonbreeding home ranges are estimated to be 340 ha and 997 ha, respectively (Davis 2009, Haufler et al. 2012. Plumb 2015, Robinson et al. 2018). Most lesser prairie-chickens retain a single home range throughout the entire year and require a broad range of vegetation resources to meet their needs during different seasonal life stages (Fuhlendorf and Engle 2001). The lesser prairie-chicken is an indicator species of grassland health, as their diverse seasonal habitats encompass that of many other grassland bird species.

Lesser prairie-chickens exhibit uniparental care; nest and brood survival is directly dependent on resource choices made by females. Because of this, female lesser prairie-chickens are thought to have the greatest influence on population demography of the species. The life history of a female lesser prairie-chicken can be divided into four stages: the breeding/lekking stage in early spring, the nesting stage in late spring to early summer, the brooding stage from mid-summer to mid-September, and the nonbreeding stage, which spans mid-September to mid-March of the following year. Females typically select less disturbed landscape patches for nesting, where grass cover and visual obstruction are greatest (Haukos and Smith 1989, Fields 2004, Grisham et al. 2014).

Less is known about the brooding stage, but females typically select areas with sparser vegetation and greater forb cover, when compared to the nesting stage (Hagen et al. 2004, 2005, 2013). In the first two weeks after hatch, broods are limited in their ability to traverse the landscape and circumvent obstacles. Sparser, more forb-dominant vegetation could facilitate movement of less motile chicks and provide greater abundances of high-protein arthropod food sources, which are associated with forb communities (Hagen et al. 2005, 2013).

Resource selection during the nonbreeding stage has been associated with patches of intermediately disturbed prairie, typically with less visual obstruction than that found during the nesting stage (Lautenbach 2017). Vegetation use during the lekking stage includes small open patches of highly disturbed grassland, where males display and court females (Haukos and Zavaleta 2016). As recruitment has the greatest influence on demography of the species, nesting and brooding habitat are considered top conservation priorities; however, successful conservation of the species must involve quality habitat provision during each life stage, which is promoted through heterogeneity in vegetation on the landscape (Fuhlendorf et al. 2017).

The lesser prairie-chicken has experienced significant declines in occupied range and population since the 1800s; declines are associated with habitat loss, fragmentation, and degradation (Taylor and Guthery 1980, Jensen et al. 2000). Remaining regional occupied range has been categorized into four ecoregions, 95% of which occur on privately-owned land

(McDonald et al. 2014, Elmore and Dahlgren 2016). In the Mixed-Grass Prairie Ecoregion, a majority of these lands are native rangeland, managed for commercial livestock production. Contemporary conservation of the lesser prairie-chicken in the Mixed-Grass Prairie Ecoregion cannot occur without the support of private landowners and the perpetuation of privately-owned grasslands. Thus, it is in the best interest of the lesser prairie-chicken to ensure the commercial success of livestock operations that preserve remaining grassland, while simultaneously optimizing grassland management strategies to provide quality habitat for the lesser prairie-chicken across all of its life stages.

Typical range management for the Mixed-Grass Prairie Ecoregion involves moderate stocking of domestic cattle on pastures that are rested for all or part of a growing season. The intention of this management style is to allow plants to regrow after grazing events, prevent soil compaction, and equally utilize plant growth throughout all management units (Fuhlendorf and Engle 2001). In most cases, these landscapes are managed without prescribed fire; however, a strong fire-grazer interaction likely occurred in this region historically, as summer precipitation allows for plants to readily regrow post-fire (McGranahan et al. 2012).

In the 1980s, a small number of landowners in the Mixed-Grass Prairie Ecoregion began burning entire pastures at the beginning of the growing season (i.e., March-April) in an effort to improve forage quality and halt encroachment of the eastern redcedar. By the early 2000s, management shifted to a patch-burning approach, where only a portion of a pasture was burned in a given year and cattle were allowed to roam freely within that pasture throughout the growing season. Burned patches were shifted within each pasture on a three to five-year rotation in an effort to mimic the hypothesized grazing patterns that once occurred on the central Great Plains (Fuhlendorf et al. 2009). This strategy was designed to alter cattle spatial distributions and increase grazing pressure on recently burned patches, while reducing pressure on nonburned patches, functionally allowing nonburned portions of the pasture to rest for that growing season (Fuhlendorf and Engle 2001).

Grassland heterogeneity is needed to provide habitat for lesser prairie-chickens during different life stages (Hagen and Elmore 2016). By rotating year-of-fire patches within pastures each year, patch-burn grazing creates a more heterogeneous landscape that may better match the seasonal microhabitat requirements of prairie grouse (Fuhlendorf et al. 2017, Lautenbach 2017). Lesser prairie-chickens have been documented using different time-since-fire patches to meet microhabitat needs during different life stages (Lautenbach 2017). Conversely, little is known about the interactions between lesser prairie-chicken habitat use and fine-scale distributions of cattle within pastures. By documenting this interaction across differently-managed landscapes, managers can determine how these strategies influence habitat quality for lesser prairie-chickens.

I tracked domestic cattle via telemetry across patch-burn grazed and rotationally grazed management treatments to assess the effects of rangeland management techniques on cattle space use, as well as vegetation structure and cover. I used resource selection to test potential drivers of cattle space use between treatments and sampled vegetation within pastures to gauge the influence of fine-scale cattle distribution on lesser prairie-chicken habitat. My objectives were to: 1) determine drivers of fine-scale cattle distribution across two differently managed landscapes; 2) understand the influence of within-pasture cattle distribution on lesser prairie-chicken habitat quality; and 3) determine the extent to which cattle distribution, vegetation structure, and vegetation cover varied within pastures between the two management types. I hypothesized that, through inclusion of spring fires within pastures, patch-burn management would create a more heterogeneous pattern of grazing intensity, resulting in greater within-pasture heterogeneity of vegetation structure and cover. This variation in vegetation would subsequently correspond to increased quality of lesser prairie-chicken habitat during different life stages. By determining how rangeland management influences lesser prairie-chicken habitat at fine spatial scales, my research will inform regional management of the species and optimize habitat creation in one of the remaining strongholds of lesser prairie-chickens.

Study Area

My study took place in the Red Hills region of south-central Kansas, in Kiowa and Comanche counties. Data collection occurred at two adjacent sites, one on a patch-burn grazed ranch, and one on a traditional rotationally-grazed ranch (Figure 1-1). The rotationally-grazed site was comprised of three grazing cells, each divided into three pastures by electric and barbed-wire fencing (Figure 1-2). Total area of this site was 3,290 ha, and grazing cell size ranged from 992 ha to 1,169 ha, with an average cell size of 1,097 ha. Pastures within cells ranged from 287 ha to 390 ha, with an average pasture size of 366 ha. Within each cell, mixed breed cow-calf pairs were stocked in early April, calves were weaned in mid-October, and cows were removed from pastures in late-October. Cattle on this site were rotated between three pastures per cell every 10 to 14 days early April to late June. Thereafter, cattle were rotated through pastures every 14 to 21 days. Stocking rates ranged from 0.67 to 0.78 animal units per acre (Table 1-1). Fire was excluded from this site for over a decade before our data collection began.

The 4,953-ha patch-burn grazed site was comprised of six patch-burn grazed pastures. Pastures at this site ranged from 402 ha to 1,392 ha, with an average pasture size of 825 ha. This site was stocked with mixed-breed domestic cattle (*Bos taurus*), either yearlings or cow-calf pairs. Yearling cattle on the patch-burn grazed treatment were kept on pasture from early spring until early fall and remained in one pasture throughout the growing season. Cow-calf pairs at this site remained on pasture year-long. The landowner at this site rotated pastures containing cow-calf pairs with those containing yearling cattle on a three to five-year schedule, with an intention to maintain abundance of palatable forbs within pastures (landowner, personal communication). Pastures in this treatment were stocked at similar densities to the rotationally grazed site. Beginning in the late 1970s, the landowner began burning whole pastures to suppress encroaching eastern redcedar, which is known to increase in this region in the absence of fire. Beginning the early 2000s, the landowner began using a patch-burn regime, where approximately one-quarter to two-fifths of each pasture was burned once every three to four years, and cattle were allowed to graze freely within different time-since-fire patches throughout the growing season (Figure 1-2). Prescribed burns at this site occurred from March 1 to May 5. The patch-burning schedule for each year depended on weather conditions, resulting in variation in the amount of area burned in each pasture annually. From 2016 to 2018, six of the 13 pastures did not contain a year-of-fire patch but still maintained a patch-mosaic burn structure (multiple time-since-fire patches within the same pasture). No prescribed fires were applied from 2011 to 2013, due to an intense regional drought. During 2018, no prescribed burns occurred within monitored pastures, as unfavorable spring weather limited the burning schedule for that season. Every patch-burn grazed pasture had at least three distinct time-since-fire patches in each year of the study.

Soil composition and topography were similar between sites. The landscape was comprised of rolling hills, with primarily sandy loams in the upland areas and clay soils in the lowlands. Terrain was rolling hill, ranging in elevation from 532 to 654 m above sea level. The site received 78.3 cm of precipitation in 2016, 60.8 cm in 2017, and 98 cm in 2018. Precipitation measurements were collected at a weather station 7.7 km from the field site from an online dataset stored by the National Oceanic and Atmospheric Administration (NOAA; https://www.ncdc.noaa.gov/cdo-web/datasets#GHCND). Average annual precipitation in this region is 64 cm (usclimatedata.com), making it the most mesic region of the lesser prairie-chicken's range. Average summertime high temperature is 33.3° C in July and average winter-time low temperature is -7.2° C, occurring in January (usclimatedata.com).

Dryland agriculture, typically for wheat and hay, was practiced in the drainages of these sites. Infrastructure associated with active crude oil exploration operations occurred within both management areas. Dominant plants in the region included big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), sideoats grama (*Bouteloua curtipendula*), buffalograss (*Bouteloua dactyloides*), blue grama (*Bouteloua curtipendula*), and silver bluestem (*Bothriochloa laguroides*). Dominant forbs include Louisiana sagewort (*Artemisia ludoviciana*), western ragweed (*Ambrosia psilostachya*), and slimflower scurfpea (*Psoralidium tenuiflorum*). The most common shrubs in the area included leadplant (*Amorpha canescens*), eastern redcedar, sand sagebrush (*Artemisia filifolia*), and sand plum (*Prunus angustifolia*). Populations of lesser prairie-chickens have remained relatively stable at this site since the 1980s (private landowner, personal communication).

Methods

Cattle Space Use

I attached tracking collars to cattle in early spring of 2016, 2017, and 2018 at both sites. I used store-on-board VHF/GPS collars (model G2110D, Advanced Telemetry Systems) to track cattle locations; collars recorded locations once every hour. I removed GPS collars from cattle in October. If cattle lost collars during the grazing period, I used a Yagi antenna to track and retrieve the collar. I used Brownian bridge models in R (package BBMM) to estimate probability of use (i.e., utilization distribution [UD]) by each collared cow, and converted each UD into a raster with a pixel resolution of 30 × 30 m. I assumed that the probability a cow would use grassland beyond the fence boundaries of its pasture was zero. Unfortunately, the initial movement models that I created could not incorporate fence boundaries and estimated probability that an animal used space beyond the boundaries of its assigned pasture as greater than zero. Models such as biased random bridge functions and kernel density functions can incorporate barriers but only if that barrier has a low tortuosity (Calenge 2006). As the fencing around pasture boundaries violated this assumption, I elected to reclassify my initial movement models to more closely resemble true cattle space use within pastures.

To reclassify rasters, I first used the ‘clip’ tool in ArcMap 10.5 and clipped the UD for each cow to the pasture that contained that cow. I used zonal statistics in ArcMap 10.5 to sum the pixel values in each raster that fell within pasture boundaries. This number is equivalent to the originally-estimated probability (i.e., < 1) that an animal’s space use must fall within the boundaries of its assigned pasture. I used the raster calculator within ArcMap 10.5 to divide the value in each raster pixel by the sum of all raster pixels that fell within each pasture boundary. This created a raster for each cow that ended at pasture boundaries and assumed a 100% probability that all locations of each animal fell within the boundaries of its assigned pasture. After clipping and reclassifying rasters, I used the raster calculator in ArcMap 10.5 to average rasters for each cow per pasture each year. This allowed me to incorporate the movement and space-use decisions of multiple cattle into one continuous probability of use for each pasture in each year of my study (Figure 1-3). I assumed that, when combined, the space use probability of multiple cattle would more accurately represent the space use of the entire herd in that pasture.

I kept the raster pixel size (30 × 30 m) constant for each raster, regardless of the pasture in which that UD was created; however, pasture size was variable throughout the study sites, ranging from 402 ha to 1,392 ha. This led to an artificial inflation of the probability of use in each UD raster pixel for smaller pastures, as each raster pixel took up a greater relative area in small pastures than in large pastures. This issue would be alleviated if I knew exact stocking densities (animal units per acre) for each pasture. As I do not yet have these specific data for the patch-burn grazed pastures, I assumed stocking densities were roughly equivalent between treatments. I then determined the area ratio of each pasture to the smallest pasture and multiplied the raster cell values in each averaged UD by that ratio. In lieu of exact stocking densities, this standardization allowed me to compare cell values in patch-burn grazed pastures to cell values in rotationally-grazed pastures, assuming stocking densities were similar between the two treatments. The output of this estimate was a continuous probability surface that incorporated space use by multiple cattle within each pasture. Because of this, I assumed that a greater probability of use within a 30-m raster pixel in a pasture would reliably detect a greater density of cattle in that 30 × 30-m area during the growing season. Throughout this chapter, I use ‘cattle space use intensity’ to describe the relationship between probability of cattle use and vegetation metrics within each pasture.

Raster Creation

I used several spatial layers to extract landscape features associated with random vegetation plots and used and paired locations of cattle. I retrieved a digital elevation model from the Kansas GIS and Support Center (www.kansasgis.org); from this raster, I derived slope, aspect, and elevation. I grouped aspect into four categories: north (316 to 45 degrees), east (46 to 135 degrees), south (136 to 225 degrees), and west (226 to 315 degrees). I grouped slopes into three categories: shallow (less than 7°), moderate (7° to 11.5°), and steep (greater than 11.5°). I grouped elevation into three categories, relative to the elevation of the study site: uplands (606 to 654 m above sea level), intermediate zones (581 to 606 m), and lowlands (532 to 580 m). I delineated all interior fences, exterior fences, and water sources across each pasture, and ground-truthed these sources during spring and summer. I converted the resulting shapefiles into raster layers and used the 'Euclidean distance' tool in ArcMap 10.5 to create a continuous distance raster for each of these features.

To attain distances to trees throughout the site, I used a spatial layer developed by the U.S. Department of Agriculture (USDA; Paull et al. 2017), and retrieved from https://www.fs.usda.gov/rds/archive/Product/RDS-2017-0025. I converted pixels in this raster classified as trees as '1' and all other values as '0', then used the 'Euclidean distance to feature' tool in ArcMap 10.5 to calculate distance to trees within each pasture. To create time-since-fire layers on the patch-burn grazed site, I delineated the boundary of each prescribed fire on the site in each year since 2010 and incorporated these spatial data into three time-since-fire rasters (one for each year 2016-2018) within ArcMap 10.5. I used time-since-fire data from Lautenbach (2017) to identify prescribed fires that occurred at this site prior to my research.

Vegetation Structure and Cover

Rangeland management techniques such as patch-burn and rotational grazing likely influence the fine-scale distribution of cattle within pastures. To determine how vegetation-based aspects of lesser prairie-chicken habitat changed across these fine-scale gradients of cattle space-use, I established a framework of vegetation sampling to compare vegetation response between treatments. During the grazing period, my knowledge of fine-scale cattle space use was limited, as I could not access GPS data from store-on-board collars until they had been removed from cattle at the end of the season. Instead, I created a framework of patches within each pasture on the patch-burn and rotationally grazed treatments, and randomly sampled vegetation from within these patches during the spring and early summer (late April to early June), and again in the mid- to late summer (late June to early August). These periods roughly correspond to two sensitive life stages for lesser prairie-chickens, nesting and brooding. Further, sampling during two temporally distinct periods allowed me to capture a more complete picture of vegetation change in each patch throughout the growing season, relative to space use by cattle.

On the rotationally-grazed site, I partitioned landscape patches by pasture and broad topoedaphic categories. Topoedaphic patches were developed from ecological site descriptions published by the Natural Resources Conservation Service (NRCS) and grouped according to similarities in slope, elevation, and soil type. I stratified landscape patches on the patch-burn grazed site by pasture, year-since-fire patch, soil type, elevation, and broad differences in tree canopy cover, using National Agriculture Imagery Program (NAIP) spatial layers. During 2016 and 2017, I sampled vegetation at 10 random plots per patch in spring and early summer and again during mid- to late summer. During 2018, I sampled vegetation at 10 random plots per patch during the spring and early summer and 5 random plots per patch during mid- to late summer.

At each plot, I measured 0%, 25%, 50%, 75%, and 100% visual obstruction in decimeters using a Robel pole (Robel et al. 1970). I replicated this measurement in each cardinal direction, exactly 4 m away from the Robel pole. I recorded percent cover of grass, forbs, shrubs, litter, and bare ground within a 60 × 60-cm Daubenmire frame (Daubenmire 1959). I measured this at each point center and in each cardinal direction 4 m from the center point. Lastly, I measured litter depth every 50 cm, for 4 m from point center, in each cardinal direction. I replicated this measurement in the northwest corner of the Daubenmire frames at point center and in each cardinal direction. After recording data at each habitat plot, I imported covariates for each plot, using the ‘Extract Multi Values to Points’ tool in ArcMap 10.5. Covariates extracted to these points included year since fire, fine-scale grazing intensity, slope, aspect, and elevation.

Data Analyses

I used a resource selection framework to determine how landscape features influence cattle densities within management units (Manly et al. 2002). I compared used points for cattle in each pasture to an equal number of randomly selected points that were available to them within that pasture. To do this, I used the ‘create random points’ tool in ArcMap 10.5 to create random locations that were equal to the number of used locations for each animal in each pasture. I then extracted values from landscape feature layers to both used and paired points within each pasture using the ‘extract multi-values to points’ tool in ArcMap 10.5. I conducted a resource-selection model for cattle using a mixed-effects regression framework in R (function glmer; package lme4, Bates et al. 2015). I chose individual animal as my random effect to gauge the relative influence of landscape features on site selection by cattle, while accounting for differences in selection made by different individuals. I tested logistic regression models for cattle in the rotationally grazed treatment, cattle in the patch-burn treatment that had access to a year-of-fire patch, and cattle on patch-burn pastures that did not have access to a year-of-fire patch. I included distance to water, distance to fences, distance to tree, slope, and elevation in each of my model suites. I included time-since-fire patch as a variable in models predicting cattle space-use within patch-burn grazed pastures. I created single-variable models for each of these landscape features and incorporated them into model suites dependent upon management (i.e., patch-burn with year of fire, patch-burn without year of fire, and rotationally-grazed pastures). I used Akaike’s

Information Criterion (AIC) to rank models based on their relative parsimony in predicting space-use by cattle. This allowed me to determine the best-fitting model for cattle in each management area.

To estimate heterogeneity within pastures, I measured the coefficient of variation in plant cover, structure (visual obstruction and litter depth), and estimated cattle densities within pastures. My aim was to evaluate possible differences in management type (patch-burn vs. rotationally grazed) and to assess possible differences within patch-burn management (i.e., pastures that contained a year-of-fire patch vs. pasture that did not contain a year-of-fire patch). I compared the coefficient of variation among patch-burn grazed pastures that contained a year-of-fire patch, patch-burn grazed pastures that did not contain a year-of-fire patch, and rotationally-grazed pastures. I used a one-way analysis of covariance in R to determine whether the change in vegetation across cattle space-use intensity differed between the rotationally-grazed and patch-burn grazed treatments. Visual obstruction at 75% influenced both nest site selection and nest survival of lesser prairie-chickens (Lautenbach et al. 2019). Therefore, I used the ‘raster calculator’ feature in ArcMap 10.5 to apply a linear regression measuring the influence of cattle space-use intensity on 75% visual obstruction to a raster layer of continuous cattle space-use intensity within each treatment. This allowed me to gauge the amount of land that was roughly available for nesting habitat (as measured by 75% visual obstruction) at fine spatial scales between the two management treatments.

Results

Data Collection

I tracked 76 cattle during the growing seasons of 2016, 2017, and 2018 (Table 1-2). Thirty-one cattle were collared in 2016, 15 in rotationally-grazed pastures and 16 in patch-burn grazed pastures. Thirty-one were collared in 2017, 11 in rotationally-grazed pastures and 20 in patch-burn grazed pastures. In 2018, 16 cattle were tracked, 10 in rotationally-grazed pastures, and 6 in patch-burn grazed pastures. While stocking rates on the patch-burn grazed site were set by the landowner, some pastures were rented to third parties who grazed yearling steers and heifers. Several of these managers opted to not attach collars to their cattle or to attach collars loosely to avoid potential physical restrictions on cattle. This resulted in data gaps within certain pastures in 2017 and 2018, where collars were not deployed or where lost collars led to insufficient data to estimate cattle space use within a pasture. I recorded 576,108 cattle relocations among 76 collared cattle during my experiment; 306,404 occurred on rotationally-grazed pastures and 269,704 occurred on patch-burn grazed pastures. Of these relocations, 137,026 occurred in patch-burn pastures containing a year-of-fire patch and 132,678 occurred in patch-burn pastures without a year-of-fire patch.

I sampled vegetation at 3,897 randomly placed vegetation plots from 2016 to 2018. I sampled 1,377 plots in 2016: 839 plots in the patch-burned treatment and 538 in the rotationally-grazed treatment. In 2017, I sampled 1,883 plots: 982 plots in the patch-burn treatment and 901 in the rotationally-grazed treatment. In 2018, I sampled 983 plots in pastures grazed by cattle; 346 of these occurred in patch-burn pastures and 637 occurred in rotationally-grazed pastures.

Cattle Space Use

I developed mixed-effects logistic regression models to evaluate potential drivers of cattle space use in rotationally-grazed pastures, patch-burned pastures with a year-of-fire patch, and patch-burned pastures without a year-of-fire patch. The top single variable model predicting space use by cattle on the rotationally-grazed treatment was distance to water (Table 1-3). Cattle selected for areas closer to water sources, relative to the total space available to them in each pasture (Figure 1-4). This model held nearly all of the model weight across all single-variable models considered. In addition, cattle on rotationally-grazed pastures were more likely to use portions of the pasture at lower elevations (Figure 1-5); however, this model received little weight relative to distance to water. On patch-burn grazed treatments containing a year-of-fire patch, the model that best predicted cattle space use was time-since-fire patch (Table 1-4). This model held all of the weight across the entire suite of models considered. Cattle selected year-of-fire patches at far greater frequencies than would be expected at random (Figure 1-6). Cattle showed little selection for or against any other time-since-fire patch in these pastures. Within these pastures, cattle did not select low elevations, which differed from cattle in rotationally-grazed pastures (Figure 1-7). On patch-burn landscapes that did not contain a year-of-fire patch, elevation was the top single-variable model, followed by time-since-fire patch (Table 1-5). Cattle were more likely to use lowland areas on these pastures when compared to uplands (Figure 1-8). Variation in cattle space use occurred along the elevation gradient only when their pasture did not contain a year-of-fire patch.

Coefficient of Variation

Across all years and all pastures, the patch-burn grazed site had a greater coefficient of variation in fine-scale cattle space use intensity, visual obstruction, litter depth, and grass, forb, and litter cover (Table 1-6) than the rotationally-grazed site. In contrast, the rotationally-grazed site had a greater coefficient of variation in bare ground and shrub cover than the patch-burn grazed site (Table 1-6). Patch-burned pastures without a year-of-fire patch had reduced variation in all metrics except bare ground cover when compared to patch-burned pastures that contained a year-of-fire patch. Patch-burn grazed pastures without a year-of-fire patch still had greater variation in litter depth, litter cover, grass cover, forb cover, and 75% and 100% visual obstruction than did rotationally-grazed pastures.

Mean grass cover was 11.9% greater and mean litter cover was 11.3% greater in the rotationally-grazed treatment than in the patch-burn grazed treatment (Table 1-7). Mean cover of forbs was 13.1% greater and mean bare ground was 88.9% greater in the patch-burn treatment compared with the rotationally-grazed treatment. Litter depth was 51.5% greater in the rotationally-grazed treatment than in the patch-burned treatment. On average, every class of VOR was greater on rotationally grazed pastures than patch-burn grazed pastures. Specifically, 0% VOR was 16.3% greater, 25% VOR was 16.5% greater, 50% VOR was 16.6% greater, 75% VOR was 22.2% greater, and 100% VOR was 31.9% greater in rotationally-grazed pastures than in patch-burned pastures.

I conducted analyses of covariance across the two sites, analyzing the relationship between cattle space use intensity and all vegetative metrics measured: structure (VOR), cover, and litter depth. Litter depth differed between treatments ($F_{1,3292} = 8.28$, $P < 0.01$) but did not differ across fine-scale cattle space use between sites ($F_{1,3292} = 3.35$, $P = 0.07$; Figure 1-9). I did not detect differences in shrub cover among management treatments ($F_{1,3292} = 3.49$, $P = 0.06$; Table 1-8, Figure 1-9). It should be noted that shrub cover was extremely low at both sites and less influential for lesser prairie-chicken habitat in the easternmost portion of its range (Figure 1-9). All other aspects of habitat that I measured differed between treatments and across fine-scale grazing densities; the relationship between these metrics and fine scale cattle densities differed among treatments as well.

With the exception of litter depth, all structural vegetation metrics changed more dramatically as fine-scale cattle density increased on the patch-burn grazed treatment, when compared to the rotationally-grazed treatment. As fine-scale cattle space use increased, grass cover ($F_{1,3292} = 8.75$, $P < 0.01$) and forb cover ($F_{1,3292} = 6.16$, $P < 0.01$) decreased more rapidly on the patch-burn grazed treatment than on the rotationally-grazed treatment (Table 1-8, Figure 1-9). Conversely, forb cover was greater at the least frequent cattle space use on patch-burn grazed areas compared with rotationally-grazed areas. Bare ground increased more rapidly on the patch-burn treatment ($F_{1,3292} = 11.95$, $P < 0.01$) and litter cover increased more rapidly across fine-scale cattle densities on the patch-burn grazed treatment, compared with the rotationally-grazed treatment ($F_{1,3292} = 81.12$, $P < 0.01$; Table 1-8, Figure 1-9). Interestingly, litter depth decreased more rapidly as cattle space use increased on the rotationally-grazed treatment, compared to the patch-burn grazed treatment ($F_{1,3292} = 8.28$, $P < 0.01$; Table 1-8, Figure 1-9). Across all VOR classes measured, visual obstruction decreased more rapidly on the patch-burn grazed treatment than the rotationally-grazed treatment as cattle space use increased (Table 1-8, Figure 1-10).

Percent cover of grass was lower in patch-burn treatments across all cattle densities, and also decreased more quickly as cattle space use increased, compared to the rotationally grazed treatment (Figure 1-9). Forb cover was greater on patch-burn grazed pastures at low cattle densities but less at high cattle densities (Figure 1-9). Bare ground increased as cattle densities increased on both treatments; however, percentage of bare ground was greater on the patch-burn grazed treatment than on the rotationally-grazed treatment across all cattle densities (Figure 1-9). All classes of visual obstruction were lower on patch-burn grazed treatments than on the rotationally-grazed treatment (Figure 1-10).

Discussion

I estimated and compared resource selection by cattle in rotationally-grazed pastures, patch-burn pastures that contained a year-of-fire patch, and patch-burn pastures that had no year-of-fire patch but still contained a mosaic of time-since-fire patches. On patch-burn grazed pastures that contained a year-of-fire patch, the top driver of cattle space use was time-since-fire. The next most significant model carried very little influence on cattle distribution when compared to time-since-fire. In patch-burn pastures without a year-of-fire patch, the top model predicting cattle space use was elevation, followed by time-since-fire. The top model predicting cattle space use in rotationally-grazed pastures was distance to water; cattle selected areas in close proximity to water sources in lowlands, consistent with prior research (Smith et al. 1992).

My data was interpreted to indicate that management strategies influence cattle space use at fine scales and that fine-scale cattle distributions subsequently produce distinctive patterns in vegetation. Lesser prairie-chickens require heterogeneity in rangelands to meet their resource needs during different life stages (Fuhlendorf et al. 2017). On hilly landscapes, patch-burn grazing further enhances lesser prairie-chicken habitat by driving variation in cattle space use within upland habitats where lesser prairie-chickens reside. Variation in fine-scale cattle space use, and concomitant variation in vegetation, occurred within both management treatments. For this heterogeneity to be useful to lesser prairie-chickens, it must be available to them within upland habitats. This suggests that all time-since-fire patches within patch-burn grazed pastures should contain upland landscapes, to ensure heterogeneity occurs within areas that are available to lesser prairie-chickens. Within rotationally-grazed pastures and patch-burn pastures not containing a year-of-fire patch, variation in cattle space use was explained in part by changes in elevation, while it was not in patch-burn grazed pastures containing a year-of-fire patch. On patch-burned pastures without a year-of-fire patch, low-elevation areas were used more heavily by cattle than high-elevation areas. Lesser prairie-chickens reportedly select moderately disturbed areas during the brooding and nonbreeding seasons but will avoid lowland areas during each of their life stages (Hagen and Giesen 2005, Fuhlendorf et al. 2017, Lautenbach 2017). In pastures without fire, this habitat may be less available to lesser prairie-chickens as it occurs within low elevations that they would normally avoid. Therefore, heterogeneity within pastures not containing a year of fire patch may be even less useful to lesser prairie-chickens than pastures containing a year-of-fire patch, as some of that variation occurs in lowlands that are not used by this species. In patch-burn pastures with a year-of-fire patch, cattle selected landscapes with little regard to elevation. The presence of a recent burn offset selection for features such as lowlands. Heterogeneity in vegetation would likely be more accessible to lesser prairie-chickens on patch-burn grazed pastures than on rotationally grazed pastures, as more of this heterogeneity would occur in upland habitats.

I found that the coefficient of variation in fine-scale cattle space use was roughly equivalent between patch-burn pastures with no year-of-fire patch and rotationally-grazed pastures. Conversely, patch-burn pastures with no year-of-fire patch still had greater heterogeneity in grass cover, forb cover, litter cover, litter depth, 75% visual obstruction, and 100% visual obstruction when compared to rotationally grazed pastures. Increased variation across these metrics was likely due to the variety of different time-since-fire patches within these pastures.

One prohibitive aspect of patch-burn grazing is the limited number of days during spring that are favorable for a safe prescribed burn. Consistent inclement weather can result in a reduced capacity to burn at the beginning of the growing season, leading to fewer pastures that contain a year-of-fire patch during that growing season. My results were interpreted to indicate that patch-burn grazed pastures which did not contain a year-of-fire patch were less heterogeneous than patch-burn grazed pastures with a year-of-fire patch, but were still more heterogeneous than rotationally-grazed pastures managed without fire. Patch burn management increases heterogeneity and subsequently provides better lesser prairie-chicken habitat compared with rotational grazing without fire, even when pastures do not contain a recently burned patch within a growing season.

Available nesting habitat differed at fine scales between the two management treatments. During nesting, lesser prairie-chickens avoid areas with >8% bare ground and select areas with 1.5 dm to 3.5 dm of 75% visual obstruction (Lautenbach et al. 2019). Lautenbach et al. (2019) also found that nest survival was maximized when nests were 75% obstructed at 2 to 4 dm. Consistent with my expectation that lesser prairie-chicken habitat would be more varied on patch-burn grazed pastures, 75% visual obstruction decreased more quickly across fine-scale cattle space use on patch-burn grazed pastures than on rotationally-grazed pastures. On average, 75% visual obstruction was 1.65 dm across all rotationally-grazed pastures and 1.35 dm across all patch-burn grazed pastures. Patch-burn grazing increases variation in grazing pressure, making pasture averages less meaningful for this management style. I applied a linear model predicting visual obstruction across fine-scale cattle densities to a raster of cattle space use. Areas with low grazer densities, which would equate to 75% VOR of 1.5 dm or greater, constituted the majority of most pastures and coincided with nonburned patches within pastures (Figure 1-11). I concluded that despite lesser average visual obstruction, patch-burn landscapes are likely creating sufficient nesting habitat by decreasing grazing pressure in later time-since-fire patches where lesser prairie-chickens would be most likely to nest. Even at the least level of cattle space use on the patch-burn treatment, average 75% visual obstruction did not reach 2 dm. While patch-burn pastures provide greater vegetative heterogeneity than rotationally-grazed pastures, reducing stocking rates on the patch-burn grazed site would likely improve quality and quantity of nesting habitat.

Brood habitat is not well understood for lesser prairie-chickens but selection for more sparse vegetation and increased forb cover has been demonstrated for lesser prairie-chickens during this biological stage. Increased forb abundance provides accessible overhead cover for broods and harbors abundant arthropods, which are a protein-rich food source for chicks. Open understory can facilitate mobility of chicks by providing unobstructed movement avenues. The patch-burn grazed treatment had greater percent cover of bare ground and lower litter depths across all gradients of fine-scale cattle space use when compared with the rotationally-grazed treatment. Forb cover was also greater in patch-burn grazed pastures than in rotationally-grazed pastures. The greatest forb cover occurred in areas least selected by cattle on the patch-burn grazed site, which corresponded to longer time-since-fire patches. In the mixed-grass prairie, palatable perennial forbs such as leadplant (*Amorpha canescens*) and purple prairie clover (*Dalea purpurea*) are readily grazed by cattle and decrease quickly as grazing pressure increases (Hickman and Hartnett 2002, Sowers et al. 2019). In contrast, Aubel (2011) found that forb consumption by cattle decreased in pastures that had been burned when compared to pastures that had not been burned. On patch-burned grazed pastures, decreased consumption of forbs in nonburned patches could be caused by forage quality increases within recently burned patches of those pastures. Springtime burns in patch-burn pastures could reduce grazing pressure on forbs in nonburned patches during the growing season by providing palatable forage in other portions of the pasture. On the patch-burn site, forb cover was greatest in areas with the lowest fine-scale cattle densities, which also corresponded to areas where 75% visual obstruction was greatest. In the first two weeks of life, lesser prairie chicken broods are limited in their ability to travel from their nest site to access brooding habitat. Increased availability of forb cover in close proximity to nest habitat could facilitate survival of broods immediately post-hatch by providing necessary resources for brood growth immediately post-hatch. By creating increased forb cover in close proximity to potential nesting habitat, patch-burn management has the potential to increase brood habitat relative to alternate management strategies.

Along gradients of fine-scale cattle space use, bare ground and litter cover was greater on patch-burn grazed pastures than on rotationally-grazed pastures and greatest in areas selected most often by cattle on patch-burn grazed landscapes. Visual obstruction was also lower on patch-burn grazed landscapes than on rotationally-grazed landscapes across all levels of cattle densities and lowest in areas of greatest cattle space use, which were most closely associated with year-of-fire patches. At the patch-level, lesser prairie-chickens typically select for 1-year post-fire patches, followed by year-of-fire patches and >2-year post-fire patches during the nonbreeding season (Lautenbach 2017). During this stage, lesser prairie-chickens select for areas with less visual obstruction, greater litter cover, and less bare ground relative to the nesting and brooding stages (Lautenbach 2017). Patch-burn grazed treatments could be more efficient in creating nonbreeding habitat, as they engineer low visual obstruction and greater litter cover in intermediately grazed portions of pastures, when compared to rotationally grazed landscapes. In contrast, patch-burn grazed treatments had more bare ground compared with rotationally-grazed treatments, which lesser prairie-chickens select against during the nonbreeding season. As bare ground is typically associated with greater disturbance, bare ground on the patch-burn grazed treatment could be reduced by decreasing stocking rates. While this has the potential to benefit lesser prairie-chickens during the nonbreeding season, a baseline has yet to be established for nonbreeding selection by lesser prairie-chickens relative to fine-scale cattle densities.

