The role of fire, microclimate, and vegetation in lesser prairie-chicken habitat selection

by

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Abstract

The lesser prairie-chicken is a prairie grouse native to the southwestern Great Plains that has experienced significant population and habitat declines since European settlement. Ongoing declines prompted the U.S. Fish and Wildlife Service to list lesser prairie-chickens as threatened under the Endangered Species Act in spring of 2014. In fall of 2015, the listing was vacated on procedural grounds and the lesser prairie-chicken was removed from listing in summer 2016. Despite the legislative change, considerable conservation efforts emerged with the initial listing and have continued following the removal of the species from the threatened and endangered species list. Understanding how lesser prairie-chickens use landscapes and how management actions can influence their space use is important for long-term strategies to meet conservation goals. I modeled lesser prairie-chicken habitat selection relative to landscape mosaics of vegetation patches generated through patch-burn grazing, microclimate, and vegetation characteristics across their range. I captured, attached GPS satellite or VHF radio transmitters to, tracked, and measured vegetation characteristics used by and available to female lesser prairie-chickens across the northern portion of their range in Kansas and Colorado. Female lesser prairie-chickens use all patch types created in a patch-burn grazing mosaic, with female selecting greater time-since-fire patches (>2-years post-fire) for nesting, 2-year post-fire patches during the spring lekking season, 1- and 2-year post-fire patches during the summer brooding period, and 1-year post-fire units during the nonbreeding season. Available vegetation structure and composition in selected patches during each life-cycle stage was similar to the needs of female lesser prairie-chickens during that life-cycle stage. To assess their selected microclimate conditions, I deployed Maxim Integrated Semiconductor data loggers (iButtons) at female flush locations and across a landscape inhabited by lesser prairie-chickens. Females selected locations that minimized thermal stress at microsite, patch, and landscape scales during peak midday temperatures during summer. Females selected midday locations based on vegetation characteristics; where selected sites had >60% forb cover and <25% grass cover, or >75% grass cover and <10% forb cover. In addition, females selected sites with greater visual obstruction. I measured vegetation composition and structure at use and available sites at four study areas located along the precipitation gradient characterizing the full extent of the lesser prairie-chicken range. Vegetation structure use by females varied in relation to long-term precipitation patterns. Females used sites with lower visual obstruction than available during the fall and spring. However, they used vegetation composition that was similar to available within each study area. Overall, my findings indicate that lesser prairie-chickens require structural and compositional heterogeneity to support a suite of habitat needs throughout the year. Therefore, management should focus on providing structural and compositional heterogeneity across landscapes. Greater heterogeneity in vegetation conditions can be achieved through management practices that allow domestic grazers to select grazing locations, such as patch-burn grazing or increased pasture area.

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Chapter 1 - Influence of patch-burn grazing on lesser prairie-chicken habitat selection in Kansas

Introduction

Grasslands were the largest biome in the United States, with grasslands of the Great Plains comprising the majority of this area (Fuhlendorf and Engle 2001). Unfortunately, grasslands are now also one of the most threatened ecosystems in North America (With et al. 2008; Fuhlendorf et al. 2012). The main threats to grassland systems throughout the Great Plains include conversion of grassland to cropland, energy development, urban development, invasive plant species, and alteration of natural ecological drivers (Samson et al. 2004; Hoekstra et al. 2005). Conversion of grasslands for anthropogenic uses can easily be quantified and assessed, but effects of the alteration of ecological drivers can be more subtle and difficult to measure.

Ecological drivers within grassland systems are dynamic and generate spatially and temporally heterogeneous landscapes (Fuhlendorf and Smeins 1999; McGranahan et al. 2012). Primary ecological drivers within grasslands include climate, fire, and grazing; these factors influence the geographical distribution of species and landscape heterogeneity at broad and fine spatial and temporal scales (Fuhlendorf and Engle 2001; Askins et al. 2007; McGranahan et al. 2012; Hovick et al. 2014a). Broad-scale heterogeneity is primarily driven by climatic factors, with precipitation and temperature influencing vegetation structure and composition across longitudinal and latitudinal gradients (Axelrod 1985; Askins et al. 2007). Fire and grazing primarily drive fine-scale heterogeneity, and are typically linked through a fire-grazing interaction, where herbivores are attracted to graze recently burned areas (Fuhlendorf and Engle 2001; Fuhlendorf et al. 2009). This interaction and the historic heterogeneity of fire occurrence generated a spatially and temporally heterogeneous grassland landscape (Axelrod 1985; Collins and Gibson 1990; Hobbs and Huenneke 1990; Vermeire et al. 2004; Fuhlendorf et al. 2009; Allred et al. 2011).

Current management strategies across most of the Great Plains decouple the fire-grazing interaction leading to landscape homogeneity. A decoupling may occur in different ways, one being the over application of fire that does not offer herbivores the choice between burned and unburned prairie (Hart 1978; Fuhlendorf and Engle 2001; Holecheck et al. 2004; Allred et al. 2014) and at the other extreme, the suppression of fire from the grassland system (Fuhlendorf et al. 1996; Brockway et al. 2002). Landscape homogeneity generated through this decoupling of the fire-grazing interaction negatively influences grassland species, in particular grassland birds (Fuhlendorf and Engle 2001).

Homogenization of the landscape has many negative implications for grassland species. The grassland bird community is particularly vulnerable to grassland homogenization as many species require varying vegetation structure across the landscape to complete their life cycle. For example, upland sandpipers (*Bartramia longicauda*) forage in patches with shorter vegetation than surrounding areas (Sandercock et al. 2015); whereas Henslow’s sparrow (*Ammodramus henslowii*) select nest sites in patches with tall, thick vegetation (Askins et al. 2007). Therefore, for these species to coexist, the landscape needs to incorporate nesting habitat for both species; thus, be heterogeneous in vegetation composition and structure. In addition, when fire is removed from the landscape tree encroachment will negatively affect grassland birds (Coppedge et al. 2001; Chapman et al. 2004; Samson et al. 2004; Engle et al. 2008).

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of conservation concern and is particularly threatened by tree encroachment into grasslands (Lautenbach et al. 2017). Lautenbach et al. (2017) found that lesser prairie-chickens avoided trees, with no nesting recorded in areas with >2 trees per hectare. In addition to avoiding trees, lesser prairie-chickens utilize areas with different vegetation structure during different parts of their life history (Hagen and Giesen 2005; Haukos and Zavaleta 2016). During the spring, males gather at communal display arenas, known as leks, in an attempt to attract females; these areas are dominated by short grasses and are located on broad hilltops or elevated areas in the landscape (Copelin 1963; Jones 1963; Taylor and Guthery 1980; Hagen and Giesen 2005; Haukos and Zavaleta 2016). During the nesting season, female lesser prairie-chickens select areas with greater visual obstruction to conceal their nests (Donaldson 1969; Suminski 1977; Riley 1978; Davis et al 1979; Wisdom 1980; Haukos and Smith 1989; Riley et al. 1992; Giesen 1994; Hagen and Giesen 2005; Pitman et al. 2005). Last, during the brood-rearing period following nest hatch, females will typically lead their broods to areas with greater forb density and more bare ground to forage and facilitate chick movement (Hagen et al. 2005; Bell et al. 2010; Lautenbach 2015).

Across most of the lesser prairie-chicken range, fire has been suppressed or removed from the system allowing trees to encroach and establish in grasslands, especially in the eastern portion of their range (Fuhlendorf et al. 2002). A strategy suggested by managers to control tree encroachment is to reintroduce fire into the system (Ortmann et al. 1998). Little is known about the ecological responses of lesser prairie-chickens to natural or prescribed fire, and research is needed to identify the effects of prescribed fire on lesser prairie-chicken ecology including space use, demography, and habitat selection (Thacker and Twidwell 2014). In addition to identifying the response by lesser prairie-chickens to prescribed fire, it is important to identify appropriate strategies to implement prescribed fire on the landscape if lesser prairie-chicken populations are not negatively influenced by fire.

The primary goal of my study was to investigate the influence of prescribed fire and identify features that are consequential for describing space use by lesser prairie-chickens in landscapes managed using fire and grazing. The study area was managed using patch-burn grazing. Patch-burn grazing is a management system where land managers annually burn only a portion of each pasture and allow livestock to select a grazing patch within the pasture, with grazers typically concentrating their activities in burned areas, thus recoupling the fire-grazing interaction that historically drove plant composition and structure on the landscape (Fuhlendorf and Engle 2001). Through rotation of the burned patch each year, this style of management generates heterogeneity within pastures and thus, across landscapes. In addition, patch-burn grazing offers the opportunity to investigate the response by lesser prairie-chickens to availability of multiple time-since-fire patches on the landscape. Specifically, my objectives were to quantify effects of patch-burn grazing on: 1) available vegetation structure and composition across the landscape and across seasons, 2) lesser prairie-chicken space use at different life stages (e.g., nesting, brooding, and non-breeding), and 3) to assess compatibility of resulting vegetation structure to vegetation used by lesser prairie-chickens during their life stages. I hypothesized that patch-burn grazing would generate vegetation heterogeneity based on time-since fire; year-of-fire patches would have the shortest vegetation and the most bare ground, greater-than-two-years post-fire patches will have the tallest vegetation with greatest percent cover of grass, and one- and two-year post-fire patches would be intermediate in vegetation height. Additionally, I hypothesized that lesser prairie-chickens would nest in greater-than-two-years post-fire patches that provide cover for nests, brood-rearing would typically occur in one-year post-fire patches with a greater proportion of forbs, and non-breeding birds would select for a variety of time-since-fire patches as no specific vegetation requirements have been identified. I hypothesized that vegetation characteristics within the greater-than-two-years post-fire patches would be similar to reported vegetation characteristics at nests; vegetation in one- and two-years post-fire patches would be similar to reported vegetation characteristics at brood locations; and vegetation at nonbreeding locations would not be related with any time-since fire patch.

Methods

Study Area

My field study was conducted on private lands in Kiowa and Comanche counties (Figure 1-1), Kansas, and encompassed approximately 14,000 ha. This study area was located within the Red Hills region of south-central Kansas, and was characterized by mixed-grass prairie on loamy soils. The dominant land use was cattle production with some row-crop agriculture. Native vegetation in this region included: little bluestem (*Schizachyrium scoparium*), hairy grama (*Bouteloua hirsuta*), blue grama (*B. gracilis*), sideoats grama (*B. curtipendula*), big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), buffalograss (*Buchloe dactyloides*), sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludoviciana*), western ragweed (*Ambrosia psilostachya*), sand sagebrush (*Artemisia filifolia*), Chickasaw plum (*Prunus angustifolia*), and eastern redcedar (*Juniperus virginiana*; Lauver et al. 1999). The average annual temperature in this region is 12.6° C, with average annual precipitation of 63.9 cm.

Climate in this area is characterized by warm summers and mild winters. The average July maximum temperature in this region is 33.2° C and average January minimum temperature is -7.4° C (US Climate Data, accessed 9/12/2016, http://www.usclimatedata.com). Most of the precipitation in this area falls between late April and August. In 2014, the average minimum temperature in January was -7.0° C, average maximum temperature in July was 32.4° C, and a total of 69.6 cm of precipitation was recorded, with 51.9 cm occurring between April and August. In 2015, the average January minimum temperature was -5.9° C, the average July maximum temperature was 33.9° C, and a total of 64.8 cm of precipitation was recorded, with 40.8 cm occurring between 1 April and 31 August.. In 2016, the average minimum temperature in January was -5.5° C and average maximum daily temperature in July was 33.6° C, and 57.3 cm of precipitation was recorded, with 53.8 cm occurring between 1 April and 31 August (total precipitation through 11 Sept 2016; Kansas Mesonet, accessed 9/12/2016, http://mesonet.k-state.edu/weather/historical/#!).

The study site was divided into 17 main pastures with an average size of 700 ha. Management varied within these pastures, with 8 pastures managed using patch-burn grazing and 9 pastures grazed with no prescribed fire. Within patch-burn grazing pastures approximately 1/3 to 1/4 of each pasture was burned during spring on a rotational basis. Prescribed fires during the study period occurred between 1 March and 30 April. With this system, the entirety of each pasture was burned every 3-4 years. Pastures were stocked with either yearling or cow-calf pair domestic cattle (*Bos taurus*) at moderate stocking rates (4.8-5.7 ha [12-14 acres]/ cow-calf pair). Pastures stocked with cow-calf pairs were grazed year round and yearling stocked pastures were grazed from ~15 April through ~15 October. Since this property is managed for production, grazing duration of yearlings varied from ~60 days to ~180 days depending on the cattle market. Pastures containing cow-calf and yearlings were rotated every 3-4 years. The amount of land burned each year depended on weather conditions and amount of time suitable for burning each year; therefore, area burned was variable from year to year. There were no prescribed fires conducted at the study site during 2011 and 2012 and in 2013 there was one 100 ha fire due to extensive drought in the region during 2011-2013. In 2014, 1,780 ha were burned in 6 pastures;

in 2015, 1,120 ha were burned in 7 pastures; and in 2016, 2,600 ha were burned in 13 pastures (Figure 1-2).

Since settlement, fire has been suppressed across much of the surrounding area. Starting in the late 1970s and early 1980s, several private landowners began burning whole pastures to combat spreading eastern redcedar. The land manager at my study site began burning in the late 1970s and started using patch-burn grazing in the early 2000s. Additionally, fire suppression in this region has led to an invasion of eastern redcedars on the landscape (Fuhlendorf et al. 2002). Previous research at this study site has found that lesser prairie-chickens show a strong avoidance of trees (Lautenbach et al. 2017). According to the land manager, populations of lesser prairie-chickens at this field site have fluctuated over the years, but the average population size has remained relatively constant since the late 1980s.

Data Collection

Influences of prescribed fire on vegetation structure and composition*:* To quantify the effects of fire and grazing on the vegetation community, I divided the study area into patches stratified by time-since-fire and pasture (Figure 1-2). For the purpose of my study, I defined patches as areas having the same number of years since last burned. Within each patch, I randomly generated 20-50 vegetation surveys points using ArcMap 10.2 (ESRI Inc., 2013, Redlands, CA). Point vegetation surveys followed protocol adopted by the USDA NRCS Lesser Prairie-Chicken Initiative and Lesser Prairie-Chicken Interstate Working Group as sampling strategies for standardization among field sites (Pitman et al. 2005; Grisham 2012). At each random location, I centered two perpendicular 8-m transects on the point Universal Transverse Mercator coordinates (UTMs) in a north-south and east-west orientation. At the point center and 4 m to the north, south, east, and west, I estimated the percent cover of grasses, forbs, shrubs, litter, and bare ground using a 60 cm x 60 cm quadrat (Daubenmire 1959). At each point, I estimated height of visual obstruction at 100%, 75%, 50%, 25%, and 0% obstruction classes to the nearest dm from a distance of 4 m and a height of 1 m using a Robel pole (Robel et al. 1970). I conducted random vegetation surveys in the spring (April and May), summer (June, July, and August), and winter (November, December, January, and February).

Lesser prairie-chicken use of burned patches: To assess female lesser prairie-chicken use of burned patches, I trapped lesser prairie-chickens at lek sites using walk-in traps (Haukos et al. 1990; Schroeder and Braun 1991) and drop nets (Silvy et al. 1990). Leks were trapped continuously throughout the lekking season (approx. 1 March-1 May). Upon capture, birds were sexed using tail coloration, pinnae length, and presence of an eye comb (Copelin 1963). Females were fitted with either a 22-g Global Positioning System (GPS) satellite transmitter (platform transmitting terminal or PTT) from Microwave Telemetry Inc. (Columbia, Maryland, USA) or a 15-g very-high-frequency (VHF) radio transmitter from Advanced Telemetry Systems (Isanti, Minnesota, USA). Satellite and VHF transmitters were assigned to every other bird. The PTTs were rump-mounted using a Teflon® ribbon harness the legs (Dzialak et al. 2011). All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee under protocol #3241, and Kansas Department of Wildlife, Parks and Tourism scientific collection permits (SC-042-2013 and SC-079-2014).

Female lesser prairie-chickens fitted with VHF radio transmitters were located 3-4 times per week throughout the year. I triangulated individuals from 3 to 5 locations using a 3-piece hand-held Yagi antenna and either an Advanced Telemetry Systems receiver (R4000, R4500, Advanced Telemetry Systems, Isanti, MN, USA) or a Communications Specialists receiver (R1000, Communications Specialists, Orange, CA, USA; Cochran and Lord 1963). Approximate locations (UTMs) and error polygon associated with the triangulations were determined using Location of a Signal (Ecological Software Solutions LLC, Hegymagas, Hungary). To maintain consistent accuracy between transmitter types, I only used locations with <1000 m^2 error polygons. Lesser prairie-chickens marked with satellite transmitters were tracked using the GPS/Argos system. GPS locations were taken every ~2 hours between 0600-2400 resulting in ~10 locations per day. Potential location error associated with the use of these transmitters was <18 m. Locations were downloaded weekly.

Lesser prairie-chicken habitat use: To determine habitat characteristics used by lesser prairie-chickens, I conducted vegetation surveys at use locations during the spring (lekking and laying periods), summer (brooding and post-breeding females), winter (non-breeding females, 15 September-14 March), and at nest sites. Nest site locations were determined by either homing and flushing birds with VHF transmitters or by navigating to a likely nest location when a bird was in the same location for >2 days and flushing the bird (satellite transmitter birds). I randomly selected 2 telemetry relocation points per bird per week to conduct vegetation surveys. I followed the same vegetation sampling protocol at these locations as specified above for available locations.

Data Analysis

Nest site selection: To assess if lesser prairie-chickens selected or avoided patches to place nests based on time-since-fire, I followed the Neu et al. (1974) method using the recommended Bailey (1980) confidence intervals, which are appropriate for these data (Cherry 1996; Alldredge and Griswold 2006). For nest-site selection, I calculated the expected number of nests in each time-since-fire patch for each year independently because patch category changed annually based on burning patterns. Once the expected number of nests in each patch was calculated, I combined the expected number of nests for each patch per year to calculate the expected proportion of nests in each patch type. This method generated a year-specific estimate for the proportion of nests in each patch type, as there were different numbers of nests found each year. If the proportion of nests in each patch type were generated based on available area alone, it would underestimate the proportion of nests in some patches while overestimating the proportion of nests in other patches. To identify if lesser prairie-chickens were selecting or avoiding a certain patch, I compared the confidence intervals of the used proportions (calculated as described above) of that patch type to the available proportion of that patch type. If the confidence intervals around use overlapped the proportion available, no selection occurred. However, if the confidence intervals did not overlap available, then lesser prairie-chickens were selecting or avoiding nesting within that patch.

Patch-level selection: To estimate probability of use of patch types by female lesser prairie-chickens in relation to available patches, I used a use vs. available study design within a resource selection framework (Boyce et al. 2002; Manly et al. 2002). For these analyses, I only used points from satellite transmittered birds. I used all locations from each satellite transmittered bird, similar to Dzialak et al. (2012). . To identify nonuse areas within the study area, I generated a number of random points equal to the number of use points the study area. Once I had generated these points, I assigned each random point a date and time of a use point so each random location was associated with a unique bird location to assess selection (Dzialak et al. 2012). I used a logistic regression to compare use to available points within each patch-type within each season (Manly et al. 2002). To understand differential patch use throughout the year, I identified different seasonal periods that encompassed the major life cycle period for each point. The major periods were the 6-month breeding period, classified as 15 March-14

September and the 6-month nonbreeding period, classified as 15 September-14 March. The breeding period was further subdivided into spring (15 March till nest initiation and between nesting attempts), nesting (laying and nest incubation period), and post-nesting (brooding and non-brooding females post nesting). Points during nest incubation were not analyzed using these methods as nest site selection was analyzed as above. Brooding and non-brooding locations post-nesting were combined due to few brooding locations. Patch category was based on time-since-fire and defined as above: in 2014, there were year-of-fire and >2-years post-fire patches; in 2015, there were year-of-fire, 1-year post-fire, and >2-years post-fire patches; and in 2016, there were year-of-fire, 1-year post-fire, 2-years post-fire, and >2-years post-fire patches. I imported all location points into ArcMap 10.2 to characterize bird location and random location relationships with *a priori* covariates other than time-since-fire patches. My *a priori* covariates were distance to nearest patch edge, elevation, and distance to tree. Distance to patch edge was used as a covariate to identify if lesser prairie-chickens were selecting areas near the edges of patches, which could facilitate the use of multiple patches. Elevation was used as a covariate because lesser prairie-chickens are known to locate leks on hill tops and lesser prairie-chicken space use has been associated with leks (Riley et al. 1994; Woodward et al. 2001; Hagen and Giesen 2005; Kukal 2010; Boal et al. 2014; Grisham et al. 2014). Distance to tree was used as a covariate because lesser prairie-chickens have been found to avoid trees (Lautenbach et al. 2017). To obtain the Euclidean distance to the nearest patch edge, I created a shapefile in ArcMap 10.2 outlining all patch edges (time-since-fire blocks) and used the “Near” tool in the “Spatial Analyst Tools” in ArcMap. To obtain elevation values for each location, I used a Digital Elevation Model (obtained Kansas Data Access and Service Center, retrieved 15 July 2014) and the tool “Extract values to points” within “Spatial Analyst Tools” to extract elevation values. To obtain distance to tree, all trees within the study area were delineated by hand and I used the "Near" tool within "Spatial Analyst Tools" to calculate the Euclidean distance between locations and trees. For each seasonal period, I fit ten generalized linear models to assess the probability of use by lesser prairie-chickens: time-since-fire, distance to patch edge, elevation, distance to tree, and additive and interactive models of time-since-fire and distance to patch edge, elevation, and distance to tree. I ranked alternative models using Akaike's Information Criteria adjusted for small samples (AIC_c) and selected the model with the lowest AIC_c (Burnham and Anderson 2002). Models were fit using Program R (R Core Development Team, version 3.0.1, Vienna, Austria) and model selection was conducted in package AICcmodavg (Mazerolle 2016).

Available vegetation characteristics: To assess vegetation differences among time-since-fire patches and seasons, I used a multivariate analysis of variance (MANOVA) to test if there was a relationship between compositional (percent cover) characteristics and structural characteristics (visual obstruction readings) among season and patches. When a significant interaction was found between these variables (patch and season; Wilks' lambda $P < 0.05$), I proceeded with separate analyses by season. To assess differences in time-since-fire patches by season I conducted a MANOVA for each season to assess the effects of time-since-fire patch on vegetation characteristics. Following a significant MANOVA (Wilks' lambda $P < 0.05$), I used an analysis of variance (ANOVA) with a Tukey post hoc analysis to identify significant differences between patch types ($P < 0.05$) separately for each dependent variable.

Used vegetation characteristics: To assess how lesser prairie-chickens selected vegetation within patches, I used a use vs. available study design. I considered available vegetation to be random vegetation points located within specific time-since fire patches and compared this to vegetation characteristics measured at lesser prairie-chicken use sites. To determine if lesser prairie-chickens were using vegetation disproportionately relative to available I used a MANOVA. Following a significant MANOVA (Wilks' lambda $P < 0.05$), I used and ANOVA with a Tukey post hoc analysis to identify specific differences for dependent variables between used and available points. I assessed vegetation selection based on time-since fire patches during each seasons (spring, summer, and winter).

Results

Available Vegetation

During 2015 and 2016, I recorded a total of 2,579 vegetation samples at random locations. Of these samples, 346 were collected in winter, 1,058 were collected in spring, and 1,175 were collected during the summer; 1,298 samples were collected in >2-years post-fire patches, 651 samples were collected in year-of-fire patches, 515 samples were collected in 1-year post-fire patches, and 166 samples were collected in 2-years post-fire patches. There was a significant interaction between time-since-fire patch and season for composition (Wilks lambda = 0.86, $P > 0.001$) and visual obstruction (Wilks lambda = 0.92, $P < 0.001$), so I proceeded with my analyses by season.

Winter*:* During winter, available vegetation differed among time-since-fire patch types by composition (Wilks lambda = 0.83, $P < 0.001$) and structure (Wilks lambda = 0.83, $P < 0.001$). During winter, >2-years post-fire patches had more grass and less bare ground than both year-of-fire patches and 1-year post fire patches (Table 1-6). There was no difference in composition between year-of-fire patches and 1-year post-fire patches. Visual obstruction was greater in all classes for >2-years post-fire patches than year-of-fire patches and 1-year post fire patches; there was no difference in visual obstruction between year-of-fire and 1-year post-fire patches (Table 1-7). There were no 2-years post-fire patches on the landscape during winter over the duration of this study; therefore, no data were collected on these patches.

Spring: During spring, available vegetation differed in composition (Wilks lambda = 0.53, $P < 0.001$) and visual obstruction (Wilks lambda = 0.65, $P < 0.001$). During spring, year-of-fire patches had the least amount of grass cover, greatest litter cover, least forb cover, and the highest bare ground cover (Table 1-6). Additionally, 1-year post-fire patches had less grass cover than >2-years post-fire and 2-years post-fire patches; more grass cover than year-of-fire patches; similar forb and litter cover to >2-years post-fire and 2-years post-fire patches; less litter cover and more forb cover than year-of-fire patches; less bare ground than year-of-fire patches; more bare ground than >2-years post-fire patches; and similar litter cover to 2-years post-fire patches (Table 1-6). The 2-year post fire patches had similar grass cover as >2-years post-fire patches, but greater grass cover than year-of-fire and 1-year post-fire patches. Two-year post-fire patches had similar cover of litter, forbs, and bare ground as >2-year post-fire and 1-year post-fire patches, but less litter and bare ground and more forbs than year-of-fire patches (Table 1-6). In >2-years post-fire patches, there was more grass and less bare ground than year-of-fire and 1-year post-fire patches, but similar grass and bare ground cover to 2-years post-fire patches. For >2-years post-fire patches, there was less litter and more forbs than year-of-fire patches, but similar cover of litter and forbs as 1- and 2-years post-fire patches (Table 1-6). During spring, year-of-fire patches consistently had the lowest visual obstruction reading in all classes (100%, 75%, 50%, 25%, and 0% obstruction), while >2-years post-fire patches had the greatest visual obstructions across all classes (but not significantly greater than 2-years post fire patches at 100% obstruction; Table 1-7). Visual obstruction did not differ between 1- and 2-years post-fire patches. However, was intermediate between year-of-fire and >2-years post-fire patches (Table 1-7).

Summer: During summer, available vegetation differed by both composition (Wilks lambda = 0.85, $P < 0.001$) and structure (Wilks lambda = 0.70, $P < 0.001$). Year-of-fire patches had the least amount of grass cover and the greatest amount of bare ground cover of all patch types (Table 1-6). There was no difference between percent cover of litter for year-of-fire patches and all other patches, while year-of-fire patches had less forb cover than 1- and >2-years post-fire patches (Table 1-6). One-year post-fire patches had less litter cover than >2-years post fire and year-of-fire patches; less litter than >2-years post-fire patches; more forbs than year-of-fire patches; and more bare ground than >2-years post-fire patches, but less bare ground than year-of-fire patches (Table 1-6). During summer, year-of-fire patches had the lowest visual obstruction at all classes and >2-years post-fire patches had the greatest visual obstruction in all classes; 1- and 2-years post-fire patches had intermediate visual obstruction readings between year-of-fire and >2-years post-fire patches and did not differ from each other (Table 1-7).

Patch Selection

Nest site selection: During the 3-year study, I located 52 nests within the experimental area; 29 nests in 2014, 17 nests in 2015, and 6 nests in 2016. For each year of the study, I calculated the number of nests in each time-since-fire patch type and then calculated the expected number of nests based on available area. I then pooled all nests across years to obtain a larger sample size. With the nests pooled, I found a difference between the number of expected and observed nests in time-since-fire patches ($\chi^2_3 = 12.2$, $P = 0.007$). Female lesser prairie-chickens avoided nesting in year-of-fire patches and disproportionately selected >2-years post-fire patches for nesting (Table 1-1). The observed number of nests in 1- and 2- year post-fire patches did not differ from expected based on availability (Table 1-1).

Nesting season patch selection: Because I already modeled nest site selection, I only modeled probability of use during the laying stage of the nesting period. During this period, I recorded a sample size of 3,424 locations. The highest ranked model with the lowest AIC_C and all of the model weight was the interactive model between time-since-fire patch type and elevation (Table 1-2). This model demonstrates a complex relationship between elevation and patch selection by female lesser prairie-chickens during the laying period. Across all patches the relative probability of selection increased with elevation (Figure 1-3). At higher elevations (>600 m), 1- and 2-years post-fire patches had a greater probability of being selected while year-of-fire and >2 years post-fire patches had a lower probability of being selected (Figure 1-3). At mid-elevations (575-600 m), there was a complex relationship and it was difficult to identify any clear patterns in these data (Figure 1-3). Within all patches, low elevations had low probability of use.

Summer patch selection: I recorded a sample size 11,501 bird locations during the post-nesting period (includes locations from both brooding and non-brooding females). The top-ranked model for these data was the interactive model between time-since-fire patch type and elevation, which received all of the model weight (Table 1-3). The patch type with the lowest probability of selection for the post-nesting season was the >2-years post-fire patch, with year-of-fire patches ranked second for probability of selection. Relative to elevation, 1-year post-fire patches had the greatest probability of selection at lower elevations, but 2-years post-fire patches had the greatest probability of selection at higher elevations (Figure 1-4). For all patches, there was a greater probability of selection at higher elevations (Figure 1-4).

Nonbreeding season selection: I recorded a sample size of 5,944 bird locations during the nonbreeding season (15 September-14 March) of 2014-2015 and 2015-2016. The top model for the nonbreeding season was the interactive model between time-since-fire patch type and elevation (Table 1-4). During this period, >2-years post-fire patches had the lowest probability of being selected; year-of-fire patches had an intermediate probability of being selected; and 1-year post-fire patches had the greatest probability of being selected (Figure 1-5). Probability of selection within all patches increased with elevation (Figure 1-5). During my study period, there were no patches that reached 2-years post-fire during the non-breeding season.

Spring patch selection: I recorded a sample size of 8,093 locations were collected during the spring season. The top ranked model receiving all of the model weight was the interactive model between time-since-fire patch type and elevation (Table 1-5). During the spring period, lesser prairie-chickens had the greatest probability of selecting 2-years post-fire patches, followed by 1-year post-fire patches, and year-of-fire patches with the lowest probability of selection occurring in the >2 years post fire patches (Figure 1-6). Within all time-since-fire patches, there was a greater probability of use at higher elevations and probability of selection increased more rapidly with elevation in 2-year post-fire patches than all other patches (Figure 1-6).

Vegetation Use

During 2015 and 2016, I collected vegetation data at 3,751 locations (2,579 random locations and 1,172 use locations). There was a significant interaction between response (use vs. available), season, and time-since-fire patches for both composition (Wilks' lambda = 0.98, $P < 0.001$) and structure (Wilks' lambda = 0.98, $P < 0.001$). Used vs. available had a significant interaction between season, and time-since-fire patch and I proceeded with the analysis by identifying vegetation selection within time-since-fire patches within each season.

Winter: Overall during winter, female lesser prairie-chickens selected vegetation composition (Wilks' lambda = 0.98, $P < 0.001$) and structure (Wilks' lambda = 0.91, $P < 0.001$) disproportionately relative to available. Overall, across all patch types, lesser prairie-chickens used areas with more litter and less bare ground than available and areas with less visual obstruction than available at all obstruction classes (Figure 1-7a, Figure 1-8a). There was a significant interaction between time-since-fire patch and response for both composition (Wilks' lambda = 0.98, $P < 0.012$) and structure (Wilks' lambda = 0.95, $P < 0.001$), so I proceeded with analyses by time-since-fire patch. Within year-of-fire patches, female lesser prairie-chicken vegetation use varied for both composition (Wilks' lambda = 0.91, $P < 0.001$) and structure (Wilks' lambda = 0.85, $P < 0.001$) during the winter. Females used areas with more grass and less bare ground than available (Figure 1-7c) and areas within greater visual obstruction at the 50% and 25% obstruction classes (Figure 1-8c). Within 1-year post-fire patches, female lesser prairie-chickens did not differentially use vegetation composition (Wilks' lambda = 0.95, $P = 0.11$) or structure compared with available (Wilks' lambda = 0.96, $P = 0.27$). Within >2-years post-fire patches, females did not differentially use vegetation composition (Wilks' lambda = 0.99, $P = 0.24$) compared with available; however, female used vegetation structure differed proportionally from available (Wilks' lambda = 0.86, $P < 0.001$). During winter, female lesser prairie-chickens used areas with lower visual obstruction than available within all obstruction classes in >2-years post-fire patches (Figure 1-8b).

