VEGETATION CHARACTERISTICS AND LESSER PRAIRIE CHICKEN RESPONSES TO LAND COVER TYPES AND GRAZING MANAGEMENT IN WESTERN KANSAS

By

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B.S., Emporia State University, 2012

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Biology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Approved by:

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Abstract

In the southern Great Plains, the lesser prairie-chicken (*Tympanuchus pallidicinctus;* hereafter LEPC), an obligate grassland species, has experienced significant population declines and range contractions with subsequent conservation concern. Management actions often use land cover types to make inference about habitat quality. Relatively little information is available related to grazed rangelands to guide conservation. The influences of land cover types and livestock grazing on LEPC habitat selection have not been researched extensively in western Kansas. I evaluated the influence of land cover types and grazing management on vegetation characteristics, habitat selection, and nest/adult survival of LEPC in western Kansas. Females were captured and radio-marked to monitor habitat use, nest success, and adult survival. Grazing and vegetation data were collected via producer correspondence and vegetation surveys, respectively. Vegetation composition and structure differed across land cover types, which can be used to make inferences about LEPC habitat quality. Habitat selection analyses corroborated the importance of breeding habitat in close proximity to leks (<3 km) and identified land cover types selected for nesting (Conservation Reserve Program, Limy Upland, Saline Subirrigated) and brooding (Conservation Reserve Program, Red Clay Prairie, Sands, Sandy Lowland). Conservation Reserve Program patches positioned near rangelands contributed to LEPC reproductive success in northwest Kansas. In grazed lands, LEPC selected habitat close to leks (<3 km) and large pastures (>400 ha), exhibiting low-moderate stocking densities (<0.4 AU/ha), and low-moderate levels of deferment during the grazing season (60-100 days). Nest site selection was negatively influenced by increasing distance from a lek and grazing pressure. Daily nest survival rates were negatively influenced by increasing grazing pressure and high levels of stocking density. Annual adult female survival was negatively influenced as forage utilization (%

forage removed) increased. Heterogeneity (coefficient of variation and standard deviation) of visual obstruction was decreased at stocking densities > 0.26 AU/ha. Future conservation actions should consider the potential of land cover types to create adequate vegetation structure, and manage rangelands with low-moderate stocking densities and deferment and greater pasture areas. The relationship between habitat selection and proximity of lek sites (< 5 km) should be used to identify quality LEPC habitat.

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Acknowledgments

First and foremost, I thank my advisor, David Haukos, for his continuing assistance, knowledge, faith and perhaps most importantly, patience, during my time at the Kansas Cooperative Fish and Wildlife Research Unit. My interactions with Dave are always positive, beneficial and productive. I look forward to future work, collaborations, and enthusiastic greetings defined by the exclamation “Hey, big fella!” from Dave. I would also like to say thanks to my committee members, Brett Sandercock and Mindy Rice for the assistance and guidance throughout my research effort. I extend a huge thank you to Matt Bain for his continued presence and influence throughout my project. Matt’s knowledge and passion for the ecosystem he works in has touched every corner of my research and I am extremely grateful for the role he has played during field work and conceptual development.

I also thank Beth Ross, Drew and Shelley Ricketts, and Gene Albanese for their professional assistance in developing ideas and concepts that are pivotal to my research. Call, text or email, these folks were always never far away and I hope I can repay the debt one day. I would also like to thank Joyce Brite for her continued patience during my shortcomings in regard to receipts, travel forms, etc.

The advantages and disadvantages of a large research lab vary by person. Wfemaleever the stresses of field work were high or low, my fellow “chicken folks” were always helpful and available wfemaleever I needed them. I would like to extend the deepest gratitude to Dan, Sam, Jonathan, Joseph, Reid, and David for not only making this group effort a success, but also contributing to the data collection, analysis, and inference of my research possible. I could not have done any of it without you. Thank you! I was blessed with extremely good technicians on my project. They were pretty fun to be around as well! Thank you to, Jake, Alix, Erica, Talesha,

Amber, Liz, Ellie, Geoff, Turtles, the Sams, Stacy, Edward, Hanna, Doug, Ashlee, Tom, Kyle, Jenny, Tyler, and Peter! I'll miss the games of stump, the lake, movies in Oakley, and the bowling alley!

On a less professional note, thank you to the remainder of my lab mates, Sarah, Kelsey, Andy, Brian, Willow and Tom, and other friends at KSU, Shelley and Drew, Femalery, Mark, Emily, Ryland, Casey, Sky, Kirsten, Ryan, Dori, and many others; thank you for always being available to watch a Royals game, play a game of poker, or just have a friendly conversation. I look forward to more good times in the future!

My project depended on the ability to collect data on privately owned property. Thank you to all of the landowners, but specifically Stacy and Chaston Hoeme, and Dwight Abell. I have never experienced such hospitality, friendliness, and fellowship as I did with these great folks.

My career at KSU has been rocky at times. No matter the trial or tribulation, my family's continued support, encouragement and no questions asked belief in me and my endeavors has allowed me to reach and achieve many accomplishments. I would not be where I am today without them. Thank you, Dad, for being whatever I needed you to be. You are the most selfless person I know and I strive to be more like you every day. Mom, your passion and motivation for the things that drive you is unbelievable. You are a tremendous role model and I hope you know how much I appreciate all that you do. Thank you to Travis and Alicia for being the responsible ones! The example you have set for me as I have gotten older will not be forgotten. Colin, I know we've had our moments, but I hope you know that I am proud to be your brother and I greatly appreciate your friendship. Thank you to all my family for all that they have done in support of me!

Thanks again to all of these mentors, friends and family members for all that you have done. Showing appreciation is not always my strong suit, but I do not take you for granted. Thank you.

Chapter 1 - Vegetation Characteristics Associated with Land Cover Types in Western, Kansas

Introduction

Environmental variables such as climate are commonly used to explain large-scale vegetation patterns around the globe (Salisbury 1926, MacArthur 1972, Box 1981, Woodward 1987). Other factors such as topography and soil characteristics are hypothesized to influence plant community structure and composition at regional (Whittaker et al. 2001, Huerta-Martínez et al. 2004), landscape (Pan et al. 1998) and smaller spatial scales (Robinson et al. 1999, Maestre et al. 2003). Similar to plant communities, soil characteristics are also a function of interacting factors including climate, organisms, topography, and time (Hoveizeh 1997). Furthermore, across relatively smaller spatial scales, the importance of soil health increases relative to plant growth (Jafari et al. 2004), species composition, and biological diversity (Critchley et al. 2002). Various land use patterns, such as livestock grazing, further complicate the implications of abiotic and biotic environmental characteristics on plant communities and vegetation structure (Milchunas and Lauenroth 1993). Models are often built to predict distributions of terrestrial plant species, plant communities, vegetation types, plant functional types, and plant biodiversity based on the above described environmental relationships (Guisan and Zimmermann 2000). Model results have the potential to provide useful information when addressing effects of environmental change on organisms, improving floristic and faunistic distribution atlases, and targeting conservation strategies.

Federal entities such as the United States Department of the Interior (USDI) and United States Department of Agriculture (USDA) have taken advantage of environmental influences on plant communities with the development of Ecological Sites (USDA 2013). The Interagency

Ecological Site Handbook for Rangelands defines an Ecological Site (ES) as “a conceptual division of the landscape that is defined as a distinctive kind of land based on recurring soil, landform, geological and climate characteristics that differs from other kinds of land in its ability to produce distinctive kinds of amounts of vegetation and in its abilities to respond similarly to management actions and natural disturbances” (USDA 2013). Furthermore, an Ecological Site Description (ESD) uses environmental (abiotic and biotic) relationships to identify, differentiate, and describe the plant community associated with a specific Ecological Site (ES) to others within the same Major Land Resource Area (MLRA) and Land Resource Region (LRR). This hierarchal ranking provides a framework for dividing landscapes into categorical classes based on potential plant communities. Moreover, ESs, ESDs, MLRAs, and LRRs are commonly used by management and research entities to delineate landscapes and inform, plan, and execute tasks associated with such landscapes. For example, the USDA Natural Resources Conservation Service (NRCS) uses ESs and ESDs to develop, implement, and monitor grazing prescriptions in working grasslands and shrublands (USDA 2013). Several entities have used ESs to monitor and evaluate landscapes for their potential as lesser prairie-chicken (*Tympanuchus pallidicinctus*; hereafter LEPC) habitat (Van Pelt et al. 2013).

In fact, categorical land cover types are commonly used to describe the relative suitability and potential for a tract of property to support LEPCs, a grassland obligate species once listed as “Threatened” under the Endangered Species Act (ESA) in May of 2014 (U.S. Fish and Wildlife Service 2014), but later the listing was vacated by a Texas federal judge in September 2015 (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]). Recently, private conservation groups petitioned the U.S. Fish and Wildlife

Service to consider the LEPC for relisting under the ESA (http://www.wildearthguardians.org/site/DocServer/LPC_petition_2016_final_opt_2.pdf, accessed September 28, 2016).

Land cover types such as sand shinnery oak (*Quercus havardii*) prairie, sand sagebrush (*Artemisia filifloria*) prairie, short-grass prairie, mixed-grass prairie, and USDA's Conservation Reserve Program (CRP; a cost-share program implemented by the Farm Service Agency [FSA] targeted at creating reclaimed grasslands from row-crop agriculture land susceptible to erosion) are commonly referenced during discussions, conservation planning, and publications regarding LEPC management (Hagen et al. 2004, Dahlgren et al. 2016, Haukos et al. 2016, Grisham et al. 2016b, Wolfe et al. 2016). Currently, the LEPC distribution is delineated into four separate ecoregions defined by vegetation community (Figure 1.1). The ecoregions are defined by the following terms; Short-grass Prairie/CRP Mosaic (SGPR) in northwest Kansas and eastern Colorado, Sand Sagebrush Prairie (SSPR) in southeast Colorado and southwest Kansas, Mixed-grass Prairie (MGPR) in Kansas, Oklahoma, and Texas, and the Sand Shinnery Oak Prairie (SOPR) in Texas and New Mexico. At smaller spatial scales, researchers have ranked and evaluated ESs across MLRAs in terms of their potential for supporting nesting and brooding habitat for LEPC (Van Pelt et al. 2014). However, these rankings were developed in the absence of peer-reviewed research and based on professional opinion. The need to quantitatively evaluate the vegetation status of ESs in terms relevant to LEPC habitat requirements is apparent. Furthermore, CRP is commonly cited as high quality habitat and an important contributor to the increase in LEPC populations in northwest Kansas (Rodgers and Hoffman 2004, Van Pelt et al. 2013). It would benefit future LEPC conservation actions to quantitatively evaluate and compare vegetation composition and structure of these frequently cited optimal habitats (e.g., CRP) to pre-established land cover types such as ESs. Furthermore, it would be most beneficial to evaluate land cover types in relation to nesting and brooding microhabitat. The amount of available high quality microhabitat for these two ecological periods is often a limiting factor on the landscape and an important component of LEPC management (Hagen et al. 2004, Hagen et al. 2013).

Defining quality nesting habitat for LEPC is a difficult proposition. Many forces influence the creation, sustainability or destruction of nesting habitat on various spatial and temporal scales (hourly, daily, monthly, and yearly). In addition to environmental conditions such as precipitation, temperature, and humidity, variables such as land use, fragmentation of grasslands, and anthropogenic structures all contribute to the amount of available nesting habitat across a landscape during a given year (Haukos and Boal 2016). At the smallest spatial scale (nest-site), female LEPC most likely select habitats based on vegetation structure. Theoretically, female LEPC select microhabitat that allows for optimum concealment and adequate thermoregulation (Hagen et al. 2007, Hagen et al. 2013, Grisham et al. 2016a). Precipitation during the previous growing season and current season, extreme winter weather events (snow and ice), livestock use, and soil conditions influence the residual vegetation cover needed by nesting LEPC. Available nesting habitat for LEPC is usually described exhibiting greater visual obstruction, grass cover, litter cover and less bare ground cover than associated random points (Riley 1978, Riley et al. 1992, Giesen 1994, Pitman et al. 2005, Davis 2009, Hagen et al. 2013, Grisham et al. 2014). Female LEPCs often select for similar vegetation structure across their species distribution. The focus of my field study was to investigate vegetation characteristics associated with land cover types across three ecoregions located in Kansas; SSPR, SGPR and MGPR. Minimal amounts of research have been completed within these three ecoregions in

Kansas. In the SGPR region in northwest Kansas, researchers reported visual obstruction levels at 2.7 dm and grass cover from 63% to 88% at nest sites (Fields 2004). Furthermore, Lautenbach (2014) suggests 2-3 dm of visual obstruction cover for adequate nesting habitat in grasslands located in the MGPR and SGPR ecoregions. Others reported that nest sites displayed greater 0% and 100% visual obstruction and less bare ground than random sites in southern MGPR (Holt 2012). Within ESs that lack the grass cover and visual obstruction values recommended for nesting conditions, shrub cover may serve as a surrogate when herbaceous vegetation structure is lacking (J. Kraft, personal obs.). Selection of shrub cover for nesting sites has been documented in the SSPR and SOPR ecoregions (Dahlgren et al. 2016, Haukos et al. 2016, Grisham et al. 2016, Wolfe et al. 2016). Other literature indicates that nests are associated with shrubs to a greater effect as grazing pressure increases (Haukos and Smith 1989).

Literature about habitat use, brood survival, movements, and diet during brooding periods is a limiting aspect of LEPC ecology (Hagen and Elmore 2016). Relative to nests, brooding habitat is less robust (less horizontal visual obstruction) and with greater bare ground cover to allow for chick movement (Jones 1963, Riley et al. 1993 Haukos and Zavaleta 2016). Greater forb cover in used rather than random sites is a common feature of quality brood microhabitat (Pitman et al. 2006, Hagen et al. 2013).

To contribute to the quantitative knowledge gap between land cover type and potential for quality LEPC nesting and brooding habitat and provide a better foundation for future management decisions, my objectives were 1) to quantify the variation in vegetation characteristics applicable to LEPC ecology across land-cover types in western Kansas and 2) make inference on availability and quality of land cover types available to satisfy various LEPC ecological needs. I estimated and compared mean vegetation values among land cover types and years. I evaluated land cover types including various ESs and CRP tracts present in western Kansas. I quantified vegetation characteristics directly applicable to aspects of LEPC ecology, including visual obstruction readings, percent canopy cover (litter, grass, forbs, bare and shrub), and litter depth. I hypothesized that visual obstruction values would be positively correlated with aboveground biomass potential listed in the ESDs for each ES (Table 1.1). Thus, ESs with greater potential for aboveground biomass will exhibit greater visual obstruction readings. Additionally, I hypothesized that CRP land cover types would exhibit the greatest amount of visual obstruction, litter cover, and grass cover and least amount of bare ground cover due to management regimes that limit disturbance.

Study Area

I sampled vegetation from three distinct areas where LEPC are abundant in western Kansas (McDonald et al. 2014; Figure 1.2). Two sites were located in the south-central region of the state. One site was located on privately owned lands within Kiowa and Comanche counties and the second site was located on private land south of Ashland, Kansas, within Clark County. In northwest Kansas, one study area was placed focused on private lands located within Logan and Gove counties.

In northwestern Kansas, the Northwest study area was divided between Logan and Gove counties. The primary land uses for both counties were livestock grazing on grasslands, energy exploration and extraction, and both dryland and irrigated row-crop agriculture. This study area was in the Shortgrass Prairie/CRP Mosaic Ecoregion (Van Pelt et al. 2013, McDonald et al. 2014, Dahlgren et al. 2016), with CRP grasslands and row-crop agriculture on silt-loam soils. Where soils permitted, plant communities resembled mixed-grass prairie. Dominant vegetation in the study area varied with cover type (e.g., native grasslands, CRP, row-crop agriculture).

Native grasslands were dominated by species such as blue grama (*Bouteloua gracilis*), buffalograss (*B. dactyloides*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*B. curtipendula*), sand dropseed (*Sporobulus cryptandrus*), western wheatgrass (*Pascopyrum smithii*), western ragweed (*Ambrosia psilostachya),* scarlet globemallow (*Sphearalcea coccinea*), small soapweed (*Yucca glauca*), russian thistle (*Salsola kali*), western salsify (*Tragopogon dubius*), slimflower scurfpea (*Psoralidium tenuiflorum*), and wavyleaf thistle (*Cirsium undulatum*) (Lauver et al. 1999). Native grass species planted in CRP fields included little bluestem, sideoats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*) (Fields 2004). The CRP fields were interseeded with forbs in the mid-late 1990s; the seed mixture included white sweet clover (*Melilotus alba*), yellow sweet clover (*M. officinalis*), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower, purple prairie clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*; Fields 2004). Wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*) were the major crops in the region.

In south-central Kansas, the Red Hills study area was centered on private lands in Kiowa and Comanche counties within the Mixed-Grass Prairie Ecoregion (Van Pelt et al. 2013, McDonald et al. 2014, Dahlgren et al. 2016, Wolfe et al. 2016). The Red Hills site consisted of mixed-grass prairie on loamy soils. Primary land uses for this area included livestock grazing, oil and gas extraction and exploration, and row-crop and dryland agriculture associated with drainages interspersed throughout the region. Dominant vegetation in south-central Kansas included little bluestem, blue grama, hairy grama, sideoats grama, buffalograss, sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludiviciana*), western ragweed

(*Ambrosia psilostachya*), sand sagebrush (*Artemisia filiafolia*), and eastern red cedar (*Juniperus virginiana*; Lauver et al. 1999).

The third study area, Clark study area, was located in Clark County on the Mixed-Grass Prairie Ecoregion and Sand Sagebrush Prairie Ecoregion boundary (McDonald et al. 2014, Haukos et al. 2016, Wolfe et al. 2016) and land use was dominated by livestock grazing, energy extraction and exploration, and row-crop agriculture. Dominant vegetation in the area included little bluestem, sideoats grama, blue grama, hairy grama, big bluestem, alkali sacaton (*Sporobolous airoides*), invasive Russian thistle, kochia (*Kochia scoparia*), annual sunflower (*Helianthus annuus*), and sand sagebrush (Lauver et al. 1999).

Methods

Vegetation Surveys

I conducted standardized vegetation surveys at each study area. Surveys were completed from May 2013 to June 2015 for the Northwest and Red Hills study area and April 2014 to January 2016 at the Clark study area. Surveys were divided into two periods (July 2013 - June 2014 [year one] and July 2014 - June 2015 [year two]) at the Northwest and Red Hills study areas. Only one sampling period occurred at the Clark study area (year two). Vegetation survey points were either stratified randomly within ESs throughout the study areas or randomly selected from a pool of locations obtained from marked LEPC individuals as part of concurrent studies (Lautenbach 2014, Plumb 2015, and Robinson 2015). All sampled land cover types patches (CRP tracts, ES, etc.) have supporting evidence indicating occupancy by LEPC (Lautenbach 2014, Plumb 2015, and Robinson 2015). Randomly generated survey points were created using the Create Random Points tool in ArcGIS 10.2 (ESRI Inc., 2013, Redlands, CA, USA). All survey points were limited to grassland habitats that could be evaluated in terms relevant to LEPC. More specifically, all points were limited to native grasslands grazed by domesticated livestock (cattle) or reclaimed grasslands in the form of CRP. Random locations were constrained to properties where access was granted in accordance to concurrent research (Lautenbach 2014, Plumb 2015, Robinson 2015).

At each survey point, I estimated percent canopy cover of shrubs, forbs, grasses, bare ground, and litter using a 60 x 60 centimeter (cm) Daubenmire frame (Daubenmire 1959) at the plot center and 4-m from the point center to the north (N), south (S), east (E), and west (W) of plot center. I recorded four visual obstruction reading (VOR) at cardinal directions using a Robel pole at the plot center from a distance of 4 m and a height of 1 m (Robel et al. 1970). I measured litter depth from the plot center out to 4 m N, S, E, and W of plot center at 0.5-m intervals (Davis et al. 1979). I averaged VOR readings, litter depth, and canopy cover measurements for each survey point to obtain a representative value for each vegetation characteristic per point.

Vegetation Survey Point Classification

After data collection and entry, I classified and categorized each survey point into the respective study area, land cover type (ecological sites and CRP lands), and sampling period. Being limited to working native grasslands and CRP tracts, I categorized survey points into either ESs, in the case of working grasslands, or CRP tracts that were (DCRP) eligible for emergency haying or grazing or were not (CRP) eligible for emergency haying or grazing. Designation for emergency haying or grazing starts with the conservation practice (CP) number associated with each CRP tract. If the CP number allows for emergency haying and grazing, the practice can only be implemented once every three years and only in years that FSA officials designate the county as eligible for emergency haying and grazing due to drought. Designations between disturbed and undisturbed CRP tracts were achieved via personal correspondence with

FSA and USDA officials. However, in the Red Hills and Clark study areas the amount of CRP did not permit this differentiation (too few samples).

Analysis

I stratified my analyses by study area because land cover types and precipitation were not consistent across sites (Figure 1.3). I used a two-way analysis of variance (ANOVA; $\alpha = 0.05$) to test for differences in mean values of vegetation characteristics (VOR, litter depth and canopy cover of grass, litter, forbs, bare ground. and shrub) among land cover types and year at the Northwest and Red Hills study areas. Although different VOR readings were recorded at each survey point, I only investigated the mean highest 100% obstructed decimeter. I used a one-way ANOVA ($\alpha = 0.05$) to evaluate differences in mean vegetation characteristic values among land cover types at the Clark study area. Land cover types that did not contain at least fifty samples in a given year were not included in the analysis. Vegetation survey points were not grouped by calendar year. Instead, I divided survey points into years starting with the 1st of July and ending with the 30th of June. Thus, two years of data were analyzed for the Northwest and Red Hills sites (July 2013 - June 2014 [year one] and July 2014 - June 2015 [year two]) and only one year of data was analyzed for the Clark study area (year two). Therefore, the investigation of year effects was limited to the Northwest and Red Hills sites. Sampling period dates were set so that an estimated majority (>50%) of primary production had occurred before the sampling period began (USDA and USDI 2013). If main effects of ANOVAs were significant ($P < 0.05$), I used a Tukey HSD post hoc analysis to conduct pair-wise tests among land cover types in the same year. I did not investigate between year differences because the variability in precipitation between years likely drives this interaction and not land cover types themselves.

Results

In total, 13,556 vegetation survey points were recorded from July 2013 to June 2015. In the Northwest and Red Hills study areas, surveys were executed during both years while only one year was surveyed in the Clark County study area. Vegetation survey points were distributed across eight, four, and nine land cover types in the Northwest, Red Hills, and Clark study areas, respectively (Table 1.1).

Visual Obstruction

The two-way interaction between visual obstruction and year was significant at both the Northwest ($F_{7,\,5625} = 14.51$, $P < 0.001$) and the Red Hills study area ($F_{3,\,4959} = 5.953$, $P < 0.001$). In the Clark study area, the effect of land cover type on vegetation characteristics was significant ($F_{8,\,2936} = 7.39$, $P < 0.001$).

Visual obstruction differed among land cover types in the Northwest site during year one ($F_{7,\,3143} = 113.7$, $P < 0.001$) and year two ($F_{7,\,2482} = 55.4$, $P < 0.001$). During year one, the land cover type exhibiting the greatest 100% VOR was CRP ($\bar{x} = 1.12$ dm) followed by Sandy Lowland ($\bar{x} = 1.00$ dm; Table 1.2). The ESs exhibiting the lowest 100% VOR were Chalk Flats, Limy Upland, Loamy Lowland, and Loamy Upland (Table 1.2). Mean values for these ESs ranged from 0.27 – 0.43 dm. In year two, the greatest mean value was once again CRP ($\bar{x} =$ 1.60 dm) followed by DCRP ($\bar{x} = 1.34$ dm; Table 1.3). All ecological site values were below one decimeter and not different ($P < 0.05$; Table 1.3).

Visual obstruction means among land cover types were also different in year one ($F_{3,\,2463} = 2.63$, $P = 0.05$) and year two ($F_{3,\,2496} = 12.1$, $P < 0.001$) at the Red Hills study area. In year one, the Tukey HSD analysis yielded no differences among land cover type mean values (Table

1.4). In year two, Red Clay prairie ($\bar{x}$ = 0.53 dm) had lower 100% visual obstruction than Limy Upland ($\bar{x}$ = 0.68 dm), Loamy Upland ($\bar{x}$ = 0.58 dm), and Sandy ESs ($\bar{x}$ = 0.63 dm; Table 1.5).

The land cover types can be separated into two different groups at the Clark study area. Choppy Sands ($\bar{x}$ = 1.30 dm), CRP ($\bar{x}$ = 1.27 dm), and Loamy Upland ($\bar{x}$ = 0.96; Table 1.6) land cover types all had 100% mean VOR values greater than Limy Upland ($\bar{x}$ = 0.81 dm), Sandy Lowland ($\bar{x}$ = 0.70 dm), Sands ($\bar{x}$ = 0.88 dm), Sandy ($\bar{x}$ = 0.79), Saline Subirrigated ($\bar{x}$ = 0.79), and Subirrigated ESs ($\bar{x}$ = 0.79; Table 1.6).

Litter Depth

The two-way interaction between land cover and year was significant for average litter depth at both the Northwest ($F_{7,\,5625}$ = 2.39, P = 0.02) and the Red Hills study area ($F_{3,\,4959}$ = 8.94, $P < 0.001$). Mean litter depths also differ among land cover types in the Clark study area ($F_{8,\,2936}$ = 34.97, $P < 0.001$).

Mean litter depth differed among land cover types in the Northwest site during year one ($F_{7,\,3143}$ = 116.3, $P < 0.001$) and year two ($F_{7,\,2482}$ = 57.55, $P < 0.001$). In year one, the land cover type exhibiting the greatest litter depth was CRP ($\bar{x}$ = 3.31 cm), followed by DCRP ($\bar{x}$ = 2.36 cm), Loamy Lowland ($\bar{x}$ = 1.89 cm) and Sandy Lowland ($\bar{x}$ = 1.62 cm; Table 1.2). The ESs exhibiting the least values of litter depth were Chalk Flats ($\bar{x}$ = 1.54 cm), Limy Upland ($\bar{x}$ = 1.48 cm), Loamy Upland ($\bar{x}$ = 1.33 cm) and Sandy ($\bar{x}$ = 1.46 cm; Table 1.2). In year two, the greatest mean value was once again CRP ($\bar{x}$ = 2.82 cm) followed by DCRP ($\bar{x}$ = 2.05 cm; Table 1.3). The land cover types with the lowest mean values of litter depth were Chalk Flats ($\bar{x}$ = 1.34 cm), Limy Upland ($\bar{x}$ = 1.27 cm) and Loamy Upland ($\bar{x}$ = 1.28 cm; Table 1.3).

Mean litter depth differed among land cover types in the Red Hills site during year one ($F_{3,\,2463}$ = 39.37, $P < 0.001$) and year two ($F_{3,\,2496}$ = 12.76, $P < 0.001$). In year one, there was only one land cover type that was significantly greater than the others ($P < 0.05$; Table 1.4). The greatest mean litter depth value was associated with the Sandy ES ($\bar{x}$ = 0.95 cm). The remainder of the ESs did not differ from one another ($P < 0.05$). This group includes Limy Upland ($\bar{x}$ = 0.91 cm), Loamy Upland ($\bar{x}$ = 0.86 cm), and Red Clay Prairie ($\bar{x}$ = 0.92 cm) ESs. In the second year of sampling, Red Clay Prairie exhibited less mean litter depth ($\bar{x}$ = 0.63 cm) than the other land cover types sampled.

At the Clark study area, CRP cover types exhibited the greatest litter depth value ($\bar{x}$ = 3.16 cm); Table 1.6). ESs exhibited varying values of litter depth. Limy Upland ($\bar{x}$ = 1.27 cm), Loamy Upland ($\bar{x}$ = 1.32 cm), Sandy ($\bar{x}$ = 1.14 cm), Saline Subirrigated ($\bar{x}$ = 1.65 cm), and Subirrigated ($\bar{x}$ = 1.23 cm) all exhibited mean litter depth values >1 cm (Table 1.6).

Litter Cover

Percent litter cover differed among land cover types in the Northwest site during year one ($F_{7,\ 3143} = 4.42$, $P < 0.001$) and year two ($F_{7,\ 2482} = 19.47$, $P < 0.001$). In year one, the land cover type exhibiting the greatest litter cover was CRP ($\bar{x}$ = 28.79%) followed by Sandy ($\bar{x}$ = 26.28%; Table 1.2). The ESs exhibiting the least values of litter cover were Chalk Flats ($\bar{x}$ = 23.98%) and Loamy Lowland ($\bar{x}$ = 23.19%; Table 1.2). In year two, the greatest mean value was once again CRP ($\bar{x}$ = 18.28%) followed by DCRP ($\bar{x}$ = 15.39%) and Loamy Lowland ($\bar{x}$ = 16.02%; Table 1.3). The land cover types with the lowest mean values of litter cover were Chalk Flats ($\bar{x}$ = 11.44%) and Loamy Upland ($\bar{x}$ = 11.99%; Table 1.3)

Percent litter cover differed among land cover types in the Red Hills site during year one ($F_{3,\ 2463} = 39.48$, $P < 0.001$) and year two ($F_{3,\ 2496} = 16.66$, $P < 0.001$). In year one, the Sandy ES was significantly greater ($\bar{x}$ = 23.33%; Table 1.4) than all other land cover types ($P < 0.05$; Table 1.4). The lowest mean litter cover value was associated with the Red Clay Prairie ES ($\bar{x}$ =

14.36%). In the second year of sampling, there was much less variation in litter cover values between land cover types. However, the land cover types with the greatest mean litter cover values were Limy Upland ($\bar{x}$ = 10.65%) and Sandy ($\bar{x}$ = 10.74%) and the two lowest values were associated with Loamy Upland ($\bar{x}$ = 8.80%) and Red Clay Prairie ($\bar{x}$ = 8.04%).

In the Clark study area, we only investigated the main effect of land cover type on vegetation characteristics. CRP cover types exhibited the greatest litter cover values ($\bar{x}$ = 12.40%; Table 1.6) followed by Sands ($\bar{x}$ = 9.38%) and Sandy ($\bar{x}$ = 9.16%) ESs (Table 1.6). The ESs with the least amount of litter cover were Limy Upland ($\bar{x}$ = 6.06%), Loamy Upland ($\bar{x}$ = 7.41%), and Sandy Lowland ($\bar{x}$ = 7.29%; Table 1.6).

Grass Cover

The two-way interaction between mean grass cover and year was significant at the Northwest ($F_{7,\,5625}$ =5.75, $P < 0.001$) study area, but the Red Hills ($F_{3,\,4959}$ = 1.03, $P < 0.39$) site did not exhibit differences between years and land cover type. The one-way ANOVA for the Clark study area was also significant ($F_{8,\,2936}$ = 55.34, P < 0.001).

Percent grass cover differed among land cover types in the Northwest site during year one ($F_{7,\,3143}$ = 15.63, $P < 0.001$) and year two ($F_{7,\,2482}$ = 34.87, $P < 0.001$). In year one, the land cover type exhibiting the greatest grass cover was CRP ($\bar{x}$ = 61.07%) followed by Limy Upland ($\bar{x}$ = 57.34%) and Loamy Upland ($\bar{x}$ = 57.70%; Table 1.2). The land cover types exhibiting the least values of grass cover were Chalk Flats ($\bar{x}$ = 49.38%), Sandy Lowland ($\bar{x}$ = 47.68%), and Sandy ($\bar{x}$ =50.66%; Table 1.3). In year two, the greatest mean value was Loamy Upland ($\bar{x}$ = 72.38%) followed by CRP ($\bar{x}$ = 71.65%), and Limy Upland ($\bar{x}$ = 71.69%: Table 1.3). The land cover types with the lowest mean values of litter cover in year two were Chalk Flats ($\bar{x}$ = 59.84%), DCRP ($\bar{x}$ = 60.89%) and Sandy Lowland ($\bar{x}$ = 54.04%; Table 1.3).

In the Red Hills study area, the main effect of land cover type was significant ($F_{3,\,4959}$ = 35.6, $P < 0.001$). Means and standard error calculated using values from year one and year two are reported in Table 1.4. Results indicate that Loamy Upland sites exhibit the greatest amount of grass cover ($\bar{x}$ = 56.60%) among the land cover types evaluated (Table 1.4).

In the Clark study area, we only investigated the main effect of land over type on vegetation characteristics. CRP cover types exhibited the greatest grass cover values ($\bar{x}$ = 66.00%) followed by Loamy Upland ($\bar{x}$ = 61.99%) and Saline Subirrigated ($\bar{x}$ = 62.00%) ESs (Table 1.6). The ESs with the least amount of litter cover were Choppy Sands ($\bar{x}$ = 30.92%) and Sands ($\bar{x}$ = 41.34; Table 1.6). All other mean values can be observed in Table 1.6.

Forb Cover

The two-way interaction between mean forb cover and year was significant at both the Northwest ($F_{7,\,5625}$ = 6.21, $P < 0.001$) and the Red Hills ($F_{3,\,4959}$ = 10.94, $P < 0.001$) study area. The one-way ANOVA for the Clark study area was also significant ($F_{8,\,2936}$ = 18.81, P < 0.001).

Percent forb cover differed among land cover types in the Northwest site during year one ($F_{7,\,3143}$ = 14.25, $P < 0.001$) and year two ($F_{7,\,2482}$ = 14.22, $P < 0.001$). In year one, the land cover type exhibiting the greatest forb cover was Sandy Lowland ($\bar{x}$ = 13.96%) followed by Chalk Flats ($\bar{x}$ = 10.77%; Table 1.2). The ESs exhibiting the least values of forb cover were CRP ($\bar{x}$ = 6.17%) and Loamy Upland ($\bar{x}$ = 6.75%; Table 1.2). In year two, the greatest mean forb cover value was DCRP ($\bar{x}$ = 13.44%) followed by Chalk Flats ($\bar{x}$ = 11.07%; Table 1.3). The land cover type with the lowest mean value of forb cover was the same as in year one, CRP ($\bar{x}$ = 4.76%).

Percent forb cover differed among land cover types in the Red Hills site during year one ($F_{3,\,2463}$ = 15.34, $P < 0.001$) and year two ($F_{3,\,2496}$ = 10.92, $P < 0.001$). In year one, the top three land cover types exhibiting the greatest values of forb cover were Limy Upland ($\bar{x}$ = 24.46%), Red Clay Prairie ($\bar{x}$ = 24.07%) and Sandy ($\bar{x}$ = 23.99%; Table 1.4). All three top land cover types were not significantly different than one another. However, Loamy Upland ($\bar{x}$ = 18.49%) exhibited significantly less forb cover than the other land cover types. In the second year of sampling, Limy Upland ($\bar{x}$ = 19.29%) and Sandy ($\bar{x}$ = 19.73%) were the land cover types with the greatest values of forb cover (Table 1.5). The land cover types with the least amount of forb cover in the second year of sampling were Loamy Upland ($\bar{x}$ = 17.54%) and Red Clay Prairie ($\bar{x}$ = 16.42%; Table 1.5).