My research was interpreted to indicate that patch-burning creates more heterogeneity across fine-scale cattle densities and better-quality habitat for lesser prairie-chickens across their entire life cycle. Further, it provides a cost-effective method of removing encroaching shrubs, increasing available forage for cattle, and lower tree density (Lautenbach et al. 2017). Greater variation in forb cover was observed across cattle space-use intensity on patch-burn grazed pastures compared with rotationally-grazed pastures. In areas less intensely used by cattle, forbs were more abundant on patch-burn grazed pastures compared with rotationally grazed pastures. Patch-burn grazing has the potential to benefit brood survival by providing abundant forbs in proximity to potential lesser prairie-chicken nesting habitat. When combined with moderate stocking rates that allow for 75% visual obstruction between 2 and 4 dm in the least grazed portions of pastures, patch-burn grazing creates a wide range in vegetation at fine scales, which provides habitat for lesser prairie-chickens during discrete life stages. Providing that stocking rates allow for creation of habitat across all life stages of the lesser prairie-chicken, this management system is likely more beneficial to lesser prairie-chickens than cattle management in absence of fire within the eastern Mixed Grass Prairie Ecoregion.

Literature Cited

Aubell, N. A. 2011. Factors affecting foraging behavior of beef cattle grazing native tallgrass range in the Kansas Flint Hills. Dissertation, Kansas State University, Manhattan, USA.

Allred, B. W., S. D. Fuhlendorf, D. M. Engle, and R. D. Elmore. 2011*a*. Ungulate preference for burned patches reveals strength of fire-grazing interaction. Ecology and Evolution 1:132–144.

Allred, B. W., S. D. Fuhlendorf, and R. G. Hamilton. 2011*b*. The role of herbivores in Great Plains conservation: comparative ecology of bison and cattle. Ecosphere 2:1-17.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67:1-48.

Brockway, D. G., R. G. Gatewood, and R. B. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie-ecosystems: initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management 65:135-152. Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43–64.

Davis, D. M. 2009. Nesting ecology and reproductive success of lesser prairie-chickens in shinnery oak-dominated rangelands. The Wilson Journal of Ornithology 121:322-327.

Elmore, R. D., and D. K. Dahlgren. 2016. Public and private land conservation dichotomy. Pages 187-203 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Engle, DM, Coppedge, BR, Fuhlendorf, SD, 2008. From the dust bowl to the green glacier: human activity and environmental change in Great Plains grasslands. Pages 253-271 *in* O. V. Auken, editor. Western North American Juniperus Communities. Springer, New York, USA

Fields, T. L. 2004. Breeding season habitat use of Conservation Reserve Program (CRP) land by lesser prairie-chickens in west central Kansas. Thesis, Colorado State University, Fort Collins, USA.

Fuhlendorf, S. D., T. J. Hovick, R. D. Elmore, A. M. Tanner, D. M. Engle, and C. A. Davis. 2017. A hierarchical perspective to woody plant encroachment for conservation of lesser prairie-chickens. Rangeland Ecology & Management 70: 9-14.

Fuhlendorf, S. D., and F. E. Smeins. 1999. Scaling effects of grazing in a semi-arid grassland. Journal of Vegetation Science 10:731-738.

Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. BioScience 51:625-632.

Fuhlendorf, S. D., D. M. Engle, J. Kerby, and R. Hamilton. 2009. Pyric herbivory: rewilding landscapes through the recoupling of fire and grazing. Conservation Biology 23:588–598.

Grisham, B. A., P. K. Borsdorf, C. W. Boal, and K. K. Boydston. 2014. Nesting ecology and nest survival of lesser prairie-chickens on the southern high plains of Texas. Journal of Wildlife Management 78:857–866.

Hagen, C. A., and R. D. Elmore. 2016. Synthesis, concllusions, and a path forward. Pages 345-374 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Hagen, C. A. B. A. Grisham, C. W. Boal, and D. A. Haukos. 2013. A meta-analysis of lesser prairie-chicken nesting and brood-rearing habitats: implications for habitat management. Wildlife Society Bulletin 37: 750-758.

Hagen, C. A., B. E. Jamison, K. M. Giesen, and T. Z. Riley. 2004. Guidelines for managing lesser prairie-chicken populations and their habitats. Wildlife Society Bulletin 32:69–82.

Hagen, C. A., G. C. Salter, J. C. Pitman, R. J. Robel, and R. D. Applegate. 2005. Lesser prairie-chicken brood habitat in sand sagebrush: invertebrate biomass and vegetation. Wildlife Society Bulletin 33:1080–1091.

Hagen, C. A. and K. M. Giesen. 2005. Lesser prairie-chicken (Tympanuchus pallidicinctus), version 2.0. In the Birds of North America (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, USA. https://doi.org/10.2173/bna.364

Haufler, J., D. Davis, and J. Caulfield. 2012. Oklahoma Lesser Prairie-Chicken conservation plan: a strategy for species conservation. Ecosystem Management Research Institute, Seeley Lake, MT.

Haukos, D. A., and J. C. Zavaleta. 2016. Habitat. Pages 99–132 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Haukos, D. A, and L. M. Smith. 1989. Lesser prairie-chicken nest site selection and vegetation characteristics in tebuthiuron-treated and untreated sand shinnery oak in Texas. Great Basin Naturalist 49:624–626.

Hickman, K. R., and D. C. Hartnett. 2002. Effects of grazing intensity on growth, reproduction, and abundance of three palatable forbs in Kansas tallgrass prairie. Plant Ecology 159:23-33.

Jensen, W. E., D. A. Robinson, and R. D. Applegate. 2000. Distribution and population trend of lesser prairie-chicken in Kansas. Prairie Naturalist 32:169–175.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Lautenbach, J. D. 2017. The role of fire, microclimate, and vegetation in lesser prairie-chicken habitat selection. Thesis, Kansas State University, Manhattan, USA.

Lautenbach, J. M., R. T. Plumb, S. G. Robinson, C. A. Hagen, D. A. Haukos, and J. C. Pitman. 2017. Lesser prairie-chicken avoidance of trees in a grassland landscape. Rangeland Ecology & Management 70:78-86.

Lautenbach, J. M., D. A. Haukos, D. S. Sullins, C. A. Hagen, J. D. Lautenbach, J. C. Pitman, R. T. Plumb, S. G. Robinson, and J. D. Kraft. 2019. Factors influencing nesting ecology of lesser prairie-chickens. Journal of Wildlife Management 83:205-215

Manly, B. F., L. L. McDonald, D. L. Thomas, T. L. McDonalf, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Springer, New York, New York, USA

McDonald, L., G. Beauprez, G. Gardner, J. Griswold, C. Hagen, F. Hornsby, D. Klute, S. Kyle, J. Pitman, T. Rintz, D. Schoeling, and W. Van Pelt. 2014. Range-wide population size of the Lesser Prairie-Chicken: 2012 and 2013. Wildlife Society Bulletin 38:536–546.

McGranahan, D. A., D. M. Engle, S. D. Fuhlendorf, S. J. Winter, J. R. Miller, and D. M. Debinski. 2012. Spatial heterogeneity across five rangelands managed with pyric herbivory. Journal of Applied Ecology 49:903-910.

Nielson, R. M., H. Sawyer, and T. L. McDonald. 2013. BBMM: Brownian bridge movement model. R package version 3.0.

Paull, D. A., J. W. Whitson, A. L. Marcotte, G. C. Liknes, D. M. Meneguzzo, and T. A. Kellerman. 2017. High-resolution land cover of Kansas 2015. Fort Collins, CO: Forest Service Research Data Archive. Updated 27 November 2017.

Pruett, C. L. M. A. Patten, and D. H. Wolfe. 2009. It’s not easy being green: wind energy and a declining grassland bird. Bioscience 59:257-262.

Plumb, R. T. 2015. Lesser prairie-chicken movement, space use, survival, and response to anthropogenic structures in Kansas and Colorado. Thesis, Kansas State University, Manhattan, USA.

Raynor, E. J., A. Joern, J. B. Nippert, and J. M. Briggs. 2016. Foraging decisions underlying restricted space use: effects of fire and forage maturation on large herbivore nutrient uptake. Ecology and Evolution 6:5843–5853.

Robel, R. J., J. M. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Robinson, S. G., D. A. Haukos, R. T. Plumb, J. M. Lautenbach, D. S. Sullins, J. D. Kraft, J. D, Lautenbach, C. A. Hagen, and J. C. Pitman. 2018. Nonbreeding home-range size and survival of lesser prairie-chickens. Journal of Wildlife Management 82:413-423.

Samson, F. B., and F. L. Knopf. 1994. Prairie Conservation in North America. BioScience 44:418-421.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: past, present, and future. Wildlife Society Bulletin 32:6-15.

Smith, M. A., J. D. Rodgers, J. L. Dodd, and Q. D. Skinner. 1992. Declining forage availability effects on utilization and community selection by cattle. Journal of Range Management 45:391-395.

Sowers, C. A., Gatson, G. A., Wolf, J. D., Fick, W. H., and Olson, K. C. 2019. Botanical composition of yearling-steer and mature-ewe diets in the Kansas Flint Hills. Rangeland Ecology & Management 72: 126-135.

Taylor, M. A., and F. S. Guthery. 1980. Status, ecology, and management of the Lesser Prairie-Chicken. USDA Forest Service, General Technical Report RM-77. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Figures

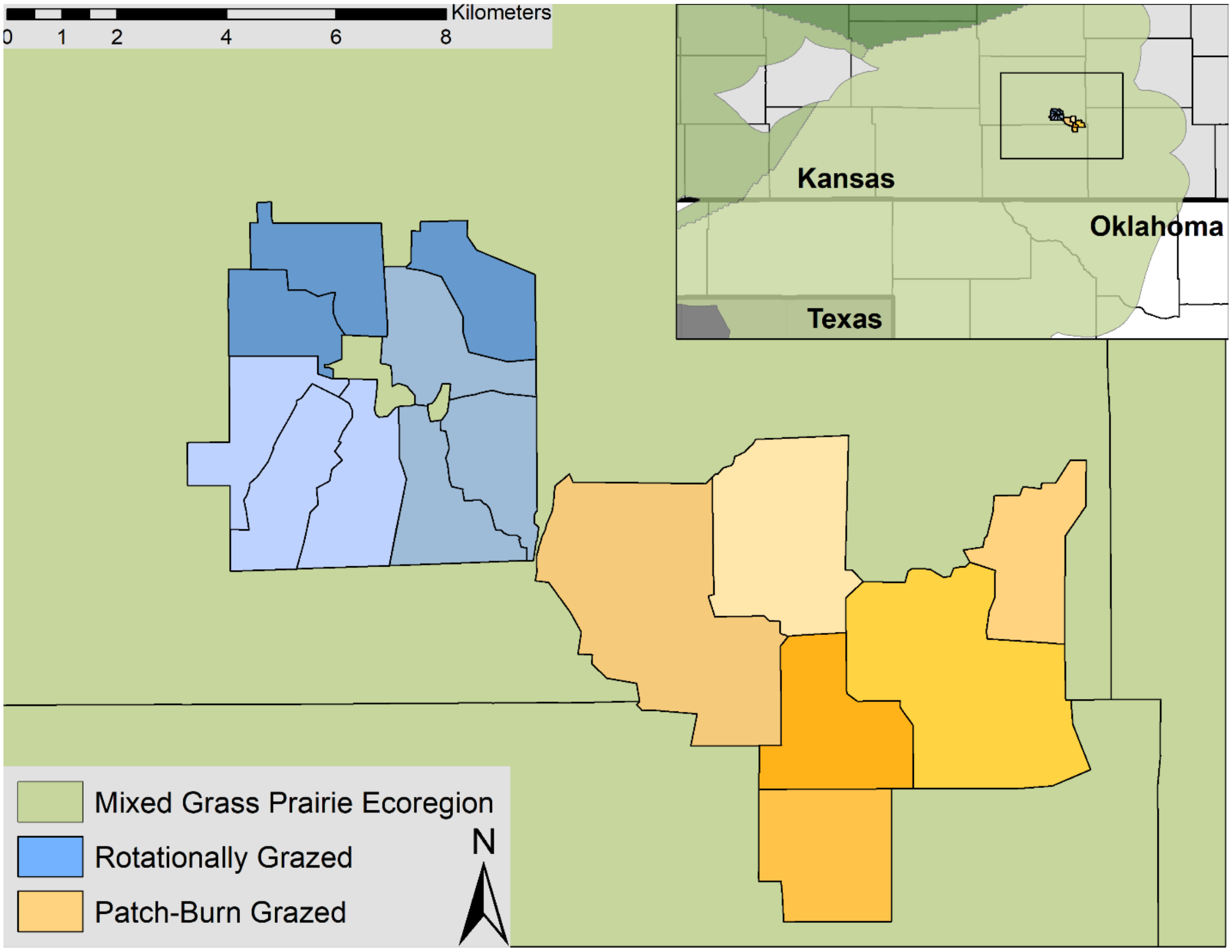

Figure 1-1 Field site where data were collected from 2016-2018. The two adjacent management treatments occur in the Red Hills region of south central Kansas, on the Mixed-Grass Prairie Ecoregion of the lesser prairie-chicken's range.

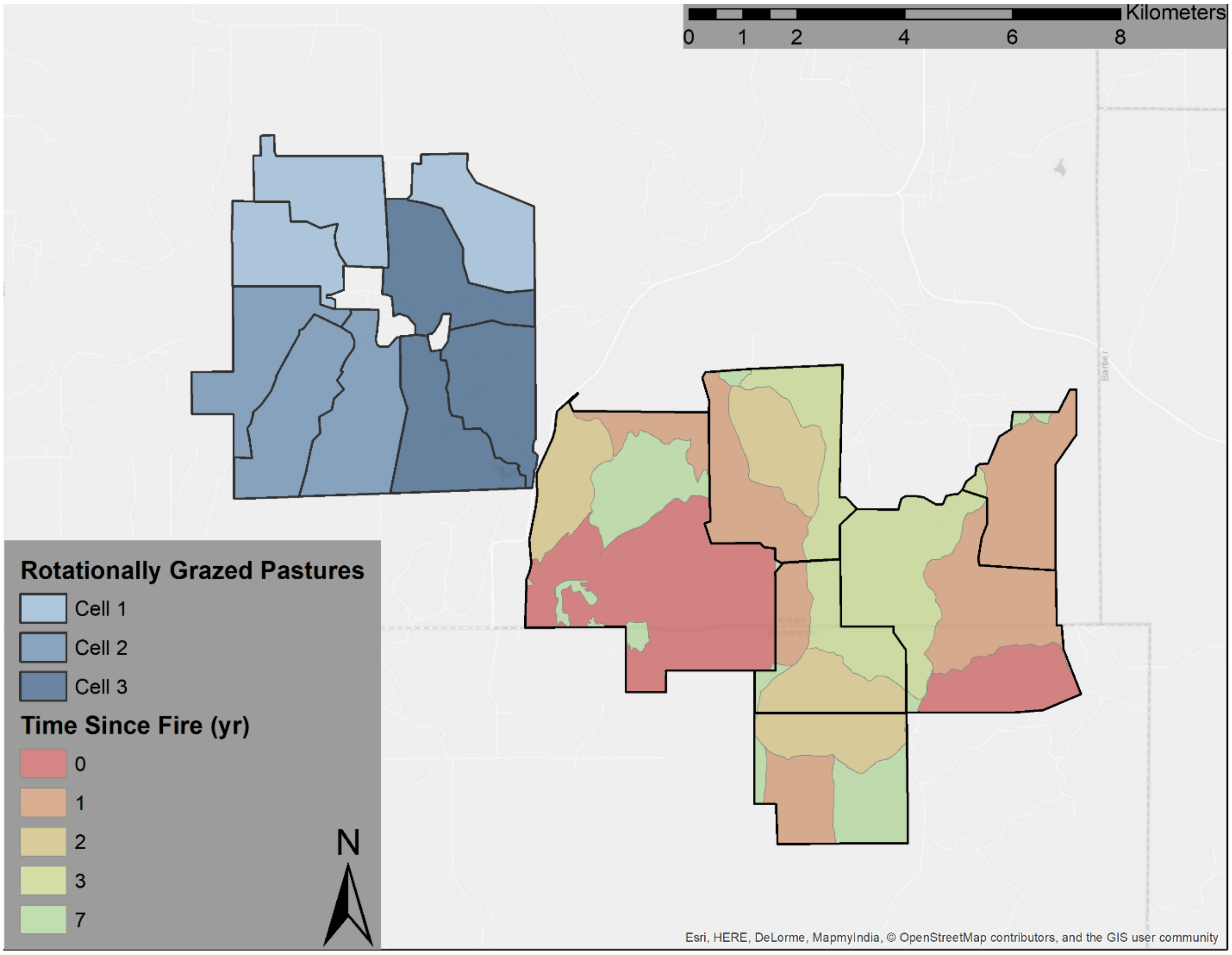

Figure 1-2 Rangeland management on the study sites from 2016 through 2018, in Comanche and Kiowa counties, Kansas. Cattle were rotated in the rotationally grazed management system through three adjacent pastures within three management cells throughout the growing season. The patch-burn management system burns 20% to 40% of each pasture every year, dependent on spring weather conditions. Cattle are not restricted by interior fencing in each pasture, and can select freely between different time-since-fire patches. This map represents time since fire patches during one year of the study, 2017.

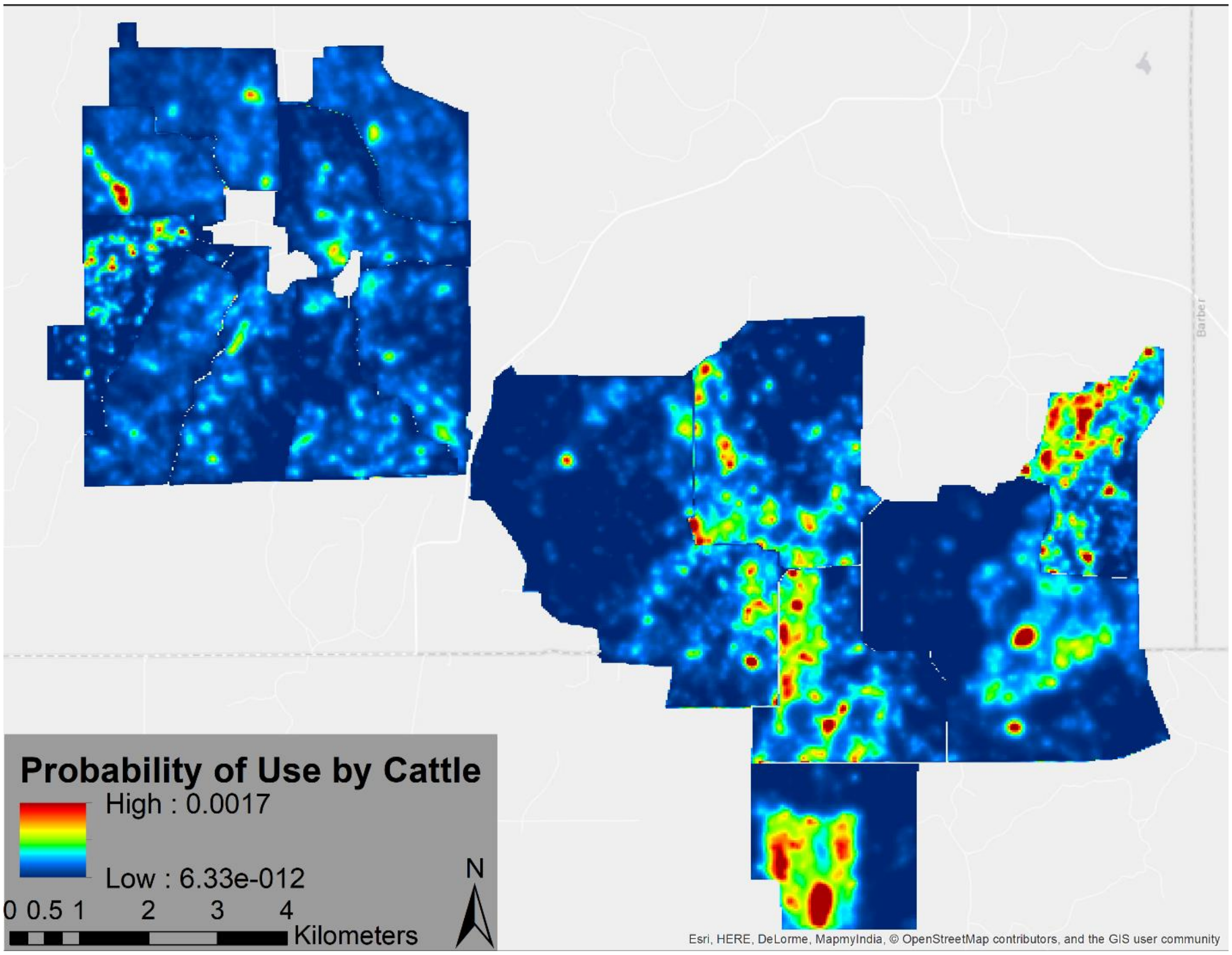

Figure 1-3 Continuous probability surface of cattle space-use within each pasture on patch-burn grazed pastures and rotationally pastures in 2016, in Comanche and Kiowa counties, Kansas. Warmer colors in each pasture indicate a greater probability of use by the herd in that pasture, and thus a subsequently greater intensity of space use by cattle within that pixel during the period when cattle were in the pasture.

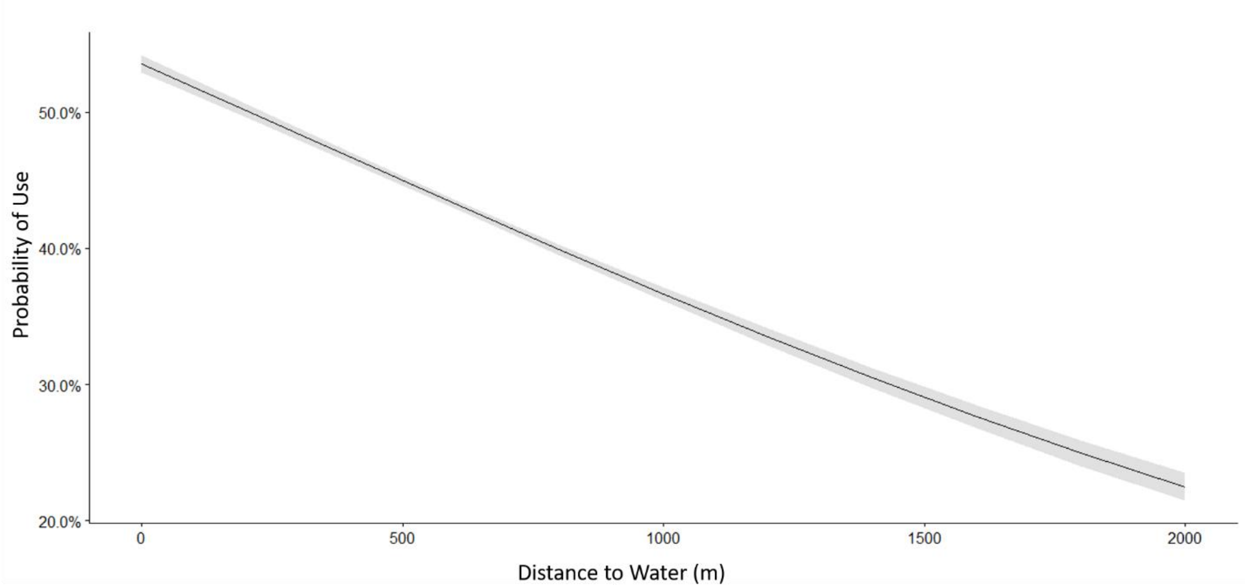

Figure 1-4 The top-ranked model (β-coefficient with 95% confidence intervals) predicting cattle resource selection in rotationally grazed pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas, indicates that cattle use in a landscape increased as distance to water decreased.

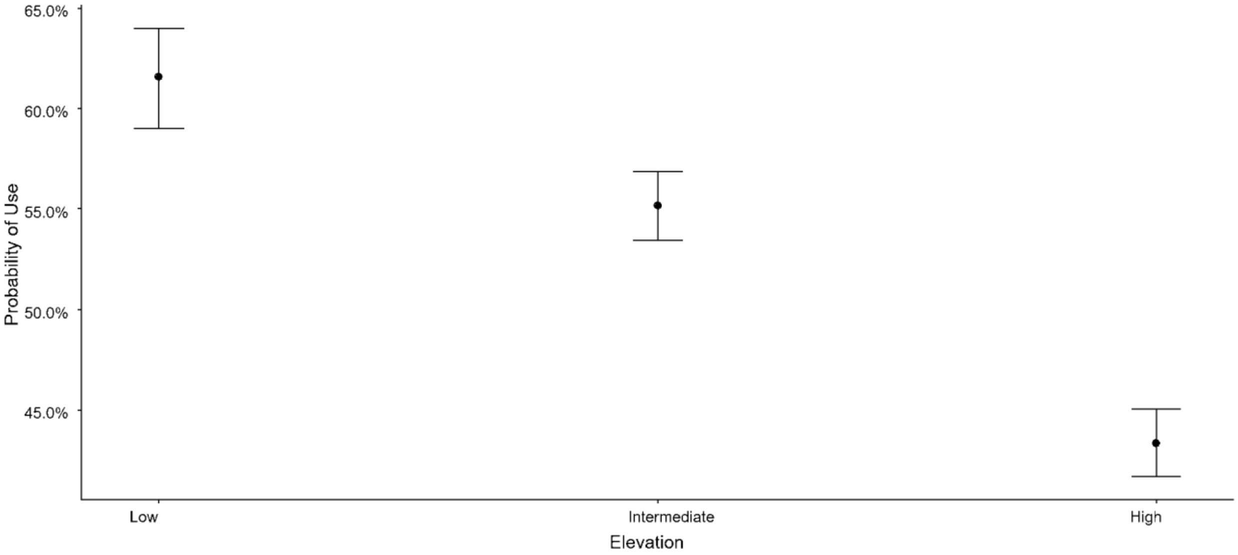

Figure 1-5 Model (β-coefficient with 95% confidence intervals) predicting cattle resource selection in rotationally-grazed pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas, indicates that that probability of selection by cattle increased as elevation decreased. Cattle selected lowlands, followed by moderate elevations and uplands on rotationally-grazed pastures.

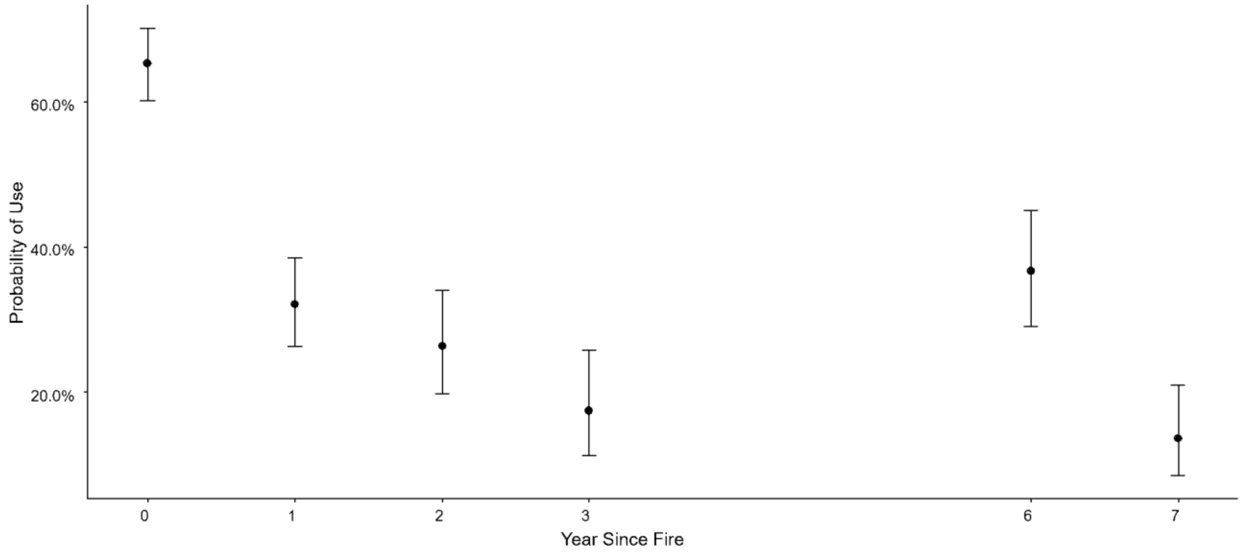

Figure 1-6 The top-rank model (β-coefficient with 95% confidence intervals) predicting cattle resource selection relative to time-since-fire patch in patch-burn grazed pastures that contained a year-of-fire patch from 2016 through 2018, in Comanche and Kiowa counties, Kansas, indicates that that cattle would select year-of-fire patches more frequently than other time-since-fire patches within these pastures.

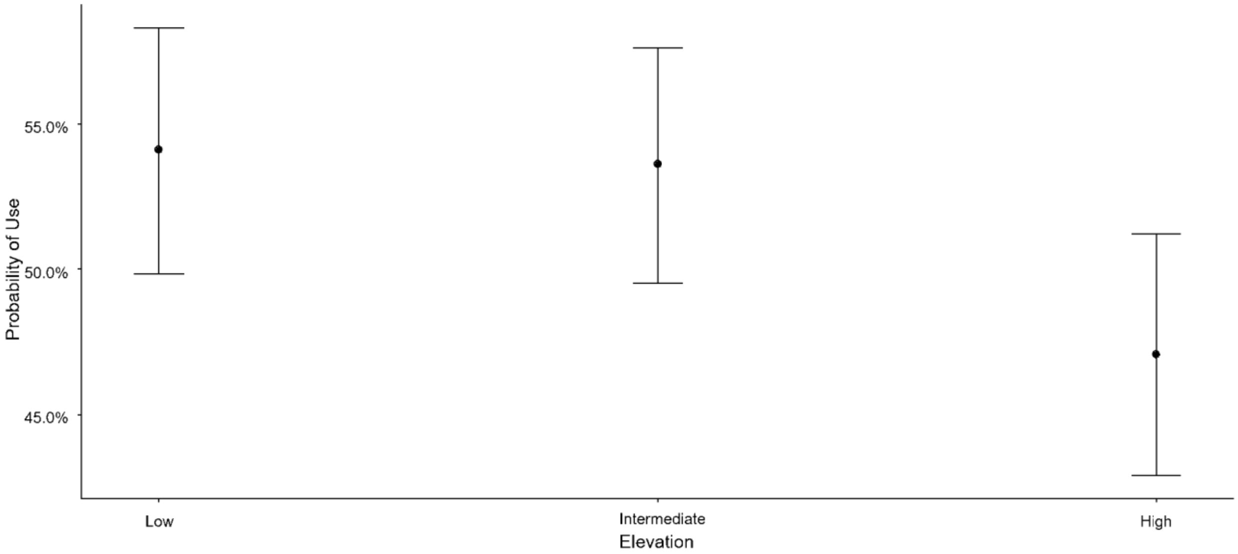

Figure 1-7 The top-rank model (β-coefficient with 95% confidence intervals) predicting cattle resource selection relative to elevation in patch-burn grazed pastures that contained a year-of-fire patch from 2016 through 2018, in Comanche and Kiowa counties, Kansas, indicates that that cattle did not select for specific elevations within these pastures, unlike cattle in rotationally grazed pastures, or patch-burn pastures without a year-of-fire patch.

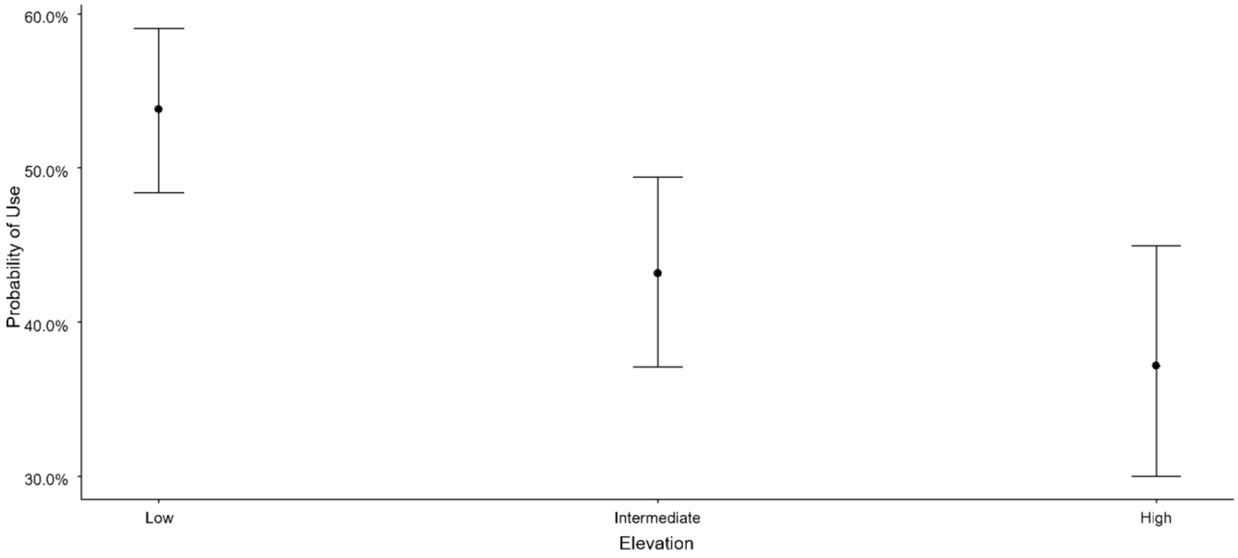

Figure 1-8 Model (β-coefficient with 95% confidence intervals) predicting cattle resource selection relative to elevation in patch-burn grazed pastures that did not contain a year-of-fire patch from 2016 through 2018, in Comanche and Kiowa counties, Kansas, indicates that that cattle selected lowlands over upland areas within these pastures.

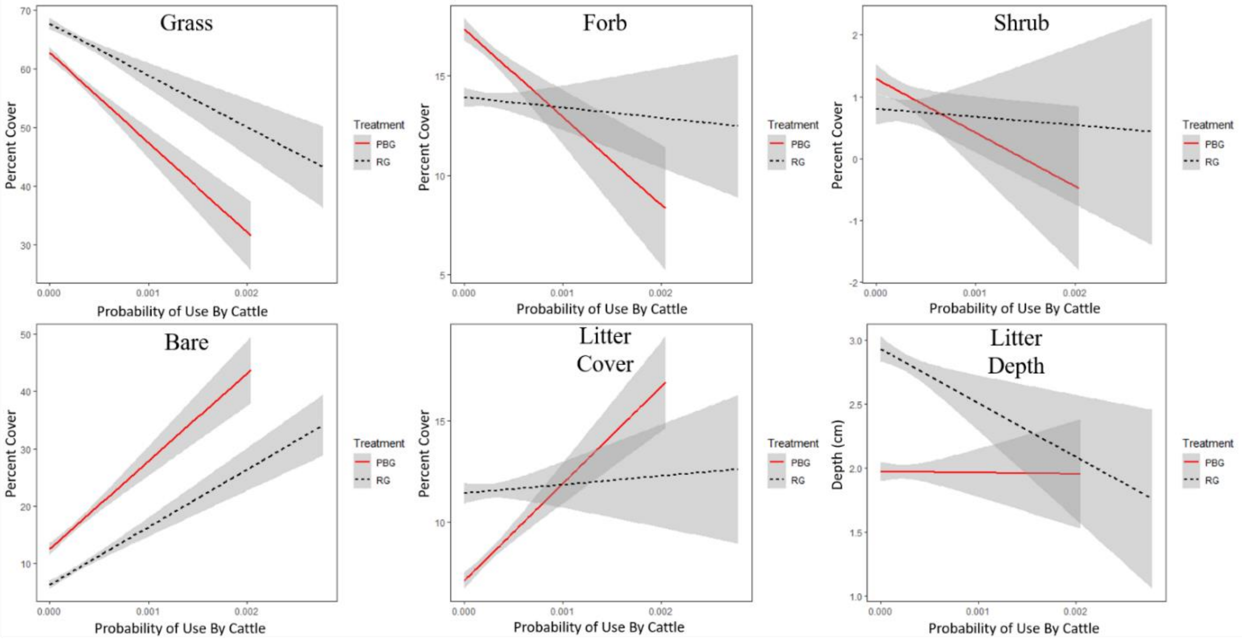

Figure 1-9 Linear models predicting vegetative cover (percent cover) and litter depth (cm) across fine-scale cattle density on two management treatments from 2016 through 2018, in Comanche and Kiowa counties, Kansas. Red lines indicate vegetation in patch-burn grazed treatments (PBG), and dotted black lines indicate vegetation in rotationally grazed treatments (RG).