Spring: Overall during spring, female lesser prairie-chickens used vegetation differently than available both compositionally (Wilks' lambda = 0.94, $P < 0.001$) and structurally (Wilks' lambda = 0.95, $P < 0.001$). Female lesser prairie-chickens used sites with more grass and forbs; less litter and bare ground; and areas with greater visual obstruction at all obstruction classes than available during spring (Figure 1-9a, Figure 1-10a). During spring, there was a significant interaction between response and time-since-fire patch for both composition (Wilks' lambda = 0.93, $P < 0.001$) and structure (Wilks' lambda = 0.96, $P < 0.001$), so I continued the analyses by time-since-fire patch type. For year-of-fire patches during spring, female lesser prairie-chickens differentially used vegetation composition (Wilks' lambda = 0.84, $P < 0.001$) and structure (Wilks' lambda = 0.82, $P < 0.001$). Within year-of-fire patches, they used sites with more grass and less litter and bare ground than available (Figure 1-9c); additionally, they used sites with greater visual obstruction at all obstruction classes than available (Figure 1-10c). Within 1-year post-fire patches, females used vegetation composition (Wilks' lambda = 0.93, $P < 0.001$) and structure (Wilks' lambda = 0.92, $P < 0.001$) different than available. With 1-year post-fire patches, females used areas with more forbs and less bare ground than available and areas with greater visual obstruction at all obstruction classes than available (Figure 1-9d, Figure 1-10d). Female vegetation use did not vary either compositionally (Wilks' lambda = 0.97, $P = 0.61$) or structurally (Wilks' lambda = 0.92, $P = 0.13$) compared to available in 2-year post-fire patches. Within >2-years post-fire patches, female lesser prairie-chicken use varied compared to available compositionally (Wilks' lambda = 0.98, $P = 0.03$) and structurally (Wilks' lambda = 0.981, $P = 0.04$). Females used sites with more forbs and less bare ground than available (Figure 1-9b). During spring, there were no statistically significant differences between the visual obstruction at used and available locations within >2 years post-fire patches (Figure 1-10b).

Summer: Within summer, female lesser prairie-chickens selected vegetation composition (Wilks' lambda = 0.97, $P < 0.001$) and structure (Wilks' lambda = 0.83, $P < 0.001$) in proportions different than available. Overall, during summer, female lesser prairie-chickens used areas with more grass and forbs; less litter and bare ground; and greater visual obstruction at all classes than available (Figure 1-11a, Figure 1-12a). During summer, there was a significant interaction between year-of-fire and response for composition (Wilks' lambda = 0.95, $P < 0.001$) and structure (Wilks' lambda = 0.94, $P < 0.001$), so I analyzed vegetation use by time-since-fire patch. Within year-of-fire patches, female lesser prairie-chickens selected vegetation composition (Wilks' lambda = 0.86, $P < 0.001$) and structure (Wilks' lambda = 0.76, $P < 0.001$) in proportions different than available. Within year-of-fire patches, females used sites with more grass, more forbs, and less bare ground than available (Figure 1-11c); also within year-of-fire patches, females used sites with greater visual obstruction at every class (Figure 1-12c). Within 1-year post-fire patches, females used different vegetation composition (Wilks' lambda = 0.98, $P < 0.001$) and structure (Wilks' lambda = 0.96, $P < 0.001$) than available. Within 1-year post-fire patches, females used sites with more grass, less litter, and less bare ground than available (Figure 1-11d) and sites with greater visual obstruction in the 0% obstruction class (Figure 1-12d). Within 2-year post-fire patches, female lesser prairie-chickens differentially used vegetation composition (Wilks' lambda = 0.91, $P < 0.001$) and visual obstruction (Wilks' lambda = 0.82, $P < 0.001$). Within 2-year post-fire patches, females used areas with more litter than available (Figure 1-11e) and less visual obstruction in all classes except 0% obstructed than available (Figure 1-12e). Lesser prairie-chickens used different vegetation composition (Wilks' lambda = 0.99, $P < 0.001$) and structure (Wilks' lambda = 0.98, $P < 0.001$) than available within >2-years post fire patches. Females selected areas with more grass and less bare ground than available (Figure 1-11b) and areas with greater visual obstruction in the 0% obstructed class (Figure 1-12b).

Discussion

My research indicates that patch-burn grazing creates a heterogeneous landscape in vegetative conditions that elicits a complex response in space use by female lesser prairie-chickens at relatively fine spatial and temporal scales. Patch-burn grazing created a patchy landscape with variation in vegetation composition and structure; more recently burned patches had lower vegetation structure and greater bare ground cover. Space use by female lesser prairie-chickens was influenced by season/life-cycle stage, availability of a gradient of time-since-fire patches, vegetation composition and structure, and relative surface elevation. Lesser prairie-chickens differentially selected time-since-fire patches and vegetation composition/structure within the heterogeneous landscape generated through patch-burn grazing, depending on the season or stage of their annual cycle as would be expected by differential habitat needs through their life history (Hagen and Giesen 2005; Haukos and Zavaleta 2016). They selected patches with the greatest visual obstruction during the nesting period to conceal nests; during the summer, females selected 1- and 2-years post-fire patches with intermediate visual obstruction and more forbs and intermediate bare ground compared with other available patches on the landscape.

My results confirm that patch-burn grazing in the eastern portion of the lesser prairie-chicken range generates heterogeneity on the landscape. I found that that patch-burn grazing created heterogeneity in vegetation composition and structure as well as creating patch heterogeneity, with areas of short vegetation (year-of-fire patches) adjacent to taller vegetation (>2-years post-fire patches) offering female lesser prairie-chickens the opportunity to select patches that suited their habitat needs. My findings further confirm those of the literature that patch-burn grazing generates a heterogeneous landscape (Fuhlendorf and Engle 2001, 2004; Fuhlendorf et al. 2009; McGranahan et al. 2012).

Within the patch-burn grazing system, female lesser prairie-chickens selected different patch types as categorized by time-since-fire throughout their annual cycle. During spring (i.e., ~2 month lekking season) and early nesting (laying stage), the greatest probability of selection was for 2-year post-fire patches with intermediate cover, but female lesser prairie-chickens selected nest sites more frequently in >2-year post-fire patches. During summer (i.e., brooding and non-brooding females post nesting) 2-years post-fire patches had the greatest probability of being selected. Patch selection during winter was for 1-year post-fire patches, which demonstrates the importance for maintaining an assortment of available patches on the landscape to offer lesser prairie-chickens multiple vegetation structure and compositions to select from. It is also important that these patches be in close proximity to each other to allow birds better access to move between them; thus limiting movement, and thus hazards such as predation (Robinson 2015). Maintaining a landscape with patches in close proximity to each other is especially important after a successful nest, when a female must relocate her brood to a suitable patch with food and cover resources (Fuhlendorf and Engle 2001; Hagen et al. 2005; Bell et al. 2010; Lautenbach 2015).

Seasonal differences in patch selection suggest that female lesser prairie-chickens require different vegetation composition and structure within each life-cycle, which I observed (Figure 1-13). Vegetation characteristics at used sites were consistent with the literature, with female lesser prairie-chickens using taller, more dense vegetation during the nesting season than other seasons and more bare ground during the summer (brooding and post-nesting) than during nesting (Figure 1-13; Patten et al. 2005; Pitman et al. 2005; Hagen et al. 2013; Lautenbach 2015;

Haukos and Zavaleta 2016; Wolfe et al. 2016). Use of such different vegetation requirements throughout the season suggests that a heterogeneous landscape is beneficial to lesser prairie-chickens and my results show that such a landscape can be created through patch-burn grazing.

Patch-burn grazing generates a heterogeneous vegetation pattern and female lesser prairie-chickens select the time-since-fire patches that contain vegetation that closely resembles their requirements during that life cycle stage. Habitat selection by female lesser prairie-chickens was principally at the patch scale. Across all seasons, female lesser prairie-chickens had the greatest probability of selecting patches whose vegetation characteristics most closely matched their needs. In winter, females had a greater probability of selecting 1-year post-fire patches; within this patch type, vegetation use did not differ from available during winter. The same pattern was evident in other seasons as females had the greatest probability of selecting 2-year post-fire patches in spring and summer with vegetation use within this patch type similar to what was available at the patch scale. Although I did not specifically measure female lesser prairie-chicken nest vegetation selection, nests were located within taller vegetation than other all other seasons (Figure 1-13). The tallest vegetation available was located in >2 years post-fire patches, which were selected for by nesting females.

My project is the first known study to compare vegetation use to available within patches generated through patch-burn grazing and patch selection in a patch-burn grazing system for lesser prairie-chickens. Patch selection within the patch-burn mosaic is consistent with predictions by Thacker and Twidwell (2014), who predicted that females would nest in 3-4 year post-fire patches and lead broods to 2-3 years post-fire patches. Winder et al. (2017) found that female greater prairie-chickens (*Tympanuchus cupido*) selected areas with lower stocking rates and avoided year-of-fire patches during the breeding season; however, they did not specifically assess vegetation use. Their results are similar to mine in that I found lesser prairie-chickens to use ≥1-year post-fire patches during the breeding season (spring and summer). Other studies of greater prairie-chickens investigated the influence of patch-burn grazing on survival and reproductive parameters but none directly related use to vegetation characteristics (McNew et al. 2012, 2015; Hovick et al. 2014). Taken together, these studies show that patch-burn grazing improves landscape suitability for greater prairie-chickens compared to conventional management. In these studies, conducted in the Flint Hills of Kansas, conventional management involves annual spring fire followed by intensive grazing, this strategy negatively affects greater prairie-chickens populations (Robbins et al. 2002; Patten et al. 2007). Based on my results, I would expect similar negative effects of annual burning on lesser prairie-chicken populations because I did not observe any nesting attempts within year-of-fire patches, which are similar to annual burning. Despite this, further research is needed to assess patch-burn grazing's effects on lesser prairie-chicken survival and reproductive parameters compared to conventional management across their range (no burning and grazing).

While female lesser prairie-chickens patch selection varied across life-cycle stages, they consistently selected for areas at greater elevations. A consistent selection for higher elevations by female lesser prairie-chickens indicates that uplands are important during all life stages. This suggests that ecological conditions at lower elevations may not provide habitat for lesser prairie-chickens. At my study site, I observed that as elevation increased, percent cover of grass, forbs, and litter all increase while percent cover of bare ground decreased (Figure 1-14). Elevational changes in vegetation composition are consistent with lesser prairie-chicken habitat use, as in general they use areas with more grass and less bare ground than available during nesting (Patten et al. 2005; Pitman et al. 2005; Hagen et al. 2013; Holt 2012; Lautenbach 2015; Haukos and

Zavaleta 2016; Wolfe et al. 2016) and areas with greater forb cover during the brooding period (Hagen et al. 2005; Pitman et al. 2006; Hagen et al. 2013; Lautenbach 2015; Haukos and Zavaleta 2016; Wolfe et al. 2016). Moreover, lowland areas within this ecoregion also typically have greater tree density, which lesser prairie-chickens avoid (Lautenbach et al. 2017). Overall, my results are not consistent with the idea that lek presence is the most important factor dictating lesser prairie-chicken habitat selection (Riley et al. 1994; Woodward et al. 2001; Hagen and Giesen 2004; Kukal 2010; Grisham et al. 2014; Plumb 2015; Robinson 2015).

While I did not directly test habitat selection in relation to proximity to leks, average lek elevation at my study site was 629 m above sea level (asl; $n = 7$) with the maximum elevation on the study site of 646 m asl, suggesting that lek location and elevation might be correlated at my site. Other studies have found elevation and lek location to be correlated for lesser prairie-chickens and other prairie grouse (Copelin 1963; Jones 1963; Taylor and Guthery 1980; Hagen and Giesen 2005; Gregory et al. 2011; Hovick et al. 2015b; Haukos and Zavaleta 2016). Thus, lek establishment might be a byproduct of the availability of quality habitat surrounding the sites. The only previous study investigating fire effects on lesser prairie-chickens showed that leks moved in response to prescribed fires (Cannon and Knopf 1979). Further supporting this idea, greater prairie-chicken lek locations have been shown to be spatially dynamic in response to heterogeneity induced by patch-burn grazing; thus, providing additional evidence that leks are placed in areas with quality habitat surrounding them (Hovick et al. 2015a).

My results indicate that patch-burn grazing is a viable management strategy for lesser prairie-chickens and adds to a growing body of literature emphasizing the importance of fire- and grazing-driven heterogeneity on the landscape (Fuhlendorf et al. 2001, 2006; McGranahan et al. 2012; Hovick et al. 2014a, b). My research is the first to assess effects of prescribed fire on female lesser prairie-chickens and shows that they respond to heterogeneity generated through patch-burn grazing by selecting patches where vegetation characteristics match their needs. My research confirms that vegetation used by female lesser prairie-chickens differs by season and supports previous findings of differential use of vegetation composition and structure (Donaldson 1969; Suminski 1977; Riley 1978; Davis et al 1979; Wisdom 1980; Haukos and Smith 1989; Riley et al 1992; Giesen 1994; Hagen et al. 2005; Hagen and Giesen 2005; Pitman et al. 2005; Bell et al. 2010; Kukal 2010; Pirius et al. 2013). These results also emphasize that lesser prairie-chickens readily utilize a heterogeneous landscape generated through patch-burn grazing selecting patches that should maximize survival and recruitment similar to their close relative, the greater prairie-chicken (McNew et al. 2012, 2015; Hovick et al. 2014b; Winder et al. 2017) and other species of sensitive grassland birds (Fuhlendorf et al. 2006; Askins et al. 2007; Hovick et al. 2014a).

Management Implications

Prescribed fire, when implemented in a patch-burn grazing system provides the necessary heterogeneity in vegetation communities for lesser prairie-chickens to fulfill their life-history requirements. In addition, previous studies have shown that prescribed fire, when conducted under the right conditions has the ability to control eastern redcedar (Twidwell et al. 2013). Given this ecological service, I recommend implementing prescribed fire in a patch-burn grazing system with a 4-6 year burn interval in the eastern portion of the lesser prairie-chickens to allow for all necessary patches to be on the landscape while still helping control eastern redcedar. I recommend implementing this strategy only in the eastern portion of the lesser prairie-chickens range as further research is needed to assess prescribed fires impacts on lesser prairie-chickens through the rest of their range.

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Figures

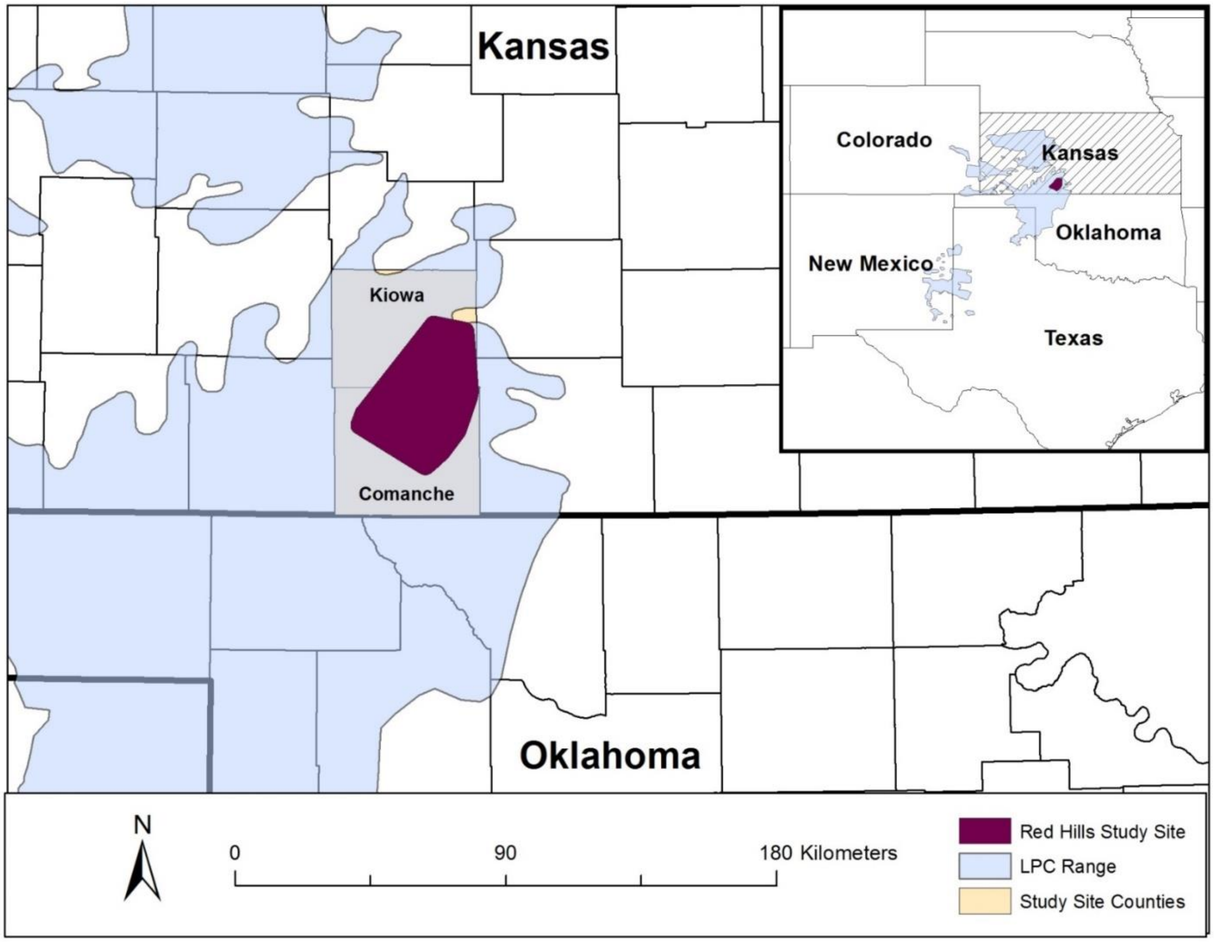


Figure 1-1: Location of the study area investigating the influence of prescribed fire on lesser prairie-chickens in Kiowa and Comanche counties, Kansas, during 2014-2016.

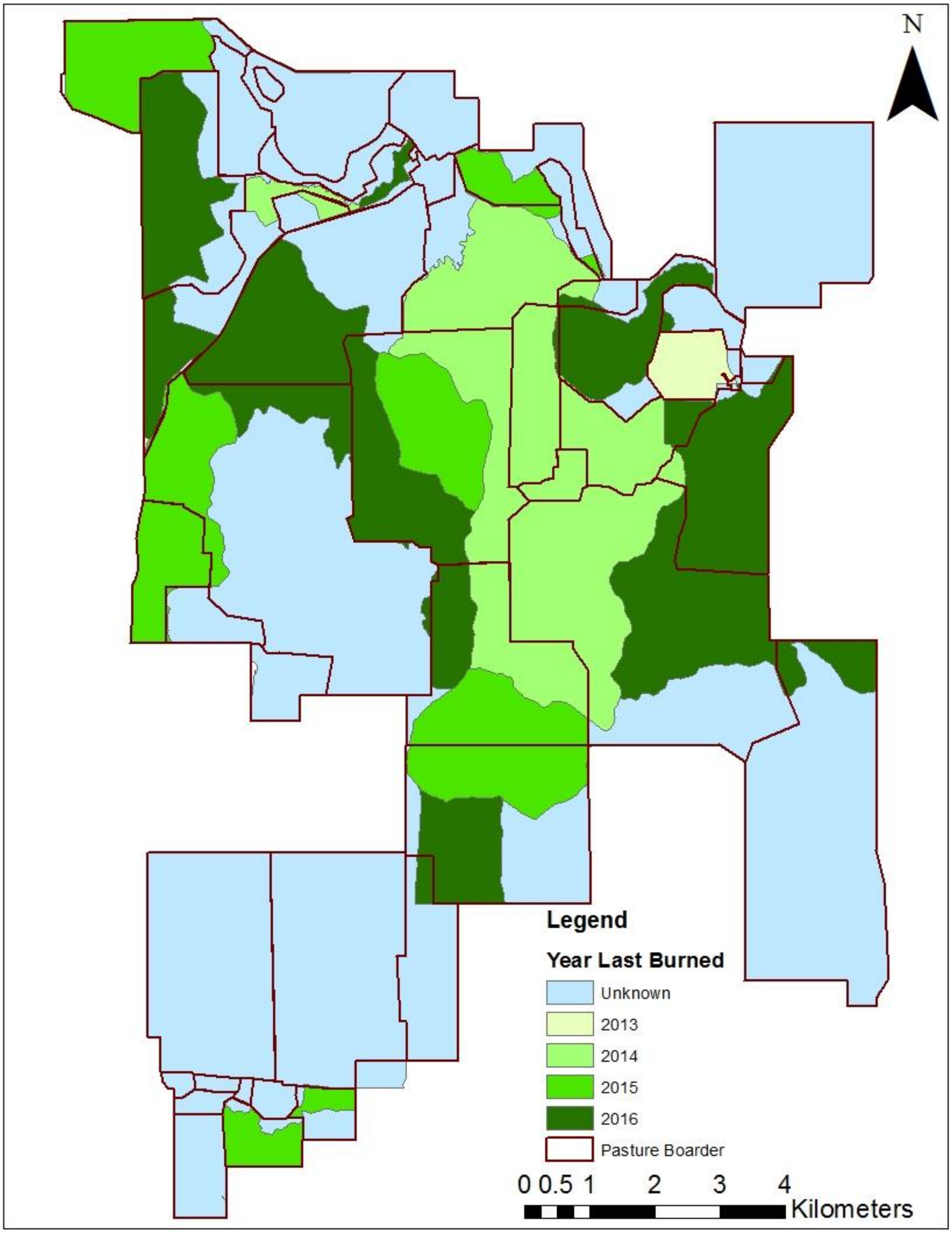


Figure 1-2 Detailed map of study area depicting pastures and the year burned for each patch. Study area located in Kiowa and Comanche counties, Kansas, during 2014-2016. "Unknown" areas were burned prior to research being conducted at this site.

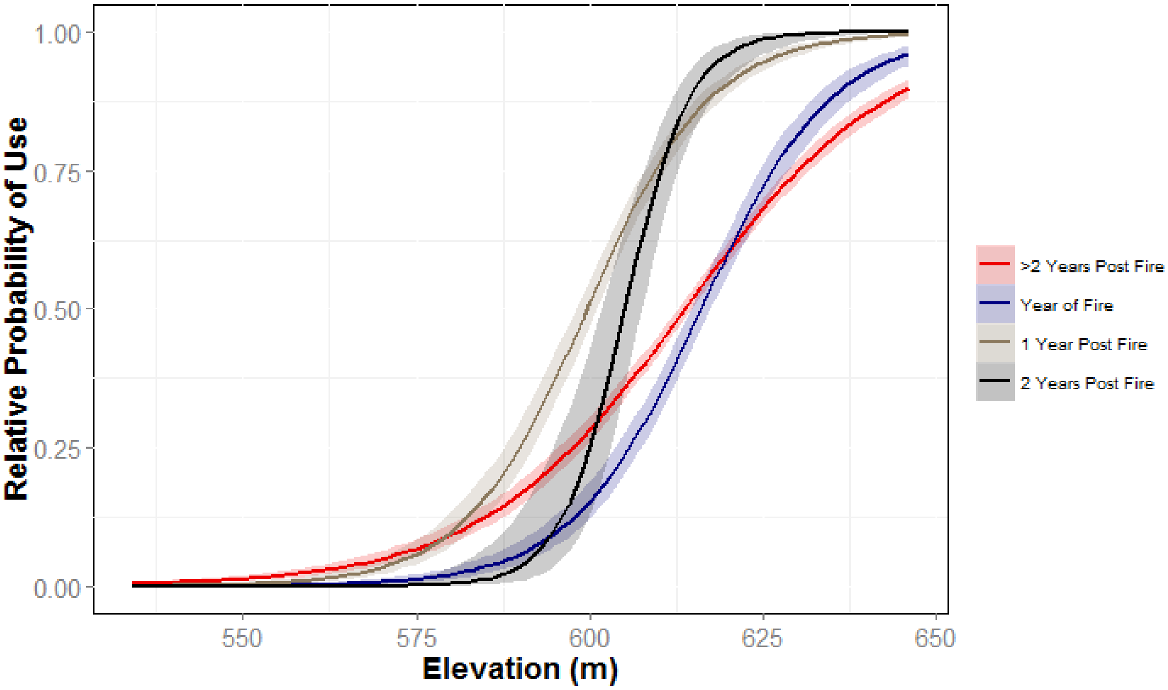


Figure 1-3: Interactive relationship of elevation and time-since-fire patches on the relative probability of use by lesser prairie-chickens during the nesting season within the Red Hills of Kansas, during 2014-2016. Shaded areas represent the 95% confidence intervals.

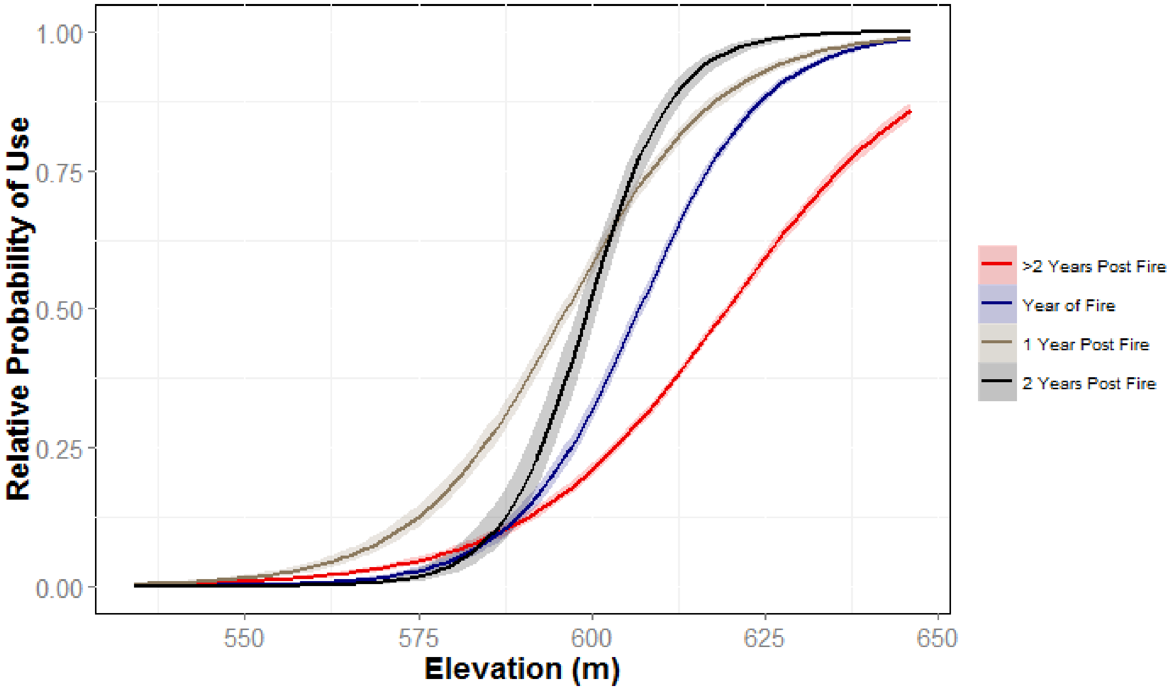


Figure 1-4: Interactive relationship of time-since-fire patch and elevation on the relative probability of use by lesser prairie-chickens during the post-nesting period (brood and non-brooding hens) within the Red Hills of Kansas, during 2014-2016. Shaded areas represent the 95% confidence intervals.

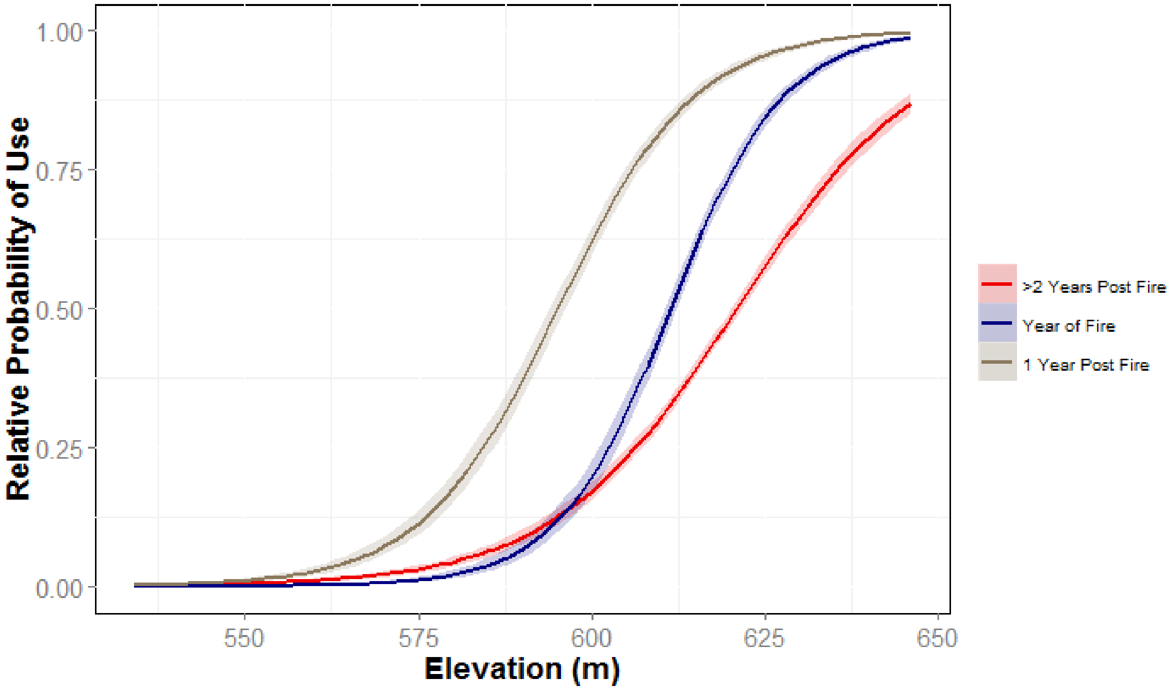


Figure 1-5: Interactive relationship of time-since-fire patches and elevation on the relative probability of use by lesser prairie-chickens during the non-breeding season in the Red Hills of Kansas, during 2014-2016. Shaded areas represent the 95% confidence intervals.

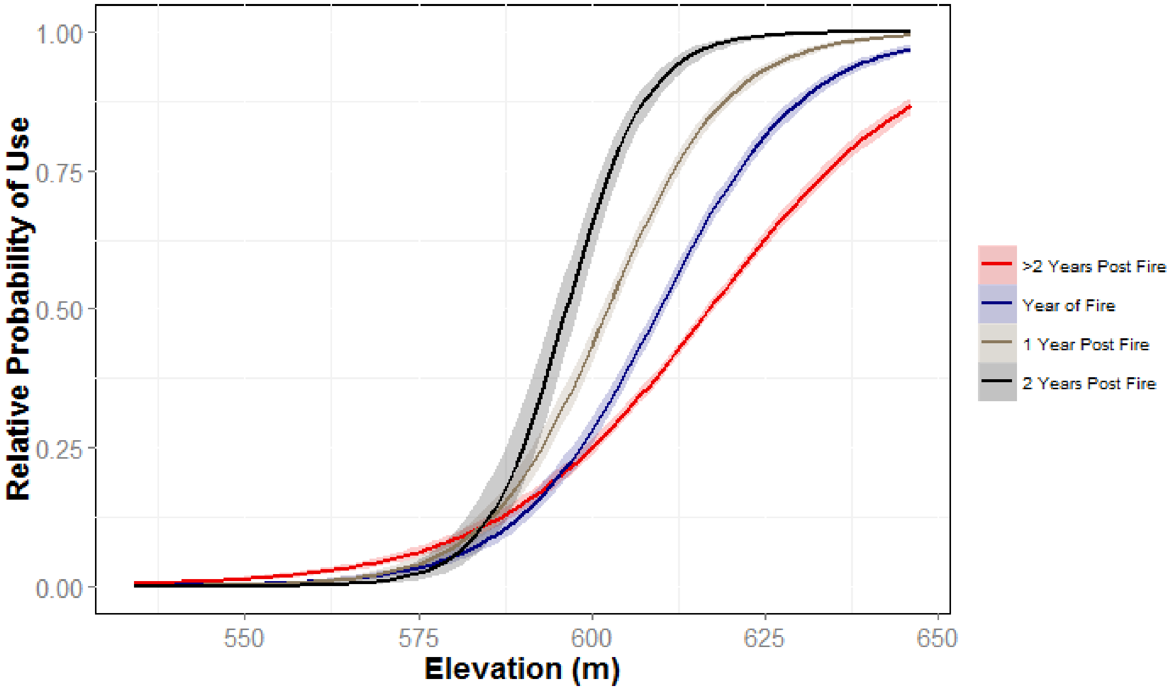


Figure 1-6 Interactive relationship time-since-fire patch and elevation on the relative probability of use by lesser prairie-chickens during the springs (~2 month lekking season) of 2014-2016 within the Red Hills of Kansas. Shaded areas represent the 95% confidence intervals.