In the Clark study area, we only investigated the main effect of land over type on vegetation characteristics. The top three land cover types in terms of forb cover were Sandy ($\bar{x}$ = 20.12%), Choppy Sands ($\bar{x}$ =19.36%), Limy Upland ($\bar{x}$ =19.13%), and Sands ($\bar{x}$ =19.90%; Table 1.6). CRP exhibited significantly less forb cover than all other land cover types at 6.63% (Table 1.6). Estimates of Loamy Upland, Sandy Lowland, Saline Subirrigated, and Subirrigated were 16.64%, 12.46%, 12.64%, and 13.93%, respectively.

Bare Ground Cover

The two-way interaction between mean bare ground cover and year was significant at both the Northwest ($F_{7,\,5625}$ = 2.605, P = 0.011) and the Red Hills ($F_{3,\,4959}$ = 5.02, P = 0.0018) study area. The one-way ANOVA for the Clark study area was also significant ($F_{8,\,2936}$ = 37.73, P < 0.001).

Percent bare ground cover differed among land cover types in the Northwest site during year one ($F_{7,\,3143}$ = 21.69, $P < 0.001$) and year two ($F_{7,\,2482}$ = 40.07, $P < 0.001$). In year one, the land cover type exhibiting the greatest amount of bare ground cover was Chalk Flats ($\bar{x}$ = 20.36%) followed by Sandy Lowland ($\bar{x}$ = 17.08%; Table 1.2). The land cover type exhibiting significantly less bare ground cover than other land cover types cover was CRP ($\bar{x}$ = 8.56%; Table 1.2). In year two, the greatest mean bare ground cover value was exhibited by Chalk Flats ($\bar{x}$ = 18.21%) followed by Sandy Lowland ($\bar{x}$ = 18.04%; Table 1.3). The land cover type with the lowest mean value of bare ground cover was the same as in year one, CRP ($\bar{x}$ = 6.54%).

Percent bare ground cover differed among land cover types in the Red Hills site during year one ($F_{3,\,2463} = 36.85$, $P < 0.001$) and year two ($F_{3,\,2496} = 19.93$, $P < 0.001$). In year one, Red Clay Prairie ($\bar{x}$ = 19.64%) exhibited significantly more bare ground cover than other land cover types (Table 1.4). In the second year of sampling, Red Clay Prairie ($\bar{x}$ = 16.42%; Table 1.5) was the land cover type illustrating the greatest amount of bare ground cover.

In the Clark study area, we only investigated the main effect of land over type on vegetation characteristics. The top land cover types in terms of bare ground cover were Choppy Sands ($\bar{x}$ = 31.34%), Sandy Lowland ($\bar{x}$ = 28.99%), and Sands ($\bar{x}$ = 25.65%; Table 1.6). The land cover types that exhibited the least amounts of bare ground cover were Loamy Upland ($\bar{x}$ = 13.96%), CRP ($\bar{x}$ = 15.07%), and Saline Subirrigated ($\bar{x}$ = 16.09%; Table 1.6).

Shrub Cover

The two-way interaction between mean shrub cover and year was significant at both the Northwest ($F_{7,\,5625} = 42.9$, $P = 0.0039$) and the Red Hills ($F_{3,\,4959} = 3.927$, $P = 0.0082$) study area. The one-way ANOVA for the Clark study area was also significant ($F_{8,\,2936} = 36.64$, $P < 0.001$). Mean values of shrub cover for each site and year are available in Tables 1.2, 1.3, 1.4, 1.5, and 1.6.

Percent shrub cover differed among land cover types in the Northwest site during year one ($F_{7,\,3143} = 57.72$, $P < 0.001$) and year two ($F_{7,\,2482} = 54.27$, $P < 0.001$). In year one, the land cover types exhibiting the greatest amount of shrub cover were Sandy Lowland ($\bar{x}$ = 6.24%) and

Sandy ($\bar{x}$ = 5.90%; Table 1.2). Chalk Flats also had a noticeable shrub cover presence at 2.36%. DCRP ($\bar{x}$ = 0.09%) and CRP ($\bar{x}$ = 0.17%) lacked shrub cover (Table 1.2). In the second year of sampling, Sandy ($\bar{x}$ = 4.82%) and Sandy Lowland ($\bar{x}$ = 4.27%) ESs exhibited the greatest amount of shrub cover once again (Table 1.3). Chalk Flats ($\bar{x}$ = 1.06%) was the only other land cover type that has mean shrub cover values above 1%.

Percent shrub cover differed among land cover types in the Red Hills site during year one ($F_{3,\,2463}$ = 28.16, $P < 0.001$) and year two ($F_{3,\,2496}$ = 14.82, $P < 0.001$). In year one, the three top land cover types in terms of shrub cover were Sandy ($\bar{x}$ = 3.21%), Limy Upland ($\bar{x}$ = 1.12%), and Loamy Upland ($\bar{x}$ = 1.05%) and were not significantly different than one another (Table 1.5). The least amount of shrub cover is exhibited by Red Clay Prairie ($\bar{x}$ = 0.63%) and is significantly less than the other land cover types (Table 1.5). In the second year, Sandy sites had the greatest amount of shrub cover at 1.90% (Table 1.5). The lowest three sites were not significantly different than one another and include Limy Upland ($\bar{x}$ = 0.75%), Loamy Upland ($\bar{x}$ = 0.65%), and Red Clay Prairie ($\bar{x}$ = 0.55).

In the Clark study area, we only investigated the main effect of land over type on vegetation characteristics. The top land cover type in terms of shrub cover was Choppy Sands ($\bar{x}$ = 10.19%) and was significantly greater than all other land cover types. The other land cover types that portray shrub cover values greater than one percent were Sandy Lowland ($\bar{x}$ = 2.58%), Sands ($\bar{x}$ = 3.20%), and Sandy ($\bar{x}$ = 1.35; Table 1.6).

Discussion

The decline of grasslands birds throughout the Great Plains (Peterjohn and Sauer 1999) highlights the need to identify, produce, and protect quality grassland habitats. Private and federal entities have begun using land cover type categories as a first step in assessing the habitat suitability of lands in consideration for imperiled bird species such as the LEPC (Van Pelt et al. 2013). However, the accuracy of these assessments is in question due to minimal scientific research. This analysis aimed to contribute to the resolution of this issue by evaluating vegetation characteristics associated with land cover types in western Kansas. More specifically, I evaluated vegetative characteristics directly related to LEPC ecology to provide inference applicable to future management considerations. My research indicates that, 1) ES descriptions and other land cover types are adequate delineation techniques for detecting vegetation differences relevant to LEPC ecology, and 2) these observed differences may have the potential to predict microhabitat suitability of land cover types for LEPC, but further research is required. Research regarding the vegetation and LEPC response to environmental variability (e.g., weather and management strategies such as livestock grazing) would be helpful in determining habitat quality for wildlife. Explicit evaluations of ecological site and CRP habitat quality predictions are also warranted.

Consistent patterns of vegetation characteristics associated with the various land cover types that I evaluated were apparent at all three study areas. In many cases, habitat conditions matched lesser prairie chicken microhabitat needs during various ecological periods (nesting and brooding). When managing microhabitat for LEPC, biologists target efforts towards the creation nesting and brooding habitat (Hagen et al. 2004). The specific habitats are often a limiting factor on a landscape scale (Hagen et al. 2013), thus it is important to speculate the potential habitat quality for each land cover type during the nesting and brood rearing periods of LEPC.

Nesting Habitat Potential

In consideration of general microhabitat requirements for nesting LEPC cited above, there are land cover types at each study area exhibiting the potential for LEPC nesting. Although most land cover types do not exhibit mean values of vegetation structure ideal for nesting LEPC, data suggests identifies land cover types with the nesting microhabitat potential.

In the Northwest study area there are no mean values of 100% visual obstruction associated with land cover types that meet the recommended levels of visual obstruction (2-3 dm; Lautenbach 2014), even with greater than average rainfall during the second year of the study. However, it is clear that distinct land cover types are more conducive for nesting microhabitat. More specifically, DCRP and CRP are often thought of as the highest quality nesting sites for LEPC due to relatively greater visual obstruction and grass cover. However, DCRP as potential for nesting likely decreases post-disturbance (haying or grazing) because of reduced litter cover and increases in bare ground cover. Mid-contract management of these CRP tracts in the form of grazing or haying can reduce mean visual obstruction, litter cover, grass cover and increases bare ground cover. Associated reduced grass cover and increased forb cover may increase the potential for DCRP as suitable brooding habitat. Other disturbance (i.e., interseeding of forbs) has influenced the selection of CRP tracts (Fields 2004).

It is more difficult to discern nesting habitat potential across ESs in rangeland due to yearly variation in management (livestock management). However, grass cover values and bare ground values may indicate potentially adequate nesting microhabitat when paired with light to moderate grazing pressure. ESs exhibiting the greatest grass potential for LEPC nesting habitat are Loamy Upland, Limy Upland, and Loamy Lowland. Limy Upland and Loamy Lowland which are most likely more suitable habitat for nesting LEPC due to plant species composition (J. Kraft, personal obs.). Loamy Uplands in the SGPR region tend to be dominated by buffalograss and blue grama. Grasslands dominated by these species do not possess the vegetation structure potential for LEPC nesting microhabitat over large landscapes. Considering the increasing use of shrub cover as grazing intensity increases (Haukos and Smith 1989, Haukos and Zavaleta 2016), the Sandy and Sandy Lowland ESs have the potential to foster adequate nesting microhabitat. In the Red Hills study area the absence of CRP lands requires all habitat to be present in working grasslands across ESs. Once again, were are no land cover types that exhibit mean visual obstruction values that met recommended levels (Lautenbach 2014). However, Limy Upland and Sandy ESs exhibit the greatest litter cover values and relatively low bare ground levels that create the potential for adequate nesting habitat. If these ESs were paired with light to moderate grazing pressure and adequate precipitation they would be the most likely to possess nesting microhabitat. The patch-burn grazing system that is employed on rangelands in the Red Hills study area also has the ability to decreases the grazing pressure on patches of habitat and thus increases visual obstruction, litter cover, and grass cover values. Furthermore, the presence of shrub cover in the form of sand sagebrush in the Sandy ESs has the potential to provide nesting habitat during periods that are lacking in adequate nesting microhabitat across other ESs.

Within the Clark county study area, it appears that CRP lands offer the most potential for nesting habitat based on relatively high values of visual obstruction, litter and grass cover, and low values of bare ground cover. Choppy Sands ecological sites exhibit the greatest amount of visual obstruction, but bare ground, grass and litter cover values are likely inadequate for quality nesting microhabitat. Litter cover values do not offer much distinction of land cover types, but grass cover values of Saline Subirrigated, Loamy Upland, and Subirrigated sites indicate potential for nesting microhabitat. These ESs also exhibit relatively low values of bare ground cover.

Brood Habitat Potential

It is more difficult to assess the potential for brood habitat across ESs. It is clear however, that females with broods are selecting for microhabitats exhibiting greater forb cover (Lautenbach 2014; J. Kraft unpublished data). Furthermore, the spare and open microhabitat required for broods is likely a product of yearly variation in management as much as a product of land cover type (Hagen et al. 2013). However, for the purposes of this research, I considered moderate levels of bare ground cover and greater values of forb cover as indicators of adequate brood microhabitat. An investigation of selected microhabitat by brooding females needs to be a significant component of future research on LEPC populations in Kansas.

In the Northwest study area, Sandy Lowland appears to offer the most potential for brood habitat with relatively greater means values of forb cover and moderate levels of bare ground cover. The other two ESs that may offer adequate brood habitat are Sandy and Chalk Flats. Once again these ESs were characterized with relatively high levels of forb cover and sufficient bare ground cover to facilitate chick movement.

In the Redhills study area, no ecological site was distinctly greater than others in terms of brooding microhabitat. However, Limy Upland and Sandy sites are perhaps relatively more conducive for brooding females than Loamy Upland or Red Clay Prairie sites. During both years of data collection, Limy Upland and Sandy sites exhibit greater forb cover and exhibit moderate levels of bare ground cover. Bare ground values of Limy Upland, Sandy, and Loamy Upland sites also appeared to be within the range of values acceptable for LEPC brood microhabitat. Red Clay Prairie appeared to be the least quality habitat for LEPC broods due to greater levels of mean bare ground cover levels.

Across ESs in the Clark study area, there were fairly clear distinctions that identify land cover types as potential brood habitats. Limy Upland and Sandy sites were potentially the most favorable land cover types for LEPC broods. Both sites exhibit relatively high mean values of forb cover and moderate levels of bare ground cover. Choppy Sands and Sands sites also portray greater levels of forb cover, but bare ground cover values greater than 25% are a potential deterrent to LEPC brood use.

Management Implications

Categorical delineations of habitat have many advantages to management of wildlife populations. Ease of accessibility, inference, and descriptions make these categorical habitats ideal for implementation of conservation actions. Ecological sites in particular have been described throughout the Great Plains, and offer managers an initial perception of habitat across a landscape or property. In western Kansas, descriptions of vegetation characteristics across these ecological sites and types of CRP described above, offer ranchers, biologists and conservation entities insight into the potential microhabitat available across categorical land cover types for LEPC. Based on these results, one can hypothesize what ecological sites and CRP types will be the most conducive for LEPC nesting and brooding.

Due to the microhabitat associated with CRP and DCRP tracts in northwestern Kansas, I prescribe the conservation and creation of these habitats to increase the quantity of both nesting and brooding habitat on the landscape. Further, considering the potential for ecological sites to be beneficial for various LEPC ecological needs, I prescribe CRP and DCRP establishment near well managed rangelands to maximize the benefit of heterogeneous habitat types. I also prescribe light levels of grazing pressure on ecological sites that do not exhibit visual obstruction and grass cover values conducive for LEPC nesting and brooding.

Further, I prescribe additional consideration when evaluating ecological sites and their habitat suitability for LEPC. The above predictions about beneficial microhabitat for LEPC across ecological sites do not consider the effects of management (livestock grazing) or other environmental influences (weather, climate, presence of trees etc.). Ultimately, the microhabitat across land cover types can alter greatly with anthropogenic management. Thus, the efficacy of grassland management for LEPC across ecological sites hinges on soil and plant community characteristics, but also management objectives.

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Figure 1.1 The delineated ecoregions of the range-wide lesser prairie-chicken species distribution. Ecoregions include the Mixed Grass Prairie (MGPR), Sand Sagebrush Prairie (SSPR), Shinnery Oak Prairie (SOPR), and Short-grass Prairie/CRP Mosaic ecoregions described in Van Pelt et al. (2013).

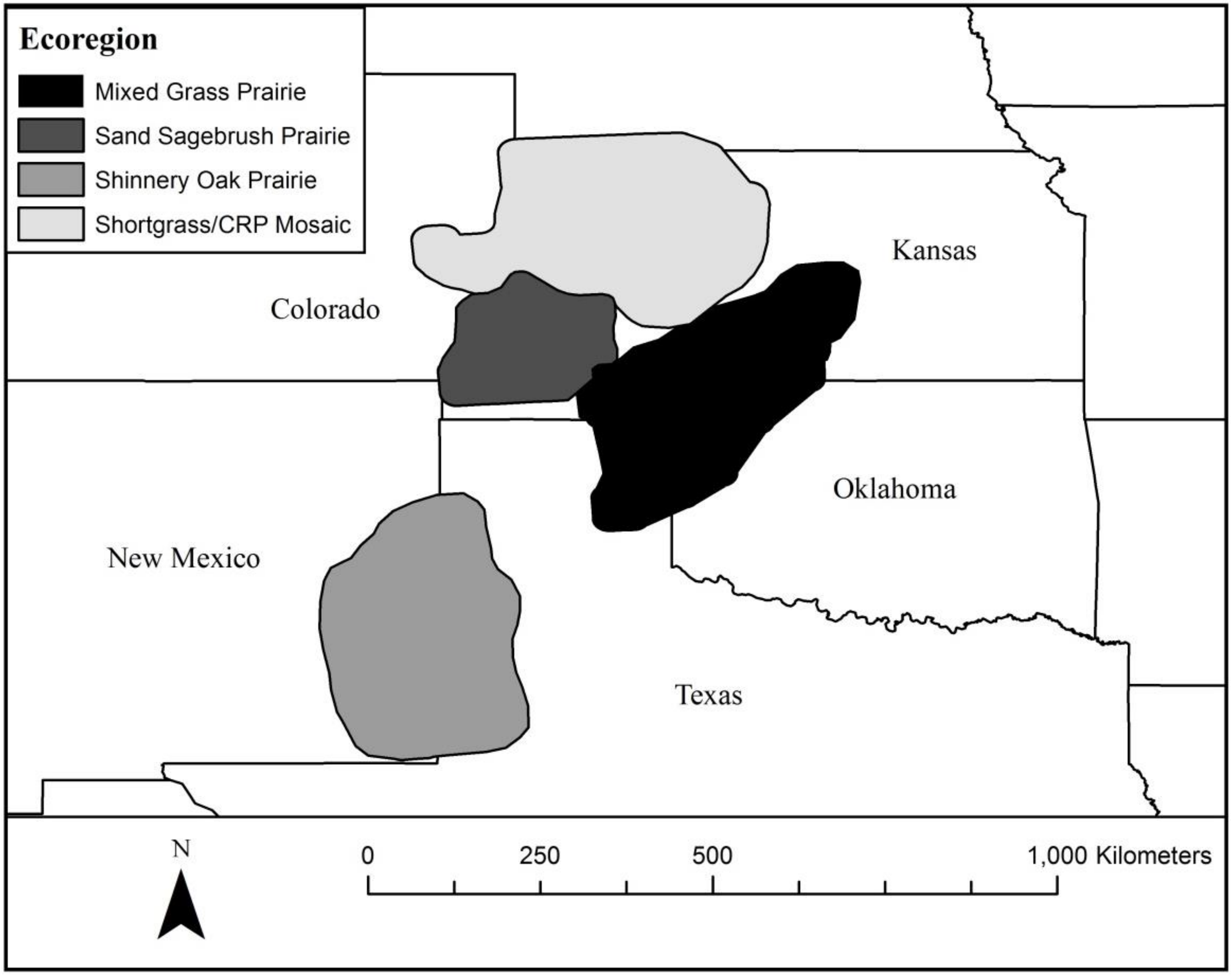

Figure 1.2 Map of study area locations where vegetative characteristic observations were collected from 2013-2015 across the lesser prairie-chicken range in Kansas, USA. The Northwest study area was located within Logan and Gove counties. The Redhills study area was located within Kiowa and Comanche counties and the Clark study area was located within Clark County.

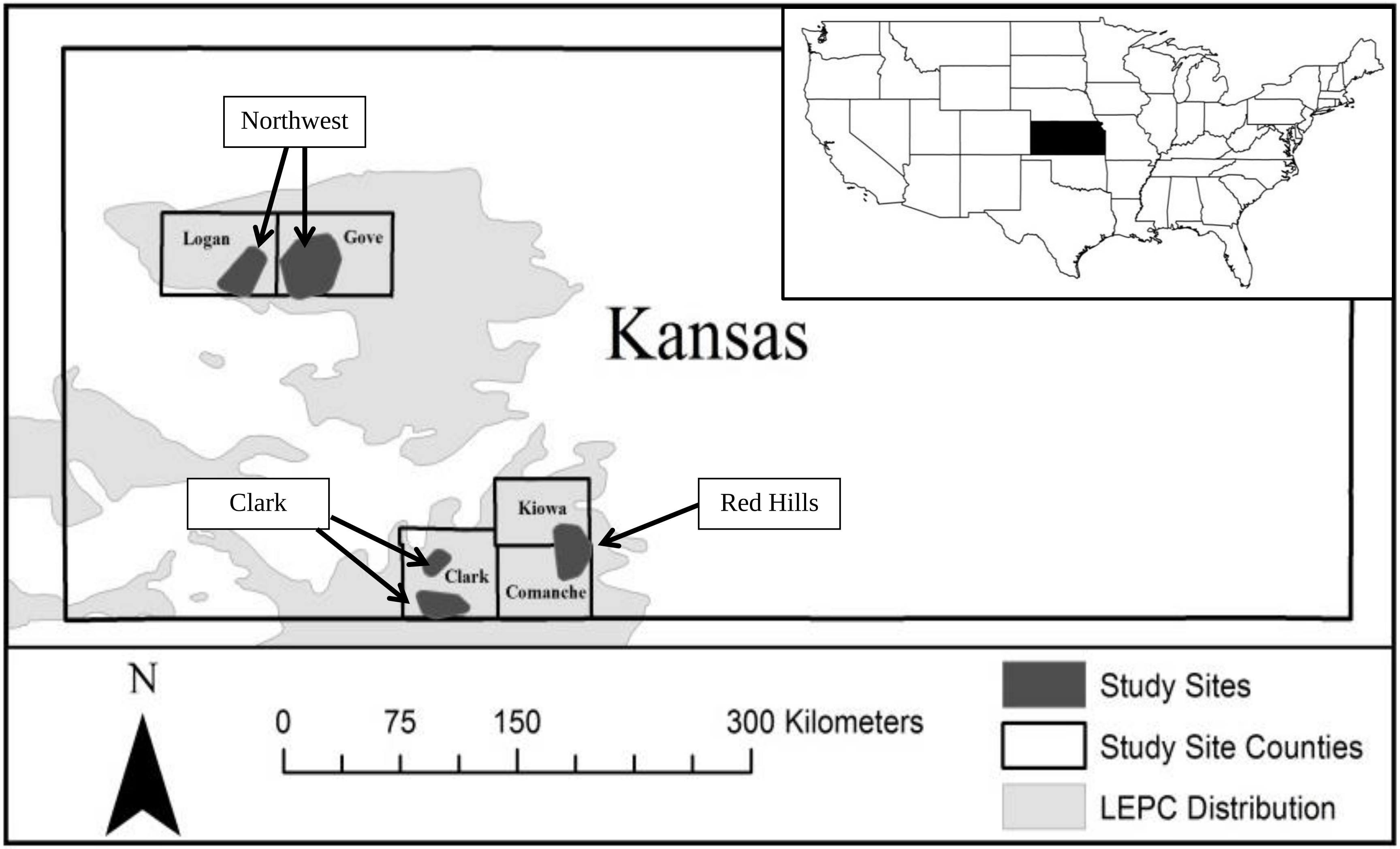

Figure 1.3 Total precipitation recorded during year one (July 2013-June 2014) and year two (July 2014-June 2015) across three lesser prairie-chicken study areas in western, Kansas, USA

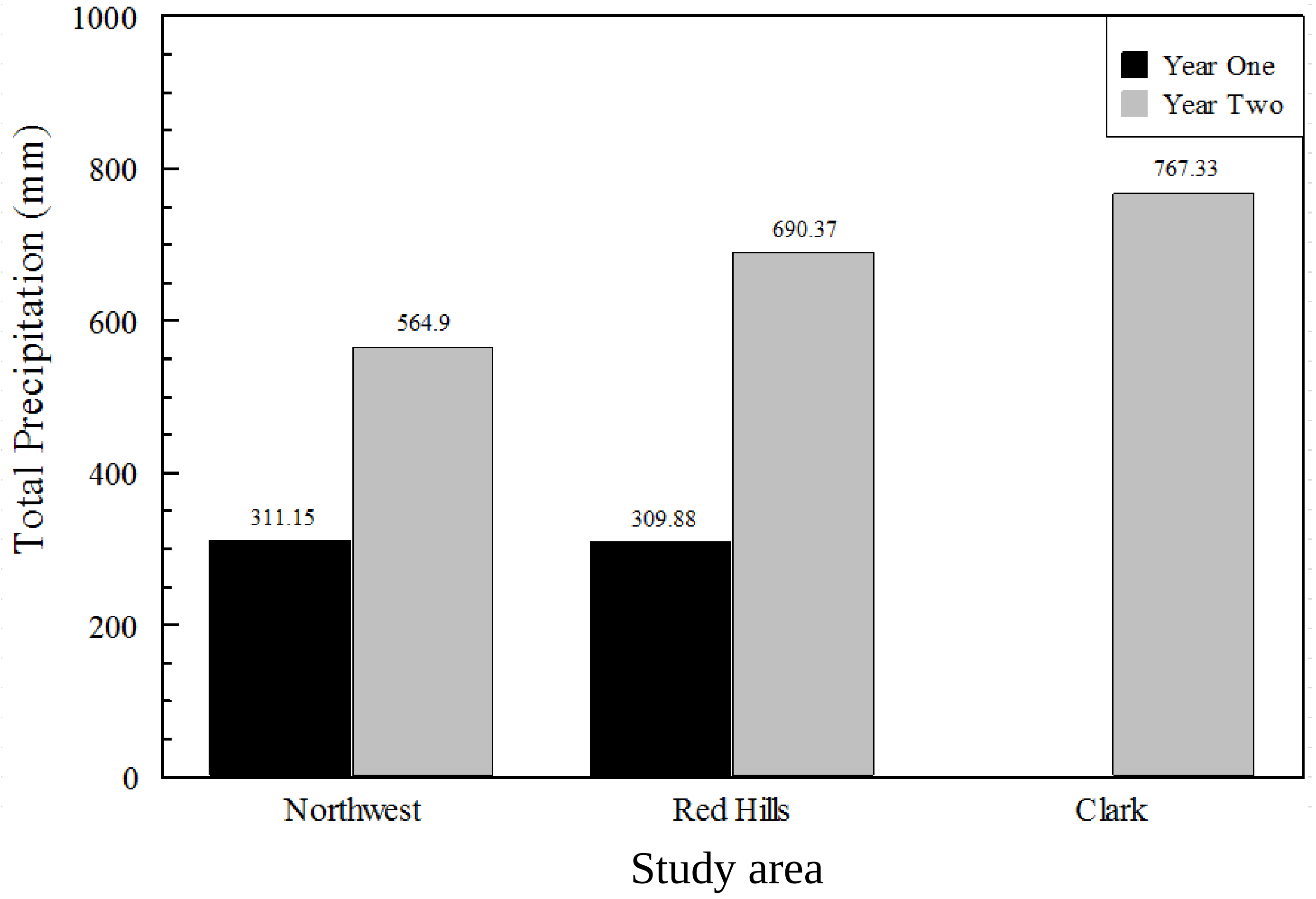

Table 1.1 Descriptions of ecological sites present within Northwest, Redhills, and Clark study areas delineated by MLRA(Major Land Resource Area). Table was adapted from Van Pelt et al. (2013). Information included describes the lesser prairie-chicken (*Tympanuchus pallidicinctus*; LEPC) Value (relative value of an ecological site to LEPC), estimated Annual Biomass Production (lbs/acre of grazing forage), and indication of potential use by LEPC within the nesting or brooding ecological periods.

MLRA	Ecological Site	LEPC Value	Annual Biomass Production (lbs/acre)	Nesting Habitat	Brood Habitat	Limited Use
72	Limy Upland	5	1500-3200	X	X	
	Loamy Upland	5	2500-3500	X	X	
	Sands	5	1500-3000	X	X	
	Sandy	5	1500-2800	X	X	
	Chalk Flats	4	1500-2200	X	X	
	Shallow Limy	4	700-1400		X	
	Loamy Terrace	3	2000-4000	X	X	
	Gravelly Hills	1	1100-1800		X	
	Loamy Lowland	1	3000-5500			X
	Saline Subirrigated	1	5000-6500			X
	Sandy Lowland	1	2000-4000			X
	Shale Breaks	1	500-1300		X	X
73	Limy Upland	5	1500-3200	X	X	
	Loamy Upland	5	2500-3500	X	X	
	Sands	5	1500-3000	X	X	
	Sandy	5	1500-2800	X	X	
	Chalk Flats	4	1500-2200	X	X	
	Clay Terrace	3	2500-4500	X	X	
	Loamy Terrace	3	2000-4000	X	X	
	Sandy Terrace	3	1500-2500	X	X	
	Gravelly Hills	1	1100-1800		X	
	Loamy Lowland	1	3000-5500			X
	Red Clay Prairie	1	200-450		X	
	Saline Subirrigated	1	5000-6500			X
	Sandy Lowland	1	2000-4000			X
	Subirrigated	1	3500-5500			X
77E	Choppy Sands	5	1200-2500	X	X	
	Loamy Upland	5	2500-3500	X	X	X
	Sands	5	1500-3000	X	X	
	Sandy	5	1500-2800	X	X	
	Limy Upland	4	1100-2200	X	X	
	Loamy Terrace	3	2000-4000	X	X	
	Sandy Terrace	3	1500-2500	X	X	
	Loamy Lowland	1	3000-5500			
	Red Clay Prairie	1	200-450		X	X
	Sandy Lowland	1	2000-4000			
	Subirrigated	1	3500-5500			X
78C	Choppy Sands	5	1200-2500	X	X	
	Loamy Upland	5	2500-3500	X	X	
	Sands	5	1500-3000	X	X	
	Sandy	5	1500-2800	X	X	
	Limy Upland	4	1100-2200	X	X	
	Loamy Terrace	3	2000-4000	X	X	
	Sandy Terrace	3	1500-2500	X	X	
	Loamy Lowland	1	3000-5500			X
	Red Clay Prairie	1	200-450		X	
	Saline Subirrigated	1	5000-6500			X
	Sandy Lowland	1	2000-4000			X
	Subirrigated	1	3500-5500			X

Table 1.2 Number of vegetation survey points used in analysis of variance models for each land cover type (ecological sites and Conservation Reserve Program types; undisturbed [UCRP] and disturbed [DCRP]) surveyed in the Northwest, Redhills, and Clark study areas in both Year One (July 2013 – June 2014) and Year Two (July 2014 – June 2015) in western Kansas, USA.

Northwest

Sampling Period	Chalk Flats	DCRP	UCRP	Limy Upland	Loamy Lowland	Loamy Upland	Sandy Lowland	Sandy	Total
Year One	381	256	556	883	118	724	82	151	3151
Year Two	405	193	388	602	159	501	86	156	2490
Total	786	449	944	1485	277	1225	168	307	5641

Redhills

Sampling Period	Limy Upland	Loamy Upland	Red Clay Prairie	Sandy	Total
Year One	1052	335	608	472	2467
Year Two	782	477	846	395	2500
Total	1834	812	1454	867	4967

Clark

Sampling Period	Choppy Sands	CRP	Limy Upland	Loamy Upland	Sandy Lowland	Sands	Sandy	Saline Subirrigated	Subirrigated	Total
Year One	153	83	240	146	274	1123	311	354	261	2945

Table 1.3 Mean values of vegetation characteristics (visual obstruction, litter depth, and canopy cover [litter, grass, forb, bare, shrub] measured across categorical cover types (ecological sites and Conservation Reserve Program types; undisturbed [UCRP] and disturbed [DCRP]) from July 2013-June 2014 in Northwest Kansas, USA.

		100% VOR (dm)		Litter Depth (cm)		Litter Cover (%)		Grass Cover (%)		Forb Cover (%)		Bare Cover (%)		Shrub Cover (%)	
Cover Type	N^{A}	$\bar{x}$*	SE	$\bar{x}$*	SE	$\bar{x}$*	SE	$\bar{x}$*	SE	$\bar{x}$*	SE	$\bar{x}$*	SE	$\bar{x}$*	SE
Chalk Flats	381	0.43^{b}	0.10	1.54^{ab}	0.35	23.98^{a}	5.36	49.38^{b}	11.04	10.77^{cd}	2.41	20.36^{d}	4.55	2.36^{d}	0.53
DCRP	256	0.71^{c}	0.044	2.36^{c}	0.15	25.24^{a}	1.58	55.35^{ac}	3.46	8.24^{abc}	0.52	13.74^{bc}	0.86	0.09^{ab}	0.0055
UCRP	556	1.12^{d}	0.048	3.31^{d}	0.14	28.79^{b}	1.22	61.07^{e}	2.59	6.17^{a}	0.26	8.56^{a}	0.36	0.17^{b}	0.0072
Limy Upland	883	0.26^{a}	0.0086	1.48^{ab}	0.050	25.98^{a}	0.87	57.34^{c}	1.93	7.85^{ab}	0.26	12.84^{bc}	0.43	1.05^{ac}	0.035
Loamy Lowland	118	0.38^{ab}	0.035	1.89^{bc}	0.17	23.19^{a}	2.13	57.70^{cde}	5.31	9.42^{abcd}	0.87	14.81^{bc}	1.36	0.57^{abc}	0.053
Loamy Upland	724	0.27^{ab}	0.010	1.33^{a}	0.049	25.76^{a}	0.96	56.67^{c}	2.11	6.75^{a}	0.25	13.56^{bc}	0.50	1.15^{c}	0.043
Sandy Lowland	82	1.00^{cd}	0.11	1.62^{ab}	0.18	23.19^{a}	2.56	47.68^{ab}	5.27	13.96^{d}	1.54	17.08^{bcd}	1.89	6.24^{e}	0.69
Sandy	151	0.70^{c}	0.06	1.46^{ab}	0.12	26.28^{ab}	2.14	50.66^{abd}	4.12	10.30^{bcd}	0.84	14.42^{ab}	1.17	5.90^{e}	0.48

[A] Number of observations used to estimate mean values for each vegetative characteristic.

* Cover type means for vegetative characteristics followed by the same letter do not exhibit within year differences ($P > 0.05$)

Table 1.4 Mean values of vegetation characteristics (visual obstruction, litter depth, and canopy cover [litter, grass, forb, bare, shrub]) measured across categorical cover types (ecological sites and Conservation Reserve Program types; undisturbed [UCRP] and disturbed [DCRP]) during Year One (July 2014-June 2015) in Northwest Kansas, USA.

		100% VOR (dm)		Litter Depth (cm)		Litter Cover (%)		Grass Cover (%)		Forb Cover (%)		Bare Cover (%)		Shrub Cover (%)	
Cover Type	N[1]	$\bar{x}$[2]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Chalk Flats	405	0.55^{a}	0.027	1.34^{a}	0.067	11.44^{a}	0.57	59.84^{ab}	2.97	11.07^{bc}	0.55	18.21^{b}	0.91	1.06^{d}	0.053
DCRP	193	1.34^{b}	0.096	2.05^{b}	0.15	15.39^{abc}	1.11	60.89^{ab}	4.38	13.44^{c}	0.97	9.27^{a}	0.67	0.10^{abd}	0.0070
UCRP	388	1.60^{c}	0.081	2.82^{c}	0.14	18.28^{c}	0.93	71.65^{c}	3.64	4.76^{a}	0.24	6.54^{a}	0.33	0.01^{ab}	0.00031
Limy Upland	602	0.74^{a}	0.030	1.27^{a}	0.052	12.54^{ab}	0.51	71.69^{c}	2.92	8.76^{b}	0.36	8.20^{a}	0.33	0.18^{ac}	0.0073
Loamy Lowland	159	0.76^{a}	0.061	1.59^{ab}	0.13	16.02^{bc}	1.27	64.77^{b}	5.14	9.77^{bc}	0.78	10.07^{a}	0.80	0.35^{abd}	0.028
Loamy Upland	501	0.70^{a}	0.031	1.28^{a}	0.057	11.99^{ab}	0.54	72.38^{c}	3.23	9.14^{b}	0.41	8.04^{a}	0.36	0.53^{abd}	0.024
Sandy Lowland	86	0.57^{a}	0.062	1.53^{ab}	0.16	15.82^{abc}	1.71	54.04^{a}	5.83	10.10^{bc}	1.09	18.04^{b}	1.95	4.27^{e}	0.46
Sandy	156	0.76^{a}	0.061	1.52^{a}	0.12	12.41^{ab}	0.99	63.71^{b}	5.10	10.91^{bc}	0.87	10.58^{a}	0.85	4.82^{e}	0.39

[1] Number of observations used to estimate mean values for each vegetative characteristic.