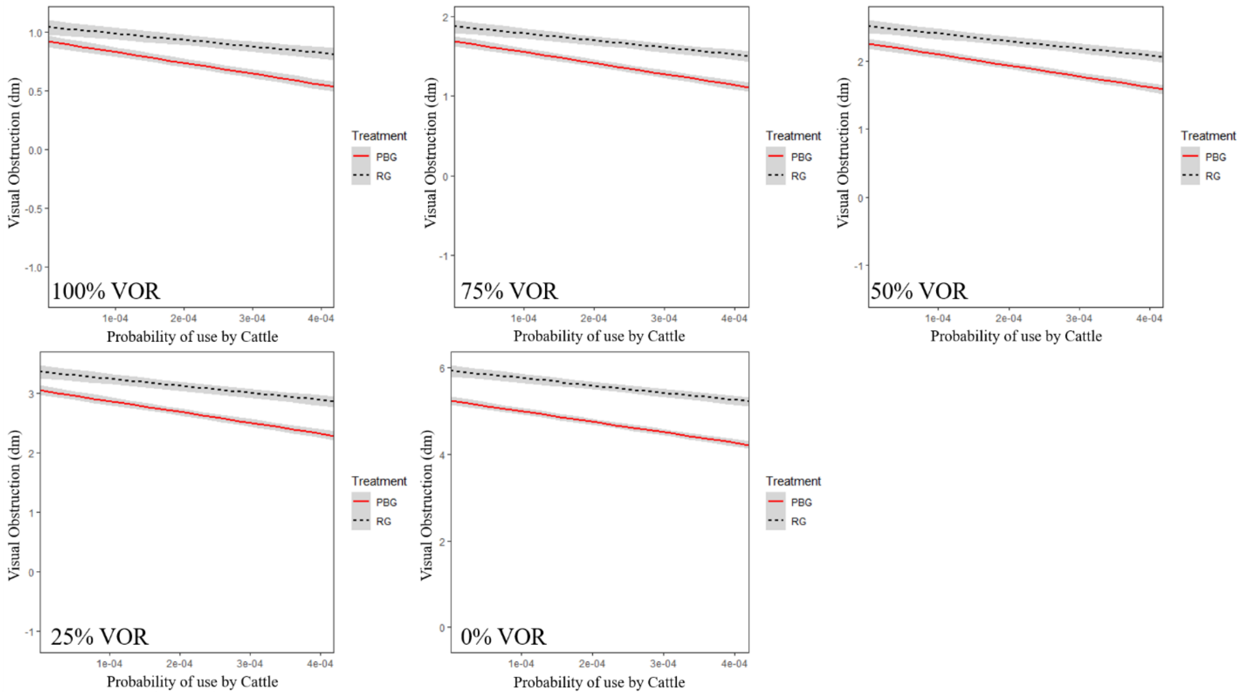

Figure 1-10 Linear models predicting visual obstruction (VOR) in decimeters (dm) across fine-scale cattle density on two management treatments from 2016 through 2018, in Comanche and Kiowa counties, Kansas. Red lines indicate vegetation in patch-burn grazed treatments (PBG), and dotted black lines indicate vegetation in rotationally grazed treatments (RG). Visual obstruction was measured across five classes: 05, 25%, 50%, 75%, and 100% obstruction.

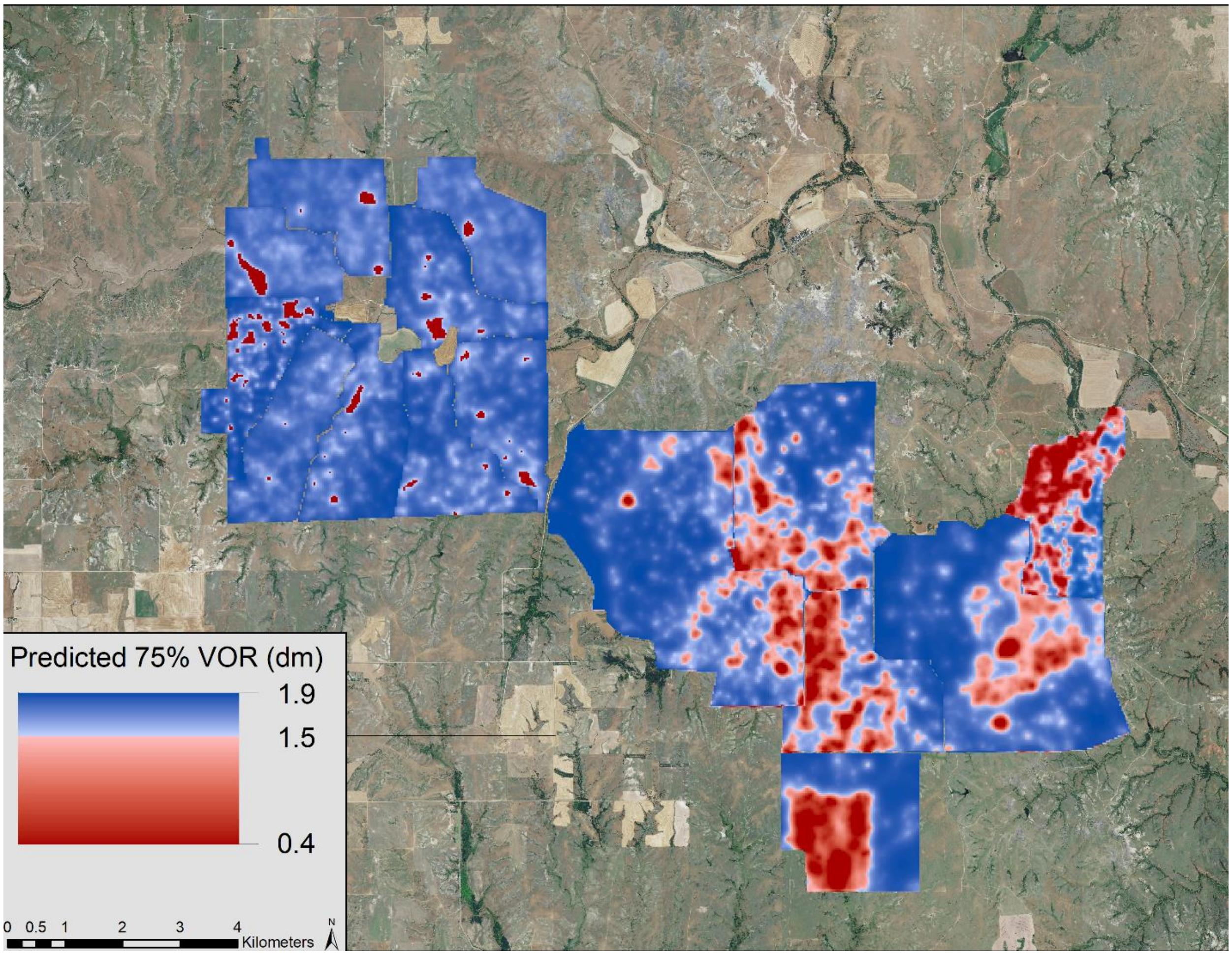

Figure 1-11 Predictive distribution of 75% visual obstruction, relative to fine-scale cattle density on two different management treatments from 2016 through 2018, in Comanche and Kiowa counties, Kansas. Areas in blue represent predicted 75% visual obstruction (VOR) above 1.5 dm, which is the minimum level of visual obstruction selected for by lesser prairie-chickens for nesting habitat. Areas in red represent predicted 75% VOR below 1.5 dm.

Tables

Table 1-1 Pasture areas and number of cattle GPS-collared and tracked by year on the patch-burn and rotationally grazed management sites, from 2016 - 2018, in Comanche and Kiowa counties, Kansas.

		Rotationally Grazed			Patch-Burn Grazed					
		Cell 1	Cell 2	Cell 3	Pasture 1	Pasture 2	Pasture 3	Pasture 4	Pasture 5	Pasture 6
Unit size (ha)		992	1130	1169	557	816	1392	1232	553	402
Collars retrieved	2016	8	3	4	4	3	3	3	3	0
	2017	3	4	4	4	3	3	6	0	4
	2018	4	6	0	2	2	0	2	0	0

Table 1-2 Stocking rates (AUM/acre; Animal Unit Month per acre) for cells on the rotationally grazed treatment. Each cell is comprised of three pastures, and one herd is rotated through each of the three pastures in each cell from early spring to early fall. Stocking rates remained constant in each cell from 2016 through 2018, in Comanche and Kiowa counties, Kansas.

Cell	Cow-Calf Pairs	AU	AUM (6 months)	Average Cell Area	Pasture Area (ha)	Pasture Area (acres)	Stocking Rate (AUM/Acre)
North	230	287.5	1725	330.58	991.74	2450.64	0.70
Southwest	300	375	2250	389.62	1168.87	2888.34	0.78
Southeast	250	312.5	1875	376.59	1129.77	2791.72	0.67

Table 1-3 Model rankings based on Akaike information criterion (AIC) predicting cattle resource selection on rotationally grazed pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas.

Model	K^i	$AIC_c{}^b$	$\Delta AIC_c{}^c$	$w_i{}^d$
Distance to Water (m)	3	407356.45	0	1
Distance to Tree (m)	3	413052.56	5696.11	0
Slope	4	414145.93	6789.48	0
Elevation	4	415123.87	7767.42	0
Distance to Fence (m)	3	416865.70	9509.25	0
Aspect	5	423351.73	15995.28	0

[a] **Number of parameters**

[b] **Akaike's Information criterion, corrected for small sample sizes**

[c] **Difference between the selected model and the most parsimonious model**

[d] **Level of support indicating that the selected model is the most parsimonious**

Table 1-4 Model rankings based on Akaike information criterion (AIC) predicting cattle resource selection on patch-burn grazed pastures that contained a year-of-fire patch pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas.

Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Year Since Fire	7	168712.26	0	1
Distance to Water (m)	3	184441.02	15728.76	0
Distance to Fence (m)	3	185270.43	16558.17	0
Distance to Tree (m)	3	185438.47	16726.21	0
Elevation	4	186624.24	17911.98	0
Slope	4	186874.14	18161.88	0
Aspect	5	189235.57	20523.31	0

[a] Number of parameters

[b] Akaike's Information criterion, corrected for small sample sizes

[c] Difference between the selected model and the most parsimonious model

[d] Level of support indicating that the selected model is the most parsimonious

Table 1-5 Model rankings based on Akaike information criterion (AIC) predicting cattle resource selection on patch-burn grazed pastures that did not contain a year-of-fire patch pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas.

Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Elevation	4	176969.38	0	1
Year Since Fire	7	177347.95	378.57	0
Distance to Water (m)	3	178845.91	1876.53	0
Slope	4	178882.32	1912.94	0
Distance to Fence (m)	3	179796.41	2827.03	0
Distance to Tree (m)	3	179970.83	3001.46	0
Aspect	5	183447.60	6478.23	0

[a] Number of parameters

[b] Akaike's Information criterion, corrected for small sample sizes

[c] Difference between the selected model and the most parsimonious model

[d] Level of support indicating that the selected model is the most parsimonious

Table 1-6 Coefficient of variation in vegetative structure (VOR, dm), cover (percent cover), litter depth (cm), and cattle probability of use on patch-burn grazed and rotationally grazed pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas. These metrics were calculated across the rotationally grazed site and the patch-burn grazed site. They were also calculated for patch-burn pastures containing a year-of-fire (YOF) patch, and for pastures not containing a year-of-fire patch.

	Rotationally Grazed	Patch-Burn Grazed		
	Site-Wide	Site-Wide	Contains YOF patch	no YOF patch
Cattle Space Use	0.97	1.04	1.07	0.97
Grass Cover	0.22	0.31	0.32	0.29
Forb Cover	0.53	0.58	0.59	0.58
Shrub Cover	4.89	3.73	4.13	3.27
Bare Ground Cover	1.26	1.13	1.12	1.15
Litter Cover	0.65	0.86	0.94	0.72
Litter Depth	0.51	0.66	0.70	0.60
0% VOR	0.35	0.38	0.41	0.32
25% VOR	0.53	0.56	0.59	0.52
50% VOR	0.63	0.69	0.72	0.63
75% VOR	0.72	0.82	0.86	0.75
100% VOR	1.02	1.20	1.26	1.12

Table 1-7 Mean and standard error of plant structure (visual obstruction, dm), litter depth (cm), and plant cover (percent cover) among rotationally grazed pastures and patch-burn grazed pastures from 2016 through 2018, in Comanche and Kiowa counties, Kansas.

	Patch-Burn Grazed		Rotationally Grazed	
	mean	SE	mean	SE
Grass Cover	59.98	0.43	67.13	0.95
Forb Cover	16.22	0.22	14.34	0.2
Bare Ground Cover	15.47	0.42	8.19	0.27
Shrub Cover	1	0.09	0.71	0.09
Litter Cover	8.17	0.17	11.3	0.19
Litter Depth (cm)	1.03	0.02	1.56	0.03
0% VOR	4.67	0.04	5.43	0.05
25% VOR	2.66	0.03	3.1	0.04
50% VOR	1.89	0.03	2.26	0.03
75% VOR	1.35	0.03	1.65	0.03
100% VOR	0.69	0.02	0.91	0.02

Table 1-8 Estimate of β-coefficients for single variable models predicting variation in vegetative cover, structure, and litter depth along a gradient of fine-scale cattle density intensity on a rotationally grazed and a patch-burn grazed management treatment in the Mixed-Grass Prairie Ecoregion of the Great Plains from 2016 through 2018, in Comanche and Kiowa counties, Kansas.

Treatment	β Coefficient	estimate	SE	z	*P*
Patch-Burn Grazed	Grass Cover (%)	-15518.6	1627.06	-9.54	<0.001
	Forb Cover (%)	-4286.96	863.80	-4.96	<0.001
	Shrub Cover (%)	-812.72	364.33	-2.23	<0.001
	Bare Cover (%)	15364.32	1617.41	9.50	<0.001
	Litter Cover (%)	4776.77	632.23	7.56	<0.001
	Litter Depth (cm)	-18.05	118.73	-0.15	<0.001
	0% VOR (dm)	-2395.19	150.96	-15.87	<0.001
	25% VOR (dm)	-1802.17	128.58	-14.02	<0.001
	50% VOR (dm)	-1580.92	112.37	-14.07	<0.001
	75% VOR (dm)	-1361.2	97.47	-13.10	<0.001
	100% VOR (dm)	-915.59	75.45	-12.14	<0.001
Rotationally Grazed	Grass Cover (%)	-9261.74	1401.97	-6.611	<0.001
	Forb Cover (%)	-358.10	724.71	-0.50	0.62
	Shrub Cover (%)	-89.60	370.88	-0.24	0.81
	Bare Cover (%)	10283.65	1072.85	9.59	<0.001
	Litter Cover (%)	333.42	744.97	0.45	0.65
	Litter Depth (cm)	-400.40	141.78	-2.82	0.004
	0% VOR (dm)	-1614.08	184.67	-8.74	<0.001
	25% VOR (dm)	-1132.47	157.05	-7.21	<0.001
	50% VOR (dm)	-1018.02	136.97	-7.43	<0.001
	75% VOR (dm)	-851.12	114.90	-7.41	<0.001
	100% VOR (dm)	-511.34	88.951	-5.75	<0.001

Chapter 2 - Effects of fine-scale cattle distribution on seasonal habitat use of lesser prairie-chickens within differently managed working grasslands

Introduction

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a grassland species with disproportionately high conservation importance due to its landscape-level population requirements, relatively large individual home ranges, and diverse resource needs during different life stages (Riley et al 1994, Fuhlendorf et al. 2002). This species is considered non-migratory; therefore, its annual home range must encompass a wide variety of resources to meet its habitat needs during different life stages (Fuhlendorf et al. 2002, Hagen et al. 2004, Haukos and Zavaleta 2016). The lesser prairie-chicken is also thought to be an indicator species for other grassland bird communities, as this varied seasonal habitat corresponds to habitat of other prairie birds (Haukos and Zavaleta 2016). Conservation practices for lesser prairie-chickens typically focus on habitat requirements of females due to their diverse seasonal resource needs and influence on population persistence (Boal and Haukos 2016).

Lesser prairie-chickens select for some common features during all life stages, such as upland habitat, close proximity to breeding grounds, and avoidance of trees (Hagen and Giesen 2004, Grisham et al. 2014, Lautenbach 2017, Lautenbach et al. 2017). Conversely, specific habitat selection patterns vary widely within seasons (Haukos and Zavaleta 2016). Female habitat selection can be broadly split into four stages: breeding, nesting, brooding, and nonbreeding (Boal and Haukos 2016). The breeding stage occurs in early spring, when females traverse the landscape to scout leks (i.e., groups of displaying males) for potential mates and to search for prospective nesting habitat. Habitat selected during this stage encompasses both lekking habitat (i.e., open patches of upland prairie with low plant structure) and nesting habitat (Plumb 2015). During nesting, females select vegetation with relatively high visual obstruction (Haukos and Smith 1989, Patten et al. 2005, Grisham et al. 2014) and adequate grass or shrub cover (Hagen et al. 2004). In eastern portions of the lesser prairie-chicken range, this habitat is found in areas with longer fire-return intervals (Fuhlendorf et al. 2017). The brooding stage occurs immediately after the nesting stage, typically from mid-June to mid-September. Brooding habitat typically has increased forb cover compared to other available sites, which is associated with more abundant arthropod food sources for chicks (Jamison et al. 2002, Hagen et al. 2005, Bell et al. 2010, Lautenbach 2015). Brooding habitat encompasses areas with moderate plant structure and patches of bare ground (Lautenbach 2015). Moderate visual obstruction in this habitat could provide refuge to broods from predators or solar radiation during hot summer months. Presence of bare ground in this habitat could facilitate movement of mobile chicks as they access food and shelter (Bell et al. 2010, Lautenbach 2015). For the purposes of this study, I considered the nonbreeding stage as the fall and winter period (September 15 to March 15) when hens are not nesting, brooding, or prospecting for potential mates. Female home ranges are larger during this stage but still remain centered around leks (Kukal 2010, Haukos and Zavaleta 2016, Robinson et al. 2018). Less is known about selection relative to vegetation during this period, but females will typically select for vegetation communities in intermediate stages of recovery from disturbance (Lautenbach 2017). Historically, this wide variety of habitat types is thought to have been governed by climate at large spatial and temporal scales and by fire and grazing at fine spatial and temporal scales. Primary ecological drivers of disturbance in this area were periodic wildfires and grazing by American bison (*Bison bison*). Fires on the Great Plains resulted in nutrient-dense regrowing forage in burned areas, relative to surrounding nonburned areas (Allred et al. 2011, Raynor et al. 2016). Bison subsequently concentrated their grazing in these recently-burned areas, leading to a divergence in foraging intensity; some areas were heavily grazed, while other areas were lightly grazed or not grazed (Allred et al. 2011, Raynor et al. 2015). Lightly grazed or non-grazed areas would subsequently develop greater fuel loads, making these areas more susceptible to wildfires. This cycle of pyric herbivory, or fire-driven grazing, led to patchy variation or heterogeneity in plant structure and species composition (Fuhlendorf et al. 2009, Winter et al. 2012).

The intensity of fire-grazer interactions increases as annual precipitation and fine fuel accumulation increases eastward across the Great Plains (Augustine and Derner 2014). The Mixed-Grass Prairie Ecoregion is the easternmost portion of the lesser prairie-chicken’s range and experiences annual precipitation that is double that of the western portion of the species’ range (Grisham et al. 2016*a*). This drives rapid plant regrowth following disturbances and strengthens the link between fire and grazers on this landscape. Effects of fire-grazer interactions often occur at the patch scale, which creates variability in vegetation structure among patches within pastures (Winter et al. 2012; Chapter I). Recently, some managers within the Mixed-Grass Prairie Ecoregion have adopted patch-burn grazing management to manage their grasslands. This technique is designed to enhance pyric herbivory by burning patches of pastures in spring (March to early May) and allowing domestic cattle to range unrestricted in that pasture during the growing season.

In the Mixed-Grass Prairie Ecoregion, patch-burn grazing improves habitat quality at the landscape scale and provides heterogeneity in vegetation structure across the landscape (Fuhlendorf et al. 2017). When combined, fire, grazing, and climate create a shifting patchwork of vegetation structure and heterogeneity that can be used by the lesser prairie-chicken during each period of its lifecycle (Fuhlendorf et al. 2017).

On modern landscapes, most management has deviated from historical patterns of disturbance. Free-roaming bison have been replaced by domestic cattle (*Bos taurus*), which are confined to pastures. In many regions, fire has been applied too frequently or too infrequently to provide necessary heterogeneity for lesser prairie-chickens. When fire and grazing are implemented too frequently or intensely, resulting grasslands exhibit homogeneously low structure, which are unsuitable for use by prairie grouse (Winder et al. 2018). On the opposite end of the spectrum, infrequent burning can result in homogeneously dense stands of grassland that may provide habitat for lesser prairie-chickens during some life stages, but do not account for diverse resource needs during all biological stages (Fuhlendorf and Engle 2001, Samson et al. 2004). Infrequent burning in this region can also lead to woody encroachment in uplands, which reduces habitat for lesser prairie-chickens (Engle et al. 2008, Fuhlendorf et al. 2017, Lautenbach et al. 2017). Most grazing management in the Mixed-Grass Prairie Ecoregion involves rotational grazing systems in absence of fire. Pastures are fenced into smaller sections and cattle are rotated through each section throughout the growing period. Rotational grazing is thought to increase residual vegetation leading to greater quality nesting habitat and increased nest survival at the landscape scale, a hypothesis that has received mixed support with respect to grouse ecology (Smith et al. 2018). In the mixed-grass and tall-grass prairie, rotational grazing is usually aimed at achieving uniform forage utilization, which can reduce vegetation heterogeneity needed by lesser prairie-chickens (Fuhlendorf and Engle 2001, Fuhlendorf et al. 2017).

Historically, the lesser prairie-chicken once inhabited a wide range of the southwestern Great Plains, but the species has undergone >90% decline in occupied range and >85% decline in population abundance since the late 19th century (Taylor and Guthery 1980, Garton et al. 2016). Primary reasons for these declines include climate change (Grisham et al. 2013), anthropogenic encroachment via oil and gas exploration (Pitman et al. 2005), conversion of prairie landscape to row-crop agriculture (Rodgers 2016), and loss and fragmentation of prairie landscapes due to mismanagement of native grassland (Woodward et al. 2001, Lautenbach 2017). While perceived declines in occupied range are apparently significant, the current extent of potential habitat has remained relatively stable since the 1950s (Spencer et al. 2017). This indicates that population declines on contemporary landscapes are more closely linked to degradation of habitat quality than habitat loss (Haukos and Zavaleta 2016). Greater than 95% of remaining lesser prairie-chicken habitat is privately owned and many of the landscape in the Mixed-Grass Prairie Ecoregion are managed for livestock production (Elmore and Dahlgren 2016). Habitat quality within these rangelands is, therefore, governed by management practices of livestock managers.

A need exists to understand habitat selection by lesser prairie-chickens within differently-managed rangelands. On the mixed-grass prairie, the influence of fine-scale variation in grazing on lesser prairie-chicken habitat is relatively unknown. I expect that grazing management decisions contribute to emergent 3rd-order (within home range) habitat selection by lesser prairie-chickens (Johnson 1980, Bertuzzo et al. 2011). My goal was to put the influence of these management strategies at fine scales into context with other processes that govern lesser prairie-chicken habitat selection. To do this, I modelled fine-scale distribution of cattle on two private rangelands, one patch-burn grazed and one rotationally grazed. Within these locations, I used resource-selection functions to determine seasonal selection of lesser prairie-chickens relative to fine-scale cattle densities and a suite of other landscape variables. I hypothesized that, within life stages, lesser prairie-chickens would select for upland habitat (above 606 m in elevation) and low tree densities at both sites but would select for different levels of fine-scale, cattle density between the patch-burn grazed and rotationally-grazed treatments. I hypothesized that habitat selection on the patch-burned site would be determined by an interaction of fine-scale cattle distribution and time-since-fire, while selection on the rotationally-grazed site would be driven primarily by fine-scale cattle distributions and elevation. My research could contribute to conservation of lesser prairie-chickens in the Mixed-Grass Prairie Ecoregion by determining how they select habitat during different reproductive life stages relative to fine-scale disturbances such as fire and grazing.

Study Area

My study occurred in the Red Hills region of south-central Kansas, in Kiowa and Comanche counties. Data collection occurred at two adjacent sites, one on a patch-burn grazed ranch and one on a traditional rotationally-grazed ranch (Figure 1-1). The rotationally grazed site was comprised of three grazing cells, each divided into three pastures by electric and barbed-wire fencing (Figure 1-2). Total area of this site was 3,290 ha and grazing-cell size ranged from 992 ha to 1,169 ha (average cell size = 1,097 ha). Pastures within cells ranged from 287 ha to 390 ha (average pasture size = 366 ha). Within each cell, mixed breed cow-calf pairs were stocked in early April, calves were weaned in mid-October, and cows were removed from pasture in late October. Cattle on this site were rotated between three pastures per cell every 10 to14 days from early April until late June. Thereafter, cattle were rotated through pastures every 14 to 21 days. Stocking rates ranged from 0.67 to 0.78 animal units per acre. No fires occurred at this site for over a decade prior to my research.

The 4,953 ha patch-burn grazed site was comprised of six patch-burned pastures. Pastures at this site ranged from 402 ha to 1,392 ha (average pasture size = 825 ha). This site was stocked with mixed-breed domestic cattle, either yearlings or cow-calf pairs. Yearling cattle on the patch-burn grazed treatment were kept on pasture from early spring until early fall and remained in one pasture throughout the growing season. Cow-calf pairs at this site remained on pasture year-long. The landowner at this site rotated pastures containing cow-calf pairs with those containing steers on a three to five-year schedule, with an intention to maintain abundance of palatable forbs within pastures (landowner, personal communication). Pastures in this treatment were stocked at rates similar rates to that of the rotationally-grazed site. Beginning in the late 1970s, the landowner began burning whole pastures to suppress encroaching eastern redcedar (*Juniperus virginiana*), which is known to increase in this region in absence of fire. Beginning the early 2000s, the landowner began using a patch-burn regime, where one-quarter to one-third of each pasture was burned once every three to four years and cattle were allowed to graze freely within different time-since-fire patches throughout the growing season (Figure 1-2). Prescribed burns at this site occurred from March 1 to May 5, in years when weather permitted burning. The patch-burning schedule for each year was dependent on weather conditions, resulting in variation in the amount of area burned in each pasture annually. From 2016 to 2018, six of the 13 pastures did not contain a year-of fire patch but still maintained a patch-mosaic burn structure (multiple time-since-fire patches within the same pasture). No prescribed fires were applied from 2011 to 2013 due to an intense regional drought. During 2018, no prescribed burns occurred within monitored pastures, as unfavorable spring weather limited the burning schedule for that season. Every patch-burn grazed pasture had at least three distinct time-since-fire patches in each year of the study.

Soil composition and topography were similar between sites. The landscape was comprised of rolling hills, with primarily sandy loams in the upland areas and clay soils in the lowlands. Terrain was rolling hills, ranging in elevation from 532 to 654 m above sea level. The site received 78.3 cm of precipitation in 2016, 60.8 cm in 2017, and 98 cm in 2018. Precipitation measurements were collected at a weather station 7.7 km from the field site from an online dataset stored by the National Oceanic and Atmospheric Administration (NOAA; https://www.ncdc.noaa.gov/cdo-web/datasets#GHCND). Average annual precipitation in this region is 64 cm (usclimatedata.com), making it the most mesic region of the lesser prairie-chicken's range. Average summer high temperature is 33.3° C in July and average winter low temperature is -7.2° C, occurring in January (usclimatedata.com).

Dryland agriculture, typically wheat and hay, was practiced in the drainages of these sites. Infrastructure associated with active oil exploration operations was present on both ranches. Dominant plants in the region included big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), sideoats grama (*Bouteloua curtipendula*), buffalograss (*Bouteloua dactyloides*), blue grama (*Bouteloua curtipendula*), and silver bluestem (*Bothriochloa laguroides*). Dominant forbs included Louisiana sagewort (*Artemisia ludoviciana*), western ragweed (*Ambrosia psilostachya*), and slimflower scurfpea (*Psoralidium tenuiflorum*). The most common shrubs in the area included leadplant (*Amorpha canescens*), eastern redcedar, sand sagebrush (*Artemisia filifolia*), and sand plum (*Prunus angustifolia*). Populations of lesser prairie-chickens have remained relatively stable at this site since the 1980s (private landowner, personal communication).

Methods

Lesser prairie-chicken capture and tracking

I used drift fencing, walk-in funnel traps, and tension drop nets to capture female lesser prairie-chickens at leks in both management areas from March 15 to May 5 during 2016, 2017, and 2018 (Haukos et al. 1990, Silvy et al. 1990). After capture, I aged and sexed birds based on color pattern and condition of plumage (Copelin 1963). I used Teflon® straps to harness 22-g, rump-mounted satellite transmitters (PTT-100 Solar Argos/GPS PTT Microwave Telemetry, Inc. Columbia, MD) to captured females. These devices transmitted location data once every two hours from 0500 to 2300 CST. Potential nests were identified though spatial patterns of hens during the spring (multiple satellite fixes in the same location). If a nest was found at that site, I counted and floated eggs to determine the approximate beginning of the egg-laying and incubation stages. I returned to the nest when females had permanently left the nest site or were suspected to have died on nest. I determined nest success by examining the nesting area for signs of egg hatching or nest depredation and further confirmed surviving nests by conducting brood flushes until early August.

Lesser prairie-chickens select for different resources during different periods of their life cycle. Management decisions applied to native rangelands can have different effects on seasonal habitat selection by this species. To account for changes in habitat use during different life stages, I separated all locations of female lesser prairie-chickens into five stages. Life stages were partitioned into the breeding stage (March 15 to June 15, excluding egg-laying and incubation phases), nesting stage (all incubation periods, typically from April 15 to June 15), post-nesting stage (June 15 to September 14, excluding stages when hens were actively brooding), brooding stage (all stages when hens were actively caring for broods), and nonbreeding stage (September 16 to March 14).

Cattle distribution and spatial resources

To estimate fine-scale cattle density within each treatment, I attached radio collars to cattle in early spring of 2016, 2017, and 2018 at both sites. I used store-on-board VHF/GPS collars (model G2110D, Advanced Telemetry Systems) to track cattle locations; collars recorded locations once every hour. I removed GPS collars from cattle in October. If cattle lost collars during the grazing period, I used a Yagi antenna to track and retrieve the collar. After retrieving collars, I downloaded cattle movement data using the ATSWinCollar application, and imported data into program R. I used Brownian Bridge Movement Models (package BBMM, Nielson et al. 2013) to estimate probability of use by generating a spatial utilization distribution (UD) by each collared animal and turned each UD into a raster with a pixel resolution of 30 m by 30 m. I assumed that the probability that an animal would use grassland beyond the fence boundaries of its assigned pasture was zero; however, the movement models that I created could not incorporate fence boundaries and estimated the probability that a cow used space beyond its assigned pasture as greater than zero. Models such as biased random bridge functions and kernel density functions can incorporate barriers but only if that barrier has a low tortuosity (Calenge 2006). As the fencing around pasture boundaries violated this assumption, I elected to reclassify my initial movement models to more closely resemble true cattle-space use within pastures.

To reclassify rasters, I first used the ‘clip’ tool in ArcMap 10.5 and clipped the UD for each cow to the pasture that contained that cow. I used zonal statistics in ArcMap 10.5 to sum the pixel values in each raster that fell within pasture boundaries. This number was equivalent to the original estimated probability (i.e., < 1) that an animal’s space use fell within its pasture. I used the raster calculator within ArcMap 10.5 to divide the value in each raster pixel by the sum of all raster pixels that fell within each pasture boundary. This created a raster for each animal that ended at pasture boundaries and estimated with 100% probability that all locations of each animal fell within the boundaries of that animal’s assigned pasture. After clipping and reclassifying rasters, I used the raster calculator in ArcMap 10.5 to average rasters for each animal per pasture each year. This allowed me to incorporate the movement and space use decisions of multiple cattle into one continuous probability-of-use for each pasture in each year of my study (Figure 2-3). I assumed that, when combined, the space use probability of multiple cattle would more accurately represent the space use of the entire herd in that pasture.

I kept the raster pixel size (30 × 30 m) constant for each raster, regardless of the pasture in which that UD was created; however, pasture sizes were variable throughout the study site (range = 402 ha to 1,392 ha). This led to an artificial inflation of the probability of use in each UD raster pixel for smaller pastures, as each raster pixel took up a greater relative area in small pastures than in large pastures. This issue would be alleviated if I knew exact stocking densities (animal units per acre) for each pasture. As I do not yet have these specific data for the patch-burn grazed pastures, I assumed stocking densities were roughly equivalent between treatments. I then determined the area ratio of each pasture to the smallest pasture and multiplied the raster cell values in each averaged UD by that ratio. In lieu of exact stocking densities, this standardization allowed me to compare cell values in patch-burn grazed pastures to cell values in rotationally-grazed pastures, assuming stocking densities were equivalent between the two treatments.

The output of this estimate is a continuous probability surface that incorporates space use by multiple cattle within each pasture. Because of this, I assumed that a greater probability of use within a 30-m raster pixel in a pasture would reliably lead to a greater density of cattle in that 30× 30-m area during the growing season. Throughout this chapter, I use ‘cattle density’ to describe the combined probability of use for multiple cattle within each pasture.

My goal for this study was to assess fine-scale cattle density relative to other landscape features that might influence habitat selection by lesser prairie-chickens. In addition to management-influenced effects (fine-scale cattle density and time-since-fire), I considered effects of innate landscape features such as slope, aspect, elevation, general soil type, tree density, and distance to trees. To collect data relative to these features, I first retrieved a digital elevation model from the Kansas GIS and Support Center (www.kansasgis.org); from this raster, I derived slope, aspect, and elevation. I grouped aspect into four categories: north (316 to 45 degrees), east (46 to 135 degrees), south (136 to 225 degrees), and west (226 to 315 degrees). I grouped slopes into three categories: shallow (less than 7°), moderate (7° to 11.5°), and steep (greater than 11.5°). Initially, I grouped elevation into three categories: uplands (606 to 654 m above sea level), intermediate zones (581 to 606 m), and lowlands (532 to 580 m); however, lesser prairie chickens within my study site were not encountered at elevations below 572 m above sea level. Selection for uplands is well documented in lesser prairie-chickens, as the species associates with lekking sites that typically occur in upland habitat; my data are consistent with these patterns of selection (Hagen and Giesen 2005, Lautenbach 2017). Because of this, I re-grouped elevation into two categories: low-to-moderate elevations (532 m to 606 m) and uplands (606 m to 654 m).

Analyses

I used resource selection functions to estimate lesser prairie-chicken seasonal response to fine-scale management influences and landscape features (Manly et al. 2002). To simulate random points at the 3rd order of habitat selection (within home range), I estimated 99% Brownian bridge home ranges for each female within each of its life stages (breeding, post-breeding, and nonbreeding). Due to a low number of broods observed during my study, I pooled brooding and non-brooding hens into the post-breeding period, which spanned from June 15 to September 15.

After these were delineated, I paired two random points to each used point within each female's seasonal home range, using the 'create random points' tool in ArcMap 10.5. I then extracted landscape variables, fine-scale cattle distributions, and time-since-fire layers to each used and available point using the 'extract multi-values to points' tool in ArcMap 10.5. I used generalized linear models (package lme4, Bates et al. 2015) to compare used to available points within each female's home range. I used the Akaike information criterion, adjusted for small sample sizes (AIC_c) to rank single-variable resource selection models within each site (Burnham and Anderson 2004). I considered any models with $\Delta AIC_c < 2$ as competitive models in explaining resource selection by lesser prairie-chickens. If the null model was within 2 units of the top model within a suite, I did not consider any models in that suite as valid predictors of lesser prairie-chicken resource selection. Within the patch-burn grazed site, I compared an additional set of models to determine seasonal resource selection by females relative to both fine-scale grazing intensity and time-since-fire patches.