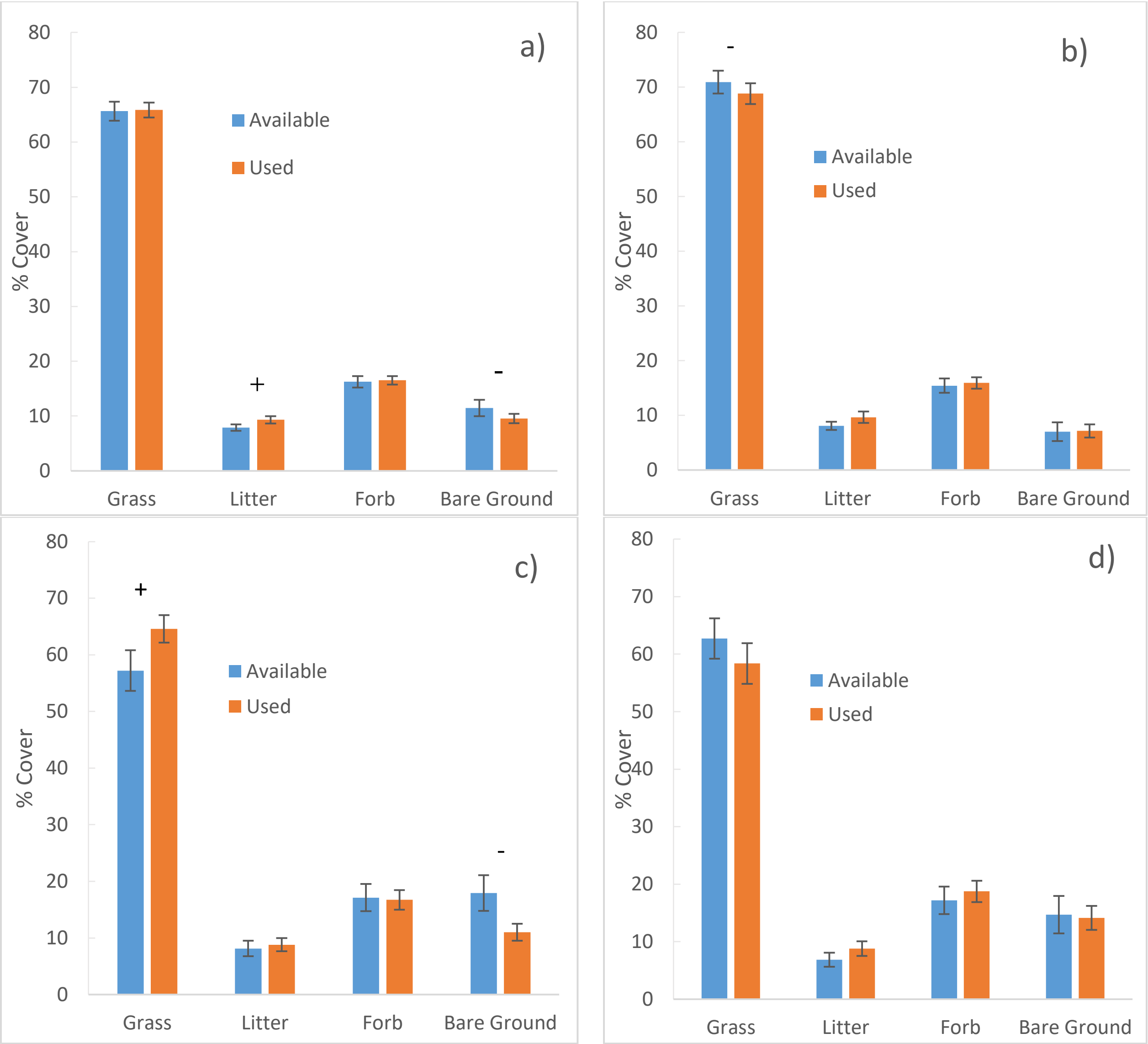


Figure 1-7: Used versus available vegetation based on percent composition of grass, litter, forbs, and bare ground within a 60 cm x 60 cm Daubenmire frame for locations of transmittered lesser prairie-chickens during winter (15 September-14 March) in the Red Hills of Kansas, during 2013-2016 within 4 patch categories: a) all patches on the landscape, b) >2-years post-fire patches, c) year-of-fire patches, and d) 1-year post-fire patches. Error bars represent the 95% confidence intervals. "+" indicates selection for greater percentage than available and "-" indicates selection of a lower percentage than available at α = 0.05.

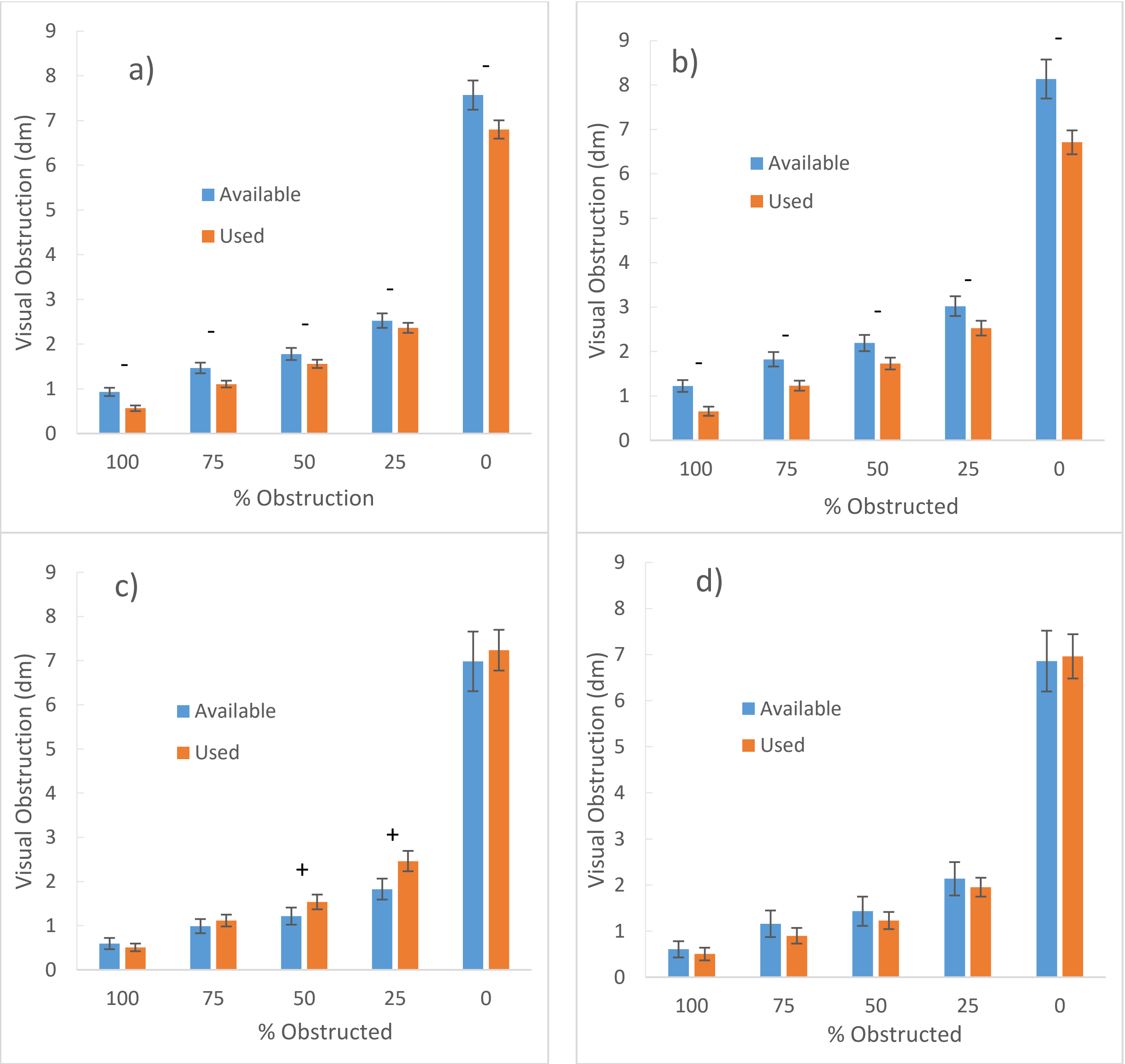


Figure 1-8: Used versus available vegetation based on maximum height in decimenters of vegetation obstruction at 5 different obstruction classes (100%, 75%, 50%, 25%, and 0% obstructed) for locations of transmittered lesser prairie-chickens during winter (15 September-14 March) in the Red Hills of Kansas, during 2013-2016 within 4 patch classes: a) all patches on the landscape combined, b) >2-years post-fire patches, c) year-of-fire patches, and d) 1-year post-fire patches. Error bars represent 95% confidence intervals. "+" indicates selection for greater visual obstruction than available and "-" indicates selection of a lower visual obstruction than available at α = 0.05.

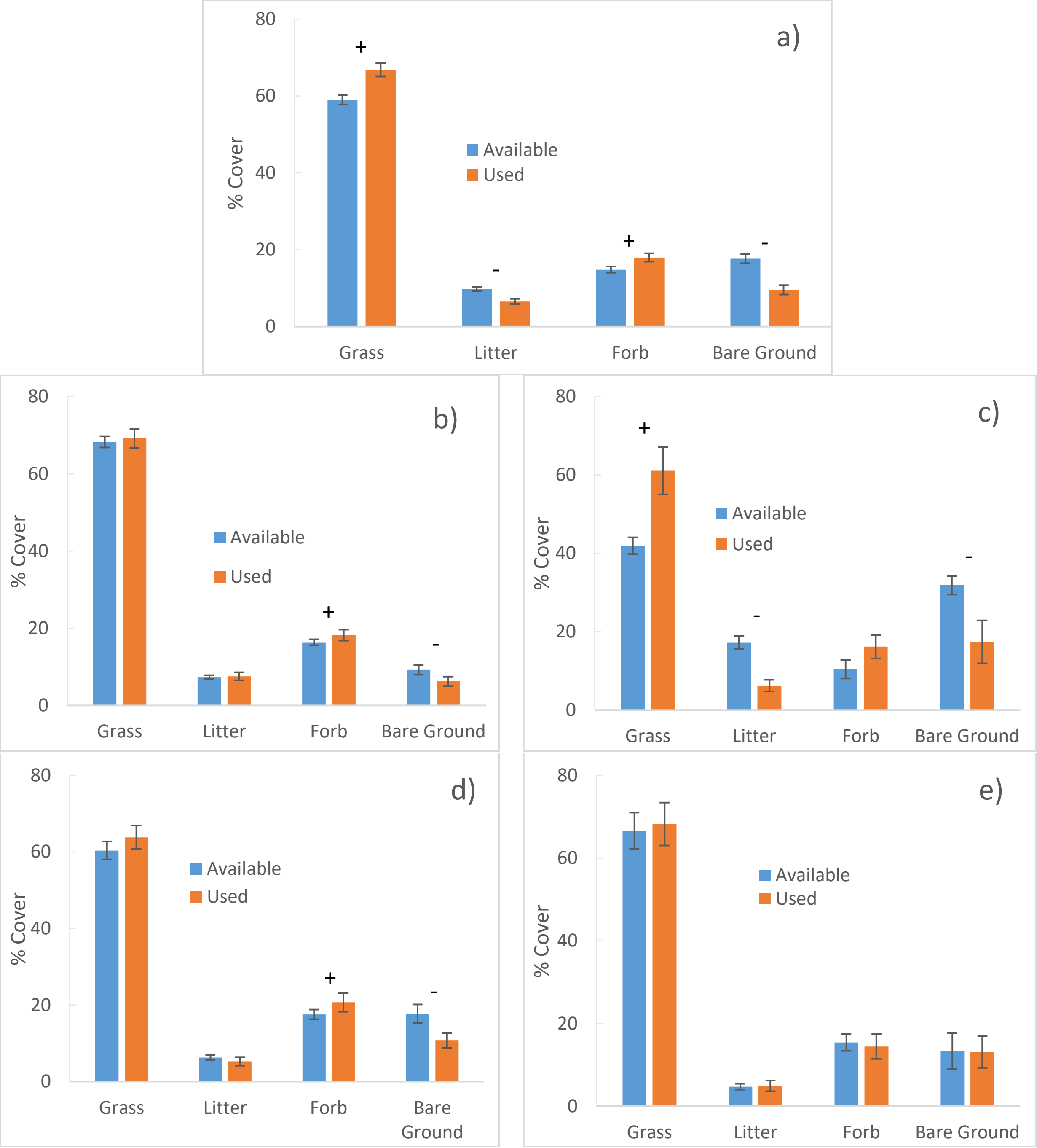


Figure 1-9: Used versus available vegetation based on percent composition of grass, litter, forbs, and bare ground within a 60 cm x 60 cm Daubenmire frame for locations of transmittered lesser prairie-chickens during spring (15 March-14 June) in the Red Hills of Kansas, during 2013-2016 within 5 patch categories: a) all patches combined, b) >2-years post-fire patches, c) year-of-fire patches, d) 1-year post-fire patches, and e) within 2-years post-fire patches. Error bars represent the 95% confidence intervals. "+" indicates selection for greater percentage than available and "-" indicates selection of a lower percentage than available at α = 0.05.

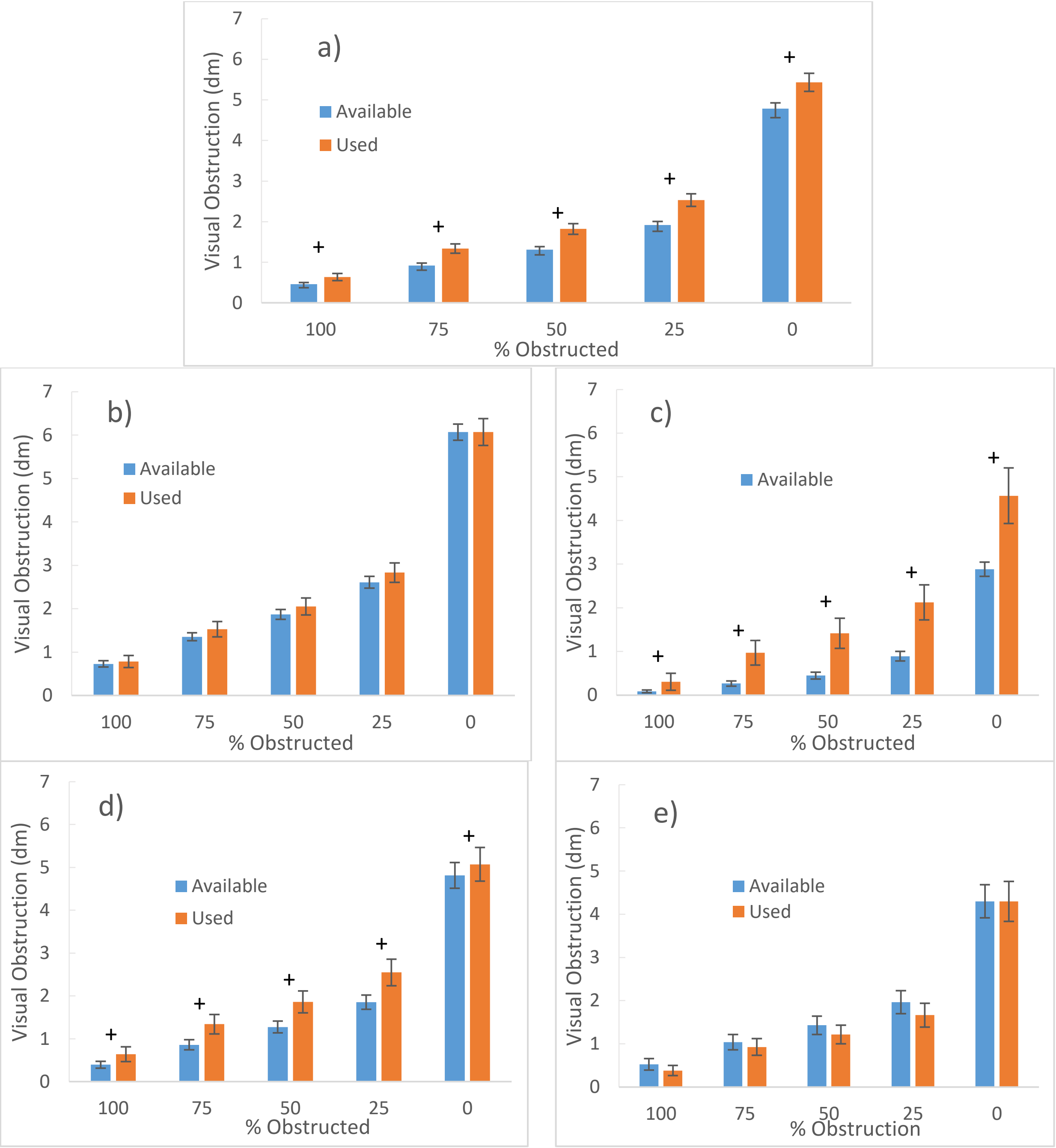


Figure 1-10: Used versus available vegetation based on maximum height in decimeters of vegetation obstruction at 5 different obstruction classes (100%, 75%, 50%, 25%, and 0% obstructed) for locations of transmittered lesser prairie-chickens during spring (15 March-14 June) in the Red Hills of Kansas, during 2013-2016 within 5 patch classes: a) all patches on the landscape combined, b) >2-years post-fire patches, c) year-of-fire patches, d) 1-year post-fire patches, and e) 2-years post-fire patches. Error bars represent 95% confidence intervals. "+" indicates selection for greater visual obstruction than available and "-" indicates selection of a lower visual obstruction than available at α = 0.05.

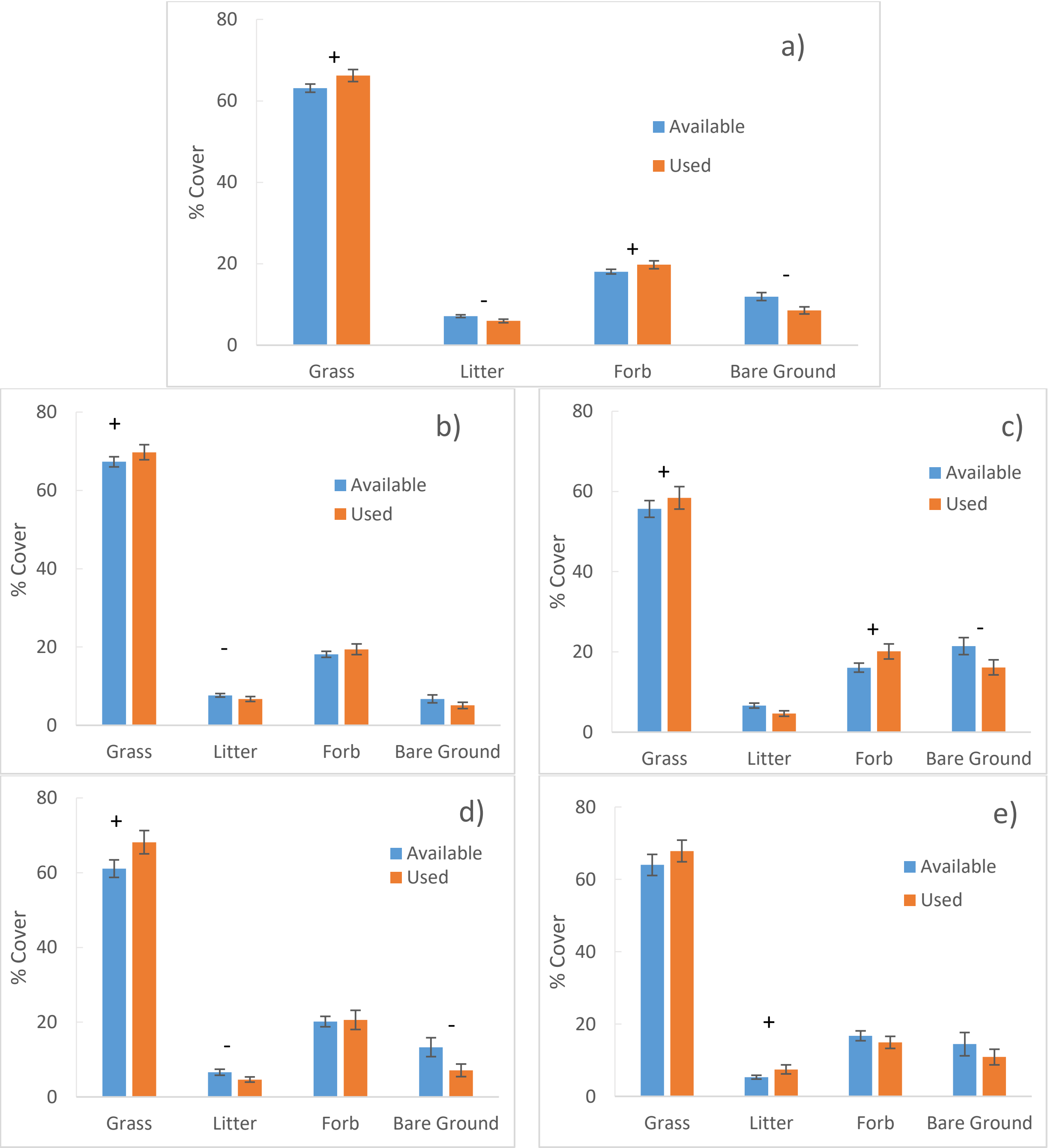


Figure 1-11: Used versus available vegetation based on percent composition of grass, litter, forbs, and bare ground within a 60 cm x 60 cm Daubenmire frame for locations of transmittered lesser prairie-chickens during summer (15 June-14 September) in the Red Hills of Kansas, during 2013-2016 within 5 patch categories: a) all patches combined, b) >2-years post-fire patches, c) year-of-fire patches, d) 1-year post-fire patches, and e) 2-years post-fire patches. Error bars represent the 95% confidence intervals. "+" indicates a selection for greater percentage than available and "-" indicates selection of a lower percentage than available at α = 0.05.

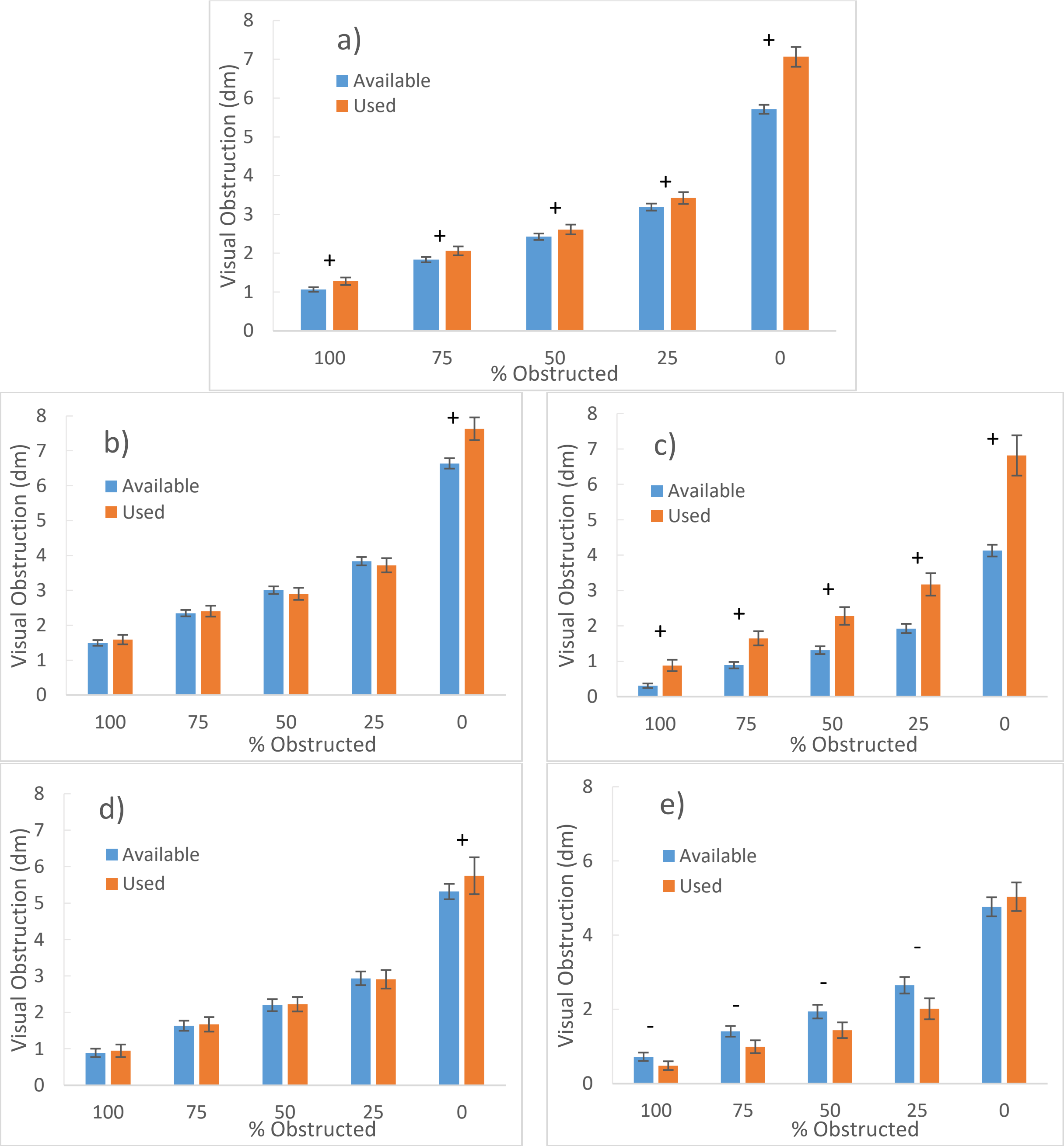


Figure 1-12: Used versus available vegetation based on maximum height in decimeters of vegetation obstruction at 5 different obstruction classes (100%, 75%, 50%, 25%, and 0% obstructed) for locations of transmittered lesser prairie-chickens during summer (15 June-14 September) in the Red Hills of Kansas, during 2013-2016 within 5 patch classes: a) all patches on the landscape combined, b) >2-years post-fire patches, c) year-of-fire patches, d) 1-year post-fire patches, and e) 2-years post-fire patches. "+" indicates selection for greater visual obstruction than available and "-" indicates selection of a lower visual obstruction than available at α = 0.05.

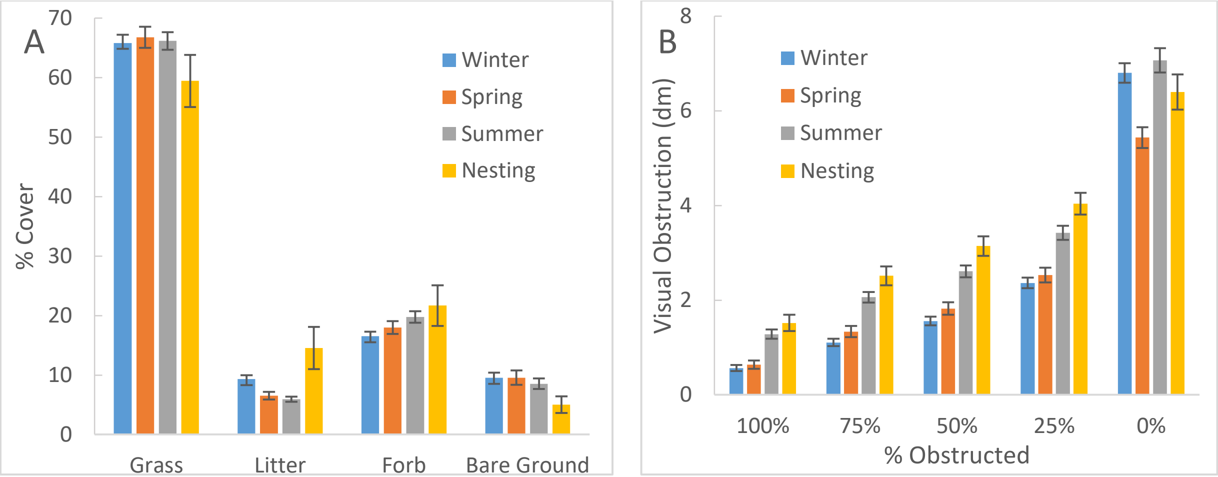


Figure 1-13: Comparison of vegetation characteristics among seasons for A) percent cover of grass, litter, forbs, and bare ground and B) visual obstruction at locations used by lesser prairie-chickens in the Red Hills of Kansas, during 2014-2016.

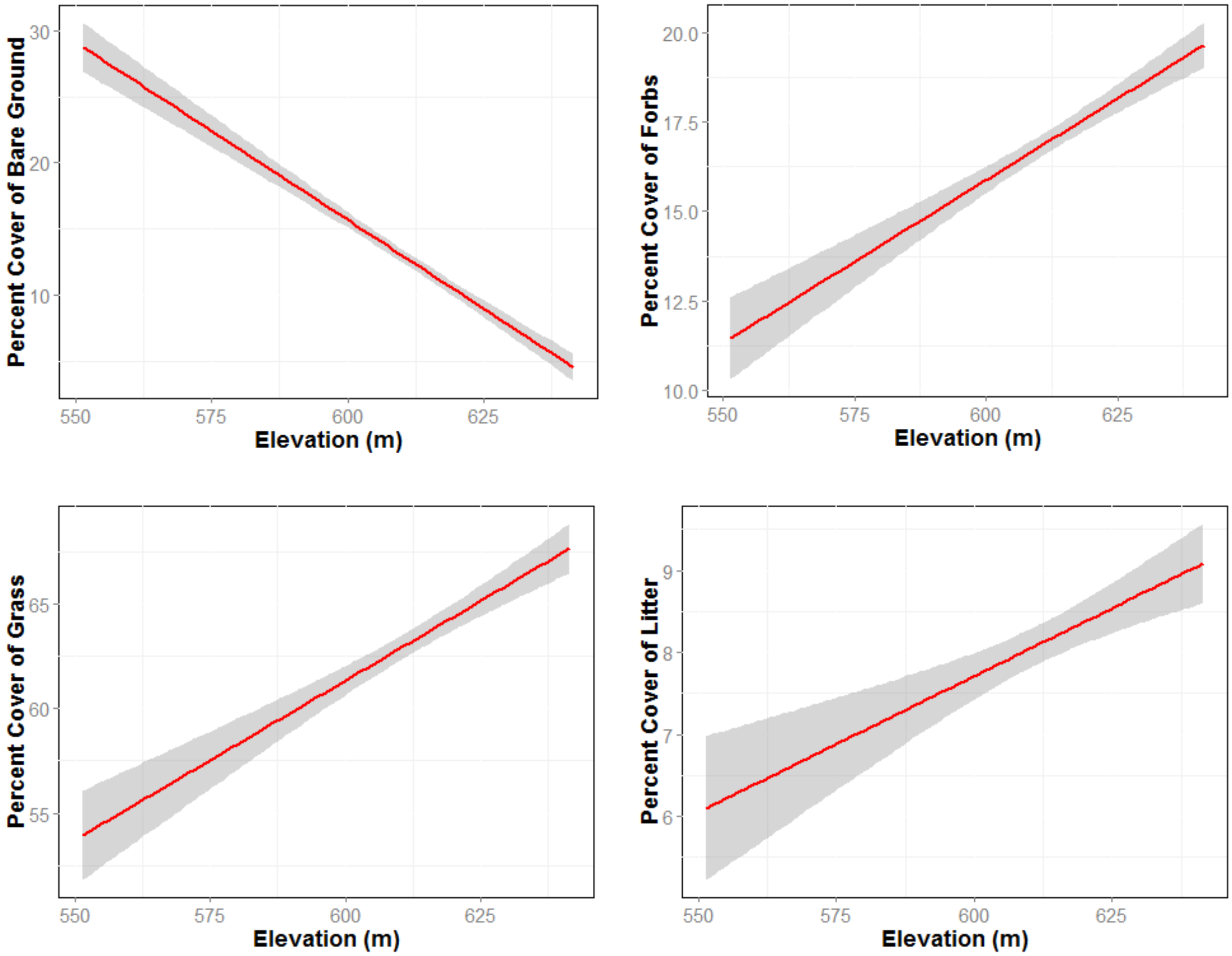


Figure 1-14: Linear relationship between elevation and A) percent cover of bare ground, B) percent cover of forbs, C) percent cover of grass, and D) percent cover of litter in the Red Hills of Kansas, during 2014-2016

Tables

Table 1-1: The cumulative percent of landscape available to nesting lesser prairie-chickens compared to the proportion of nests in each time-since-fire patch type in the Red Hills of Kansas during 2014-2016. The presented 95% confidence interval is for percent used; if this range does not overlap the available percentage, then there is selection or avoidance for the specific patch type.