[2] Cover type means for vegetative characteristics followed by the same letter do not exhibit within year differences ($P > 0.05$)

Table 1.5 Mean values of vegetation characteristics (visual obstruction, litter depth, and canopy cover [litter, grass, forb, bare, shrub]) measured across categorical cover types (ecological sites) during Year Two (July 2013-June 2014) in Red Hills, Kansas, USA

		100% VOR (dm)		Litter Depth (cm)		Litter Cover (%)		Grass Cover (%)[2]		Forb Cover (%)		Bare Cover (%)		Shrub Cover (%)	
Cover Type	N[1]	$\bar{x}^3$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Limy Upland	1052	0.72^a	0.10	0.91^a	0.35	22.13^{bc}	5.36	-	0.51	24.46^a	2.41	13.39^a	4.55	1.12^a	0.53
Loamy Upland	355	0.68^a	0.044	0.86^a	0.15	19.93^b	1.58	-	0.78	18.49^b	0.52	11.81^a	0.86	1.05^a	0.0055
Red Clay Prairie	608	0.83^a	0.048	0.92^a	0.14	14.36^a	1.22	-	0.59	24.07^a	0.26	19.64^b	0.36	0.63^a	0.0072
Sandy	472	0.79^a	0.0086	0.95^b	0.050	23.33^c	0.87	-	0.28	23.99^a	0.26	11.14^a	0.43	3.21^b	0.035

[1] Number of observations used to estimate mean values for each vegetative characteristic.
[2] Means calculated using samples from both years due to insignificant ANOVA interaction terms

[3] Cover type means for vegetative characteristics followed by the same letter do not exhibit within year differences (P > 0.05)

Table 1.6 Mean values of vegetation characteristics (visual obstruction, litter depth, and canopy cover [litter, grass, forb, bare, shrub]) measured across categorical cover types (ecological sites) from July 2014-June 2015 in Red Hills, Kansas, USA

		100% VOR (dm)		Litter Depth (cm)		Litter Cover (%)		Grass Cover (%)		Forb Cover (%)		Bare Cover (%)		Shrub Cover (%)	
Cover Type	N[1]	$\bar{x}$[2]	SE	$\bar{x}*$	SE	$\bar{x}*$	SE	$\bar{x}*$	SE	$\bar{x}*$	SE	$\bar{x}*$	SE	$\bar{x}*$	SE
Limy Upland	782	0.68^{a}	0.023	0.76^{a}	0.027	10.65^{b}	0.38	58.29^{a}	2.08	19.29^{b}	0.69	11.97^{a}	0.43	0.75^{a}	0.027
Loamy Upland	477	0.58^{a}	0.026	0.78^{a}	0.036	8.80^{ab}	0.40	63.29^{b}	2.90	17.54^{ab}	0.80	10.94^{a}	0.50	0.65^{a}	0.030
Red Clay Prairie	846	0.53^{b}	0.061	0.63^{b}	0.13	8.04^{a}	1.27	59.28^{a}	5.14	16.51^{a}	0.78	16.42^{b}	0.80	0.55^{a}	0.028
Sandy	395	0.63^{a}	0.031	0.75^{a}	0.038	10.74^{b}	0.54	55.92^{a}	2.81	19.73^{b}	0.99	12.81^{a}	0.64	1.90^{b}	0.096

[1] Number of observations used to estimate mean values for each vegetative characteristic.

[2] Cover type means for vegetative characteristics followed by the same letter do not exhibit within year differences ($P > 0.05$)

Table 1.7 Mean values of vegetation characteristics (visual obstruction, litter depth, and canopy cover [litter, grass, forb, bare, shrub]) measured across categorical cover types (ecological sites and Conservation Reserve Program types) from July 2014-June 2015 in Clark County, Kansas, USA.

		100% VOR (dm)		Litter Depth (cm)		Litter Cover (%)		Grass Cover (%)		Forb Cover (%)		Bare Cover (%)		Shrub Cover (%)	
Cover Type	N[1]	$\bar{x}$[2]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Choppy Sands	153	1.30^{a}	0.10	0.78^{a}	0.063	8.26^{abc}	0.67	30.92^{a}	2.50	19.36^{d}	1.57	31.34^{c}	2.53	10.19^{e}	0.824
CRP	83	1.27^{a}	0.14	3.16^{d}	0.35	12.40^{d}	1.36	66.00^{e}	7.24	6.63^{a}	0.73	15.07^{a}	1.65	0.23^{abc}	0.025
Limy Upland	240	0.81^{b}	0.052	1.27^{b}	0.082	6.06^{a}	0.39	55.11^{cd}	3.56	19.13^{d}	1.23	18.64^{a}	1.20	0.58^{ab}	0.037
Loamy Upland	146	0.96^{a}	0.080	1.32^{cb}	0.11	7.41^{abc}	0.61	61.99^{de}	5.13	16.64^{bd}	1.38	13.96^{a}	1.16	0.35^{a}	0.029
Sandy Lowland	274	0.70^{b}	0.042	0.95^{ab}	0.057	7.29^{ab}	0.44	49.96^{c}	3.02	12.46^{ab}	0.75	28.99^{bc}	1.75	2.58^{cd}	0.156
Sands	1123	0.88^{b}	0.026	0.90^{a}	0.027	9.38^{cd}	0.28	41.34^{b}	1.23	19.90^{d}	0.59	25.65^{b}	0.77	3.20^{d}	0.096
Sandy	311	0.79^{b}	0.045	1.14^{ab}	0.064	9.16^{bcd}	0.52	49.25^{c}	2.79	20.12^{d}	1.14	18.38^{a}	1.04	1.35^{abc}	0.077
Saline Subirrigated	354	0.80^{b}	0.043	1.65^{c}	0.088	8.45^{bc}	0.45	62.00^{e}	3.30	12.64^{ab}	0.67	16.09^{a}	0.85	0.49^{a}	0.026
Subirrigated	261	0.79^{b}	0.049	1.23^{b}	0.076	8.65^{bc}	0.54	57.90^{de}	3.58	13.93^{b}	0.86	17.70^{a}	1.10	0.92^{abc}	0.057

[1] Number of observations used to estimate mean values for each vegetative characteristic.

[2] Cover type means for vegetative characteristics followed by the same letter do not exhibit within year differences ($P > 0.05$)

Chapter 2 - Lesser Prairie-Chicken Female Habitat Selection Across Land Cover Types in Western Kansas

Introduction

Resource or habitat selection analyses are commonly used to describe selected or desired habitat for a species, population or an individual (Manly et al. 2002). Often, resource selection studies attempt to obtain this information by defining what resources are available to populations and then drawing conclusions (avoided, selected, or no difference relative to availability) about which resources are important (Manly et al. 2002). It is important to note the difference between the selection or avoidance of a resource and the simple use of a resource. Selection is often denoted by the disproportionate use of a resource, based on the availability of said resource at a specific scale (Johnson 1980). The focus of resource selection studies varies with research objectives, but analyses commonly focus on aspects of habitat. Because habitat is defined at the species or population scale, resource selection studies are often limited to one species located in a specific portion of the occupied range (Manly et al. 2002). Targets of habitat selection studies can vary from landscape scale habitat variables (land use, cover types, and anthropogenic structures) to fine scale habitat characteristics (vegetation characteristics). Selection of habitats is a complex process in which populations or individuals make decisions based on behavioral cues or perceived advantages or disadvantages associated with explicit components of their environment (Fretwell and Calver 1969). Biologists often assume that decisions about habitat selection are conducive for fundamental ecological success (Manly et al. 2002). Furthermore, the spatial scale in which resources are evaluated determines the order of selection (1st, 2nd, 3rd, or 4th; Johnson 1980). Once again, objective-driven questions and hypotheses determine the order of selection investigated by researchers. Most often, explicit research into wildlife resource selections is focused at the 2nd (space and resource use within the occupied range of a population) or 3rd order scales of selection (space and resource use within the home range on an individual; Johnson 1980).

Considering imperiled species, identification of habitat needs for all ecological functions across all orders of selection is essential to conservation. Due to the relative accessibility and functionality of land cover types in wildlife conservation, anthropomorphic delineations of habitat are often used to evaluate and quantify habitat availability and quality for wildlife species (Haukos and Zavaleta 2016). In the southern Great Plains, categorical land cover types are commonly used to describe the relative suitability and potential for a tract of property to support lesser prairie-chickens (*Tympanuchus pallidicinctus*; hereafter LEPC), a grassland obligate species that was listed as “Threatened” under the Endangered Species Act (ESA) in May of 2014 (U.S. Fish and Wildlife Service 2014), but later the listing was vacated by a Texas federal judge in September 2015 (*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]). Recently, private conservation groups petitioned the U.S. Fish and Wildlife Service to consider the LEPC for relisting under the ESA (http://www.wildearthguardians.org/site/DocServer/LPC_petition_2016_final_opt_2.pdf, accessed September 28, 2016).

When assessing habitat quality for LEPC, biologists evaluate the presence of habitat availability for various ecological periods such as lekking, nesting, and brooding (Hagen et al. 2004, Van Pelt et al. 2013; Chapter I, Table 1.1). Considering that microhabitat quality for nesting and brooding is often a limiting factor on the landscape (Hagen et al. 2004, Pitman et al. 2006a, Hagen et al. 2013, Van Pelt et al. 2013), the availability of land cover types for these two ecological periods is described most often in conservation plans. To date, LEPC biologists have speculated on the microhabitat potential of various land cover types in western Kansas for nesting and brooding LEPC (Van Pelt et al. 2013). Sand sagebrush (*Artemisia filifloria*) prairie, short-grass prairie, mixed-grass prairie, and U.S. Department of Agriculture's Conservation Reserve Program (CRP; a cost-share program implemented by the Farm Service Agency [FSA] targeted at creating reclaimed grasslands from row-crop agriculture land susceptible to erosion) are commonly referenced during discussions, conservation planning, and publications regarding LEPC management (Hagen et al. 2004, Dahlgren et al. 2016). Further, these CRP contracts can be described in terms of two different mid-contract management regimes (personal correspondence with FSA and NRCS officials). Disturbed CRP (DCRP) describes tracts of CRP that exhibit potential for mid-contract management in the form of emergency haying or grazing. This form of management can only occur one in every three years on individual CRP tracts in the LEPC occupied range. Furthermore, FSA and NRCS limit the extent of emergency haying and grazing to ≤ 50% of the area of each CRP tract within one year. Another form of mid-contract management is called interseeding. Interseeding is a method designed to disturb soils and plant communities using farm equipment and subsequently broadcasting forbs species that may be beneficial to LEPC microhabitat and foraging. Interseeding of CRP has been shown to influence use by LEPC (Fields 2004). CRP tracts that are not eligible for emergency haying or grazing (UCRP) do not likely exhibit any mid-contract management.

At a population scale, LEPC are distributed across four separate ecoregions within Kansas and adjoining states (McDonald et al. 2014). The ecoregions are defined by the following terms; Short-Grass Prairie/CRP Mosaic (SGPR) in northwest Kansas and eastern Colorado, Sand Sagebrush Prairie (SSPR) in southeast Colorado and southwest Kansas, Mixed-

Grass Prairie (MGPR) in Kansas, Oklahoma, and Texas, and the Sand Shinnery Oak Prairie (SOPR) in Texas and New Mexico (McDonald et al. 2014; Chapter I, Figure 1.1). Within each ecoregion, biologists have identified and quantified the relative importance of land cover types to LEPC populations (Van Pelt et al. 2013). At local spatial scales, biologists have evaluated and ranked Ecological Sites (USDA 2013; ESs) across Major Land Resource Areas (MLRA) in terms of their relative potential for supporting nesting and brooding habitat for LEPCs (Van Pelt et al 2013; Chapter I, Table 1.1). However, rankings were developed in the absence of quantitative findings and based on expert opinion. Further investigation into the use and selection of ESs by LEPC during functional ecological periods is needed to improve habitat predictions. Further, because of the plant community composition and microhabitat observations, CRP tracts are often assumed to be optimal habitats for nesting and brooding LEPC in northwestern Kansas (Rodgers and Hoffman 2004, Dahlgren et al. 2016). Additionally, considering the influence of extreme weather events and climate on LEPC population numbers and predictions of increased temperature and extreme drought events in the future (Ross et al. 2016), it is important to understand relative importance of CRP (a resilient and manageable land cover resource) across the occupied range of LEPC. Similarly, the use of rangelands and various ecological sites for livestock production could amplify the future influence of weather and climate on grasslands occupied by LEPCs. Objective research evaluating LEPC selection or avoidance of land cover types across various ecological periods and weather conditions is needed for improved conservation planning and implementation.

Resource selection efforts of LEPC in Kansas investigating land cover types as predictors of quality habitat for LEPC populations are rare (Fields 2004). Resource selection investigations in the past have targeted the influence of trees, anthropogenic structures, or nesting and brooding microhabitat (Fields 2004; Hagen et al 2005; Pitman et al. 2005, 2006; Lautenbach 2014; Plumb 2015). In consideration of past findings (including apparent microhabitat selection by LEPCs during nesting and brooding periods) and my results in Chapter I, predictions can be made regarding the relative quality of ESs across regions in western KS to LEPC ecological needs during the nesting and brooding seasons. However, explicit findings are needed to evaluate the response of LEPC in regard to these predictions across regions.

In this chapter, my goal was to meet research needs highlighted above in regard to LEPC habitat selection of land cover types across ecological periods, region, and variation in weather conditions. More specifically, my objectives were to 1) evaluate the relative use of land cover types (ES and CRP) by LEPCs during non-breeding, nesting, and brooding ecological periods, 2) investigate how use of these land cover types varies among regions in western Kansas, and 3) determine if variation in seasonal weather condition determines transitions in habitat use by female LEPC. I hypothesized that increasing distance from a recorded lek will be negatively related with female LEPC use (Winder et al. 2015). Based on anecdotal observations, and overall microhabitat characteristics, I hypothesized that non-breeding female LEPC will use Sandy, Sandy Lowland, and CRP land cover types more than expected at random in the SGPR region and Limy Upland and Sandy land cover types more than expected in the MGPR ecoregion, and Sandy Lowland, Saline Subirrigated, Sands and Sandy sites more than expected in the SSPR. I predicted that CRP tracts will exhibit the greatest relative probability of nest site placement in the SGPR following drought conditions, but other land cover types will be selected during periods following drought-free environmental conditions. I predicted that Limy Upland sites will be selected by nesting LEPCs in the MGPR. In the SSPR, I predicted that Saline Subirrigated sites will exhibit the greatest probability of nest site placement by LEPCs. I predicted that brooding LEPCs will select Sandy Lowland sites over alternatives in the SGPR; Limy Upland sites in the MGPR; and Sands sites in the SSPR. Furthermore, I predicted that use of CRP tracts in SGPR will be positively correlated with age of brood and broods originating from nests located in rangelands will exhibit a low probability of selecting other land cover types. I predicted differences in the use of CRP and DCRP tracts during nesting and brooding ecological periods.

Study Area

I investigated my objectives in three distinct areas where LEPC were abundant in western Kansas (McDonald et al. 2014; Chapter I, Figure 1.2). Two sites were located in the south-central region of Kansas. One site was located on privately owned lands within Kiowa and Comanche counties and the second site was located on private land south of Ashland, Kansas, within Clark County. In northwest Kansas, the study area focused on private lands located within Logan and Gove counties. Weather, precipitation in particular, varied between years and among regions (Chapter I, Figure 1.3).

In northwestern Kansas, the Northwest study area was divided between Logan and Gove counties. The primary land uses for both counties were livestock grazing on grasslands, energy exploration and extraction, and both dryland and irrigated row-crop agriculture. This study area was in the Short-Grass Prairie/CRP Mosaic Ecoregion (Van Pelt et al. 2013, McDonald et al. 2014, Dahlgren et al. 2016), with CRP grasslands and row-crop agriculture on silt-loam soils. Where soils permitted under adequate moisture, plant communities resembled mixed-grass prairie. Dominant vegetation in the study area varied with cover type (e.g., native grasslands, CRP, row-crop agriculture). Native grasslands were dominated by species such as blue grama (*Bouteloua gracilis*), buffalograss (*B. dactyloides*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*B. curtipendula*), sand dropseed (*Sporobulus cryptandrus*), western wheatgrass (*Pascopyrum smithii*), western ragweed (*Ambrosia psilostachya*), scarlet globemallow (*Sphearalcea coccinea*), small soapweed (*Yucca glauca*), Russian thistle (*Salsola kali*), western salsify (*Tragopogon dubius*), slimflower scurfpea (*Psoralidium tenuiflorum*), and wavyleaf thistle (*Cirsium undulatum*; Lauver et al. 1999; J. Kraft pers. obs.). Native grass species planted in CRP fields included little bluestem, sideoats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*) (Fields 2004). The CRP fields were interseeded with forbs in the mid-late 1990s; the seed mixture included white sweet clover (*Melilotus alba*), yellow sweet clover (*M. officinalis*), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower, purple prairie clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*; Fields 2004). Wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*) were the major crops in the region.

In south-central Kansas, the Red Hills study area was centered on private lands in Kiowa and Comanche counties within the Mixed-Grass Prairie Ecoregion (Van Pelt et al. 2013, McDonald et al. 2014, Wolfe et al. 2016). The Red Hills site consisted of mixed-grass prairie on loamy soils. Primary land uses for this area included livestock grazing, oil and gas extraction and exploration, and row-crop and dryland agriculture associated with drainages interspersed throughout the region. Dominant vegetation in south-central Kansas included little bluestem, blue grama, hairy grama, sideoats grama, buffalograss, sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludiviciana*), western ragweed (*Ambrosia psilostachya*), sand sagebrush, and eastern red cedar (*Juniperus virginiana*; Lauver et al. 1999). The third study area, Clark, was located in Clark County on the Mixed-Grass Prairie Ecoregion and Sand Sagebrush Prairie Ecoregion boundary (McDonald et al. 2014, Dahlgren et al. 2016, Haukos et al. 2016).

Land use was dominated by livestock grazing, energy extraction and exploration, and row-crop agriculture. Dominant vegetation in the area included little bluestem, sideoats grama, blue grama, hairy grama, big bluestem, alkali sacaton (*Sporobolous airoides*), invasive Russian thistle, kochia (*Kochia scoparia*), annual sunflower (*Helianthus annuus*), and sand sagebrush (Lauver et al. 1999).

Methods

Capture

To obtain location data and nest data, I deployed walk-in funnel traps (Haukos et al. 1990) and magnetic drop nets (Silvy et al. 1990) to capture LEPC females at leks during spring (mid-March – mid May) 2013, 2014, and 2015. Upon capture, I recorded a suite of morphometric measurements and observations for each bird. Age and gender of each captured individual were determined using plumage characteristics (Ammann 1944, Copelin 1963). Upon capture, I fitted females with either a very-high-frequency (VHF) radio transmitter or a global-positioning system (GPS) satellite transmitter (Platform Transmitting Terminals or SAT-PTT) in an alternating pattern. The two transmitter types do not appear to affect annual survival of LEPC (Plumb 2015, Robinson 2015). The VHF transmitters (12 or 15 g) were attached using a bib-style harness to all individuals >500g. The transmitters had an estimated battery life of 790 days (Advanced Telemetry Systems, Isanti, MN, USA; hereafter ATS). Status of the female was monitored via an eight-hour mortality switch installed in the transmitter. The GPS SAT-PTT (22 g) transmitters were only fitted to females weighing >700 g. I attached the GPS SAT-PTTs using a rump-style method utilizing Teflon tape and elastic ribbon (Dzialak et al. 2011). The units contained a solar charging component and battery life was not an issue. Status of these birds was determined via sensors that monitored ambient temperature and movement (Microwave

Telemetry, Columbia, MD, USA). After all measurements were recorded and transmitters fitted, captured LEPC were immediately released at the lek of capture. All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee protocol (3241) and Kansas Department of Wildlife, Parks and Tourism scientific wildlife permits (SC-042-2013, SC-079-2014, SC-001-2015).

Locations

Radioed females were monitored and specific locations recorded to measure nest locations, habitat selection, survival, movements, and other variables. I located VHF-fitted females using fixed-location triangulation 3-4 times/week throughout the lifespan of bird or transmitter (Cochran and Lord 1963). Handheld ATS receivers and a three-element yagi antennae were used to collect ≥3 bearings per individual. Telemetry bearings were entered into Location of a Signal software (hereafter LOAS; Ecological Software Solutions, Florida, USA) to obtain Universal Transverse Mercator (UTM) coordinates of the estimated location. Locations of GPS SAT-PTT were taken every two hours during 0400-2200 (depending of sunlight and battery charge). Recorded GPS fixes were then uploaded to Argos satellites every three days. Potential error of these points was ±18 m. If VHF-marked individuals could no longer be located due to potential dispersal from the study areas, I attempted to find birds with a survey using a fixed-wing Cessna aircraft. If a mortality signal was observed, I used either homing (VHF) or previous GPS locations to locate the transmitter and determine cause-specific mortality or reasons for transmitter loss.

Nest and Brood Locations

I identified nest locations by homing in on VHF-marked females after the females were located in the same relative location for three consecutive days (Pitman et al. 2005). Females marked with GPS SAT-PTTs were monitored remotely after initial nest flush when GPS locations indicated nest incubation. Once a nest was initially located the female was flushed, I recorded the number of eggs present in the nest. I floated eggs to estimate the nest incubation date, nest initiation date, and predicted hatch date (Coats 1955, Pitman et al. 2006). Nests were approached using rubber boots and latex gloves to avoid scent pollution. Nest locations were recorded using hand-held GPS units. Post initial nest discovery, nesting females were monitored by either radio-transmitted signals (VHF) or downloaded satellite locations (GPS SAT-PTT) until locations indicated that the female had left the nest. Once females departed the nest location for a period greater than three days, the nest was revisited to determine success or failure. Nests were considered successful if ≥1 eggs hatched. Eggs found within the nest that exhibited pipping were deemed successful. I recorded the number of hatched eggs from the nest.

If nests were successful, the female and brood were flushed within 7 days of hatch to get an estimate of hatched young that survived the first week following hatch. Additional brood flushes were conducted at approximately 14, 21, 28, 35, 42, 48, and 56 days since hatch female suitable weather conditions and available locations for satellite-tagged females allowed (Lautenbach 2014). Brood flushes were conducted at or before sunrise because females were brooding the chicks, making chicks easier to locate (Schole et al. 2011). Flush locations were recorded via handheld GPS unit. Broods were monitored until the chicks dispersed from the female, or there were no chicks encountered on two consecutive brood flushes. In addition to brood flushes, we tracked females with broods equipped with VHF transmitter to estimate brood locations. If a female with a brood was equipped with a PTT, we used GPS fixes for brood locations. I used VHF and PTT locations in analysis only when flush records confirmed the presence of at least one chick.

Statistical Analyses

Habitat selection was evaluated using Resource Selection Functions (RSF; Manly et al. 1992, Boyce et al. 2002). I employed three RSFs for each study area to evaluate (1) non-breeding habitat selection, (2) nest site selection by LEPC females, and habitat selection by female LEPC with active (3) broods (≥1 chick). Each RSF was completed using a used versus available study design (Manly et al. 1992, Boyce et al. 2002). For PTT-marked individuals, I randomly selected one location per day to account for temporal and spatial autocorrelation. Locations for each day were chosen using the r.sample command in Geospatial Modeling Environment for a random selection of the points within one calendar day (Beyer 2012). Each location was then described as a nest site, brood or non-breeding location. Locations designated as nest sites describe the specific location of an observed LEPC nest. Locations were designated as brood locations if the female was currently raising a brood (≥1 chick). The presence of a brood was determined using nest success evaluations and subsequent brood flush events described above. All other recorded locations were designated as non-breeding. Thus, non-breeding locations could occur at any time during the calendar year and included successful (successful nests) and non-successful (failed nest or no recorded nest attempt) breeders. For each non-breeding and brooding RSF, I distributed one paired random location for each LEPC location recorded. Due to a smaller sample size of nests than non-breeding and broods, availability for the nest site placement RSFs was determined by distributing five random locations for each nest site.

To conduct 2nd order selection analyses, I constrained random locations to the landscape defined by the three delineated study areas (Northwest, Red Hills, and Clark) or “populations”. These study areas were delineated using a Minimum Convex Polygon (MCP), using the Minimum Bounding tool in ArcGIS 10.2 (ESRI Inc., 2013, Redlands, CA, USA) surrounding all telemetry locations for each site (Plumb 2015, Robinson 2015). Random locations were created using the Create Random Points tool in ArcGIS 10.2. Locations describing dispersal movements (≥5 km in one week) were excluded from the analysis. Furthermore, I could associate a date with each random and LEPC location to assign Palmer Drought Severity Index values. PDSI values were obtained and implemented at the regional scale. PDSI data was obtained for the Kansas divisions labeled as 4, 7 and 8. Land cover types and presence of sand sagebrush (≥1% canopy cover of sand sagebrush at the ecological site scale; Chapter I) were assigned to each location used in analyses using the Identity Tool in ArcGIS 10.2. Distance to lek variables were calculated for each location used in the non-breeding RSF using the Near Tool in ArcGIS 10.2.

Logistic regression was used to compare used versus available points (Boyce et al. 2002). Nine (three per study area) *a priori* model sets were developed to investigate non-breeding, nest site, and brooding habitat selection. I designed model sets in relation to hypotheses regarding distance to a lek, land cover type (ecological sites, UCRP, DCRP, Cropland, and Other; LCT), general land cover type (Rangeland, UCRP, DCRP, Cropland, Other; hereafter GLCT), presence of sand sagebrush (≥1% canopy cover of sand sagebrush; Sage, Chapter I), season (breeding [March 15th - Sept. 15th] or winter [Sept. 16th - March 14th]), and average PDSI ($\bar{x}$ PDSI during the growing season [April-September] calculated on a monthly basis; PDSI). The difference between LCT and GLCT is included to account for the possibility that not all ecological sites were available to broods because of nest site placement and ecological site distribution on the landscape. By lumping all ecological sites into one category instead of 4 or greater rangeland habitat categories, I could still make inference on rangeland habitat quality if ecological sites did not fit the data well. Six average PDSI values were calculated entire growing season average was applied to locations from October to March. Variables describing general land cover type of the nest associated with a brood (Nest GLCT) and days since hatch (DSH) were investigated within brooding RSFs. I included a null model in each model set. Due to the relatively strong relationship associated with distance to lek, I included the variable in all RSFs evaluating non-breeding habitat selection, but excluded it from nest site placement and brooding RSFs to avoid confounding interpretations of other model variables. I did not include year terms because I hypothesized that PDSI and season values would account for temporal variation in habitat selection. Unless a LCT related to specific research objectives, I removed all LCT categories that did not account for at least 5% of the randomly generated locations for non-breeding selection estimates. The categories were pooled into one category (Other). Reference communities were predetermined for non-breeding, nesting and brooding RSFs based on relative availability of a LCT or *a priori* hypotheses about the quality of each LCT for nesting or brooding LEPC (Chapter I). I tested for correlations between variables and avoided including correlated variables in the same model ($r > 0.40$). For each model set, I used an information theoretic approach, Akaike Information Criterion for small sample sizes (e.g., AIC_c), to rank and select competing individual models for inference (Anderson and Burnham 2002). Models with $\Delta AIC_c \leq 2$ were considered competitive. If beta estimates from top models differed than zero (coefficient $\neq 0$; standard errors of beta estimate did not overlap zero, $P = < 0.05$), female I determined the variable to be influential. To visualize predicted probability of use curves for top models in each set, I used the following logistic function:

$$f(x) = [\exp(\beta_0 + \beta_1(x_1) + \beta_2(x_2))] \,/\, [\ 1 + \exp(\beta_0 + \beta_1(x_1) + \beta_2(x_2))]$$

I conducted all RSFs in Program R (R core development team, version 3.0.1, 2013, Vienna, Austria) and used the glm package for generalized linear models.

Results

I caught 232 female LEPC during spring trapping efforts at Northwest, Red Hills, and Clark study areas from 2013-2015. After pooling of all PTT and VHF locations and selecting one daily used location for each bird, I had a total of 5,820, 8,898, and 3,238 locations to use for non-breeding habitat selection analyses at the Red Hills, Northwest and Clark study areas, respectively. The relative proportion between used and available (random) locations at the landscape scale varied among LCTs at each of the three study areas (Figure 2.1). I located 87, 80, and 53 nests at the Northwest, Red Hills, and Clark study areas, respectively. Following successful nests, I monitored 23, 12, and 6 broods in the Northwest, Red Hills, and Clark study area, respectively.

Habitat Use

From the broadest perspective (non-breeding), the relative proportion of used versus available points within each LCT varied considerably among study areas (Figure 2.1). At the Northwest study area, DCRP (used = 74%), UCRP (used =72%), Sandy Lowland (used = 71%), Sandy (used = 94%), and Limy Upland (used = 60%) sites exhibit proportions of used locations greater than available locations within each LCT (Figure 2.1). At the Red Hills site, the only LCT that exhibited a distinct difference between proportions of used vs. available locations was Limy Upland with 68% of locations being used and 42% being available locations (Figure 2.1). At the Clark study area, Sands (used = 58%), Sandy Lowland (used = 64%), Saline Subirrigated (used = 62%), Subirrigated (used = 66%), and Limy Upland (used = 58%) LCTs exhibit proportions of used points distinctly greater than available locations within each LCT (Figure 2.1).

Non-Breeding Habitat Selection

The top model evaluating female LEPC selection of LCTs in the Northwest study area included distance to lek, LCT, and an interaction between PDSI and LCT (Table 2.1). The top model carried 93% of the data set weight. Beta estimates indicate a negative influence of distance from lek on habitat use by female LEPC (Table 2.2, Figure 2.2). Predicted probability of use by female LEPC fell below 10% at distances >8,000 m from a known lek. The reference community for non-breeding habitat selection at the Northwest site was Loamy Upland, due to its wide-scale availability on the landscape. Beta estimates for LCTs suggest Loamy Upland cover types were selected more than Limy Upland, Chalk Flats, and Cropland and selected less than CRP and Sandy sites (Table 2.2). Interactions between PDSI and Loamy Upland, Limy Upland, DCRP, and UCRP were also detected (Table 2.2). Selection of Limy Upland and DCRP was negatively correlated with increasing PDSI values (decrease in drought severity). In contrast, selection of Loamy Upland and UCRP was positively correlated with increasing PDSI values (Figure 2.3).

The best performing model evaluating selection of LCTs at the Red Hills site included distance to a lek, LCT, and an interaction between LCT and season (breeding and winter; Table 2.3). The top model carried 100% of the data set weight. Beta estimates once again indicated a strong negative trend with habitat use and increasing distance to lek (Figure 2.2). Predicted probability of use for female LEPC dropped below 10% at distances less than 4,000 m away from a lek. The 10% threshold of use was reached at ~ 4 km in the Red Hills study area than the Northwest study area (Figure 2.2). Limy Upland was set as the reference community for this model set. Beta estimates of the top model indicate that only Limy Upland sites were selected more often than Red Clay Prairie sites during the breeding season; but during the winter season, Limy Upland, Loamy Upland, and Sandy sites all exhibited more use than Red Clay Prairie (Table 2.4).

At the Clark study area, the top model evaluating selection of LCTs by female LEPC was the same as the Red Hills site. The top model included distance to a lek, LCT and an interaction between LCT and season (Table 2.5). The top model carried 100% of the weight associated with the data set. Beta estimates once again indicate a strong negative relationship between habitat use and increasing distance to lek (Figure 2.2). The predicted probability of use curve for Clark was similar to the Northwest prediction curve in relation to distance from a lek, where use by female LEPCs fell below 10% at distances slightly less than 8,000 m (Figure 2.2). Limy Upland was the only LCT selected more often in the breeding season than my reference community; Saline Subirrigated. During the winter, Cropland was selected at a much greater degree than Saline Subirrigated. Subirrigated sites were the most selected rangeland LCT (Table 2.4).

Nesting

Nest site selection by LEPC was best explained using the single variable model including LCT (Table 2.6). This model carried 100% of the weight of the data set. The reference community in the Northwest study area for nest site placement was UCRP because of its relative potential for nesting habitat to other LCTs in northwest Kansas (Chapter I, Dahlgren et al. 2016). Beta estimates indicate that UCRP was selected relative to available greater than all LCTs other than Sandy Lowland and Sandy ecological sites (Table 2.7).

At the Red Hills site, the individual variable model including LCT carried 99% of the weight in the data set (Table 2.8). The reference community at the Red Hills site was Limy Upland. Beta estimates indicate that Limy Upland, Loamy Upland, and Red Clay Prairie sites do not exhibit difference in use by nesting LEPC. However, use of Sandy sites was calculated to be less than the reference community (Table 2.7).

Similarly to the Northwest and Red Hills sites, the Clark study area top model evaluating nest site placement was the individual variable model containing the main effect of LCT with 100% of the model weight (Table 2.9). Saline Subirrigated was the reference community for this model set. Beta estimates indicate that no LCT type exhibited more or less selection than the Limy Upland. The other LCTs were the only LCT to exhibit a statistically less chance of selection compared to the reference community (Table 2.7).

Brooding

After evaluation of my *a priori* model set of 14 models, the top model was multivariate and included the main effect of GLCT and the interactions between GLCT, Nest GLCT, and DSH (Table 2.10). This model carried 100% of the data set weight. The reference community was set at Rangeland based on previous hypotheses. Beta estimates indicate that DCRP was the most used selected cover type (Table 2.11). Furthermore, rangelands were selected over UCRP tracts and Cropland. Broods that hatched from nests within DCRP exhibited a decreasing probability of using rangelands as DSH increased (β = -0.05, SE = 0.05, 95% CI = -0.078 and -0.02; Figure 2.4) and an increasing probability of using UCRP (β = 0.17, SE = 0.03; Figure 2.4). Broods that hatched from nests located in rangelands exhibited an increasing probability of using UCRP as DSH increased (β = 0.04, SE = 0.004, 95% CI = 0.034 and 0.051; Figure 2.5). Broods hatching from nests located in UCRP exhibited an increasing probability of use of UCRP tracts as DSH increased (β = 0.04, SE = 0.01, 95% CI = 0.03 and 0.055; Figure 2.6) and a decreasing probability of using rangelands as DSH increased (β = -0.14, SE = 0.01, 95% CI = -0.16 and -0.12; Figure 2.6). In order to also make inference on the selection of ecological sites I also examined the results from a single variable model evaluating LCT on brood habitat selection. The reference community for this model was established as Sandy Lowland. DCRP tracts and Sandy ecological sites exhibited greater probabilities of use than the reference community and other LCTs (Table 2.12). The reference community was also used more than all other LCTs except Sandy Lowland and DCRP.

