LESSER PRAIRIE-CHICKEN MOVEMENT, SPACE USE, SURVIVAL, AND RESPONSE TO ANTHROPOGENIC STRUCTURES IN KANSAS AND COLORADO

by

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Abstract

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is an endemic North American prairie grouse once widely distributed in the southwestern Great Plains. Recent population declines and continued threats to lesser prairie-chicken populations prompted the U.S. Fish and Wildlife Service to list the species as “threatened” under the protection of the Endangered Species Act of 1973 in May 2014. The northern extent of the species range in Kansas and Colorado supports 2/3 of the remaining range-wide population of lesser prairie-chickens, but has thus far been relatively understudied. Concern for species viability has created a need to fill current knowledge gaps in lesser prairie-chicken ecology, provide more recent demographic information, and develop appropriate conservation actions. I evaluated female survival, movement, space use, and effects of anthropogenic features during the breeding seasons of 2013 and 2014. I captured and radio-tagged 201 females with satellite GPS (N = 114) and VHF (N = 82) transmitters within the three ecoregions of Kansas and Colorado. Mean daily movement varied by region, year, and breeding season period but the amount of space used was consistent between ecoregions and years. On average, females moved 1352 m ± 12 [SE] per day. Females moved the greatest distances during the lekking period of the breeding season with females moving 2074 m ± 36 per day. Females were most sedentary during the brooding period moving only 780 m ± 14 per day. Mean breeding season home range size was estimated to be 340 ha ± 27. The lekking period had the greatest amount of movement as a result of females visiting leks to find mates, copulate, and search for nest locations. Female’s movements were reduced during the brooding period because of physical limitations of the brood mobility. Variation in movement between ecoregions was most likely a product of fragmentation as females moved 10-30% more in northwest Kansas compared to the study sites, which was characterized by

northwest Kansas having the greatest degree of fragmentation. Survival varied by ecoregion with females in northwest Kansas having the lowest probability of surviving the 6-month breeding season compared to other ecoregions. Estimated 6-month breeding season survival during 2013 and 2014 was 0.455 (95% CI = 0.38 – 0.53). Survival was lowest during the nesting period, which claimed 59.5% of all observed mortalities. Survival increased from 2013 to 2014 in northwest Kansas as grassland habitats recovered from extreme drought conditions in 2013. Drought was less severe in south-central Kansas and survival rates remained fairly consistent across years. Avian and mammalian predators caused 45.7% and 34.3% of breeding season mortalities, respectively. Other mortalities were either cause by snakes or were unknown (5.7%, 14.3%). Overhead cover may have been limited from drought conditions causing nesting females to be more visible to avian predators during incubation. When pooled across years and ecoregions, rump-mounted GPS transmitters did not adversely affect female survival when compared to commonly used necklace style VHF transmitter (VHF: 0.48 95% CI = 0.39 – 0.58; GPS: 0.50 95% CI = 0.38 – 0.64). Distance to distribution power lines and lek were significant predictors of female space use within their home range with females behaviorally avoiding distribution power lines and using space closer to leks. Space use decreased with increasing oil well density. Females avoided areas that had well densities of 23 wells/250 ha. Observed female locations were further from anthropogenic features but closer to leks on average than at random. Avoidance behavior of anthropogenic features may result in functional habitat loss and reduce the amount of suitable habitat available; compounding previously fragmented landscapes. Anthropogenic features may limit movement by acting as barriers on the landscape and potentially disrupt population connectivity. Furthermore, habitats selected for nesting and brooding may result in potential ecological traps because of reduce breeding success when impacted by increased occurrence and densities of anthropogenic features. Reduced breeding success can have significant negative impacts on population persistence. Average home range size across all ecoregions indicated that female lesser prairie-chickens need at least 340 ha of habitat to fulfill her life-history requirements during the breeding season. Brooding habitats need to be in close proximity (≤ 750 m) to nesting cover to reduce distance traversed by newly hatched broods. Reducing grazing pressure will ensure that sufficient vertical habitat structure is available during the nesting period and increase female survival; especially in times of drought. Mangers should restrict construction of anthropogenic features near or within suitable lesser prairie-chicken habitat with emphasis on distribution power lines. Well densities should not exceed 1 well/60 acres (11 wells/section) for a >10% probability of use. However, because the affect that density of wells has on demographic rates of lesser prairie-chickens has yet to be determined, a conservative approach where well densities in or adjacent to grassland patches should be minimized as much as possible is best.

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Chapter 1 - Breeding Season Movement, Space Use, and Habitat Use of Female Lesser Prairie-Chickens in Kansas and eastern Colorado

Introduction

Undertaken either by their own locomotion, transported by physical processes, or organic agents, movement is a ubiquitous trait that is shared by most, if not all, living organisms on the planet (Holyoak et al. 2008); this is especially true for all animal taxa. Most movements occur within a discrete amount of space that an animal uses in normal activities or the home range (Dingle 1996, Roshier and Reid 2003, Patten et al. 2011). An organism moves through this continuous space to find resources it needs to fulfill its life history requirements. Movement patterns that are exhibited by an animal within its home range are not isolated processes and are shaped by numerous intrinsic and extrinsic selective pressures. Intrinsically, movement and space use are influence by demographic factors such as sex, age, and survivorship as well as life history stages such as reproduction and growth. Moreover, movement patterns and space use are also influenced by extrinsic pressures such as habitat extent, food availability, landscape fragmentation or habitat loss, anthropogenic barriers, and environmental variability (Southwood 1977, Patten et al. 2011).