			95% Confidence Intervals	
All Years Nests	% Available	% Used	Lower	Upper
Year-of-fire	0.173	0.000	0.000	0.089
1-year post-fire	0.075	0.057	0.003	0.187
2-years post-fire	0.020	0.038	0.0001	0.158
>2 years post-fire	0.730	0.903	0.733	0.974

Table 1-2: Ranking of 10 models testing the relative influence of the year a patch was burned, elevation (m above sea level), distance to tree (m), and distance to a patch edge (m) in determining time-since-fire patch use by female lesser prairie-chickens during the nesting season 2014-2016 in the Red Hills of Kansas.

	K[a]	ΔAIC_C[b]	w_i[c] ≤	Dev.[d]
Elevation * Year Burned	8	0.00[e]	1	7024.8
Elevation + Year Burned	5	97.18	0.001	7128.0
Distance to Tree * Year Burned	8	236.99	0.001	7261.8
Distance to Tree + Year Burned	5	266.90	0.001	7297.7
Elevation	2	477.97	0.001	7514.8
Distance to Tree	2	569.07	0.001	7605.9
Distance to patch edge * Year Burned	8	1486.20	0.001	8511.0
Distance to patch edge + Year Burned	5	1708.73	0.001	8739.5
Distance to patch edge	2	2030.17	0.001	9067.0
Year Burned	4	2280.73	0.001	9313.5

[a] Number of parameters
[b] Difference in Akaike's Information Criterion, adjusted for small sample size
[c] Akaike weights
[d] Deviance
[e] Minimum AIC_c = 7040

Table 1-3: Ranking of 10 models testing the relative influence of the year a patch was burned, elevation (m above sea level), distance to tree (m), and distance to a patch edge (m) in determining time-since-fire patch use by female lesser prairie-chickens during summer 2014-2016 in the Red Hills of Kansas.

	K[a]	ΔAIC_C[b]	w_i[c] $\leq$	Dev.[d]
Elevation * Year Burned	8	0[e]	1	23344.0
Elevation + Year Burned	5	261.7	0.001	23611.7
Distance to Tree * Year Burned	2	3938.9	0.001	27294.9
Distance to Tree + Year Burned	5	3162.6	0.001	26512.6
Distance to Tree	8	3078.8	0.001	26422.9
Elevation	2	2726.3	0.001	26082.3
Distance to patch edge * Year Burned	8	5684.1	0.001	29028.1
Distance to patch edge + Year Burned	5	6309.0	0.001	29659.0
Distance to patch edge	2	6324.9	0.001	29680.9
Year Burned	4	7708.3	0.001	31060.3

[a] Number of parameters
[b] Difference in Akaike's Information Criterion, adjusted for small sample size
[c] Akaike weights
[d] Deviance
[e] Minimum AIC_c = 23360

Table 1-4: Ranking of 10 models testing the relative influence of the year a patch was burned, elevation (m above sea level), distance to tree (m), and distance to a patch edge (m) in determining time-since-fire patch use by female lesser prairie-chickens during winter 2014-2015 and 2015-2016 in the Red Hills of Kansas.

	K[a]	ΔAIC_C[b]	w_i[c] $\leq$	Dev.[d]
Elevation * Year Burned	6	0[e]	1	11375.1
Elevation + Year Burned	4	87.0	0.001	11466.1
Distance to Tree * Year Burned	2	2847.8	0.001	14230.9
Distance to Tree + Year Burned	4	2408.7	0.001	13787.7
Distance to Tree	6	2310.3	0.001	13685.3
Elevation	2	1748.2	0.001	13131.3
Distance to patch edge * Year Burned	6	3500.3	0.001	14875.4
Distance to patch edge + Year Burned	4	3708.0	0.001	15087.0
Distance to patch edge	2	4012.8	0.001	15395.9
Year Burned	3	4395.3	0.001	15776.3

[a] Number of parameters
[b] Difference in Akaike's Information Criterion, adjusted for small sample size
[c] Akaike weights
[d] Deviance
[e] Minimum AIC_c = 11387

Table 1-5: Ranking of 10 models testing the relative influence of the year a patch was burned, elevation (m above sea level), distance to tree (m), and distance to a patch edge (m) in determining time-since-fire patch use by female lesser prairie-chickens during spring, 2014-2016 in the Red Hills of Kansas.

	K[a]	ΔAIC_C[b]	w_i[c] $\leq$	Dev.[d]
Elevation * Year Burned	8	0[e]	1	16646.5
Elevation + Year Burned	5	253.4	0.001	16905.9
Distance to Tree * Year Burned	8	1019.6	0.001	17666.0
Distance to Tree + Year Burned	5	1079.0	0.001	17731.5
Elevation	2	1439.2	0.001	18097.7
Distance to Tree	2	1657.9	0.001	18316.4
Distance to patch edge * Year Burned	8	3973.1	0.001	20619.6
Distance to patch edge + Year Burned	5	4647.2	0.001	21299.7
Distance to patch edge	2	4867.5	0.001	21526.0
Year Burned	4	5364.6	0.001	22019.1

[a] Number of parameters

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

[c] Akaike weights

[d] Deviance

[e] Minimum $AIC_c = 16662$

Table 1-6: Vatiation in the percent cover of grass, litter, forbs, and bare ground by season among time-since-fire patches for 2014, 2015, and 2016 vegetation in the Red Hills of Kansas.

Season	Grass*	Litter*	Forbs*	Bare*
Winter				
Year of Fire	57.22 ± 3.58^{a}	8.14 ± 1.37	17.12 ± 2.40	17.94 ± 3.14^{b}
1-year post -fire	62.71 ± 3.53^{a}	6.86 ± 1.22	17.19 ± 2.37	14.68 ± 3.27^{b}
>2-years post-fire	70.93 ± 2.10^{b}	8.10 ± 0.73	15.44 ± 1.29	7.02 ± 1.73^{a}
Spring				
Year of Fire	41.91 ± 2.11^{a}	17.20 ± 1.65^{c}	9.26 ± 0.85^{a}	31.83 ± 2.39^{c}
1-year post -fire	60.36 ± 2.38^{b}	6.24 ± 0.66^{a}	17.53 ± 1.28^{b}	17.40 ± 2.37^{b}
2-years post-fire	66.61 ± 4.40^{c}	4.53 ± 0.68^{a}	15.44 ± 2.02^{b}	13.29 ± 4.34^{a,b}
>2-years post-fire	68.16 ± 1.46^{c}	7.33 ± 0.49^{b}	16.35 ± 0.80^{b}	9.20 ± 1.27^{a}
Summer				
Year of Fire	55.64 ± 2.11^{a}	6.63 ± 0.65	16.09 ± 1.13^{a}	21.43 ± 2.11^{c}
1-year post -fire	61.09 ± 2.37^{b}	6.59 ± 0.80^{a}	20.16 ± 1.37^{b}	13.30 ± 2.54^{b}
2-years post-fire	62.01 ± 3.99^{b}	5.94 ± 0.82^{a}	17.67 ± 1.83	15.44 ± 4.69^{b}
>2-years post-fire	67.33 ± 1.29^{a}	7.67 ± 0.47^{b}	18.17 ± 0.79^{b}	6.75 ± 1.01^{a}

*Means followed by the same superscript do not differ among time-since-fire patch types within each vegetation composition variable.

Table 1-7: Variation in the visual obstruction (dm) at 100%, 75%, 50%, 25% and 0% obstruction classes by season among time-since-fire patches for 2014, 2015, and 2016 vegetation in the Red Hills of Kansas.

Season	100% VOR*	75% VOR*	50% VOR*	25% VOR*	0% VOR*
Winter					
Year of Fire	0.59 ± 0.13^{a}	0.99 ± 0.16^{a}	1.22 ± 0.19^{a}	1.83 ± 0.24^{a}	6.98 ± 0.68^{a}
1-year post -fire	0.61 ± 0.17^{a}	1.16 ± 0.29^{a}	1.43 ± 0.32^{a}	2.14 ± 0.36^{a}	6.86 ± 0.66^{a}
>2-years post-fire	1.22 ± 0.13^{b}	1.83 ± 0.17^{b}	2.19 ± 0.18^{b}	3.02 ± 0.22^{b}	8.13 ± 0.44^{b}
Spring					
Year of Fire	0.09 ± 0.03^{a}	0.27 ± 0.06^{a}	0.45 ± 0.08^{a}	0.89 ± 0.11^{a}	2.88 ± 0.16^{a}
1-year post -fire	0.39 ± 0.08^{b}	0.86 ± 0.12^{b}	1.27 ± 0.14^{b}	1.85 ± 0.17^{b}	4.81 ± 0.3^{b}
2-years post-fire	0.52 ± 0.13^{b,c}	1.04 ± 0.18^{b}	1.43 ± 0.21^{b}	1.96 ± 0.27^{b}	4.3 ± 0.38^{b}
>2-years post-fire	0.73 ± 0.07^{c}	1.35 ± 0.09^{c}	1.87 ± 0.11^{c}	2.61 ± 0.14^{c}	6.07 ± 0.19^{c}
Summer					
Year of Fire	0.31 ± 0.06^{a}	0.89 ± 0.09^{a}	1.32 ± 0.11^{a}	1.93 ± 0.13^{a}	4.13 ± 0.17^{a}
1-year post -fire	0.89 ± 0.12^{b}	1.63 ± 0.14^{b}	2.2 ± 0.17^{b}	2.93 ± 0.19^{b}	5.32 ± 0.21^{b}
2-years post-fire	0.87 ± 0.16^{b}	1.67 ± 0.2^{b}	2.31 ± 0.25^{b}	3.13 ± 0.3^{b}	5.1 ± 0.34^{b}
>2-years post-fire	1.49 ± 0.08c	2.35 ± 0.09c	3.01 ± 0.11c	3.84 ± 0.12c	6.64 ± 0.15c

*Means followed by the same superscript do not differ among time-since-fire patch types within each vegetation visual obstruction class variable.

Chapter 2 - Quantifying landscape and vegetative characteristics of lesser prairie-chicken habitat during extreme temperature events

Introduction

Global temperatures have increased during the past 50 years and are forecasted to continue to rise, influencing terrestrial systems in various ways (Karl et al. 2009; IPCC 2013; Grisham et al. 2016). Under different carbon emission scenarios, global temperatures are expected to increase between 1.0° C and 4.2° C by 2100 (IPCC 2013). Temperature rise in some areas is expected to be more pronounced than others. In addition to increasing average temperatures, climate change is expected to alter local weather patterns, increasing the frequency of extreme weather events such as heat waves, cold snaps, floods, and severe storms.

Due to a warming climate and increased frequency of extreme weather, temperature-sensitive species will seek areas with favorable microclimates known as thermal refugia (Dobrowski 2011). By seeking out thermal refugia, animals can limit thermal stress. Thermal stress occurs when ambient thermal conditions exceed a species' thermal tolerance level, which decreases survival and alters reproduction parameters (Guthery et al. 2005; Grisham et al. 2013; Hovick et al. 2014; Melin et al. 2014; Street et al. 2015). Thermal refugia can occur at different spatial scales (e.g., regional and local). The regional scale (e.g., ≥100 km^2) provides large-scale thermal refugia for populations, enabling species to adjust their occupied range as climate changes (Birks and Willis 2008; Rull 2009; Dobrowski 2011; Bennie et al. 2013). At a local scale (e.g., <1 km^2), thermal refugia are typically available for individuals enabling individuals to escape extreme heat events for short durations, increasing individual survival and reproductive output (With and Webb 1993; Suggitt et al. 2011; Ashcroft and Gollan 2012; Hovick et al. 2014; Melin et al. 2014; Cunningham et al. 2015; Martin et al. 2015).

Topography can affect microclimate at both regional and local scales. Topographic features affecting microclimate include aspect, elevation, and slope (Rull 2009; Dobrowski 2011; Suggitt et al. 2011; Ashcroft and Gollan 2012). Geographic features can influence the amount of solar radiation received by an area, altering plant transpiration rates, soil temperatures, photosynthesis rates, and snow-melt (Rich et al. 1995; Fu and Rich 2002). When altered, these processes influence microclimate in various ways. Increased solar radiation increases leaf and soil temperature (Fu and Rich 2002); thus increasing near-surface temperature. Conversely, increased solar radiation may increase transpiration rates (Rich et al. 1995; Fu and Rich 2002); thereby increasing evaporative cooling for plants and lowering near-surface temperatures (Teuling et al. 2010). To maximize evaporative cooling and minimize direct temperature effects of solar radiation, animals will seek out thermal refugia that balance these two opposing effects of solar radiation. In addition, transpiration rates, soil temperature, photosynthesis rates, and snow-melt influence the vegetation community in an area, which can further influence microclimate conditions, offering refugia for temperature- sensitive species (Bennie et al. 2006).

Land management practices also have the potential to alter microclimate, but in a controllable way (Savage and Vermeulen 1983; Chen et al. 1995; Zheng et al. 2000; Moore et al. 2005). In forest ecosystems, managers harvest timber in various patterns, altering near surface microclimate within and adjacent to the harvested area (Chen et al. 1995; Zheng et al. 2000; Moore et al. 2005). Microclimate at the surface is altered due to increased solar radiation reaching the forest floor (Chen et al. 1995; Zheng et al. 2000; Moore et al. 2005). Alteration of the thermal environment affects species differently based on their thermal needs; thus, it is important to manage for a variety of microclimates (Sutton et al. 2014). Management actions in grasslands can have similar, albeit less dramatic effects on microclimate. Similar to harvesting a forest, prescribed fire or mowing in grasslands reduces the canopy cover of grasses and forbs, increasing the amount of solar radiation reaching the soil surface (Savage and Vermeulen 1983). The near-surface thermal environment in the tall-grass prairie of North America varies spatially and temporally in a patch-burn grazing mosaic (Allred et al. 2013; Hovick et al. 2014).

Historically, grasslands of the Great Plains burned frequently and in an irregular pattern, creating a spatially and temporally heterogeneous landscape (Collins and Gibson 1990; Hobbs and Huenneke 1996; Fuhlendorf and Engle 2001; Fuhlendorf et al. 2009). Further, topoedaphic (interaction of soils and topography) variation across the Great Plains adds additional heterogeneity to the landscape (Suggitt et al. 2011; Winter et al. 2011; Ashcroft and Gollan 2012). Heterogeneity generated by fire and topoedaphic variability potentially results in a diverse thermal environment, with ample opportunities for animals to seek thermal refugia during extreme thermal events, though this has not been quantified. Since European settlement, the southwestern Great Plains has seen a reduction in the amount of fire within the ecosystem (Fuhlendorf and Engle 2001; Thacker and Twidwell 2014). Fire suppression has allowed the vegetation structure to become more homogeneous across much of the remaining landscape, potentially eliminating thermal refugia for grassland obligate species that inhabit these areas (Coppedge et al. 2001; Fuhlendorf and Engle 2001; Fuhlendorf et al. 2006; Engle et al. 2008; Doxon et al. 2011; McGranahan et al. 2013). In a warming climate, it is important to retain landscape heterogeneity to allow animals the option of seeking out thermal refugia (Hovick et al. 2014).

With climate change, the Great Plains are expected to experience increased temperatures, altered precipitation patterns, and increased frequency and intensity of exteme weather events (e.g., heat waves, flooding, drought, etc.; Karl et al. 2009; IPCC 2013; Hovick et al. 2014; Grisham et al. 2016). One of the main aspects of climate change predicted to inordinately influence grassland species is the increase in frequency and intensity of heat waves (Hovick et al. 2014). Therefore, many species in the Great Plains are expected to experience an increase in the number of days that they experience thermal stress, resulting in decreased reproduction and survival of these species (Hovick et al. 2014; Grisham et al. 2016).

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie-grouse found in the southwestern Great Plains that has experienced a population decline over the past century (Taylor and Guthery 1980; Hagen et al. 2004; Hagen and Giesen 2005; McDonald et al. 2014; Garton et al. 2016). Climate change is one factor that may affect population viability across the range of the lesser prairie-chicken (Grisham et al. 2016). An increase in average temperature between 1.4° C and 3.3° C is predicted across the range of the lesser prairie-chicken under different carbon emission scenarios by 2050 (Girvetz et a. 2009; Grisham et al. 2016). Due to a predicted increase in temperature, lesser prairie-chickens are expected to experience an increased number of days of thermal stress. Understanding habitats used by lesser prairie-chickens as thermal refugia is important for managers to prioritize conservation efforts to maximize available thermal refugia across the landscape.

The primary goal of my study was to quantify the thermal scape of lesser prairie-chicken habitat during peak midday temperatures during summer. Specifically, my objectives were 1) to identify if lesser prairie-chickens selected areas that minimize thermal stress (cooler, more humid areas) at microsite, patch, and landscape scales; 2) to determine vegetative characteristics selected by female lesser prairie-chickens at patch and microsite scales; and 3) to assess the relative influence of landscape features, such as topography, time-since-fire, tree densities, and soils, on microclimate characteristics and habitat selection by female lesser prairie-chickens. I hypothesized that female lesser prairie-chickens would select areas with cooler, more humid environments at all scales to reduce thermal stress; selected areas would be characterized by taller vegetation and contain more forbs than available at random at both patch and microsite scales; lowland areas would be cooler and have higher atmospheric moisture than uplands and slopes, but female selection would not reflect this condition due to minimal use of lowland areas; north and west aspect slopes would have cooler, more humid microclimate than east and south slopes, and will be selected by female lesser prairie-chickens; patches without fire for several years would have cooler, more humid microclimates and that lesser prairie-chickens would select areas based on these characteristics; and variation in microclimate among soil types would not be influentially in habitat selection by female lesser prairie-chickens. Finally, areas with greater tree densities would have cooler, more humid microclimates, but I hypothesize that female lesser prairie-chickens would not select habitat in relation to available microclimates based on tree density (Lautenbach et al. 2017).

Methods

Study Area:

My study area was located on private lands in Kiowa and Comanche counties, Kansas, and encompassed ~ 13,250 ha (Figure 2-1). The study site was located within the Red Hills region of south-central Kansas and characterized by mixed-grass prairie on loamy soils. The dominant land use in this site was cattle production with some interspersed row-crop agriculture. Native vegetation in this region includes: little bluestem (*Schizachyrium scoparium*), hairy grama

(*Bouteloua hirsuta*), blue grama (*B. gracilis*), sideoats grama (*B. curtipendula*), big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), buffalograss (*Bouteloua dactyloides)*, sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludoviciana*), western ragweed (*Ambrosia psilostachya*), sand sagebrush (*Artemisia filifolia*), Chickasaw plum (*Prunus angustifolia*), and eastern redcedar (*Juniperus virginiana*; Lauver et al. 1999).

Climate in this area is characterized by warm summers and mild winters. The 30-year average maximum temperature in this region is 19.6° C and the 30-year average minimum temperature is 5.3° C. During July, the 30-year average maximum temperature in this region is 33.2° C and the 30-year average January minimum temperature is -7.4° C (US Climate Data, accessed 9/12/2016, http://www.usclimatedata.com). The 30-year average annual precipitation is 63.9 cm, with 40.0 cm occurring between 1 April and 31 August (US Climate Data, accessed 9/12/2016, http://www.usclimatedata.com). During 2015, the average maximum temperature was 21.3° C and average minimum temperature was 7.2° C. The average January minimum temperature in 2015 was -5.9° C and the average July maximum temperature was 33.9° C. During 2015, a total of 64.8 cm of precipitation was recorded with 40.8 cm occurring between 1 April and 31 August (Kansas Mesonet, accessed 9/12/2016, http://mesonet.k-state.edu/weather/historical/). During this study, temperature and precipitation were slightly above average.

Data Collection:

Bird Use: To measure lesser prairie-chicken habitat selection in relation to microclimate, I captured female lesser prairie-chickens at lek sites using walk-in traps (Haukos et al. 1990; Schroeder and Braun 1991) and drop nets (Silvy et al. 1990). Upon capture, I determined the sex of each captured bird using tail coloration, presence and size of eye-combs, and pinnae length (Copelin 1963). Captured females were fitted with either a 22-g Global Positioning System (GPS) satellite transmitter (platform transmitting terminal or PTT) from Microwave Telemetry Inc. (Columbia, Maryland, USA) or a 15-g very-high-frequency (VHF) radio transmitter from Advanced Telemetry Systems (Isanti, Minnesota, USA). The PTTs were rump mounted using Teflon® ribbon (Dzialak et al. 2011).

Birds fitted with VHF transmitters were located using triangulation (Cochran and Lord 1963). Approximate locations (UTMs) and error polygon associated with the triangulations were determined using Location of a Signal software (Ecological Software Solutions LLC, Hegymagas, Hungary). Individual birds were located 3-4 times each week. Lesser prairie-chickens marked with satellite transmitters were tracked using the GPS/Argos system. All GPS locations were taken approximately every 2 hrs between 0600-2400 resulting in approximately 10 locations per day. Potential location error associated with the use of these transmitters was <18 m.

Additionally, to assess midday site selection during peak daytime temperatures (1200-1700) in the summer (mid-June to late August), I obtained near-surface temperature and humidity data at use and paired non-use locations using a Maxim Integrated Semiconductor data logger (Maxim Integrated Products, Sunnyville, California, USA; hereafter “iButton”). Female lesser prairie-chickens without a brood or nest and fitted with VHF collars were flushed between 1200 and 1700 once per week from July-early September 2015. Birds were flushed on days when weather (temperature and cloud cover) was forecasted to remain similar to the flush date for several succeeding days. I placed four iButtons in association with each flush location to assess selection at the microsite and patch scale. I placed 1 iButton at the flush location, 1 iButton 4 m east and 1 iButton 4 m west of the location (microsite), and 1 paired iButton 100 m away in a random direction (patch). All iButtons were set to record temperature and relative humidity every 5 min for >36 hrs. For each 5-min measurement, I calculated the vapor pressure deficit (VPD) in millibars (mbar), which is the difference between the amount of moisture currently in the air and amount of moisture the air can hold when saturated, by using the simultaneously collected temperature and relative humidity data from each iButton (Anderson 1936; Grisham et al. 2016).

Vegetation Selection: To assess selected vegetation during peak midday temperature, I conducted vegetation surveys at use (flush) and paired non-use (patch) locations. At each of these two points, I followed vegetation survey protocol adopted by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) Lesser Prairie-Chicken Initiative and Lesser Prairie-Chicken Interstate Working Group as a sampling strategy for standardization among field sites (Pitman et al. 2005; Grisham 2012). At each location, I centered two perpendicular 8-m transects in a north-south and east-west orientations on the point defined by Universal Transverse Mercator coordinates (UTMs). At the point center and 4 m to the north, south, east, and west, I estimated the percent cover of grasses, forbs, shrubs, litter, and bare ground using a modified (60 cm x 60 cm) Daubenmire frame (Daubenmire 1959). At each point, I estimated height of visual obstruction at 100%, 75%, 50%, 25%, and 0% obstruction classes to the nearest dm from a distance of 4 m and a height of 1 m using a Robel pole (Robel et al. 1970).

Thermal landscape: To assess microclimate use and availability at the landscape scale, I delineated different patch types across my study site based on slope position, slope aspect, management prescriptions (time-since-fire), tree density, and general soil class (Figure 2-2). Patch types were generated in ArcMap 10.2 (ESRI Inc., 2013, Redlands, CA, USA) To classify slope position, I used a digital elevation model (DEM) from the Kansas GIS and Support Center (http://www.kansasgis.org) and classified the landscape as > or < 7% slope using “Slope” tool within the “Spatial Analysis Tools” toolbox in ArcMap 10.2. Boundaries were manually smoothed and areas >7% slope were classified as being on the slope and areas <7% slope were classified as either uplands or lowlands based on their relative elevation. Slope aspect was extracted from a DEM using the “Aspect” tool within the “Spatial Analysis Tools” toolbox in ArcMap 10.2. Time-since-fire was digitized in ArcMap 10.2, with patches classified as being year-of-fire, 1-year post-fire, or ≥2 years post-fire. To obtain tree density, individual trees were hand digitized in ArcMap 10.2 using National Agricultural Inventory Program (NAIP, Farm Service Agency, USDA) 1-m spatial resolution imagery. Tree density was calculated at the 1-ha scale and categorized as being either <2 trees/ha, 2-10 trees/ha, or >10 trees/ha. Soil survey data were obtained from the NRCS SSURGO (Soil Survey Staff, NRCS, USDA, Web Soil Survey, http://websoilsurvey.nrcs.usda.gov/) and classified as being either sandy, clay, Kiowa Shale, loamy/limy, or sub-irrigated. All categorical patch-types were combined to create 531 unique patch-types. Within each patch-type, I generated two random points in ArcMap 10.2. At each random point, I placed an iButton set to record temperature and relative humidity every 5 min (Allred et al. 2013) for a 24-hr period. At each iButton location, I conducted a vegetation survey to estimate the percent cover of forbs, grasses, shrubs, litter, and bare ground using a modified Daubenmire frame (Daubenmire 1959). Additionally, I estimated visual obstruction at 100%, 75%, 50%, 25%, and 0% obstruction classes to the nearest dm from a distance of 4 m and a height of 1 m using a Robel pole (Robel et al. 1970). I recorded ambient weather data on the study site using an Onset HOBO U30 weather station equipped with temperature, relative humidity, wind speed, and wind direction sensors (Onset Computer Corporation, Bourne, Massachusetts, USA) set to record weather data every 5 min. I calculated the VPD for each iButton and corresponding ambient weather data. I computed the difference between iButton temperature and VPD and ambient temperature and VPD to get the relative difference between ambient and near-surface temperature and VPD.

Data Analysis

Midday site selection: To identify thermal and vegetation characteristics at selected midday locations, I implemented a use versus available study design. I used temperature and VPD data from 1200-1800 hrs the day after the bird was flushed. I used an analysis of variance (ANOVA) with a Tukey post-hoc test to identify if there was a difference in temperature and VPD between selected midday flush locations (point center), microsites (4 m east and 4 m west), and the patch (100 m). To identify vegetation characteristics at use locations, I used a logistic regression model in a resource selection framework. I modeled vegetation variables at use locations compared to paired locations and vegetation characteristics at point center compared to the microsite. For use versus paired analysis (patch-scale selection), I compared 10 *a priori* models testing the influence of visual obstruction on midday loafing location selection, which included decimeters obstructed at 100, 75, 50, 25, and 0% obstruction classes and quadratic of each of these classes. To identify composition characteristics selected at the patch scale, I compared 10 *a priori* models investigating the relative importance of percent cover of litter, grass, forbs, bare ground, and shrubs and quadratic of each of these variables. To identify vegetation composition selected at the microsite scale (4 m), I tested 12 *a priori* models testing the influence of percent cover of litter, grass, forbs, bare ground, and shrubs and vegetation height and quadratic of each of these variables. All models within each category were ranked using Akaike's Information Criterion adjusted for small sample size (AIC_c); the model with the lowest AIC_c value was selected to explain female lesser prairie-chicken midday vegetation composition and structure selection.

Midday landscape selection: To identify if female lesser prairie-chickens select microclimate at the landscape scale to minimize thermal stress, I quantified temperature and VPD at use and non-use available locations. I calculated the difference between landscape iButton weather data and ambient weather data from the onsite weather station for each iButton deployed in a landscape patch-type. If more than one sample was obtained from a landscape patch-type, I averaged temperature and vapor pressure deficit data. Averaged temperature and VPD data from each patch-type were projected to a raster to create a continuous surface of available temperatures and VPD on the landscape. To quantify microclimate selection, I used locations from satellite transmittered individuals from mid-May through mid-September 2015 during midday (1200-1800 hrs) and I generated an equal number of random points to assess available microclimate conditions on the landscape in ArcMap 10.2 (ESRI Inc., 2013, Redlands, CA). All locations were imported into ArcMap 10.2 where I used the “Identity” tool within “Analysis Tools” to determine the landscape patch-type of each point and therefore, temperature and VPD. I used a logistic regression model in a resource selection framework to compare use and available temperatures and VPDs to identify if female lesser prairie-chickens select microclimates at the landscape scale that minimize thermal stress.

Influence of landscape features on habitat selection: I used a logistic regression model in a resource selection framework to model selection by female lesser prairie-chickens for patches of each landscape feature. I generated a logistic regression model for each landscape feature (slope positions, aspect, time-since-fire, tree density, and soils) to identify landscape patches selected by female lesser prairie-chickens during midday. I used the same locations that I used to model midday landscape temperature and VPD selection above. I identified each landscape feature patch that each point was in using the “Extract multiple values to points” tool within the Spatial Analysis toolbox in ArcMap 10.2. I modeled a single, univariate, logistic regression for each landscape feature and patch was considered to be selected if it had a positive beta coefficient and avoided if the beta coefficient was negative. If the confidence intervals overlapped zero, than no selection or avoidance occurred.

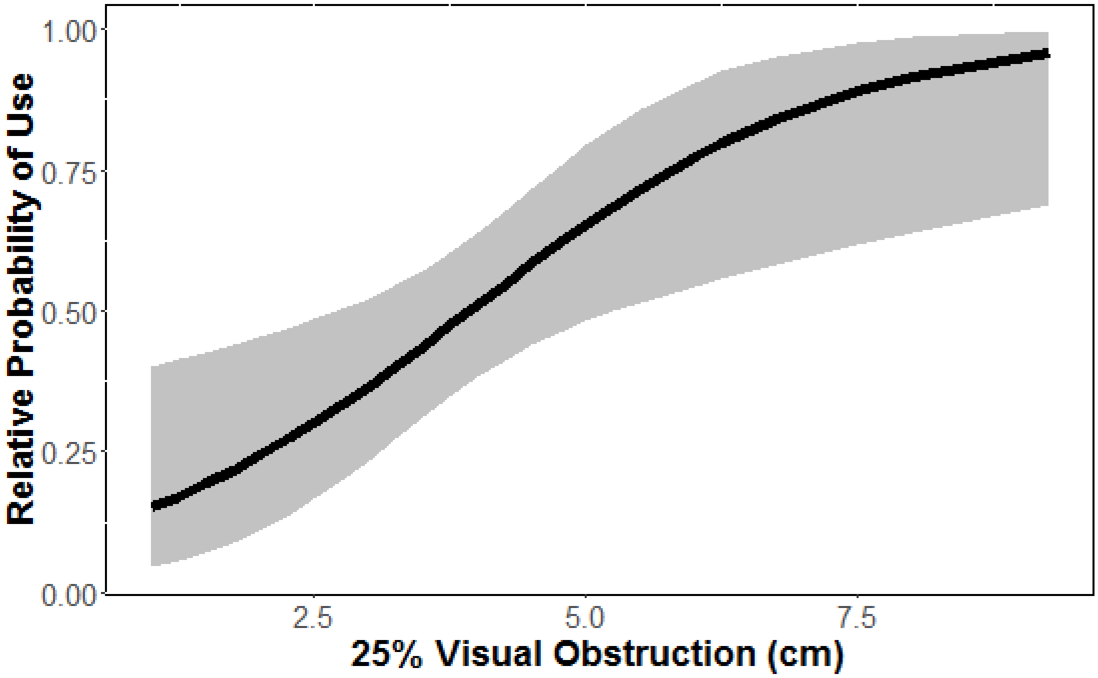
Influence of landscape characteristics on microclimate: I generated 10,000 random points within the portion of my study area where landscape temperature and VPD data were collected using ArcMap 10.2 to assess the influence of landscape characteristics on near-surface temperature and VPD. Points were classified according to the temperature and vapor pressure associated with the patch-type within which they were located, slope position, slope aspect, time-since-fire, tree density category, and soil type associated with the location. I used the same landscape temperature and VPD raster surfaces generated to assess midday landscape selection. I used a one-way ANOVA with a Tukey post hoc test to identify temperature and VPD differences among landscape feature patches to identify the influences of each landscape feature on microclimate conditions.

Results

Midday site selection

During summer of July, August, and early September 2015, I recorded 33 flush locations from 4 females that were not attending either a nest or a brood. From these flushes, I obtained 8640 temperature and Vapor Pressure Deficit (VPD) readings, 2160 readings from each flush location, 4 m west, 4 m east, and paired location. Female lesser prairie-chickens selected sites with cooler temperatures and lower VPD than both microsite (4 m) and patch (paired; 100 m) scales (temperature: $F_{2,\,6333} = 201.9$, $P < 0.001$; VPD: $F_{2,\,6032} = 189.4$, $P < 0.001$; Figure 2-3).