At the Red Hills and Clark study area, top models were determined to be single variable models containing the main effects of LCT (Tables 2.13, 2.14). The reference community was set as Limy Upland at the Red Hills study area. At the Clark study area, Sands was set as the reference community. At the Red Hills site, Red Clay prairie was the most used brooding habitat, followed by Limy Upland, Sandy and Loamy Uplands (Table 2.12). In Clark County, Sands was the most selected habitat by brooding female LEPC (Table 2.12). All other LCTs were statistically less utilized in comparison.

Discussion

The use of categorical habitats to predict quality or quantity of habitat for wildlife species is often debated (Alldredge and Griswold 2006). The anthropogenic perspective on habitat boundaries, quality, and quantity can be highly subjective. However, merit is gained female delineations of habitat or land cover assist in the explanation of animal movements and behavior. In the case of the lesser prairie-chicken, I believe, my research evaluating the habitat selection of female LEPC across LCTs and weather variation has reached several useful conclusions. Three major findings resulted from my field projects include: 1) if combined with known vegetation characteristics (Chapter I), ecological sites showed potential for inferring LEPC habitat quality at small spatial scales across functional ecological periods; 2) the relative importance of CRP tracts and rangeland LCTs to LEPC populations as ecological periods and weather change; 3) that consideration of distance to lek continues to appear as a concrete target for localized LEPC conservation efforts.

To date, true resource selection studies of LEPC have been rare. The negative effects of anthropogenic structures on the landscape are apparent for both LEPC and greater prairie-chickens (*Tympanuchus cupido*; Plumb 2015, Winder et al. 2015). The negative influence of tree encroachment into grasslands on space use of LEPC in the MGPR is a new, but well accepted finding (Lautenbach et al 2016). Evaluation of microhabitat use during brooding and nesting is included in nearly every LEPC research effort (Haukos and Zavaleta 2016). However, categorical habitats are often mentioned during conservation planning for LEPC and used to infer habitat quality and quantity (Van Pelt et al. 2013). Little explicit research has evaluated categorical LCTs in terms of LEPC habitat selection or fitness.

Based on microhabitat characteristics, I hypothesized the high quality habitats for LEPC nesting and brooding periods across regions in western Kansas (Chapter I). More specifically, based on observed visual obstruction and grass and litter cover values, I predicted those LCTs at each site that would be the most conducive for nesting. My predictions were supported by habitat selection analyses. UCRP, Sandy, and Sandy Lowland sites exhibited relatively greater use than all other LCTs in the Northwest. These categories exhibit greater values of visual obstruction, grass cover, and litter cover. Past research confirms the selection of these microhabitat characteristics within the SGPR, MGPR, and SSPR in Kansas (Lautenbach 2014, Dahlgren et al. 2016, Haukos et al. 2016, Wolfe et al. 2016). Although greater fitness may not be achieved by LEPC nesting in these LCTs, the greater visual obstruction and grass cover values associated with selected LCTs indicates that female LEPCs are selecting plant communities and microsites based on a greater ability to adequately conceal both themselves and the nest.

It is important to note the limited of use in DCRP tracts by nesting LEPCs. It is likely that nesting LEPC females are avoiding microhabitat characteristics created by the grazing or haying of these DCRP tracts. Both haying and grazing would reduce grass cover and litter cover essential to LEPC nesting needs and thus decrease use (Hagen 2004, Hagen et al. 2013). Microhabitat values calculated in Chapter I support this hypothesis. At the Red Hills site, it appears female LEPC were once again keying in on greater visual obstruction and grass cover values associated with Limy Upland, Loamy Upland, and Red Clay Prairie. However, microhabitat characteristics of selected LCTs seem to be variable at the Red Hills study area. It is likely that tree encroachment and patch-burn grazing management has a greater influence on the microhabitat available across the site than soils, elevation, ecological sites, and other environmental characteristics (Lautenbach 2014, Lautenbach et al 2016). Thus, conservation considerations based on these findings need to also consider corresponding landscape features affecting vegetation characteristics or LEPC habitat use. At the Clark study area, Saline Subirrigated, Sandy Lowland, and Subirrigated sites were used relatively more than other LCTs. Similarly to Northwest and Red Hills analyses, it appears birds were keying on greater visual obstruction and grass cover values. However, Sandy Lowland in the Clark County site exhibited relatively low visual obstruction and grass cover (Chapter I). Most likely, LEPC females were selecting Sandy Lowland sites at the Clark county study area because of increased values of shrub cover and concealment potential associated with overhead cover provided by sand sagebrush.

Microhabitat needs for broods during the first two weeks of life could be key to the recruitment of new birds into populations (Hagen et al. 2013, Lautenbach 2014; D. Sullins, unpublished data). Greater values of forb cover and moderate levels of bare ground cover appear to define brood habitat in Kansas (Pitman et al. 2006, Lautenbach 2014). Due to relatively well understood microhabitat needs and vegetation observations (Chapter I), the use of habitat by brooding females was predictable for each study area across LCTs. At the Northwest site, Sandy, Sandy Lowland and DCRP, appear to be the most utilized LCTs by brooding LEPC females due to their relatively greater values of forb cover and moderate levels of visual obstruction and bare ground cover. Increased bare ground and forbs allowed for the optimal movement and foraging for young chicks (Lautenbach 2014, Dahlgren et al. 2016). At the Red Hills site, sites used by broods (i.e., Red Clay Prairie, Limy Upland, and Sandy) were characterized by increased cover of forbs and bare ground. However, Loamy Upland was avoided because of low forb cover and bare ground cover values. In the Clark study area, the most selected habitat (Sands) was associated with greater values of forb cover and moderate bare ground cover (Chapter I).

The microhabitat needs for LEPCs as individuals transition from nest site placement, nest incubation, and brood-rearing have been described in the literature (Hagen et al. 2013, Lautenbach 2014, Dahlgren et al. 2016, Haukos et al. 2016, Wolfe et al. 2016). Microhabitat needs transition from selecting relatively greater visual obstruction and grass cover for concealment and thermal regulation of nest sites to increased bare ground cover and greater values of forb cover that facilitates increased forage and movement for broods (Haukos and Zavaleta 2016). Depending on small-scale management of grasslands (e.g., livestock grazing, CRP establishment) within the occupied range of LEPC, the proximity of these habitats to one another varies. At the Northwest study area, the LCT exhibiting the greatest use for nesting LEPC was CRP. However, these highly attractive nesting sites were less conducive for brooding LEPC due to vegetation characteristics (Chapter I). My investigations into brood habitat selection revealed the influence of days since hatch and LCT of the corresponding nest on probability of use by brooding LEPC. Results suggest brooding females selected rangeland or DCRP habitats when broods are younger than 20 days old. Furthermore, broods hatching from nests in rangelands tend to stay in rangeland habitats until fledging. Habitat selection could be related to microhabitat characteristics of rangelands, but availability of CRP may also be constrained due to the limited movement ability of young LEPC broods. Furthermore, broods hatching from nests within UCRP exhibited a tendency to move to rangelands immediately after hatching. However, as days since the hatch date increases the probability of returning to UCRP habitats increased. Results indicate that broods hatching from nests located within DCRP tend to continue to use DCRP. However, the number of broods that hatched from DCRP habitats is small (n = 2), limiting the evidence of an established pattern. My findings indicate that rangeland habitats may be the most desired for brooding LEPC in northwest Kansas. Furthermore, considering the high mortality associated with broods during the first two weeks of life (Lautenbach 2014), it could be important for quality brood habitats (rangelands) to be located next to highly attractive nesting habitats (UCRP).

The effects of weather and climate patterns on short-term and long-term population levels of LEPC are becoming increasingly understood (Ross et al. 2016). During times of high environmental stress (low PDSI), biologists assume that certain habitats serve as refugia when environmental factors (e.g., precipitation, livestock grazing, soils) compound the effect of drought to further degrade grassland habitats past the point of suitability for LEPC. In particular, CRP tracts in northwestern KS are hypothesized to provide refugia and contribute to the persistence of LEPC during periods of environmental stress (Dahlgren et al. 2016). I investigated the influence of PDSI on the selection of LCTs by LEPC to test these assumptions. My results indicate that PDSI may not be the best climate variable to predict LEPC habitat selection consistently across LCTs. I detected relationships between LCTs (Limy Upland, Loamy Upland, DCRP, and UCRP) and average PDSI value during the growing season. However, beta estimates were conflicting between rangeland and CRP LCTs and did not imply strong relationships. I recommend cautious interpretation of my results in regard to the influence of PDSI on habitat selection. Continued investigation into the relationship of LEPC habitat use of CRP as climate and weather varies is needed. More specifically, a longer monitoring period coupled with larger variances of PDSI would likely increase the consistency of results.

Perhaps most importantly, conservation planning in regard to LEPC populations includes significant discussions in regard to grazing management in rangelands and climate change. For ecological sites to be considered in those conversations, more research is needed to quantify the response of these ecological sites and corresponding plant communities to various livestock grazing management strategies and climate change predictions. The role of precipitation in creating the microhabitat characteristics associated with each ES is also important for future conservation in the Great Plains. Furthermore, investigations into habitat selection by female LEPC across land cover types (UCRP and DCRP), weather and climate will be useful in the future as management tools for LEPC.

Management Implications

In the case of LEPC populations, categorical habitats are often referenced to in conservation discussions, but are rarely incorporated into management prescriptions (Van Pelt et al. 2013). My research highlights the potential for ecological sites and other categorical habitat delineations to be used in habitat quality assessments when they are presented alongside vegetation characteristics relevant to LEPC ecological needs. The quantification of microhabitat at the LCT scale can assist when assessing the relevant value of a habitat to LEPC. In addition to microhabitat characteristics, variability associated with seasonal and yearly management (livestock grazing, herbicide treatment, fire, etc.) needs to be considered when determining the role of a particular ecological site or CRP planting in conservation actions at small scales.

Based on microhabitat characteristics associated with ecological sites across each of my study areas (Chapter I) and the relative use of these sites by LEPC outlined above, I recommend alterations to the LEPC Values assigned to each ecological site I sampled across all three sites (Table 2.16). Originally, these values were assigned by expert opinion, but I make these LEPC value recommendations based on both the microhabitat characteristics and LEPC use across ecological periods. To reiterate, I do not prescribe the quantification or qualification of LEPC habitat to be based solely on these LEPC value recommendations, but rather a starting point to infer the relative potential of a particular property or landscape to LEPC conservation.

Using these results to guide applied management is plausible on a site by site basis. Initially, I recommend the delineation of ecological sites across properties in consideration of LEPC management actions. Using considerations of both expert opinion and LEPC response to ecological sites in this chapter, I propose a relative ranking system on a pasture by pasture basis. Rankings or evaluations for each pasture should be followed by a subsequent description of the microhabitat characteristics via field surveys associated with each ecological sites at the pasture scale. WAFWA and NRCS currently use this approach to define habitat across a property. Second, I propose consideration of these rankings alongside paired surveys of microhabitat characteristics for focusing grazing management across different pastures located on properties in question. In grazed landscapes, if forage utilization goals or plant communities (i.e., communities dominated by plant species not capable of producing nesting habitat) are not conducive to nesting and brooding, I recommend that less relative grazing pressure be concentrated on ecological sites exhibiting sand sagebrush cover or other plant species that exhibit the potential to produce suitable nesting microhabitats. It appears sand sagebrush may act as habitat refugia for LEPC in northwestern Kansas as other grasslands are degraded by grazing (Chapter III). The quality and resiliency of refugia habitat is of growing importance when one considers the climate change predictions in the Great Plains. The quality of refugia habitat needs to be preserved to maximize benefits during times of drought and high heat (Ross et al. 2016).

Although, I do not recommend evaluating LEPC habitat suitability solely on ecological site classification, it is apparent that ecological sites have the potential to infer habitat quality for LEPC. When paired with other environmental characteristics such as grazing management, tree invasion and fire, the potential for ecological sites to infer about LEPC use is increased. Further research about LEPC response to ecological sites as plant community characteristics change is needed.

Results outlined above indicate the relative use of CRP in comparison to ecological sites. In areas of limited habitat quantity and where precipitation limits the suitability of grasslands for LEPC use, I propose continued CRP establishment in close proximity rangeland habitats exhibiting LEPC presence (< 1 km). It is also apparent that a portion of these CRP lands need to be eligible for mid-contract management to appeal to all LEPC ecological needs. Due to the resiliency of CRP lands as extreme climate events increase, the increase in habitat quantity achieved by adding CRP tracts to the landscape may be longer lasting than improving livestock management on working lands that are vulnerable to drought and high grazing intensities.

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Figure 2.1 Proportions of available (random) versus used locations used to estimate non-breeding lesser prairie-chicken habitat use using Resource Selection Functions across the Northwest (A), Red Hills (B), and Clark (C) study areas in in western Kansas, USA. Figures illustrate the proportional change in habitat use across land cover types associated with each study area. Land cover types include undisturbed Conservation Reserve Program (UCRP), disturbed CRP (DCRP), Sandy Lowland (SALO), Sandy, Limy Upland (LIUP), Loamy Upland (LOUP), Chalk Flats (CHFL), Red Clay Prairie (RCP), Sands, Saline Subirrigated (SASUB), Subirrigated (SUB), Choppy Sands (CHSA), Cropland, and Other.

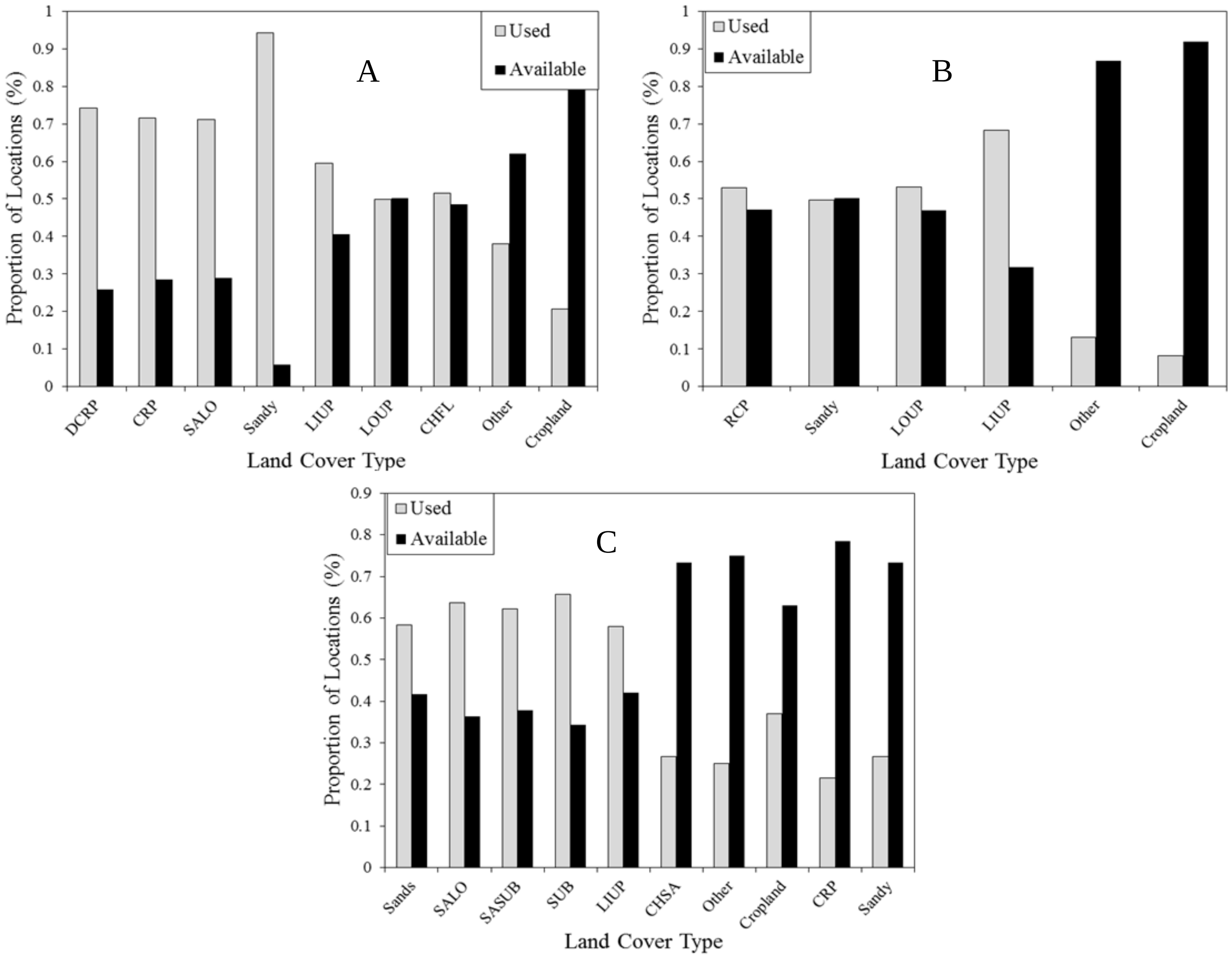

Figure 2.2 Predicted probability of use by non-breeding female lesser prairie-chickens in relation to the distance (m) from a known lek site across three study areas (Northwest, Red Hills, and Clark) from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

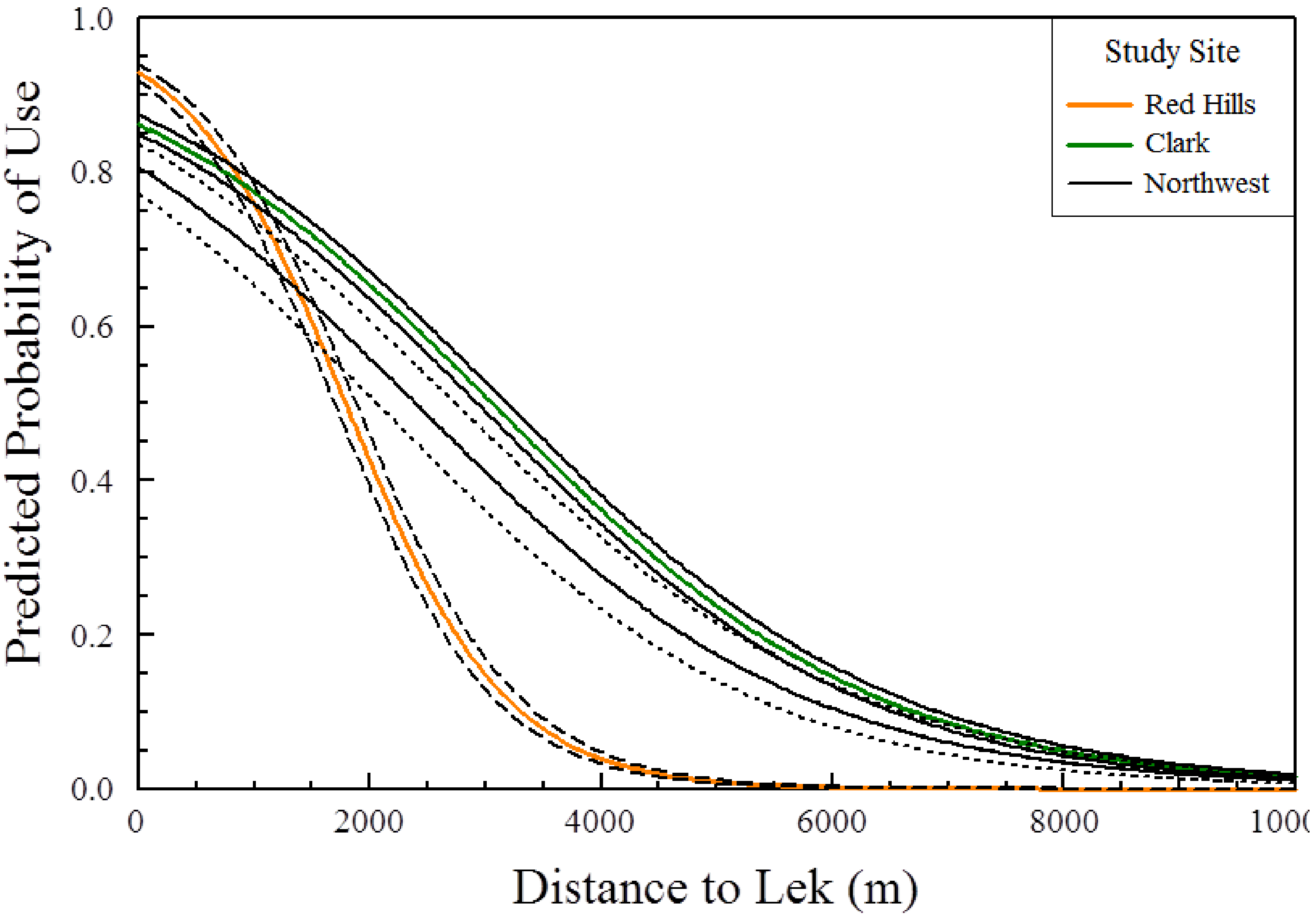

Figure 2.3 Predicted probability of use by female lesser prairie-chickens in relation to values of average growing season Palmer Drought Severity Index (from -4 to 4; <0 = dry and >0 = wet) 2013-2015 across four land cover types (Loamy Upland, Limy Upland, DCRP [CRP tracts eligible for emergency haying and grazing], and UCRP [CRP tracts eligible for emergency haying and grazing]) present in the Northwest study area in western Kansas, USA. Shown with 95% confidence intervals.

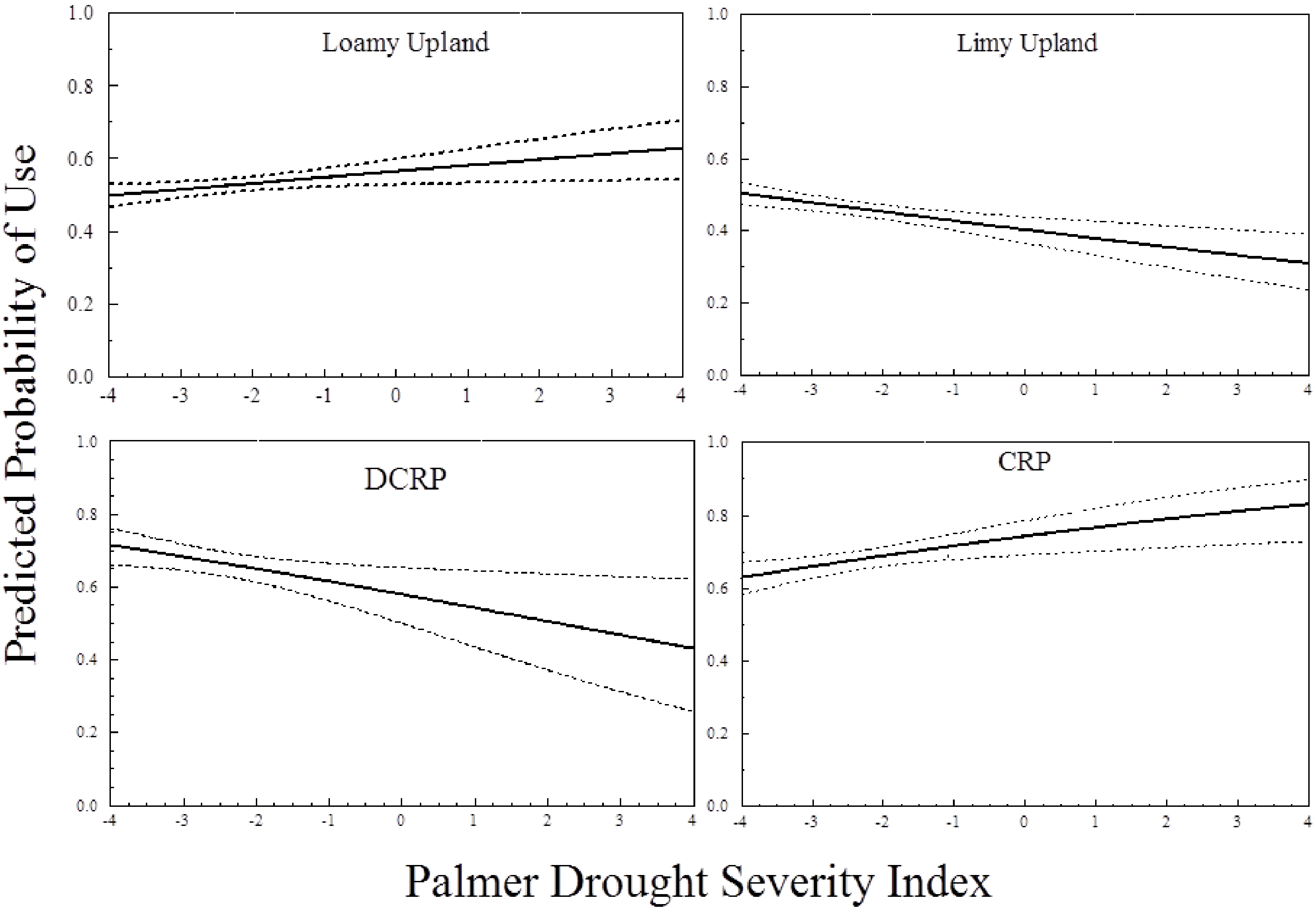

Figure 2.4 Predicted probability of using UCRP (CRP tracts not eligible for haying and grazing) and Rangeland by females lesser prairie-chickens with broods in relation to days since hatch and when the nest site location was in DCRP from 2013-2015 in the Northwest study area in western Kansas, USA. Shown with 95% confidence intervals.

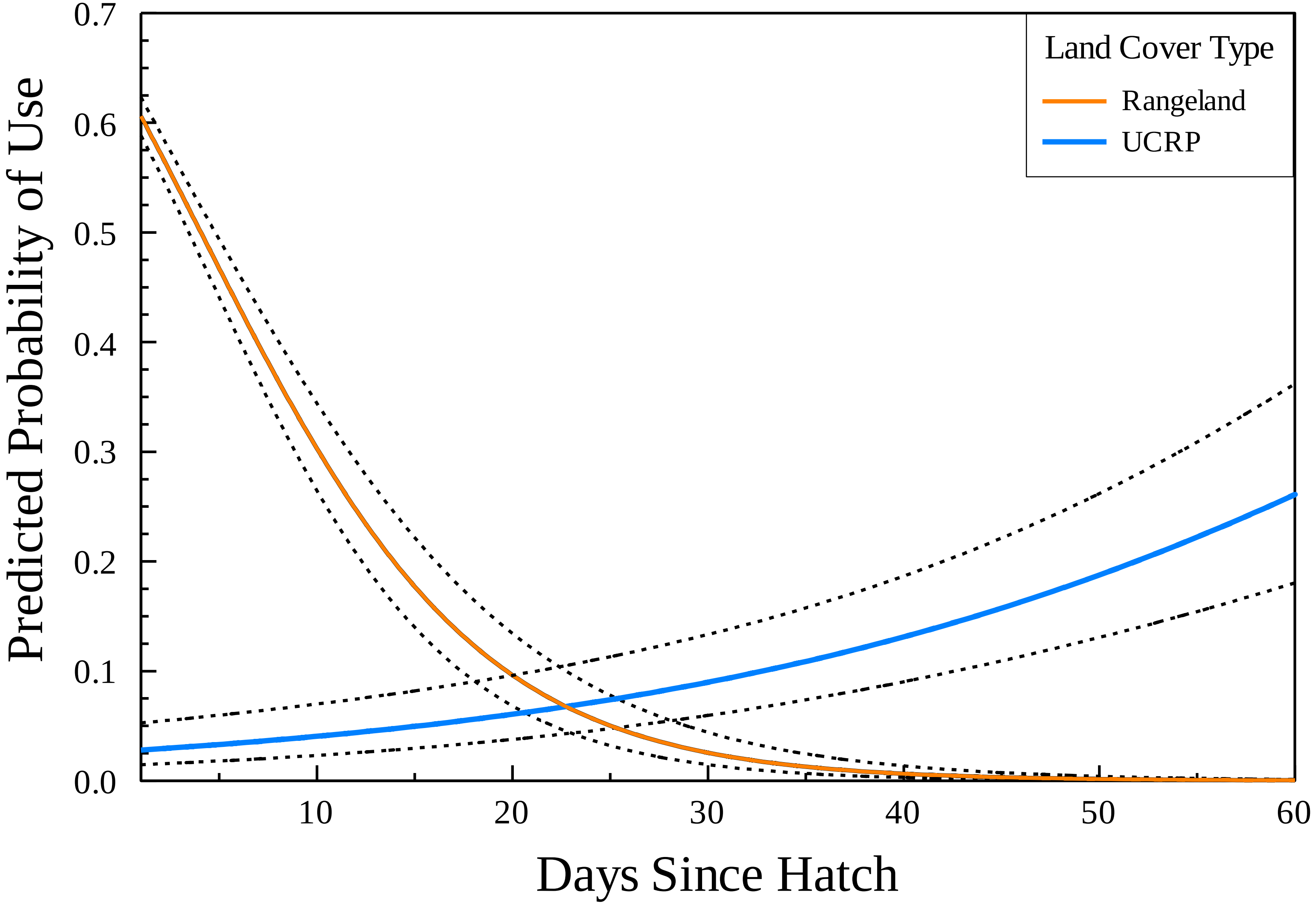

Figure 2.5 Predicted probability of using UCRP (CRP tracts not eligible for haying and grazing) by female lesser prairie-chickens with broods in relation to days since hatch, and when the nest site was located in rangeland from 2013-2015 in the Northwest study area in western, Kansas, USA. Shown with 95% confidence intervals.

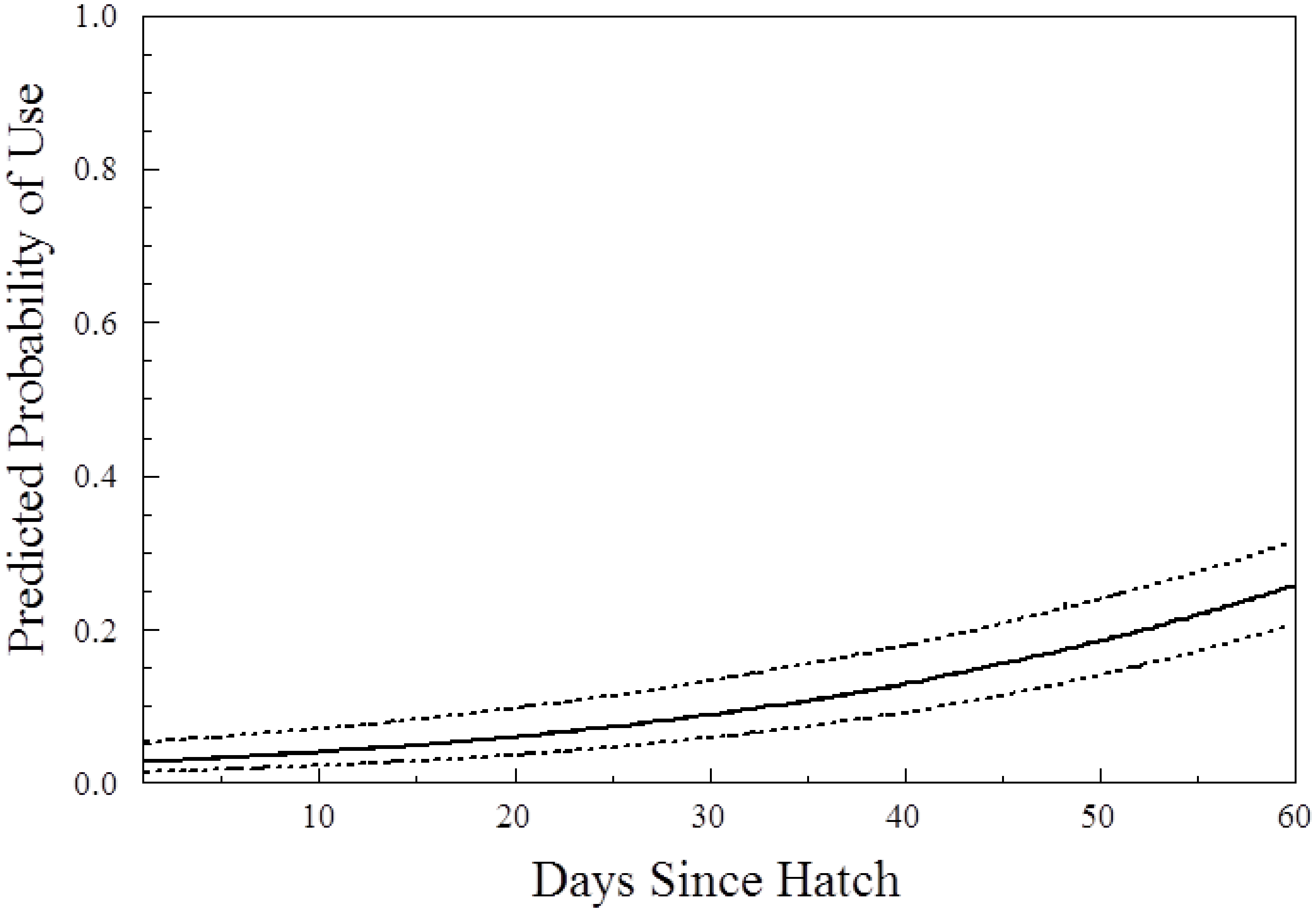

Figure 2.6 Predicted probability of using UCRP (CRP tracts not eligible for haying and grazing) or rangelands by female lesser prairie-chickens with broods in relation to days since hatch, and when the nest site was located in UCRP in the Northwest study area from 2013 -2015 in western, Kansas, USA. Shown with 95% confidence intervals.