I did not use Brownian bridge models to delineate home ranges for nest site selection, as these models would be biased by multiple repeated fixes that occurred at the nesting site. Instead, I created three circular buffers with radii of 300 m, 1,040 m, and 1,780 m around each nest. Within each of these buffers, I created nine random points and extracted landscape features to both used and paired points within each nest buffer. I used generalized linear models to compare used versus available points within each buffer. For each treatment, I fit models for each scale of selection into separate model suites and used AIC_c to rank single-variable resource selection models within each site (Burnham and Anderson 2004). The purpose of this multi-scale analysis was to determine if patterns of nest-site selection relative to fine-scale cattle distribution differed among different spatial scales. In addition to nest-site selection, I estimated apparent nest survival by dividing the number of successful nests within each management treatment by the number of attempted nests within each management treatment. I used a dataset of nests that had been recorded at this site from 2013 to 2018 to accomplish this.

Results

Cattle

I tracked 76 cattle from 2016 to 2018. Thirty-one cattle were collared in 2016, 15 in rotationally grazed pastures and 16 in patch-burn grazed pastures. Thirty-one were collared in 2017, 11 in rotationally grazed pastures and 20 in patch-burn grazed pastures. In 2018, 16 cattle were tracked, 10 in rotationally grazed pastures and 6 in patch-burn grazed pastures. While stocking rates on the patch-burned site site were set by the landowner, some pastures were rented to third parties who grazed yearling steers and heifers on certain pastures. Several of these managers opted to not attach collars to their cattle or attached collars loosely to avoid potential physical restrictions on cattle. This resulted in data gaps within certain pastures in 2017 and 2018, where collars that were either not deployed or were lost led to insufficient data to estimate cattle space use within a pasture. I recorded 576,108 relocations among 76 collared cattle. Of these, 306,404 occurred on rotationally grazed pastures and 269,704 occurred on patch-burn grazed pastures. Furthermore, 137,026 relocations occurred in patch-burn pastures containing a year-of-fire patch and 132,678 relocations occurred in patch-burn pastures containing no year-of-fire patch.

Seasonal data collection

I tracked 23 female lesser prairie-chickens on pastures containing collared cattle from 2016 to 2018; 13 of these were tracked on patch-burned pastures and 10 were tracked on rotationally-grazed pastures. I tracked 13 individuals during the post-breeding stage; eight of these occurred on patch-burn pastures and five occurred on rotationally-grazed pastures. I tracked 10 individuals during the nonbreeding stage; seven on the patch-burn site and three on the rotationally-grazed site. This resulted in 9,948 relocations on patch-burn pastures containing collared cattle and 10,684 relocations on rotationally-grazed pastures containing collared cattle. I recorded 16 nests within pastures containing collared cattle from 2016 to 2018; eight of these nests occurred on patch-burned pastures and eight nests occurred on rotationally-grazed pastures. To estimate apparent nest survival between treatments (i.e., patch-burn versus rotational management, regardless of fine-scale cattle distribution), I used a dataset of 95 nests recorded across both management sites from 2013 to 2018. I recorded 76 of these nests on patch-burn grazed pastures and 19 nests on rotationally grazed pastures. I did not detect any nests in the rotationally-grazed treatment during 2013 or 2018.

Breeding season selection

The top-ranked model predicting lesser prairie-chicken space use during the breeding season on rotationally-grazed pastures was percent tree canopy cover within 16 ha (Table 2-1). Probability of selection by lesser prairie-chickens increased as percent canopy cover decreased on the landscape (Figure 2-4). Within the rotationally grazed treatment, lesser prairie-chickens also selected for upland landscapes over lower elevations (Table 2-2). Lesser prairie-chickens did not show selection relative to cattle within elevational gradients during this stage (Figure 2-5). When I applied a quadratic function relating breeding season selection to cattle density, I found that selection by lesser prairie-chickens peaked at low to moderate cattle densities across the entire rotationally-grazed site (Figure 2-6).

The top-ranked model predicting breeding-season resource selection on the patch-burn grazed treatment included effects of time-since-fire patch and elevation (Table 2-1). This model carried 81.8% of the weight within the model suite. Lesser prairie-chickens within patch-burned rangelands selected for upland habitats and avoided year-of-fire and 4+ year-since-fire patches during the breeding season (Table 2-3). No interaction between time-since-fire and elevation was detected in this model (Table 2-3). Small sample size during the breeding period on patch-burn pastures could have limited my inference, as a relationship between time-since-fire and elevation has been previously documented (Lautenbach 2017).

I found a quadratic relationship between cattle and lesser prairie-chickens on the patch-burned treatment during the breeding season. This model indicated that lesser prairie-chickens selected against moderately-grazed areas during the spring; selection increased as fine-scale cattle densities decreased below moderate levels (Figure 2-7). While lesser prairie-chickens on both treatments selected areas with low cattle density during this period, the quadratic relationship between fine-scale cattle density and female lesser prairie-chicken selection differed between treatments. Within uplands, lesser prairie-chickens selected for less-used areas by cattle, relative to what was available. This pattern was similar to that observed on the rotationally-grazed site (Figure 2-8). Within 1- and 2-year-since-fire patches, lesser prairie-chickens also selected for areas less used by cattle, relative to what was available within these patches (Figure 2-9).

Nest site selection

I conducted resource selection functions for nest-site selection at three different scales: within 300 m, 1,040 m, and 1,780 m of nest sites. These distances corresponded to 28 ha, 340 ha, and 995 ha areas, respectively. At the smallest scale tested, I found that the null model outcompeted all other models within both patch-burned and rotationally-grazed model suites (Table 2-4). At the 340-ha scale on the patch-burned site, the top model was a linear model including the effect of cattle distribution (Table 2-5); however, this model was within 2 ΔAIC_c of the null model, indicating that it was not a competitive predictor of nest-site selection. The top model on the rotationally-grazed site at the 340-ha scale was the null model. At the 995-ha scale on the rotationally grazed site, the top model predicting nest site selection was distance-to-tree (Table 2-6). Probability of lesser prairie-chicken nest-site selection increased as distance-to-tree increased. A quadratic model including the effect of cattle distribution was also ranked above the null model within this suite but did not have an effect on nest-site selection. At this same scale within the patch-burn treatment, the top model predicting nest site selection was cattle distribution. As this model was within 2 ΔAIC_c of the null model, I did not consider it a competitive predictor of nest-site selection.

Post-breeding season selection

Drivers of resource selection differed between treatments during the post-breeding season. On the rotationally-grazed treatment, a quadratic model of fine-scale cattle space use best predicted lesser prairie-chicken resource selection. This model held 99% of the weight within its model suite (Table 2-7). Lesser prairie-chicken selection peaked at moderate to high cattle space use within rotationally-grazed pastures during the post-breeding season (Figure 2-10). Females during this life stage selected for areas with greater fine-scale cattle space use intensities when compared to the breeding stage. Within uplands and moderate elevations on the rotationally grazed treatment, female lesser prairie-chickens selected for high cattle densities during this life stage (Figure 2-11).

On the patch-burn grazed treatment, lesser prairie-chicken resource selection during the post-breeding stage was best predicted by a combination of time-since-fire and elevation (Table 2-7). This model carried all of the relative weight within its model set. Lesser prairie-chickens selected against year-of-fire patches and 3 year-since-fire patches, but selected for 1-, 2-, and 4+-year-of-fire patches (Table 2-8). Within 1-, 2-, and 4+- year-since-fire patches, the probability of lesser prairie-chicken use increased as cattle space use intensity decreased on the landscape. Within year-of-fire patches, lesser prairie-chicken use increased as cattle space-use intensity increased (Figure 2-12). I found a quadratic relationship between post-breeding habitat selection by female lesser prairie-chickens and fine-scale cattle space use (Figure 2-13). Lesser prairie-chicken probability of use decreased as fine-scale cattle space use intensity increased, similar to the selection patterns observed during the breeding season. In contrast, this pattern was dissimilar to the relationship observed between lesser prairie-chickens and cattle space use on the rotationally-grazed treatment. Lesser prairie-chicken probability of use increased as cattle space use intensity decreased within moderate and high elevations (Table 2-8).

Nonbreeding season selection

On the rotationally-grazed site, an additive model combining the effects of grazing intensity during the growing season and elevation best predicted lesser prairie-chicken use during the nonbreeding stage. This model carried 63.3% of the total weight of all models (Table 2-9). While cattle had been removed from pastures by this time, fine-scale grazing intensity during the grazing period still influenced selection by lesser prairie-chickens during the fall and winter nonbreeding stage. Probability of use by lesser prairie-chickens increased as cattle space use intensity increased within rotationally-grazed pastures (Figure 2-14).

On the patch-burned site, an additive model including time-since-fire and elevation best predicted lesser prairie-chicken resource selection during the nonbreeding stage (Table 2-9). This model carried 85.3% of the weight within its suite of models. Lesser prairie-chickens selected against year-of-fire patches and selected for 4+ year-since-fire patches and upland landscapes (Table 2-10). Across the entire patch-burn grazed treatment, lesser prairie-chickens selected for the lowest fine-scale cattle densities available within their home ranges. This observation was relatively consistent with selection during other life stages in the patch-burn grazed treatment (Figure 2-15). Relative to both grazing and fire, lesser prairie-chickens selected for areas least used by cattle within 1-, 3-, and 4+ year-since-fire patches but selected areas used most by cattle in year-of-fire patches (Figure 2-16). An interactive model including cattle space use and elevation indicated that lesser prairie-chickens did not select for specific cattle space use intensities within upland, patch-burned landscapes (Table 2-10).

Apparent nest survival

I measured apparent nest survival of lesser prairie-chickens on patch-burn and rotationally-grazed treatments from 2013 to 2018. Apparent nest survival was annually variable between treatments during this period; this was not surprising, as breeding success of lesser prairie-chickens is highly sensitive to annual changes in habitat caused by variable weather patterns (Merchant 1982; Grisham et al. 2014, 2016*b*). Despite annual fluctuations, apparent nest success was equivalent between sites. On the patch-burn treatment, apparent nest survival was 28.9% overall, whereas apparent nest success on the rotationally-grazed treatment was 31.6% overall (Table 2-8).

Discussion

This experiment is among the first to analyze seasonal lesser prairie-chicken resource selection relative to prescribed fire and fine-scale cattle distribution. Most notably, I found that lesser prairie-chickens responded differently to fine-scale cattle space use intensity between patch-burn and rotationally-grazed rangelands. Furthermore, my data were interpreted to indicate that seasonal selection by lesser prairie-chickens was directly influenced by cattle distributions at fine spatial scales on both sites. On the rotationally-grazed site, lesser prairie-chickens were most influenced by fine-scale cattle densities, tree densities, or a combination of fine-scale cattle densities and elevation. Across all seasons on the patch-burn treatment, lesser prairie-chickens were most influenced by a combination of time-since-fire patches and elevation, followed by a combination of fine-scale cattle densities and time-since-fire patches.

Lesser prairie-chickens selected for variable fine-scale cattle densities within discrete time-since-fire patches on patch-burn grazed rangelands. This confirmed my hypotheses that the two management treatments would alter lesser prairie-chicken resource selection relative to cattle distributions and that lesser prairie-chickens would respond to disturbance at fine scales within discrete time-since-fire patches. During the spring breeding season, lesser prairie-chickens selected for the least heavily grazed portions of 1- and 2-year-since-fire patches and the most heavily grazed portions of 3-year-since-fire patches. Lesser prairie-chickens displayed seasonal selection for different time-since-fire patches, but it appeared that they were selecting landscapes relative to disturbance at even finer scales than previously documented (Kraft 2016, Lautenbach 2017). Furthermore, these patterns shifted among life stages on the patch-burn grazed ranch. This indicates that, both within and between seasons, fine-scale cattle distributions significantly influenced within-patch habitat selection by lesser prairie-chickens.

On the rotationally-grazed site, probability of use by lesser prairie-chickens peaked at moderate-to-low cattle space use intensity during the breeding stage (spring) and at moderate-to-high cattle space use intensity during the post-breeding stage (summer). During the nonbreeding stage (fall and winter), probability of use by lesser prairie-chickens increased as cattle space use increased on rotationally-grazed pastures. Probability of use during this season was greatest in upland habitats with high cattle space use intensity. On the patch-burn grazed landscape, I found that probability of use by lesser prairie-chickens during nonbreeding stages increased as cattle space use intensity decreased. During the breeding and post-breeding stages, lesser prairie-chickens avoided areas used moderately by cattle within patch-burn grazed rangelands, which contradicted the pattern observed on rotationally-grazed rangeland. Despite these two rangelands being managed at similar stocking densities, lesser prairie-chickens showed contrasting patterns of selection relative to fine-scale cattle distributions.

The breeding stage occurs prior to egg laying and incubation in the spring. During this period, females traverse the landscape to scout potential mates at leks and search for suitable nesting habitat (Plumb 2015). While I did not find a strong relationship between nest-site selection and cattle distribution, I anticipated that breeding season selection would roughly correspond to potential nesting habitat on both treatments. On rotationally-grazed pastures, habitat selection was driven most strongly by tree canopy cover at the 16-ha scale and by an interaction between fine-scale cattle distribution and elevation. Probability of use by lesser prairie-chickens increased as cattle space use decreased; this resulted in selection for low-to-moderate cattle space use intensity within these pastures. Grass cover and visual obstruction increased as cattle density decreased on rotationally-grazed landscapes (Chapter 1). This indicates that lesser prairie-chickens were selecting for cattle distributions that were conducive to high-quality nesting habitat during the breeding period on rotationally-grazed pastures (Lautenbach et al. 2019).

Within patch-burned grazed rangelands, lesser prairie-chickens avoided moderate cattle densities, and selected for the lowest available cattle densities within pastures. These areas also corresponded to greater visual obstruction and grass cover, which relates to high quality nesting habitat (Fields 2004, Lautenbach et al. 2019; Chapter 1). While lesser prairie-chickens were responding differently to fine-scale cattle densities within treatments, it appeared that on both treatments that they were selecting levels of disturbance (e.g., grazing and fire) that corresponded to the best nesting habitat available during the breeding season.

Post-breeding selection on patch-burned rangelands occurred in areas with low fine-scale cattle space use intensities; these areas corresponded to the greatest amount of visual obstruction and the greatest forb cover on patch-burned landscapes (Chapter 1). On the rotationally-grazed site, post-breeding habitat selection occurred at the most intensely-grazed areas available within upland sites. This corresponded to areas with low litter depth and increased bare ground (Chapter 1). These features were consistent with high-quality brooding habitat, which would be likely to facilitate chick mobility while providing overhanging cover and abundant arthropod forage (Hagen et al. 2005). On patch-burned landscapes, lesser prairie-chickens selected similar habitats during the breeding and post-breeding periods. These areas were associated with high-quality brood habitat (Chapter 1).

During the first two weeks after hatch, broods have limited mobility and require high quality brooding habitat within close proximity to a nest (Plumb 2015). Lesser prairie-chickens on patch-burn pastures may have been attempting to maximize their breeding success by selecting for landscapes with abundant forbs during both the breeding and post-breeding periods.

While apparent nest success was similar between sites, patch-burn grazing could be facilitating greater recruitment of chicks by providing nesting and brooding habitat within close proximity to one another.

Relatively little is known about vegetation-related resource selection during the nonbreeding stage. Lesser prairie-chickens tend to congregate within 1.7 km of leks during this stage, and habitat use is thought to overlap with breeding season habitat (Pirius et al. 2013). Additional research reported that lesser prairie-chickens selected for intermediate levels of disturbance on landscapes (Lautenbach 2017). While cattle were not being monitored on pastures for most of the nonbreeding season (September 15-March 15), the fine-scale space use by cattle during the grazing period likely still influenced nonbreeding habitat selection. On the rotationally-grazed site, nonbreeding habitat was best predicted by elevation and fine-scale cattle densities. Lesser prairie-chickens selected upland habitat and their probability of use increased as cattle space-use intensity increased at this site. This selection pattern differs from that of other life history stages, indicating that female lesser prairie-chickens have unique resource needs during this stage. This further highlights the importance of heterogeneity on rangelands to support all needs of lesser prairie-chickens' life stages.

Nonbreeding habitat selection on patch-burn grazed rangelands was driven most by elevation and time-since-fire. Similar to the rotationally-grazed site, lesser prairie-chickens on patch-burn pastures selected uplands. Conversely, I found that females on the patch-burned site avoided areas that were recently burned and selected for longer fire-return patches. While I found a difference in nonbreeding resource selection relative to cattle densities between the two treatments, it is still unclear what is driving this difference. Differences in selection within time-since-fire patches during each life stage indicates the need for fine-scale heterogeneity in habitat during each life stage.

Lesser prairie-chickens selected against proximity to trees during nesting, which was consistent with prior research (Lautenbach et al. 2017). There was also some indication that lesser prairie-chickens selected habitat disturbed by fine-scale cattle distribution. Previous research documented the importance of undisturbed grassland for lesser prairie-chicken nest site selection at broad scales. I expected to find a similar trend at fine spatial scales relative to cattle distribution within pastures (Kraft 2016); however, I had a relatively small sample of nests within pastures containing collared cattle. This may have limited my ability to detect patterns in selection.

Apparent nest success was equivalent between treatments. While further analysis is needed to determine demographic influence of rangeland management on lesser prairie-chickens, these data were interpreted suggest that abundant nesting habitat is available in both patch-burned and rotationally-grazed sites. While apparent nest success was equivalent between treatments, rotationally-grazed pastures had greater litter depths, decreased bare ground, and decreased forb cover when compared with patch-burned sites, indicating that they may be less efficient in providing brooding habitat for lesser prairie-chickens immediately after hatch (Chapter 1). In contrast, lesser prairie-chicken resource selection on patch-burned rangelands corresponded to areas of low fine scale cattle space use intensities during both the breeding and post-breeding periods. These landscapes were associated with increased quality of potential brooding habitat (Hagen et al. 2004, 2005; Chapter 1). Patch-burning may be more efficient in providing brooding habitat for lesser prairie-chickens, when compared to rotationally-grazed rangelands.

The presence of pyric herbivory on patch-burn grazed landscapes shifted seasonal selection patterns of lesser prairie-chickens, relative to traditional rangeland management. Patch-burning grazing created more vegetative heterogeneity and may increase brood survival by providing high quality nesting and brooding habitat in habitats selected by lesser prairie-chickens in the breeding and post-breeding seasons.

It is clear that rangeland management techniques influence 3rd-order habitat of lesser prairie-chickens at fine spatial scales. In the eastern Mixed-Grass Prairie Ecoregion, a patch-mosaic grazing management strategy would allow increased vegetation heterogeneity within pastures, while simultaneously providing high-quality nesting and brooding habitat in close proximity to one another.

Literature Cited

Allred, B. W., S. D. Fuhlendorf, D. M. Engle, and R. D. Elmore. 2011. Ungulate preference for burned patches reveals strength of fire-grazing interaction. Ecology and Evolution 1:132-144.

Augustine, D. J., and J. D. Derner. 2014. Controls over the strength and timing of fire-grazer interactions in a semi-arid rangeland. Journal of Applied Ecology 51:242-250.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67:1-48.

Bell, L. A., S. D. Fuhlendorf, M. A. Patten, D. H. Wolfe, and S. K. Sherrod. 2010. Lesser prairie-chicken hen and brood habitat use on sand shinnery oak. Rangeland Ecology and Management 63:478-486.

Bertuzzo, E., S. Suweis, L. Mari, A. Maritan, I. Rodriguez-Iturbe, and A. Rinaldo. 2011. Spatial effects on species persistence and implications for biodiversity. Proceedings of the National Academy of Science 108:4346-4351.

Boal, C. W., and D. A. Haukos. 2016. The lesser prairie-chicken. Pages 1-11 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference: Understanding AIC and BIC in model selection. Sociological Methods and Research 33: 261-304.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Copelin, F. F. 1963. The lesser prairie chicken in Oklahoma. Oklahoma Wildlife Conservation Department. Oklahoma City, USA.

Elmore, R. D., and D. K. Dahlgren. 2016. Public and private land conservation dichotomy. Pages 187-203 in D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Engle, DM, Coppedge, BR, Fuhlendorf, SD, 2008. From the dust bowl to the green glacier: human activity and environmental change in Great Plains grasslands. Pages 253-271 *in* O. V. Auken, editor. Western North American Juniperus Communities. Springer, New York, USA

Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. BioScience 51:625-632.

Fuhlendorf, S. D., A. J. W. Woodward, D. M. Leslie, and J. S. Shackford. 2002. Multi-scale effects of habitat loss and fragmentation on lesser prairie-chicken populations of the US Southern Great Plains. Landscape Ecology 17:617-628.

Fuhlendorf, S. D., D. M. Engle, J. Kerby, and R. Hamilton. 2009. Pyric herbivory: rewilding landscapes through the recoupling of fire and grazing. Conservation Biology 23:588-598.

Fuhlendorf, S. D., T. J. Hovick, R. D. Elmore, A. M. Tanner, D. M. Engle, and C. A. Davis. 2017. A hierarchical perspective to woody plant encroachment for conservation of prairie-chickens. Rangeland Ecology and Management 70:9-14.

Garton, E. O., C. A. Hagen, G. M. Beauprez, S. C. Kyle, J. C. Pitman, D. D. Schoeling, W. E. Van Pelt. 2016. Population dynamics of the lesser prairie-chicken. Pages 49-76 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Grisham, B. A., C. W. Boal, D. A. Haukos, D. M. Davis, K. K. Boydston, C. Dixon, and W. R. Heck. 2013. The predicted influence of climate change on lesser prairie-chicken reproductive parameters. PLoS ONE 8:e68225.

Grisham, B. A., P. K. Borsdorf, C. W. Boal, and K. K. Boydston. 2014. Nesting ecology and nest survival of lesser prairie-chickens on the southern high plains of Texas. Journal of Wildlife Management 78:857-866.

Grisham, B. A., A. J. Godar, and C. P. Griffin. 2016*a*. Climate Change. Pages 221-242 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Grisham, B. A., A. J. Godar, C. W. Boal, and D. A. Haukos. 2016*b*. Interactive effects between nest microclimate and nest vegetation structure confirm microclimate thresholds for lesser prairie-chicken nest survival. Condor 118:728-746.

Hagen, C. A., B. E. Jamison, K. M. Giesen, and T. Z. Riley. 2004. Guidelines for managing lesser prairie-chicken populations and their habitats. Wildlife Society Bulletin 32:69-82.

Hagen, C. A., G. C. Salter, J. C. Pitman, R. J. Robel, and R. D. Applegate. 2005. Lesser prairie-chicken brood habitat in sand sagebrush: invertebrate biomass and vegetation. Wildlife Society Bulletin 33:1080-1091.

Hagen, C. A. and K. M. Giesen. 2005. Lesser prairie-chicken (Tympanuchus pallidicinctus), version 2.0. In the Birds of North America (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, USA. https://doi.org/10.2173/bna.364

Haukos, D. A, and L. M. Smith. 1989. Lesser prairie-chicken nest site selection and vegetation characteristics in tebuthiuron-treated and untreated sand shinnery oak in Texas. Great Basin Naturalist 49:624-626.

Haukos, D. A., L. M. Smith, and G. S. Broda. 1990. Spring trapping of lesser prairie-chickens. Journal of Field Ornithology 61:20-25.

Haukos, D. A., and J. C. Zavaleta. 2016. Habitat. Pages 99–132 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Jamison, B. E., R. J. Robel, J. S. Pontius, R. D. Applegate. 2002. Invertebrate biomass: associations with lesser prairie-chicken habitat use and sand sagebrush density in southwestern Kansas. Wildlife Society Bulletin 30:517-526.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Kukal, C. A. 2010. The over-winter ecology of Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) in the northeast Texas Panhandle. M.S. thesis, Texas Tech University, Lubbock, TX.

Lautenbach, J. M. 2015. Lesser prairie-chicken reproductive success, habitat selection, and response to trees. Thesis, Kansas State University, Manhattan, USA.

Lautenbach, J. M., R. T. Plumb, S. G. Robinson, C. A. Hagen, D. A. Haukos, and J. C. Pitman. 2017. Lesser prairie-chicken avoidance of trees in a grassland landscape. Rangeland Ecology & Management 70:78-86.

Lautenbach, J. M., D. A. Haukos, D. S. Sullins, C. A. Hagen, J. D. Lautenbach, J. C. Pitman, R. T. Plumb, S. G. Robinson, and J. D. Kraft. 2019. Factors influencing nesting ecology of lesser prairie-chickens. Journal of Wildlife Management 83:205-215

Lautenbach, J. D. 2017. The role of fire, microclimate, and vegetation in lesser prairie-chicken habitat selection. Thesis, Kansas State University, Manhattan, USA.

Manly, B. F., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Springer, New York, New York, USA.

Merchant, S. S. 1982. Habitat use, reproductive success, and survival of female lesser prairie-chickens in two years of contrasting weather. Thesis, New Mexico State University, Las Cruces, USA.

Nielson, R. M., H. Sawyer, and T. L. McDonald. 2013. BBMM: Brownian bridge movement model. R package version 3.0.

Patten, M., D. Wolfe, E. Shochat, and S. Sherrod. 2005. Effects of microhabitat and microclimate selection on adult survivorship of the lesser prairie-chicken. Journal of Wildlife Management 69:1270-1278.

Paull, D. A., J. W. Whitson, A. L. Marcotte, G. C. Liknes, D. M. Meneguzzo, and T. A. Kellerman. 2017. High-resolution land cover of Kansas 2015. Fort Collins, CO: Forest Service Research Data Archive. Updated 27 November 2017.

Pirius, N. E., C. W. Boal, D. A. Haukos, and M. C. Wallace. 2013. Winter habitat use and survival of lesser prairie-chickens in West Texas. Wildlife Society Bulletin 37:759-765.

Pitman, J. C., C. A. Hagen, R. J. Robel, T. L. Loughin, and R. D. Applegate. 2005. Location and success of lesser prairie-chicken nests in relation to vegetation and human disturbance. Journal of Wildlife Management 69:1259-1269.

Plumb, R. T. 2015. Lesser prairie-chicken movement, space use, survival, and response to anthropogenic structures in Kansas and Colorado. Thesis, Kansas State University, Manhattan, USA.

Raynor, E. J., A. Joern, and J. M. Briggs. 2015. Bison foraging responds to fire frequency in nutritionally heterogeneous grassland. Ecology 96:1586-1597.

Raynor, E. J., A. Joern, J. B. Nippert, and J. M. Briggs. 2016. Foraging decisions underlying restricted space use: effects of fire and forage maturation on large herbivore nutrient uptake. Ecology and Evolution 6:5843-5853.

Riley, T.Z., C. A. Davis, M. A. Candelaria, and H. R. Suminski. 1994. Lesser prairie-chicken movements and home ranges in New Mexico. Prairie Naturalist 26:183-186.

Robinson, S. G., D. A. Haukos, R. T. Plumb, J. M. Lautenbach, D. S. Sullins, J. D. Kraft, J. D. Lautenbach, C. A. Hagen, and J. C. Pitman. 2018. Nonbreeding home-range size and survival of lesser prairie-chickens. Journal of Wildlife Management 82:413-423.

Rodgers, R. D. 2016. A history of lesser prairie-chickens. Pages 15-38 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosystems: past, present, and future. Wildlife Society Bulletin 32:6-15.

Silvy, N. J., M. E. Morrow, E. Shanley, and R. D. Slack. 1990. An improved drop net for capturing wildlife. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 44:374-378.

Smith, J. T., J. D. Tack, L. I. Berkeley, M. Szczypinski, and D. E. Naugle. 2018. Effects of rotational grazing management on nesting greater sage-grouse. Journal of Wildlife Management 82:103-112.

Spencer, D. A., D. A. Haukos, S. D. Fuhlendorf, C. A. Hagen, M. D. Daniels, and D. G. Goodin. 2017. Conservation Reserve Program Mitigates grassland loss in the lesser prairie-chicken range of Kansas. Global Ecology and Conservation 9:21-38.

Taylor, M. A., and F. S. Guthery. 1980. Status, ecology, and management of the Lesser Prairie-Chicken. USDA Forest Service, General Technical Report RM-77. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Winder, V. L., L. B. Mcnew, J. C. Pitman, and B. K. Sandercock. 2018. Effects of rangeland management on survival of female greater prairie-chickens. Journal of Wildlife Management 82:113-122.

Winter, S. L., S. D. Fuhlendorf, C. L. Goad, C. A. Davis, K. R. Hickman, and D. M. Leslie. 2012. Restoration of the fire-grazing interaction in Artemisia filifolia shrubland. Journal of Applied Ecology 49:242-250.

Woodward, A. J. W., S. D. Fuhlendorf, D. M. Leslie, and J. Shackford. 2001. Influence of landscape composition and change on lesser prairie-chicken (*Tympanuchus pallidicinctus*) populations. American Midland Naturalist 145:261-274.

Figures

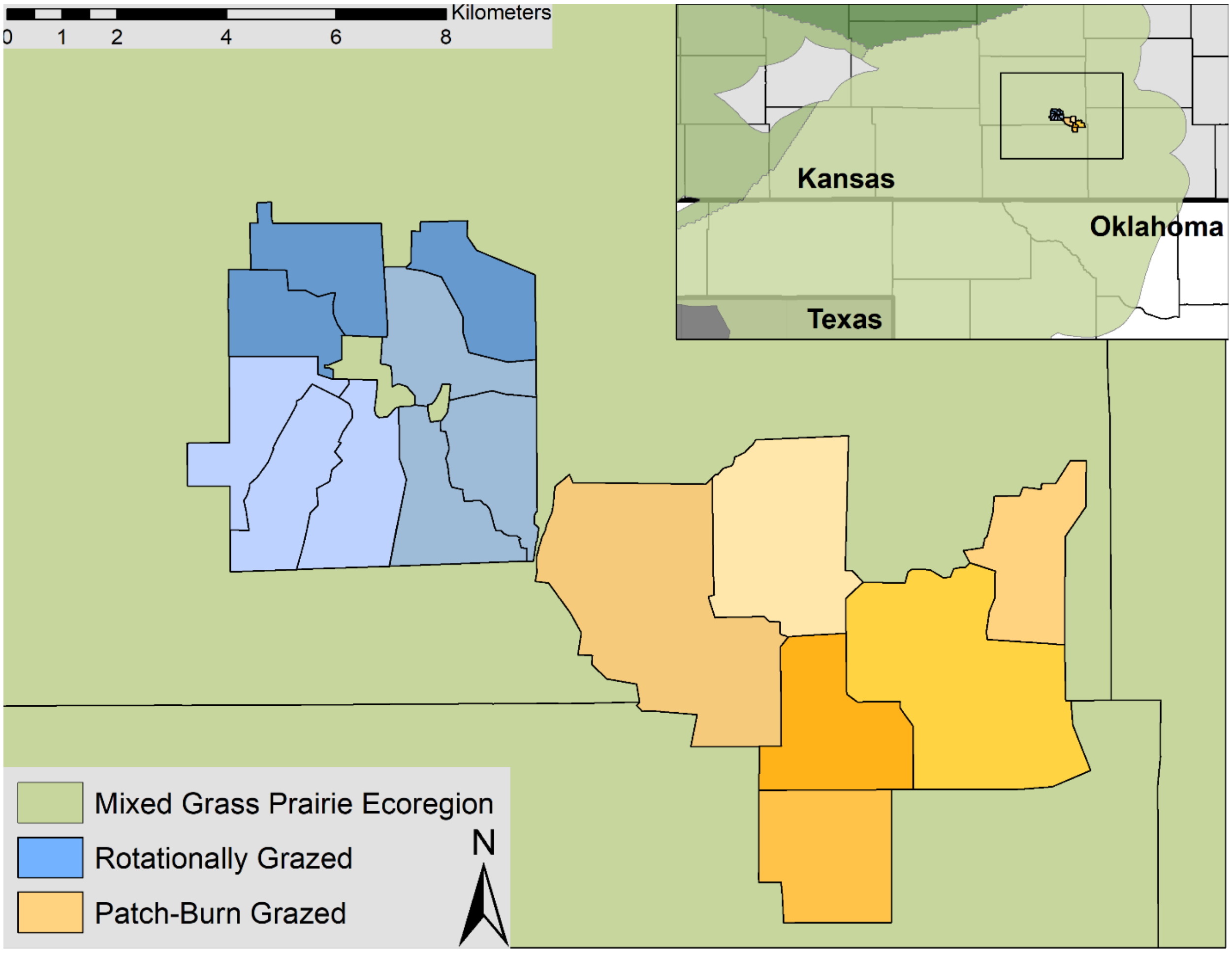

Figure 2-1 Field site where data were collected from 2016-2018. The two adjacent management treatments occur in the Red Hills region of south central Kansas, on the Mixed-Grass Prairie Ecoregion of the lesser prairie-chicken's range. Field site consisted of three rotationally grazed cells, comprised of three pastures each, and six patch-burn grazed pastures with no interior fencing.

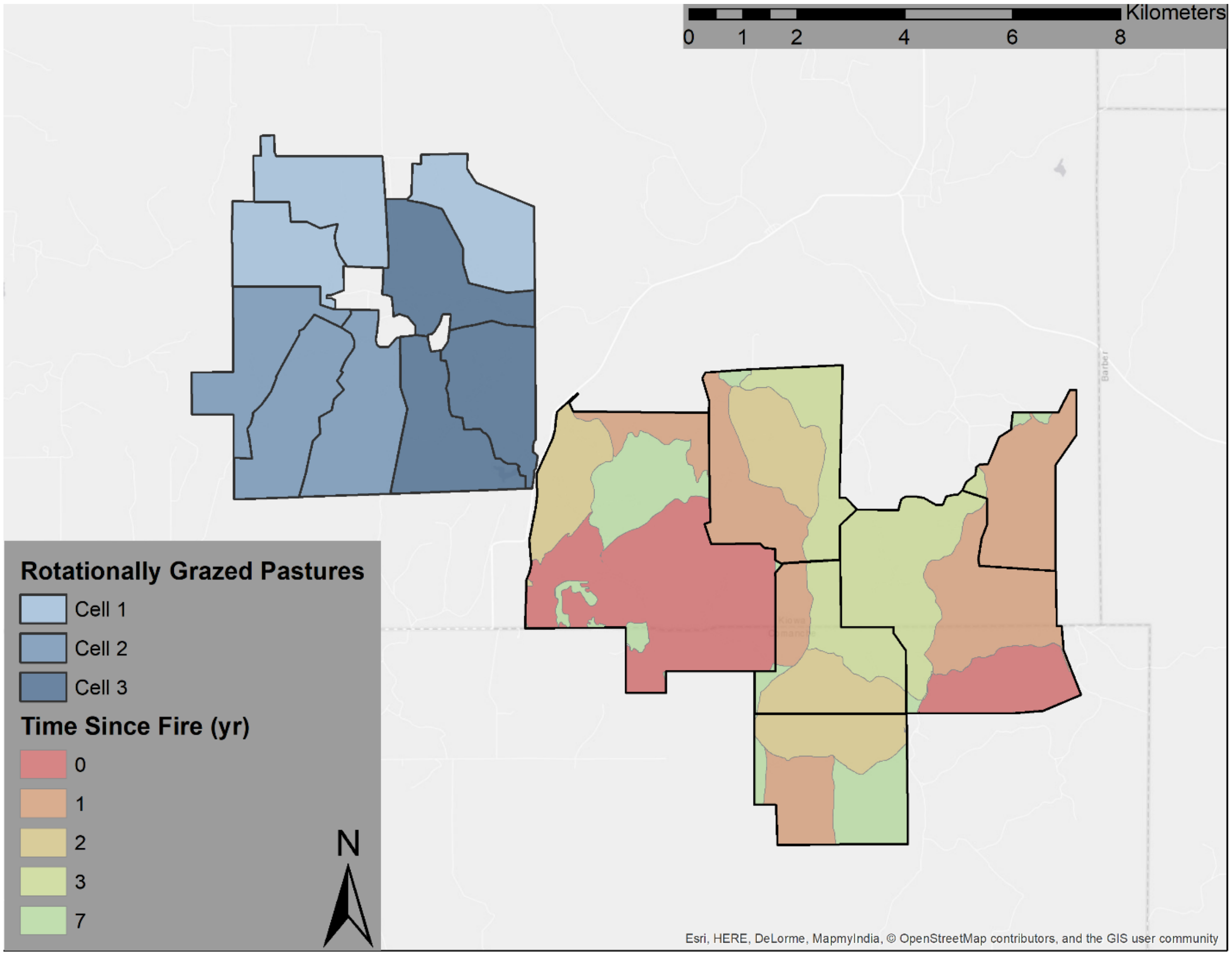

Figure 2-2 An example of both rangelands at my study site in 2017, in Comanche and Kiowa counties, Kansas. Cattle were rotated in the rotationally grazed management system through three adjacent pastures within three management cells throughout the growing season. The patch-burn management system burns roughly 20% to 40% of each pasture every year, dependent on spring weather conditions. Cattle are not restricted by interior fencing in each pasture, and can select freely between different time-since-fire patches.