Patch scale**: The top-ranked model for assessing habitat selection based on visual obstruction of vegetation was the linear model for decimeters obstructed at 25% obstruction (Table 2-1). There were 4 other models with $\Delta AIC_c < 2$ (quadratic 25% obstruction, linear and quadratic 50% obstruction, and quadratic 75% obstruction); these models had similar trends with increasing probability of selection as visual obstruction increased with the quadratic models demonstrating a peak obstruction height. The general models for all quadratic and linear models were similar for all obstruction classes, so I present results for the linear and quadratic 25% obstruction models. With the linear 25% obstruction model, probability female lesser prairie-chickens selecting a site increased with greater visual obstruction (**Figure 2-4), with the quadratic model, probability of selection increased with greater obstruction to about 7 dm where it started to decrease (Figure 2-5). The top-ranked model for selection of vegetation composition at the patch scale was the linear model of forbs, with the quadratic model of forbs also competitive with $\Delta AIC_c < 2$ (Table 2-2). Upon inspection, these models had similar structure, so I proceeded with the linear model of forbs only. Female lesser prairie-chickens had a greater probability of selecting areas with more forbs at the patch scale (Figure 2-6).



Microsite scale: The top-ranked model for vegetation selection at the microsite scale was the quadratic model of percent cover of grass (Table 2-3). Female lesser prairie-chickens had a greater probability of selecting sites with >75% or <25% grass (Figure 2-7). Forb cover was important for habitat selection at the patch scale, and I present results from the top forb model to identify the relationship of selection of forbs at the microsite scale. Similar to grass cover, the top ranked forb model was the quadratic relationship between relative probability of use and percent cover of forbs (Table 2-3). Female lesser prairie-chickens had a greater probability of selecting areas with <10% or >60% forb cover (Figure 2-8). Grass and forb cover were negatively correlated ($r^2 = 0.55$, $P < 0.001$).

Midday landscape microclimate selection

I deployed 664 iButtons across the landscape in a total of 376 patch-types resulting in 47,808 temperature and VPD readings during May and June 2015. The complete dataset resulted in a heterogeneous landscape of temperature and VPD conditions (Figure 2-9). During June, July, August, and September 2015, a total of 1744 locations for 7 birds were recorded. Female lesser prairie-chickens had a higher probability of selecting sites with lower temperatures and lower VPD relative to ambient across the landscape (Figure 2-10).

Midday landscape selection

I used selection models to determine patch-type selection by lesser prairie-chickens within each landscape feature category. For slope position, female lesser prairie-chickens avoided lowlands, showed strong selection for upland sites, and selected slopes during midday (Table 2-4). Female lesser prairie-chickens selected areas on east facing slopes, but avoided south, west, and to a lesser extent, north slopes during the midday (Table 2-4). For time-since-fire patches, female lesser prairie-chickens selected year-of-fire patches while avoiding 1- and

>2-years post-fire patches during midday (Table 2-4). During peak temperatures, female lesser prairie-chickens showed strong avoidance for patches with densities of 2-10 and >10 trees/ha while selecting <2 trees/ha patches (Table 2-4). Female lesser prairie-chickens avoided Kiowa shale soils, clay soils, and loamy/limy soils, but selected sandy soils relative to the proportion of soil types available on the landscape; there was no significant relationship with subirrigated soils, but weak avoidance of areas with these soils was detected (Table 2-4).

Influence of landscape features on microclimate

I generated 10,000 random locations with associated temperature and VPD characteristics across the landscape (Figure 2-9). Across the landscape, temperatures and VPDs were standardized by calculating the difference from ambient; therefore, I am reporting these results as relative to microclimate conditions available on the landscape (i.e., lowest temperature areas are relative to the rest of the landscape, not ambient conditions). For slope position, I found that lowlands had the lowest temperatures, with the greatest temperatures occurring on slopes and in the uplands ($F_{2,\,9996} = 228.5$, $P < 0.001$; Table 2-5). Slope position had a similar effect on VPD at the landscape scale, with lowlands having the lowest VPD and the greatest VPDs for slopes and uplands ($F_{2,\,9881} = 533.3$, $P < 0.001$; Table 2-5). For slope aspect, I found that north slopes had the lowest temperatures, followed by west slopes and east slopes, with south slopes having the greatest temperatures ($F_{3,\,9995} = 875.9$, $P < 0.001$; Table 2-5). Slope aspect had a similar effect on VPD, where west slopes had the lowest VPD, followed by north and east slopes, and south slopes had the greatest VPD ($F_{3,\,9880} = 95.4$, $P < 0.001$; Table 2-5). Year-of-fire patches had the lowest temperatures, followed by >2-years post-fire, and 1-year post fire patches had the greatest temperatures ($F_{3,\,9995} = 201.5$, $P < 0.001$; Table 2-5). In addition, year-of-fire patches had the lowest VPDs, followed by 1-year post-fire patches, and >2-years post-fire patches having the greatest VPDs ($F_{3, 9880} = 219.4$, $P < 0.001$; Table 2-5). Areas with >10 trees/ha had the lowest temperature, followed by areas with <2 trees/ha, and areas with 2-10 trees/ha had the greatest temperature ($F_{2, 9996} = 52.9$, $P < 0.001$; Table 2-5). Tree density influenced VPD availability differently than temperature, with <2 trees/ha areas having the lowest VPD, followed by areas with >10 trees/ha, and areas with 2-10 trees/ha had the greatest VPD ($F_{2, 9881} = 51.4$, $P < 0.001$; Table 2-5). By assessing temperature difference by soils, I found subirrigated soils had the coolest temperatures, followed by loamy/limy soils, clay soils, Kiowa shale soils, and sandy soils had the greatest temperatures ($F_{4, 9994} = 539.0$, $P < 0.001$; Table 2-5). Soil type had a different impact on VPD, areas with subirrigated soils had the lowest VPD difference followed by clay soils, Kiowa shale soils, loamy/limy soils, and sandy soils had the greatest VPD ($F_{4, 9879} = 51.06$, $P < 0.001$; Table 2-5).

Discussion

Female lesser prairie-chickens have a complex pattern of habitat selection during the hottest time of the day in summer with respect to landscape features and vegetation characteristics. My study is the first known project to characterize and assess habitat selection for lesser prairie-chickens based on microclimate conditions at multiple scales. My results demonstrate that lesser prairie-chickens select areas that minimize thermal stress with lower temperatures and vapor pressure deficit (VPD) at microsite, patch, and landscape scales. My results are consistent with a growing body of literature indicating that grassland animals select areas to minimize thermal stress during peak midday temperatures (With and Webb 1993; Guthery et al. 2005; Allred et al. 2013; Larsson et al. 2013; Hovick et al. 2014; Carroll et al. 2015a, b; Tanner et al. 2016).

At microsite and patch scales, lesser prairie-chickens select cooler, more humid sites, thus minimizing temperature exposure and providing thermal refugia. Selected sites were characterized by >75% grass and <10% forb cover, or >60% forbs and <25% grass cover. The areas were also characterized by having taller, more dense vegetation compared to patch locations. Suggitt et al. (2011) found that as vegetation height increases, the capacity of the landscape to moderate temperatures (i.e., provide thermal refugia) increases, which is consistent with female lesser prairie-chickens selecting for taller vegetation as thermal refugia. However, there is a threshold to how tall vegetation can be. My second top model was a quadratic model that predicted probability of use is maximized at 70 cm in the 25% visual obstruction class before it begins to decrease. The concept of a threshold to vegetation height was also found by Lautenbach (2015) at nest and brood locations. In addition, if lesser prairie-chickens were to select the tallest vegetation that provides the best thermal cover, they would use areas with greater tree densities, which my and previous research show they avoid (Lautenbach et al. 2017).

At the landscape scale, female lesser prairie-chickens selected habitat with relatively low temperatures and VPD to minimize thermal stress. However, these results were confounded when relationships among landscape features, microclimate conditions, and selection were investigated. I found that lesser prairie-chickens did not select habitat that provided the best thermal cover for most landscape features (slope position, slope aspect, tree density, and soil type). However, female lesser prairie-chickens do select time-since-fire patch that provided the best thermal cover (i.e., year-of-fire).

Vegetation structure and composition are driven by time-since-fire (Fuhlendorf and Engle 2001; Fuhlendorf et al. 2009; McGranahan et al. 2013; Chapter 1). Female lesser prairie-chickens primarily select midday habitat based on vegetation structure and not landscape features such as topography, tree density, and soils. The observed pattern likely occurs because female lesser prairie-chickens are unable to perceive the microclimate differences generated by topeodaphic features. Across all landscape features, the difference between greatest and least temperatures did not exceed 2° C (except for subirrigated soils, which had a limited sample size). These differences might appear negligible to lesser prairie-chickens compared to the 2-4° C temperature differences between microsite and patch locations and used locations.

Past studies have found that vegetation characteristics are important in predicting microclimate conditions (Suggitt et al. 2011; Carroll et al. 2016). These characteristics were more influential than topographic features in predicting microclimate conditions (Carroll et al. 2016). However, these studies investigated effects of broad vegetation classes such as herbaceous, low woody cover, and tall woody cover on microclimate conditions, not effects of point-specific herbaceous cover parameters such as visual obstruction, percent cover of grass, forbs, bare ground, shrubs, and litter on microclimate conditions. Therefore, continued research into effects of grassland vegetation structure and composition on microclimate conditions is recommended.

Knowing that female lesser prairie-chickens select thermal refugia based on vegetation characteristics that minimize thermal stress within certain patch types, managers can provide these characteristics on the landscape. Providing thermal refugia is important for grassland species because it limits thermal stress and has the potential to increase nest success, which has been shown to decrease with increased nest temperatures in both lesser and greater prairie-chickens (*Tympanuchus cupido*; Hovick et al. 2014; Grisham et al. 2016). One way to provide thermal refugia is to use a heterogeneity-based management system that offers domestic livestock an opportunity to select grazing patches such as patch-burn grazing or increased pasture size. These rangeland management strategies seek to focuses grazing on some sites while letting other areas rest, offering heterogeneity in available microclimates and offers lesser prairie-chickens and other grassland species the ability to select a location that suits their thermal needs (Fuhlendorf and Engle 2001; Fuhlendorf et al. 2009; Hovick et al. 2014; Kraft 2016). This style of management will also benefit many other grassland species if they experience the same thermal stresses and also attempt to minimize thermal stress (Walsberg 1981; With and Webb 1993; Gloutney and Clark 1997; Guthery et al. 2005; Bell et al. 2010; Borsdorf 2012; Larsson et al. 2013; Hovick et al. 2014; Cunningham et al. 2015; Martin et al. 2015).

My results are consistent with other studies on habitat selection by upland gamebirds in relation to microclimate conditions (Guthery et al. 2005; Larsson et al. 2013; Hovick et al. 2014; Carroll et al. 2015a, b; Tanner et al. 2016). Past studies found that upland gamebirds select areas that minimize thermal stress at nesting, brooding, and midday loafing sites. Vegetative heterogeneity is an important factor for the persistence of upland gamebirds and other ground nesting species in grass- and shrub-land landscapes (Guthery et al. 2005; Larsson et al. 2013; Hovick et al. 2014; Carroll et al. 2015a, b; Tanner et al. 2016). Providing heterogeneity of vegetation composition and structure on the landscape will be particularly important for lesser prairie-chickens as their range is expected to be subject to increases in average temperature and extreme temperature events as a result of projected climate change (Girvetz et al. 2009; Grisham et al. 2016). Furthermore, Grisham et al. (2013) predicted that low nest success driven by climate change would not allow for lesser prairie-chickens to persist in some areas as soon as 2050. Population projections demonstrate a need to manage areas within the lesser prairie-chickens range for heterogeneity in vegetation structure and composition, and therefore, microclimate conditions.

Management Implications

Given that heterogeneity in vegetation structure and composition provides the most diverse microclimate conditions, I recommend a management strategy that maximizes this in both space and time throughout the range of lesser prairie-chickens. Patch-burn grazing is a management strategy where only a portion of the landscape is burned each year, and grazers preferentially focus grazing efforts on these areas, generating a landscape heterogeneous in vegetation structure and composition (Fuhlendorf and Engle 2001). Patch heterogeneity generated through patch-burn grazing has been found to be readily used by lesser prairie-chickens in the eastern portion of their range (Chapter 1). Further research is needed to assess the viability of a patch-burn grazing system in the western portion of the lesser prairie-chicken range. Other management strategies that increase vegetation heterogeneity, and therefore microclimate heterogeneity on the landscape, include increasing pasture size allowing cattle to focus grazing on certain patches while ignoring others (Kraft 2016).

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Figures

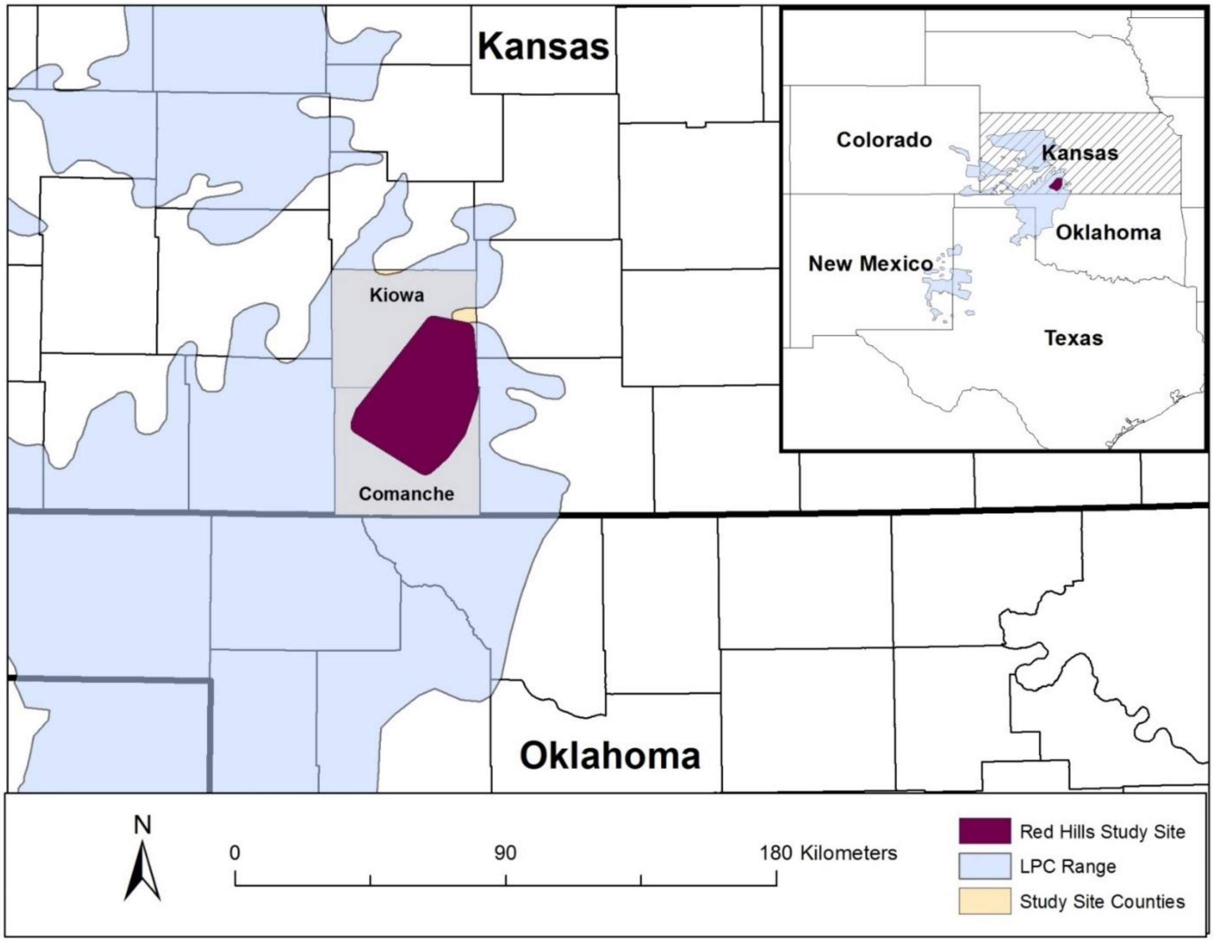

Figure 2-1: Location of the study area investigating the influence of microclimate conditions on lesser prairie-chickens in Kiowa and Comanche counties, Kansas, during summer 2015.

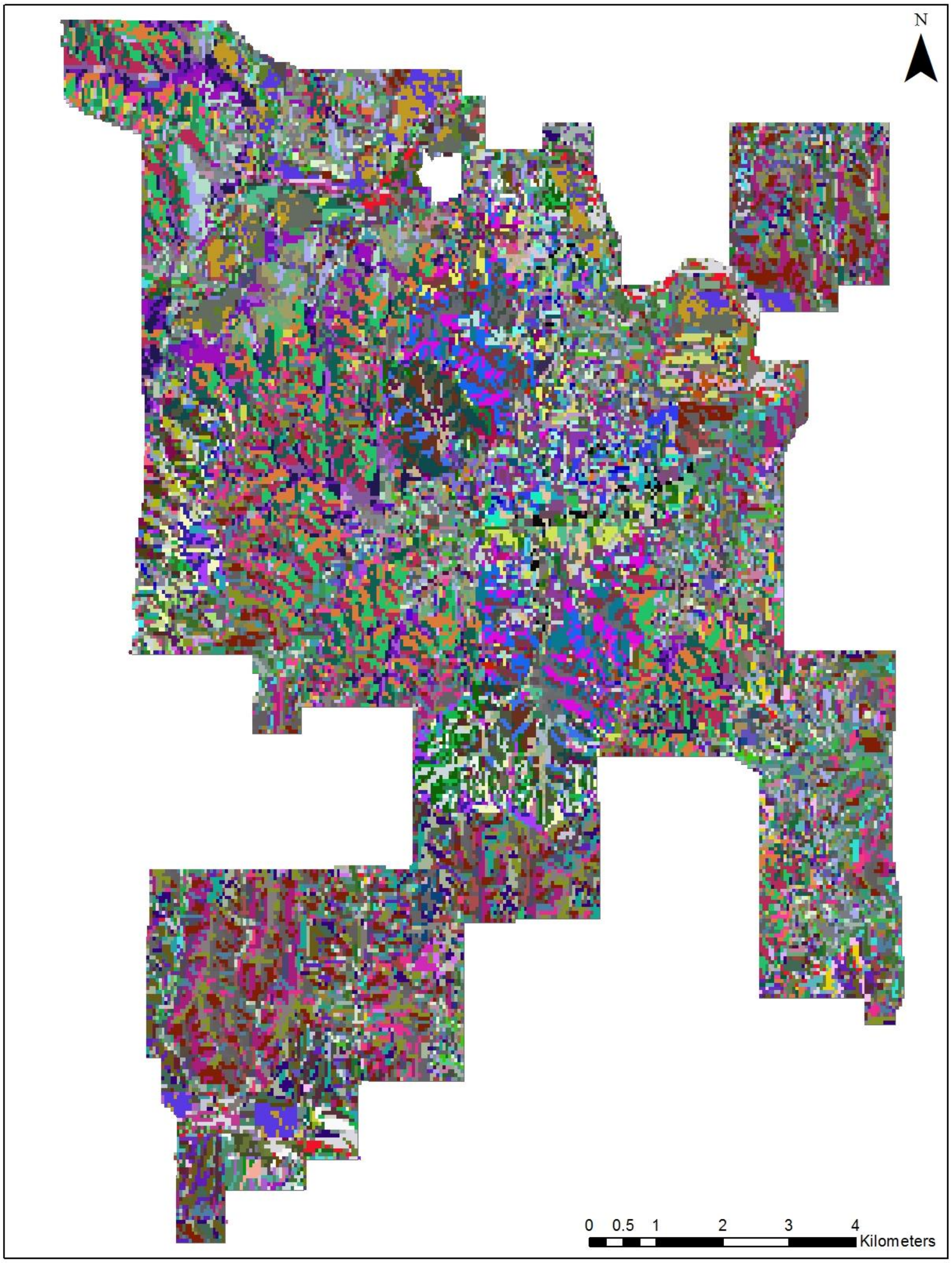

Figure 2-2: Landscape (13,250 ha) depicting 531 available patch-types sampled for microclimate characteristics in Kiowa and Comanche counties, Kansas during summer 2015. Different colors represent different combinations of landscape features (slope position, slope aspect, time-since-fire, tree densities, and soil type). Included to highlight the diversity of patches available on the landscape.

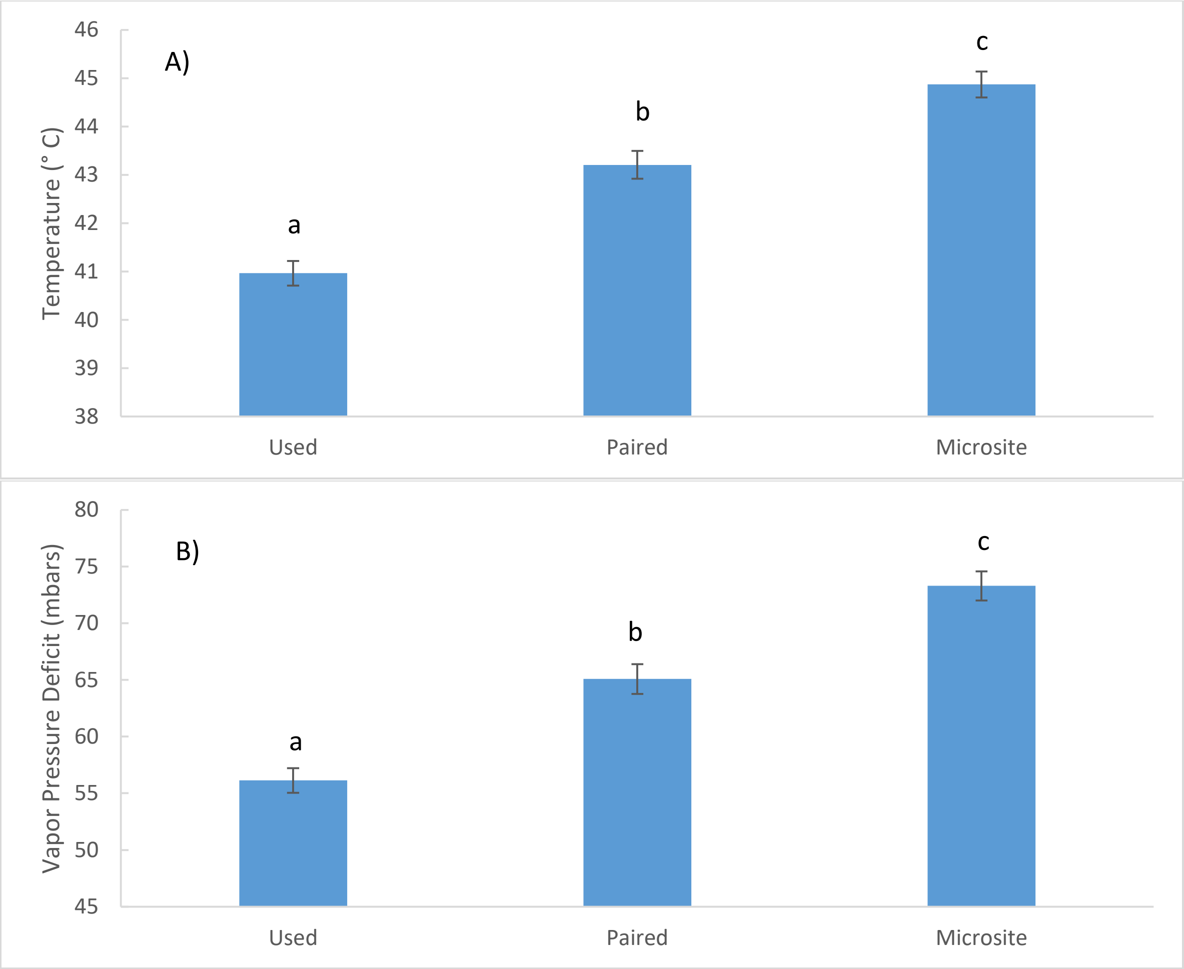

Figure 2-3: Difference between A) temperature (° C) and B) vapor pressure deficit (mbars) among used, patch (paired), and microsite microclimate at midday flush locations of female lesser prairie-chickens in Kiowa and Comanche counties, Kansas, during summer 2015. Error bars represent 95% confidence intervals, mean values with the same letter do not differ ($P > 0.05$).

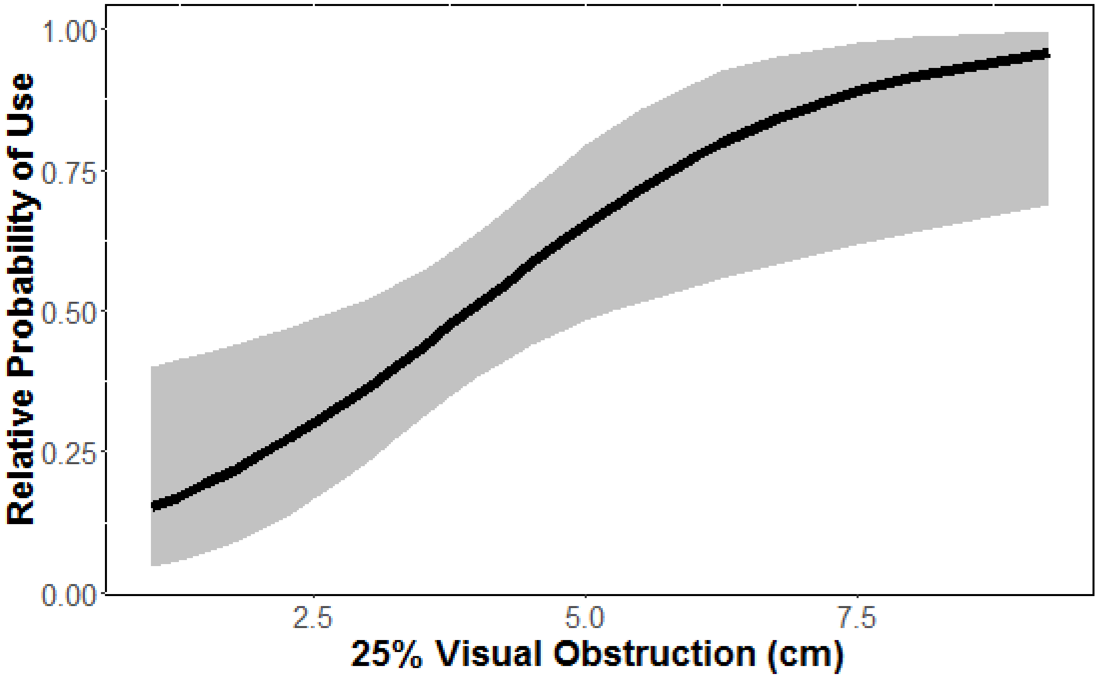

Figure 2-4 Linear model highlighting lesser prairie-chicken selection for visual obstruction at the 25% obstruction class at midday flush locations during summer 2015 in Kiowa and Comanche counties, Kansas.

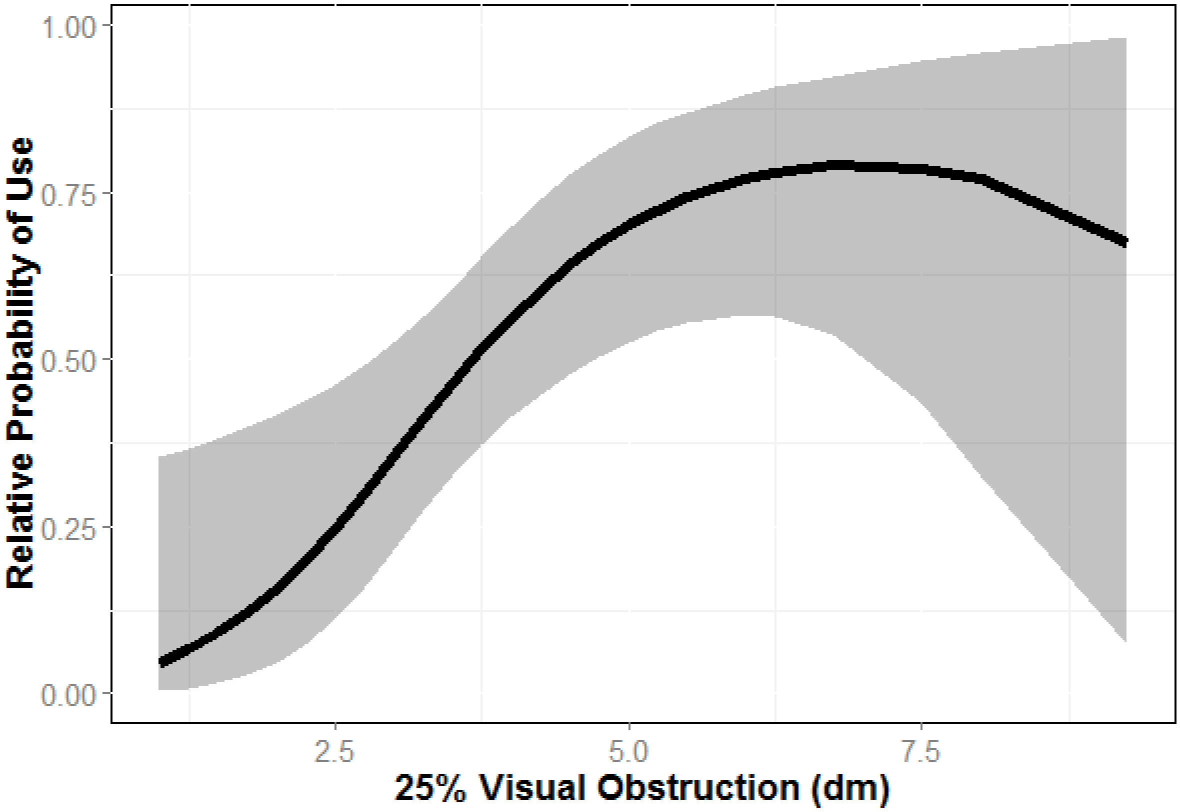

Figure 2-5: Quadratic model highlighting lesser prairie-chicken selection for visual obstruction at the 25% obstruction class at midday flush locations during summer 2015 in Kiowa and Comanche counties, Kansas.

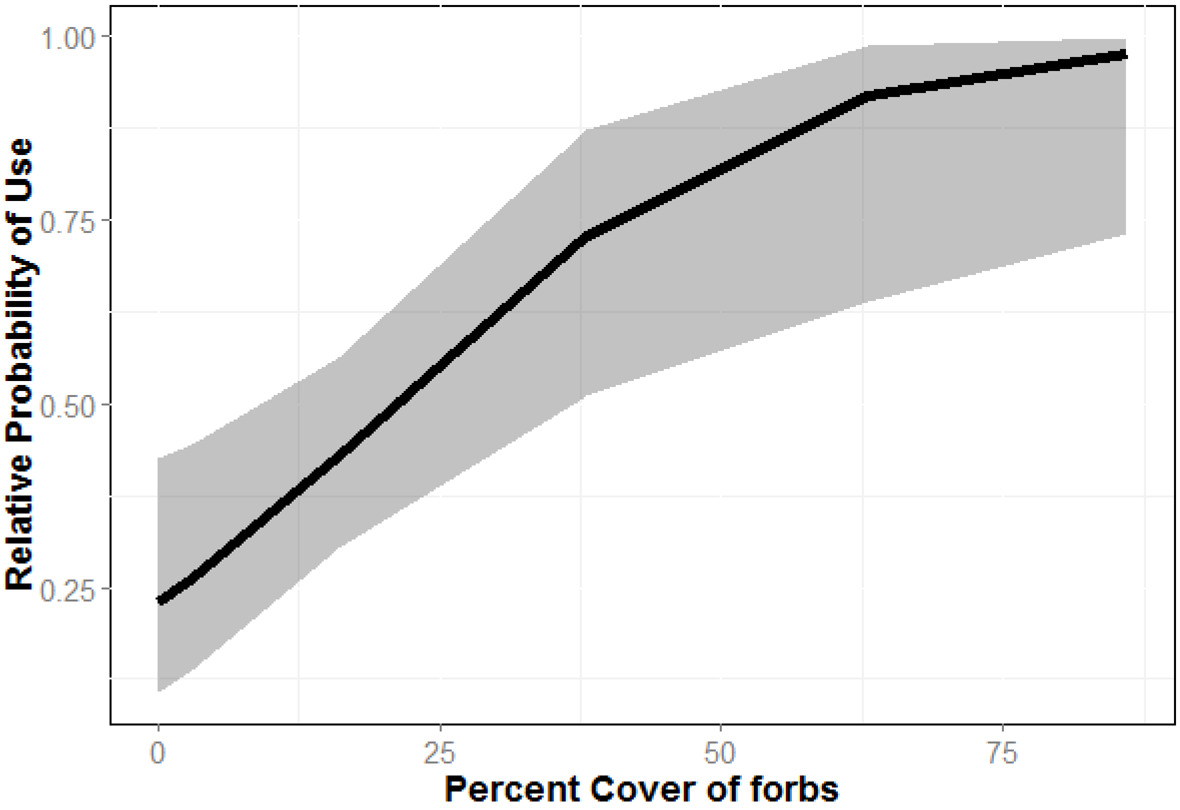

Figure 2-6: Linear model representing lesser prairie-chicken selection for percent cover of forbs at the patch scale for midday flush locations during summer 2015, Kiowa and Comanche counties, Kansas.