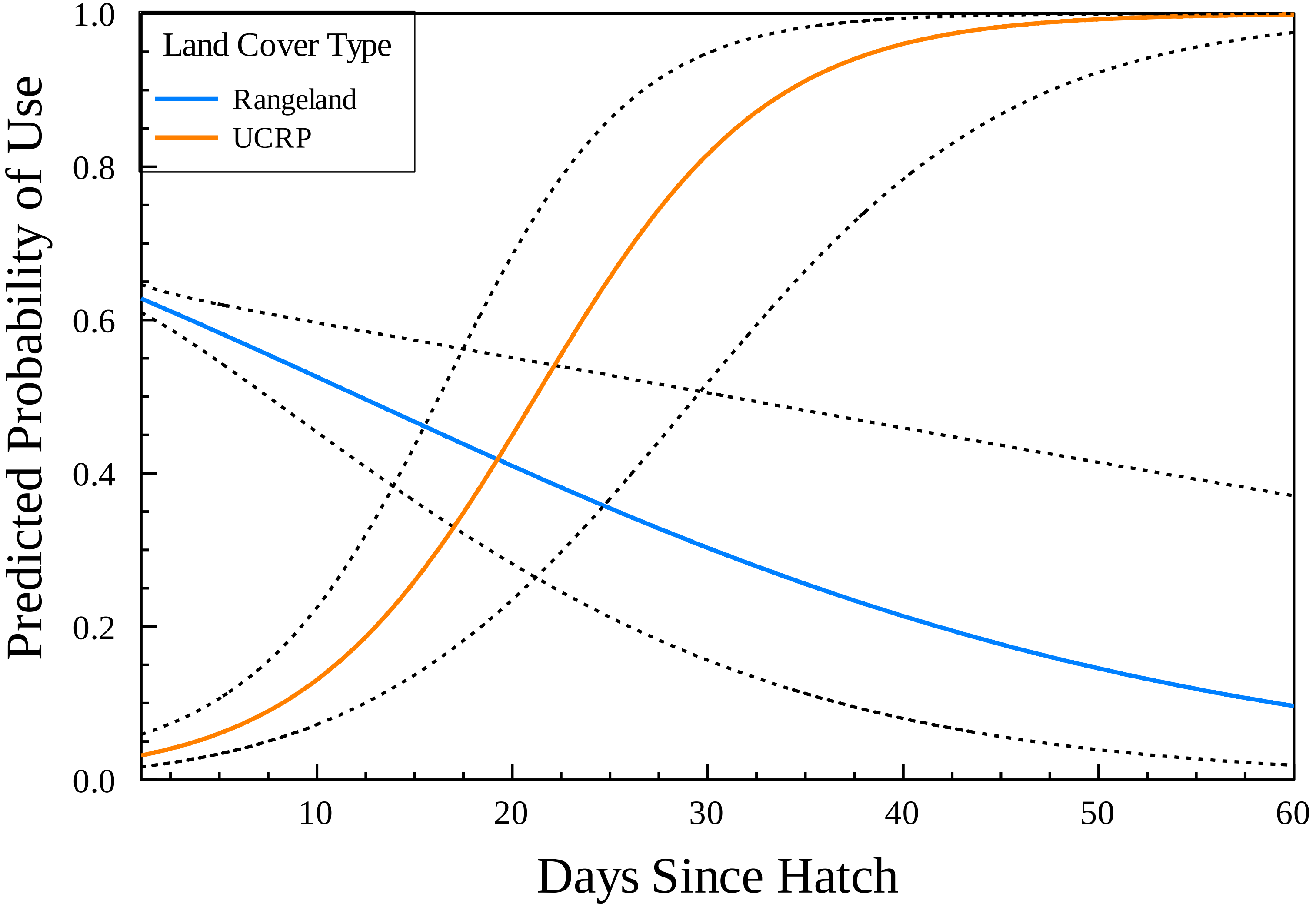

Table 2.1 Resource selection functions evaluating habitat selection by non – breeding female lesser prairie-chickens in relation to distance from a lek (m; Dist. to Lek), land cover type (LCT), lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season [April-September]; PDSI), presence of sand sagebrush (>1% canopy cover at the 8 m scale; Sage), and season from 2013-2015 in the Northwest study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
Dist. to Lek + LCT + PDSI + LCT:PDSI	17744.4	20	0	0.93
Dist. to Lek + LCT + Season + LCT:Season	17749.5	20	5.11	0.07
Dist. to Lek + Sage + Season + Sage:Season	18771.5	6	999.04	<0.001
Dist. to Lek + Sage + PDSI + Sage:PDSI	18774.7	6	1002.31	<0.001
Dist. to Lek	18928.3	2	1149.91	<0.001
Sage	24097.5	2	6319.09	<0.001
LCT	21716.4	9	3952.01	<0.001
Null	24670.5	1	6890.06	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 17782.43

Table 2.2 Resource selection beta estimates, standard errors, *z* values and probabilities for the top model evaluating non-breeding habitat use by female lesser prairie-chickens in relation to proximity to a lek (m; Dist. to Lek), land cover types (ecological sites, UCRP, and CRP), and lag PDSI (cumulative x̄ of PDSI during the growing season calculated monthly during the growing season [April-September]; PDSI) from 2013-2015 in the Northwest study area in western Kansas, USA.

Study area	Coefficient	Estimate	Standard Error	*z* value	Pr > │z│
Northwest **RC = Loamy Upland**	Intercept	1.99	0.08	24.63	<0.001*
	Dist. to Lek (-)	-0.001	0.00001	-52.42	<0.001*
	Chalk Flats (-)	-0.68	0.14	-5.05	<0.001*
	Cropland (-)	-0.50	0.10	-4.77	<0.001*
	Other (-)	-1.23	0.15	-8.22	<0.001*
	DCRP	0.07	0.18	0.37	0.71
	Limy Upland (-)	-0.65	0.11	-6.10	<0.001*
	UCRP (+)	0.80	0.15	5.50	<0.001*
	Sandy Lowland	-0.33	0.25	-1.30	0.19
	Sandy (+)	1.59	0.33	4.79	<0.001*
	Loamy Upland : PDSI	0.07	0.03	2.37	0.018*
	Chalk Flats : PDSI	0.05	0.04	1.11	0.27
	Cropland : PDSI	0.29	0.03	9.49	<0.001*
	Other : PDSI	-0.08	0.05	-1.57	0.12
	DCRP : PDSI	-0.15	0.06	-2.44	0.01*
	Limy Upland : PDSI	-0.10	0.03	-3.56	<0.001*
	UCRP : PDSI	0.13	0.05	2.85	<0.001*
	Sandy Lowland : PDSI	-0.09	0.09	-1.00	0.32
	Sandy : PDSI	0.02	0.12	0.16	0.88

RC = reference community used for calculate β estimates

Significance determined at $P < 0.05$ and denoted by (*)

(-) or (+) assigned to significant variables to indicate habitat use relative to the reference community

Table 2.3 Resource selection functions evaluating habitat selection by non –breeding female lesser prairie-chickens in relation to distance from a lek (m; Dist. to Lek), land cover type (LCT), lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season [April-September]; PDSI), and season from 2013-2015 in the Red Hills study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
Dist. to Lek + LCT + Season + LCT:Season	8602.5	13	0	1
Dist. to Lek + LCT + PDSI + LCT:PDSI	8623.84	13	21.33	<0.001
Dist. to Lek	9019.88	2	395.35	<0.001
LCT	14265.64	6	5649.13	<0.001
Null	16125.38	1	7498.84	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 8628.53 for best fit model

Table 2.4 Resource selection beta estimates, standard errors, *z* values and probabilities for the top models evaluating non-breeding habitat use by female lesser prairie-chickens in relation to proximity to a lek (m; Dist. to Lek), land cover types (ecological sites and Conservation Reserve Program tracts), and season (breeding [March 15-September 15] and winter [September 16 – March 14; W]), in the Red Hills and Clark study areas from 2013-2015 in western Kansas, USA.

Study area	Coefficient	Estimate	Standard Error	*z* value	Pr >│z│
Red Hills **RC = Red Clay Prairie**	Intercept	2.60	0.08	31.18	<0.001*
	Dist. to Lek (-)	-0.001	0.00003	-48.59	<0.001*
	Cropland (-)	-0.55	0.21	-2.55	0.01*
	Other (-)	-1.29	0.15	-8.38	<0.001*
	Limy Upland (+)	0.78	0.09	8.52	<0.001*
	Loamy Upland	0.08	0.12	0.69	0.49
	Sandy	0.04	0.10	0.39	0.70
	Red Clay Prairie : W	0.18	0.12	1.44	0.15
	Cropland : W	-0.17	0.39	-0.44	0.66
	Other : W (+)	1.14	0.20	5.73	<0.001*
	Limy Upland : W (+)	0.28	0.11	2.61	0.01*
	Loamy Upland : W (+)	0.85	0.15	5.51	<0.001*
	Sandy : W (+)	0.43	0.12	3.71	<0.001*
Clark **RC = Saline Subirrigated**	Intercept	1.43	0.11	13.50	<0.001*
	Dist. to Lek (-)	0.00	0.00	-24.62	<0.001*
	Choppy Sands (-)	-1.35	0.19	-7.05	<0.001*
	Cropland (-)	-4.15	0.59	-7.02	<0.001*
	UCRP (-)	-1.40	0.27	-5.19	<0.001*
	Other (-)	-0.82	0.17	-4.86	<0.001*
	Limy Upland (+)	1.95	0.20	9.78	<0.001*
	Sandy Lowland	0.26	0.14	1.82	0.07
	Sands	0.07	0.12	0.60	0.55
	Sandy (-)	-0.70	0.18	-3.82	<0.001*
	Subirrigated	-0.17	0.17	-0.98	0.33
	Saline Subirrigated : W	-0.15	0.16	-0.94	0.35
	Choppy Sands : W	0.02	0.27	0.09	0.93
	Cropland : W (+)	4.84	0.59	8.20	<0.001*
	CRP : W	0.48	0.36	1.33	0.18
	Other : W	-0.08	0.22	-0.35	0.73
	Limy Upland : W (-)	-1.54	0.23	-6.64	<0.001*
	Sandy Lowland : W	-0.14	0.17	-0.81	0.42
	Sands : W (-)	-0.35	0.11	-3.32	<0.001*
	Sandy : W (-)	-0.67	0.33	-2.06	0.04*
	Subirrigated : W (+)	0.61	0.24	2.59	0.01*

RC = reference community used for calculate β estimates

Significance determined at $P < 0.05$ and denoted by (*)

(-) or (+) assigned to significant variables to indicate habitat use relative to the reference community

Table 2.5 Resource selection functions evaluating habitat selection by non –breeding female lesser prairie-chickens in relation to distance from a lek (m; Dist. to Lek), land cover type (LCT), lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season [April-September]; PDSI), presence of sand sagebrush (>1% canopy cover at the 8 m scale; Sage), and season from 2014-2015 in the Clark study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
Dist. to Lek + LCT + Season + LCT:Season	7128.0	21	0	1
Dist. to Lek + LCT + PDSI + LCT:PDSI	7325.3	21	197.28	<0.001
Dist. to Lek + Sage + Season + Sage:Season	7872.7	5	712.56	<0.001
Dist. to Lek + Sage + PDSI + Sage:PDSI	7892.8	5	732.64	<0.001
Dist. to Lek	7913.0	2	746.86	<0.001
LCT	8359.7	10	1209.59	<0.001
Sage	8953.5	2	1787.34	<0.001
Null	8974.9	1	1806.72	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 7170.15 for best fit model

Table 2.6 Resource selection functions evaluating nest site selection by female lesser prairie-chickens in relation to land cover type (LCT), lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season[April-September]; PDSI), presence of sand sagebrush (>1% canopy cover at the 8 m scale; Sage) at the Northwest Study Area in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
LCT	410.34	10	0	0.99
LCT + LCT:PDSI	397.88	20	8.52	0.01
Sage	504.62	2	77.95	<0.001
Sage + Sage:PDSI	504.44	4	81.82	<0.001
Null	511.72	1	83.04	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 430.69 for best fit model

Table 2.7 Resource selection beta estimates, standard errors, *z* values and probabilities for the top models evaluating nest site placement by female lesser prairie-chickens in relation to land cover types (ecological sites, UCRP and CRP) in the Northwest, Red Hills and Clark study areas from 2013-2015 in western Kansas, USA.

Study area	Coefficient	Estimate	Standard Error	*z* value	Pr > |*z*|
Northwest **RC = UCRP**	Intercept	0.13	0.37	0.37	0.715
	Chalk Flats (-)	-1.31	0.49	-2.66	0.01*
	Cropland (-)	-5.49	1.07	-5.15	<0.001*
	Other (-)	-3.00	0.81	-3.68	<0.001*
	DCRP (-)	-1.78	0.61	-2.92	<0.001*
	Limy Upland (-)	-1.63	0.44	-3.72	<0.001*
	Loamy Lowland (-)	-1.78	0.61	-2.92	<0.001*
	Loamy Upland (-)	-1.94	0.45	-4.30	<0.001*
	Sandy Lowland	-1.43	0.75	-1.92	0.055
	Sandy	0.78	0.91	0.86	0.391
Red Hills **RC = Limy Upland**	Intercept	-1.04	0.21	-5.00	<0.001
	Cropland (-)	-2.69	1.03	-2.61	0.01*
	Loamy Upland	-0.38	0.36	-1.04	0.30
	Other (-)	-1.24	0.45	-2.78	0.01*
	Red Clay Prairie	-0.33	0.35	-0.94	0.35
	Sandy (-)	-0.94	0.38	-2.45	0.01*
Clark **RC = Saline Subirrigated**	Intercept	-1.02	0.39	-2.63	0.01*
	Choppy Sands	-1.42	0.83	-1.71	0.09
	Cropland	-17.54	931.81	-0.02	0.98
	CRP	-1.46	1.11	-1.32	0.19
	Limy Upland	-0.18	0.61	-0.30	0.76
	Other (-)	-2.35	1.09	-2.15	0.03*
	Sandy Lowland	0.11	0.57	0.18	0.85
	Sands	-0.19	0.47	-0.41	0.68
	Sandy	-1.12	0.84	-1.33	0.18
	Subirrigated	0.33	0.67	0.49	0.62

RC = reference community used for calculate β estimates

Significance determined at $P < 0.05$ and denoted by (*)

(-) or (+) assigned to significant variables to indicate habitat use relative to the reference community

Table 2.8 Resource selection functions evaluating nest site placement by female lesser prairie-chickens in relation to land cover type (LCT), and lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season [April-September]; PDSI) from 2013-2015 in the Red Hills study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
LCT	410.38	6	0	0.99
LCT + LCT:PDSI	407.32	12	9.42	0.01
Null	432.54	1	11.99	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 422.56 for best fit model

Table 2.9 Resource selection functions evaluating nest site placement by female lesser prairie-chickens in relation to land cover type (LCT), lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season [April-September]; PDSI), presence of sand sagebrush (>1% canopy cover at the 8 m scale; Sage), from 2014-2015 in the Clark study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
LCT	251.84	10	0	0.97
LCT + LCT:PDSI	236.46	20	6.72	0.03
Sage	285.28	2	16.77	<0.001
Null	288	1	17.48	<0.001
Sage + Sage:PDSI	285.12	4	20.71	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 293.26 for best fit model

Table 2.10 Resource selection functions evaluating habitat use by female lesser prairie-chickens with broods in relation to general land cover type (GLCT), Nest GLCT, land cover type (LCT), lag Palmer Drought Severity Index (average growing season index calculated monthly during the growing season [April-September]; PDSI), presence of sand sagebrush (>1% canopy cover at the 8 m scale; Sage), and days since hatch (DSH) from 2013-2015 in the Northwest study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
GLCT + GLCT: Nest GLCT:DSH	12402.0	16	0	1
GLCT + GLCT: Nest GLCT	13011.8	12	601.75	<0.001
LCT + LCT:PDSI	13168.6	20	774.62	<0.001
GLCT + GLCT:Nest GLCT:DSH:PDSI	13380.8	16	978.81	<0.001
GLCT + GLCT: Nest GLCT:PDSI	13521.5	16	1119.54	<0.001
LCT	13585.3	10	1171.3	<0.001
GLCT + GLCT:PDSI	14532.9	8	2114.82	<0.001
Sage + Sage:DSH:Nest GLCT:PDSI	17330.6	7	4910.53	<0.001
Sage + Sage:DSH:Nest GLCT	17286.7	7	4866.63	<0.001
Sage + Sage:Nest GLCT	17280.6	5	4856.59	<0.001
Sage + Sage:DSH	17412.6	4	4986.57	<0.001
Sage + Sage:PDSI	17378.7	4	4952.65	<0.001
GLCT + GLCT:DSH	14399.1	8	1981.03	<0.001
Sage	17414.7	2	4984.66	<0.001
Null	18190.6	1	5758.51	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 12434.05 for best fit model

Table 2.11 Resource selection beta estimates, standard errors, *z* values and probabilities associated for the top model evaluating habitat selection by female lesser prairie-chickens with broods in relation to general land cover types (Rangeland, DCRP, UCRP, Cropland; GLCT), GLCT of nest site (Nest GLCT), and DSH (Days Since Hatch) in the Northwest study area from 2013-2015 in western Kansas, USA.

Study area	Variable	Coefficient	Standard Error	z value	Pr >│z│
Northwest **RC = Rangeland**	Intercept	0.57	0.04	14.76	<0.001*
	Cropland (-)	-1.95	0.13	-14.82	<0.001*
	DCRP (+)	3.45	0.41	8.45	<0.001*
	CRP (-)	-4.16	0.34	-12.11	<0.001*
	GLCT (Rangeland) : Nest GLCT (UCRP) : DSH	-0.05	0.01	-3.21	<0.001*
	GLCT (Cropland) : Nest GLCT (UCRP) : DSH	0.05	0.01	3.35	0.01*
	GLCT (DCRP) : Nest GLCT (UCRP) : DSH	-22.15	5227.00	0.00	0.99
	GLCT (CRP) : Nest GLCT (UCRP) : DSH	0.17	0.03	6.42	<0.001*
	GLCT (Rangeland) : Nest GLCT (Rangeland) : DSH	0.00	0.00	-0.54	0.59
	GLCT (Cropland) : Nest GLCT (Rangeland) : DSH	-0.04	0.00	-8.46	<0.001*
	GLCT (DCRP) : Nest GLCT (Rangeland) : DSH	-16.12	181.30	-0.09	0.93
	GLCT (UCRP) : Nest GLCT (Rangeland) : DSH	0.04	0.00	10.12	<0.001*
	GLCT (Rangeland) : Nest GLCT (DCRP) : DSH	-0.14	0.01	-14.22	<0.001*
	GLCT (Cropland) : Nest GLCT (DCRP) : DSH	-11.37	126.10	-0.09	0.93
	GLCT (DCRP) : Nest GLCT (DCRP) : DSH	-0.01	0.01	-1.08	0.28
	GLCT (UCRP) : Nest GLCT (DCRP) : DSH	0.04	0.01	6.71	<0.001*

RC = reference community used for calculate β estimates

Significance determined at $P < 0.05$ and denoted by (*)

(-) or (+) assigned to significant variables to indicate habitat use relative to the reference community

Table 2.12 Resource selection beta estimates, standard errors, *z* values and probabilities for the top models evaluating habitat use by female lesser prairie-chickens with broods in relation to land cover types (ecological sites and Conservation Reserve Program tracts (DCRP and UCRP) in the Northwest, Red Hills and Clark study areas from 2013-2015 in western Kansas, USA.

Study area	Variable	Coefficient	Standard Error	*z* value	Pr > |*z*|
Northwest **RC = Sandy Lowland**	Intercept	0.967	0.1375	7.033	<0.001*
	CHFL (-)	-0.5903	0.1482	-3.984	<0.001*
	Cropland (-)	-3.6437	0.1594	-22.852	<0.001*
	Other (-)	-1.9875	0.1796	-11.068	<0.001*
	DCRP (+)	1.0701	0.1612	6.64	<0.001*
	Limy Upland (-)	-0.359	0.1426	-2.517	0.01*
	Loamy Lowland (-)	-1.5569	0.1687	-9.231	<0.001*
	Loamy Upland (-)	-1.1781	0.1435	-8.208	<0.001*
	UCRP(-)	-1.7017	0.167	-10.193	<0.001*
	Sandy (+)	2.0397	0.2192	9.305	<0.001*
Red Hills **RC = Limy Upland**	Intercept	0.1575	0.04788	3.29	<0.001*
	Cropland	-16.72357	129.18715	-0.129	0.90
	Other (-)	-1.85449	0.10013	-18.521	<0.001*
	Loamy Upland (-)	-0.69963	0.09439	-7.412	<0.001*
	Red Clay Prairie (+)	0.71232	0.06765	10.529	<0.001*
	Sandy	0.05403	0.06619	0.816	0.41
Clark **RC = Sands**	Intercept	0.87115	0.04396	19.817	<0.001*
	Sandy (-)	-3.1962	0.22761	-14.042	<0.001*
	Choppy Sands (-)	-2.22295	0.15254	-14.573	<0.001*
	Cropland (-)	-1.83092	0.10741	-17.046	<0.001*
	CRP (-)	-1.70947	0.15593	-10.963	<0.001*
	Other (-)	-2.45329	0.15848	-15.48	<0.001*
	Sandy Lowland (-)	-0.33754	0.09614	-3.511	<0.001*
	Saline Subirrigated (-)	-2.77983	0.16922	-16.427	<0.001*
	Subirrigated (-)	-0.9371	0.15471	-6.057	<0.001*

RC = reference community used for calculate β estimates

Significance determined at $P < 0.05$ and denoted by (*)

(-) or (+) assigned to significant variables to indicate habitat use relative to the reference community

Table 2.13 Resource selection function evaluating habitat use by female lesser prairie-chickens with broods in relation to land cover type (LCT) from 2013-2015 in the Red Hills study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
LCT	9344.88	6	0	1
Null	10782.6	1	1427.71	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 9356.89 for best fit model

Table 2.14 Resource selection functions evaluating habitat use by female lesser prairie-chickens with broods in relation to land cover type (LCT), presence of sand sagebrush (>1% canopy cover at the 8 m scale; Sage) from 2014-2015 in the Clark study area in western Kansas, USA. Models ranked using Akaike Information Criterion corrected for a small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
LCT	5891.98	9	0	1
Sage	6575.92	2	669.92	<0.001
Null	7154.48	1	1246.47	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 5910.01 for best fit model

Table 2.15 List of predominant ecological sites at each study area (Northwest, Red Hills, and Clark) in western Kansas, USA, and corresponding WAFWA estimates of LEPC use or non-use during nesting and brooding periods and the predicted LEPC value (1-5; 5 equals highest quality, 1 equals lowest quality) for each ecological site based on expert opinion, compared to habitat selection and avoidance detected for each ecological site by marked LEPC females from 2013-2015, and an updated recommended LEPC value.

		WAFWA Estimates				Habitat Selection Analysis			
	Land Cover Type	**Nesting**	**Brooding**	**Limited Use**	**LEPC Value**	**Nesting**	**Brooding**	**Non-Breeding**	**Recommended Value**
Northwest	Limy Upland	X	X		5	X	X	X	5
	Loamy Upland	X	X		5		X	X	3
	Sandy	X	X		5	X	X	X	5
	Chalk Flats	X	X		4		X	X	4
	Sandy Lowland			X	1	X	X	X	5
	Loamy Lowland			X	1				1
Red Hills	Limy Upland	X	X		5	X	X	X	5
	Loamy Upland	X	X		5	X		X	4
	Sandy	X	X		5		X	X	4
	Red Clay Prairie		X		1		X	x	3
Clark	Choppy Sands	X	X		5		X		3
	Loamy Upland	X	X		5	X		X	3
	Sands	X	X		5		X	X	4
	Sandy	X	X		5		X	X	4
	Limy Upland	X	X		4	X	X	X	5
	Saline Subirrigated			X	1	X		X	4
	Subirrigated			X	1	X	X	X	5
	Sandy Lowland			X	1	X	X	X	5

Chapter 3 - Lesser Prairie-Chicken and Vegetation Response to Grazing Strategies in Western Kansas

Introduction

Grasslands are among the most imperiled ecosystems across the globe (Samson et al. 2004). Due to their relatively accessible resources, grassland systems are prone to disturbance and degradation by anthropogenic sources. The presence of imperiled species such as the lesser prairie-chicken (*Tympanuchus pallidicinctus;* hereafter LEPC) indicates that the southern Great Plains region is no exception. The LEPC, grassland obligate, is a species of grouse endemic to the southern Great Plains, inhabiting portions of Colorado, Kansas, Oklahoma, New Mexico, and Texas. Contemporary estimates of population numbers and occupied range indicates a >90% reduction from historical range and population level estimates post-European settlement (Crawford and Bolen 1976, Hagen et al. 2004). The predominant drivers of declines include fragmentation and conversion of grassland for agricultural practices; invasive species; avoidance of anthropogenic structures; and climate change (Hagen et al. 2004). Population indices that project long-term decline further elicit concern and conservation need for the species into the 21st century (Hagen et al. 2004, Rodgers 2016, Ross et al. 2016a). In May 2014, the U.S. Fish and Wildlife Service (USFWS) listed the LEPC as a threatened species under the Endangered Species Act (ESA) of 1973 (USFWS 2014). Previously, Texas, New Mexico, and Oklahoma ceased sport hunting seasons on the species; Kansas closed prairie-chicken hunting in areas solely occupied by LEPC in 2014 (Hagen et al. 2004, Rodgers 2016). Colorado listed LEPC as state threatened in the early 1970s. Increased attention and concern has also led an increased recognition of the need for additional research through universities and state/federal entities to address knowledge gaps in population ecology (Hagen et al. 2004).

Weather and climate have been shown to influence large-scale population status of LEPC. Results from a distribution-wide population survey indicated a 50% reduction in abundance between 2012 and 2013 in response to an extreme drought event on the Great Plains (McDonald et al. 2014). Recent distribution-wide estimates report some regional population increases in response to greater levels of precipitation (McDonald et al. 2016). Ross et al. (2016a) reported a positive relationship between lek attendance and increased precipitation (high PDSI) during the previous spring. Furthermore, extreme drought and weather events can have significant effects on population size (Grisham et al. 2016c). With the threat of climate change, an increase in extreme weather events such as prolonged drought is expected, resulting in further degraded habitat across the occupied distribution (Grisham et al. 2016c). Future conservation planning needs to account for the influence of these events. Resiliency of LEPC populations to extreme events will be improved by responsible land use at landscape scales. More specifically, greater quantities of resilient habitats (CRP) and improvements in the efficacy of management prescriptions for livestock grazing on working lands are needed (Hagen and Elmore 2016).

The current Kansas population contains portions of three different distinct populations or ecoregions; Short-Grass Prairie/CRP mosaic (SGPR) Ecoregion in northwest Kansas, Sand Sagebrush (*Artemisia filifloria*) Prairie (SSPR) Ecoregion in southwest Kansas, and Mixed-Grass Prairie (MGPR) Ecoregion in south-central Kansas. Each one of these populations has unique characteristics and different population trajectories (Van Pelt et al. 2013, McDonald et al 2014). Across these ecoregions, land cover and corresponding land use vary as environmental characteristics (soils, precipitation, plant communities) change. Our understanding of how LEPC respond to different land uses (grazing, tree removal, and fire) across ecoregions needs to improve to ensure the efficacy of conservation prescriptions (Hagen and Elmore 2016).

Roughly 54% (14,025 of 25,651 individuals) of the range-wide LEPC population is thought to occur within the SGPR Ecoregion of eastern Colorado and northwest Kansas (McDonald et al. 2014). The range occupied in northwest Kansas can be described as a mosaic dominated by short-grass prairie grazed by livestock, row-crop production, and lands enrolled in the USDA Conservation Reserve Program (CRP), a land retirement program designed to reduce soil erosion and provide wildlife habitat. The MGPR Ecoregion extending from south-central Kansas through Oklahoma into northeast portions of the Texas panhandle contains a significant proportion of the remaining population (~27%; 6,891 of 25,651 individuals; McDonald et al. 2014). Landscape characteristics in this region include large expanses of mixed-grass prairie grazed by livestock with pockets of row-crop agriculture. The LEPC population occupying the SSPR Ecoregion in southwest Kansas and southeast Colorado represent perhaps the most imperiled population. During the past 50 years, LEPC density was thought to be greatest in the SSPR Ecoregion, but during the past 15 years, density has sharply declined (Haukos et al. 2016). However, estimates over the past few years indicate a slight increase in population size in response to greater levels of annual precipitation (1,479 individuals in 2016; McDonald et al. 2016). The region is characterized by sand sagebrush/mixed-grass prairie grazed by livestock, center pivot agriculture, and CRP. Recent research indicates variation in space use and demographics across all three of these ecoregions (Lautenbach 2014, Plumb 2015, Robinson 2015).

Considering a high proportion (>94%; Elmore and Dahlgren 2016) of privately owned land within the LEPC distribution, the predominant driver of grassland condition and resulting biological community on a large proportion of the LEPC distribution is livestock grazing. Within the Great Plains, researchers suggest that agricultural land use practices (i.e., grazing and cash crops) have significant effects on LEPC and other native grassland birds (Knopf 1994). Variation in livestock grazing management can create, destroy or produce habitats essential to wildlife and other members of grassland communities (Knopf 1994). To date grazing practices that degrade microhabitat in rangelands past LEPC suitability are often cited as a catalyst for LEPC declines and an impediment to LEPC recovery (Hagen et al. 2004, Elmore and Dahlgren 2016, Hagen and Elmore 2016). Literature suggests that mismanaged (i.e., grazing objectives that do not include the creation of quality LEPC microhabitat) grazing may be a reason for LEPC declines in the southern extent of their range through the degradation of nesting habitat (Bailey et al. 2000, Brennan and Kuvlesky Jr 2005). In the western Great Plains, grasslands that are continuously grazed at high intensities can be degraded by shifting vegetation composition from beneficial mixed-grass dominated shrublands and grasslands to an ecological condition unlikely to support LEPC life history requirements based on vegetation composition and structure (Jackson and DeArment 1963) . Shifts in plant community could negatively influence LEPC populations due the tendency of LEPC to use shrub cover as a response to overgrazing (Haukos and Smith 1989). Currently, the threshold of grazing intensity encouraging shifts in habitat use is unknown. Most likely, as in Texas, there are multiple degradation factors that contribute to reduction of adequate nesting habitat such as overgrazing, herbicide use, and fragmentation caused by land cover or land use conversion (Haukos and Smith 1989, Fuhlendorf et al. 2002). Range-wide meta-analysis indicates that adequate nesting habitat is comprised of grasses taller and more visually obstructive than paired locations (Hagen et al. 2013), but grazing has been shown to reduce the mean plant height of the grasses important to nesting in New Mexico (Davis et al. 1979). In Colorado, researchers reported that unmanaged grazing led to a 16% reduction in nest success (Giesen 1994). In Oklahoma, researchers report that LEPC utilize moderately grazed pastures more than heavily grazed areas (Copelin 1963). In New Mexico, the density or success of grassland bird nests were not affected by low intensity herbicide and grazing treatments (Grisham et al. 2014). Varying climate variables affect LEPC use of grazed habitats as well. In a year of drought, LEPC used areas of light grazing, but a contrasting precipitation amount the following year indicated that more heavily grazed areas can also be utilized (Merchant 1982). In consideration of these data and observations, negative implications of mismanaged grazing on LEPC populations are well accepted.

However, in years of adequate precipitation, properly implemented grazing practices have the potential to produce heterogeneous habitat in grasslands that is adequate or beneficial for LEPCs (Derner et al. 2009). Researchers propose that beneficial grazing management is met via rotational systems. Experts recommend consideration of placement of watering and supplemental feeding structures, implementation of light-moderate stocking rates, and using home range estimations for the species of interest as a guide for designing habitat patch size for livestock management (Derner et al. 2009). In Kansas, the Natural Resource Conservation Service (NRCS) has made recommendations for grazing plans that will create available microhabitat for nesting and brooding LEPCs (Kansas Range Technical Note KS-9 2014). In short, NRCS recommends light (33% forage utilization) to moderate (40-50% forage utilization) grazing pressure applied over a fraction of the year to produce quality habitat for nesting or brooding periods. The timing of grazing is dictated by objectives set at the pasture scale (i.e., designation of pastures for nesting or brooding habitat). Early season (April-July) weighted grazing pressure is recommended for brooding habitat while late to dormant season grazing pressure is recommended for creating nesting habitat.

There has also been emphasis placed on the importance of creating heterogeneous microhabitats to meet LEPC resource needs for all ecological periods: lekking, nesting, brooding, and non-breeding (Hagen and Elmore 2016). In areas of greater precipitation, patch-burn grazing systems have been shown to increase heterogeneity of vegetation structure on the landscape and provide the adequate microhabitat needed by greater prairie-chickens (*Tympanuchus cupido*) for multiple ecological periods (Fuhlendorf and Engle 2001, Fuhlendorf et al. 2006, Fuhlendorf et al. 2009). The relationship is driven by greater forage quality/palatability associated with more recently burned patches on the landscape. As time since fire increases for an individual patch, proportional grazing pressure decreases. The patch-brun grazing system results in distinct patches of light to heavy grazing pressure across each individual pasture. In turn, patches representing a range of vegetation structure are created. However, NRCS does not recommend patch-burn grazing systems in regions with <71 cm annual precipitation, which includes most of the LEPC range in Kansas except for the easternmost population in the MGPR Ecoregion (Kansas Range Technical Note KS-9 2014). Fuhlendorf and Engle (2001) called for design and research of new grazing systems that may create heterogeneity similar to a patch-burn grazing system. In regions where patch-burn grazing systems are not plausible, beneficial habitat heterogeneity may be achieved using other grazing management principles. Reports indicate a strong positive correlation between heterogeneity of forage utilization and pasture area (Malechek et al. 2008). Increasing heterogeneity of grazing pressure across pasture would theoretically create heterogeneous microhabitat suitable for multiple LEPC ecological needs. Stocking densities also influence grazing distribution in a pasture. At smaller pasture sizes and increased stocking densities, the distribution of grazing in a pasture becomes more uniform (Bailey and Brown 2011). By encouraging variation in grazing distribution through adjusting stocking density, grazing intensity, and pasture residency time, managers may also produce levels of vegetation structure and composition heterogeneity beneficial for wildlife and grassland ecosystems. However, grazing management that increases the heterogeneity of grazing distribution may be detrimental to grassland health, cattle performance, and economic viability of ranching operations (Teague et al. 2011). Briske et al. (2008) argues that a notion of perceived superiority of rotational grazing systems is founded in anecdotal observations instead of objective experimentation. It is widely accepted that recommended grazing systems need to be conducive for both cattle and LEPC population persistence (Applegate and Riley 1998, Hagen et al. 2004). One could argue that the definitions of various grazing systems are becoming convoluted with the constant adaptive management being implemented by producers and managers in response to drought, commodity prices, conservation concerns and incentives, and other factors unique to individual situations. Grazing systems vary greatly and can be as complex or simple as desired with the same vegetation condition result as long as forage utilization and other variables are constant (Fuhlendorf et al. 2012). For this reason, it may be more valuable to investigate the influence of grazing management components on LEPC habitat use and fitness opposed to grazing systems that are not consistently defined across managers and regions.

In response to the lack of empirical research among livestock grazing operations and LEPC habitat use and fitness (Jamison et al. 2002, Hagen and Elmore 2016), my objectives were to: 1) investigate the influence of grazing management components (grazing pressure, forage utilization, pasture area, stocking density, deferment, etc.), the presence of shrubs as sand sagebrush, and lek proximity on non-breeding habitat selection and nest site selection of female LEPC, 2) evaluate the influence of grazing management components on LEPC nest survival and adult survival, and 3) investigate the influence of grazing management components on vegetation structure (visual obstruction and vegetation height) values pertinent to LEPC microhabitat quality. I hypothesized a negative relationship between non-breeding LEPC habitat selection and grazing pressure (AUM/ha) and stocking density (AU/ha) and a positive relationship with pasture area (ha) and deferment (# of days deferred during the grazing season [April 15th – September 15th]). I predicted that nest site placement will be dictated by proximity to lek and pasture area. I hypothesized that nest survival rates will be positively correlated with deferment and pasture area. I hypothesized that pasture area values will be positively correlated with annual adult female survival. I predicted that mean values of vegetation structure (visual obstruction and vegetation height) will be negatively correlated with grazing pressure and stocking density. Last, I predicted a negative correlation between heterogeneity of vegetation structure (visual obstruction and vegetation height) and both grazing pressure and stocking density.

Study Area

Research efforts were concentrated two distinct areas where LEPC are abundant in western Kansas (McDonald et al. 2016; Chapter I, Figure 1.1). One site was located on private lands south of Ashland, Kansas, within Clark County and the other in northwest Kansas, focused on private lands located within Logan and Gove counties.