Since European settlement in the 19th century and advent of John Deere's steel plow, the estimated loss of grassland ecosystems in North America has exceeded 80% (Samson and Knopf 1994, Knopf 1994). Continental population declines and range contractions of North America's grassland avifauna have been well documented in scientific literature with habitat loss as the primary culprit (Brennan and Kuvlesky 2005). Grassland obligate prairie grouse have been shown to be extremely sensitive to prairie ecosystem health and many species have been designated as at risk (Hagen et al. 2007). The lesser prairie-chicken (*Tympanuchus pallidicinctus)* is a prairie grouse species once widely distributed across the southern Great Plains of Texas, New Mexico, Oklahoma, Kansas, and Colorado in North America. Their range and population have been reduced by an estimated 90% since European settlement in the 1800s (Taylor and Guthery 1980). More recent and continued range-wide population declines prompted the U.S. Fish and Wildlife Service (USFWS) to list the LPC as a threatened species under the ESA in May of 2014 (USFWS 2014). The northern extent of the species range of Kansas and Colorado has been of particular interest to conservationists as it was recently shown to hold roughly 2/3rds of the remaining range-wide population (McDonald et al. 2014). With the increased concern for the species viability, it is evident that further research on lesser prairie-chicken ecology is needed to fill current knowledge gaps and provide more contemporary and robust information for conservation planning and management of the species.

Similar to the greater sage grouse (*Centrocercus urophasianus),* lesser prairie-chicken populations have been indicated as being associated with landscape-level structure and stability as authors have speculated that a population needs ~ 5,000 – 20,000 ha of contiguous native prairie for self-sustaining leks or populations (Taylor and Guthery 1980, Applegate and Riley 1998, Mote et al. 1999, Connelly et al. 2000, Fuhlendorf et al. 2002, Bidwell et al. 2003, Davis 2005, Haufler et al. 2012, Haukos and Zavaleta 2015). Throughout its range, lesser prairie-chicken populations are found within a wide array of landscapes that vary spatially by vegetative composition and intensities of anthropogenic fragmentation and land uses (Fuhlendorf 2002, McDonald et al. 2014). Furthermore, environmental conditions vary spatially and temporally throughout the Great Plains. Lesser prairie-chicken populations encompass gradients of precipitation, temperature, and growing season with more stable environmental conditions increasing as one moves west to east. Extreme and prolonged droughts are common across the range; especially in the High Plains (Haukos and Zavaleta 2015). Variability in environmental conditions can continuously affect the availability of food resources, nesting habitat, and/or brooding habitat as precipitation is the primary driver of vegetative growth

(Grisham et al, 2015). Such spatial and temporal heterogeneity in landscape structure and environmental conditions can create dynamic landscapes in which lesser prairie-chickens are found (Haukos and Zavaleta 2015).

The pattern of movement and habitat type and quality within a lesser prairie-chicken's home range is dependent upon the habitat available on the landscape and landscape structure (Dingle 1996). Because the quantity, quality, and distribution of resources that lesser prairie-chickens need to complete multiple aspects of their life histories varies spatially and temporally (seasonally) between landscapes, movement patterns and space use should vary in response to these changes. Literature is generally lacking for explicitly testing movement or space use to distribution of habitats on the landscape for prairie grouse species; however, Patten et al. (2011) showed that as contiguous habitat patch size decreases the amount of space use increased for greater prairie-chickens (*T. cupido*). Movement and space use patterns of lesser prairie-chickens has been shown to vary with environmental conditions, periods within years, among years, and across studies and regions (Copelin 1963, Sell 1979, Ahlborn 1980, Taylor and Guthery 1980, Merchant 1982, Jamison et al. 2002, Bidwell et al. 2003, Hagen and Giesen 2005, Pirius 2011, Pirius et al. 2013). However, most estimates of lesser prairie-chickens movement and space use have centered on single populations and landscapes. Additionally, there is little temporal overlap among single population studies restricting comparisons among different populations and their associated landscapes as well as incorporating seasonal variation in precipitation among these landscapes (Table 1.1, 1.2). Characterizing and assessing the effects of different landscapes resulting from different habitat types and landuses as well as the effects of inter- and intra-annual variation in precipitation on movement and space use will provide insight into the drivers of movement and amount of space needed by lesser prairie-chickens. This will facilitate an understanding of how movement patterns and space use changes within a population as well as similarities among populations in response to differing distributions of resources on the landscape. Characterizing this variation and quantifying the amount of movement and space needed for female lesser prairie-chickens will help determine adequately sized management areas for populations; which is relevant to the recovery of the species (USFWS 2014, Haukos and Zaveleta 2015).