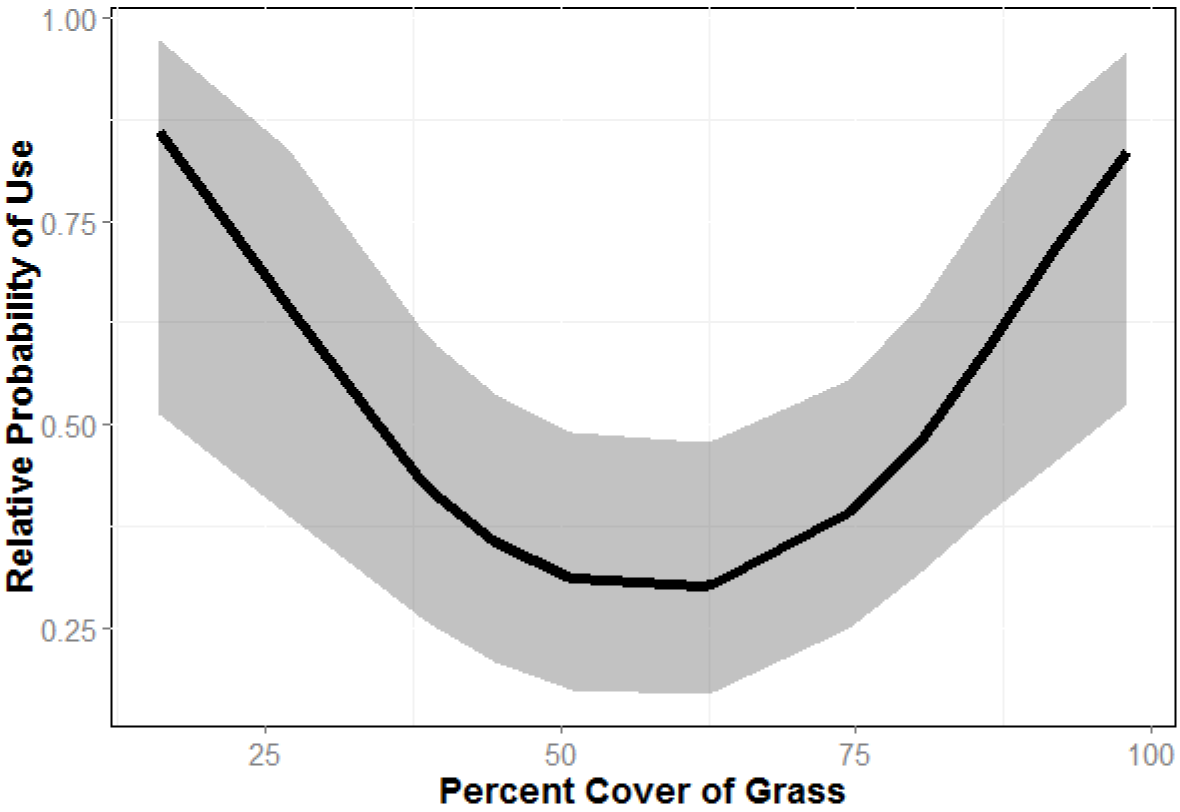

Figure 2-7: Quadratic relationship of the relative probability of female lesser prairie-chicken use and percent cover of grass at the microsite scale (4m) during midday, summer 2015 in Kiowa and Comanche counties, Kansas.

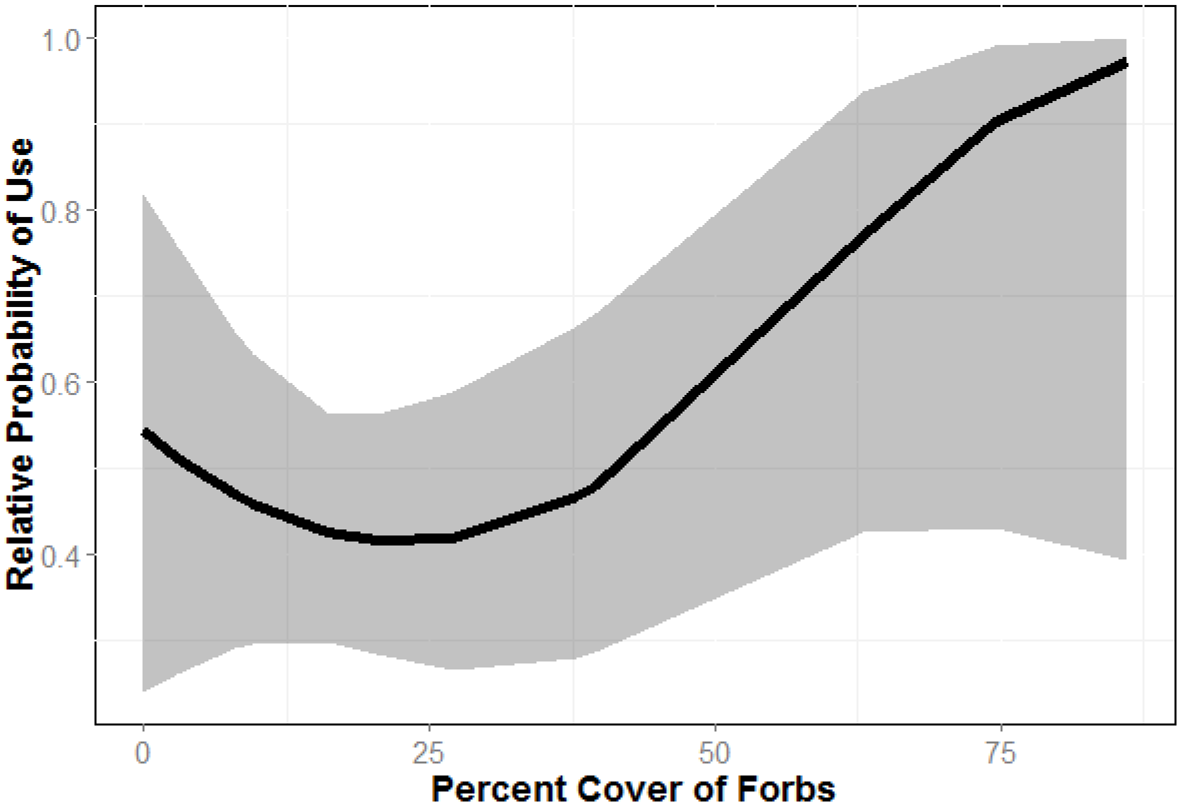

Figure 2-8: Quadratic relationship of the relative probability of female lesser prairie-chicken use and percent cover of forbs at the microsite scale (4m) during midday, summer 2015 in Kiowa and Comanche counties, Kansas.

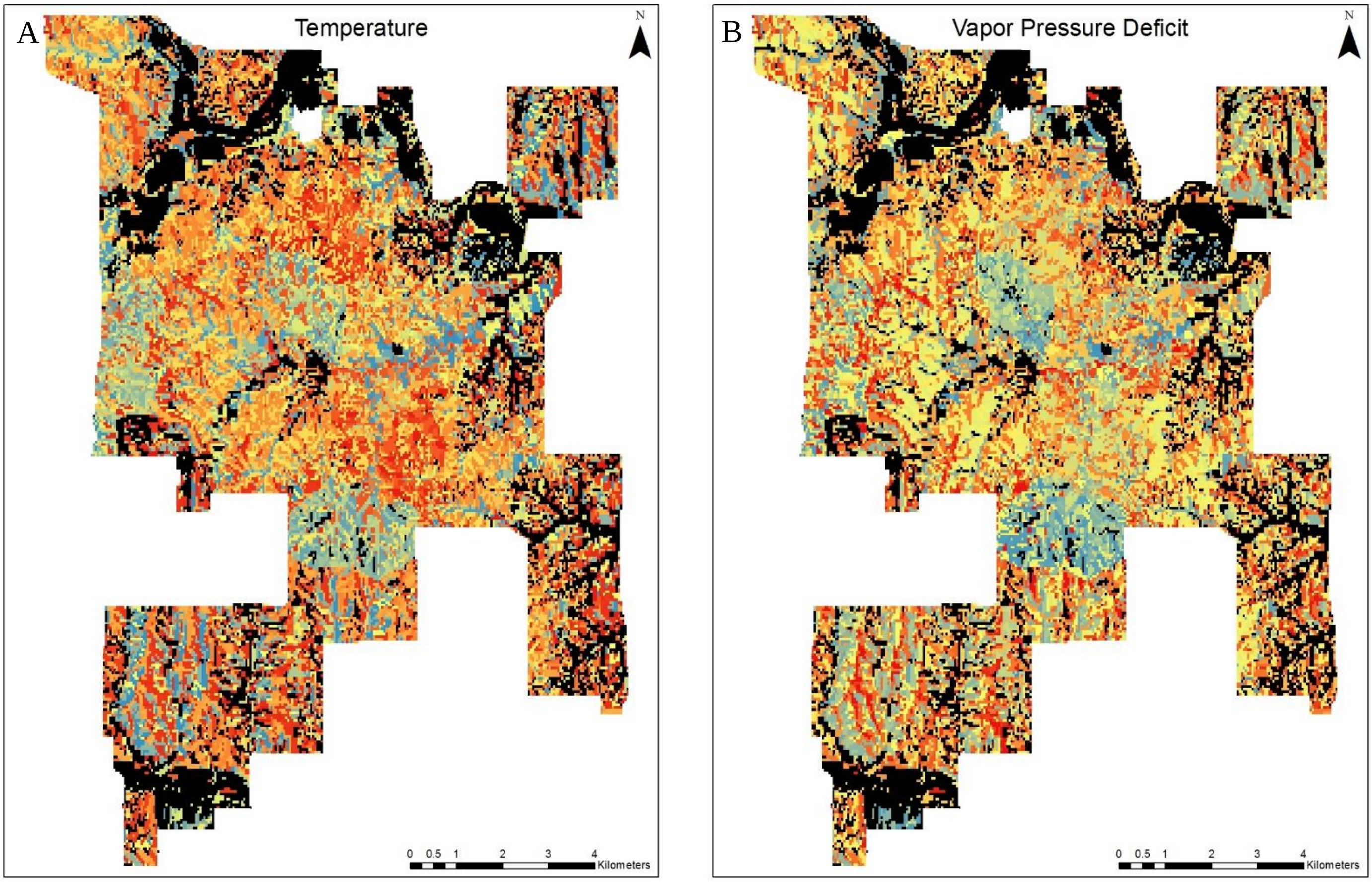

Figure 2-9: Available microclimate across the landscape derived from 664 iButtons placed in 376 unique patch types based on landscape features (slope position, slope aspect, time-since-fire, tree density, and soil type) in Kiowa and Comanche counties, Kansas, during the summer of 2015. A) represents the temperature conditions relative to ambient with blue colors representing smaller differences (lower temperatures) and red representing greater differences (higher temperatures) than ambient and B) representing vapor pressure deficit (VPD) differences from ambient, with blue areas representing smaller differences (lower VPD) and red representing areas with greater differences (greater VPD) than ambient. Black areas were not sampled.

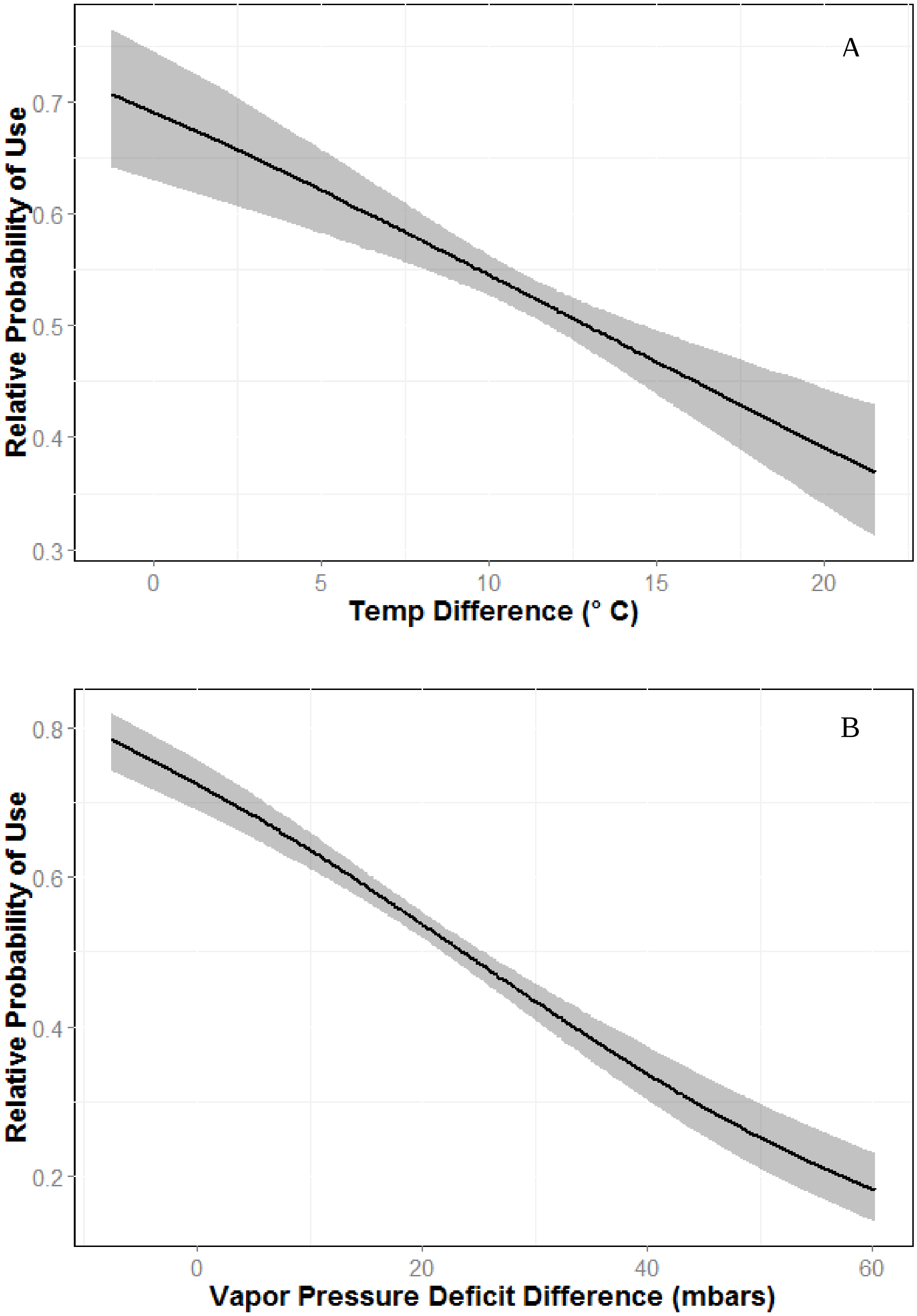

Figure 2-10 Linear models representing the relative probability of use by lesser prairie-chicken in relation to available A) temperature and B) vapor pressure deficit at the landscape scale during summer 2015 in Kiowa and Comanche counties, Kansas.

Tables

Table 2-1: Ranking of 10 models testing the relative influence of different visual obstruction classes on female lesser prairie-chicken habitat selection at the patch scale during midday, summer 2015 in Kiowa and Comanche counties, Kansas.

	K[a]	ΔAIC_C[b]	w_i[c]	Dev.[d]
25% visual obstruction (dm)	2	0[e]	0.25	81.66
Quadratic 25% visual obstruction (dm)	3	0.08	0.24	79.54
50% visual obstruction (dm)	2	0.39	0.21	82.06
Quadratic 50% visual obstruction (dm)	3	1.52	0.12	81.00
75% visual obstruction (dm)	2	1.74	0.1	83.42
Quadratic 75% visual obstruction (dm)	3	3.31	0.05	82.78
100% visual obstruction (dm)	2	5.45	0.02	87.12
Quadratic 100% visual obstruction (dm)	3	6.88	0.01	86.34
Quadratic 0% visual obstruction (dm)	3	7.88	0.00	87.36
0% visual obstruction (dm)	2	9.29	0.00	90.96

[a] Number of parameters

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

[c] Akaike weights

[d] Deviance

[e] Minimum $AIC_c = 85.86$

Table 2-2: Ranking of 10 models testing the relative influence of percent cover of grass, litter, forbs, bare ground, and shrubs on female lesser prairie-chicken habitat selection at the patch scale during midday, in Kiowa and Comanche counties, Kansas during summer 2015.

	K^a	$\Delta AIC_C{}^b$	$w_i{}^c$	Dev.^{d}
Forbs	2	0^e	0.55	78.62
Quadratic forbs	3	0.56	0.41	76.98
Grass	2	6.11	0.03	84.72
Quadratic grass	3	7.55	0.01	83.96
Quadratic shrub	3	12.24	0.00	88.66
Shrubs	2	12.56	0.00	91.18
Bare Ground	2	12.85	0.00	91.46
Quadratic litter	2	12.88	0.00	91.50
Litter	2	12.88	0.00	91.50
Quadratic bare	3	13.36	0.00	89.78

[a] Number of parameters
[b] Difference in Akaike's Information Criterion, adjusted for small sample size
[c] Akaike weights
[d] Deviance
[e] Minimum $AIC_c = 82.8$

Table 2-3: Ranking of 12 models assessing the relative influence of percent cover of grass, litter, forbs, bare ground, shrubs, and vegetation height on female lesser prairie-chicken habitat selection at the microsite scale during midday, in Kiowa and Comanche counties, Kansas during summer 2015.

	K[a]	ΔAIC_C[b]	w_i[c]	Dev.[d]
Quadratic grass	3	0[e]	0.53	81.72
Quadratic bare	3	3.12	0.11	84.84
Quadratic forbs	3	4.1	0.07	85.82
Quadratic shrub	3	4.16	0.07	85.88
Forbs	2	4.17	0.07	88.08
Shrub	2	5.03	0.04	88.94
Bare Ground	2	5.12	0.04	89.04
Vegetation Height	2	5.7	0.03	89.62
Litter	2	6.58	0.02	90.5
Grass	2	7.54	0.01	91.46
Quadratic vegetation height	3	7.84	0.01	89.56
Quadratic litter	3	7.89	0.01	89.62

[a] Number of parameters

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

[c] Akaike weights

[d] Deviance

[e] Minimum AIC_c = 88.11

Table 2-4: Coefficients for female lesser prairie-chicken habitat selection during midday based on landscape features, in Kiowa and Comanche counties, Kansas during summer 2015. Positive values represent selection for landscape features while negative values represent avoidance of landscape features.

Landscape Feature		Estimate	
		Beta Estimate ± 95% CI	*P* ≤
Slope Position			
	Lowlands	-1.215 ± 0.226	0.001
	Uplands	1.733 ± 0.264	0.001
	Slopes	1.402 ± 0.243	0.001
Slope Aspect			
	East	0.488 ± 0.131	0.001
	South	-0.587 ± 0.188	0.001
	West	-0.930 ± 0.210	0.001
	North	-0.215 ± 0.185	0.023
Time-since-fire			
	Year-of-fire	1.092 ± 0.156	0.001
	1-year post-fire	-2.001 ± 0.256	0.001
	>2-year post-fire	-1.138 ± 0.178	0.001
Tree Density			
	<2 Trees per ha	0.371 ± 0.074	0.001
	2-10 Trees per ha	-3.158 ± 0.545	0.001
	>10 Trees per ha	-5.349 ± 1.968	0.001
Soil Type			
	Sandy	0.776 ± 0.197	0.001
	Clay	-0.369 ± 0.223	0.001
	Kiowa Shale	-6.147 ± 1.975	0.001
	Loamy/limy	-0.896 ± 0.229	0.001
	Subirrigated	-13.343 ± 450.072	0.954

Table 2-5: Mean vapor pressure deficit (mbars; ±95% CI) and temperature (° C; ±95% CI) differences from ambient among landscape features (slope position, slope aspect, time-since-fire, tree density, and soil type) in Kiowa and Comanche counties, Kansas during summer 2015.

	Microclimate Variable*	
Landscape Feature	Vapor Pressure Deficit	Temperature
Slope Position		
Lowlands	20.26 ± 0.36^a	10.31 ± 0.12^a
Uplands	29.54 ± 0.64^c	12.26 ± 0.12^c
Slope	22.1 ± 0.22^b	11.57 ± 0.08^b
Aspect		
East	24.48 ± 0.39^c	11.64 ± 0.11^c
South	25.36 ± 0.51^d	12.09 ± 0.12^d
West	21.09 ± 0.34^a	11.19 ± 0.11^b
North	21.81 ± 0.35^b	10.73 ± 0.15^a
Time-since-fire		
Year-of-fire	16.07 ± 0.52^a	9.34 ± 0.13^a
1-year post-fire	22.68 ± 0.45^b	11.95 ± 0.14^c
>2-years post-fire	24.64 ± 0.25^c	11.65 ± 0.07^b
Tree Density		
<2 trees/ha	22.68 ± 0.24^a	11.37 ± 0.07^b
2-10 trees/ha	25.58 ± 0.6^c	12.16 ± 0.17^c
>10 trees/ha	24.5 ± 0.64^b	10.9 ± 0.24^a
Soil Type		
Sandy	25.47 ± 0.55^e	12.19 ± 0.13^e
Clay	21.54 ± 0.27^b	11.54 ± 0.09^c
Kiowa Shale	23.21 ± 0.43^c	11.84 ± 0.13^d
Loamy/limy	24.19 ± 0.42^d	10.98 ± 0.12^b
Subirrigated	13.99 ± 1.98^a	8.3 ± 0.92^a

*Means followed by the same superscript do not differ among landscape patches within each landscape feature variable.

Chapter 3 - Variation in lesser prairie-chicken vegetation use and availability across the northern extent of their range

Introduction

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie grouse found in the Southern Great Plains of the United States that has experienced a >90% population decline over the past century (Taylor and Guthery 1980; Hagen et al. 2004; Hagen and Giesen 2005; McDonald et al. 2014). Lesser prairie-chickens require large patches of grasslands to survive and reproduce, and the majority of their population decline has been attributed to the conversion or degradation of native grassland by row-crop agriculture, energy exploitation, invasive species, and tree encroachment (Fuhlendorf et al. 2002; Hagen and Giesen 2005; Boal and Haukos 2016; Haukos and Zavaleta 2016). Population declines and ongoing conversion of grasslands led the United States Fish and Wildlife Service (USFWS) to list the lesser prairie-chicken as threatened under the Endangered Species Act in April 2014 (U.S. Fish and Wildlife Service 2014). However, in September 2015, a federal judge in Texas vacated this decision (*Permian Basin Petroleum Association et al. v. Department of Interior, U.S. Fish and Wildlife Service*, [Case 7:14-cv-00050-RAJ, U.S. District Court, Western District of Texas, Midland-Odessa Division]), resulting in considerable uncertainty regarding the regulatory status of the lesser prairie-chicken. Despite regulatory status uncertainty, the initial petition to list and eventual listing of the lesser prairie-chicken prompted a number of conservation agreements and management actions to benefit lesser prairie-chickens across their range (Rodgers 2016).

Conservation agreements and management recommendations target four ecoregions currently occupied by lesser prairie-chickens: Sand Shinnery Oak Ecoregion, Mixed-Grass Prairie Ecoregion; Sand Sagebrush Prairie Ecoregion, and the Short-Grass Prairie/ Conservation

Reserve Program (hereafter CRP) Mosaic Ecoregion (Van Pelt et al. 2013; McDonald et al. 2014). The Sand Shinnery Oak Ecoregion in western Texas and eastern New Mexico is characterized by sand shinnery oak (*Quercus harvardii*) and represents the most arid climate of the species extant range (McDonald et al. 2014; Grisham et al. 2016a, b). The Mixed-Grass Prairie Ecoregion of south-central Kansas, northern Oklahoma, and the northeastern Texas panhandle is characterized by mixed-grass prairie with a relatively mild climate (most mesic portion of the species range; McDonald et al. 2014; Wolfe et al. 2016). The Sand Sagebrush Prairie Ecoregion of southeastern Colorado and southwestern Kansas is characterized by sand sagebrush (*Artemisia filifolia*) prairie and relatively dry climate (McDonald et al. 2014; Haukos et al. 2016). The Short-Grass Prairie/CRP Mosaic Ecoregion is characterized by a matrix of USDA Conservation Reserve Program (CRP) grasslands, short-grass prairie, mixed-grass prairie, and row-crop agriculture, with a distinct precipitation gradient of semi-arid to relatively mesic (McDonald et al. 2014; Dahlgren et al. 2016).

Management recommendations within these ecoregions focus on providing nesting habitat, which is characterized by vegetation composition and recommendations specific to each ecoregion (Hagen et al. 2013; Van Pelt et al. 2013). Managing solely for vegetation composition at nests may be problematic because lesser prairie-chickens require different vegetation characteristics during different parts of their annual cycle; therefore, nesting cover may not be selected for year-round vegetation or habitat requirements (Hagen and Giesen 2005; Haukos and Zavaleta 2016). Additionally, managing for composition may not be the best action given the primary management within native grasslands for lesser prairie-chickens is cattle (*Bos taurus*) grazing (Elmore and Dahlgren 2016; Kraft 2016). Cattle grazing readily influences vegetation structure, with increased grazing pressure on portions of the landscape decreasing vegetation height; therefore, it would make sense to manage native grasslands based on vegetation structure (Derner et al. 2009). Limited research is available on lesser prairie-chicken structural requirements throughout the year; however, lesser prairie-chickens select nest sites with greater visual obstruction than available (Davis et al. 1979, 1981; Haukos and Smith 1989; Riley et al. 1992; Patten et al. 2005; Davis et al 2009; Hagen et al. 2013; Lautenbach 2015). Given that management recommendations are based on vegetation structure for nests and are similar across their range, there is a need to identify used vegetation structure during all seasons of the year and across the range of the species.

A challenge for determining management recommendations for vegetation structure is the precipitation gradient that occurs from west to each across the lesser prairie-chicken range (Grisham et al. 2016a). Across the northern portion of the lesser prairie-chicken range (Kansas and Colorado), average annual precipitation ranges from ~40 cm in the west to ~65 cm in the east. This precipitation gradient results in differential growth potential for herbaceous vegetation across the northern range of the lesser prairie-chicken, with the potential for taller, more robust herbaceous vegetation in the east relative to the west. Given this variation in precipitation, it is more difficult to obtain the recommended vegetation structure for lesser prairie-chicken nesting solely based on herbaceous vegetation in the western portion of the species range (D. Sullins, unpublished data).

My primary goal was to assess the relative importance of vegetation structure and composition for lesser prairie-chicken use across the precipitation gradient of the northern extent of their range in Kansas and Colorado. My objectives were to 1) assess the relative influence of vegetation composition and structure in driving use across seasons and the spatial precipitation gradient and 2) determine how lesser prairie-chickens select vegetation relative to availability across a precipitation gradient.

Methods:

Study Area:

I used four study areas located across the west to east precipitation gradient within three defined Ecoregions of the northern portion of the lesser prairie-chicken range (Figure 3-1). The Colorado study area was located on the western edge of the lesser prairie-chickens range in southeastern Colorado. This study area was comprised of two sites, one on private land within Cheyenne County and the other on private lands in Prowers County. The Prowers County study site (1,146 ha) was located within the Short-Grass Prairie/CRP Mosaic Ecoregion with principally loamy soils. Land use in this area was dominated by dryland and irrigated row-crop agriculture, but included grasslands (primarily CRP with some native pastures used for cattle grazing). The Cheyenne County study site (16,968 ha) was located within the Sand Sagebrush Prairie Ecoregion on sandy soils. Primary land use was cattle grazing on native sand sagebrush grasslands. The 30-year average annual precipitation and annual temperature for this study area is 40.3 cm and 11.8° C, respectively. The 30-year average January minimum and July maximum temperature is -9.7° C and 33.9° C, respectively (US Climate Data, accessed 2/11/2016, http://www.usclimatedata.com). During the study period (2013-2015), the average annual temperature was 12.6° C, average annual precipitation was 44.5 (36.88 – 50.06 cm), average January minimum temperature was -10° C (-11 to -9° C), and the average July maximum temperature was 34° C (34 to 34° C; Weather Underground, accessed 2/14/2016, http://www.wunderground.com). Dominant vegetation in this region included blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), sideoats grama (*B. curtipendula*), little bluestem

(*Schizachyrium scoparium*), sand sagebrush, kochia (*Kochia scoparium*), and Russian thistle (*Salsola tragus*). Major crops in this region were wheat and grain sorghum.

The northwest Kansas study area consisted of two study site, one in Gove County and the other in Logan County. This study area was at the northern extent of the lesser prairie-chicken range within the Short-Grass Prairie/CRP Mosaic Ecoregion. Study sites were located on private land in Gove County (study site size: 87,822 ha), with the Logan County study site centered on the Smoky Valley Ranch (41,940 ha), which is owned and operated by The Nature Conservancy. The 30-year average annual temperature and annual precipitation is 10.8° C and 51.0 cm, respectively. The 30-year average January low and July maximum temperatures is -9.2° C and 32.7° C, respectively (US Climate Data, accessed 2/11/2016, http://www.usclimatedata.com). During the study period, the average annual temperature was 12° C, average annual precipitation was 45.0 cm (37.6 – 50.4 cm), average January minimum temperature and July maximum were -7° C (-9 to -6° C) and 31.3° C (31 to 32° C), respectively (Weather Underground, accessed 2/14/2016, http://www.wunderground.com). These sites were located within a mosaic of short-grass and mixed-grass prairies, CRP grasslands, and row-crop agriculture on silt loam soils. Land use practices in this area were cattle production, row-crop agriculture, and CRP grasslands. Dominant vegetation in native range areas included blue grama, hairy grama, sideoats grama, buffalo grass (*Bouteloua dactyloides*), little bluestem, big bluestem, Illinois bundleflower (*Desmanthus illinoenisis*), prairie sunflower (*Helianthus petiolaris*), annual buckwheat (*Eriogonum annum*), sand milkweed (*Asclepias arenaria*), nine-anther dalea (*Dalea enneandra*), and western ragweed (*Ambrosia psilostachya*; Lauver et al. 1999). Species planted in the CRP grasslands in this area included little bluestem, sideoats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalo grass, and Indian grass (*Sorghastrum nutans*; Fields et al. 2006). After original planting of CRP in the late 1980s, some fields were inter-seeded with forbs in the mid to late 1990s including sweet clover (*Melilotus* spp.), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower, purple prairie-clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*) (Fields et al. 2006). Major crops in this area included wheat, grain sorghum, and corn.

The Clark County study area (47,466 ha) was located along the ecotone of the Mixed-Grass Prairie and Sand Sagebrush Prairie Ecoregions. The 30-year average annual temperature and annual precipitation are 13.3° C and 58.0 cm, respectively. The 30-year average January minimum and July maximum temperatures are -8.4° C and 34.7° C, respectively (US Climate Data, accessed 2/11/2016, http://www.usclimatedata.com). Over the duration of the study, average annual temperature was 13.9° C, average annual precipitation was 65.4 cm (50.9 – 80.3 cm), average January minimum July maximum temperatures were -5.3° C (-5 to -6° C) and 31.7° C (30 to 33° C), respectively (Weather Underground, accessed 2/14/2016, http://www.wunderground.com). Soils in this area were primarily classified as loamy or sandy, but also contained alkali flats along major drainages. Land uses in this area were dominated by cattle production and row-crop agriculture. Dominant vegetation in this area included little bluestem, sideoats grama, blue grama, hairy grama, big bluestem, alkali sacaton (*Sporobolus airoides*), Russian thistle, kochia, annual sunflower (*Helianthus annuus*), and sand sagebrush (Lauver et al. 1999).