The Northwest study area was divided between Logan and Gove counties. The primary land uses for both counties were livestock grazing on grasslands, energy exploration and extraction, and both dryland and irrigated row-crop agriculture. This study area was in the Short-Grass Prairie/CRP Mosaic Ecoregion (Van Pelt et al. 2013, Dahlgren et al. 2016); Chapter I, Figure 1.1), with CRP grasslands and row-crop agriculture on silt-loam soils. Where soils permitted, plant communities resembled mixed-grass prairie. Dominant vegetation in the study area varied with cover type (e.g., native grasslands, CRP, row-crop agriculture). Native grasslands were dominated by species such as blue grama (*Bouteloua gracilis*), buffalograss (*B. dactyloides*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*B. curtipendula*), sand dropseed (*Sporobulus cryptandrus*), western wheatgrass (*Pascopyrum smithii*), western ragweed (*Ambrosia psilostachya),* scarlet globemallow (*Sphearalcea coccinea*), small soapweed (*Yucca glauca*), Russian thistle (*Salsola kali*), western salsify (*Tragopogon dubius*), slimflower scurfpea (*Psoralidium tenuiflorum*), and wavyleaf thistle (*Cirsium undulatum*; Lauver et al. 1999, J. Kraft pers. obs.). Native grass species planted in CRP fields included little bluestem, sideoats grama, big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*) (Fields 2004). The CRP fields were interseeded with forbs in the mid-late 1990s; the seed mixture included white sweet clover (*Melilotus alba*), yellow sweet clover (*M. officinalis*), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower (*Desmanthus illinoensis*), purple prairie clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*; Fields 2004). Wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*) were the major crops in the region. Properties used to monitor LEPC and grazing management were grazed using rotational strategies that allowed for rest during the grazing season (April 15 – September 15). No monitored properties were subjected to dormant season grazing pressure. Cow-calf (spring born) and yearling beef cattle were present at all monitored properties. Forage utilization goals were set between 20 – 50% (% of forage removed or destroyed during a grazing year).

The second study area was located in Clark County on the Mixed-Grass Prairie Ecoregion and Sand Sagebrush Prairie Ecoregion boundary (McDonald et al. 2014, Dahlgren et al. 2016, Haukos et al. 2016). Land use was dominated by livestock grazing, energy extraction and exploration, and row-crop agriculture. Dominant vegetation in the area included little bluestem, sideoats grama, blue grama, hairy grama, big bluestem, alkali sacaton (*Sporobolous airoides*), invasive Russian thistle, kochia (*Kochia scoparia*), annual sunflower (*Helianthus annuus*), and sand sagebrush (Lauver et al. 1999). Properties used to monitor LEPC and grazing management were grazed using rotational strategies that generally allowed for rest during the grazing season (April 15 – September 15). Dormant season grazing was also common in this area. Cow-calf (spring born) and yearling beef cattle were common within this region. Forage utilization goals were targeted between 40 and 50% of annual forage production.

Methods

Capture

To obtain location data and nest data, I deployed walk-in funnel traps (Haukos et al. 1990) and magnetic drop nets (Silvy et al. 1990) to capture LEPC females on leks during springs (mid-March – mid May) of 2013, 2014, and 2015. Upon capture, I recorded a suite of measurements. Age and gender of each captured individual were determined using plumage characteristics (Copelin 1963, Ammann 1944). Upon capture, I fitted females with either a very-high-frequency (VHF) radio transmitter or global-positioning system (GPS) satellite transmitter (Platform Transmitting Terminals or SAT-PTT) in an alternating pattern. These two transmitter types do not appear to affect survival of LEPC (Plumb 2015, Robinson 2015). The VHF transmitters (12 or 15 g) were attached using a bib-style harness to all individuals >500g. These transmitters had an estimated battery life of 790 days (Advanced Telemetry Systems, Isanti, MN, USA; hereafter ATS). Status of the female was monitored via an eight-hour mortality switch installed in the transmitter. The GPS SAT-PTT (22 g) transmitters were only fitted to females weighing >700 g. I attached the GPS SAT-PTT using a rump-style method utilizing Teflon tape and elastic ribbon (Dzialak et al. 2011). These units contained a solar charging component and battery life was not an issue. Status of these birds was determined via sensors that monitored temperature and movement (Microwave Telemetry, Columbia, MD, USA). After all measurements were recorded and transmitters fitted, captured LEPC were released at the lek of capture. All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee protocol (3241) and Kansas Department of Wildlife, Parks and Tourism scientific wildlife permits (SC-042-2013, SC-079-2014, SC-001-2015).

Locations

Marked individuals were monitored and specific locations recorded to observe nest locations, habitat selection, survival, movements, and other variables. I located VHF-fitted females using fixed-location triangulation 3-4 times/week throughout the lifespan of bird or transmitter (Cochran and Lord 1963). Handheld ATS receivers and a three-element yagi antennae were used to collect ≥3 bearings per individual. Telemetry bearings were entered into Location of a Signal software (hereafter LOAS; Ecological Software Solutions, Florida, USA) to obtain Universal Transverse Mercator (UTM) coordinates of the estimated location. Locations of GPS SAT-PTT were taken every two hours during 0400-2200 (depending of sunlight and battery charge). Recorded GPS fixes were then uploaded to Argos satellites every three days. Potential error of these points was <18 m. If VHF-marked individuals could no longer be located due to potential dispersal from the study areas, I attempted to find birds using a fixed-wing Cessna aircraft. If a mortality signal was obtained, I used either homing (VHF) or previous GPS locations to locate the transmitter and determine cause-specific mortality or another reason for transmitter loss.

Nest Location, Timing and Survival

I identified nest locations by homing in on VHF-marked females after the females were located in the same relative location for three consecutive days (Pitman et al. 2005). Females marked with GPS SAT-PTTs were monitored remotely after initial nest flush when GPS locations indicated nest incubation. Once a nest was initially located and female flushed, I recorded the number of eggs present in the nest. I floated eggs in order to estimate the nest incubation date, nest initiation date, and predicted hatch date (Coats 1955, Pitman et al. 2006). Nests were approached using rubber boots and latex gloves to avoid creating scent trails. Nest locations were recorded using hand-held GPS units. Post initial nest discovery, the nesting female was monitored by either radio-transmitted signals (VHF) or downloaded satellite locations (GPS SAT-PTT) until locations indicated that the female had left the nest. Once females left the nest location, the nest was revisited to determine success or failure. Nests were considered if ≥1 eggs hatched. Eggs found within the nest that exhibited pipping were considered successful. I recorded the number of hatched eggs from the nest. If nests are deemed successful, the female and brood were flushed within 7 days of hatch in order to get an estimate of hatched young that survived the first week following hatch.

Grazing Management Information

At each study area, I identified ranching operations that displayed potential for LEPC capture and grazing management monitoring. I attempted to locate ranches that represented a gradient of grazing strategies and intensities. At each ranching operation, grazing management data were collected via correspondence with producers. For each pasture, I recorded the days or grazing periods that occurred within one grazing year (April-March) and animal classifications (i.e. cow/calf pairs, yearlings, bulls, etc.) for each grazing period. From grazing management data, I calculated grazing pressure (Animal Unit Months per hectare; AUM/ha), stocking density (Animal Unit per hectare), and deferment (number of grazing days a pasture was rested during the grazing period [April-September]). Grazing pressure (GP; AUM/ha) was calculated continuously on a weekly basis throughout each grazing period/year. Forage Utilization (FU; % of annual forage production removed) was calculated using the estimated climax community forage production (kg/ha) for each ecological site and the estimated forage consumption by grazing livestock during grazing events. Climax community forage production estimates were obtained State and Transition Models unique to each ecological site (USDA and USDI 2013). First, I calculated the total coverage (ha) for each ecological site within each pasture. Average values of annual forage production for each ecological site were then used to estimate the total forage available across a pasture. Next, based on GP calculations, I determined forage consumption estimates for each pasture. Consumption rates were based on a consumption rate of 358 kg per day per 1.0 AUs (454 kg cow). To determine FU for each pasture, I multiplied the forage consumption estimate by two (to account for the destruction of forage via trampling, urinating and defecating) and divided by the forage available to get an estimate of FU for each pasture. FU values were calculated on a weekly basis throughout the year. Pasture area (ha) was recorded using the Calculate Geometry tool in ArcGIS 10.2 (ESRI Inc., 2013, Redlands, CA, USA). I created Ecological Site (USDA and USDI 2013) maps for each pasture as well using ArcGIS 10.2 to estimate the area for each ecological site (ha) in each pasture (Chapter I).

Vegetation Surveys

I conducted standardized vegetation surveys at each ranching operation. Surveys were completed during the period October-March during the years of 2013-14 and 2014-15. Vegetation survey points were either stratified randomly within monitored pasture units or randomly selected from a pool of locations obtained from transmittered LEPC individuals as part of concurrent studies (Lautenbach 2014, Plumb 2015, Robinson 2015). Randomly generated survey points were created using the Create Random Points tool in ArcGIS 10.2. All survey points were limited to grassland pastures in which grazing management data were collected.

At each survey point, I recorded four 100% cm visual obstruction readings (VOR) at the cardinal directions using a Robel pole at the plot center from a distance of 4 m and a height of 1 m (Robel et al. 1970). I recorded the tallest vegetation present within a 60 x 60 cm Daubenmire frame located at plot center, and 4 m out from plot center in each cardinal direction (Daubenmire 1959). I averaged visual obstruction and vegetation height for each survey point to obtain a representative value for each vegetation characteristic per point. Subsequently, I calculated means values of visual obstruction, vegetation height, coefficient of variation, and standard deviation at the pasture scale.

Statistical Analysis

Habitat Selection

Habitat selection was evaluated using Resource Selection Functions (RSF; Manly et al. 1992, Boyce et al. 2002). I employed RSFs to evaluate non-breeding habitat selection and nest site selection by LEPC females. Each RSF was completed using a used versus available study design (Manly et al. 1992, Boyce et al. 2002). Each location included in a RSF was described as a nest site or non-breeding location. Locations designated as nest sites describe the specific location of an observed LEPC nest. Locations were described as non-breeding when a female was not incubating a nest or raising a brood. Thus, non-breeding locations could occur at any time during the calendar year and included successful (successful nests) and non-successful (failed nest or no recorded nest attempt) breeders. Females were determined to be raising a brood

(≥1 chick) based on determination of a successful nest and subsequent brood flushes (Chapter 2). For each non-breeding RSF, I distributed one paired random location for each LEPC location recorded. Random locations were limited to the contiguous property associated with the individual ranching operation where a LEPC location was recorded. Thus, each ranching operation had the same number of random locations as LEPC locations. Furthermore, I could associate a date with each random and LEPC location to assign grazing management variables as they changed throughout the grazing period/year. Random locations were created using the Create Random Points tool in ArcGIS 10.2. Due to a limited number of nests, I randomly generated five paired locations for each nest location using the same method described for non-breeding locations above. Grazing management components assigned to used and available nest sites were descriptive of the previous year's grazing management. For instance, a covariate associated with a nest in May of 2015 were grazing management values (GP, SD, deferment) associated with the 2014 grazing year. Due to the requirement of residual cover for nests (Hagen et al. 2004) and current year grazing influence was not extensive enough to affect nest site placement.

Logistic regression was used to compare used and available points (Boyce et al. 2002). Eight different RSFs including a *priori* models were developed to satisfy research objectives regarding non-breeding and nest site habitat selection. I designed model sets in relation to hypotheses regarding GP, a quadratic function of GP (GP^2), FU, a quadratic function of FU (FU^2), stocking density (SD), deferment, pasture area, the presence of sand sagebrush at the ecological site scale, and distance to an active lek. Presence of sand sagebrush was determined as exhibiting >1% canopy cover of shrubs at the 8-m scale. Values of shrub cover were taken from previous vegetation surveys (Chapter I). I included a null model in each model set as well.

Distance to lek was included in all RSFs evaluating nest site placement. I did not include year or site terms because the range of grazing intensities represented would have been reduced. Due to the research being concentrated on ranching operations that exhibited relatively light to moderate grazing intensities and pressure, the range of grazing management components was somewhat limited. I was explicitly interested in evaluating grazing management components, so I did not include microhabitat characteristics. I wanted to examine the relationships between GP and FU and SD, pasture area, and deferment. Thus, I avoided including pasture area, SD or deferment terms in the same model or model set. By delineating model sets in this way I could investigate each hypothesized relationship individually without convoluting inference associated with complicated multivariate models. For each model set, I used an information theoretic approach, Akaike Information Criterion for small sample sizes (e.g., AIC_C) to rank and select individual models for inference (Burnham and Anderson 2002). Models with $\Delta AIC_c \leq 2$ were considered equally parsimonious. If beta estimates from top models differed than zero (coefficient $\neq 0$; 95% confidence intervals of beta estimate did not overlap zero), then I determined the variable to be influential and plotted the predicted probability of use curve. To visualize predicted probability of use curves for the top model in each set, I used the following logistic function:

$$f(x) = [\exp(\beta_0 + \beta_1(x_1) + \beta_2(x_2))] \,/\, [\ 1 + \exp(\beta_0 + \beta_1(x_1) + \beta_2(x_2))]$$

I conducted all RSFs in Program R (R core development team, version 3.0.1, 2013, Vienna, Austria) using the glm() command.

Nest Survival

To determine if grazing strategy components influenced nest survival rates of LEPC, I used the nest survival model in Program MARK to estimate nest survival rates in relation to GP, FU, SD, deferment, pasture area, and date of the nesting season. Grazing strategy components assigned to nests were descriptive of the grazing management during the previous year. For instance, covariates associated with a nest in May of 2015 were grazing management values (GP, SD, deferment) describing the 2014 grazing year. Due to the requirement of residual cover for nests (Hagen et al. 2004) and current year grazing intensity not being extensive enough to affect nest survival.

An *a priori* model set consisting of 20 models testing hypotheses related to grazing management components and daily survival rate and one constant model was developed. Models were ranked using AIC_C (Burnham and Anderson 2002). Models with $\Delta AIC_c \leq 2$ were considered competing models. If beta estimates from top models differed from zero (coefficient ≠ 0; 95% confidence intervals of beta estimate did not overlap zero), I determined the variable to influential and plotted the daily nest survival curve.

Adult Survival

I used Anderson-Gill (AG) modeling to determine how continuous, encounter specific grazing management covariates affect hazard rates for female lesser prairie-chickens (Dinkins et al. 2014). By using Cox proportional hazard models evaluated by entry date, exit date, and an event for each encounter per individual, we can evaluate the influence of the grazing management components mentioned above (Anderson and Gill 1982). All available locations were used for encounters of VHF-marked LEPC. I randomly selected PTT marked bird locations at the rate of one point per bird per day (8-10 points per day available). The pool of location obtained allowed for the modeling of daily survival on a daily encounter history. Random locations were selected for the day using the r.sample command in Geospatial Modeling Environment (Beyer 2012). Only points and mortalities located within monitored ranching operations were used. An *a priori* model set was created using individual grazing strategy components (GP, FU, SD, pasture area, deferment) and a distance to fence (m) variable. Decreasing distance to a fence has been shown to be negatively associated with LEPC daily survival rates (Robinson 2015). Models were limited to single variables due to a low number of mortalities. Models were ranked (e.g. $\mathrm{AIC_C}$) using an information theoretic approach (Burnham and Anderson 2002). Models with $\Delta\mathrm{AIC_c} \leq 2$ were considered competing models. Model diagnostics were tested with the cox.zph function to determine if the data met assumptions for proportional hazard functions (Fox 2002). If beta estimates from top models differed from zero (coefficient $\neq 0$; 95% confidence intervals of beta estimate did not overlap zero), then I determined the variable influential and plotted the predicted risk curve.

Vegetation Response Analysis

I used two-sample *t*-tests to evaluate the change in 100% visual obstruction at the cm level and vegetation height to grazing management components (mean, coefficient of variation [CV], standard deviation [STDV]). Vegetation survey points were classified and organized into specific pasture units and sampling periods (Year One = October 2013 – March 2014 or Year Two = October 2014 – March 2015). I calculated vegetation responses for each pasture (sampling unit) and year. However, due to a low number sampling units across years, I did not investigate differences between years. Grazing management components (GP, FU, SD, pasture area, deferment) calculated at the pasture scale were assigned to corresponding vegetation response values. Next, I separated grazing management component values in two groups at the median for each vegetation response. Thus, I had two group means for each grazing management component in which to calculate a *t*-test. Means were determined to be different at $P < 0.05$.

Results

Non-breeding Habitat Selection

I captured 116 female LEPC on monitored ranches during spring 2013, 2014 and 2015. Following pooling of all VHF and GPS SAT-PTT marked individuals and deleting locations of nesting, and brooding females, I used 20,373 LEPC locations for analysis. Combined with available locations, I used 40,746 locations to estimate non-breeding habitat selection. GP values ranged from 0 – 2.29 AUM/ha. The mean value of GP across all locations was 0.42 AUM/ha (SD = 0.34). SD values ranged from 0.07 – 1.04 AU/ha. Mean of SD across all locations was 0.43 AU/ha (SD = 0.22). FU values ranged from 0 – 100%, with a mean FU value across all locations of 22% (SD = 19%). Pasture area values ranged from 33 to 736 ha, with a mean pasture area across all locations of 443.36 ha (SD = 155.71). Deferment values across all locations ranged from 65 to 180 days. Mean value of deferment across all locations was 137.14 days (SD = 31.5).

Proportion of used points increased as pasture area increased in 100-ha increments from 0 to ≥600 ha (20%, 38%, 47%, 49%, 59%, 45%; Figure 3.1). Proportions were calculated by pooling all locations included in the non-breeding habitat selection analysis into groups based on pasture area and calculating the proportion of used locations and proportion of random/available locations within the same pasture area increment. Habitat use was examined using the same method for deferment, SD, and ecological sites exhibiting sand sagebrush cover. The greatest proportional difference in habitat use in relation to deferment was within the 60 – 100 days deferred category (30% available, 70% used; Figure 3.1) indicating LEPC used pastures that exhibited longer grazing periods during the grazing season. LEPC use (16% of locations) of pastures exhibiting relatively greater values of stocking density (>0.75 AU/ha) was drastically lower than available (84% of locations). In contrast, LEPC appeared to use (69% of locations) moderate stocking densities (0.26 – 0.50 AU/ha), in greater proportion than available (31% of locations; Figure 3.1). The use and availability of ecological sites exhibiting less than or greater than 1% of Sand Sagebrush canopy cover at the 8-m scale did not appear to be different.

The first set of RSF models I investigated the influence of GP and FU on habitat selection by non-breeding female LEPC. I investigated GP and FU first to establish a baseline relationship between LEPC and grazing to help in interpretation of the influences detected across other grazing management components. Furthermore, I used this model to determine the variable of grazing intensity (term describing the relative severity of grazing applied to an individual pasture; GP, GP^2, FU, or FU^2) that best explains LEPC habitat use. This variable was carried on into other *a priori* model sets. The highest ranked model carried 100% of the model weights and included additive effects of GP and GP^2 (Table 3.1). Furthermore, the model ranking order indicates that GP was a better predictor of habitat selection by non-breeding LEPC than estimates of FU (Table 3.1). Due to this finding, I only used GP and GP^2 in subsequent models investigating the interactive effects between GP and other grazing management components. The negative beta estimate associated with the GP in the top model indicated negative influence of grazing pressure on predicted use by LEPC (Table 3.2). The predicted probability of use (PPU) curve indicates a quadratic relationship between GP and LEPC habitat selection where the greatest PPU by LEPC was between GP values of 0.25 and 1.0 AUM/ha (Figure 3.2).

The top model within the RSF model set evaluating the presence of sand sagebrush (Table 3.3) on LEPC habitat selection indicated an interactive influence of GP^2 and presence of sand sagebrush. The top model carried 100% of the data set weight and included additive effects of GP, GP^2, and presence of sand sagebrush and an interaction between GP^2 and presence of sand sagebrush. All beta estimates associated with the top model differed from zero (Table 3.2). The PPU curve indicated an increase in use of sand sagebrush habitats as GP increased (Figure 3.3). In contrast, the PPU indicated a strongly negative relationship between LEPC use and GP values above 1.0 AUM/ha in areas with no sand sagebrush presence (Figure 3.3).

The top RSF evaluating the influence of pasture area on LEPC use indicated an interaction between GP and pasture area (Table 3.4). Variables included in this model were the additive effects of GP, GP^2, pasture area, and an interaction between GP^2 and pasture area. Beta estimates indicate negative influences of both GP^2 and pasture area on LEPC use (Table 3.2). The PPU curve indicated little influence of pasture area when GP was relatively low (0.08 AUM/ha; mean GP across all locations minus one standard deviation) or moderate (0.42 AUM/ha; mean GP across all locations) (Figure 3.4). However, at relatively heavy GP (0.75 AUM/ha; mean GP across all locations plus one standard deviation) LEPC use was strongly related with increasing pasture area (Figure 3.4).

The top ranked model evaluating the influence of deferment during the grazing season on LEPC use carried 100% of the model weights and included additive effects of GP, GP^2, and deferment, and an interaction term between GP^2 and deferment (Table 3.5). Beta estimates indicate a negative relationship between increasing deferment and LEPC use (Table 3.2). In other words, probability of LEPC use decreased as the number of grazing days decreased. The PPU curve indicated little influence of deferment at relatively low (0.08 AUM/ha; mean GP across all locations minus one standard deviation) or moderate (0.42 AUM/ha; mean GP across all locations) (Figure 3.5). However, at relatively heavy GP (0.75 AUM/ha; mean GP across all locations plus one standard deviation) LEPC use was reduced significantly as deferment increased (Figure 3.5).

Similarly to other grazing management component RSF model sets, my investigation of stocking density revealed a top model with an interaction between GP and SD. Terms included in the top model were additive effects of GP, GP^2, and SD plus an interaction term between GP^2 and SD (Table 3.6). Beta estimates indicate a negative relationship between increasing SD and LEPC use (Table 3.2). Furthermore, the PPU indicates this relationship was evident along a large gradient of GP (Figure 3.6).

Nest Site Placement

Three RSF model sets were employed to evaluate the influence of grazing components on LEPC nest site placement. The top model on nest site placement included additive effects of distance to lek and GP with an interaction term between distance to lek and GP (Table 3.7). This model carried 78% of model weights (Table 3.7). Beta estimates indicated negative influences of increasing distance to lek and GP on LEPC nest site placement (Table 3.2). The PPU curve illustrating the relationship between distance to lek and nest site placement indicated a drastic reduction in probability of use as distance to lek increased (Figure 3.7). Probability of nest site placement was below 5% at distances greater than 2 km (Figure 3.7). Although confidence intervals were large, the PPU curve illustrating the relationship between GP and LEPC nest site placement indicated a < 20% probability of nest site placement at GP values > 1.0 AUM/ha (Figure 3.9).

Model ranking revealed two competing models evaluating the influence of sand sagebrush presence on nest site placement of LEPC. The top model carried 51% of the model weights and included additive terms of distance to lek and presence of sand sagebrush (Table 3.8, Figure 3.7). Once again, distance to lek was negatively associated with LEPC nest site placement (Table 3.2). However, the main effect of sand sagebrush presence was not different than zero (Table 3.2).

The last RSF model set investigated the influence of other grazing management variables (pasture area, SD, and deferment) on nest site placement by LEPC. The top model included additive effects of SD and distance to lek and an interaction term between SD and distance to lek (Table 3.9). Beta estimates indicated a negative relationship between SD and LEPC nest site placement, but standard errors of the beta estimate overlapped zero. Once again, distance to lek was negatively associated with LEPC nest site placement (Table 3.8).

Nest Survival

I located 34 nests in the spring of 2015 on properties monitored for grazing management effects. I was limited to 2015 nests due to the tendency for the previous year's grazing data to affect a current year's nest survival, limited amount of grazing data collected in 2013, and lack of trapping of birds or monitoring of nests in 2016. Thus, 2014 grazing data and 2015 nest attempts were the only ones I could analyze in accordance to my objectives. Of the 34 nests, 28 were first attempts and 6 were renests. Overall apparent survival of nests on monitored rangeland in 2015 was 50%. Apparent survival was 33% and 54% for renests and initial nests, respectively.

Of the 21 *a priori* nest survival models tested, only one was deemed a competing model according to ΔAIC_c values (<2) The top model exhibited additive effects of day of the nesting season (Date), a quadratic function of day of the nesting season (Date^2), GP, and SD. Beta estimates and associated standard errors indicated a curvilinear relationship between daily survival rate and Date^2 ($\beta_{\text{Date}}{}^2$ = -0.205, SE = 0.098; Figure 3.9). Daily survival rate estimates indicated a drop in daily nest survival between days 40 (June 10th) and 70 (July 10th) of the nesting season (Figure 3.11). The top model also predicted a strong negative relationship between GP and daily survival rate ($\beta_{GP} = -2.179$, SE = 0.955; Figure 3.10). Although a positive relationship was indicated by the SD beta estimate ($\beta_{SD} = 3.584$, SE = 1.848), the 95% confidence intervals overlapped zero and the estimate was determined insignificant.

Adult Survival

A total of 14 mortality events were used to model the effect of grazing management components on hazard rates during the bird year from March 15, 2014 to March 14, 2015. A total of 39 bird years were used. The single top model within the set of models evaluated included a single variable of FU and carried 90% of the weight within the model set (Table 3.11). Regression coefficients associated with the top model indicate an increased risk associated with increased values of FU (coefficient = 6.36, SE = 2.162, $P = 0.003$; Figure 3.11). Because my research objectives required investigation of other grazing strategy components on adult survival, I also examined regression coefficients associated with GP, SD, pasture area, and deferment (Table 3.11). The second most competitive model included a single variable of GP and the only regression coefficient different from zero (Coefficient = 1.486, SE = 0.624, $P = 0.017$). Regression coefficients and predicted hazard rate curve indicated a positive relationship between risk and GP for female LEPC (Figure 3.12).

Vegetation Response

Means of visual obstruction (100% cm), vegetation height (cm), and mean CVs and STDVs of visual obstruction and vegetation height were calculated for four grazing management components (GP, FU, pasture area, deferment) across 33 sampling units (pastures) and across 26 sampling units for SD over two sampling periods (Year One [October 2013 – March 2014] and Year Two [October 2014 – March 2015]). Pastures subjected to relatively lower values of SD (<0.26 AU/ha) exhibited greater values of STDV ($t_{21.067} = 2.79$, $P = 0.011$) and CV ($t_{18.89} = 3.17$,

P = 0.005) of 100% cm visual obstruction than pastures subjected to relatively greater values of SD (> 0.26 AU/ha) (Figure 3.13).

Discussion

My study is the most in-depth investigation of the effect of grazing management on LEPC habitat use and fitness. These findings need to be preceded by characterization of site-specific characteristics associated with the areas I conducted this research (Chapters I, II). When ranches were evaluated and selected for this research in 2013, LEPC populations were under high duress due to prolonged drought during 2010 – 2013. The quality state of habitat and LEPC population numbers limited my work to ranches exhibiting responsibly managed rangelands that exhibited the “best available” habitat within the landscapes where I was conducting research. Thus, these results and implications may not be representative of lesser prairie-chicken responses to grazing practices on poor quality rangelands (e.g., overgrazed, poor plant community composition). My work confirmed the potential negative influence of mismanaged (i.e., grazing objectives that do not consider LEPC microhabitat quality) grazing on LEPC habitat use, nest survival, adult survival, and microhabitat, but also outlines potential management strategies could possibly mitigate negative influences of increasing grazing intensity. More specifically, my research indicates that: (1) in rangelands lacking sand sagebrush canopy cover, the negative effect of GP was perceived at lower grazing pressures (~1.0 AUM/ha) than in rangelands exhibiting sand sagebrush (~2.0 AUM/ha); (2) at relatively greater values of GP (>0.75 AUM/ha), LEPC probability of use increases with increasing pasture areas over 300 ha; (3) probability of use by LEPC is negatively influenced by increasing SD, especially at values ≥ ~0.3 AU/ha; (4) greater levels of deferment during the grazing season negatively impact LEPC use; (5) nest site placement of LEPC is constrained by the proximity of a lek (≤2 km) and negatively impacted by GP; (6) daily survival rates of LEPC nests decreased with increasing day of the nesting season and increasing GP; (7) hazard rates of LEPC adult females increased with greater values of FU, and GP and (8) and variation (CV and STDV; heterogeneity) of visual obstruction at the pasture scale decreased at SD values ≥0.26 AU/ha.

Little information describing LEPC responses to grazing management across the species distribution limits the extent of prescriptions available for managers. Currently, the Western Association of Fish and Wildlife Agencies (WAFWA) recommends FU values of ~33% to create habitat available for LEPC. NRCS currently recommends a "light" stocking rate that exhibits a forage efficiency (% of forage consumed by grazers) of 16.5% for nesting habitat and a "moderate" stocking rate exhibiting 20 – 25% forage efficiency for creating brooding habitat (Haukos et al. 2015). These recommendations are limited by supporting data and consideration of the environmental variation across regions.

The negative impacts of mismanaged grazing on LEPC populations are well accepted (Hagen et al. 2004, Elmore and Dahlgren 2016, Hagen and Elmore 2016). In general, as the grazing intensity increases (e.g., GP, FU), the negative impacts on microhabitat quality increase. Although nest site placement was negatively influenced by even light levels of GP, my investigation of the influence of GP and FU revealed habitat use by female LEPCs is not explained solely by the intensity of grazing within a pasture. Non-breeding female LEPC use was relatively constant until GP reached values ≥1.5 AUM/ha. The relationship between GP and LEPC use was likely due to the variation in precipitation and vegetation community across study areas and resulting resilience/vulnerability of associated microhabitats to grazing (Chapter I). Probability of nest site placement by female LEPCs was ≤20% at ≥1.0 AUM/ha. Probability of nest site placement decreased due to the tendency of females to place nests in areas of greater grass cover, litter cover, and visual obstruction (Riley 1978, Riley et al. 1992, Giesen 1994, Pitman et al. 2005, Davis 2009, Hagen et al. 2013, Grisham et al. 2014). Further, all microhabitat characteristics important for nesting LEPC are reduced as GP increases.

In contrast to non-breeding use by female LEPC, it appears that fitness and reproduction potential of LEPC populations may be sensitive to increases in GP or FU. As GP increased from 0 – 1.2 AUM/ha, I observed a reduction in daily nest survival of LEPC. Paired with hazard rates of adult LEPC associated with increasing values of FU and GP, it is apparent that LEPC fitness is affected at even low intensities of grazing on the landscape. Reductions in fitness are likely due to the reduction of visual obstruction and overhead cover by grazing. Considering this pattern and the requirement for various microhabitat needs of LEPC across ecological periods (Chapter II, Lautenbach 2014), it is obvious that heterogeneity of microhabitat and GP across landscapes is important. If heterogeneity of microhabitat is adequate, LEPCs will theoretically be able to select habitats that offer protection from predators and microclimate elements (e.g., temperature, humidity, light intensity and radiation) while allowing for areas adequate for foraging and movement by chicks. However, it is unclear if LEPCs are perceiving and subsequently selecting areas of greater heterogeneity of resources at specific scales or if LEPC are selecting specific microhabitat aspects (e.g., 100% VOR > 20 cm) present in areas of greater habitat variability. Along with microhabitat needs across ecological periods, heterogeneity across a pasture, ranch, or landscape would also aid in ensuring the presence of quality habitat as GP progresses beyond critical thresholds, or when weather and climate amplify the effects of GP during drought years or periods of extreme heat (Ross et al. 2016b). The presence of refugia habitat is important if one considers the predicted increase of extreme weather events (e.g., prolonged drought) in the future.

Presence of sand sagebrush across ecological sites has a profound impact on LEPC habitat use. Findings indicate use of ecological sites exhibiting sand sagebrush cover over ecological sites lacking sand sagebrush cover when GP values are ≥0.55 AUM/ha. Others have reported a similar response of shrub use by nesting LEPCs to increases in grazing (Haukos and Smith 1989). Most likely, this pattern is not an indication of improved habitat quality caused by GP in shrub dominated ecological sites. Rather, the higher probabilities of use associated with sand sagebrush cover as GP increases, speaks to the degradation of microhabitat (i.e., visual obstruction, grass cover, vegetation height) as grazing increases. Thus, to meet concealment needs, LEPCs are required to select plant communities where overhead cover is not susceptible to grazing. Sand sagebrush has the potential to provide overhead cover and other microhabitat needs as other habitats are degraded by increasing grazing pressure. The presence of sand sagebrush did not, however, explain variation in nest site placement, nest survival, or adult survival. Due to the high availability of habitat below the 0.55 AUM/ha threshold ($\bar{x}$ = 0.42 AUM/ha across all non-breeding locations), nesting LEPC were not required to select plant communities that offered greater overhead concealment potential. Similarly, due to low GP across all sites and little mortality, presence of sand sagebrush did not explain patterns in adult female hazard rates.

Pasture area, SD, and deferment all carry implications for LEPC habitat use. Individually, larger pastures positively impact habitat use by LEPCs, increases in SD negatively impact LEPC habitat use, and pastures exhibiting greater values of deferment have negative influence on habitat use by female LEPCs. The positive impact of larger pastures on use by female LEPC is likely explained by a relationship between environmental characteristics and scale (Wiens 1989). Until a threshold of heterogeneity is reached and all potential environmental variability is represented, an increase in pasture area will be correlated with an increase in heterogeneity of environmental characteristics such as soils, plant communities, GP, and microhabitat structure (Wiens 2000). Thus, as pasture area increases, so does the probability of a desired habitat or resource being present. By examining habitat use by female LEPCs at the pasture scale, I may have investigated the influence of environmental heterogeneity as well. Intensive grazing management has been proposed as a way to create this inherent heterogeneity at smaller scales in the form of patch-burn grazing or focused disturbance grazing (Fuhlendorf 2001). The tendency of continuous (grazing applied over a continuous grazing period during the growing season; Hart et al. 1988) grazing management strategies to create environmental heterogeneity is also recognized (Fuhlendorf 2001). Results indicate that non-breeding female LEPCs are keying in on an aspect of habitat structure present at larger pastures. Most likely, the increase in heterogeneity available at larger pasture sizes ensures the presence of desired habitats (microhabitat or plant community composition) by female LEPCs. Grazing management components (e.g., SD, deferment, water distribution, mineral and supplement placement) associated with larger pastures and continuous grazing also play a role in microhabitat heterogeneity and habitat use by female LEPCs (Fuhlendorf et al. 2001, 2006)

Pasture area, SD, and deferment were all correlated ($r \geq |0.40|$). Thus, at larger pasture sizes, SD and deferment values are lower. Correlated values are due to the tendencies of ranchers to rotate cattle through pastures while keeping animal units and forage consumption goals constant. In other words, as pasture area increases the number of ha available for each animal unit increases and the duration of grazing period also increases. Therefore, SD is likely the grazing management component that drives heterogeneity of microhabitat and creates and maintains the distinct habitat structure female LEPC used within each pasture (Fuhlendorf et al.