During the breeding season, female lesser prairie-chickens move and utilize the landscape to forage, find mates, and locate suitable habitat for nesting and brooding rearing. As a female survives through the breeding season, she transitions through multiple behavioral states; which are caused by breeding season stages she may enter and exit (lekking, nesting, brooding, and pot-breeding). Relating how these behavioral states effect the amount of movement or physical space needed by an animal is a key characteristic of the "Movement Ecology" paradigm as it advocates that movement and/or space use should not be viewed as sequential positions in space and time but also how movement or space use relates to the physiological and/or behavioral state of the organism (Nathan et al. 2008). Understanding how these shifts through different behavioral states effects the amount and pattern of movement and space use is paramount to understanding lesser prairie-chicken movement ecology. Moreover, it will aid conservation and management of habitat patches by providing insights as to how the spatial distribution and juxtaposition of different habitat patches are best arranged on the landscape for different periods of the breeding season. The spatial distribution and juxtaposition of habitat patches is of particular importance during reproduction when female movement and space use is constrained by reproductive inputs such as a nest or brood. Hagen et al. 2009 showed that the reproductive parameters are most important; therefore, understanding space use requirements during these periods may be most important to understand and manage for.

Lesser prairie-chickens are found within three distinct vegetative ecoregions within the northern portion of the species range of Kansas and Colorado: the Mixed-Grass Prairie Ecoregion in south-central Kansas, Short-Grass Prairie /CRP Mosaic Ecoregion in northwest Kansas, and Sand Sagebrush (*Artemisia filiafolia*) Prairie Ecoregion of southwest Kansas (Figure 1.1; McDonald et al. 2014). Information on female lesser prairie-chicken movement ecology in Kansas and Colorado is lacking; but provides a unique opportunity to compare movement and space use between multiple populations. Schwilling (1955) reported the first thorough observational study of lesser prairie-chickens in southwest Kansas. His research however, was conducted before the widespread availability of reliable, light-weight radio-telemetry equipment (Jamison 2000, Walker 2000). Only five studies have been conducted in the northern range that investigated lesser prairie-chicken movement, space use, or habitat selection (Giesen 1994, Jamison 2000, Walker 2000, Pitman 2003, Fields 2004). The majority of these studies were conducted in the sand sagebrush prairie of southwestern Kansas and southeastern Colorado (Giesen 1994, Jamison 2000, Walker 2000, Pitman 2003) with one study in the Short-Grass Prairie /CRP Mosaic Ecoregion of northwest Kansas. However, the study in northwest Kansas investigated nest and brood habitat selection and survival and did not characterize the seasonal movement patterns for that population (Fields 2004). Movement and space-use ecology, to my knowledge, have not been investigated or characterized for the south-central or northwest ecoregions in Kansas. No studies have quantified lesser prairie-chicken movement ecology across multiple populations/ecoregions or investigated similarities and differences among them. Moreover, movement and space-use dynamics have not been related to physiological and/or behavioral states that female lesser prairie-chickens progress through during the breeding season.

The objectives of this research were to 1) characterize breeding season movement and space use of female lesser prairie-chickens for each population filling knowledge gaps for the northern extent of the species range where the majority of extant lesser prairie-chicken population occur, 2) determine if movement and space use of female lesser prairie-chickens differ among years and populations in varying ecoregions, and 3) assess movement and space use changes as individuals shift through behavioral states and whether identified patterns differed between ecoregions and years. Because habitat type, landscape structure, and precipitation vary across Kansas as a result of different ecoregions, landuses, and precipitation gradients, I hypothesized that these differences would affect the amount of movement and space used by female lesser prairie-chickens. I predicted that movement and space use would vary between ecoregions as a result of differing landscape characteristics in which lesser prairie-chickens fulfill their life history requirements. More specifically, I predicted the northwest Kansas population would show consistently greater amounts of movement and space use than the other lesser prairie-chicken populations under investigation as the landscape is more fragmented. Moreover, I predicted that movement and space use would vary between years due to changing environmental conditions. I hypothesized that the lekking and post-breeding periods of the breeding season would have the most movement and greatest amount of space used as females are not constrained by reproductive events such as a nest or a brood. The lekking period would also see the greatest amount of movement and space used as females will be searching for mates and nest sites. I further predict that LPC movement and space use patterns for each life-cycle period would remain consistent across years and regions as these behavioral states are constrained by their evolutionary life history.

Study Area

Study sites were located in Kiowa, Comanche, and Clark counties within south-central Kansas; Gove and Logan counties within northwest Kansas; and Cheyenne, Baca and Prowers counties within eastern Colorado (McDonald et al. 2014; Figure 1.1). The northwest Kansas study area in the Short-Grass Prairie/CRP Mosaic Ecoregion encompassed two separated sites; one located in Gove County and one in Logan County. Research in Gove and Logan Counties were conducted solely on private lands. Research in Logan County was centered on The Smoky Valley Ranch, which is owned and managed by The Nature Conservancy, as well as private lands surrounding the ranch. As a whole, the northwest Kansas study site was a mosaic of short-grass and mixed-grass prairies, land enrolled in the Conservation Reserve Program (CRP) of the U.S. Department of Agriculture, and agriculture on silt loam soils. The dominant land uses in northwest Kansas were livestock grazing, row-crop agriculture, CRP, oil and gas exploration and extraction, and rural towns. Dominant vegetation in the area included: blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), buffalograss (*Buchloe dactyloides*), little bluestem (*Schizachyrium scoparium*), side oats grama (*B. curtipendula*), big bluestem (*Andropogon gerardii*), Illinois bundleflower (*Desmanthus illinoensis*), prairie sunflower (*Helianthus petiolaris*), annual buckwheat (*Eriogonum annum*), sand milkweed (*Asclepias arenaria*), nine-anther dalea (*Dalea enneandra*), and western ragweed (*Ambrosia psilostachya*; Lauver et al. 1999). Some of the grass species originally planted within the CRP fields during the late 1980s included: little bluestem, side oats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*; Fields et al. 2006). After original planting, some CRP fields were interseeded with forbs in the mid to late 1990s including: 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 et al. 2006). Wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*) were the major crops in the region.