The Red Hills study area was located in Kiowa and Comanche counties, Kansas, and encompassed 49,111 ha. This study area was located on the eastern edge of the lesser prairie-chickens range in the Mixed-Grass Prairie ecoregion. This study site was located within the Red Hills region of south-central Kansas and characterized by mixed-grass prairie on loamy soils.

The 30-year average annual temperature and annual precipitation are 12.6° C and 63.9 cm, respectively. The 30-year average January minimum and July maximum temperature are -7.8° C and 33.3° C, respectively (US Climate Data, accessed 2/11/2016, http://www.usclimatedata.com). Over the duration of the study, average annual temperature was 13.15° C, average annual precipitation was 68.3 cm (53.4 – 83.9 cm), average January minimum and July maximum temperatures were -6° C (-5 to -7° C) and 31.3° C (30 to 33° C), respectively (Weather Underground, accessed 2/14/2016, http://www.wunderground.com). The dominant land use was cattle production with some row-crop agriculture. Dominant vegetation in this region included little bluestem, hairy grama, blue grama, sideoats grama, big bluestem, Indian grass, buffalograss, sand dropseed, Louisiana sagewort (*Artemisia ludoviciana*), western ragweed, sand sagebrush, Chickasaw plum (*Prunus angustifolia*), and eastern redcedar (*Juniperus viginiana*; Lauver et al. 1999).

Field Methods

Available Vegetation: Available vegetation within each study area was measured by stratifying each study area into patches of similar vegetation composition and land use (row-crop agriculture, native grassland, and CRP grassland) with a minimum patch size of 10 ha. Native grassland patches were further categorized by elevation (upland or lowland), time-since-fire (where applicable), and USDA Natural Resource Conservation Service (NRCS) Ecological Site Description (hereafter ESD). All patches were delineated using ArcGIS 10.2 (ESRI Inc., 2013, Redlands, CA).

Within each patch, I conducted random vegetation surveys to measure vegetation composition and structure. I established 5-10 random points in each patch using ArcGIS 10.1. Vegetation surveys followed the protocol adopted by the USDA NRCS Lesser Prairie-Chicken

Initiative and Lesser Prairie-Chicken Interstate Working Group as sampling strategies for standardization among field sites (Pitman et al. 2005; Grisham 2012). At each random point, I centered two perpendicular 8-m transects on the point Universal Transverse Mercator coordinates (UTMs) in north-south and east-west orientations. At the point center and 4 m to the north, south, east, and west, I estimated percent cover of grass, forbs, litter, and bare ground using a modified (60 cm x 60 cm) Daubenmire frame (Daubenmire 1959). At each point, I estimated height of visual obstruction at 100%, 75%, 50%, 25%, and 0% obstruction classes to the nearest dm from a distance of 4 m and a height of 1 m using a Robel pole (Robel et al. 1970). Random vegetation surveys were conducted in spring (April and May), summer (June, July, and August), and fall/winter (November, December, January, and February).

Lesser prairie-chicken vegetation use: To assess female lesser prairie-chicken vegetation use, I trapped birds at lek sites using walk-in traps (Haukos et al. 1990; Schroeder and Braun 1991) and drop nets (Silvy et al. 1990). I assessed the sex of each captured bird using tail coloration, pinnae length, and eye comb presence (Copelin 1963). Females were fitted with either a 22-g Global Positioning System (GPS) satellite transmitter (platform transmitting terminal or PTT) from Microwave Telemetry Inc. (Columbia, Maryland) or a 15-g very-high-frequency (VHF) radio transmitter from Advanced Telemetry Systems (Isanti, Minnesota). Satellite and VHF transmitters were assigned at random to every other bird. The PTTs were rump mounted using Teflon® ribbon (Dzialak et al. 2011) and contained a sensor to transmit calibrated indices for unit temperature and bird motion to determine if the bird was alive. The VHF transmitters were bib/collar mounted and had a 10-12 hr. mercury mortality switch.

Lesser prairie-chickens fitted with VHF radio transmitters were located using triangulation (Cochran and Lord 1963). Approximate locations (UTMs) and error polygon associated with the triangulations were determined using Location of a Signal (Ecological Software Solutions LLC, Hegymagas, Hungary). Individual birds were located 3-4 times each week. Lesser prairie-chickens marked with satellite transmitters were tracked using the Argos system. GPS locations were recorded approximately every 2 hours between 0600-2400 resulting in approximately 10 locations per day. Potential location error associated with the use of these transmitters was <18 m. Locations were downloaded weekly.

I conducted vegetation surveys following the same protocol as the patch vegetation random points at two randomly chosen locations per bird per week across all seasons. Used vegetation surveys were divided into three seasons, spring (15 March – 31 May), summer (1 June – 14 September), and fall/winter (15 September – 14 March).

Statistical Analysis

I used a multivariate analysis of variance (MANOVA) to identify if female lesser prairie-chickens differently used vegetation across a precipitation gradient relative to available vegetation and during the different seasons. Following a significant MANOVA (Wilks' lambda $P < 0.05$) for an interaction among study area, use vs available, and season I continued my analysis by season. I used a MANOVA to test for a significant interaction between use vs available and study area within each season; following a significant MANOVA (Wilks' lambda $P < 0.05$), I proceeded with analysis by site (use vs available) or by used vegetation among study areas. To identify if there was a difference between used vegetation characteristics among study areas, I used a MANOVA; following a significant MANOVA (Wilks' lambda $P < 0.05$) I used an analysis of variance (ANOVA) with a Tukey post hoc to identify differences ($P < 0.05$) for each dependent variable among study sites during each season. To identify if there was a significant difference between used and available vegetation characteristics within each study area, I used a MANOVA, following a significant MANOVA (Wilks' lambda $P < 0.05$), I used an ANOVA to identify if there were differences ($P < 0.05$) for each dependent variable during each season. I analyzed vegetation composition and structure in separate models.

Results

During 2013, 2014, 2015, and early 2016, I conducted a total of 19,593 vegetation samples at both lesser prairie-chicken use sites and available sites. 8,672 samples were conducted at lesser prairie-chickens use sites while 10,921 were sampled at available sites. Of the used samples, 2,536 were recorded during the spring (15 March – 31 May), 3,046 during the summer (1 June – 14 September), and 3,090 during the fall/winter (15 September – 14 March). Of the available points, 3,100, 5,859, and 1,962 were from spring, summer, and fall/winter, respectively. In total, 1,238 used sites were sampled in Colorado, 3,140 used sites were sampled in northwest Kansas, 1,221 used sites were sampled in Clark County, and 3,073 used sites were sampled in the Red Hills. There was a significant interaction among season, study area, and used vs available (Wilks' lambda = 0.99, $P < 0.001$), so I proceeded to analyze these data by season.

Spring

During the spring (15 March – 31 May), a total of 2,536 used location were sampled; 312 samples were from Colorado, 894 samples were from northwest Kansas, 356 samples were from Clark County, and 974 samples were from the Red Hills. A total of 3,100 available samples were measured during spring; no samples were measured in Colorado during spring, 914 samples were measured in northwest Kansas, 756 samples were measured in Clark County, and 1,430 samples were measured in the Red Hills. There was a significant interaction between study area and use vs available for both vegetation composition (Wilks' lambda = 0.96, $P < 0.001$) and structure (Wilks' lambda = 0.98, $P < 0.001$), so I proceeded with analysis of vegetation composition and structure for used sites among study areas along a precipitation gradient and tested use vs available within each study area.

Used vegetation along a precipitation gradient: During spring, used vegetation composition varied by study area (Wilks' lambda = 0.93, $P < 0.001$). During spring, females differentially used grass ($F_{3, 5,500} = 235.6$, $P < 0.001$), litter ($F_{3, 5,500} = 206.2$, $P < 0.001$), forb ($F_{3, 5,490} = 299.5$, $P < 0.001$), and bare ground ($F_{3, 5,489} = 176.3$, $P < 0.001$) cover among study areas; however, there was not pattern between precipitation and percent cover of grass or litter (Figure 3-2 A, D). For percent cover of litter and forbs, there were general trends along a precipitation gradient, with the percent cover of forbs at used sites increasing with increasing precipitation and percent cover of litter at used sites decreasing with increased precipitation (Figure 3-2 B, C). Vegetation structure also varied by study site (Wilks' lambda = 0.89, $P < 0.001$). Females differentially used vegetation structure at 100% ($F_{3, 5,512} = 58$, $P < 0.001$), 75% ($F_{3, 5,512} = 64.5$, $P < 0.001$), 50% ($F_{3, 5,513} = 102.8$, $P < 0.001$), 25% ($F_{3, 5,513} = 213.4$, $P < 0.001$), and 0% ($F_{3, 5,513} = 195.9$, $P < 0.001$) obstruction classes among study areas; however, there were no trends along a precipitation gradient (Figure 3-3).

Use vs available vegetation during spring

Northwest Kansas: Within northwest Kansas, used vegetation differed from available both compositionally (percent cover; Wilks' lambda = 0.95, $P < 0.001$) and structurally (visual obstruction; Wilks' lambda = 0.90, $P < 0.001$). In northwest Kansas, female lesser prairie-chickens used sites with an average of 1.9% less grass cover, 1.4% greater litter cover, 2.6% greater forb cover, and similar bare ground cover to available during spring (Table 3-1). Females used sites with similar visual obstruction at 100%, 75%, 50%, and 25% obstruction classes to available and sites with average of 1.2-times lower visual obstruction than available at the 0% obstruction class during spring in northwest Kansas (Table 3-2).

Clark County: During spring, female lesser prairie-chicken vegetation use differed from available compositionally (Wilks' lambda = 0.98, $P < 0.001$). Compositionally, females used sites with similar percent cover of grass, litter, and forbs and sites with an average of 4.3% more bare ground than available during the spring (Table 3-1). Although vegetation use did not statistically vary structurally (Wilks' lambda = 0.99, $P = 0.13$), females tended to use sites with shorter visual obstruction than available (Table 3-2).

Red Hills: During spring, female lesser prairie-chickens within the Red Hills used vegetation composition (Wilks' lambda = 0.86, $P < 0.001$) and structure (Wilks' lambda = 0.92, $P < 0.001$) differentially from available. Females used sites with an average of 7.4% less grass, 8.5% more bare ground, 5.5% more forbs, and 5.2% less bare ground than available (Table 3-1). They used sites with 1.2-times shorter visual obstruction at 100% obstruction, 1.1-times greater visual obstruction at 25% obstruction, and 1.1-times greater obstruction at 0% obstruction compared to available; used obstruction heights were similar to available at 75% and 50% obstruction (Table 3-2).

Summer

During summer (1 June – 14 September), I collected a total of 3,043 vegetation samples from female lesser prairie-chicken use site; 570 from Colorado, 1,049 from northwest Kansas, 447 from Clark County, and 977 from the Red Hills. I measured vegetation characteristics at 5,859 available sites; 359 were in Colorado, 1,456 were in northwestern Kansas, 1,151 were in Clark County, and 2,893 were in the Red Hills. There was a significant interaction between used vs available and study area for both composition (Wilks' lambda = 0.99, $P < 0.001$) and structure

(Wilks' lambda = 0.97, $P < 0.001$), so I continued my analysis comparing used vegetation characteristics among study areas and tested use vs available within each study area.

Used vegetation characteristics along a precipitation gradient: During summer, vegetation use among study areas differed both compositionally (Wilks' lambda = 0.92, $P < 0.001$) and structurally (Wilks' lambda = 0.92, $P < 0.001$). During summer, females differentially used grass ($F_{3,\,8{,}758} = 203.6$, $P < 0.001$), litter ($F_{3,\,8{,}758} = 512.8$, $P < 0.001$), forbs ($F_{3,\,8{,}758} = 292.1$, $P < 0.001$), and bare ground ($F_{3,\,8{,}758} = 296.3$, $P < 0.001$) among study areas; however, there was no observed pattern between increased precipitation and grass and bare ground cover. There was a general pattern of decreased litter cover use as precipitation increased with females in Colorado using 9% more litter cover than females in the Red Hills (Figure 3-4B). There was an opposite pattern for forb cover, with forb cover use increasing as precipitation increased; females in Colorado used 10% less forb cover than females in the Red Hills (Figure 3-4C). Females differentially used vegetation structure during summer at 100% ($F_{3,\,8{,}790} = 112.7$, $P < 0.001$), 75% ($F_{3,\,8{,}790} = 159$, $P < 0.001$), 50% ($F_{3,\,8{,}790} = 159.1$, $P < 0.001$), 25% ($F_{3,\,8{,}790} = 272.3$, $P < 0.001$), and 0% ($F_{3,\,8{,}790} = 195.4$, $P < 0.001$) obstruction classes among study areas; however, there was no trend along the precipitation gradient for 25% and 0% obstruction classes (Figure 3-5). Along the precipitation gradient, visual obstruction at used sites increased with increased precipitation at 100%, 75%, and 50% visual obstruction (Figure 3-5). Females in the Red Hills used, on average, vegetation with 2-times greater visual obstruction heights at 100% and 75% visual obstruction and 1.75-times greater obstruction heights at 50% obstruction than females in Colorado (Figure 3-5).

Use vs available vegetation during summer

Colorado: During summer, female lesser prairie-chickens used vegetation composition (Wilks' lambda = 0.91, $P < 0.001$) and composition (Wilks' lambda = 0.94, $P < 0.001$) differently than available. During summer, females used sites with similar percent cover of litter and bare ground to available and they used sites with an average of 5% less grass cover and 4.5% less forb cover than available (Table 3-3). They used sites with similar visual obstruction at 100%, 75%, and 50% obstruction to available, but used sites with an average of 1.2-times shorter obstruction at 25% and 1.1-times shorter at 0% compared to available (Table 3-4).

Northwest Kansas: During summer in northwest Kansas, female vegetation use differed both compositionally (Wilks' lambda = 0.94, $P < 0.001$) and structurally (Wilks' lambda = 0.97, $P < 0.001$) from available. Females used sites with an average of 4% greater grass and forb cover and an average of 5.5% less litter cover and 4% less bare ground cover (Table 3-3). Females used sites with similar obstruction heights to available at both 100% and 75% obstruction classes and sites with 1.1-times greater obstruction heights for 50%, 25%, and 0% obstruction classes (Table 3-4).

Clark County: Within Clark County, female lesser prairie-chicken vegetation use differed compositionally (Wilks' lambda = 0.98, $P < 0.001$) and structurally (Wilks' lambda = 0.97, $P < 0.001$) from available during the summer. Females used sites with similar percent cover of grass and bare ground to available; used sites had an average of 1% less litter and 4% more forb cover than available sites (Table 3-3). Females used sites with 1.1-times greater visual obstruction at 100% obstruction; 1.2-times greater visual obstruction at 75%, 50%, and 25% obstruction; and 1.04-times greater obstruction at 0% obstruction compared to available (Table 3-4).

Red Hills: In the Red Hills, female lesser prairie-chicken vegetation use differed both compositionally (Wilks' lambda = 0.94, $P < 0.001$) and structurally (Wilks' lambda = 0.96, $P < 0.001$). Females used sites with 3% less grass cover, 1% more litter cover, 7% more forb cover, and 5% less bare ground cover than available (Table 3-3). They used sites with an average of 1.2-times greater visual obstruction than available at all obstruction classes (Table 3-4).

Fall/Winter

I measured vegetation characteristics at 3,090 used sites during fall/winter 2013, 2014, and 2015; 356 were surveyed in Colorado, 1,197 were surveyed in northwest Kansas, 418 surveys were conducted in Clark County, and 1,119 were surveyed in Red Hills. I sampled a total of 1,962 available vegetation locations; 382 in Colorado, 256 in northwestern Kansas, 315 in Clark County, and 1,009 in the Red Hills. There was a significant interaction between used vs available and study area for both composition (Wilks' lambda = 0.99, $P < 0.001$) and structure (Wilks' lambda = 0.99, $P < 0.001$), so I continued the analysis comparing used characteristics among study sites and tested use vs available within study areas.

Used vegetation along a precipitation gradient: Female lesser prairie-chickens vegetation use differed both compositionally (Wilks' lambda = 0.90, $P < 0.001$) and structurally (Wilks' lambda = 0.85, $P < 0.001$) by study area. Female differentially used grass ($F_{3,\,4{,}765}$ = 266.3, $P < 0.001$), litter ($F_{3,\,4{,}765}$ = 400.6, $P < 0.001$), forbs ($F_{3,\,4{,}766}$ = 178, $P < 0.001$), and bare ground cover ($F_{3,\,4{,}765}$ = 259, $P < 0.001$); however, use did not demonstrate a pattern along a precipitation gradient for grass and bare ground cover. As precipitation increased, percent cover of litter decreased and percent cover of forbs increased at used sites (Figure 3-6). Females used 20% more litter cover and 7% less forb cover in Colorado than in the Red Hills (Figure 3-6). Females differentially used vegetation structure at 100% ($F_{3,\,4{,}799}$ = 44.1, $P < 0.001$), 75% ($F_{3,}$

$_{4,799}$ = 97.2, $P < 0.001$), 50% ($F_{3, 4,799}$ = 97.5, $P < 0.001$), 25% ($F_{3, 4,799}$ = 188.6, $P < 0.001$), and 0% ($F_{3, 4,799}$ = 20.7, $P < 0.001$) obstruction classes among study areas; however, there was no pattern along the precipitation gradient at 100% and 25% obstruction classes. At 75%, 50%, and 0% obstruction, visual obstruction increased with increased precipitation (Figure 3-7); visual obstruction was 1.3-, 1.2-, and 1.04-times greater in the Red Hills than Colorado at 75%, 50%, and 0% obstruction classes, respectively (Figure 3-7).

Used vs available vegetation characteristics during fall/winter

Colorado: During fall/winter in Colorado, female lesser prairie-chicken vegetation use differed both compositionally (Wilks' lambda = 0.96, $P < 0.001$) and structurally (Wilks' lambda = 0.92, $P < 0.001$) from available. Females used sites with similar grass, forb, and bare ground cover as available; used sites had an average of 4% greater litter cover than available (Table 3-5). Used sites had 1.5, 1.5, and 1.6 times greater visual obstruction at 100%, 75%, and 50% obstruction classes, respectively, compared to available; used visual obstruction at 25% and 0% obstruction classes did not differ from available (Table 3-6).

Northwest Kansas: During fall/winter in northwest Kansas, female lesser prairie-chicken vegetation use differed compositionally (Wilks' lambda = 0.96, $P < 0.001$) and structurally (Wilks' lambda = 0.96, $P < 0.001$) compared to available. Females used sites with similar grass and litter cover as available; used sites had 2.8% greater forb cover and 2.2% less bare ground cover than available (Table 3-5). Used sites were represented by 1.7-, 1.4-, 1.2-, 1.1-, and 1.2-times less visual obstruction than available at 100%, 75%, 50%, 35%, and 0% obstruction classes, respectively (Table 3-6)

Clark County: Within Clark County, female vegetation use differed compositionally (Wilks' lambda = 0.95, $P < 0.001$) and structurally (Wilks' lambda = 0.94, $P < 0.001$) from available during fall/winter. Females used vegetation with similar grass, litter, and forb cover as available; used sites had 4.5% greater bare ground cover than available sites on average (Table 3-5). Females used vegetation with 1.7-, 1.3-, 1.3-, 1.2-, and 1.1-times greater visual obstruction than available at 100%, 75%, 50%, 35%, and 0% obstruction classes, respectively, during fall/winter (Table 3-6).

Red Hills: Female lesser prairie-chicken vegetation use differed compositionally (Wilks' lambda = 0.96, $P < 0.001$) and structurally (Wilks' lambda = 0.99, $P < 0.001$) compared to available within the Red Hills during fall/winter. Females used sites with similar grass cover as available; used sites had 1% greater litter cover, 2% greater forb cover, and 2% less bare ground cover than available sites (Table 3-5). Females used sites with similar visual obstruction at 100%, 75%, and 50% obstruction classes to available; visual obstruction at used sites was 1.1-times less than available at both 25% and 0% obstruction classes (Table 3-6).

Discussion

Vegetation use by female lesser prairie-chickens differed compositionally and structurally along a west to east precipitation gradient. For used sites across all seasons, percent cover of litter decreased and percent cover of forbs increased with precipitation. Female use of vegetation structure also varied along the precipitation gradient, with females generally using sites with greater visual obstruction as precipitation increased among my four study areas. Although females within the Red Hills study area followed the pattern of increasing visual obstruction use along the precipitation gradient, visual obstruction was not as high as would be expected for the Mixed-Grass Prairie Ecoregion. This is likely due to management differences at this site where prescribed fire is an annually applied management tool on >25% of the study area. Within the study area, females use recently burned patches (0- to 2-years post-fire) that have shorter vegetation than the unburned patches, likely resulting in the lower visual obstruction values than expected (Chapter 1).

Females used vegetation composition and structure differently than available within each study area. Limited research is available comparing used and available vegetation outside of the nesting and brood-rearing periods; however, my results is consistent with nesting studies comparing used and available vegetation at nest sites (Donaldson 1969; Suminski 1977; Riley 1978; Davis et al 1979; Wisdom 1980; Haukos and Smith 1989; Riley et al 1992; Giesen 1994; Hagen and Giesen 2005; Pitman et al. 2005; Hagen et al. 2013; Lautenbach 2015). For vegetation composition, there were few general trends among my four study areas (e.g., females did not use greater percent cover of grass than available at all study areas); however, females used vegetation functional type relatively similar (within 9%) to available across all seasons. There were general trends in used vegetation structure compared to available vegetation structure. Females used sites with similar or lower visual obstruction heights than available during the spring; greater visual obstruction heights compared to available during the summer; and lower visual obstruction heights than available during the fall/winter across all study areas. Contrary to past management recommendations, this suggests that management for vegetation composition without a structure component will not provide adequate vegetation requirements during all seasons (Hagen et al. 2013; Van Pelt et al. 2013). However, management based on vegetation structure has the potential to benefit lesser prairie-chickens during all seasons, as lesser prairie-chickens use vegetation structure differently than available during all seasons.

Vegetation structure use by females varied among seasons, ecoregions, and along a precipitation gradient. Variation is selection suggests that management across the range of the lesser prairie-chicken should be based on vegetation structure at an ecoregion scale. Differences in structural use among seasons suggest that vegetation structure be heterogeneous across the landscape, which is consistent with a growing body of literature recommending vegetation heterogeneity across the landscape to satisfy differential habitat requirements (Fuhlendorf et al. 2009; Hovick et al. 2014; McNew et al. 2013, 2015; Carroll et al. 2016; Winder et al. 2017). In addition, structural recommendations should vary along the precipitation gradient, with recommendations for shorter visual obstruction in the western portion of their range compared to the eastern portion of their range acknowledging the reduced vegetation growth potential relative to the precipitation gradient.

It has been suggested that lesser prairie-chickens use areas with greater visual obstruction than available to avoid detection by predators (Applegate and Riley 1998; Hagen et al. 2013). I observed females using areas with less visual obstruction than available during the fall/winter and similar to available within spring. During these seasons raptor abundance was greater (D. Haukos, unpublished data) and coyotes were observed more frequently during the daytime (J.D. Lautenbach, personal observation) than summer. My observed pattern (shorter vegetation during greater predation risk) suggests that females use areas with lower visual obstruction during greater predation risk to enable them to perceive predators more clearly, which is further supported by lesser prairie-chickens flushing more readily during the fall/winter than during the summer (J.D. Lautenbach, personal observation). Thus, during summer, used sites with greater visual obstruction is likely a result of these areas providing thermal cover (Suggitt et al. 2011; Carroll et al. 2016, Chapter 2).

Management Implications:

My results indicate that structural vegetation heterogeneity is important to manage lesser prairie-chicken habitat needs across all life history requirements. Using management techniques to promote selective grazing by cattle in a patch mosaic manner will benefit lesser prairie-chickens by generating vegetation structural heterogeneity on the landscape. Patch-burn grazing is a management strategy that allows cattle to select burned areas for grazing, allowing the unburned patches in the pasture to rest, generating structural vegetation heterogeneity (Fuhlendorf and Engle 2001; Fuhlendorf et al, 2009; McGranahan et al. 2012; Chapter 1). Likewise, increasing pasture area offers cattle the opportunity to differentially select the most beneficial patches to graze, allowing other areas of the pasture to rest and provide structural heterogeneity (Kraft 2016). Additionally, my results indicate that female lesser prairie-chickens use vegetation structure differently across a precipitation gradient; therefore, I recommend differential management goals for vegetation structure across this gradient. I recommend that managers provide patches with the greatest visual obstruction within the structurally heterogeneous landscape to have >10 cm 100% obscured and ≥50 cm tall in the western portion of the lesser prairie-chicken range. In the eastern portion of their range, I recommend providing patches with the greatest visual obstruction within the heterogeneous landscape to have ≥15 cm 100% obscured and ≥60 cm tall.

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Figures

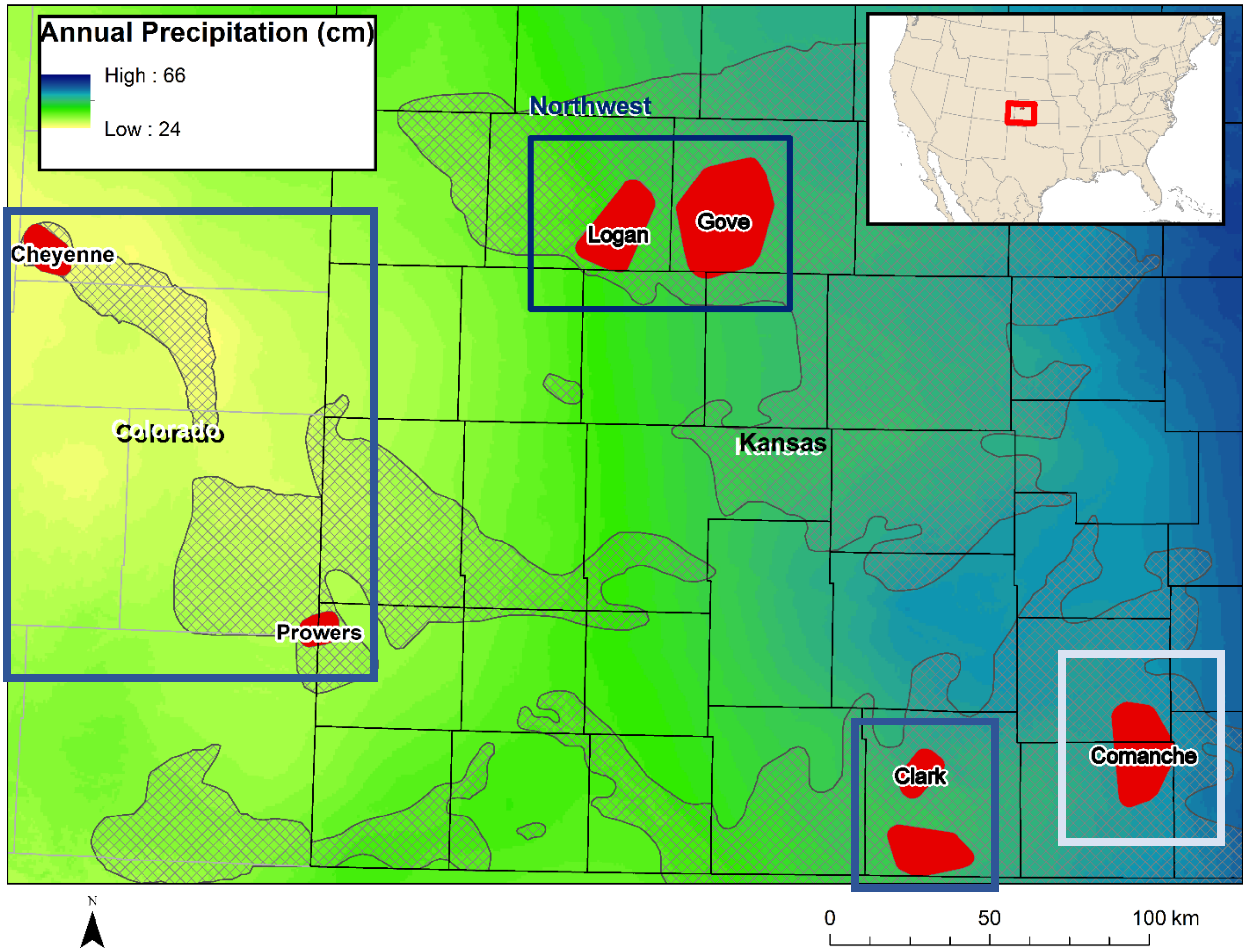

Figure 3-1: Map of the four study sites across the northern range of the lesser prairie-chicken where vegetation structure and composition were measured across a precipitation gradient during 2013, 2014, and 2015. Lighter background colors represent areas receiving lower amounts of precipitation. Study areas are outlined in rectangles.

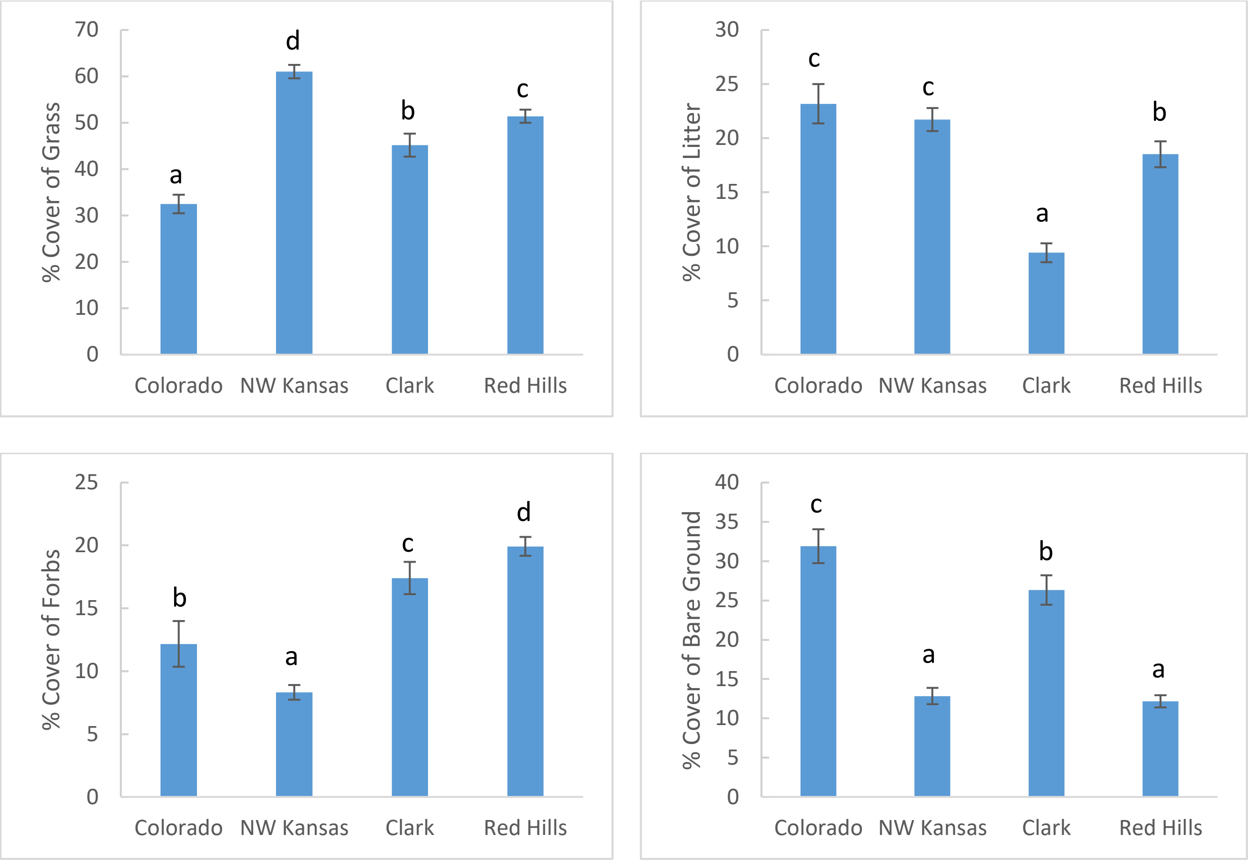

Figure 3-2: Comparison of average percent cover of A) grass, B) litter, C) forbs, and D) bare ground at lesser prairie-chicken use sites during spring (15 March – 31 May) 2013, 2014, and 2015 among four study areas along a dry to wet precipitation gradient in Colorado and Kansas.