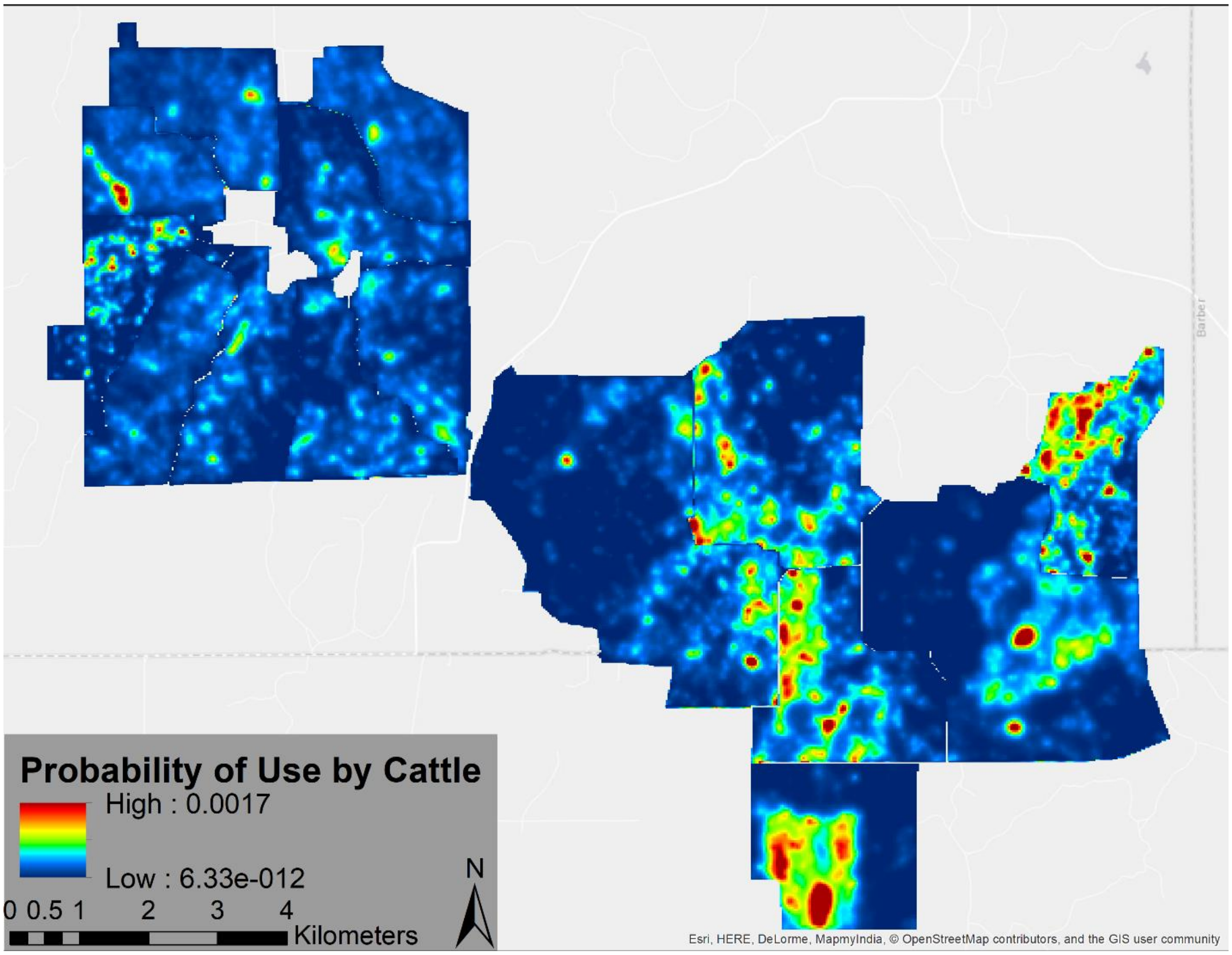

Figure 2-3 Continuous probability surface of cattle space-use within each pasture on patch-burn grazed pastures and rotationally pastures in 2016, in Comanche and Kiowa counties, Kansas. Warmer colors in each pasture indicate a greater probability of use by the herd in that pasture, and thus a subsequently greater density of cattle within that pixel during the period when cattle remain in the pasture.

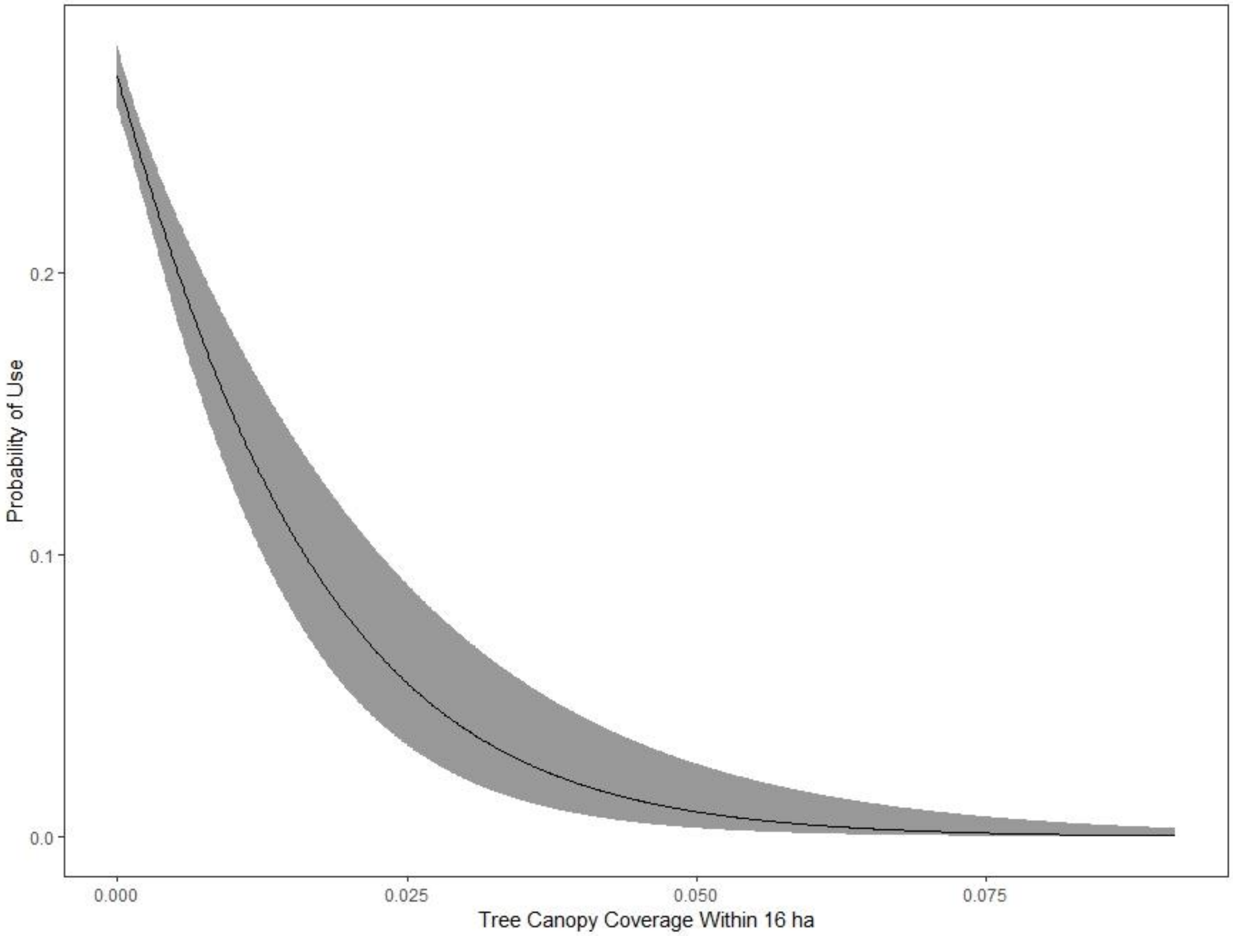

Figure 2-4 The top-ranked model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in rotationally grazed pastures, during the spring breeding period in Comanche and Kiowa counties, Kansas, during 2016-2018, indicates that lesser prairie-chicken probability of use increased as percent tree canopy cover decreased, at the 16 ha scale.

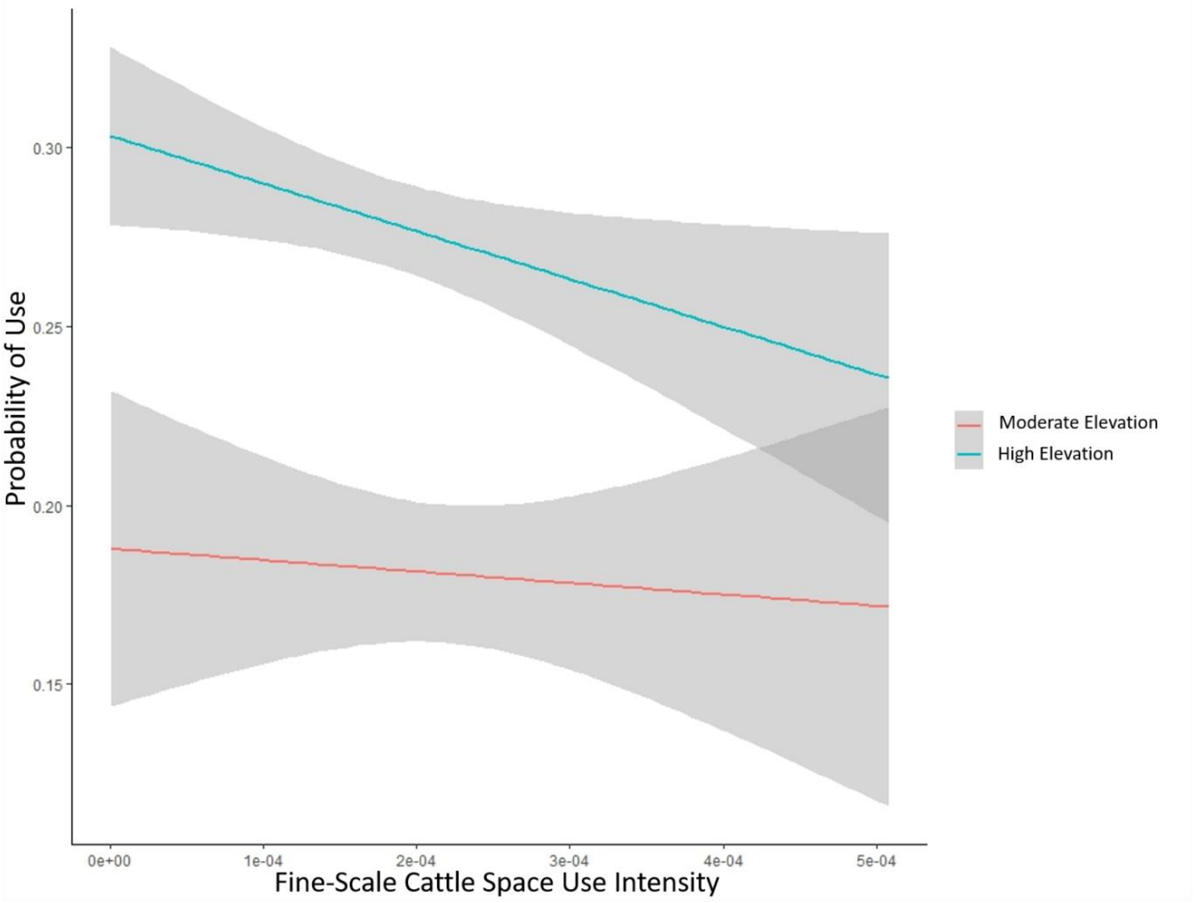

Figure 2-5 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in rotationally grazed pastures, during the spring breeding period, in Comanche and Kiowa counties, Kansas, 2016-2018. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

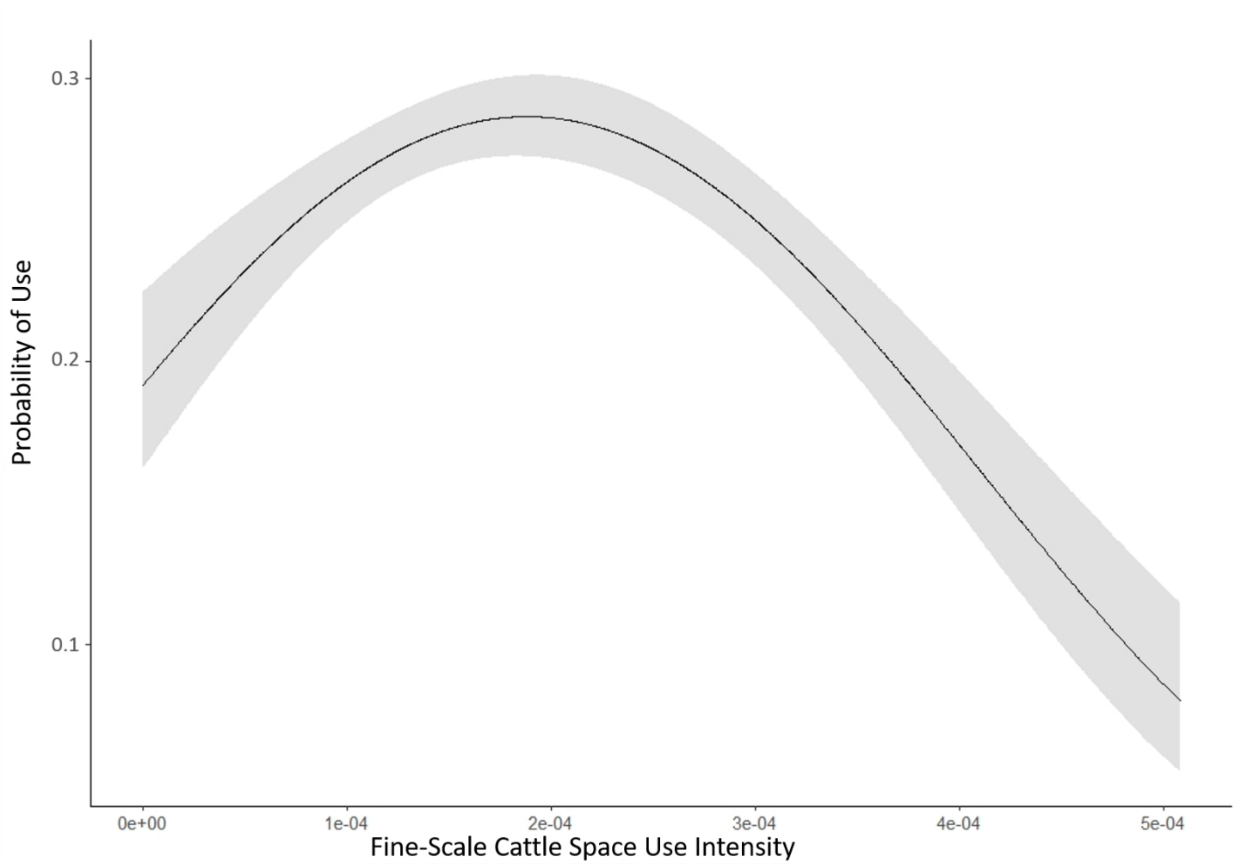

Figure 2-6 Quadratic model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in rotationally grazed pastures, during the spring breeding period, in Comanche and Kiowa counties, Kansas, indicates that lesser prairie-chicken use peaked at moderate to low fine-scale cattle space use intensities. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

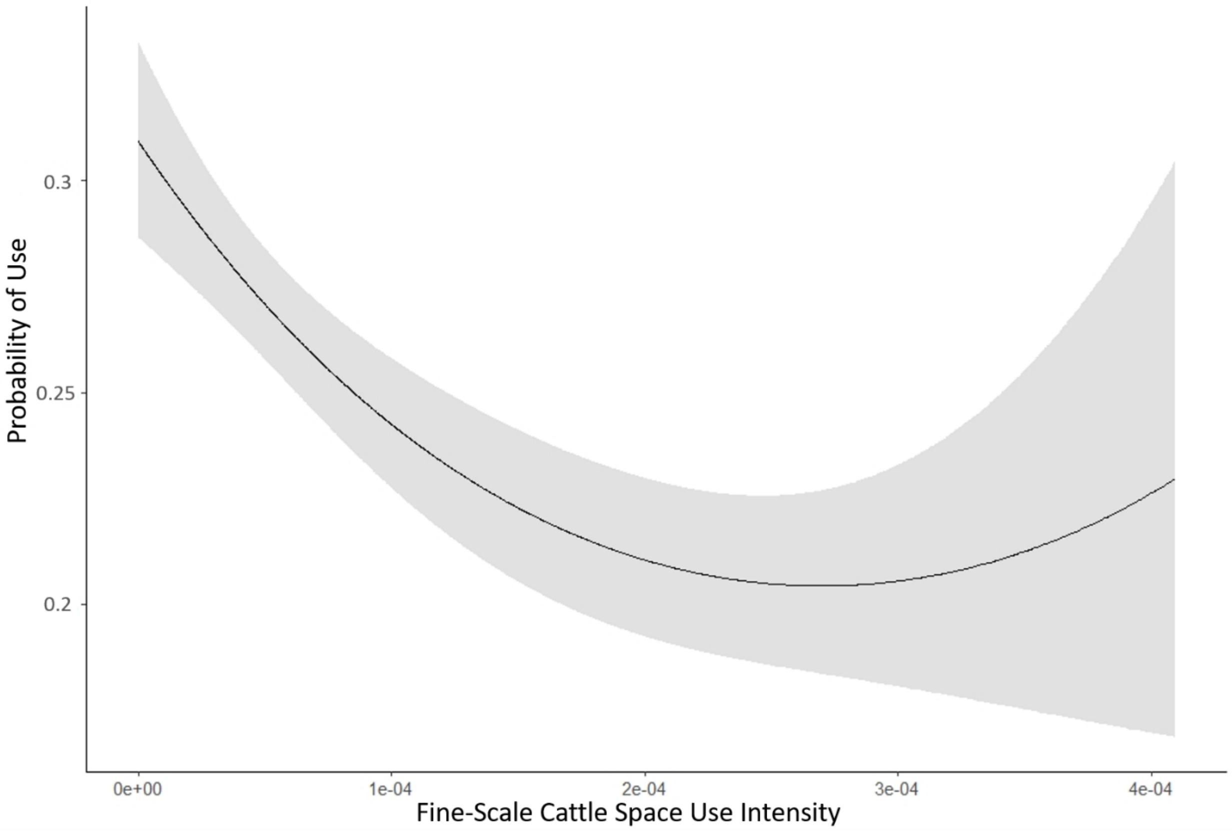

Figure 2-7 Quadratic model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the spring breeding period, in Comanche and Kiowa counties, Kansas, indicates that lesser prairie-chicken use peaked at low fine-scale cattle space use intensities. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

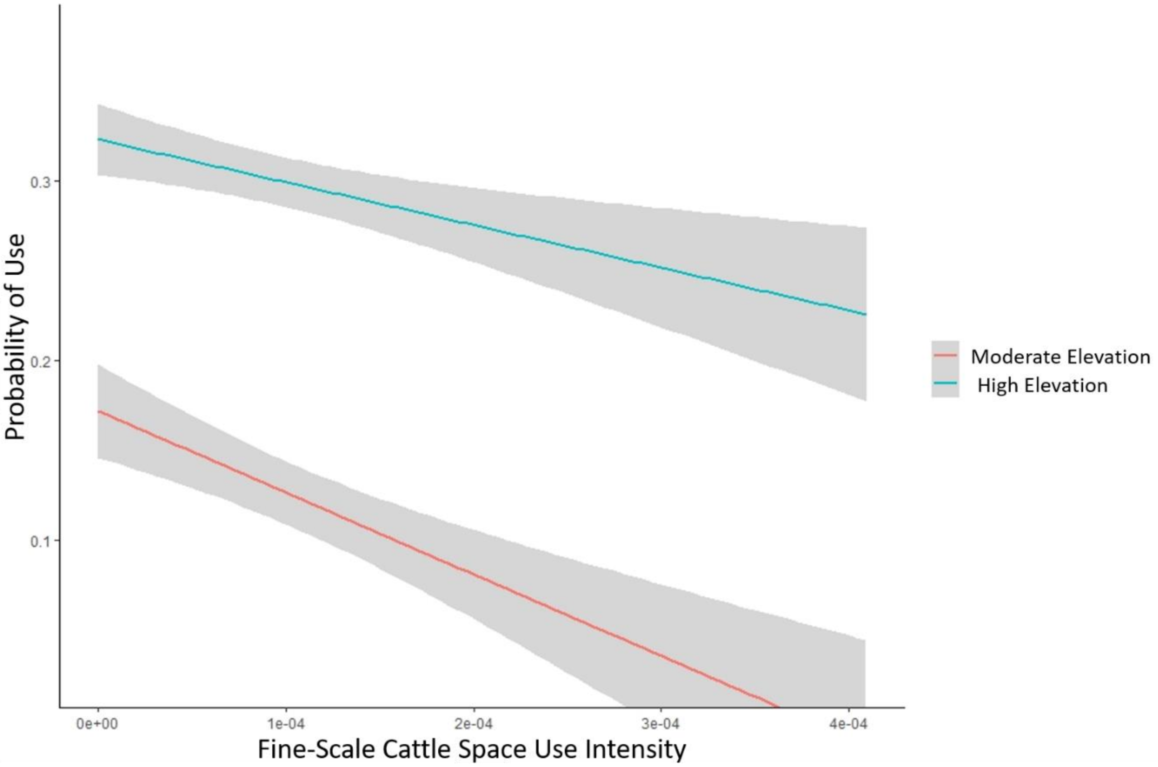

Figure 2-8 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the spring breeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use increased as fine-scale cattle space use decreased within both moderate and high elevations. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

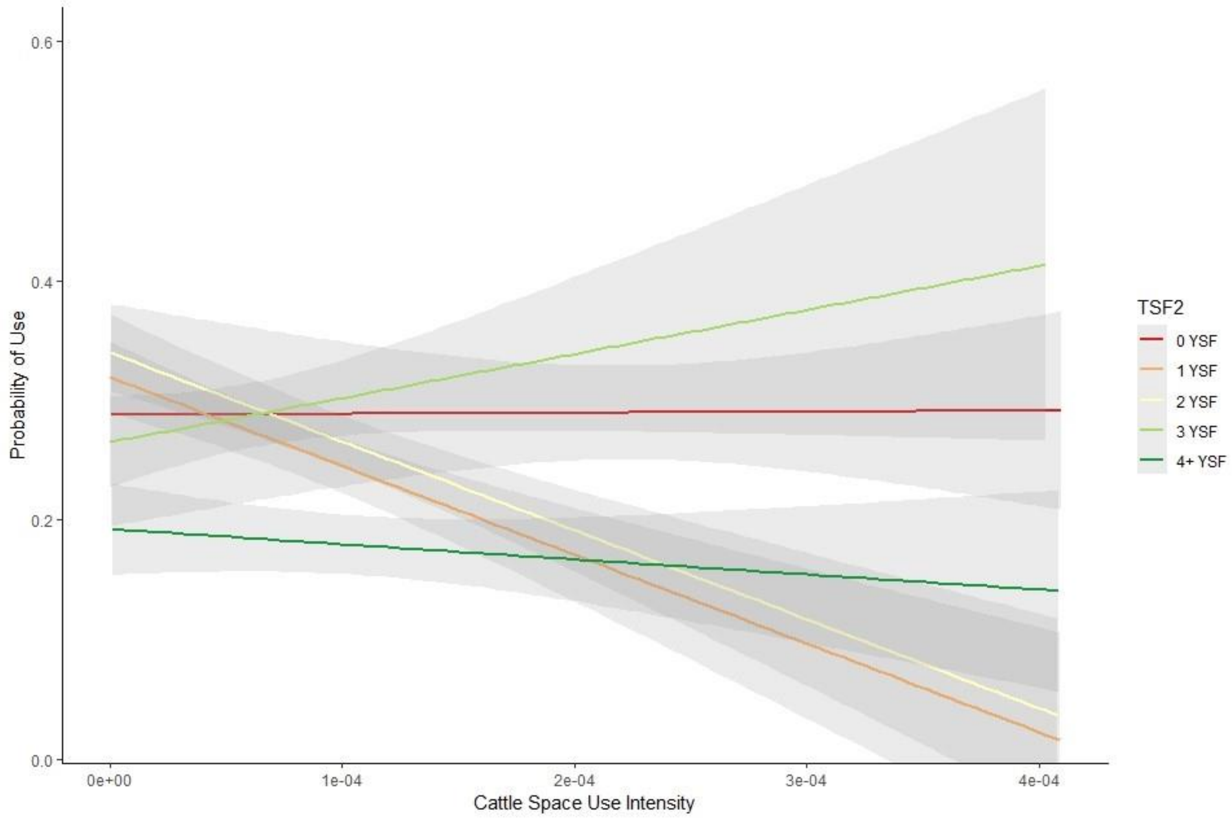

Figure 2-9 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the spring breeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use increased as fine-scale cattle space use decreased on 1- and 2- year-since-fire patches. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

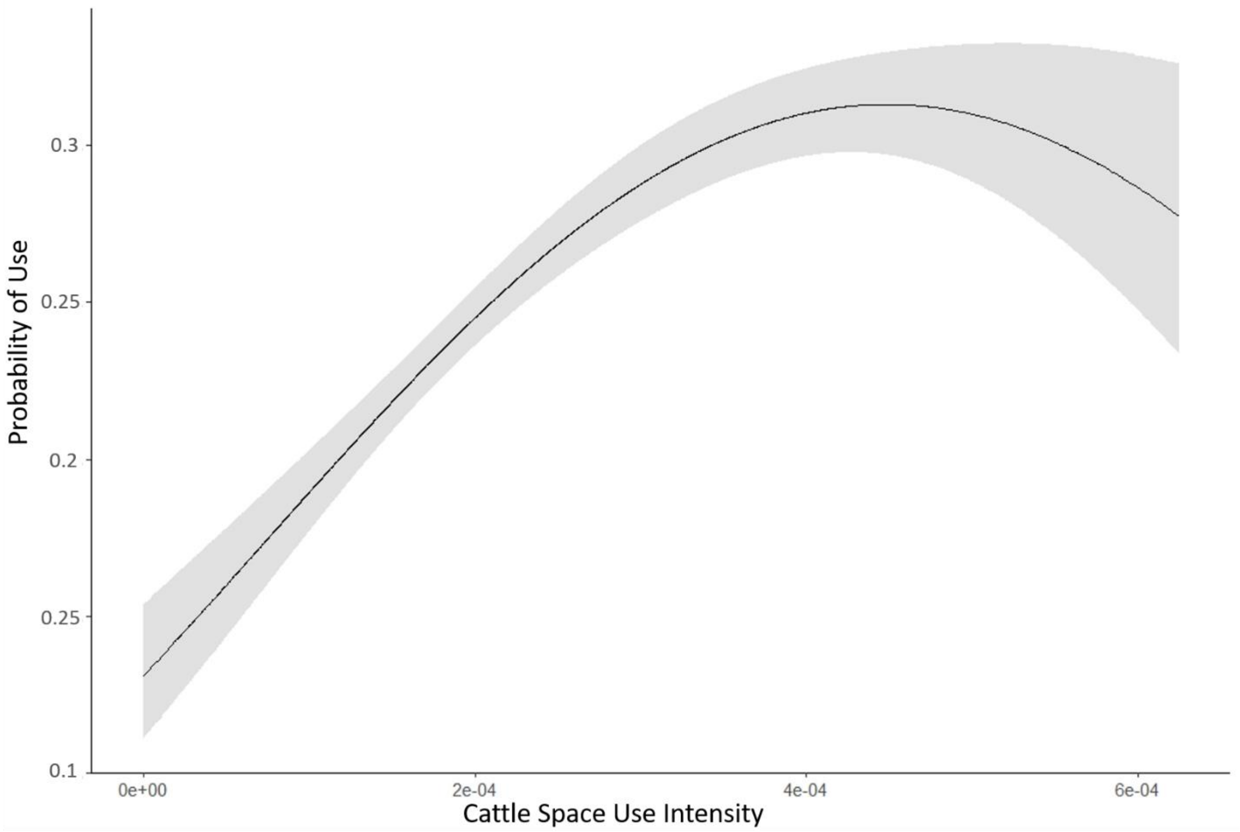

Figure 2-10 Top model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in rotationally grazed pastures, during the summer post-breeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use peaked at moderate to high fine-scale cattle space use intensities. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

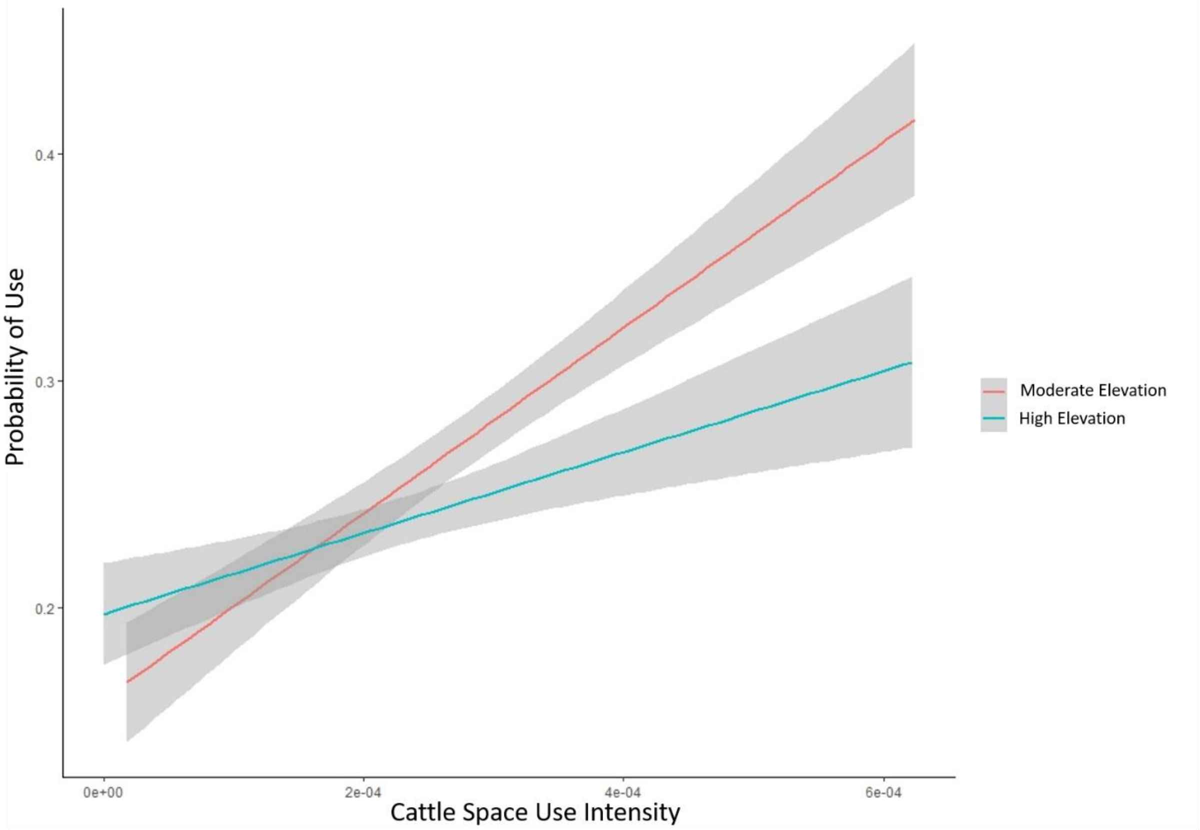

Figure 2-11 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in rotationally grazed pastures, during the summer post-breeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use selected moderate elevations over uplands at high fine-scale cattle space use intensities. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

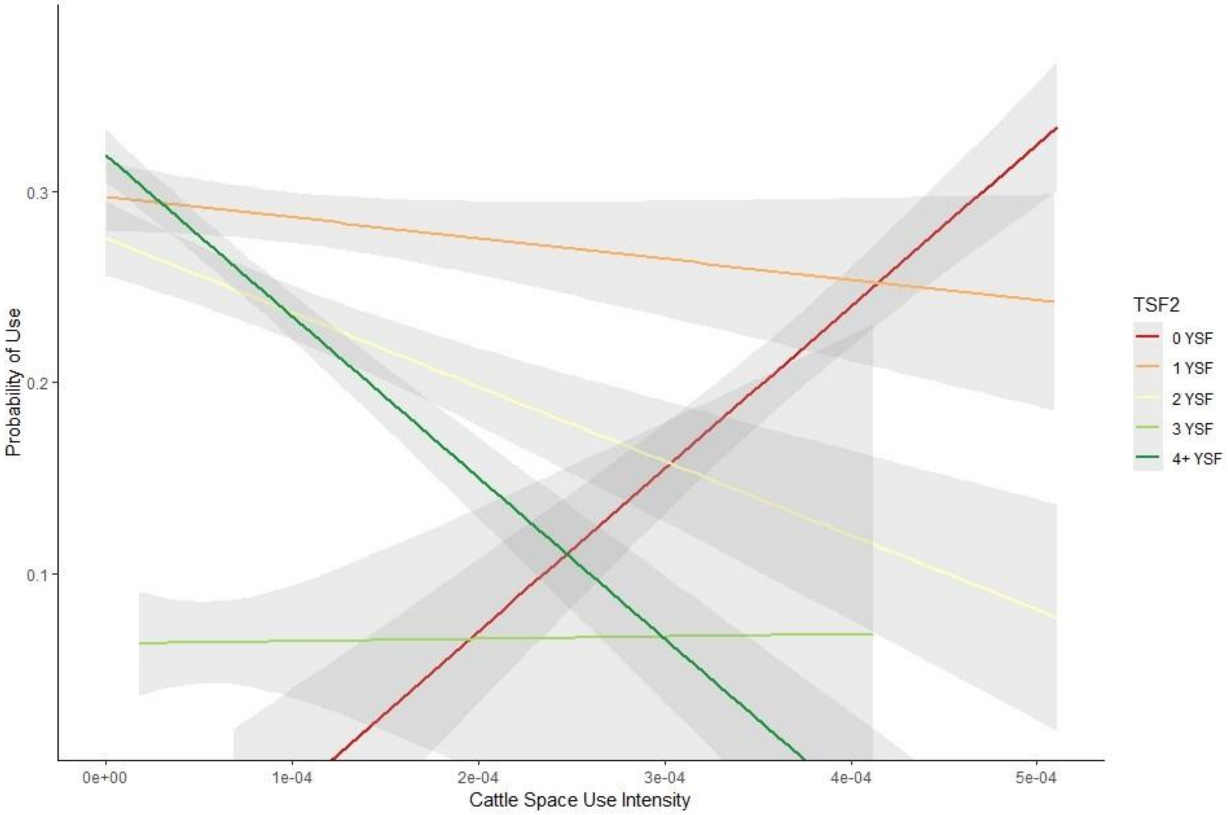

Figure 2-12 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the summer post-breeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use increased as fine-scale cattle space use decreased on 2- and 3- year-since-fire patches, and that use increased on 0-year-since-fire patches as fine-scale cattle space use intensity increased. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