The south-central Kansas site was located on private lands in Kiowa and Comanche counties within the Mixed-Grass Prairie Ecoregion (McDonald et al. 2014, Figures 1.1, 1.2). The south-central Kansas site consisted of mixed-grass prairie on loamy soils. Primarily land uses for this area included ranching/pastureland, oil and gas extraction and exploration, with row-crop agriculture interspersed throughout the region. Dominant vegetation in south-central Kansas includes: little bluestem, blue grama, hairy grama, sideoats grama, buffalograss, sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludiviciana*), western ragweed, sand sagebrush *(Artemisia filiafolia)*, and eastern red cedar (*Juniperus virginiana*; Lauver et al. 1999).

The Ashland, Kansas, site in Clark County within south-central Kansas was located at the edge of the Mixed-Grass Prairie and Sand Sagebrush Prairie Ecoregion boundary (McDonald et al. 2014; Figure 1.1, 1.2). Land use was dominated by livestock grazing, oil and gas extraction, and row-crop agriculture. In addition to mixed-grass and sand sagebrush prairies plant species described previously, the study site had considerable alkali flats along drainages. Dominant vegetation in the area included: little bluestem, side oats grama, blue grama, hairy grama, big bluestem, alkali sacaton (*Sporobolous airoides*), Russian thistle (*Salsola kali*), kochia (*Kochia scoparia*), annual sunflower (*H. annuus*), and sand sagebrush.

Within eastern Colorado, the study sites were located on private lands in Cheyenne, Baca, and Prowers counties (Figure 1.2). The study site was within the Sand Sagebrush Prairie Ecoregion (McDonald et al. 2014; Figure 1.1). Land use within the study site included livestock grazing, row-crop agriculture, and CRP grasslands. Dominant vegetation in the region included: blue grama, hairy grama, side oats grama, buffalograss, little bluestem, big bluestem, sand sagebrush, kochia, and

Russian thistle. Major crops within the region included wheat, sorghum, and corn. Oil and gas development was low in this area.

Highly variable environmental conditions were experienced across all the study areas during 2013 and 2014. Much of the western portion of Kansas and eastern Colorado was in moderate to extreme drought conditions from 2012 to 2014, according the Palmer Drought Severity Index (Index Value = -2.00 to -4.00 or below; NOAA 2014). The long-term average annual precipitation for western Kansas and eastern Colorado is ~47 cm (HPRCC 2013). During 2012, the region received a total of ~ 25 cm of precipitation; increasing slightly in 2013 to 31 cm (Kansas Mesonet 2014). Coupled with the lack of rain, most areas grazed by livestock were in poor range condition. The vegetative growth was highly suppressed and resulted in CRP fields being emergency hayed, a policy allowed under emergency drought conditions in CRP as declared by the USDA Farm Service Agency for individual counties (R. Plumb, personal observation). Drought-relieving precipitation began in mid-May through early August 2014, with an approximate total precipitation of 35 cm between 1 January – 31 August, 20.5 cm of which fell between 15 May – 15 July (Kansas Mesonet 2014; Figure 1.3). Prairie ecosystems responded positively to precipitation and stable temperatures with robust vegetation growth in summer of 2014 (R. Plumb, personal observation).

Environmental conditions in south-central Kansas were slightly better compared to the more western region of the state and eastern Colorado. The Palmer Drought Severity Index placed south-central Kansas under moderate – severe drought conditions during 2012 and early 2013 (Palmer Index Value = -2.00 to - 3.99; NOAA 2014). The long-term annual average precipitation for south-central Kansas is ~ 70.7 cm (HPRCC 2013). The region received an approximate total of 42.5 cm of precipitation during 2012 and 55 cm in 2013. South-central Kansas received weekly precipitation events from mid-March to mid-June in 2013 and received roughly 43% more precipitation than northwest Kansas and Colorado (Kansas Mesonet 2014). Although this region received greater precipitation than other portions of the lesser prairie-chicken range in Kansas and Colorado in 2013, it was approximately 22% less than the average precipitation for this area. The drought continued into 2014 with very dry conditions persisting until late May. The drought continued in early summer when the region received approximately 53 cm of precipitation from 1 January – 31 August with ~ 77% from 1 June – 31 July (Kansas Mesonet 2014; Figure 1.3). Increased vegetation growth was witnessed during 2014 (Lautenbach 2014). The Ashland, Kansas, study area was established in 2014 and environmental conditions were similar to the rest of the south-central portion of Kansas (D. Sullins, personal communication).