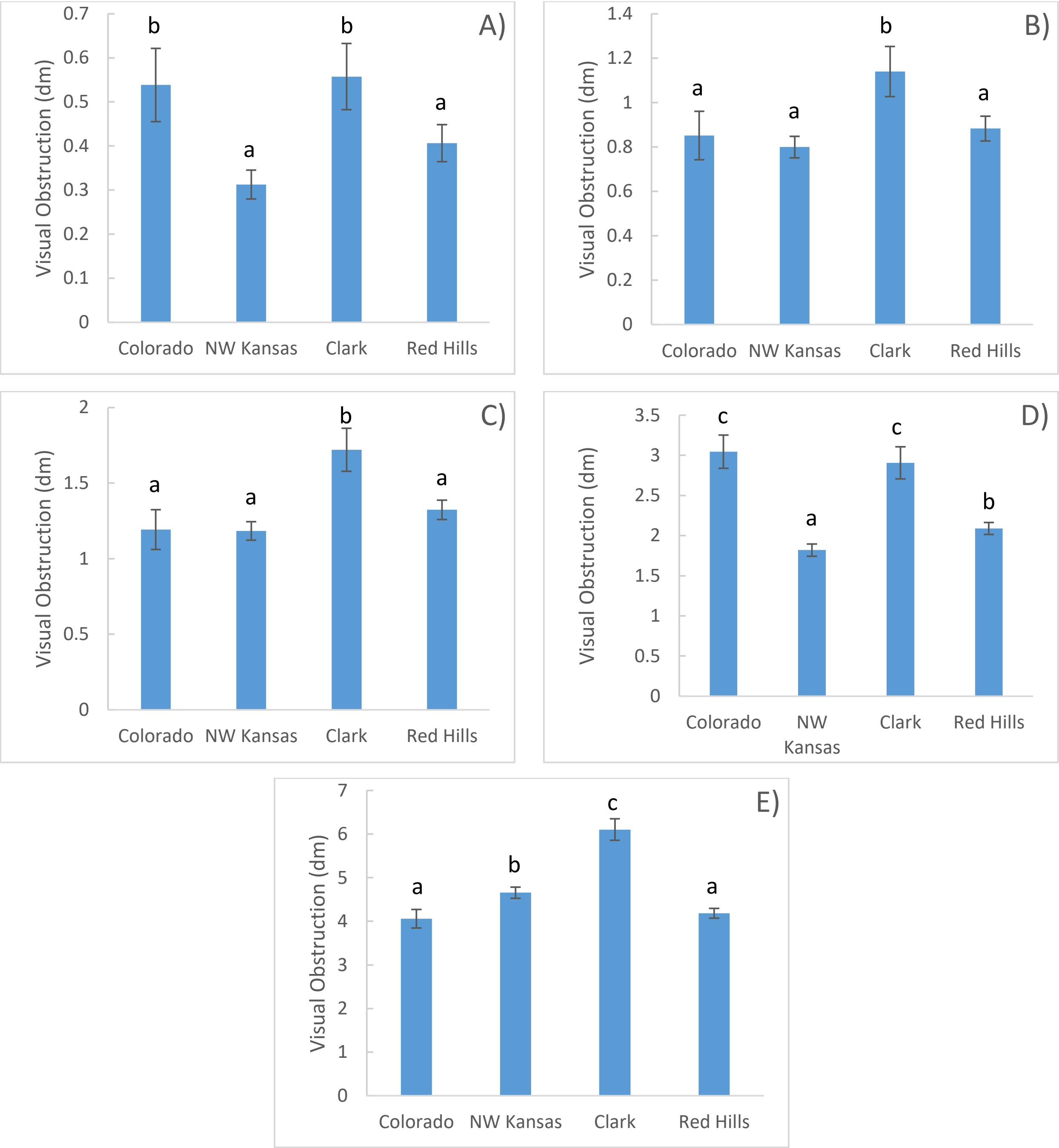

Figure 3-3: Comparison of visual obstruction (dm) at A) 100%, B) 75%, C) 50%, D) 25%, and E) 0% obstruction classes at sites used by female lesser prairie-chickens during spring (15 March – 31 May) 2013, 2014, and 2015 along a dry to wet precipitation gradient among four study sites in Kansas and Colorado.

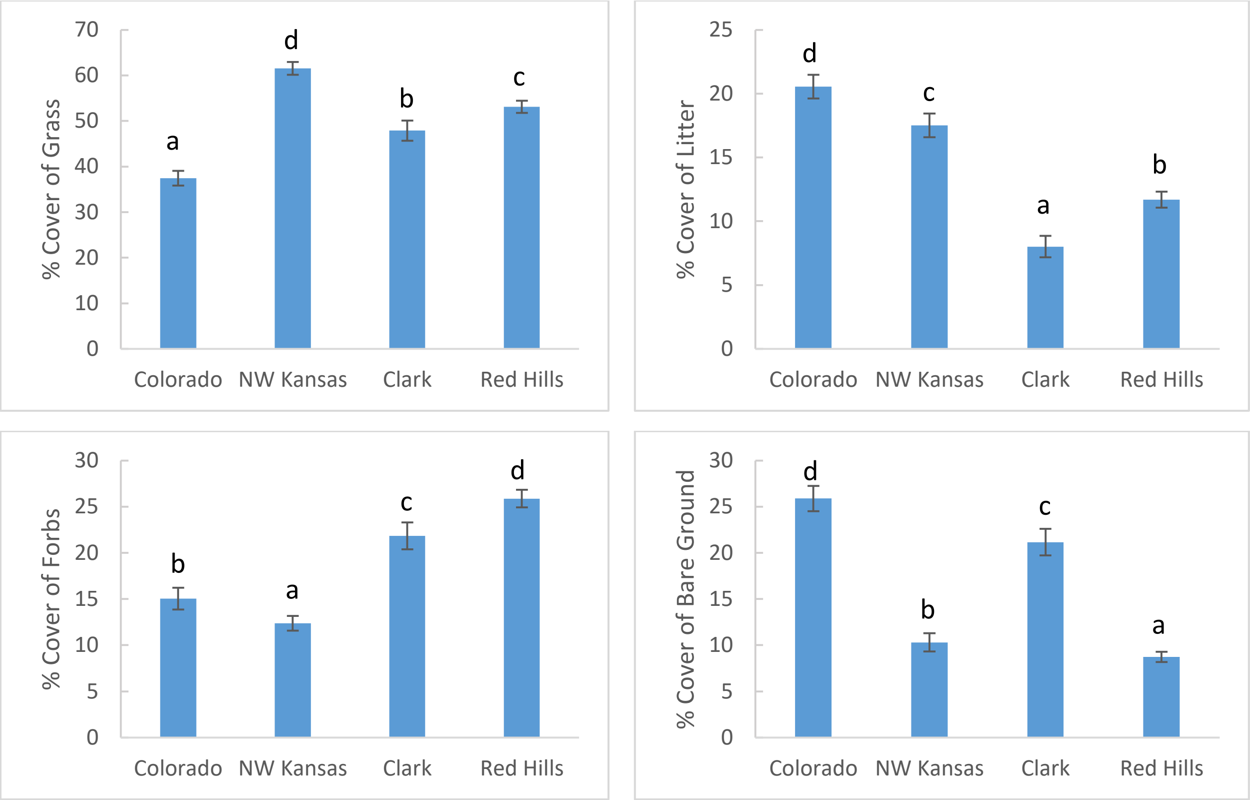

Figure 3-4: Comparison of average percent cover of A) grass, B) litter, C) forbs, and d) bare ground at lesser prairie-chicken use locations during summer (1 June – 14 September) 2013, 2014, and 2015 along a dry to wet precipitation gradient among four study areas in Kansas and Colorado.

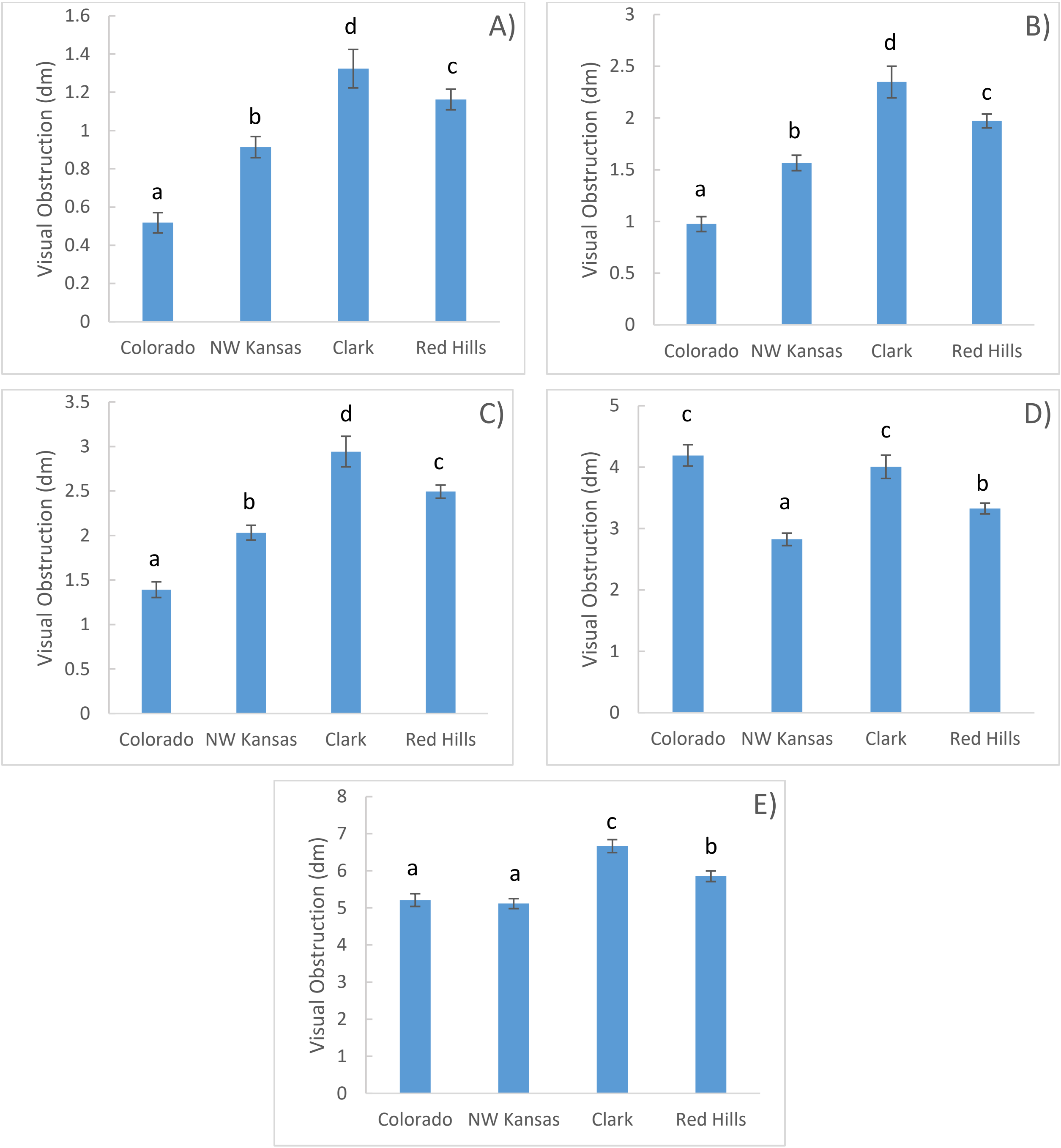

Figure 3-5: Comparison of visual obstruction (dm) at A) 100%, B) 75%, C) 50%, D) 25%, and E) 0% obstruction classes at sites used by female lesser prairie-chickens during summer (1 June – 14 September) 2013, 2014, and 2015 along a dry to wet precipitation gradient among four study areas in Kansas and Colorado.

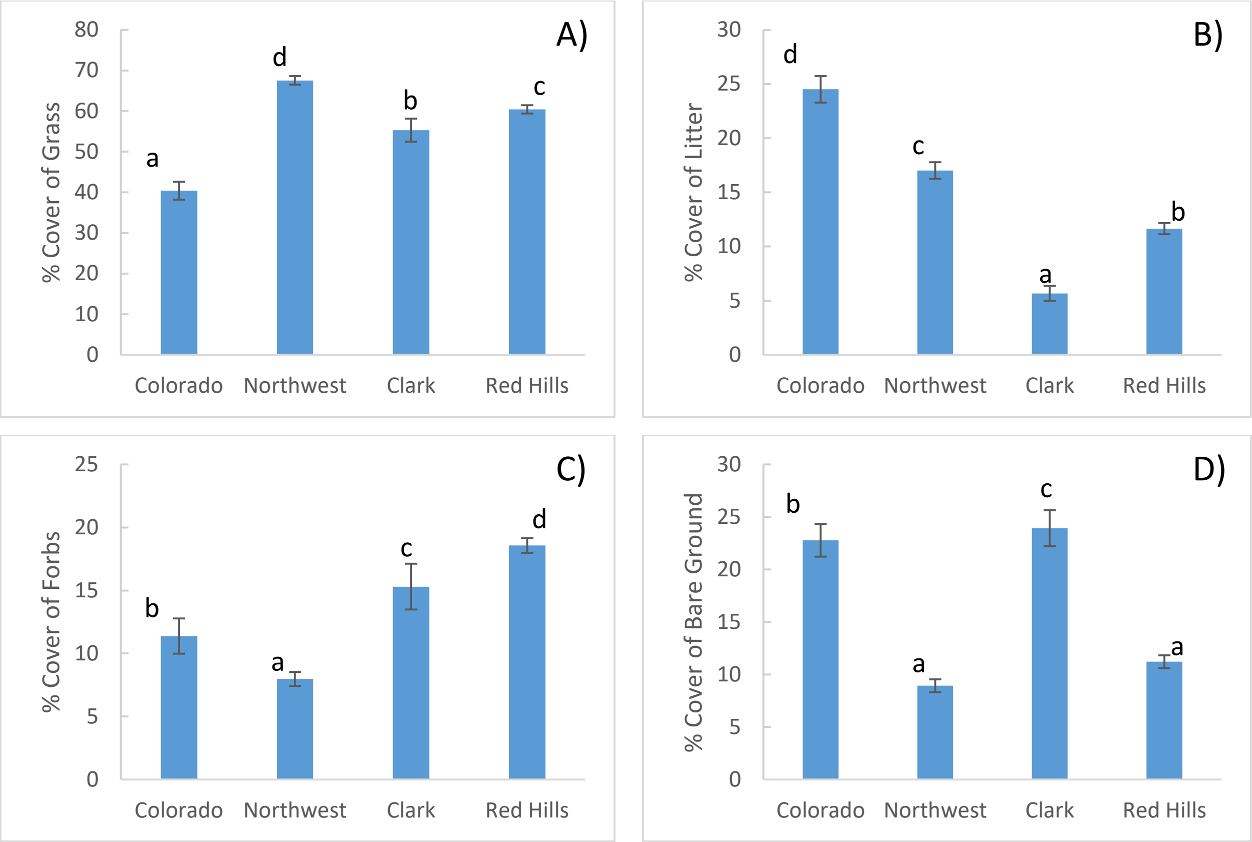

Figure 3-6: Comparison of average percent cover of A) grass, B) litter, C) forbs, and D) bare ground at lesser prairie-chicken use location during fall/winter (15 September – 14 March) 2013, 2014, and 2015 along a dry to wet precipitation gradient among four study areas in Kansas and Colorado.

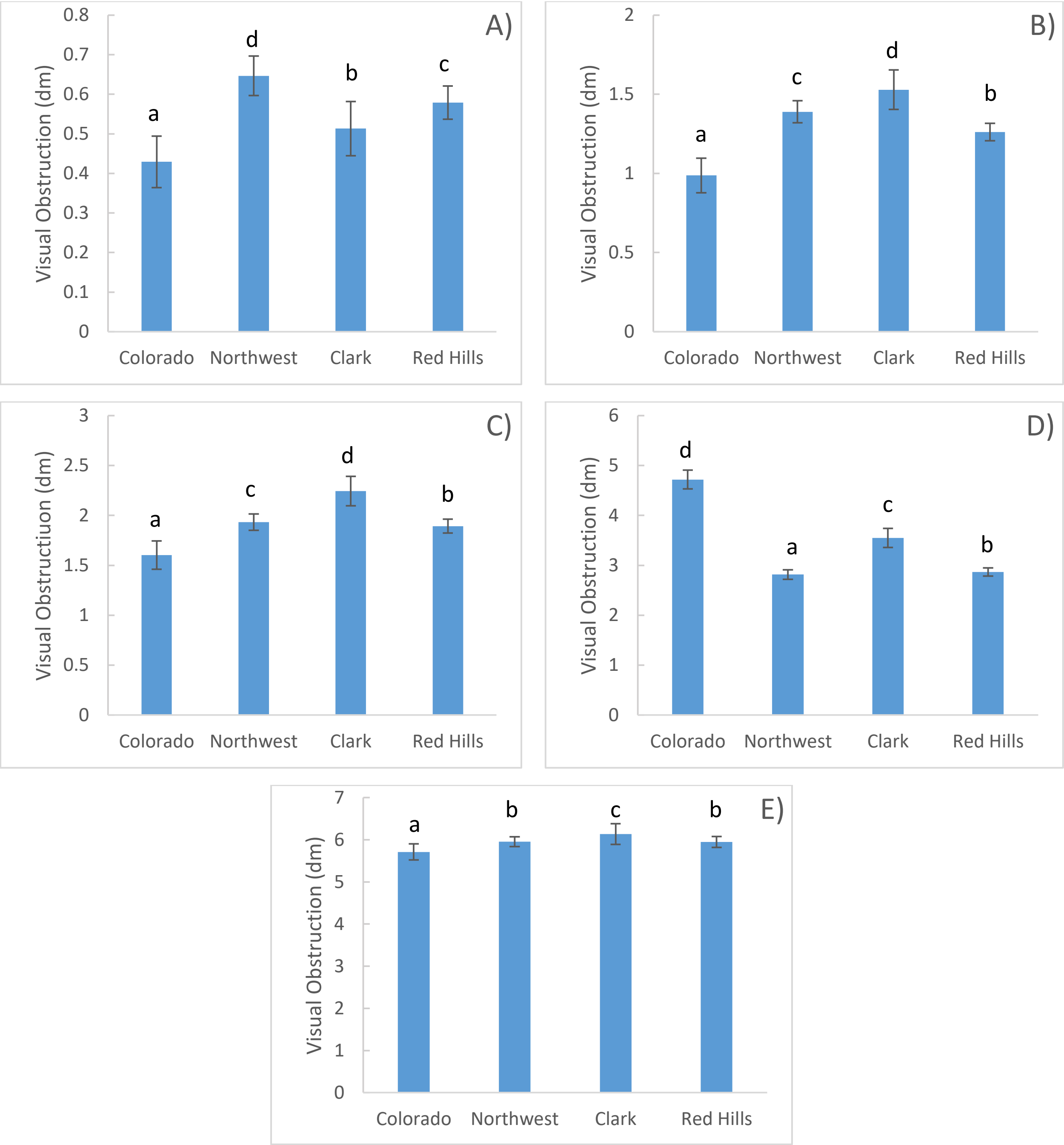

Figure 3-7: Comparison of visual obstruction (dm) at A) 100%, B) 75%, C) 50%, D) 25%, and E) 0% obstruction classes at sites used by female lesser prairie-chickens during fall/winter (15 September – 14 March) 2013, 2014, and 2015 along a dry to wet precipitation gradient among four study areas in Kansas and Colorado.

Tables

Table 3-1: Comparisons among percent cover of grass, litter, forbs, and bare ground between use sites and sites available to lesser prairie-chickens during spring (15 March – 31 May) 2013, 2014, and 2015 within four study areas located along a precipitation gradient in

Kansas and Colorado. Available vegetation was not measured in Colorado during the spring.

Study Area		Used	Available	DF	*F*	*P* ≤
Colorado						
	Grass	32.47 ± 2.02	NA			
	Litter	23.17 ± 1.82	NA			
	Forbs	12.16 ± 1.81	NA			
	Bare Ground	31.89 ± 2.17	NA			
NW Kansas						
	Grass	61.01 ± 1.46	62.93 ± 1.17	1, 1678	9.49	0.002
	Litter	21.70 ± 1.07	20.03 ± 0.83	1, 1678	4.83	0.028
	Forbs	8.32 ± 0.58	5.68 ± 0.5	1, 1678	47.98	0.001
	Bare Ground	12.84 ± 1.03	12.49 ± 0.87	1, 1678	0.38	0.539
Clark						
	Grass	45.15 ± 2.45	45.58 ± 1.89	1, 1107	0.07	0.792
	Litter	9.40 ± 0.86	9.92 ± 0.67	1, 1107	0.77	0.380
	Forbs	17.39 ± 1.28	18.69 ± 1.22	1, 1107	1.65	0.199
	Bare Ground	26.33 ± 1.87	22.04 ± 1.32	1, 1107	13.35	0.001
Red Hills						
	Grass	51.37 ± 1.43	58.74 ± 1.09	1, 2401	66.27	0.001
	Litter	18.51 ± 1.2	10.04 ± 0.51	1, 2401	204.80	0.001
	Forbs	19.91 ± 0.75	14.40 ± 0.49	1, 2401	159.30	0.001
	Bare Ground	12.18 ± 0.78	17.37 ± 1.06	1, 2401	50.05	0.001

Table 3-2: Comparisons among visual obstruction (dm) at 100%, 75%, 50%, 25%, and 0% obstruction classes between lesser prairie-chicken use sites and sites available to lesser prairie-chickens during fall/winter (15 March – 31 May) 2013, 2014, and 2015 within four study areas sites located along a precipitation gradient in Kansas and Colorado. Available vegetation was not measured in Colorado during the spring.

Study Area	Used	Available	DF	*F*	*P* ≤
Colorado					
100% Obstruction	0.54 ± 0.08	NA			
75% Obstruction	0.85 ± 0.11	NA			
50% Obstruction	1.19 ± 0.13	NA			
25% Obstruction	3.05 ± 0.21	NA			
0% Obstruction	4.06 ± 0.21	NA			
Northwest					
100% Obstruction	0.31 ± 0.03	0.30 ± 0.04	1, 1678	1.71	0.191
75% Obstruction	0.8 ± 0.05	0.78 ± 0.06	1, 1678	1.56	0.212
50% Obstruction	1.18 ± 0.06	1.14 ± 0.07	1, 1678	1.90	0.169
25% Obstruction	1.82 ± 0.08	1.82 ± 0.08	1, 1678	0.16	0.687
0% Obstruction	4.66 ± 0.13	5.44 ± 0.15	1, 1678	58.88	0.001
Clark*					
100% Obstruction	0.56 ± 0.08	0.70 ± 0.06			
75% Obstruction	1.14 ± 0.11	1.34 ± 0.09			
50% Obstruction	1.72 ± 0.14	1.98 ± 0.11			
25% Obstruction	2.91 ± 0.2	3.24 ± 0.16			
0% Obstruction	6.1 ± 0.25	6.47 0.22			
Red Hills					
100% Obstruction	0.41 ± 0.04	0.49 ± 0.03	1, 2401	8.25	0.004
75% Obstruction	0.88 ± 0.06	0.95 ± 0.05	1, 2401	2.82	0.093
50% Obstruction	1.32 ± 0.06	1.34 ± 0.06	1, 2401	0.24	0.627
25% Obstruction	2.09 ± 0.07	1.96 ± 0.07	1, 2401	5.19	0.023
0% Obstruction	4.18 ± 0.11	4.68 ± 0.12	1, 2401	32.34	0.001

*Visual obstruction did not differ between used and available for all obstruction classes (MANOVA, $P > 0.05$)

Table 3-3: Comparisons among percent cover of grass, litter, forbs, and bare ground between lesser prairie-chicken use sites and sites available to lesser prairie-chickens during summer (1 June – 14 September) 2013, 2014, and 2015 within four study areas located along a precipitation gradient in Kansas and Colorado.

Study Area	Used	Available	DF	*F*	*P* ≤
Colorado					
Grass	37.44 ± 1.59	42.75 ± 2.2	1, 910	15.47	0.001
Litter	20.54 ± 0.92	19.34 ± 1.06	1, 910	2.75	0.098
Forbs	15.05 ± 1.18	19.56 ± 2.07	1, 910	15.98	0.001
Bare Ground	25.88 ± 1.36	24.05 ± 1.63	1, 910	2.84	0.092
Northwest					
Grass	61.56 ± 1.39	57.88 ± 1.16	1, 2396	14.59	0.001
Litter	17.5 ± 0.93	23.03 ± 0.86	1, 2396	70.63	0.001
Forbs	12.37 ± 0.8	8.66 ± 0.61	1, 2396	52.46	0.001
Bare Ground	10.30 ± 1	14.31 ± 0.86	1, 2396	30.67	0.001
Clark					
Grass	47.90 ± 2.22	48.83 ± 1.55	1, 1577	0.40	0.527
Litter	8.01 ± 0.83	9.43 ± 0.58	1, 1577	6.57	0.010
Forbs	21.83 ± 1.46	17.89 ± 0.97	1, 1577	18.31	0.001
Bare Ground	21.15 ± 1.44	21.53 ± 0.96	1, 1577	0.19	0.664
Red Hills					
Grass	53.12 ± 1.35	56.54 ± 0.81	1, 3870	10.02	0.002
Litter	11.69 ± 0.62	10.49 ± 0.37	1, 3870	17.40	0.001
Forbs	25.88 ± 0.94	18.94 ± 0.44	1, 3870	211.90	0.001
Bare Ground	8.73 ± 0.55	12.55 ± 0.58	1, 3870	51.19	0.001

Table 3-4: Comparisons among visual obstruction (dm) at 100%, 75%, 50%, 25%, and 0% obstruction classes between lesser prairie-chicken use sites and sites available to lesser prairie-chickens during fall/winter (1 June – 14 September) 2013, 2014, and 2015 within four study areas sites located along a precipitation gradient in Kansas and Colorado.

Study Area	Used	Available	DF	*F*	*P* ≤
Colorado					
100% Obstruction	0.52 ± 0.05	0.46 ± 0.06	1, 910	0.99	0.321
75% Obstruction	0.98 ± 0.07	0.94 ± 0.09	1, 910	0.02	0.893
50% Obstruction	1.39 ± 0.09	1.38 ± 0.1	1, 910	0.13	0.715
25% Obstruction	4.19 ± 0.17	4.9 ± 0.22	1, 910	33.01	0.001
0% Obstruction	5.21 ± 0.17	5.9 ± 0.22	1, 910	33.17	0.001
Northwest					
100% Obstruction	0.91 ± 0.06	0.89 ± 0.05	1, 2396	0.21	0.644
75% Obstruction	1.57 ± 0.07	1.46 ± 0.07	1, 2396	3.00	0.083
50% Obstruction	2.03 ± 0.08	1.86 ± 0.08	1, 2396	6.70	0.010
25% Obstruction	2.82 ± 0.1	2.49 ± 0.09	1, 2396	20.57	0.001
0% Obstruction	5.12 ± 0.14	4.58 ± 0.12	1, 2396	27.93	0.001
Clark					
100% Obstruction	1.32 ± 0.1	1.19 ± 0.07	1, 1577	4.52	0.033
75% Obstruction	2.35 ± 0.15	1.96 ± 0.1	1, 1577	17.42	0.001
50% Obstruction	2.94 ± 0.17	2.51 ± 0.11	1, 1577	16.72	0.001
25% Obstruction	4.00 ± 0.19	3.40 ± 0.12	1, 1577	26.04	0.001
0% Obstruction	6.66 ± 0.18	6.40 ± 0.14	1, 1577	3.85	0.050
Red Hills					
100% Obstruction	1.16 ± 0.05	0.95 ± 0.04	1, 3870	34.21	0.001
75% Obstruction	1.97 ± 0.07	1.63 ± 0.05	1, 3870	59.09	0.001
50% Obstruction	2.49 ± 0.08	2.14 ± 0.05	1, 3870	48.26	0.001
25% Obstruction	3.32 ± 0.09	2.87 ± 0.06	1, 3870	62.93	0.001
0% Obstruction	5.85 ± 0.14	5.03 ± 0.07	1, 3870	119.50	0.001

Table 3-5: Comparisons among percent cover of grass, litter, forbs, and bare ground between lesser prairie-chicken use sites and sites available to lesser prairie-chickens during fall/winter (15 September – 14 March) 2014, 2015, and 2016 within four study areas sites located along a precipitation gradient in Kansas and Colorado.

Study Area	Used	Available	DF	*F*	*P* ≤
Colorado					
Grass	40.38 ± 2.19	42.09 ± 2.01	1, 736	1.28	0.258
Litter	24.52 ± 1.23	20.30 ± 1.16	1, 736	24.21	0.001
Forbs	11.38 ± 1.39	13.13 ± 1.57	1, 736	2.64	0.104
Bare Ground	22.78 ± 1.56	24.02 ± 1.66	1, 736	1.13	0.288
NW Kansas					
Grass	67.53 ± 1.06	65.50 ± 2.28	1, 1236	3.54	0.06
Litter	17.01 ± 0.77	18.06 ± 1.42	1, 1236	1.31	0.253
Forbs	7.98 ± 0.55	5.13 ± 0.91	1, 1236	10.60	0.001
Bare Ground	8.93 ± 0.62	11.08 ± 1.43	1, 1236	8.47	0.004
Clark					
Grass	55.34 ± 2.84	58.75 ± 2.99	1, 687	2.63	0.106
Litter	5.67 ± 0.7	6.44 ± 0.79	1, 687	2.09	0.149
Forbs	15.31 ± 1.81	13.18 ± 1.71	1, 687	2.76	0.097
Bare Ground	23.94 ± 1.72	19.47 ± 2.08	1, 687	10.77	0.001
Red Hills					
Grass	60.42 ± 1.02	61.02 ± 1.16	1, 2126	0.62	0.431
Litter	11.64 ± 0.52	10.51 ± 0.57	1, 2126	8.33	0.004
Forbs	18.57 ± 0.59	15.57 ± 0.6	1, 2126	49.79	0.001
Bare Ground	11.21 ± 0.61	13.26 ± 0.87	1, 2126	14.67	0.001

Table 3-6: Comparisons among visual obstruction (dm) at 100%, 75%, 50%, 25%, and 0% obstruction classes between lesser prairie-chicken use sites and sites available to lesser prairie-chickens during fall/winter (15 September – 14 March) 2014, 2015, and 2016 within four study areas located along a precipitation gradient in Kansas and Colorado.

Study Area	Used	Available	DF	F	*P* ≤
Colorado					
100% Obstruction	0.43 ± 0.07	0.28 ± 0.04	1, 736	10.48	0.001
75% Obstruction	0.99 ± 0.11	0.66 ± 0.06	1, 736	20.41	0.001
50% Obstruction	1.60 ± 0.14	1.03 ± 0.08	1, 736	36.89	0.001
25% Obstruction	4.72 ± 0.19	4.55 ± 0.21	1, 736	0.02	0.899
0% Obstruction	5.71 ± 0.19	5.55 ± 0.21	1, 736	0.19	0.663
NW Kansas					
100% Obstruction	0.65 ± 0.05	1.11 ± 0.13	1, 1236	8.486	0.004
75% Obstruction	1.39 ± 0.07	1.93 ± 0.19	1, 1236	39.43	0.001
50% Obstruction	1.93 ± 0.08	2.33 ± 0.21	1, 1236	16.75	0.001
25% Obstruction	2.82 ± 0.10	3.13 ± 0.24	1, 1236	7.40	0.007
0% Obstruction	5.96 ± 0.12	7.30 ± 0.38	1, 1236	84.30	0.001
Clark					
100% Obstruction	0.51 ± 0.07	0.85 ± 0.10	1, 687	34.49	0.001
75% Obstruction	1.53 ± 0.12	1.94 ± 0.15	1, 687	18.46	0.001
50% Obstruction	2.24 ± 0.15	2.88 ± 0.20	1, 687	27.54	0.001
25% Obstruction	3.55 ± 0.19	4.23 ± 0.23	1, 687	21.35	0.001
0% Obstruction	6.13 ± 0.25	6.72 ± 0.28	1, 687	10.20	0.001
Red Hills					
100% Obstruction	0.58 ± 0.04	0.64 ± 0.05	1, 2126	3.43	0.064
75% Obstruction	1.26 ± 0.05	1.31 ± 0.07	1, 2126	1.03	0.311
50% Obstruction	1.89 ± 0.07	2.00 ± 0.09	1, 2126	3.09	0.079
25% Obstruction	2.87 ± 0.08	3.03 ± 0.12	1, 2126	4.86	0.028
0% Obstruction	5.95 ± 0.13	6.39 ± 0.18	1, 2126	15.66	0.001