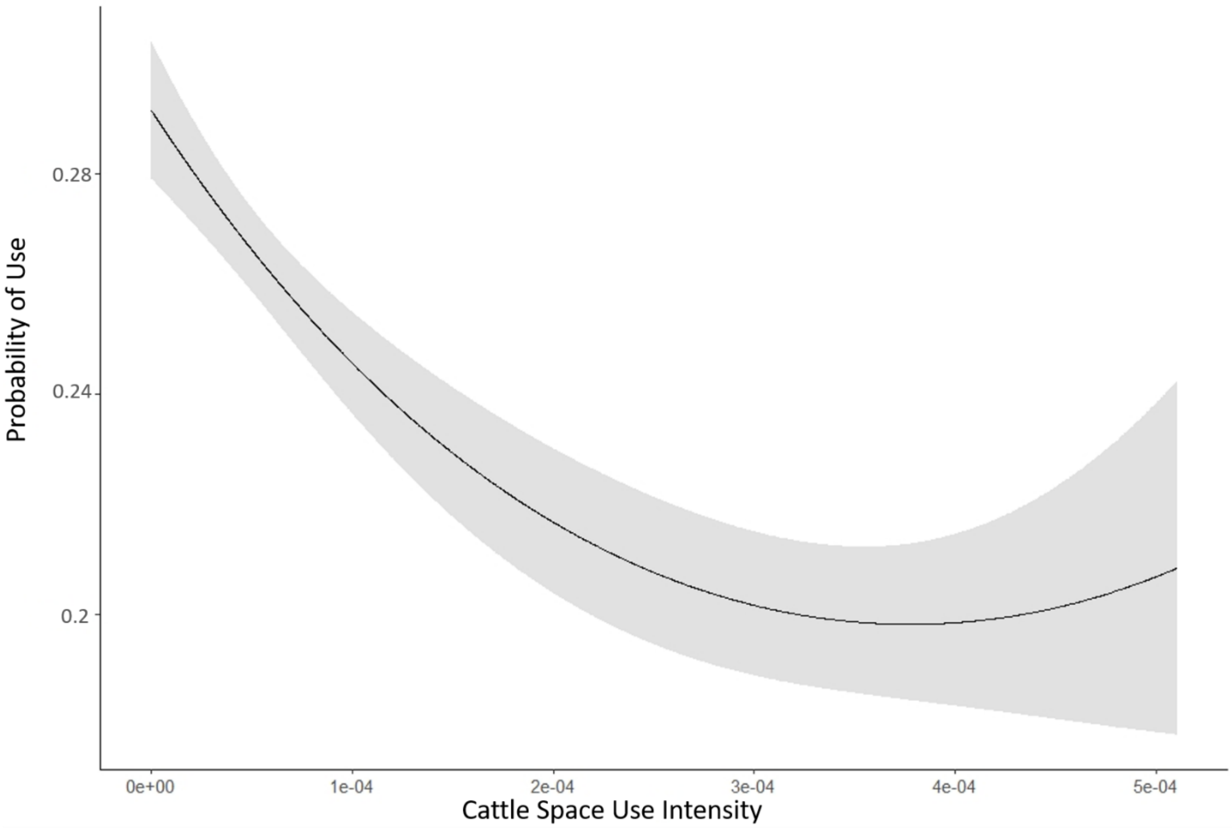

Figure 2-13 Quadratic model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the summer post-breeding period, in Comanche and Kiowa counties, Kansas, 2015-2018, indicates that lesser prairie-chicken use peaked at low fine-scale cattle space use intensity, and was minimal at moderate to high fine-scale cattle space use intensity. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

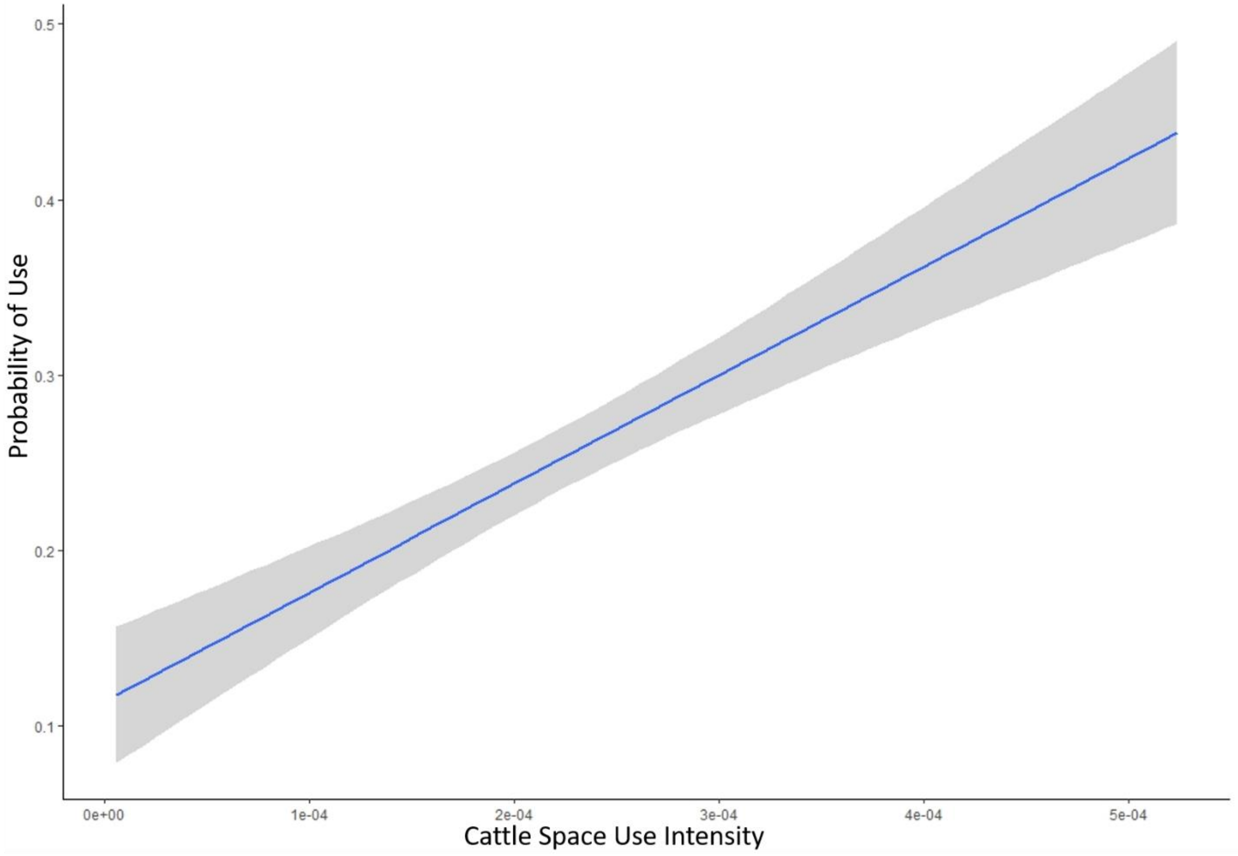

Figure 2-14 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in rotationally grazed pastures, during the fall and winter nonbreeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken probability of use increased as fine-scale cattle space use intensity increased within rotationally grazed landscapes during the nonbreeding stage. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

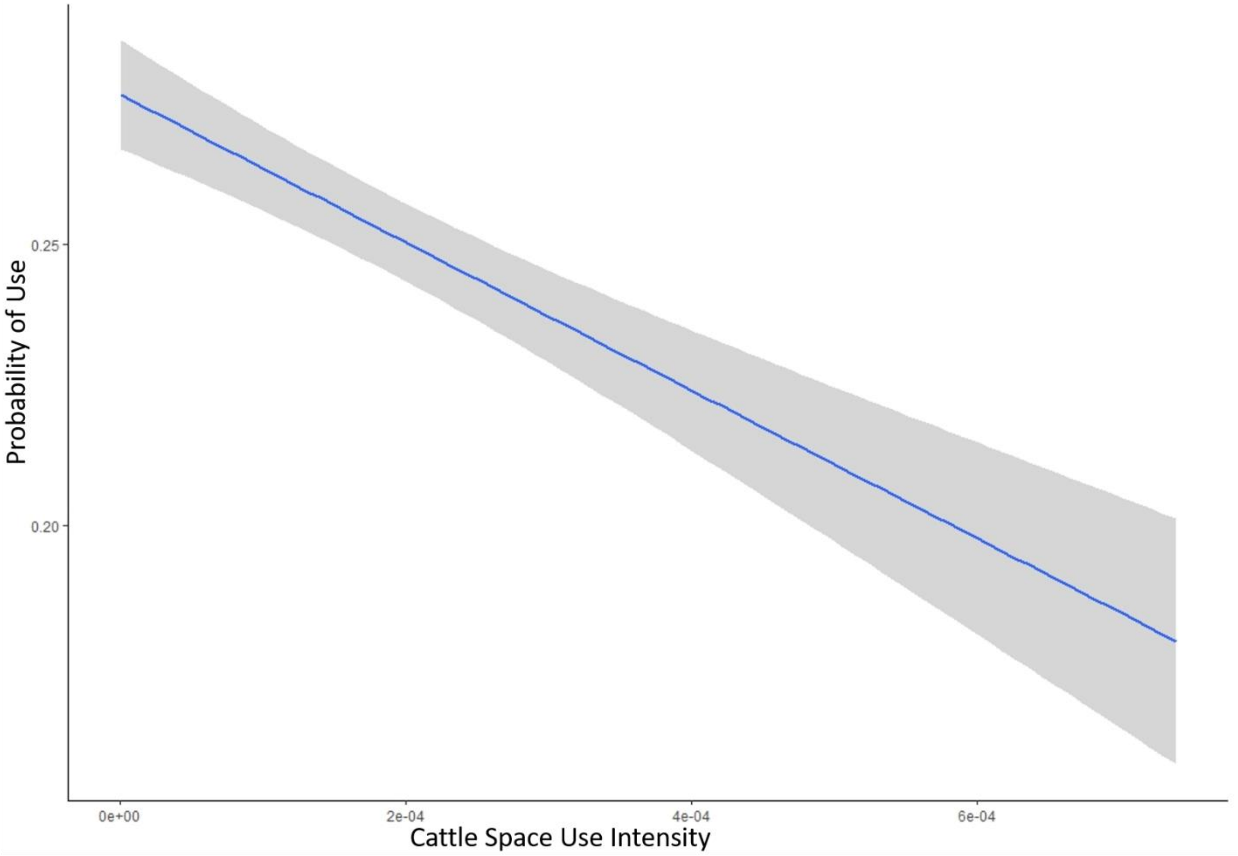

Figure 2-15 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the fall and winter nonbreeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use increased as fine-scale cattle space use decreased on the landscape. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

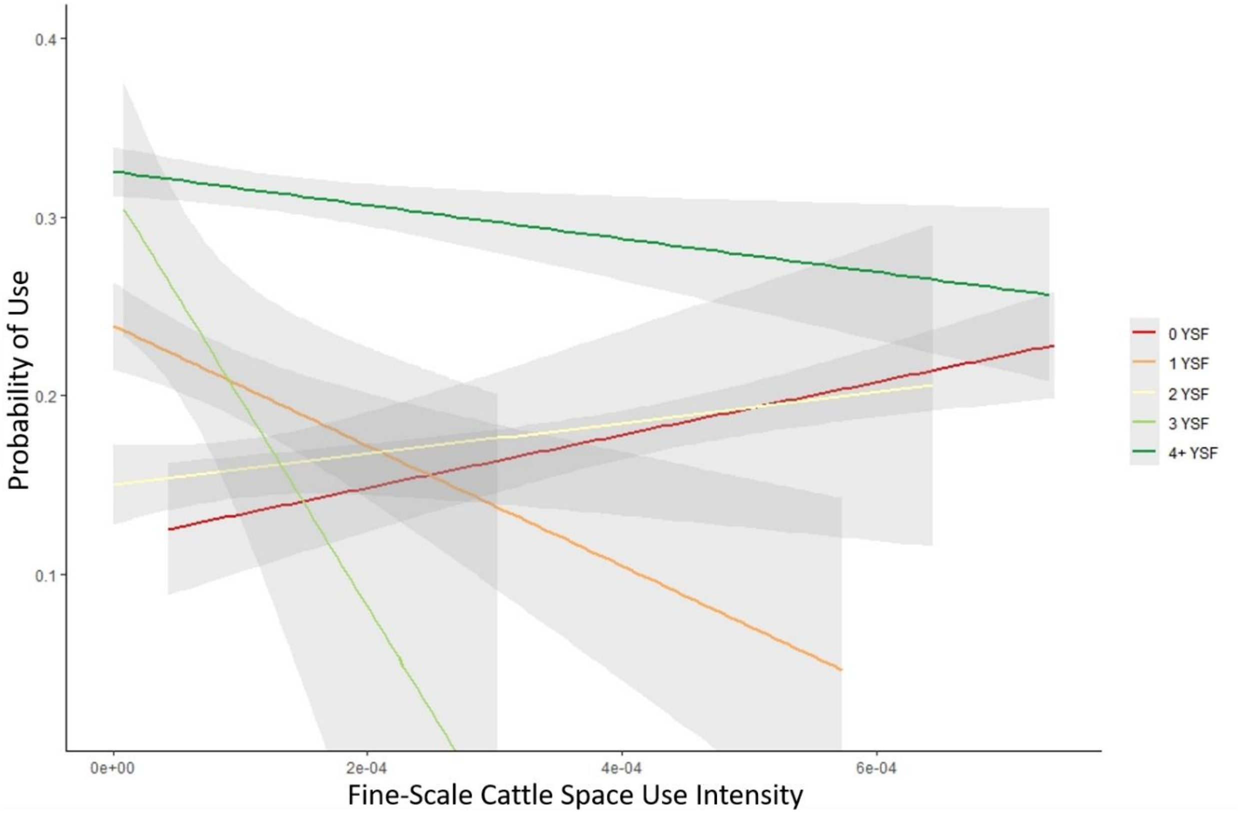

Figure 2-16 Model (β-coefficient with 95% confidence intervals) predicting female lesser prairie-chicken resource selection in patch-burn grazed pastures, during the fall and winter nonbreeding period, in Comanche and Kiowa counties, Kansas, 2016-2018, indicates that lesser prairie-chicken use increased as fine-scale cattle space use intensity decreased on 1-, 3-, and 4- year-since-fire patches, but use increased as cattle space use intensity increased in 0-year-since-fire patches. The x-axis represents the likelihood that an area would be grazed by cattle during the growing period. Higher values indicate a greater likelihood of an area being disturbed by cattle.

Tables

Table 2-1 Ranking of models predicting lesser prairie-chicken resource selection in patch-burn and rotationally grazed treatments during the breeding period (March 15-June 15, excluding nesting) in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included fine scale cattle distribution (CD), percent tree canopy cover within 16 ha (Canopy), distance to tree, elevation, slope, aspect, and year-since-fire patch (YSF)

Site	Model	K[a]	Dev.[b]	ΔAIC_c[c]	w_i[d]
Rotationally Grazed	Canopy	2	7502.82	0	1.000
	Slope	3	7525.18	22.36	<0.001
	CD * Elevation	4	7526.37	23.55	<0.001
	Elevation	2	7527.39	24.56	<0.001
	CD^2	3	7536.32	33.49	<0.001
	Distance to Tree	2	7566.05	63.23	<0.001
	Aspect	4	7573.74	70.92	<0.001
	CD	2	7579.77	76.94	<0.001
	Null	1	7588.28	85.45	<0.001
Patch-Burn Grazed	YSF * Elevation	10	6142.08	0	0.818
	YSF + Elevation	6	6145.08	3.00	0.182
	CD * Elevation	4	6166.18	24.10	<0.001
	Elevation	2	6198.94	56.86	<0.001
	Canopy	2	6279.79	137.71	<0.001
	CD * YSF	10	6284.12	142.04	<0.001
	CD + YSF	6	6314.00	171.92	<0.001
	YSF	5	6347.39	205.31	<0.001
	CD^2	3	6350.47	208.39	<0.001
	CD	2	6354.60	212.52	<0.001
	Aspect	4	6356.12	214.04	<0.001
	Distance to Tree	2	6377.02	234.94	<0.001
	Null	1	6380.90	238.82	<0.001

[a] Number of Parameters

[b] Akaike's Information Criterion, adjusted for a small sample size

[c] Difference in Akaike's Information Criterion, adjusted for a small sample size

[d] Akaike weights

Table 2-2 Beta coefficients of models predicting lesser prairie-chicken resource selection within rotationally grazed rangelands during three biological periods in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included percent tree canopy coverage within 16 ha (Canopy), fine-scale cattle distribution within pastures (CD), and elevation (high and moderate elevations)

Season	Model	Coefficient	Estimate	SE	*z*	*P*
Breeding	Canopy	Canopy	-74.182	11.120	-6.671	<0.001
	CD * Elevation	CD	-0.037	0.106	-0.346	0.729
		Moderate	-1.511	0.066	-22.785	<0.001
		Upland	0.534	0.074	7.175	<0.001
		CD: Upland	-0.077	0.118	-0.652	0.515
	Elevation	Moderate	-1.510	0.066	-22.793	<0.001
		Upland	0.560	0.073	7.653	<0.001
	CD^2	CD	-0.172	0.050	-3.436	<0.001
		CD^2	-0.431	0.067	-6.451	<0.001
Post-Breeding	CD^2	CD	0.340	0.032	10.716	<0.001
		CD^2	-0.168	0.034	-4.894	<0.001
	CD * Elevation	CD	0.352	0.040	8.775	<0.001
		Moderate	-1.007	0.032	-31.432	<0.001
		Upland	-0.118	0.045	-2.653	0.008
		CD: Upland	-0.183	0.059	-3.091	0.002
	Elevation	Moderate	-0.980	0.031	-31.183	<0.001
		Upland	-0.191	0.043	-4.449	<0.001
Non-Breeding	CD + Elevation	CD	0.474	0.064	7.404	<0.001
		Moderate	-1.209	0.068	-17.687	<0.001
		Upland	0.325	0.098	3.312	0.001
	CD	CD	0.466	0.064	7.314	<0.001
	Elevation	Moderate	-1.236	0.068	-18.303	<0.001
		Upland	0.300	0.097	3.096	0.002

Table 2-3 Beta coefficients of models predicting lesser prairie-chicken resource selection within patch-burn grazed rangelands during the breeding period (March 15-June 15) in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included year since fire patch (YSF), fine-scale cattle distribution (CD), and elevation (uplands and moderate elevations).

Model	Coefficient	Estimate	SE	z	P
YSF * Elevation	0 YSF	-1.986	0.403	-4.927	<0.001
	1 YSF	0.025	0.432	0.058	0.954
	2 YSF	0.316	0.419	0.755	0.45
	3 YSF	-0.705	0.501	-1.407	0.16
	4+ YSF	-0.637	0.531	-1.201	0.23
	Upland	1.19	0.415	2.864	0.004
	1 YSF: Upland	-0.04	0.448	-0.089	0.929
	2 YSF: Upland	-0.194	0.436	-0.446	0.656
	3 YSF: Upland	0.82	0.516	1.588	0.112
	4+ YSF: Upland	0.029	0.548	0.053	0.957
CD * Elevation	CD	-0.98	0.208	-4.713	<0.001
	Moderate	-2.228	0.112	-19.95	<0.001
	Upland	1.324	0.118	11.209	<0.001
	CD: Upland	0.758	0.22	3.453	<0.001
CD * YSF	CD	0.008	0.181	0.046	0.964
	0 YSF	-0.901	0.122	-7.398	<0.001
	1 YSF	-0.465	0.151	-3.078	0.002
	2 YSF	-0.34	0.143	-2.372	0.018
	3 YSF	0.132	0.16	0.826	0.409
	4+ YSF	-0.659	0.154	-4.283	<0.001
	CD: 1 YSF	-0.871	0.242	-3.59	<0.001
	CD: 2 YSF	-0.839	0.233	-3.598	<0.001
	CD: 3 YSF	0.322	0.267	1.207	0.227
	CD: 4+ YSF	-0.178	0.258	-0.688	0.491
YSF	0 YSF	-0.897	0.097	-9.264	<0.001
	1 YSF	-0.139	0.113	-1.228	0.219
	2 YSF	-0.099	0.113	-0.884	0.377
	3 YSF	-0.008	0.118	-0.066	0.947
	4+ YSF	-0.63	0.13	-4.855	<0.001
CD^2	CD	-0.369	0.065	-5.657	<0.001
	CD2	0.276	0.11	2.502	0.012

Table 2-4 Ranking of models predicting lesser prairie-chicken resource selection at fine scales (within 28 ha of nests) in patch-burn and rotationally grazed treatments during the nesting stage in Comanche and Kiowa counties, Kansas, from 2016-2018. Models included fine-scale cattle distribution (CD), percent tree canopy coverage within 16 ha (Canopy), distance to tree (m), elevation, slope, and year since fire patch (YSF).

Site	Model	K^a	$AIC_c{}^b$	$\Delta AIC_c{}^c$	$w_i{}^d$
Patch-Burn Grazed	Null	1	55.66	0	0.34
	Slope	3	56.44	0.78	0.23
	CD	2	57.57	1.90	0.13
	Distance to Tree	2	57.71	2.05	0.12
	CD^2	3	57.75	2.09	0.12
	Elevation	3	59.61	3.95	0.05
	YSF	5	63.50	7.84	0.01
Rotationally Grazed	Null	1	55.66	0	0.30
	CD^2	3	56.28	0.62	0.22
	Slope	3	57.14	1.48	0.15
	CD	2	57.70	2.04	0.11
	Elevation	2	57.71	2.05	0.11
	Distance to Tree	2	57.75	2.09	0.11

[a]Number of Parameters

[b]Akaike's Information Criterion, adjusted for a small sample size

[c]Difference in Akaike's Information Criterion, adjusted for a small sample size

[d]Akaike weights

Table 2-5 Ranking of models predicting lesser prairie-chicken resource selection within 340 ha of nests in patch-burn and rotationally grazed treatments during the nesting stage in Comanche and Kiowa counties, Kansas, from 2016-2018. Models included fine-scale cattle distribution (CD), distance to tree (m), elevation, slope, aspect, and year since fire patch (YSF).

Site	Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Patch-Burn Grazed	CD	2	46.22	0	0.35
	Null	1	47.57	1.36	0.18
	Aspect	4	48.02	1.81	0.14
	CD^2	3	48.24	2.03	0.13
	Slope	3	48.66	2.45	0.10
	Distance to Tree	2	49.42	3.20	0.07
	Elevation	3	51.34	5.12	0.03
	YSF	5	53.78	7.57	0.01
Rotationally Grazed	Null	1	60.56	0	0.22
	Slope	3	61.04	0.48	0.18
	CD^2	3	61.14	0.58	0.17
	Distance to Tree	2	61.33	0.77	0.15
	Aspect	4	62.03	1.47	0.11
	CD	2	62.05	1.49	0.11
	Elevation	3	63.08	2.52	0.06

[a] Number of Parameters

[b] Akaike's Information Criterion, adjusted for a small sample size

[c] Difference in Akaike's Information Criterion, adjusted for a small sample size

[d] Akaike weights

Table 2-6 Ranking of models predicting lesser prairie-chicken resource selection within 995 ha of nests in patch-burn and rotationally grazed treatments during the nesting stage in Comanche and Kiowa counties, Kansas, from 2016-2018. Models included fine-scale cattle distribution (CD), distance to tree (m), elevation, slope, aspect, and year since fire patch (YSF).

Site	Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Patch-Burn Grazed	CD	2	45.70	0	0.41
	Null	1	47.57	1.87	0.16
	CD^2	3	47.85	2.15	0.14
	Aspect	4	48.36	2.66	0.11
	Distance to Tree	2	49.44	3.74	0.06
	Slope	3	49.77	4.07	0.05
	Elevation	3	50.65	4.95	0.03
	YSF	5	51.05	5.35	0.03
Rotationally Grazed	Distance to Tree	2	58.34	0	0.45
	CD^2	3	60.47	2.14	0.15
	Null	1	60.56	2.22	0.15
	Slope	3	61.32	2.98	0.10
	Elevation	3	62.48	4.14	0.06
	CD	2	62.49	4.16	0.06
	Aspect	4	63.15	4.82	0.04

[a] Number of Parameters

[b] Akaike’s Information Criterion, adjusted for a small sample size

[c] Difference in Akaike’s Information Criterion, adjusted for a small sample size

[d] Akaike weight

Table 2-7 Ranking of models predicting lesser prairie-chicken resource selection in patch-burn and rotationally grazed treatments during the post-breeding period (June 15-September 15) in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included fine-scale cattle distribution (CD), percent tree canopy coverage within 16 ha (Canopy), distance to tree (m), elevation, slope, aspect, and time-since-fire patch.

Site	Model	K^a	$AIC_c{}^b$	$\Delta AIC_c{}^c$	$w_i{}^d$
Rotationally Grazed	CD^2	3	13021.99	0	0.997
	CD * Elevation	4	13033.47	11.48	0.003
	CD + Elevation	3	13041.05	19.06	<0.001
	Cattle Density	2	13044.66	22.67	<0.001
	Canopy	2	13064.51	42.51	<0.001
	Slope	3	13081.58	59.58	<0.001
	Elevation	2	13121.17	99.18	<0.001
	Aspect	4	13124.32	102.32	<0.001
	Null	1	13138.93	116.93	<0.001
Patch-Burn Grazed	Time Since Fire * Elevation	9	17353.39	0	1
	CD * Time Since Fire	10	17563.02	209.63	<0.001
	Time Since Fire + Elevation	6	17704.93	351.54	<0.001
	CD + Time Since Fire	6	17809.45	456.06	<0.001
	CD * Elevation	4	17819.36	465.97	<0.001
	Canopy	2	17847.44	494.05	<0.001
	Time Since Fire	5	17870.63	517.24	<0.001
	Elevation	2	17897.28	543.89	<0.001
	CD^2	3	17964.26	610.87	<0.001
	CD	2	17971.37	617.98	<0.001
	Aspect	4	17995.75	642.36	<0.001
	Slope	3	18005.88	652.49	<0.001
	Distance to Tree	2	18036.19	682.80	<0.001
	Null	1	18036.23	682.84	<0.001

[a]Number of Parameters

[b]Akaike's Information Criterion, adjusted for a small sample size

[c]Difference in Akaike's Information Criterion, adjusted for a small sample size

[d]Akaike weights

Table 2-8 Beta coefficients of models predicting lesser prairie-chicken resource selection within patch-burn grazed rangelands during the post-breeding period (June 15-September 15) in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included year since fire patch (YSF), fine-scale cattle distribution within pastures (CD), and elevation (uplands and moderate elevations).

Model	Coefficient	Estimate	SE	z value	Pr>|z|
YSF * Elevation	0 YSF	-4.618	0.578	-7.985	<0.001
	1 YSF	3.956	0.582	6.801	<0.001
	2 YSF	2.467	0.589	4.186	<0.001
	3 YSF	-1.657	0.194	-8.554	<0.001
	4+ YSF	1.840	0.599	3.073	0.002
	Upland	3.588	0.582	6.166	<0.001
	1 YSF: Upland	-3.926	0.587	-6.693	<0.001
	2 YSF: Upland	-2.373	0.595	-3.991	<0.001
	4+ YSF: Upland	-1.676	0.603	-2.780	0.005
CD * YSF	CD	1.417	0.171	8.278	<0.001
	0 YSF	-2.638	0.184	-14.315	<0.001
	1 YSF	1.688	0.189	8.933	<0.001
	2 YSF	1.283	0.193	6.660	<0.001
	3 YSF	-0.026	0.500	-0.051	0.959
	4+ YSF	0.826	0.201	4.110	<0.001
	CD:1 YSF	-1.543	0.188	-8.195	<0.001
	CD:2 YSF	-1.981	0.200	-9.888	<0.001
	CD:3 YSF	-1.370	0.893	-1.533	0.125
	CD:4+ YSF	-3.000	0.219	-13.685	<0.001
CD * Elevation	CD	-0.654	0.119	-5.501	<0.001
	Moderate	-1.783	0.066	-27.055	<0.001
	Upland	0.740	0.070	10.621	<0.001
	CD: Upland	0.406	0.125	3.262	0.001
YSF	0 YSF	-1.306	0.062	-21.115	<0.001
	1 YSF	0.397	0.070	5.666	<0.001
	2 YSF	0.145	0.074	1.962	0.050
	3 YSF	-1.381	0.193	-7.158	<0.001
	4+ YSF	0.291	0.068	4.255	<0.001
Elevation	Moderate	-1.566	0.048	-32.607	<0.001
	Upland	0.591	0.052	11.374	<0.001
CD^2	CD	-0.346	0.041	-8.420	<0.001
	CD^2	0.192	0.063	3.027	0.002

Table 2-9 Ranking of models predicting lesser prairie-chicken resource selection in patch-burn and rotationally grazed treatments during the nonbreeding period (September 15-March 15) in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included fine-scale cattle distribution within pastures (CD), percent tree canopy coverage within 16 ha (Canopy), distance to tree (m), elevation, slope, aspect, and time since fire patch.

Site	Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Rotationally Grazed	CD + Elevation	3	2511.69	0	0.633
	CD * Elevation	4	2512.95	1.26	0.337
	Canopy	2	2518.71	7.03	0.019
	CD	2	2520.66	8.97	0.007
	CD^2	3	2521.71	10.02	0.004
	Aspect	4	2529.58	17.89	<0.001
	Slope	3	2544.56	32.87	<0.001
	Distance to Tree	2	2552.14	40.46	<0.001
	Elevation	2	2564.79	53.10	<0.001
	Null	1	2572.37	60.68	<0.001
Patch-Burn Grazed	Time Since Fire + Elevation	6	16207.57	0	0.853
	Time Since Fire * Elevation	10	16211.08	3.51	0.147
	CD * Elevation	4	16557.69	350.12	<0.001
	Elevation	2	16605.74	398.17	<0.001
	CD * Time Since Fire	10	16939.18	731.61	<0.001
	Time Since Fire	5	16966.77	759.20	<0.001
	CD + Time Since Fire	6	16967.66	760.09	<0.001
	Slope	3	17010.41	802.84	<0.001
	Aspect	4	17217.43	1009.86	<0.001
	CD	2	17270.97	1063.40	<0.001
	CD^2	3	17272.82	1065.25	<0.001
	Canopy	2	17312.46	1104.89	<0.001
	Distance to Tree	2	17315.10	1107.53	<0.001
	Null	1	17317.96	1110.38	<0.001

[a] **Number of Parameters**

[b] **Akaike's Information Criterion, adjusted for a small sample size**

[c] **Difference in Akaike's Information Criterion, adjusted for a small sample size**

[d] **Akaike weights**

Table 2-10 Beta coefficients of models predicting lesser prairie-chicken resource selection within patch-burn grazed rangelands during the nonbreeding period (September 15-March 15) in Comanche and Kiowa counties, Kansas, during 2016-2018. Models included fine-scale cattle distribution within pastures (CD), elevation (uplands and moderate elevations), and year since fire (YSF).

Model	Coefficient	Estimate	Standard Error	*z*	*P*
YSF + Elevation	0 YSF	-2.887	0.078	-36.972	<0.001
	1 YSF	0.115	0.074	1.556	0.120
	2 YSF	-0.115	0.078	-1.486	0.137
	3 YSF	0.201	0.156	1.287	0.198
	4+ YSF	0.782	0.052	14.963	<0.001
	Upland	1.589	0.068	23.496	<0.001
CD * Elevation	CD	-0.221	0.095	-2.324	0.020
	Moderate	-2.425	0.067	-35.990	<0.001
	Upland	1.537	0.070	21.829	<0.001
	CD: Upland	0.042	0.099	0.427	0.669
Elevation	Moderate	-2.386	0.064	-37.313	<0.001
	Upland	1.524	0.067	22.751	<0.001
CD * YSF	CD	0.240	0.073	3.277	0.001
	0 YSF	-1.725	0.086	-20.126	<0.001
	1 YSF	0.092	0.143	0.646	0.519
	2 YSF	0.126	0.124	1.011	0.312
	3 YSF	-0.824	0.681	-1.210	0.226
	4+ YSF	0.904	0.091	9.983	<0.001
	CD:1 YSF	-0.808	0.183	-4.411	<0.001
	CD:2 YSF	-0.091	0.161	-0.568	0.570
	CD:3 YSF	-2.402	0.956	-2.513	0.012
	CD:4+ YSF	-0.347	0.086	-4.039	<0.001
YSF	0 YSF	-1.494	0.045	-32.983	<0.001
	1 YSF	0.180	0.073	2.470	0.013
	2 YSF	-0.175	0.076	-2.291	0.022
	3 YSF	0.384	0.156	2.469	0.014
	4+ YSF	0.712	0.051	13.871	<0.001
CD	CD	-0.175	0.025	-6.891	<0.001

Chapter 3 - Lesser prairie-chicken resource selection during dispersal events in the Mixed-Grass Prairie and Short-Grass Prairie/CRP Mosaic Ecoregions

Introduction

Since European settlement of the Great Plains, grasslands of the central United States have undergone extensive conversion, fragmentation, and anthropogenic change (Sampson and Knopf 1994). These alterations have resulted in habitat loss for grassland-obligate species, as well as significant declines in local, regional, and national biodiversity (Fletcher et al. 2018). Landscape conversion, fragmentation, and concurrent habitat loss on the Great Plains have also resulted in reduced opportunity for less mobile species to migrate, disperse, and access disparate portions of their potential range. Urbanization, grassland conversion to cropland, oil wells, roads, wind turbines, and other anthropogenic features have negative fitness effects on many grassland species, as they expose organisms to increased predation risk and mortality (Sovacool 2009, Behney et al. 2012, Ng et al. 2019). These features can also result in avoidance by grassland species, resulting in loss of connectivity within populations and reduced available habitat (Pruett et al. 2009, Plumb et al. 2019).

One species that is particularly susceptible to landscape conversion and fragmentation is the lesser prairie-chicken (*Tympanuchus pallidicinctus*). Habitat loss and fragmentation have transformed a single large population of lesser prairie-chickens across a continuous landscape into a metapopulation structure (DeYoung and Williford 2016). These subpopulations occupy semi-isolated islands of habitat, separated by expanses of non-habitat matrix. Habitat for the species occurs across four different ecoregions, each with varying levels of connectivity. Genetic continuity still exists among the three northern ecoregions: the Sand Sagebrush Prairie in southwestern Kansas and eastern Colorado; the Short-Grass Prairie/Conservation Reserve Program (CRP) Mosaic of northwestern Kansas; and the Mixed-Grass Prairie of south-central Kansas, northwestern Oklahoma, and Texas Panhandle. Conversely, the Sand Shinnery Oak Prairie Ecoregion population in eastern New Mexico and west Texas exists in isolation of the other ecoregions.

Populations of lesser prairie-chicken occupy sizable landscapes, as individuals have a large home range and require a wide range of habitat types throughout their life cycles. As such, the lesser prairie-chicken is an umbrella species for other prairie birds and an indicator of grassland health (Sandercock 2011, Fritts et al. 2018). Lesser prairie-chickens are non-migratory and spend most of their lives within 4.8 km of the center of their home range (Boal and Haukos 2016). Dispersals beyond this range are relatively uncommon and are usually made by females during the breeding season (Earl et al. 2016). Dispersal events can maintain genetic connectivity among subpopulations, provided the dispersing individual: a) survives its long-distance movement and b) breeds or reproduces with an individual from a different subpopulation (Oyler-McCance et al. 2016). Facilitating these successful dispersal events must be a management priority for species in a metapopulation structure.

Lesser prairie-chicken populations fluctuate dramatically in response to annual precipitation, which is a primary driver of habitat quality. Such a boom-bust demographic structure results in steep population declines during intensive drought events, which are expected to become more frequent and more severe across the lesser prairie-chicken’s range (Karl et al. 2009). This effect is compounded by increased landscape fragmentation and habitat loss, which could prevent rescue effects that would bolster dwindling populations following a drought.