Methods

Capture and Marking

Lesser prairie-chickens were captured using walk-in drift traps and drop nets during the spring lekking period; March – mid May (Haukos et al. 1990). At first, lesser prairie-chickens were sexed, aged (Copelin 1963) and females were fitted with a 22-g (<3% body weight), solar-powered, satellite-received transmitter (Wegge et al. 2007). In Kansas, we used model 100 GPS Platform Transmitting Terminals (PTT) by Microwave Telemetry Inc. (Columbia, Maryland, USA) whereas in Colorado, we used model 22 GPS PTT by NorthStar Science and Technology, LLC (King George, Virginia, USA) with a modified rump-mounting harness (Bedrosian and Craighead 2007). Females and males both received a color leg band combination to indicate year of capture, lek of capture, and individual identity (Sell 1979). Males received an individually numbered aluminum leg band (Hagen et al. 2007). Captured individuals were released within 60 min at the capture site. All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee under protocol #3241 and Kansas Department of Wildlife, Parks, and Tourism scientific collection permit numbers SC-042-2013 and SC-079-2014, and the Colorado Parks and Wildlife permit numbers 13TRb2053 and 14TRb20153.

Tracking

Satellite-marked birds were tracked using GPS/Argos system. GPS locations were taken every 2 hours from 0400 – 2200 hours resulting in ~ 10 locations per day per bird. Number of locations varied depending on the solar charge the device gets for that day. Locations were uploaded every 3-4 days when the likelihood of a satellite pass was greatest. Microprocessor controlled battery charge management allowed the PTTs to charge during the day, collect data, and transmit at night.

Biological Periods

Space use of individuals can vary depending on the behavioral state that the individual is in (Nathan et al. 2008). Succession of breeding season behavioral states through time is not linear. The transition between these behavioral states is individually dynamic as individuals can enter and exit different states at the same point in time (Figure 1.4). Females transition through four biologically-relevant periods during the breeding season. The behavioral states were defined as: lekking, nesting, brooding, and post-breeding. I defined the lekking period as the time from capture or start of the breeding season (15 March) to the start of nest initiation and the time between a failed nest and nest initiation of a renest attempt (Riley et al. 1994). The nesting period was pooled across all nest attempts and began at the start of nest initiation until the fate of the nest was determined. At this point, females could either enter the brooding period if the nest was successful, or back into the lekking period for another breeding attempt, or omit breeding attempts and enter the post-breeding period (Figure 1.4). Females that had successful nests entered the brooding period until the fate of the brood was determined by brood flushes. If a brood failed between brood flushes, the median date was used as the transition from the brooding period into the post-breeding period. Females could either end the breeding season in the brooding period as the brood would be leaving the female or in the post-breeding period Females that were considered to be in the post-breeding period were those that either omitted breeding during that year, had failed nest attempts, or a failed brood but where still within the breeding season. The end of the breeding season was determined as the approximated date of brood break up (15 September).

Data Analysis

Landscape Structure

The degree of fragmentation for each region was estimated using the 2009 Playa Lake Joint Venture (PLJV) landcover classification layer. Landcover layers were created for each study region using ArcMap 10.0 (ESRI Inc., 2011, Redlands, CA). The size of the landscape was based on the generated GPS locations from GPS marked females from each site. Landscape structure of each study region was analyzed using the public domain software FRAGSTATS 4.0 (McGarigal et al. 2002). Fragmentation was characterized at the landscape level which measures all landscape components in relation to one another. No one metric has the ability to accurately characterize the degree of fragmentation on a landscape so four different landscape metrics were used: total number of patches, mean patch area, total edge, and contagion index. A patch is defined as a discrete area categorized by a specific habitat type based on species composition and structure of vegetation that is completely surrounded by a different habitat type. The number of patches represent the total number of individual patches in each landscape, mean patch area is the average patch-size of all patches within each landscape, total edge represents the total amount of edge created from contrasting landcover types, and the contagion index that measure the aggregation of habitat by subsuming dispersion and interspersion of that habitat on the landscape. High contagion values represent landscapes with few small and dispersed patches where lows values represent landscape with many small and dispersed patches (McGarigal et al. 2002).

Movements

Movements were analyzed from a subset of all marked females. Females equipped with rump-mounted GPS transmitters were used as those locations had the greatest temporal resolution and degree of accuracy. GPS transmitters provided a position every two hours, generally between 0400 – 2200 H (8-10 locations per day). Linear distances between consecutive locations were measured and summed for each day each individual was alive. Daily sums were then averaged across all days for each biological period, region, and year.

Mean daily movements between periods, regions, and years were compared using a three-way factorial Analysis of Variance (ANOVA; $\alpha = 0.05$). Significant interaction terms were investigated using simple effects with one-way ANOVAs for one factor while holding the others constant. If simple effects ANOVAs were significant ($P < 0.05$) and contained more than 2 levels, I used a Tukey HSD post hoc analysis to compare all possible combinations of the factors. Investigation of year effects was restricted to only the northwest Kansas and south-central Kansas regions where we had a complete two-year set of data.

Home-Range

Utilization distributions (hereafter, UD) of GPS marked females were estimated using the Brownian Bridge Movement Model (hereafter, BBMM; Horne et al. 2007) with the BBMM function in the BBMM package (Nielson et al. 2012) of the statistical program R (R-core development team, version 3.1.2, 2014, Vienna, Austria). The BBMM is a continuous–time stochastic model of movement in which the probability of being in a specific space at a given time is conditioned on starting and ending locations, the time elapsed between those two locations, the error associated with the transmitters, and the mobility of the organism (Horne et al. 2007). The Brownian Bridge methodology explicitly makes use of auto-correlated telemetry data and is well suited for GPS data (Bullard 1991, Walter et al. 2011).