2006, 2009). My investigation of vegetation response (CV and STDEV of visual obstruction) to SD values above or below 0.26 AU/ha supports this hypothesis. Vegetation heterogeneity is most likely driven by the inherent variation of forage quality (plant species composition) across a pasture. Cattle perceive the variation in forage quality across a pasture regardless of SD, but when SD is low and pasture area is large, competition for high quality forage is reduced and the grazing distribution across a pasture is variable (Barnes et al. 2008). Moreover, the intensity of grazing is high in areas of high forage quality, but reduced in areas of lower forage quality. In contrast, at high levels of SD, competition for high quality forage increases and cattle are forced to graze in lower quality areas (Barnes et al 2008). Competition for available forage leads to greater uniformity of grazing pressure and habitat structure across a pasture (Fuhlendorf 2001). Considering these principles, it appears that when SD is low, the influence of greater environmental heterogeneity achieved at larger pastures is compounded by the variation in grazing across the same pasture. Decreasing levels of deferment is also a result of decreasing SD (i.e., less cattle need more time to reach the same forage consumption goal for larger pastures) and is not likely the driving variable of increased use by female LEPCs, but instead a linked management tendency of ranchers employing a rotational grazing system.

I suspect that the tendency for female LEPC to select larger pasture sizes, lower SDs, and longer grazing periods (decreasing deferment) is a product of a two-fold relationship between grazing management components and microhabitat. Initially, female LEPCs selected pastures that exhibit heterogeneity (i.e., soils, plant communities, grazing distribution) that is present inherently in larger areas. Selection of larger areas is driven by the variable needs of LEPCs as they move through ecological periods (i.e., nesting, brooding, non-breeding) and the need for these habitat characteristics to be in close proximity to one another. Second, when GP objectives are targeted for LEPC (<1.5 AUM/ha), grazing management components correlated with larger pasture sizes compound the inherent landscape heterogeneity by allowing for a patchy, less uniform grazing distribution. The two fold influence on microhabitat is beneficial because LEPCs require a variation of habitats to meet predator avoidance goals, diet needs (D. Sullins, unpublished data), and acquisition of resources such as water, and shelter from inclement weather (Grisham et al. 2016). In light of observed patterns trends, it appears that high quality LEPC habitat and livestock presence on the landscape is plausible. In fact, LEPC and grasslands likely depend on grazing disturbance as a member of ecosystem function (Chapter II). However, it appears that if GP and FU are not managed responsibly, fitness (adult and nest survival) and habitat quality will decrease as the refugia aspect of rangelands disappears. Although nest survival was decreased by increasing grazing pressure, working landscapes can still be conducive for high levels of nest success by creating a gradient of grazing pressure and habitat heterogeneity at multiple scales. More specifically, if a significant proportion of the grazing pressure values are targeted below 0.5 AUM/ha, then the range of extrapolated (26 day exposure period) nest success would be 86% (0 AUM/ha) to 65% (0.5 AUM/ha). Nest success rates in this range are above average and would representative of a stable or growing population (Hagen et al. 2013).

The management of working rangelands within the distribution of LEPC has implications for other wildlife species as well. Often cited as an umbrella, indicator, or surrogate species, incorporating LEPCs as a focus of grazing management in the southern Great Plains would provide positive effects for a host of other obligate grassland bird species (Svedarsky 2000, Poiani et al 2001, Hagen and Giesen 2005, Sandercock et al. 2011). More specifically, grazing management implemented and designed with my findings in consideration would provide not only habitats that are conducive for species that require similar habitat needs, but also for grassland birds that specific habitat needs are not met by contemporary grazing systems (e.g., high intensity, rotational systems). Grazing management focused in this fashion will return the role of “manager” to natural ecosystem functions instead planned and focused grazing prescriptions.

Objectives for grazing management in the southern Great Plains should not be limited to wildlife populations. As a significant economic component in most rural communities within the LEPC distribution, the viability of grazing operations in terms of cattle performance, profitability of ranching operations and grassland ecosystem health should also be considered. Managing rangelands in the way described above would push grazing components towards a continuous, large pasture, full-season grazing system and away from rotational or short duration, high-rest systems with smaller pastures that have been predominately prescribed in the past (Merrill 1954, Savory 1978, 1983, 1988; Savory and Parsons 1980). There has been much debate on benefits and disadvantages associated with historic and contemporary grazing systems, but there does not appear to be substantial evidence suggesting the superiority of either system to the other in terms of plant or animal production (Briske et al. 2008).

The future conservation of LEPCs across the occupied distribution needs to include the implications of mismanaged grazing. This is evident in light of predicted weather and climactic changes and the overwhelming amount of private working lands within the LEPC species distribution. With adequate management, grazing has the potential to affect large landscapes during short time periods and contribute to the resiliency of LEPC populations. However, the effect of grazing management across environmental variability needs to be considered, and explicitly researched to make efficient grazing prescriptions into the future.

Management Implications

It is likely that a blanket grazing management prescription focused on LEPC fitness and habitat suitability is not possible. Variation in environmental characteristics and varying interpretation across managers and regions would limit the viability of such prescription. However, my findings speak to general trends associated with grazing management components and may be useful in designing and implementing grazing plans for specific pastures or ranches in western Kansas.

First and foremost, initial efforts targeting the alteration of grazing management within areas occupied by LEPC should be focused in areas or ranches containing active lek sites. Targeting occupied areas may improve fitness and reproduction of female LEPCs and subsequently facilitate greater dispersal rates into unoccupied rangelands. Furthermore, LEPC occupancy may indicate relative rangeland health or potential resiliency to grazing.

In consideration of the shifting precipitation values and plant community composition across the LEPC occupied range in Kansas, I propose that GP and FU objectives for LEPC management be reflective of forage production potential calculated on a pasture by pasture basis. The mean forage availability across pastures in my study was 1512 kg/ha (SD = 383.64). Based on a forage consumption rate of 11.93 kg/day (26.3 lbs/day) and an animal unit equivalent of 1.0, I recommend a GP of 0.75 AUM/ha for pastures exhibiting forage availability close to 1500 kg/ha (~1340 lbs/acre) for non-breeding use. 0.75 AUM/ha applied in areas exhibiting 1500 (kg/ha) of forage production is equivalent to ~26% forage efficiency (percentage of forage availability consumed by livestock) rate and a ~52% FU rate. Recommendations for FU rates across other forage availability values are presented in Table 3.12. Recommendations for management of rangelands to be conducive for nesting LEPC are also present (Table 3.12). However, I do not recommend forage utilization values to exceed 50% utilization.

Pastures within LEPC occupied rangeland should be created or maintained to be as large as infrastructure and resources allow so that environmental heterogeneity is maximized and low stocking densities are plausible even when herd sizes are large. I recommend targets for pasture area should be ≥300 ha (~740 acres). SD values should be set as low as possible, and should not exceed 0.3 AU/ha. As we did not investigate the interaction between pasture area and SD, or the influence on female LEPC use, I cannot speak to effective SD values as pasture size changes. I suspect habitat quality would be improved if SD values held as low as possible at all pasture sizes. When pasture area values meet recommendations, objectives related to SD and FU should dictate the duration of grazing events. I cannot speak to the relative effect of grazing periods longer than 120 days on LEPC habitat use or microhabitat characteristics.

Additional construction of permanent fences within rangelands occupied by LEPC is not recommended. In addition to possible microhabitat degradation in smaller pastures, adult hazard rates increase as the distance to a fence decreases (Robinson 2015) and fence collision potential may increase (Robinson et al. 2016, Wolfe et al. 2007). However, when large pastures and low stocking densities are not plausible, temporary fencing (two-wire electric fence) may be warranted to create undisturbed habitat or reduced grazing pressure in close proximity to leks to increase habitat quality for nesting. Furthermore, placement of supplements and water can be used to focus or limit grazing in areas exhibiting microhabitat resilience or sensitivity.

In regard to distribution of grazing pressures at the ranch scale, I recommend using the ranches monitored in my research as a template for managment. For instance, 54% of the rangeland area that we monitored was subjected to grazing pressure within the range of 0-0.5 AUM/ha, 30% exhibited grazing pressure values between 0.51 and 1.0 AUM/ha, and 16% was subjected to grazing pressure values greater than 1.0 AUM/ha. If ranches are managed at proportions approximate to observed proportions in this study, we can provide reasonable nest success (86-65%; extrapolated from daily nest survival rates) in areas grazed below 0.5 AUM/ha and the potential for high quality brood habitat in areas grazed >0.5 AUM/ha. Considering the habitat quality and LEPC presence on the ranches I monitored, managing ranching landscapes at the proportions described above has the potential to boast the success and sustainability of LEPC populations in Kansas.

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Figure 3.1 Proportions of available and used locations used to estimate non-breeding Resource Selection Functions for lesser prairie-chickens across monitored rangelands in western Kansas, USA. Figures illustrate the proportional changes in habitat use across pasture sizes (B), deferment during the growing season, (C), stocking density (number of animals per unit area, (D), and ecological sites categorized by the presence (>1% canopy cover at the 8-m scale) of sand sagebrush (D).

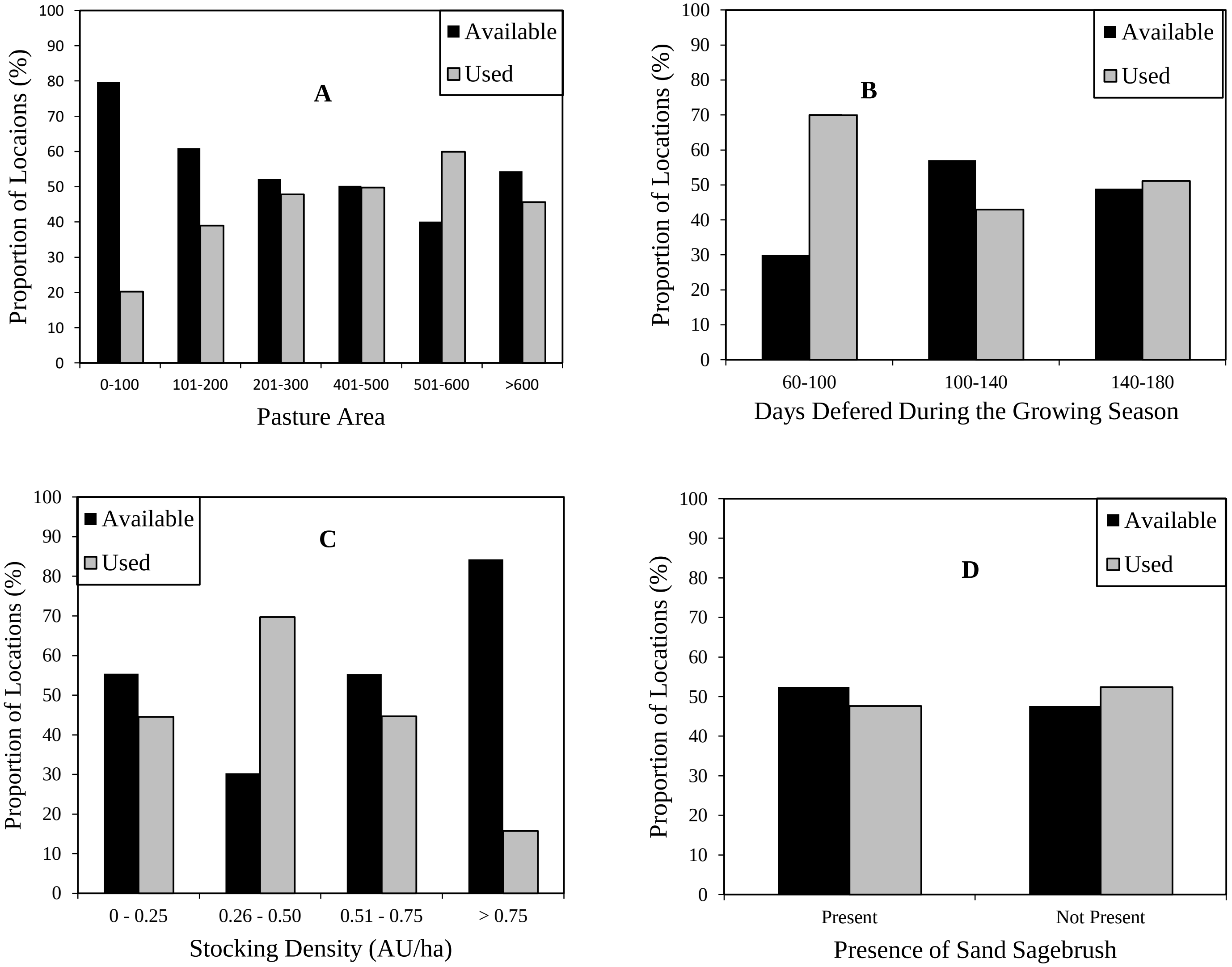

Figure 3.2 Predicted probability of use by non-breeding female lesser prairie-chickens in relation to grazing pressure (AUM/ha) observed within monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

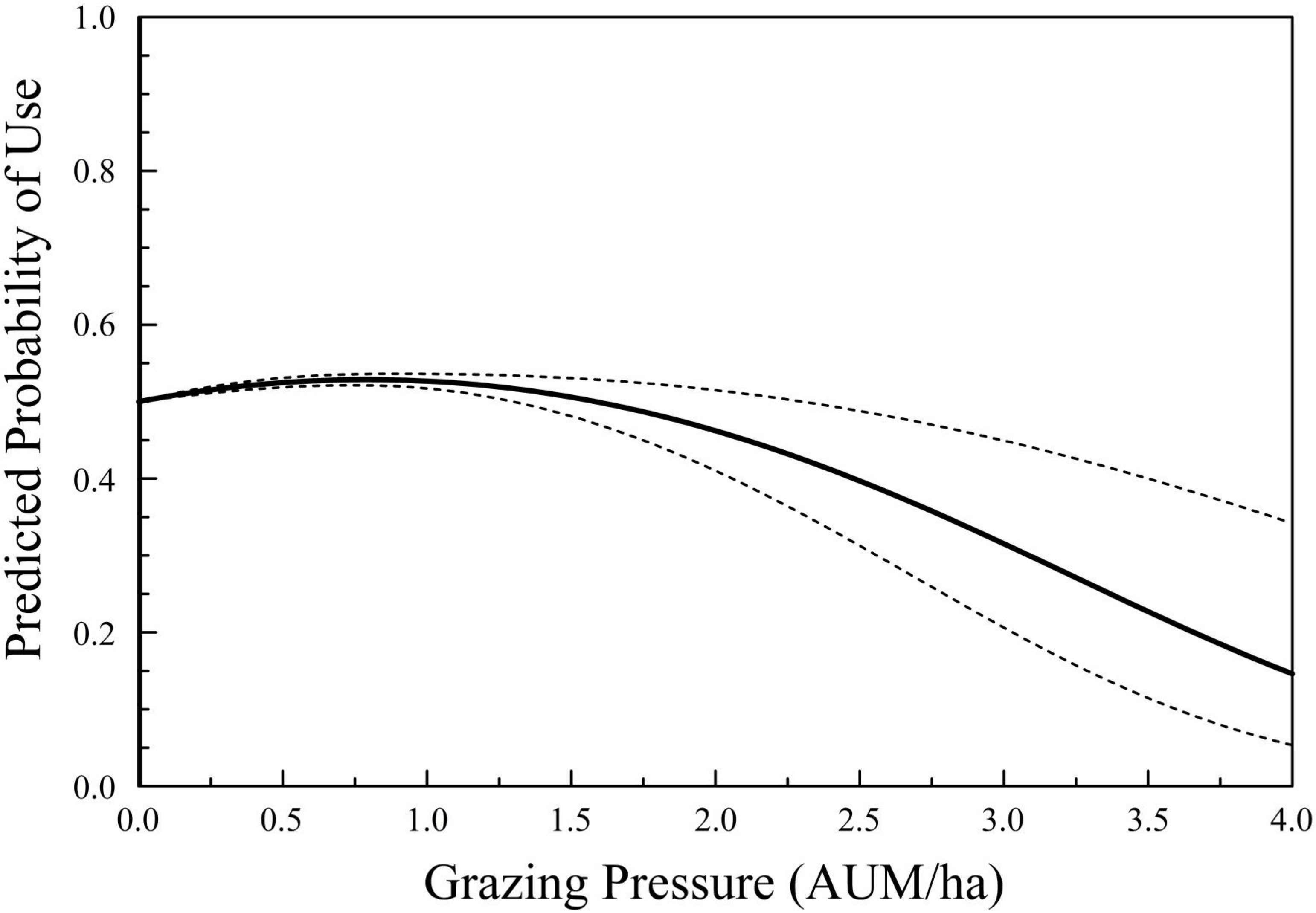

Figure 3.3 Predicted probability of use of non-breeding female lesser prairie-chickens in relation to grazing pressure (AUM/ha) and ecological sites with the presence (>1% mean shrub cover within an ecological site) or absence of sand sagebrush in monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals

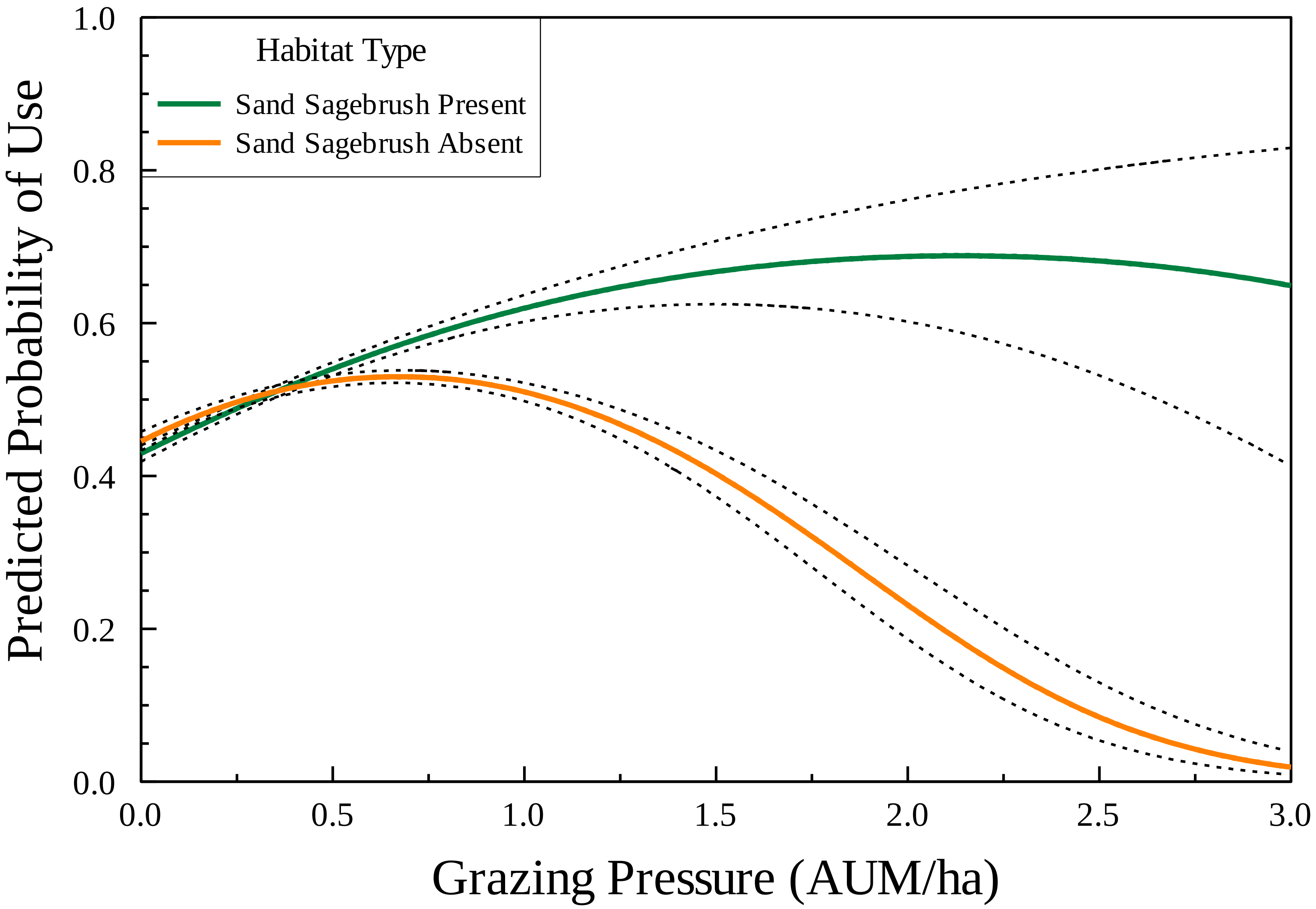

Figure 3.4 Predicted probability of use by non-breeding female lesser prairie-chickens in relation to pasture area (ha) and three different levels of grazing pressure (0.08 AUM/ha, 0.42AUM/ha, and 0.75 AUM/ha) in monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

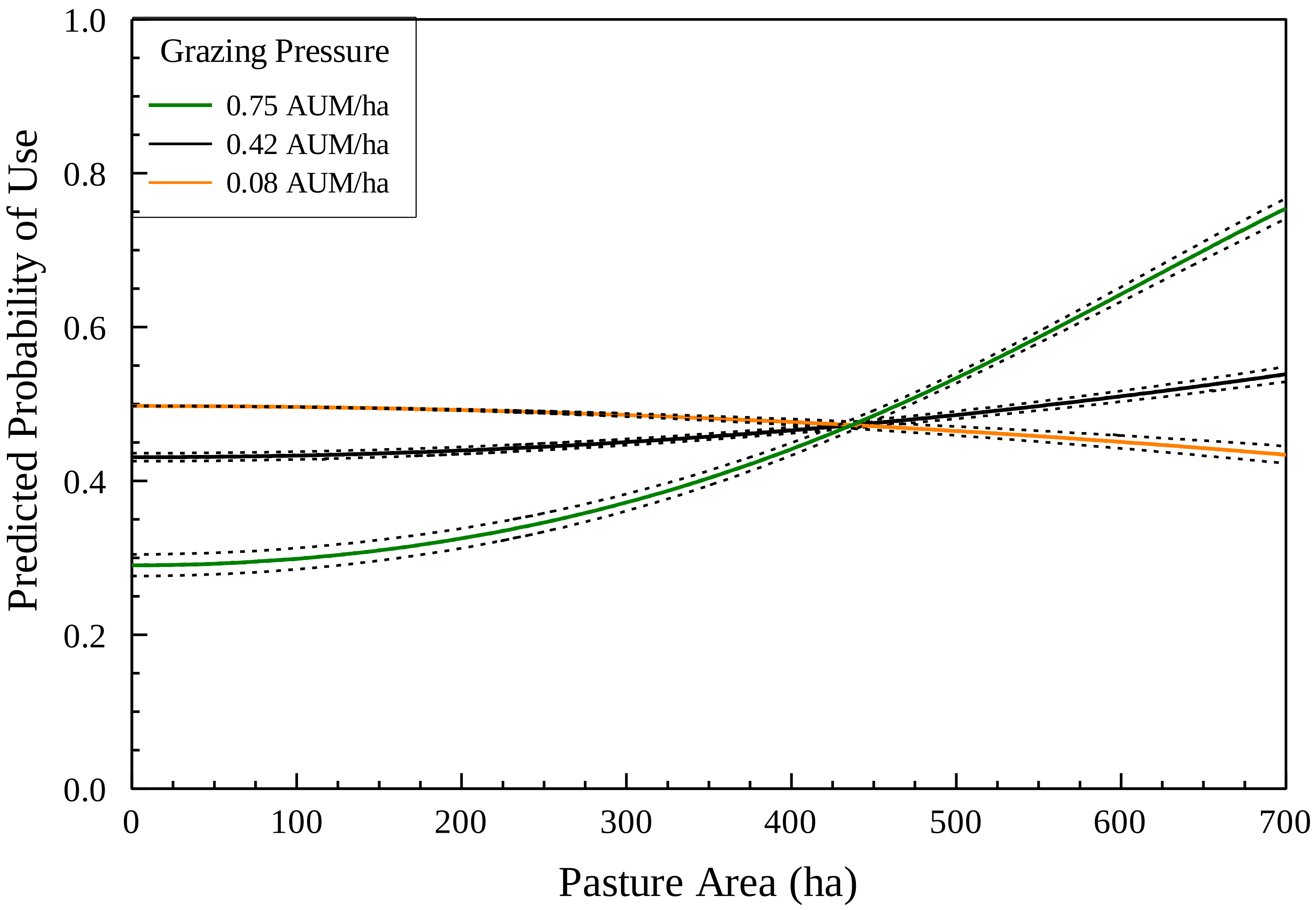

Figure 3.5 Predicted probability of use by non-breeding female lesser prairie-chicken in relation to deferment (number of days deferred during the growing season) and three different levels of grazing pressure (0.08 AUM/ha, 0.42AUM/ha, and 0.75 AUM/ha) in monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

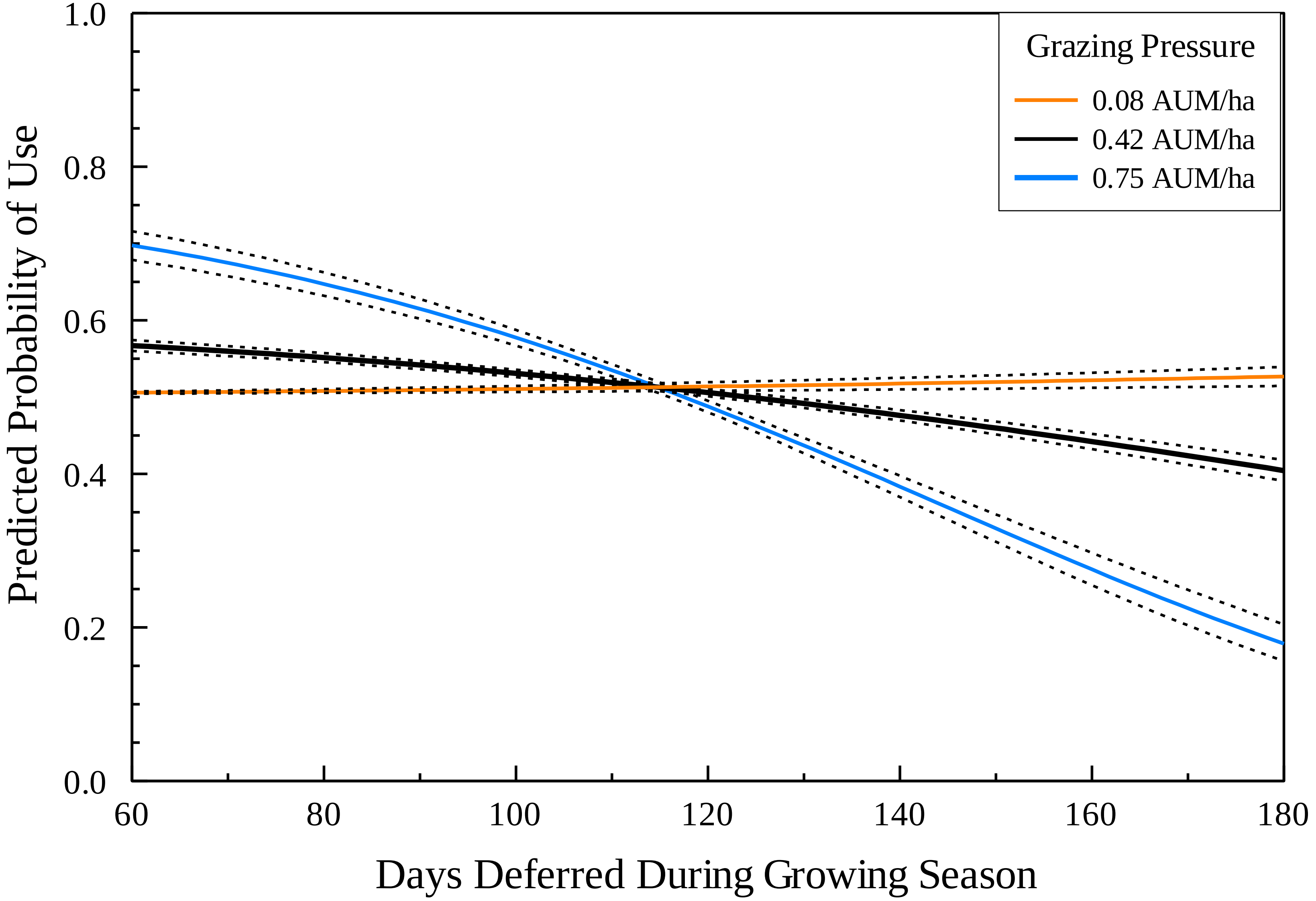

Figure 3.6 Predicted probability of use by non-breeding female lesser prairie-chickens in relation to stocking density (AU/ha) and three different levels of grazing pressure (0.08 AUM/ha, 0.42AUM/ha, and 0.75 AUM/ha) in monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

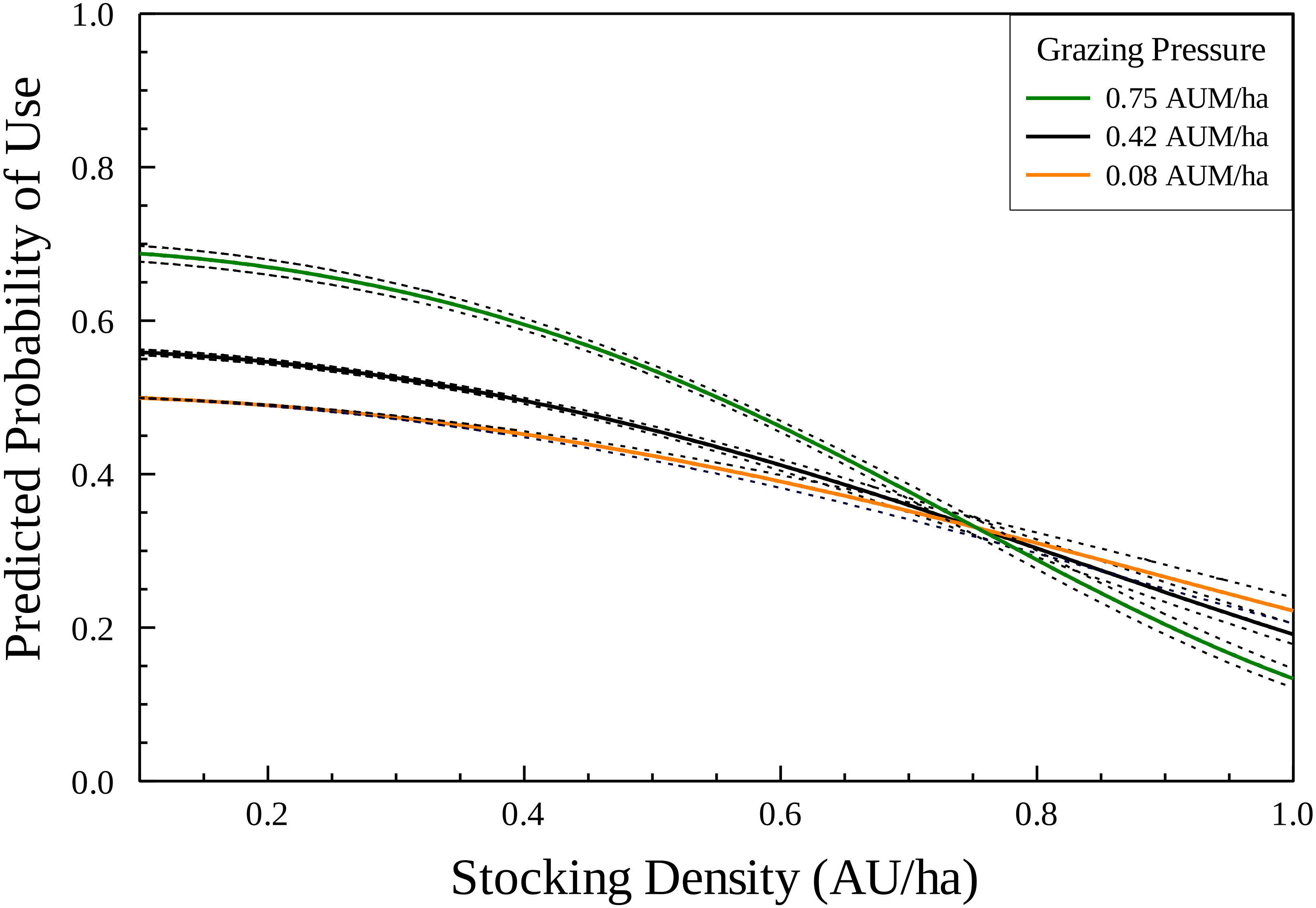

Figure 3.7 Predicted probability of nest site placement by female lesser prairie-chickens in relation to the distance (m) from a known lek in monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

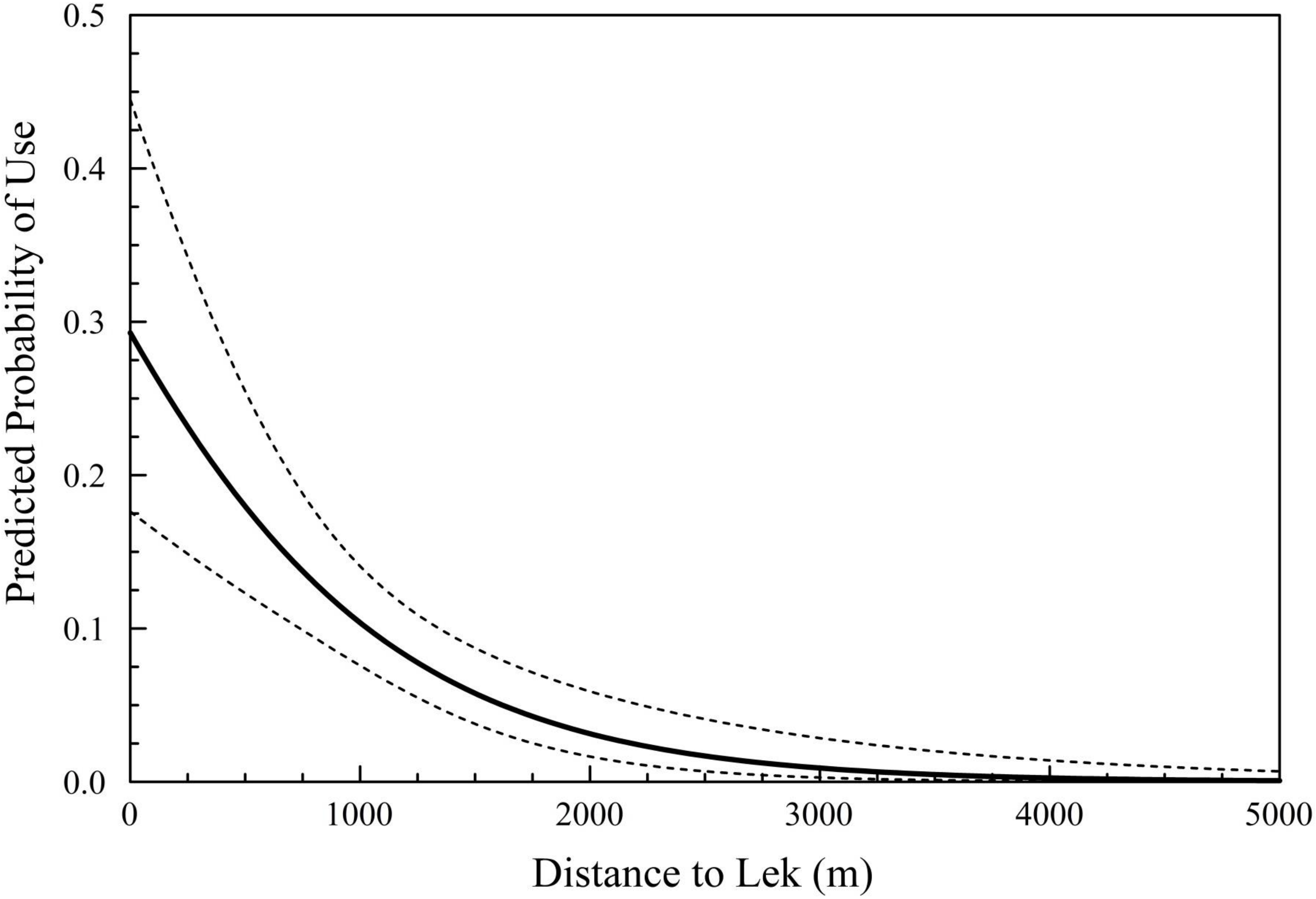

Figure 3.8 Predicted probability of nest site placement by female lesser prairie-chicken in relation to grazing pressure (AUM/ha) in monitored rangelands from 2013-2015 in western Kansas, USA. Shown with 95% confidence intervals.