Fragmentation could also reduce fitness by interrupting genetic connectivity; consequences of this have been reported in a closely-related grouse species (Bollmer et al. 2011, Hammerly et al. 2013). While gene flow within and among these ecoregions is partially understood (Oyler-McCance et al. 2016), a description of the physical mechanisms of this gene dispersal is lacking. This encompasses both movement patterns and resource selection by lesser prairie-chickens beyond their home ranges. Development of stepping-stone corridors among focal areas of lesser prairie-chicken habitat is the most defensible method of maintaining genetic connectivity and bolstering lesser prairie-chicken subpopulations (Pruett et al. 2009, Oyler-McCance et al. 2016).

Maintaining connectivity within the lesser prairie-chicken metapopulation is a major conservation priority. To address this conservation need, the Western Association of Fish and Wildlife Agencies (WAFWA) delineated rangewide lesser prairie-chicken habitat into three zones: focal zones, expansion zones, and connectivity zones. Within these zones, management strategies were developed for lesser prairie-chicken core habitation areas, expansion into new regions, and connectivity between focal areas. Agencies manage these areas by establishing goals for how much land within each zone should be conserved as lesser prairie-chicken habitat and by offering monetary incentives to manage landscapes to restore or maintain lesser prairie-chicken habitat. In conjunction with these efforts, enrollment in the U.S. Department of Agriculture Conservation Reserve Program (hereafter CRP) has resulted in a 12% increase in potential lesser prairie-chicken habitat across parts of their range since 1985 and has bolstered lesser prairie-chicken populations in the Short-Grass Prairie/CRP Mosaic and Sand Sagebrush ecoregions (Spencer et al. 2017, Sullins et al. 2018). Unfortunately, the area of CRP within lesser prairie-chicken range has been decreasing since 2008, due in part to U. S. public policy on ethanol production. This trend is expected to continue for the next 5 to10 years. As CRP is often found in agricultural matrices thought to be non-habitat for lesser prairie-chickens, these patches do have potential to be used as temporary stepping stones for individuals dispersing beyond their home ranges. These management strategies provide a strong foundation for preserving connectivity across the occupied range of the lesser prairie-chicken but effectiveness could be increased by determining what landscape-level features are the strongest drivers of resource selection during dispersal.

I attached satellite transmitters to female lesser prairie-chickens at five sites across the northern extent of the lesser prairie-chicken's range and recorded dispersal movements across multiple years. I used step-selection analysis to identify landscape features most influential to lesser prairie-chicken movements during dispersal at different spatial scales. My objectives were to: 1) determine which landscape-level characteristics most influenced movement steps along lesser prairie-chicken dispersal paths; 2) understand the scale at which these landscape features were most important; and 3) determine ecoregion-specific impediments to lesser prairie-chicken movement paths. I expected that grassland cover and CRP cover would have the greatest influence on selection at large spatial scales (78.5 km^2) and that anthropogenic feature densities would similarly influence selection at large spatial scales (12.5 km^2). This information will allow an improved understanding of how landscape features influence dispersing lesser prairie-chickens, and at which scales these influences occur.

Study Area

Capture efforts were divided among three sites in western Kansas: the northern site was located in the Short-Grass Prairie/CRP Mosaic Ecoregion, and the western and southeastern sites were located in the Mixed-Grass Prairie Ecoregion (McDonald et al. 2014). The northern site was located in Logan and Gove counties (Figure 3-1). The Gove County site was 87,822 ha and the portion in Logan County was 41,940 ha. Landscape configuration was 54% grassland, 7.4% CRP, and 36% cropland (Robinson et al. 2018). Grassland management consisted of working rangelands where yearling cattle and cow-calf pairs (*Bos taurus*) were grazed in a rest-rotation pattern.

Average annual precipitation across this area ranges from 47 to 52 cm (PRISM 2016). Agricultural crops in this region are primarily wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*; Kraft 2016). This area has seen extensive conversion to row-crop agriculture but reconversion of these lands to CRP has mitigated the loss of native rangeland and provided vegetation structure that supports lesser prairie-chicken populations (Spencer et al. 2017, Sullins et al. 2018).

Dominant plants included blue grama (*Bouteloua gracilis*), sideoats grama (*Bouteloua curtipendula*), sand dropseed (*Sporobolus cryptandrus*), western wheatgrass (*Pascapyron smithii*), little bluestem (*Schizachyrim scoparium*), broom snakeweed (*Gutierrezia sarothrae*), purple threeawn (*Aristida purpurea*), and annual bromes (*Bromus tectorum*; Kraft 2016). Vegetation compositon within CRP in the northwest site consisted of little bluestem, sideoats grama, switchgrass (*Panicum virgatum*), blue grama, buffalograss (*Bouteloua dactyloides*), and Indian grass (*Sorghastrum nutans*). These fields have also been interseeded with forbs including white sweet clover (*Melilotus alba*), yellow sweet clover (*M. officinalis*), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower (*Desmanthus illinoensis*), purple prairie clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*; Fields et al. 2006).

The southeastern site consisted of 49,111 ha of working rangelands in the Red Hills region and located in Kiowa and Comanche counties (Figure 3-1). This was the most mesic field site, receiving an average of 69 cm precipitation annually (PRISM 2016). Management at this site consisted of rotational and patch-burn grazed cattle pastures, managed with either yearlings or cow-calf pairs. This site was 87% grassland, 2.2% CRP, and 8.9% cropland (Robinson et al. 2018). Dominant species included little bluestem, sideoats grama, Indian grass, blue grama, silver bluestem (*Bothriochloa laguroides*), western ragweed (*Ambrosia psilostachya*), Louisiana sagewort (*Artemisia ludoviciana*), and sand plum (*Prunus angustifolia*; Lautenbach et al. 2019). Lands enrolled in CRP within this portion of the Mixed-Grass Prairie Ecoregion were planted with native warm-season grasses with greater forb abundances compared to other southern portions of this ecoregion (Ripper et al. 2008).

The southwestern site was located in Clark County. This site was located in the Red Hills region on the western border of the Mixed-Grass Prairie Ecoregion with the Sand Sagebrush Prairie Ecoregion. The study area consisted of two ranches separated by 20 km. The southern ranch was 32,656 ha and the northern ranch was 14,810 ha. Landscape configuration at this site was 77% grassland, 5.5% CRP, and 14% cropland. These ranches incorporated rest-rotation grazing to achieve roughly 50% forage utilization within pastures. Average annual rainfall at the site was 59 cm. Dominant plants included sand dropseed (*Sporobolus cryptandrus*), western ragweed (*Ambrosia psilostachya*), blue grama, Russian thistle (*Salsola tragus*), little bluestem, alkali sacaton (*Sporobolus airoides*), and sand sagebrush (Lautenbach et al. 2019; PRISM 2016).

Methods

Capture and Tracking

To track dispersal movements of lesser prairie-chickens, I captured and equipped females with satellite transmitters at the four field sites. I trapped at leks from early March to early May using walk-in traps (Haukos et al. 1990) and tension drop nets (Silvy et al. 1990) from 2013 to 2018. Once captured, I aged and sexed birds based on wing and tail plumage and overall coloration (Copelin 1963). I attached 22-g, rump-mounted satellite transmitters (PTT-100 Solar Argos/GPS PTT Microwave Telemetry, Inc. Columbia, MD) via Teflon® harnesses to captured females. These transmitters collected location data once every two hours from 0500 to 2300 CST. Captures occurred in the northern site from 2013 through 2015, at the southwestern site from 2015 through 2016, and at the southeastern site from 2013 through 2018 (Figure 3-1).

Identifying Dispersal Events

For each radio-tagged female lesser prairie-chicken, I delineated dispersal movements as those movements that differed from movements within a bird's home range. I identified primary home ranges visually using ArcMap 10.5, based on location clustering of relocations in space and time. If I suspected that an individual dispersed beyond its home range, I categorized any other relocation clusters beyond its initial range into secondary and, when applicable, tertiary home ranges. I considered any relocations clustered for greater than two consecutive weeks as a secondary or tertiary home range. After categorizing each relocation, I created spatial cores (50% isopleths) for primary, secondary, and tertiary home ranges using Brownian Bridge Movement Models in package 'move' in Program R (Kranstauber et al. 2019). I calculated the geographic centroid of these cores, then buffered the centroid by a 5-km radius circle. This distance is a conservative estimate derived from literature designating lesser prairie-chicken daily movements as occurring within 4.8 km of the center of its home range (Boal and Haukos 2016).

I categorized long-distance movements into four categories, roughly following Earl et al. (2016): foray loop, true dispersal, round-trip movement, and one-way trip. During foray loops, females took an exploratory trip beyond their home range, before returning to the home range that they had most recently exited. Round-trip movements involved multiple long-distance trips between more than one home range, where a female returned to a previous home range in at least one subsequent trip. True dispersals were movement paths that took the bird to a secondary or tertiary home range that were not connected by subsequent movement paths. One-way trips were long-distance movements that took the bird beyond its home range but did not result in the establishment of a home range following dispersal. These events concluded due to bird mortality or transmitter failure.

For individuals that displayed foray loops or one-way movements, I considered any relocations beyond their 5-km home range buffer as a step during a dispersal movement. For birds that established secondary or tertiary home ranges, I considered the dispersal of that individual to begin at the first relocation beyond the 5-km buffer of its initial home range and to end at the first relocation that occurred within the 5-km buffer of the individual's subsequent home range. I chose to use these buffers as an additional precaution against including any non-dispersal locations in my analysis.

Indicators of selection

I hypothesized that certain features increased the permeability of landscapes, such as the presence of CRP and other grassland patches. I also hypothesized that certain features decreased the permeability of landscapes, making it more difficult for lesser prairie-chickens to traverse areas due to avoidance (Plumb et al. 2019). These features included oil wells, electrical transmission lines, major roads, minor roads, trees, and anthropogenic vertical structures. I measured grassland and anthropogenic features at spatial scales determined by Sullins (2017).

Landscape-level selection and avoidance can occur at multiple spatial scales. To account for how individuals may be sensing and responding to landscape-level resource gradients at different spatial scales, I used a moving window analysis (focal statistics tool, ArcMap 10.5) to calculate the average cover of grassland and CRP features at multiple spatial scales. I derived grassland cover from the 2011 NLCD land cover classification map. I considered grassland to encompass pastures, hay fields, and areas classified as grassland/herbaceous. Grassland features of this layer included fields enrolled in the CRP and I also used a spatial layer identifying CRP grasslands as separate features to assess the influence that this management tool had on lesser prairie-chicken dispersal (Sullins et al. 2018).

Information about grassland cover at large spatial scales (5 km) is needed to support lesser prairie-chickens within their home ranges (Sullins 2017); however, lesser prairie-chicken resource needs during relatively brief dispersal movements may be different than resource needs during more typical within-home range behaviors. To assess influence of grassland cover on dispersal movements at multiple scales, I first converted the grassland layer into 30 × 30 m pixel rasters, where pixels containing grassland were assigned a value of 1 and pixels without grassland were assigned a value of 0. I averaged the number of raster cells containing grassland within 400-, 800-, 1,600-, 2,000-, 2,400-, 2,800-, 3,200-, 4,000-, and 5,000-m radii of each focal cell and assigned that focal cell the averaged value of the raster cells around it. I calculated this for each cell in the raster.

I conducted a similar analysis for CRP, where all 30 × 30 m raster cells containing CRP were assigned a value of 1 and all raster cells without CRP were assigned a value of 0. I calculated the average pixel density at the same scales as the combined grassland layer. Presence of CRP had a greater influence on lesser prairie-chicken populations in the less mesic (i.e., western) portions of their range (i.e., Short-Grass Prairie/CRP Mosaic Ecoregion; Sullins et al. 2018). I hypothesized that this same pattern might hold for lesser prairie-chicken dispersal events. To account for this, I used a spatial layer of 30-year annual precipitation averages from the PRISM climate group (http://www.prism.oregonstate.edu/normals/) and incorporated this raster into models including CRP cover.

I attained a spatial layer of tree canopy cover developed by the U.S. Department of Agriculture (USDA; Paull et al. 2017), retrieved from https://www.fs.usda.gov/rds/archive/Product/RDS-2017-0025. For each cell in this layer, I used focal-point statistics to estimate the average tree canopy coverage within a 226-m radius circle (equivalent to 16 ha) of that cell. This corresponded to the scale of selection by which lesser prairie-chickens select landscapes to nest, relative to tree density (Lautenbach et al. 2017). I used a conversion function in Lautenbach et al. (2017) to convert average canopy cover to tree density. This resulted in a raster of tree densities per 16-ha for the entirety of the lesser prairie-chicken range.

I obtained locations of active oil wells in Kansas from the Kansas Geological Survey and active and temporarily-halted oil wells in Colorado from the Colorado Oil and Gas Conservation Commission (http://www.kgs.ku.edu/PRS/petroDB.html). Transmission line locations in Kansas were obtained from the Kansas Corporation Commission.

I incorporated vertical structures (i.e., cell towers, wind turbines, oil wells, and large buildings but excluded transmission lines) into my analyses, as these correspond to avoidance behavior in lesser prairie-chickens (Robel et al. 2004, Pitman et al. 2005, Plumb et al. 2019). I retrieved a GIS layer that included wind turbines, grain elevators, cell phone towers, and other structures that stood at least 150 feet (~50 m) tall. I converted this point shapefile into a 30-m^2 raster and summed raster cell values where multiple points overlapped. This layer was created by the Federal Communications Commission.

Roads are reported to be an impediment to wildlife (Pruett et al. 2009) but the degree to which roads might inhibit bird movements could be related to how heavily trafficked these features may be. To account for this, I used two different layers. One was based on major roads (state and federal highways) and the other was based on country roads, which were primarily either dirt or gravel. Road locations in Kansas were collected from the Kansas GIS Data Access and Support Center.

Selection against certain landscapes may be based on individual features (e.g., distance to an individual oil well), rather than composition of feature densities across a broader landscape (Pitman et al. 2005). To account for this, I incorporated measures of distance to features and feature densities at multiple spatial scales into my analysis. I used the Euclidean distance function (ArcMap 10.5) to calculate distance from each point location during dispersal to major roads, county roads, transmission lines, individual oil wells, and vertical structures, which I included as variables in my logistic regression models. I prepared anthropogenic layers containing discrete locations (oil wells and all vertical structures) for a moving-window analysis by converting point shapefiles to 30-m^2 rasters in ArcMap 10.5. If more than one feature occurred in the same raster cell, I summed the number of features. Line features were buffered by 30 m, before being converted to a 30 × 30 m cell raster by which feature densities could be estimated. After calculating density rasters for each anthropogenic feature, I used the focal statistics tool in ArcMap 10.5 to estimate the summed density of each feature within concentric radii of 500 m, 1,000 m, and 1,500 m. These scales were consistent with previous research that described the lesser prairie-chicken's sensitivity to anthropogenic features (Pruett et al. 2009, Plumb et al. 2019).

Step Selection

The Mixed-Grass Prairie and Short-Grass Prairie/CRP Mosaic ecoregions have different landscape configurations that could have differential influences on lesser prairie-chicken resource selection during dispersal. For instance, the Mixed-Grass Prairie Ecoregion is being affected by substantial invasive tree encroachment (e.g., eastern redcedar [*Juniperus virginiana*]; Fuhlendorf 2002, Lautenbach et al. 2017), more so than the less mesic Short-Grass Prairie/CRP Mosaic Ecoregion. These differences in resource availability and selection could obscure inference of resource selection if I were to examine use relative to tree presence and CRP availability across both regions combined. To avoid this, I stratified the sample of dispersals by ecoregion.

I used step-selection analysis (SSA) to determine the relative influence of landscape features on lesser prairie-chicken movement patterns during dispersal. This analysis is well suited to dispersal movements (Fortin et al. 2005, Thurfjell et al. 2014, Newton et al. 2017). Within this modeling framework, movement paths for each individual were split into bursts of movement steps. These are consecutive relocations that incorporate the step length, turning angle, and first and second position of the individual in that step. When delineating bursts, I only considered steps that were two hours apart, as this was the finest temporal frequency at which our transmitters recorded relocations. I excluded any points greater than two hours apart from our bursts, as individuals could have made a variety of movement choices within that time frame, which could lead to inaccuracy in estimates of resource selection during each burst (Thurfjell et al. 2014). Once locations were categorized into individual bursts, I created paired 10 available steps with each true step along the individual's movement path. I randomly sampled available steps from the empirical distribution of all step lengths and turning angles that each individual made along its dispersal path. This restricted available steps to what each bird could foreseeably access within two hours of its initial position at each step. I extracted each landscape feature layer to the endpoints of both used and paired steps and used conditional logistic regression in R (package AMT; Avgar et al. 2011) to assess the influence that these features have on dispersal movement.

I separated potential models into separate suites for each category of landscape variable (i.e., grassland, CRP, oil wells, electrical transmission lines, major roads, county roads, and vertical structures) to compare relative influence of similar landscape features at different scales. I used an information-theoretic approach, by incorporating model averaging and Akaike's Information Criterion (AIC), to rank and determine the most parsimonious model within each suite of candidate models (Burnham and Anderson 2004). I also included a null model into each model suite to assess relative fit of the top ranked models. I incorporated the top ranked models for each suite into a global model suite, where I determined the best fitting single-variable model of lesser prairie-chicken resource selection during dispersal.

Results

Capture and Tracking

I captured 166 female lesser prairie-chickens across the three field sites from 2013 to 2018. Within this sample, I identified 68 dispersal events across 40 female lesser prairie-chickens, equal to 24% of all monitored females (Table 3-1). In the Short-Grass Prairie/CRP Mosaic Ecoregion, I recorded twenty-two dispersals (32% of dispersals) across 15 females (38% of females) from 2013 to 2015. In the Mixed-Grass Prairie Ecoregion, I recorded 46 dispersals (68% of dispersals) across 25 females (63% of females). Twenty of these events (43% of dispersals) occurred from 2014 to 2016 at the southwestern capture site (Clark County) and the remaining twenty-six dispersal events (57% of dispersals) occurred at the southeast capture site from 2013 to 2018 (Kiowa and Comanche counties). Notably, of the six years that I captured birds at the southeastern site, I recorded only one dispersal across 2017 and 2018. Twenty-nine of the dispersing females (73% of females) were second-year (SY), seven birds (18% of females) were after-second-year (ASY), and four birds (10% of females) were recorded as after-hatch-year (AHY), as they had conflicting morphological characteristics that prevented an accurate age estimation.

I examined dispersal events by season and found that 45 (66%) movements occurred in spring (March 1 through May 15), 15 (22%) occurred in fall (September 1 through November 15), and 8 (12%) occurred during summer (June 1 through August 31). Twenty-one dispersal events were foray loops, where a female conducted an exploratory path before returning to her original home range. Twenty dispersal events were a part of round-trip movements, where a female established multiple interconnected home ranges. Twenty-seven long distance movements were one-way trips, where a female either left her original home range and established a permanent home range elsewhere or where a female was not recorded finishing her long-distance movement, either due to transmitter failure or mortality.

Broad Movement Patterns

In the Mixed-Grass Prairie Ecoregion, net displacement of all long-distance movements averaged 10.17 km beyond the initial home range (range = 72 to 52,306 m; Table 3-2). Estimated total distance traveled during long-distance events was 17.38 km (range = 92 to 63,143 m) and average time length of dispersal events was 110.4 hours, roughly 4.6 days (range = 6 to 715 hours). I estimated the average relative movement speed across the entire dispersal event and found that females moved an average of 206.5 meters per hour (range = 9 to 624 meters per hour) during long distance movements. In the Short-Grass Prairie/CRP Mosaic, I found that females had a mean net displacement of 13.1 km (range = 1,565 to 51,620 m) from their home range and traveled 24.4 km (range = 2,751 to 75,308 km) on average. Mean dispersal time was

151.6 hours (range = 24 to 402 hours), roughly 6.3 days. Relative movement speed was similar to the Mixed-Grass Prairie Ecoregion with an average of 206.6 meters per hour (range = 36 to 540 meters per hour) during dispersals.

I found no differences in dispersal time ($F_{1,66} = 1.65$, $P = 0.204$), distance ($F_{1,66} = 2.44$, $P = 0.12$), speed ($F_{1,66} = 0.001$, $P = 0.99$), or max displacement ($F_{1,66} = 1.01$, $P = 0.32$) among ecoregions. There were no differences in dispersal distance ($F_{4,63} = 1.33$, $P = 0.27$) , speed ($F_{4,63} = 0.88$, $P = 0.48$), or maximum displacement ($F_{4,63} = 1.33$, $P = 0.27$) among years. Dispersal time was greater in 2018 ($F_{4,63} = 10.61$, $P < 0.001$) but this stemmed from a single sample in 2018. Lastly, I found no differences in dispersal time ($F_{2,65} = 0.29$, $P = 0.75$), distance ($F_{2,65} = 0.407$, $P = 0.67$), speed ($F_{2,65} = 0.23$, $P = 0.80$), or maximum displacement ($F_{2,65} = 0.54$, $P = 0.59$) among season of dispersal.

I compared dispersal behaviors (i.e., foray loops, one-way dispersals, and round-trip events) and found no differences in dispersal time ($F_{2,65} = 0.17$, $P = 0.84$), distance ($F_{2,6 5} = 0.007$, $P = 0.99$), speed ($F_{2,65} = 0.82$, $P = 0.44$), or max net displacement ($F_{2,65} = 2.85$, $P = 0.06$) among these. In contrast, differences in broad movement patterns between second-year and after-second-year birds were detected; ASY females had slower movement speeds during dispersal ($F_{1,62} = 8.05$, $P = 0.006$, $\eta^2 = 11\%$; Figure 3-2) than SY females. Additionally, ASY females moved shorter distances during dispersal than did SY females ($F_{1,62} = 11.57$, $P = 0.001$, $\eta^2 = 6\%$; Figure 3-3). Younger females appear to be moving further and more quickly than after-second-year females during dispersal movements.

Of the 68 dispersal events, I found seven events where the dispersing bird neither returned to its original range nor established a new home range. These events occurred due to either mortality or transmitter failure. Six and one of these events occurred in the Mixed-Grass

Prairie and Short-Grass Prairie/CRP Mosaic ecoregions, respectively. I found that long-distance paths that did not end in a home range were longer ($F_{1,66} = 4.413$, $P = 0.04$, $\eta^2 = 6\%$; Figure 3-4) than any dispersal paths that ended in a home range.

Resource Selection: Mixed-Grass Prairie Ecoregion

I fit step-selection functions to dispersal events and input single-variable models into eight model suites. Two suites assessed the fit of models related to grassland and CRP cover at different spatial scales. Six suites assessed the fit of single-variable models that included Euclidean distance to anthropogenic features and feature density at different scales. The features included oil wells, electrical transmission lines, major roads (paved), county roads (unpaved), vertical structures, and trees.

In the Mixed-Grass Prairie Ecoregion, I found that four models outcompeted the null model, indicating a potential relationship between these features and resource selection by dispersing individuals. These single variable models included tree density within 0.16 km^2, grassland cover within 0.5 km^2, Euclidean distance to nearest tree, and vertical structure densities within 3.1 km^2 (Table 3-3). When examining the beta coefficients of these models, I found that only two coefficients did not overlap zero at 95% confidence (Table 3-4). I concluded that lesser prairie-chickens selected for greater grassland cover within 0.5 km^2 in greater proportions than its availability on the landscape and that trees were avoided during dispersal movements (Figure 3-5).

I found that six single variable models outcompeted the null model across all model suites for the Short-Grass Prairie/CRP Mosaic Ecoregion. Transmission line density within 12.6 km^2, 3.14 km^2, and 0.8 km^2 all outcompeted the null model (Table 3-5). Additionally, I found that CRP cover within 32.2 km^2, tree density within 0.16 km^2, and Euclidean distance-to tree all outcompeted the null model (Table 3-5). Examination of the beta coefficients for these single variable models revealed that transmission line density within 12.5 km^2 was the only coefficient that did not overlap zero at 95% confidence (Table 3-4). The model including Euclidean distance-to-tree neared significance but had no observable influence on lesser prairie-chicken resource selection during dispersal (Figure 3-6). I concluded that dispersing females selected against areas with electrical transmission lines while moving through the Short-Grass Prairie/CRP Mosaic Ecoregion.

Resource Selection: Short-Grass Prairie/CRP Mosaic Ecoregion

In the Short-Grass Prairie/CRP Mosaic Ecoregion, I found that dispersal steps occurred an average of 821 m from county roads, 9,414 m from major roads, 1,507 m from oil wells, 12,744 m from transmission lines, 1,496 m from vertical features, and 1,888 m from the nearest tree (Table 3-6). Paired steps occurred an average of 819 m from county roads, 7,826 m from major roads, 1,512 m from oil wells, 12,727 m from transmission lines, 1,495 m from vertical structures, and 1,868 m from the nearest tree.

In the Mixed-Grass Prairie Ecoregion, I found that dispersal steps occurred an average of 780 m from major and county roads, 1,383 m from oil wells, 7,370 m from transmission lines, 1,294 m from vertical features, and 922 m from the nearest tree (Table 3-6). Paired steps occurred an average of 782 m from major and county roads, 1,389 m from oil wells, 7,372 m from transmission lines, 1,301 m from vertical structures, and 903 m from trees. Used and available steps during dispersals in the Mixed-Grass Prairie Ecoregion were nearer to oil wells, vertical structures, trees, and major and county roads, than used and available dispersal steps in the Short-Grass Prairie/CRP Mosaic Ecoregion. Average distance to transmission lines along dispersal paths was 5.37 km greater in the Shortgrass Prairie/CRP Mosaic Ecoregion.

Discussion

Trees, anthropogenic features, and grassland cover all influenced lesser prairie-chicken resource selection during dispersal. I found a disparity in selection between ecoregions. Dispersals in the Mixed-Grass Prairie Ecoregion were most influenced by tree density and grassland cover, whereas dispersals in the Short-Grass Prairie/CRP Mosaic Ecoregion were influenced most by transmission-line density. Additionally, I found differences in dispersal distance and movement speed during dispersal when comparing SY female and ASY females.

Second-year birds are more abundant than after-second-year females, making them more likely to provide a rescue effect. This assumes they do not disperse into a population sink (Garton et al. 2016, DeYoung and Williford 2016). I found that second-year females moved farther and dispersed at greater speeds than older females. Lesser prairie-chickens exhibit r-selected demographic patterns, such as quick generational turnover, high annual productivity, and high energy expenditure in ensuring reproductive success (DeYoung and Williford 2016). Age-related dispersal behavior in lesser prairie-chickens may be a behavioral response to such demographic patterns. Innate behavioral mechanisms that drive second-year birds to disperse farther and faster would facilitate a boom-bust life strategy, allowing birds hatched during a year of abundance to disperse farther and recolonize landscapes more rapidly in the following year. These adaptations would be most advantageous for younger females, as lesser prairie-chickens typically have short life spans (Hagen and Geisen 2004). This is encouraging, provided that dispersing individuals are not moving into a population sink during dispersal.

I did not find any differences in movement patterns (i.e., net displacement, total distance traveled, time during dispersal, and dispersal speed) across years, indicating that annual variation in habitat quality may be less influential in driving dispersal patterns than innate responses related to age and sex. Annual changes in precipitation drive these lesser prairie-chicken populations and could increase the perceived permeability of landscapes by increasing habitat quality in areas surrounding an individual's home range (Robinson et al. 2018). Apart from a single event in 2018, I did not detect any changes in dispersal time, movement speed, distance traveled, or net displacement among years; however, I did not explicitly estimate dispersal probability relative to year. While movement patterns showed little variation among years, probabilities of dispersal may still shift in response to annual variations.

Long distance movements that did not end in a home range (one-way trips) were significantly longer than long distance movements that ended in home ranges (i.e., true dispersal, round trip movements, or foray loops). I hypothesized that one-way movements would be shorter than true dispersals, as unsuccessfully dispersing individuals were likely unable to reach their destination and finish their full movement. This evidence was interpreted to suggest that increasing dispersal movement distance may negatively impact fitness, as seen in other species (Johnson and Gaines 1990, Yoder et al. 2004, Johnson et al. 2009). There is likely a greater risk of mortality associated with longer dispersals, as dispersing females are moving through unfamiliar, non-matrix habitat.

Mortality risk may also be increased if lesser prairie-chickens move through non-matrix habitat with a greater density of anthropogenic features that what may normally be found within their home ranges. I found that both used and available locations during dispersal were nearer, on average, to anthropogenic features when compared to females moving within home ranges (Plumb et al. 2019; Table 3-6). Similar movement patterns emerged regardless of annual variations in local habitat quality, which indicated that movement during dispersal events was likely an innate response rather than behavior driven by external factors. On contemporary landscapes, this is driving females beyond their home range into areas more densely packed with anthropogenic features, which could have a negative effect on survival during dispersal.

Many of the mechanisms that dictate 2nd-order selection by lesser prairie-chickens are thought to be extra-hierarchical and to occur at large spatial scales based on established home range (78 km^2, Sullins 2017). Conversely, patterns that dictated selection during dispersal in the Mixed-Grass Prairie Ecoregion occurred at much smaller spatial scales (0.16 to 0.5 km^2). This may indicate that habitat needs during dispersal could be quite different than habitat needs within a home range. Unsurprisingly, lesser prairie-chickens selected for areas with more grassland cover during dispersal than what was available on the landscape within the Mixed-Grass Prairie Ecoregion; however, the only significant grassland model was at the smallest spatial scale that I estimated (i.e., within 400 m of a focal point). During long distance movements, lesser prairie-chickens are making quick forays through unfamiliar territory. It could be that their knowledge of grassland habitat at larger spatial scales is limited in these unfamiliar areas, which subsequently limits their ability to select for grassland at relatively small scales. Alternately, lesser prairie-chickens could have increased tolerance of low grassland densities at large spatial scales, provided there are sufficient small “islands” of grassland for refugia during dispersal events. During long-distance movements, multiple small-scale selections may then become emergent to drive patterns across broader landscapes.

The top single-variable model predicting resource selection during dispersal in the Mixed-Grass Prairie Ecoregion was tree density within 0.16 ha. At this scale, lesser prairie-chickens avoided areas with even minimal tree densities (e.g., as little as 8 to 2 trees/ha at the 2nd- and 3rd-order of selection, respectively; Lautenbach et al. 2017). My results were interpreted to indicate that tree encroachment represents a significant deterrent for dispersing lesser prairie-chickens and could interrupt gene flow by reducing the permeability of landscapes in the Mixed-Grass Prairie Ecoregion.

Historically, regular wildfires prevented the encroachment of trees such as the eastern redcedar on these landscapes. As fire was removed from these landscapes, trees aggressively encroached onto upland prairie habitat, reducing and fragmenting habitat for lesser prairie-chickens (Coppedge et al. 2001, Lautenbach et al. 2017). Reintroduction of fire on the landscape is a relatively cost-effective method of reducing tree encroachment and maintaining tree densities at manageable rates for lesser prairie-chickens (Fuhlendorf et al. 2008). This technique would also be effective for maintaining broad "corridors" for lesser prairie-chicken movements during dispersal.

The top model predicting lesser prairie-chicken resource selection during dispersal in the Short-Grass Prairie/CRP Mosaic Ecoregion was electrical transmission line density within 2 km. Transmission lines are tall structures that deter lesser prairie-chickens or other grouse via visual obtrusion or by providing perches for raptors (Pruett et al. 2009). In the Sand Sagebrush Prairie Ecoregion, lesser prairie-chickens avoided transmission lines during nesting, placing nests from 1,254 to 1,385 m from transmission lines (Pitman et al. 2005). My research was interpreted to suggest that these structures can also impede selection during dispersal. Because these linear features span much of western Kansas, they create barriers to dispersal and pose a threat to connectivity among lesser prairie-chicken populations and ecoregions. Apart from transmission line density, I found little evidence for selection of available resources within a two-hour time step of dispersal movements by lesser prairie-chickens in the Short-Grass Prairie/CRP Mosaic Ecoregion.

I analyzed lesser prairie-chicken step selection at a fine temporal scale (two-hour steps), but it is possible that lesser prairie-chickens are only able to interpret or respond to resource signals across broader spatial and temporal scales during dispersals. In a step-selection analysis framework, the scale at which available steps are paired can affect the reliability of resource selection models (Thurfjell et al. 2014). The mean two-hour step length for a dispersing female was 197 m and 293 m in the Mixed-Grass Prairie and Short-Grass Prairie/CRP Mosaic ecoregions, respectively. Steps at this time interval may be so small that they do not allow for a biologically meaningful variation between used and unused landscapes within a two-hour step of the starting relocation. For example, the average distance to vertical structures on the Short-Grass Prairie/CRP Mosaic Ecoregion was 1,496 m for used points and 1,495 m for available points. Plumb et al. (2019) suggested that vertical structures may deter lesser prairie-chicken nest site selection within distances of 3 km. If selection against this feature is consistent between nesting and dispersing, then paired steps at small spatial and temporal scales (~300 m, 2 hours) may not detect a difference in used versus available habitat, particularly if lesser prairie-chickens are well beyond the minimum threshold of distance to a feature. If this were the case, then 200 to 300 m variations in distances to anthropogenic feature may be not be meaningful, provided a bird is well beyond a minimum threshold distance to a feature.

Alternately, individuals moving through unfamiliar landscapes may have limited ability to select resources, as they have little information on the breadth of resources available to them in that landscape. Lesser prairie-chickens will often make foray loops, where females travel beyond their home range, likely to prospect for leks or nesting habitat in the breeding season (Earl et al. 2016). In a scenario where lesser prairie-chickens are naïve to landscapes beyond their home range, they would be less able to select for or against landscape features such as CRP cover or vertical structure density, as they would be unaware of the ‘best’ options available to them during dispersal as they moved beyond their home range. Similarly, within a two-hour time step, lesser prairie-chickens would be less able to sense and respond to negative features on the landscape, as they typically only moved 200 to 300 m per two-hour time step. Within a two-hour time step, lesser prairie-chickens typically moved 200 to 300 m. Across this short spatial and temporal scale, lesser prairie-chickens may be less able to interpret and respond to cues on the landscape, such as a transmission line or oil well. With this is mind, an individual lesser prairie-chicken might be less able to avoid these features during dispersal, especially if an individual must be in relatively close proximity to anthropogenic features to sense them in the first place. This may indicate that lesser prairie-chickens are only able to sense and respond to landscape features at a time scale greater than two hours during dispersals.

I found a disparity in selection between ecoregions: lesser prairie-chickens only selected against transmission lines at wide spatial scales in the Short-Grass Prairie/CRP Mosaic, while individuals selected for grassland and against tree densities at small scales in the Mixed-Grass Prairie. This information will allow managers to develop ecoregion-specific management plans for increasing the permeability of landscapes surrounding core ranges, potentially making connectivity zones among populations more permeable. In the Mixed-Grass Prairie Ecoregion, regular removal of encroaching trees within stepping-stone dispersal corridors would facilitate long-range movement among populations. In the Short-Grass Prairie/CRP Mosaic Ecoregion, it may be necessary to prevent additional transmission lines from being established within connectivity corridors among lesser prairie-chicken populations.

Dispersal movements are an evolutionary response that can increase genetic connectivity and buffer against population declines within the lesser prairie-chicken metapopulation (Earl et

a. 2016, Garton et al. 2016). Innate dispersal behavior likely results in a fitness cost within human-altered landscapes; forays into non-habitat place lesser prairie-chickens nearer to anthropogenic features, which could decrease their survival. Management could increase the success of these movements by applying ecoregion-specific habitat improvements. The Western Association of Fish and Wildlife Agencies (WAFWA) has developed a Critical Habitat Assessment Tool (CHAT) that delineates lesser prairie-chicken range into core areas, expansion areas, and connectivity areas. The purpose of connectivity areas is to promote population connectivity by creating corridors between core areas. Landscape-level management can be informed by my findings of resource selection relative to trees and transmission lines within these CHAT connectivity zones.

Literature Cited

Avgar, T., J. R. Potts, M. A. Lewis, and M. S. Boyce. 2016. Integrated step selection analysis: bridging the gap between resource selection and animal movement. Methods in Ecology and Evolution 7:619-630.