It has yet to be determined how many satellite locations are needed to accurately represent the entirety of a breeding season home-range for female lesser prairie-chickens. Girard et al. (2002) estimated that 100-300 locations are necessary to accurately estimate annual space use for moose (*Alces alces*). However, number of locations could be species specific as the amount of space used is dependent on the mobility and life history requirements of the organism under investigation. Thus, to determine if differences existed between breeding season home-ranges for regions and years, only home-ranges of birds that survived the entire breeding season were used. UDs were calculated for the entire breeding season (15 March – 15 September) and each biological period separately for 2013 and 2014. Entire breeding season UDs were calculated for females that survived the entire breeding season (N = 1424 ± 23 SE locations) and period UDs were calculated for females that had >90 locations (~10 days) within each period (see biological period definitions). Segments of the animal track that had starting and ending locations with elapsed time between them >2880 minutes (2 days) were not used in the UD calculation.

Home-range and core areas were defined as the area within the 95% and 50% isopleths of the BBMM UD, respectively. Isopleths were generated for each estimated BBMM UD. UDs were imported into the Geospatial Modeling Environment (Beyer 2012) and isopleths created using the Isopleth tool. Isopleth line files were imported into ArcGIS 10.0 (ESRI Inc., 2011, Redlands, CA) and transformed into shapefiles. I used the calculate geometry function in ArcGIS 10.0 to estimate the area of each 95% and 50% polygon.

To determine if differences in home range size existed among regions for each year, I used a one-way ANOVA for each year. A Tukey HSD post hoc analysis was used to determine differences among all possible combinations following a significant *F*-test ($P < 0.05$). Differences between years were compared using a one-way ANOVA, which summed across regions and tested between years. A Tukey HSD test was not conducted as only two levels were present. To determine if an interaction between year and region was present, I used a two-way ANOVA with a region*year interaction term. Only data from northwest Kansas and south-central Kansas regions were used as they had a complete two year set of data. If an interaction term was significant, I investigated the simple effects using one-way ANOVAs for one factor while holding the others constant. All combinations for the one-way ANOVAs were then compared using a Tukey HSD post hoc analysis following a significant *F*-test ($P < 0.05$).

To investigate whether differences exist between biological periods, two 2-way ANOVAs were used; one investigated the interactions between periods and regions and the other investigated the interaction between periods and years. If interaction terms were significant, I investigated the simple effects using one-way ANOVA's for one factor while holding the others constant. All combinations for the one-way ANOVA's were then compared using a Tukey HSD post hoc analysis following a significant *F*-test ($P < 0.05$).

Results

Landscape

Fragstats results indicate that northwest Kansas had the greatest degree of fragmentation compared to all other sites as it had 1.8 times the number of patches and 1.7 times the total amount of edge as the next greatest landscape. Northwest Kansas was tied for the lowest contagion value with Ashland, Kansas, indicating that habitat patches were smaller and more dispersed on the landscape.

Kansas and had the second lowest average patch size. Colorado had the smallest average patch size which was 57.4% smaller than northwest Kansas. South-central Kansas had the least amount of fragmentation, and had the least number of patches, second lowest amount of total edge, greatest average patch size, and the greatest contagion index value (Figure 1.5). The degree of fragmentation in Ashland, Kansas, and Colorado were fairly similar to one another; though Colorado seems to exhibit slightly more fragmentation as it 59.7% smaller patches and a 13.5% greater contagion index value (Figure 1.5).

Movement

A total of 193 female lesser prairie-chickens were captured in northwest (n = 106) and south-central (n = 56) Kansas during the springs of 2013 and 2014, resulting in a total of 114 GPS transmitters being deployed (Table 1.3). GPS marked females generated 42,109 and 60,901 locations in 2013 and 2014, respectively, equating to a total of 10,627 daily movement, 265 period home-range, and 56 entire breeding season home range estimates. Entire breeding season home range estimates were not derived for all marked females as they did not survive from the start of the breeding season (15 March) to the end of the breeding season (15 September).

Initial investigations of mean daily movement between biological period, region, and year did not result in a significant three-way interaction ($F_{3,10604} = 1.41$, $P = 0.24$). The two-way interactions between period and year ($F_{3,10619} = 6.91$, $P < 0.001$), period and region ($F_{(8,10612)} = 18.8$, $P < 0.001$) and region and year ($F_{3,8403} = 41.35$, $P < 0.001$) were significant for mean daily movement. Simple main effects analysis showed that mean daily movement differed among regions within each year (2013: $F_{2,4339} = 91.64$, $P < 0.001$; 2014: $F_{2,6282} = 68.86$, $P < 0.001$). Northwest Kansas consistently had the greatest amount of movement when compared to the other study areas with females moving 1556 m ± 26.09 (SE) per day in 2013 and 1506 m ± 27.42 per day in 2014. South-central Kansas had the lowest average daily movement in 2013 but Ashland Kansas, showed the lowest movement in 2014 (Table 1.4). Average daily movement for south-central Kansas increased 31.9% from 1033 m ± 25.35 in 2013 to 1362 ± 31.14 in 2014 ($F_{1,3261} = 60.43$, $P < 0.001$) but did not differ between years for northwest Kansas ($F_{1,5142} = 1.67$, $P = 0.20$; Table 1.4).