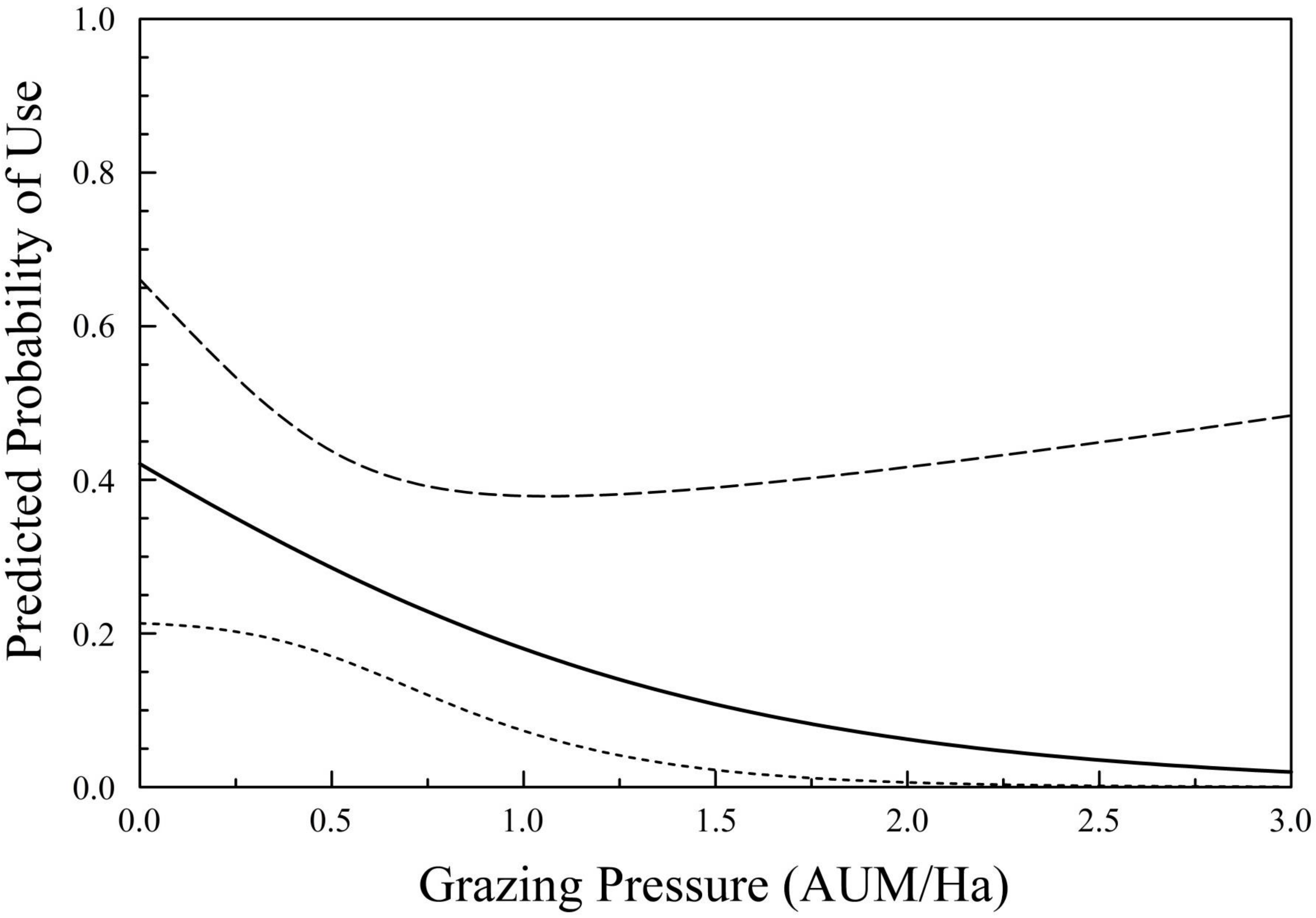

Figure 3.9 Daily nest survival rates of lesser prairie-chickens through time during the nesting period in monitored rangelands of western Kansas, USA, during 2015. Shown with 95% confidence intervals

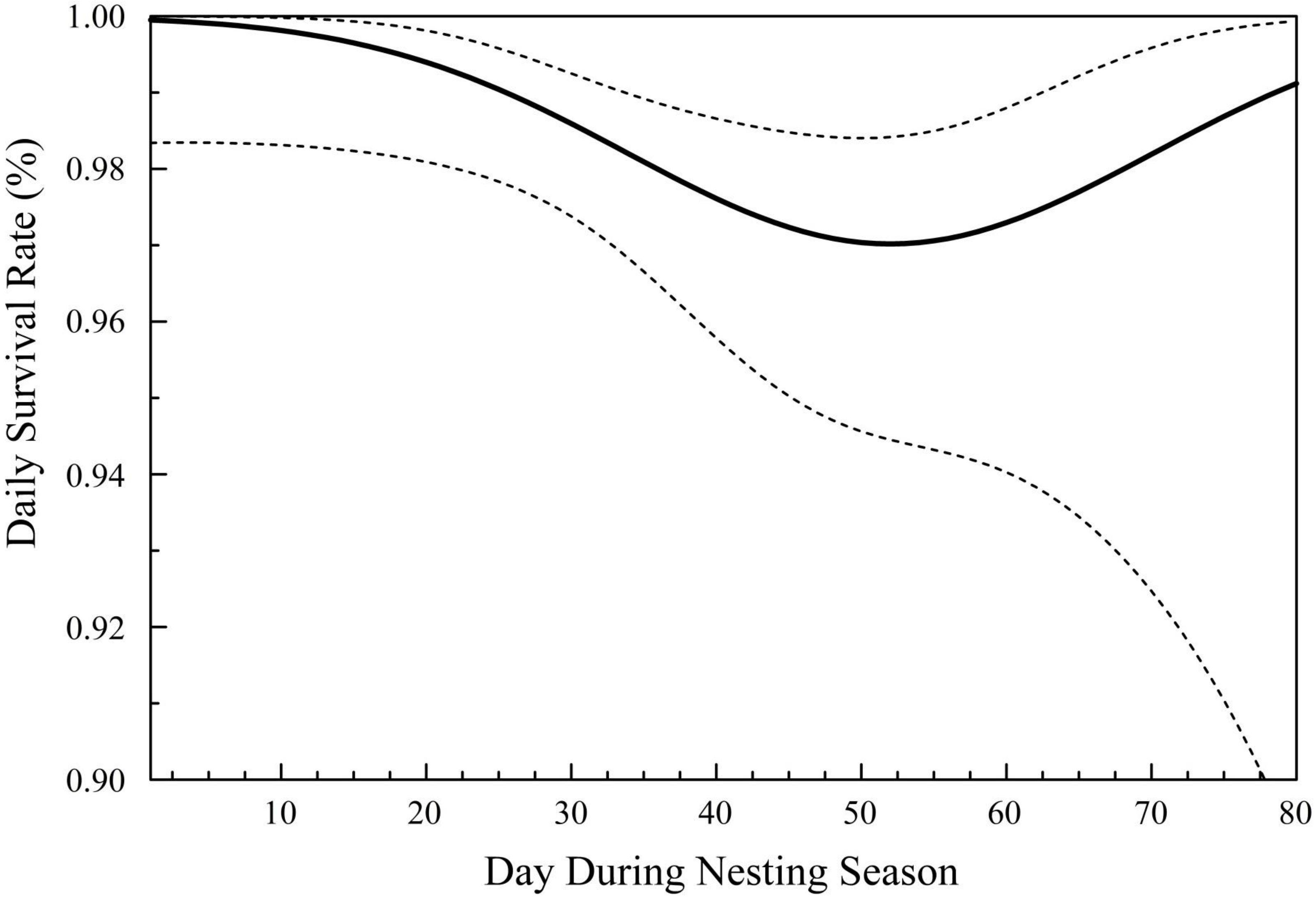

Figure 3.10 Daily nest survival rate of lesser prairie-chickens in relation to grazing pressure (AUM/ha) in monitored rangelands of western Kansas, USA, during 2015. Shown with 95% confidence intervals

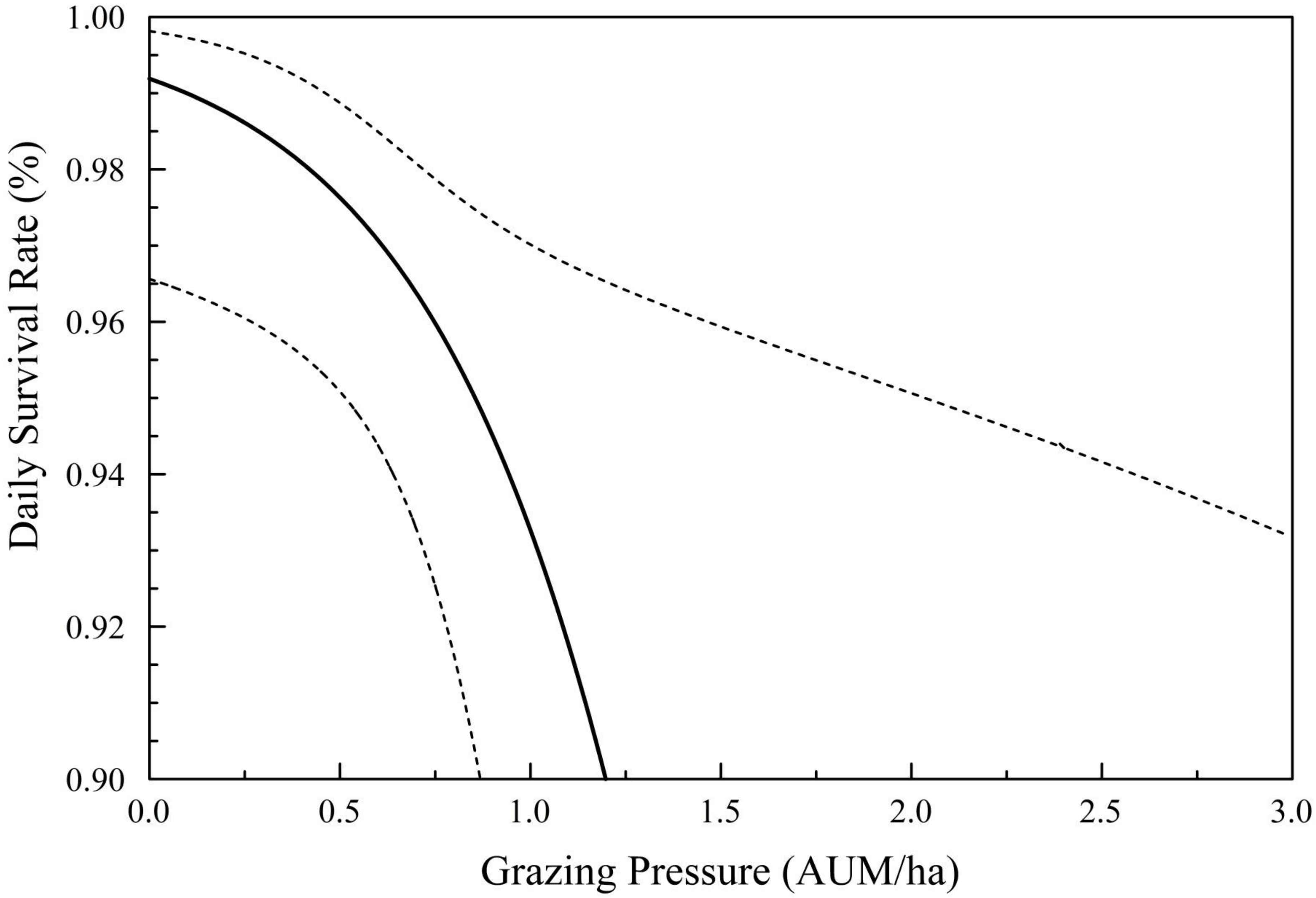

Figure 3.11 Predicted daily hazard rate curve for female lesser prairie-chickens in relation to forage utilization estimates (% forage removed) from Anderson-Gill models for continuous covariates in rangelands during 2014-2015 in western Kansas, USA. Shown with ± SE.

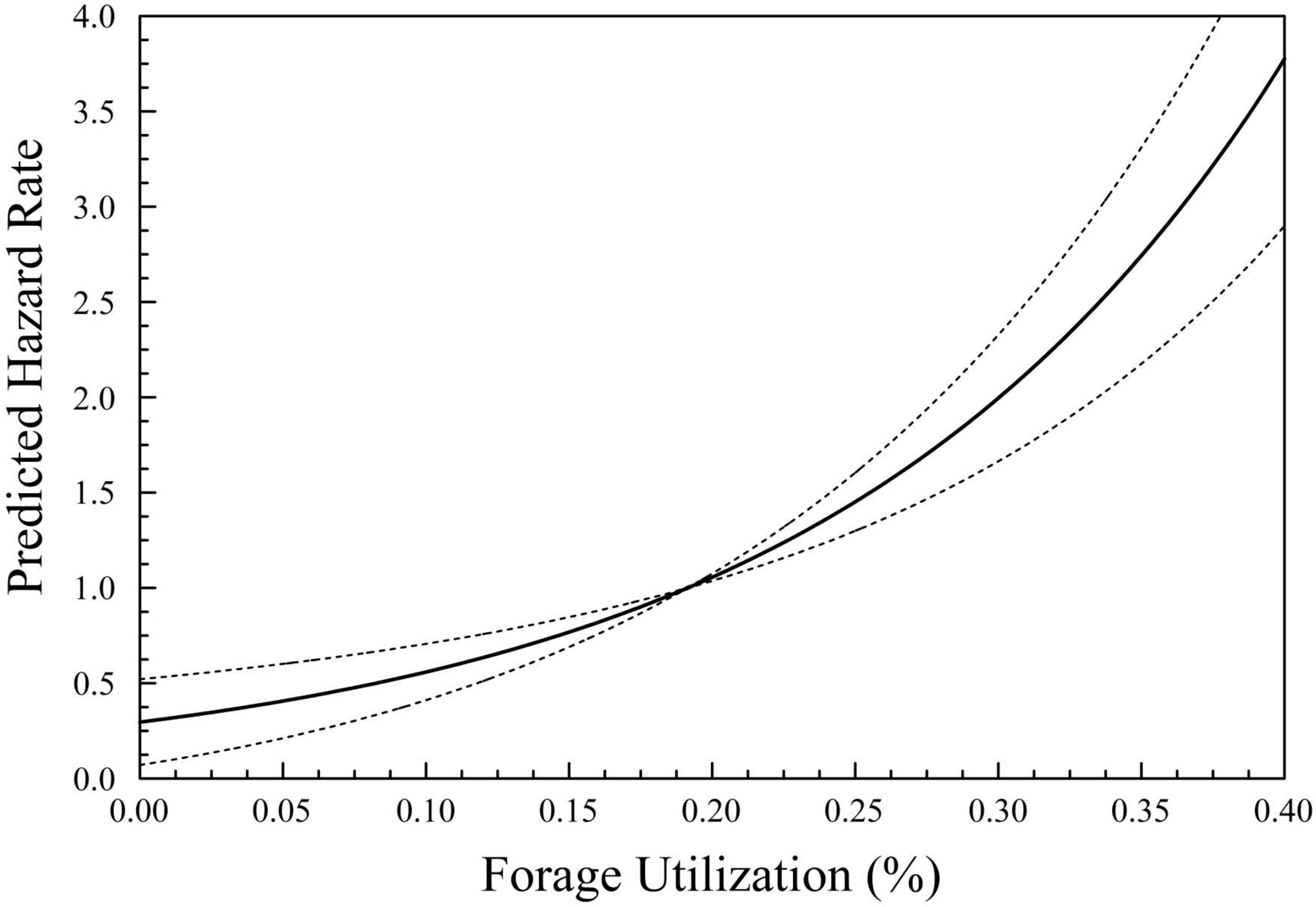

Figure 3.12 Predicted daily hazard rate curve for female lesser prairie-chickens in relation to grazing pressure (AUM/ha) from Anderson-Gill models for continuous covariates in rangelands during 2014-2015 in western Kansas, USA. Shown with ± SE.

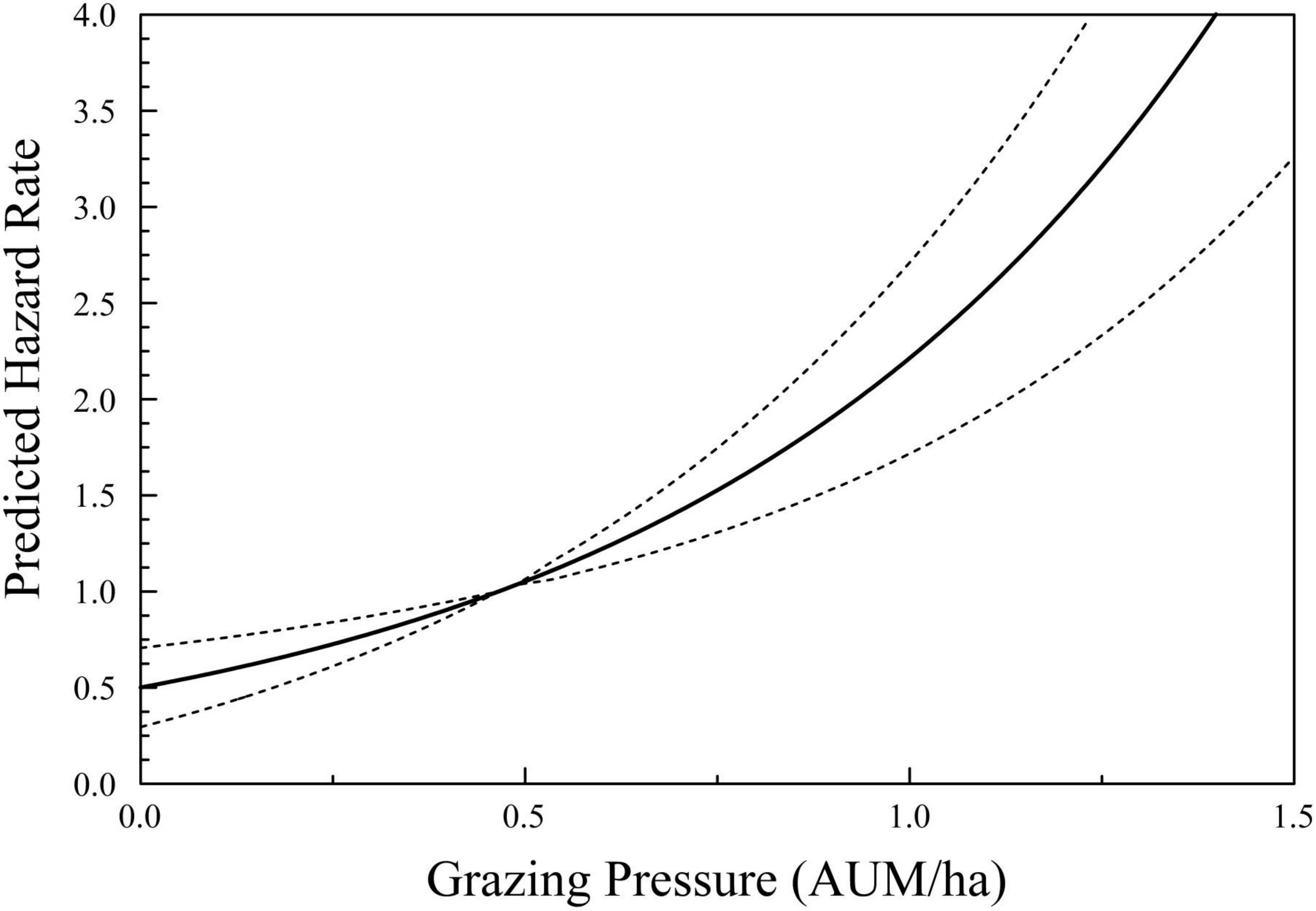

Figure 3.13 Mean estimates and standard errors of (A) CV (coefficient of variation) of 100% Visual Obstruction (cm) and (B) STDV (standard deviation) of 100% visual obstruction (cm) associated with two categories of stocking density (≤0.26 and >0.26 AUM/ha) applied to pastures in western Kansas, USA. (*) denotes significant difference between means as determined by a two-sample t-test

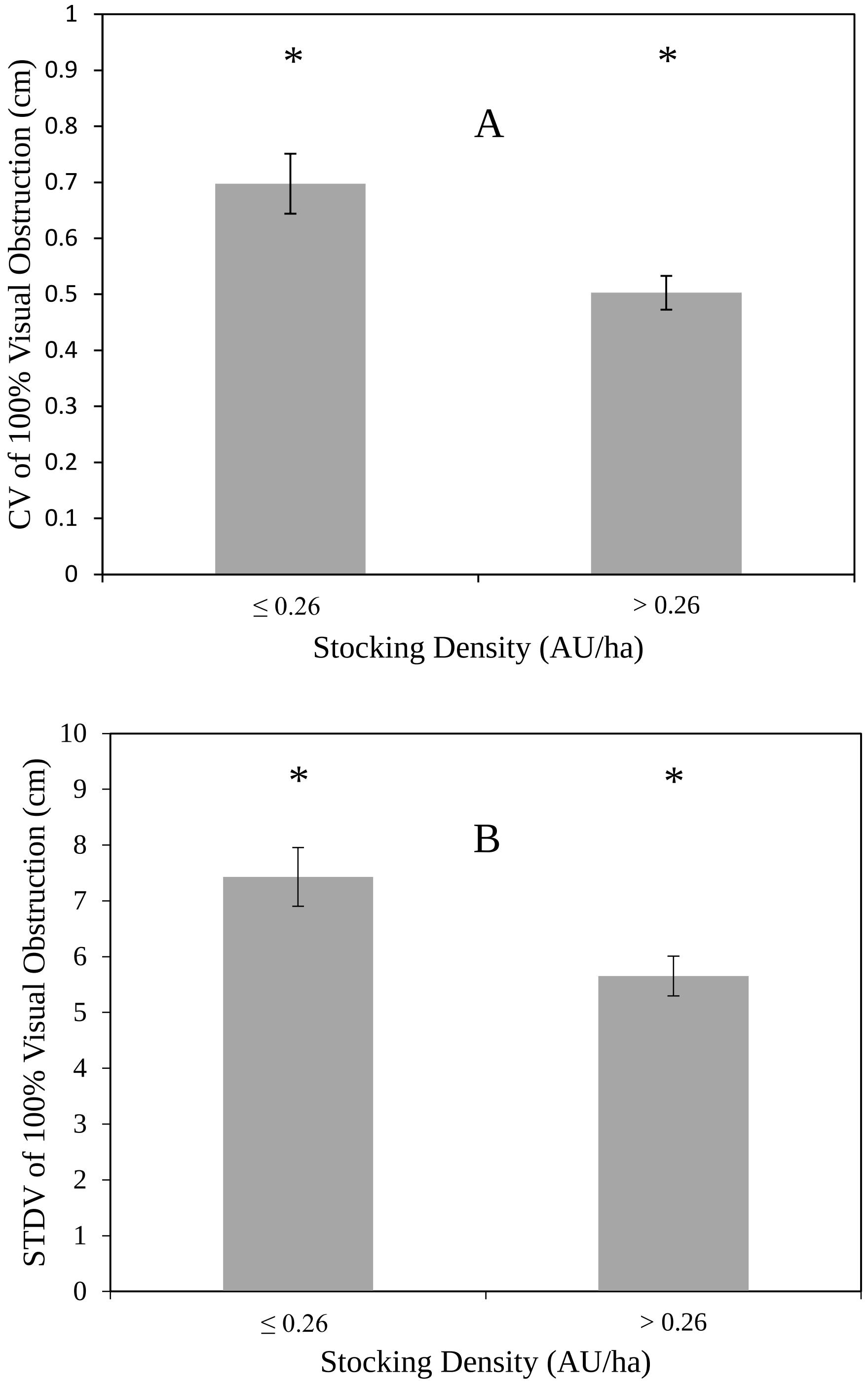

Table 3.1 Resource selection functions of female lesser prairie-chicken non-breeding habitat use in relation to a quadratic function of grazing pressure (AUM/ha; GP) and estimated forage utilization (AUM/ha; FU) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
GP + GP^2	56202.23	2	0	1
GP	56218.86	1	14.63	<0.001
FU + FU^2	56235.93	2	33.7	<0.001
FU	56243.14	1	38.91	<0.001
Null	56485.95	1	281.72	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 56206.23 for best fit model

Table 3.2 Resource selection function beta estimates, standard errors, *z* values, and probabilities for top models across five model sets investigating non-breeding habitat selection and three model sets investigating nest site selection of LEPC females in rangelands monitored in western Kansas, USA. Model sets investigate the influence of grazing pressure (AUM/ha; GP), forage utilization (% forage removed; FU), quadratic functions of GP (GP2) and FU (FU2), presence of sand sagebrush (>1% shrub canopy cover at the 8-m scale), pasture area (ha; Area), deferment (# of days deferred during the grazing season; Defer), stocking density (AU/ha; SD), and distance to lek (m; Dist. to Lek).

Type of Selection	Model Set	Coefficient	Estimate	Standard Error	z value	Pr > |*z*|
Non-Breeding Habitat Selection	Grazing Pressure and Forage Utilization	GP	0.28971	0.04352	6.656	<0.001
		GP^2	-0.18276	0.04492	-4.068	<0.001
	Presence of Sand Sagebrush	GP	1.00766	0.07848	12.84	<0.001
		GP^2	-0.74946	0.06278	-11.939	<0.001
		Sage (present)	-0.21848	0.02554	-8.556	<0.001
		Sage (absent)	-0.28394	0.02238	-12.69	<0.001
		GP^2 : Sage (present)	0.51341	0.05296	9.694	<0.001
	Pasture Area	GP	1.13000	0.09010	12.54	<0.001
		GP^2	-4.39400	0.16610	-26.45	<0.001
		Area	-0.00064	0.00005	-14.14	<0.001
		GP2 : Area	0.00797	0.00025	31.37	<0.001
	Deferment	GP	0.66672	0.09013	7.397	<0.001
		GP^2	3.58694	0.23224	15.445	<0.001
		Defer	-0.07737	0.0312	-2.48	0.0131
		GP2 : Defer	-6.43176	0.35054	-18.348	<0.001
	Stocking Density	GP	1.30496	0.10961	11.9	<0.001
		GP^2	0.64378	0.15936	4.04	<0.001
		SD	-1.15067	0.06505	-17.69	<0.001
		GP2 : SD	-2.02089	0.17634	-11.46	<0.001
Nest Site Selection	Grazing Pressure	Dist. to Lek	-0.00188	0.00021	-8.853	<0.001
		GP	-1.5699	0.54542	-2.878	0.004
		Dist. to Lek : GP	0.00093	0.00035	2.633	0.00845
	Presence of Sand Sagebrush	Dist. to Lek	-0.00113	0.00029	-3.888	<0.001
		Sage	-14.2000	1028.0	-0.014	0.989
		Sage (absent)	-0.86190	0.33520	-2.571	0.010
		Sage (present)	-1.34300	0.45330	-2.962	0.003
	Grazing Management Components	SD	-1.05979	0.72606	-1.46000	0.144
		Dist. to Lek	-0.00181	0.00017	-10.49200	<0.001
		SD : Dist. to Lek	0.00055	0.00039	1.40700	0.16

Table 3.3 Resource selection functions of female lesser prairie-chicken non-breeding habitat use in relation to a quadratic function of grazing pressure (AUM/ha; GP) and presence of sand sagebrush (presence = >1% canopy cover at 8-m scale; Sage) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AIC).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
GP + GP^2 x Sage	55939.72	5	0	1
GP + GP^2 + Sage	56037.41	4	95.69	<0.001
GP + GP^2	56202.23	2	256.51	<0.001
Null	56485.95	1	538.23	<0.001
Sage	56485.95	2	540.23	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 55949.72 for best fit model

Table 3.4 Resource selection functions of female lesser prairie-chicken non-breeding habitat use in relation to a quadratic function of grazing pressure (AUM/ha; GP) and pasture area (ha; Area) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
GP + GP^2 x Area	54949.06	4	0	1
GP + GP^2 + Area	56229.16	3	1278.1	<0.001
GP + GP^2	56246.68	2	1293.62	<0.001
Area	56452.21	1	1499.15	<0.001
Null	56485.95	1	1532.89	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 55080.74 for best fit model

Table 3.5 Resource selection functions of female lesser prairie-chicken non-breeding habitat use in relation to quadratic functions of grazing pressure (AUM/ha; GP) and deferment (number of days deferred during April to October; Defer) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
GP + GP^2 x Defer	25100.94	4	0	1
GP + GP^2 + Defer	25475.40	3	372.46	<0.001
Defer	25534.28	2	429.33	<0.001
GP + GP^2	56202.22	2	31097.28	<0.001
Null	56485.96	1	31379.00	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 25159.20 for best fit model

Table 3.6 Resource selection functions of female lesser prairie-chicken non-breeding habitat use in relation to quadratic functions of grazing pressure (AUM/Ha; GP) and stocking density (AU/ha; SD) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
GP + GP^2 x SD	44917.40	4	0	1
GP + GP^2 + SD	45069.54	3	150.13	<0.001
SD	46176.08	1	1252.67	<0.001
GP + GP^2	56202.22	2	11280.82	<0.001
Null	56485.96	1	11562.54	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 44325.17 for best fit model

Table 3.7 Resource selection functions of female lesser prairie-chicken nest site placement in relation to grazing pressure (AUM/Ha; GP) and distance to a known lek (meters) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
Dist. to Lek x GP	44319.16	3	0	0.78
Dist. to Lek + GP	45044.96	2	2.66	0.21
Dist. to Lek	45625.05	1	7.84	0.02
Null	56246.68	1	28.47	<0.001
GP	56485.95	1	164.53	<0.001

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 214.29 for best fit model

Table 3.8 Resource selection functions of lesser prairie-chicken nest site placement in relation to functions of grazing pressure (AUM/ha; GP), presence of sand sagebrush (presence = >1% canopy cover at 8-m scale; Sage) and distance to a known lek (meters; Dist. to Lek) on monitored rangeland sites in western Kansas, USA, during 2013-2015. Models ranked using Akaike Information Criterion corrected for small sample size (AICc).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
Dist. to Lek + Sage	236.70	4	0	0.51
Dist. to Lek x Sage	232.93	6	0.31	0.43
Dist. to Lek	247.12	1	4.35	0.06
Sage	258.55	3	19.82	0
GP + Sage	257.03	4	20.33	0
GP x Sage	256.26	6	23.64	0
Null	267.76	1	24.99	0

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] Minimum AIC_c= 244.78 for best fit model

Table 3.9 Model ranking of lesser prairie-chicken nest survival estimation for nests in rangelands monitored in western Kansas, USA. Nest survival models were evaluated in Program MARK. A priori models included variable combinations of date during the nesting season (Date), a quadratic function of Date (Date^2), grazing pressure (AUM/ha; GP), stocking density (AU/ha; SD), pasture area (ha; Area), forage utilization (% forage removed; FU), deferment (# of days deferred during the grazing season; Defer) and a constant model

Model	Dev.[a]	K[b]	ΔAICc	w_i[d]
Date + Date^2 + GP + SD	161.76	5	0.00	0.35
Date + Date^2	168.19	3	2.39	0.11
Date + Date^2 + GP	166.45	4	2.67	0.09
Date + Date^2 + SD	167.03	4	3.25	0.07
Date + Date^2 + Area	167.49	4	3.71	0.06
Date + Date^2 + GP +Area	165.68	5	3.91	0.05
Date + Date^2 + FU	168.13	4	4.35	0.04
Date + Date^2 + GP + Defer	168.14	4	4.36	0.04
Date + Date^2 + SD+ Defer	166.44	5	4.68	0.03
Date + Date^2 + FU + SD	166.73	5	4.97	0.03
Constant	175.07	1	5.26	0.03
Date + Date^2 + FU + Area	167.31	5	5.54	0.02
GP	173.75	2	5.94	0.02
Area	174.04	2	6.23	0.02
Date + Date^2 + FU + Defer	168.11	5	6.35	0.01
SD	174.92	2	7.11	0.01
Defer	175.00	2	7.19	0.01
FU	175.07	2	7.26	0.01
GP + Defer	1504.13	3	1338.33	0.00
GP + SD	1504.13	3	1338.33	0.00
GP + Area	1504.13	3	1338.33	0.00

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] AIC_c= 171.82 for best fit model

Table 3.10 Model ranking for Anderson-Gill models, based on Akaike Information Criterion corrected for small sample size (AICc) for six models determining the effects of grazing strategies on annual survival of female lesser prairie-chickens within rangelands monitored in western Kansas, USA. A priori models included single variable models of forage utilization (% forage removed), grazing pressure (AUM/ha), distance to fence (m), stocking density (AU/ha), and pasture area (ha).

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i^d
Forage Utilization	62.76	1	0.00	0.90
Grazing Pressure	67.86	1	5.11	0.07
Null	73.38	0	8.62	0.01
Distance to Fence	72.4	1	9.64	0.01
Stocking Density	72.46	1	9.70	0.01
Pasture Area	73.36	1	10.62	0.00

[a] Deviance

[b] Number of Parameters

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

[d] Akaike weights

[e] AIC_c= 64.75 for best fit model

Table 3.11 Forage utilization (total amount of forage removed from consumption and destruction; %) recommendations to create microhabitat suitable for non-breeding or nesting use by female LEPC across different levels of forage production (annual forage production; lbs/ac) in western, Kansas, USA.

Management Objective	Annual Forage Production (lbs/ac)	Recommended Forage Utilization (%)
LEPC Non-breeding Use	800	10%
	900	20%
	1000	28%
	1100	35%
	1200	40%
	1300	45%
	1400	49%
	1500	50%
	1600	50%
	1700	50%
	1800	50%
	1900	50%
	2000	50%
LEPC Nesting Use	800	0%
	900	0%
	1000	0%
	1100	< 6%
	1200	< 14%
	1300	< 20%
	1400	< 26%
	1500	< 31%
	1600	< 35%
	1700	< 39%
	1800	< 43%
	1900	< 46%
	2000	< 48%