Boal, C. W., and D. A. Haukos. 2016. The lesser prairie-chicken. Pages 1-11 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Bollmer, J. L. , E. A. Ruder, J. A. Johnson. J. A. James, and P. O. Dunn. 2011. Drift and selection influence geographic variation at immune loci of prairie-chickens. Molecular Ecology 20:4695-4706.

Behney, A. C., C. W. Boal, H. A. Whitlaw, and D. R. Lucia. 2012. Raptor community composition in the Texas southern High Plains lesser prairie-chicken range. Wildlife Society Bulletin 36:291-296.

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference: Understanding AIC and BIC in model selection. Sociological Methods and Research 33:261-304.

Copelin, F. F. 1963. The lesser prairie chicken in Oklahoma. Oklahoma Wildlife Conservation Department. Oklahoma City, USA.

Coppedge, B. R., D. M. Engle, S. D. Fuhlendorf, R. E Masters, and M. S. Gregory. 2001. Landscape cover types and pattern dynamics in fragmented southern Great Plains grasslands, USA. Landscape Ecology 16:677-690.

DeYoung, R. W., and D. L. Williford. 2016. Genetic Variation and Population Structure in the Prairie Grouse. Pages 77-97 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Earl, J. E., S. D. Fuhlendorf, D. Haukos, A. M. Tanner, D. Elmore, and S. A. Carleton. 2016. Characteristics of lesser prairie-chicken (*Tympanuchus pallidicinctus*) long-distance movements across their distribution. Ecosphere 7(8).

Fields, T. L., G. C. White, W. C. Gilgert, and R. D. Rodgers. 2006. Nest and brood survival of lesser prairie-chickens in west central Kansas. Journal of Wildlife Management 70:931-938.

Fletcher, Jr, R. J., R. K. Didham, C. Banks-Leite, J. Barlow, R. M. Ewers, J. Rosindell, R. D. Holt, A. Gonzalez, R. Pardini, E. I. Damschen, F. P.L. Melo, L. Ries, J. A. Prevedello, T. Tscharntke, W. F. Laurance, T. Lovejoy, and N. M. Haddad. 2018. Is habitat fragmentation good for biodiversity? Biological Conservation 226:9-15.

Fortin, D., H. L. Beyer, M. S. Boyce, D. W. Smith, T. Duchesne, and J. S. Mayo. 2005. Wolves influennnce elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology 86:1320-1330.

Fritts, S. R., B. A. Grisham, R. D. Cox, C. W. Boal, D. A. Haukos, P. McDaniel, C. A. Hagen, D. U. Greene. 2018. Interactive effects of severe drought and grazing on the life history cycle of a bioindicator species. Ecology and Evolution 8:9550-9562.

Fuhlendorf, S. D., A. J. W. Woodward, D. M. Leslie Jr, and J. S. Shackford. 2002. Multi-scale effects of habitat loss and fragmentation on lesser prairie-chicken populations of the US Southern Great Plains. Landscape Ecology 17:617-628.

Fuhlendorf, S. D., S.A. Archer, F. Smeins, D. M. Engle, and C. A. Taylor. 2008. The combined influence of grazing, fire, and herbaceous productivity on tree–grass interactions. Pages 219-238 *in* O. V. Auken, editor. Western North American Juniperus Communities. Springer, New York, USA.

Garton, E. O., C. A. Hagen, G. M. Beauprez. S. C. Kyle, J. C. Pitman, D. D. Schoeling, and W. E. Van Pelt. 2016. Population Dynamics of the Lesser Prairie-Chicken. Pages 49-76 *in* D. A. Haukos and C. W. Boal, editors. Ecology and conservation of lesser prairie-chickens. University of California Press, Berkeley, USA.

Hammerly, S. C., M. E. Morrow, and J. A. Johnson. 2013. A comparison of pedigree- and DNA-based measures for identifying inbreeding depression in the critically endangered Attwater's Prairie-Chicken. Molecular Ecology 22:5313-5328.

Hagen, C. A., and K. M. Giesen. [online]. 2004. Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*). Birds of North America 364. <http://bna.birds.cornell.edu/bna/species/364/articles/introduction> (20 January 2014).

Haukos, D. A., L. M. Smith, and G. S. Broda. 1990. Spring trapping of lesser prairie-chickens. Journal of Field Ornithology 61:20-25.

Johnson, C. A., J. M. Fryxell, I. D. Thompson, and J. A. Baker. 2009. Mortality increases with natal dispersal distance in American martens. Proceedings of the Royal Society B 276:3361-3367.

Johnson, M. L., and M. S. Gaines. 1990. Evolution of dispersal: theoretical models and empirical tests using birds and mammals. Annual Review of Ecology and Systematics 21:449-480.

Karl, T. R., J. M. Melillo, and T. C. Peterson. 2009. Global climate change impacts in the United States. Cambridge University Press, New York, New York, USA.

Kraft, J. D. 2016. Vegetation characteristics and lesser prairie-chicken responses to land cover types and grazing management in western Kansas. Thesis, Kansas State University, Manhattan, USA.

Kranstauber, B., M. Smolla, and A. K. Scharf. 2019. move: Visualizing and Analyzing Animal Track Data. R package version 3.2.0. <https://CRAN.R-project.org/package=move>

Lautenbach, J. M., R. T. Plumb, S. G. Robinson, C. A. Hagen, D. A. Haukos, and J. C. Pitman. 2017. Lesser prairie-chicken avoidance of trees in a grassland landscape. Rangeland Ecology & Management 70:78-86.

Lautenbach, J. M., D. A. Haukos, D. S. Sullins, C. A. Hagen, J. D. Lautenbach, J. C. Pitman, R. T. Plumb, S. G. Robinson, and J. D. Kraft. 2019. Factors influencing nesting ecology of lesser prairie-chickens. Journal of Wildlife Management 83:205-215

Newton, R. E., J. D. Tack, J. C. Carlson, M. R. Matchett, P. J. Fargey, and D. E. Naugle. 2017. Longest sage-grouse migratory behavior sustained by intact pathways. Journal of Wildlife Management 81:962-972.

Ng, C. S., P. G. Des Brisay, and N. Koper. 2019. Chestnut-collared longspurs reduce parental care in the presence of conventional oil and gas development and roads. Animal Behaviour 148:71-80.

Oyler-McCance, S. J., R. W. DeYoung, J. A. Fike, C. A. Hagen, J. A. Johnson, L. C. Larsson, and M. A, Patten. 2016. Rangewide genetic analysis of lesser prairie-chicken reveals population structure, range expansion, and possible introgression. Conservation Genetics 17:643-660.

Pitman, J. C., C. A. Hagen, R. J. Robel, T. M. Loughin, and R. D. Applegate. 2005. Location and success of lesser prairie-chicken nests in relation to vegetation and human disturbance. Journal of Wildlife Management 69:1259-1269.

Plumb, R. T., J. M. Lautenbach, S. G. Robinson, D. A. Haukos, V. L. Winder, C. A. Hagen, D. S. Sullins, J. C. Pitman, and D. K. Dahlgren. 2019. Lesser prairie-chicken space use in relation to anthropogenic structures. Journal of Wildlife Management 83:216-230.

PRISM Climate Group.2016. Oregon State University. <http://www.prism.oregonstate.edu/normals/>

Paull, D. A., J. W. Whitson, A. L. Marcotte, G. C. Liknes, D. M. Meneguzzo, and T. A. Kellerman. 2017. High-resolution land cover of Kansas 2015. Fort Collins, CO: Forest Service Research Data Archive. Updated 27 November 2017.

Pruett, C. L. M. A. Patten, and D. H. Wolfe. 2009. It’s not easy being green: wind energy and a declining grassland bird. Bioscience 59:257-262.

Ripper, D., M. McLachlan, T. Toombs, and T. VerCauteren. 2008. Assessment of Conservation Reserve Program fields within the current distribution of Lesser Prairie-Chicken. Great Plains Research 18:205–218.

Robel R. J., J. A. Harrington Jr, C. A. Hagen, J. C. Pitman, and P. R. Reker. 2004. Effect of energy development and human activity on the use of sand sagebrush habitat by lesser prairie-chickens in southwestern Kansas. Transactions of the North American Wildlife and Natural Resource Conference 69:251-266.

Robinson, S. G., D. A. Haukos, R. T. Plumb, J. M. Lautenbach, D. S. Sullins, J. D. Kraft, J. D, Lautenbach, C. A. Hagen, and J. C. Pitman. 2018. Nonbreeding home-range size and survival of lesser prairie-chickens. Journal of Wildlife Management 82:413-423.

Sampson, F., and F. Knopf. 1994. Prairie Conservation in North America. BioScience 44:418-421.

Sandercock, B. K., K. Martin, and G. Segelbacher (editors). 2011. Ecology, management and conservation of grouse. Studies in Avian Biology No. 39, Cooper Ornithological Society, University of California Press, Berkeley, USA.

Silvy, N. J., M. E. Morrow, E. Shanley, and R. D. Slack. 1990. An improved drop net for capturing wildlife. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 44:374–378.

Sovacool, B. K. 2009. Contextualizing avian mortality: a preliminary appraisal of bird and bat fatalities from wind, fossil-fuel, and nuclear electricity. Energy Policy 37:2241-2248.

Spencer, D., D. Haukos, C. Hagen, M. Daniels, and D. Goodin. 2017. Conservation Reserve Program mitigates grassland loss in the lesser prairie-chicken range of Kansas. Global Ecology and Conservation 9:21-38.

Sullins, D. S., J. D. Kraft, D. A. Haukos, S. G. Robinson, J. H. Reitz, R. T. Plumb, J. M. Lautenbach, J. D. Lautenbach, B. K. Sandercock, and C. A. Hagen. 2018. Demographic consequences of Conservation Reserve Program grasslands for lesser prairie-chickens. Journal of Wildlife management 82:1617-1632.

Sullins, D. S. 2017. Regional variation in demography, distribution, foraging, and strategic conservation of lesser prairie-chickens in Kansas and Colorado. Dissertation, Kansas State University, Manhattan, USA.

Thurfjell, H, S. Ciuti, and M. S. Boyce. 2014. Applications of step-selection functions in ecology and conservation. Movement Ecology 2(1).

Yoder, J. M., E. A. Marshall, and D. A. Swanson. 2004. The cost of dispersal: predation as a function of movement and site familiarity in ruffed grouse. Behavioral Ecology 15:469-476.

Figures

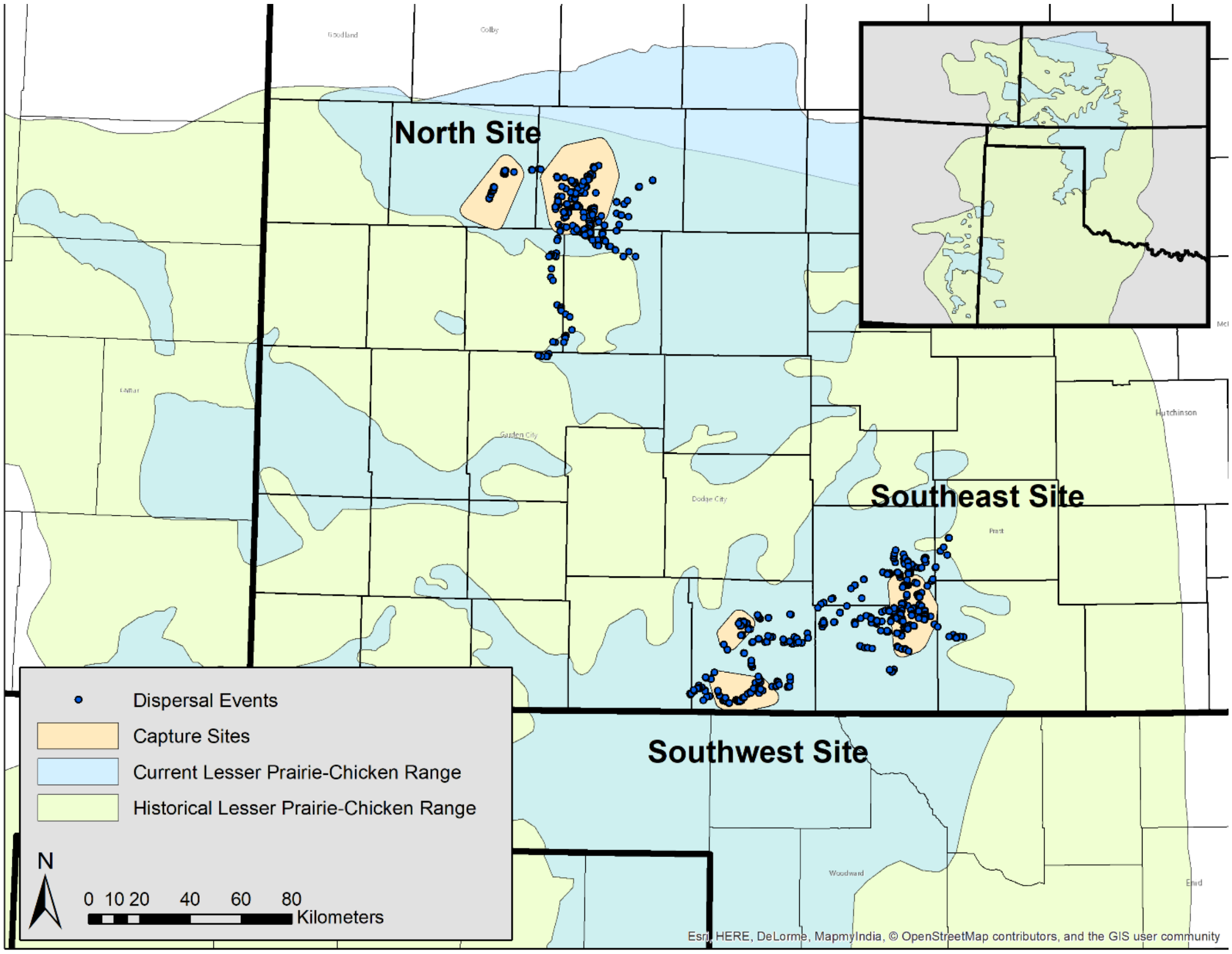

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Figure 3-1 Map displaying all dispersal points, overlaid across capture locations in the Short Grass and Mixed Grass Prairie Ecoregions. Dispersals were recorded in these regions from 2013 to 2018.

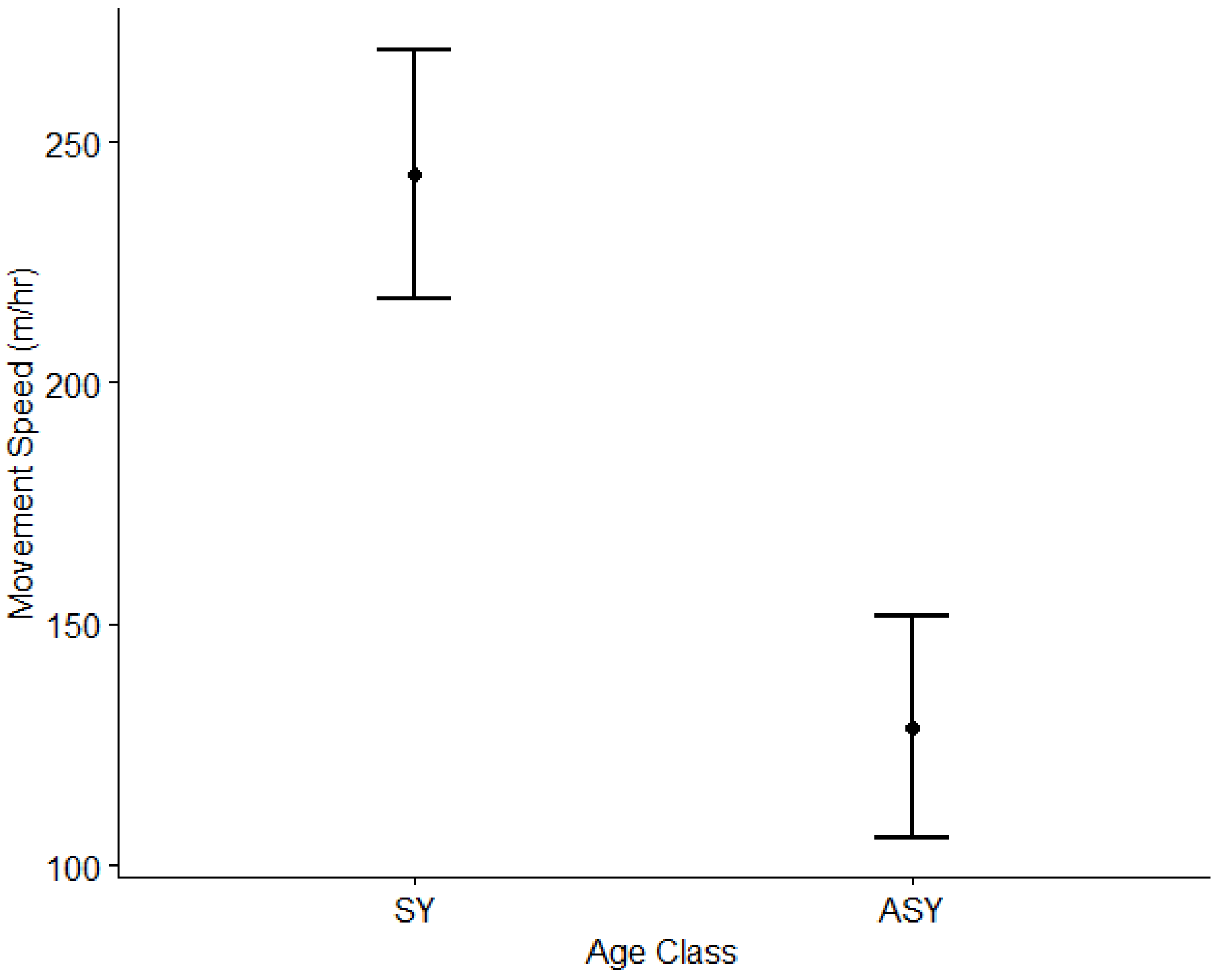

Figure 3-2 Movement speed during dispersals between Second Year (SY) and After Second Year (ASY females. Individuals were pooled across years and Ecoregions.

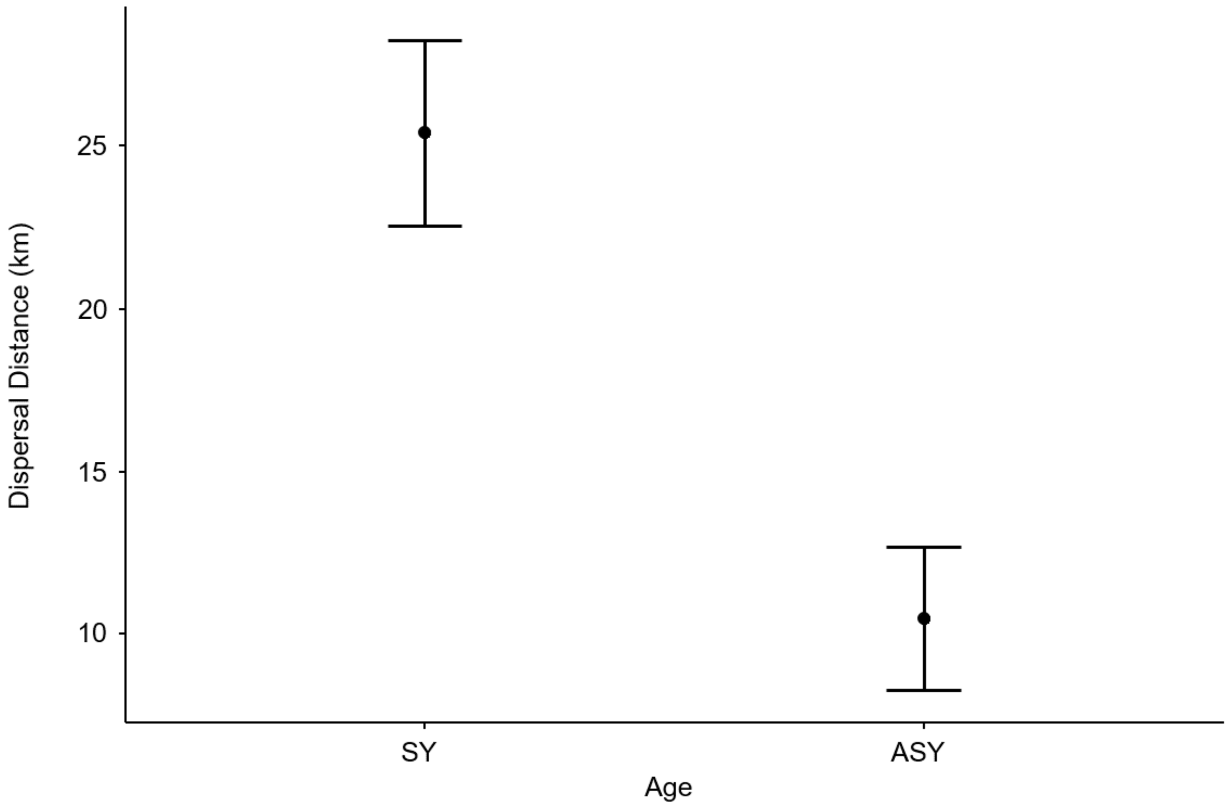

Figure 3-3 Difference in estimated dispersal distance (km) between Second Year (SY) and After Second Year (ASY) females.

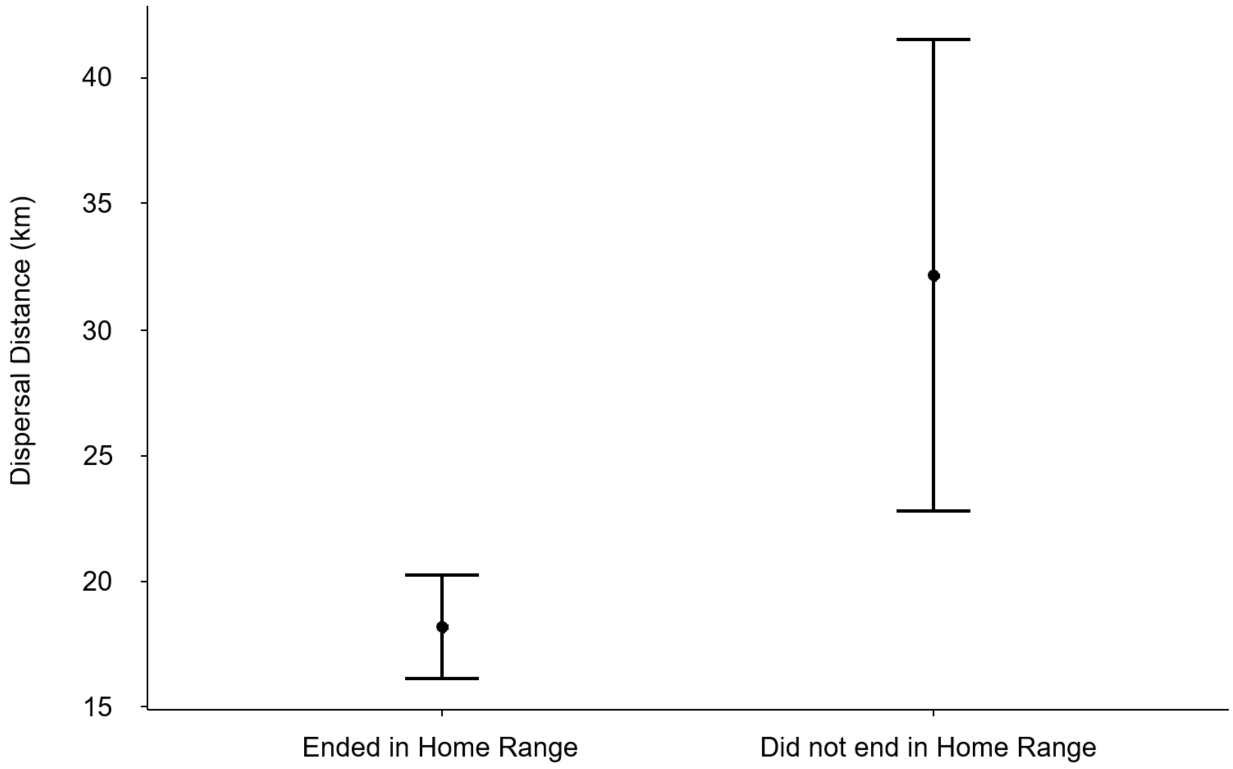

Figure 3-4 Difference in estimated dispersal distance between long distance movements that ended in a home range, and long distance movements that did not end in a home range, either due to mortality or transmitter failure.

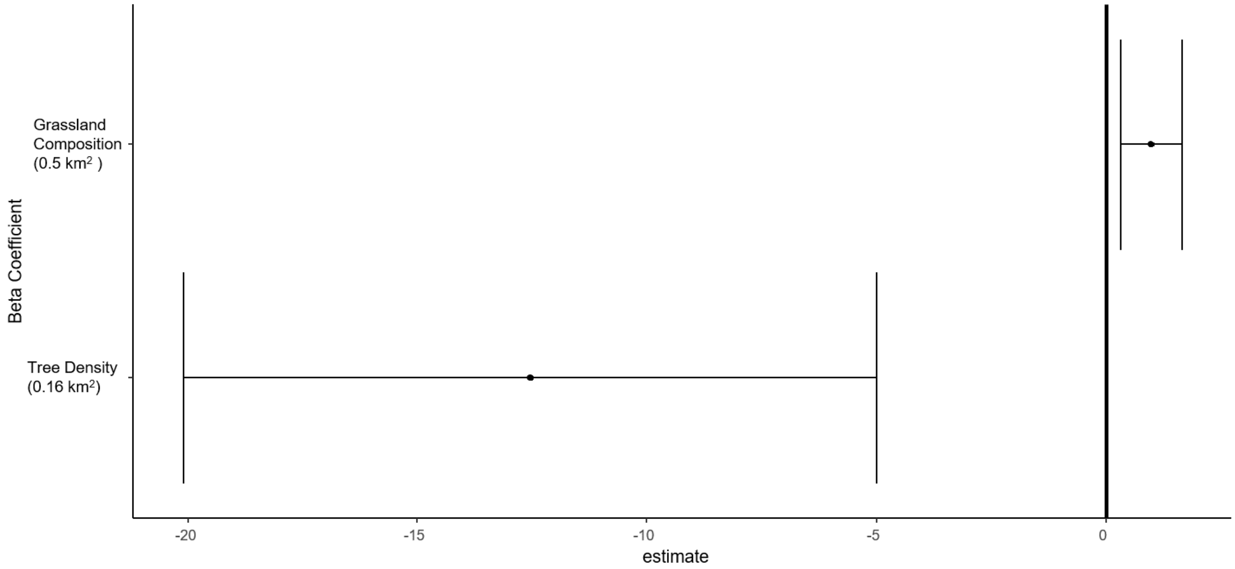

Figure 3-5 Beta coefficients with 95% confidence intervals for top ranking models predicting lesser prairie-chicken resource selection during dispersal in the Mixed Grass Prairie. Lesser prairie-chickens selected against high tree densities while dispersing, and selected for higher grassland cover at small spatial scales (within 0.16 km^2 and 0.5 km^2, respectively).

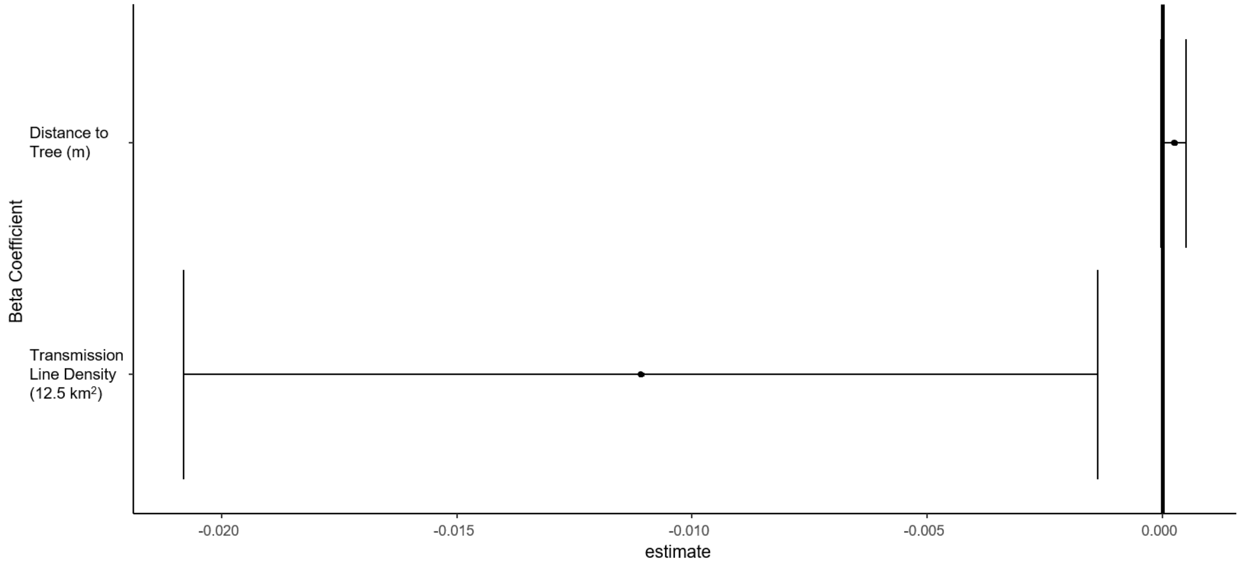

Figure 3-6 Beta coefficients for top ranking models predicting lesser prairie-chicken resource selection during dispersal in the Mixed Grass Prairie. Lesser prairie-chickens selected against high densities of transmission lines, although the influence of these features on lesser prairie-chicken resource selection is small.

Tables

Table 3-1 Number of capture (Capt.) and dispersal (Disp.) of female lesser prairie-chickens across three capture sites in central and western Kansas. The north site occurred in Logan and Gove counties, in the Short-Grass Prairie/CRP Mosaic Ecoregion (SGP) of the lesser prairie-chicken's range. The East and West sites occurred in the Mixed-Grass Prairie Ecoregion (MGP), in Kiowa, Comanche, and Clark counties. Capture did not occur at the North or West site from 2016 to 2018, and did not occur at the West site in 2013.

	North Site (SGP)		West site (MGP)		East Site (MGP)		Total	
	Capt.	Disp.	Capt.	Disp.	Capt.	Disp.	Capt.	Disp.
2013	32	6	0	0	14	2	46	8
2014	23	4	17	6	15	7	55	17
2015	12	5	10	2	11	2	33	9
2016	0	0	0	0	15	5	15	5
2017	0	0	0	0	9	0	9	0
2018	0	0	0	0	8	1	8	1
Total	67	15	27	8	72	17	166	40

Table 3-2 Average ($\bar{x}$ ± SD) net displacement, distance traveled, dispersal time, and dispersal speed of all recorded long distance movements made by female lesser prairie-chickens in the Mixed Grass and Short Grass Prairie Ecoregions from 2013 to 2018 (n=40).

	Mixed-Grass Prairie		Short Grass Prairie	
	$\bar{x}$	SD	$\bar{x}$	SD
Net Displacement (km)	10.17	10.68	13.05	11.82
Distance Traveled (km)	17.38	15.53	24.43	20.89
Time During Dispersal (hr)	110.39	129.13	151.64	112.15
Movement Speed (m/hr)	206.53	165.27	206.57	149.79

Table 3-3 Model rankings based on Akaike Information Criterion for small sample sizes (AIC_c) predicting lesser prairie-chicken resource selection during dispersal movements in the Mixed-Grass Prairie Ecoregion. Tree densities were estimated at the 0.16-km^2 scale, grassland area was measured at the 0.5-km^2 scale, and vertical structure densities were estimated at the 3-km^2 scale. Euclidean distance to tree was measured in meters.

Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Grassland + Vertical Structures + Tree Density	3	5814.14	0.00	0.42
Tree Density + Grassland	2	5814.47	0.33	0.36
Tree Density * Grassland	3	5816.33	2.20	0.14
Tree Density + Vertical Structures	2	5819.29	5.15	0.03
Tree Density	1	5819.68	5.54	0.03
Tree Density * Vertical Structures	3	5821.22	7.08	0.01
Distance to Tree	1	5825.08	10.94	0.00
Grassland + Vertical Structures	2	5829.67	15.53	0.00
Grassland	1	5830.26	16.13	0.00
Grassland * Vertical Structures	3	5831.58	17.44	0.00
Vertical Structures	1	5835.86	21.72	0.00
null	0	5836.48	22.34	0.00

Table 3-4 Estimate of Beta-coefficients for single variable models predicting lesser prairie-chicken resource selection along long-distance movements in the Mixed Grass Prairie and Short Grass Prairie Ecoregions.

	β Coefficient	estimate	SE	*z*	*P*	Lower 95% CI	Upper 95% CI
Mixed Grass Prairie	Grassland (0.5 km)	0.98	0.34	2.89	0	0.32	1.65
	Tree Density (0.16 km)	-12.55	3.85	-3.26	0	-20.1	-5
	Distance to Tree (m)	0	0	3.65	0	0	0
	Vertical Structures (3.1 km)	-0.08	0.05	-1.61	0.11	-0.18	0.02
Short Grass Prairie	Transmission Lines (12.5 km)	-0.01	0	-2.23	0.03	-0.02	0
	Distance to Tree (m)	0	0	1.85	0.06	0	0
	Transmission Lines (3.1 km)	-0.04	0.03	-1.59	0.11	-0.09	0.01
	CRP cover (32.2 km)	3.67	2.48	1.48	0.14	-1.19	8.54
	Tree Density (0.16 km)	-21.56	16.14	-1.34	0.18	-53.19	10.07
	Transmission Lines (0.8 km)	-0.18	0.17	-1.05	0.3	-0.53	0.16

Table 3-5 Table displaying the top models predicting lesser prairie-chicken resource selection during long-distance movements in the Short-Grass Prairie Ecoregion. Tree densities were estimated at the 0.16 km^2 scale, Transmission line densities were estimated as km/13 km^2, and CRP cover was measured at the 32 km^2 scale.

Model	K^a	AIC$_c$^{b}	ΔAIC$_c$^{c}	w_i^{d}
Transmission lines (2 km)	1	0.00	1.00	0.30
Transmission lines (0.5 km)	1	0.84	0.66	0.19
Transmission lines (1 km)	1	1.18	0.55	0.16
Distance to tree	1	1.79	0.41	0.12
Tree Density (16 ha)	1	2.01	0.37	0.11
CRP cover (3.2 km)	1	3.12	0.21	0.06
Null model	0	3.34	0.19	0.06

Table 3-6 Mean and standard deviation of feature densities and distance to features at both used and paired steps, along dispersal routes in the Mixed Grass Prairie and Short Grass Prairie Ecoregions.

		Mixed Grass Prairie				Short Grass Prairie			
		Used		Available		Used		Available	
	Landscape Feature	mean	SD	mean	SD	mean	SD	mean	SD
Feature Density (km^2)	Grassland (0.5)	0.87	0.25	0.86	0.26	0.76	0.32	0.76	0.33
	Grassland (78.5)	0.83	0.14	0.83	0.14	0.68	0.18	0.68	0.18
	CRP (32)	0.06	0.07	0.06	0.07	0.11	0.11	0.11	0.11
	County rds. (12.5)	231.73	151.41	231.67	152.83	213.46	111.71	213.11	113.44
	Major rds. (12.5)	10.25	32.36	10.24	32.23	7.56	28.55	7.28	28.07
	Oil wells (12.5)	3.74	3.99	3.74	4.02	4.13	4.79	4.15	4.88
	Utility lines (12.5)	13.68	37.91	13.53	37.69	2.52	14.47	3.31	17.33
	Vert. structures (12.5)	4.04	4.92	4.04	4.93	4.05	4.63	4.09	4.73
	Trees (.16)	0	0.01	0	0.03	0	0	0	0.01
Dist. to Feature (m)	Tree	923	523	904	541	1888	954	1868	959
	County rd.	780	635	782	641	821	630	819	640
	Major rd.	7826	4259	7826	4261	9414	4287	9404	4274
	Oil Well	1383	876	1389	881	1507	938	1512	937
	Utility Line	7370	4373	7372	4378	12744	5840	12727	5855
	Vert. Structure	1294	863	1301	872	1496	945	1495	945