Average daily movement varied between breeding season periods for northwest Kansas ($F_{3,5140} = 338.3$, $P < 0.001$), south-central Kansas ($F_{3,3259} = 134.2$, $P < 0.001$), Colorado ($F_{2,639} = 18.91$, $P < 0.001$), and Ashland, Kansas, ($F_{3,1574} = 80.13$, $P < 0.001$) with the lekking period exhibiting the greatest amount of average daily movement compared to all other periods (Table 1.5). Females exhibited 66% greater movement per day during the post-breeding period (1395 m ± 41.55) than during the nesting period (840 m ± 104.51) in Colorado. This however, was opposite for the other regions were females moved more during the nesting period in northwest Kansas, south-central Kansas, and Ashland, Kansas, than the post-breeding period. The lowest amount of movement for each region occurred during the brooding period. However, average daily movement did not differ between the brooding (636 m ± 21.86) and post-breeding period (749 m ± 40.78) in Ashland, Kansas (Table 1.5).

Average daily female movement within breeding period varied among sites ($F_{3,10619} = 80.13$, $P < 0.001$) with northwest Kansas having the greatest amount of movement for the lekking, nesting, and brooding periods (Table 1.5). Ashland, Kansas, had the lowest amount of movement daily movement for the lekking, brooding, and post-breeding periods; however, the lekking period did not differ from Colorado. Colorado's average lekking movement did not vary from south-central Kansas. Females in Colorado moved the least during the nesting period compared to females from all other study sites. Nesting and brooding movement on average did not differ between south-central Kansas and Ashland, Kansas. No data on brood movements were collected for Colorado. Post-breeding movements differed significantly among all regions, with females in Colorado exhibiting the greatest amount of daily movement (Table 1.5).

Pooling across regions, average daily movement differed among periods within each year for 2013 and 2014 ($F_{3,4338}$ = 184.80 , $P < 0.001$; $F_{3,6281}$ = 328.10 , $P < 0.001$). Average daily movement was greatest during the lekking period and lowest during the brooding period for both years (Table 1.6). Daily movements during nesting period were greater on average than post-breeding period for both 2013 and 2014 (Table 1.6). Average daily movement during the lekking, nesting, and brooding periods did not differ between years ($F_{1,2336}$ = 0.42 , $P = 0.52$; $F_{1,2843}$ = 0.88 , $P = 0.35$; $F_{1,1125}$ = 3.75 , $P = 0.05$). Average daily movements did vary between years during the post-breeding ($F_{1,4315}$ = 37.36 , $P < 0.001$) with movement decreasing 15.2% from 1118 m ± 19.32 in 2013 to 948 m ± 19.84 in 2014 (Table 1.6). The pattern of movement witnessed through the breeding periods was consistent between sites and years (Figure 1.6).

Space Use

The average amount of space required by female lesser prairie-chickens surviving the entire breeding season did not differ among regions in 2013 or 2014 ($F_{2,22}$ = 1.67 , $P = 0.21$, $F_{2,25}$ = 3.16 , $P = 0.06$) or between years ($F_{1,36}$ = 0.37 , $P = 0.54$; Table 1.7). Females in Kansas and Colorado consistently used 340 ha ± 53 (SE) of space during the breeding season. No significant interactions between study site and period or between year and period were found for average period home range estimates ($F_{3,257}$ = 0.84 , $P = 0.47$, $F_{8,250}$ = 0.55 , $P = 0.82$). Average period home range size did not differ between years ($F_{1,263}$ = 1.76 , $P = 0.19$) or among regions ($F_{3,261}$ = 1.40 , $P = 0.24$; Table 1.8), but differed among periods pooled across regions and years ($F_{3,261}$ = 7.20 , $P < 0.001$). Lesser prairie-chicken females used 2 times the amount of space during the lekking periods compared to the nesting period and 4 times more space than during the brooding period (Table 1.9). Average home range size did not differ among nesting, brooding, or post-breeding periods but the pattern of space use mirrored the pattern of movement through the breeding season (Figure 1.9). Female lesser prairie-chicken core area home-range sizes ranged from 29.11 – 63.25 ha depending on the site and year (Table A-1).

Discussion

Movement and space use ecology of lesser prairie-chickens in the northern extent of the species range has been relatively understudied when compared the southern portion of their range. This study was the first to characterize the movement and space use patterns for females during the breeding season in northwest and south-central regions of Kansas, characterize movement and space use through the breeding season as it relates to shifts in female behavioral states, and investigate breeding season and space use patterns between different landscapes and concurrently through time. My research indicates that 1) movement and space use varied as females transitioned through the periods of the breeding season, 2) average daily movement during the breeding season varied among all study sites, 3) annual variation in movement was not consistent between sites, and 4) amount of space used by female lesser prairie-chickens during the breeding season was consistent across the northern extent of the species range and did not vary between years.

During the breeding season, female lesser prairie-chickens move and utilize the landscape to forage, find mates, and locate suitable habitat for nesting and brooding rearing. Movement and space use through the breeding season appears to be dictated in part by intrinsic behavioral states that females transition through as a result of breeding season life history stages. Average daily movement and space use was greatest during the lekking period among all study sites with females moving 175% more and using 405% more space on average than the brooding period; which exhibited the lowest amount of average daily movement and smallest home range size across all study sites. As females began to initiate nests and incubate clutches, average daily movement decreased from the lekking period to the nesting. Once, females were no longer tied to a reproductive event (e.g., nest or brood), the amount of average daily movement once again increased during the post-breeding period. Average daily movement during the post-breeding period was 36.3% greater than movement during the brooding period but 30.5% lower than those observed during the nesting period. Space use did not differ between the nesting, brooding, and post-breeding periods. Similar movement patterns were reported for female lesser-prairie chickens in the southern portion of their range as well as for other prairie-chicken species. Movement was greatest during the early portion of the spring followed by reduced movements through late spring and summer and then once again increasing through the summer months into early fall (Robel et al. 1970, Candelaria 1979, Lockwood et al 2005).

My results indicated that female lesser prairie-chickens moved and used the most space during the lekking period of the breeding season. Similar results were found for lesser prairie-chickens females in New Mexico where the lekking or pre-nesting period exhibited the greatest amount of movement and space use compared to other periods of the breeding season (Riley et al. 1994). I hypothesize that they are attributed to females searching for mates, foraging, and locating potentially suitable nest sites (Riley et al. 1994).

I predicted that the lekking and post-breeding periods would have the greatest amounts of movement and space used as females are not tied to reproductive event and are moving to find food resources to maintain their physical condition, cover to reduce possible predation, or visit lekking sites to find mates and copulate. My results indicated that this was true for the lekking period but was not the case with the post-breeding period. Counterintuitively, females moved 43% more during the nesting period than the post-breeding period. Nesting period movement can be explained in part by initial egg laying. Female lesser prairie-chickens will lay ~ 1 egg a day but will not start incubating until the last egg in the clutch is laid; which is approximately 10-12 days after nest initiation but varies depending on clutch size (Hagen and Giesen 2005). After her egg is laid, she will move off the nest and continue normal daily activities. Additionally, it was observed that females would venture off the nest during incubation to presumably forage. Movements off nest were usually unidirectional and distances covered between successive locations were within small time scales. These patterns of nest movements suggest females are leaving the nest location under flight in a possible effort to limit time away from the nest; especially the further into incubation the nest survives (Candelaria 1979; Figure 1.8). Reduced movements of females that entered into the post-breeding period, in comparison to the nesting period, may be the result of increased resource abundance such as increased forage and vegetative cover during the late spring and summer months (May-August). Females that are no longer tied to a reproductive event become focused on their individual fitness and survival, which is driven by food and cover resources. For example, as food and cover resources increase in abundance during the late spring and summer months, which coincides with peak precipitation events (Figure 1.3), females would have no need to move further to find such resources if they are more readily available. Robel et al. (1970) showed that for greater prairie-chickens (*Tympanuchus cupido)*, the summer months were characterized by the least extensive movements as food was readily available. My results indicate that spring and summer precipitation, and therefore resource abundance, may be a major driving factor of movement for females in the post-breeding period. Average daily movement during the post-breeding period significantly decreased from 2013 to 2014 as drought relieving precipitation returned to the area in the spring of 2014. Movement of nesting females did not differ between years, indicating that movement was probably driven by the reproductive event and not annual weather.

Average daily movements of females that successfully hatch nests and were tending broods were lower than all other periods. Two possible reasons for this are 1) the physical ability of the brood to move and 2) suitable habitat and food resources. Within the first two weeks of life, broods are flightless and less capable of moving compared to the later portion of the brood-rearing period (Pitman et al. 2006). Female movements mirror the movement ability of the brood as they are heavily tied to the success of the brood. Additionally, brooding females are selecting habitats that facilitate easier movement through vegetation, adequate cover from predators, and have ample invertebrates for the brood to forage on (Hagen et al. 2005). Quality brooding habitat has been define by Hagen et al. (2013) as having ~ 2.7 dm of visual obstruction, with less shrub (8%) and grass cover (13%) and increased forb cover (14%) than nest sites. When females reach such habitats it is possible they will be less likely to leave because the negative tradeoffs of not finding another suitable habitat patch and/or the dangers associated with moving her brood to a new location: thereby reducing movement of the female. Moreover, if the amount of movement required by the female and her brood to reach quality brooding habitat negatively affects the survival of the brood, then managing for brooding habitat adjacent to nesting habitat could potentially increase brood survival and recruitment back to the population (Hagen et al. 2008).

Female lesser prairie-chickens that enter into the post-breeding period do not move more on average than the nesting or lekking period or use more space than the nesting or brooding periods. With the peak productivity of the Great Plains being centered on the late spring and summer months, it is reasonable to conclude that females may not move more during the post-breeding period because of the high abundance of forage, increased vegetative cover, and not being tied to a reproductive effort. Forage abundance could change between years as precipitation is the main driver of vegetation growth and therefore, invertebrate populations (Grisham et al. 2015). My data supports this conclusion as average daily movement during the brooding period differed between years and was the only period to do so. Average daily movement of females during the brooding period decreased approximately 15% from 2013 to 2014, which coincided with 26 – 28% increase in precipitation across the species' range.

The magnitude of movements and space use are a result of the spatial arrangement of resources on the landscape and the resulting processes underlying resource acquisition (Haukos and Zalveleta 2015). Lesser prairie-chickens evolved in landscapes of the Southern Great Plans that were historically naturally heterogeneous from natural processes such as fire, large ungulates, and drought. Lesser prairie-chickens distribute themselves throughout these landscapes based on the availability of suitable habitat, their physical limitations of mobility, and the cost/benefit relationship of moving to reach these habitat patches (Haukos and Zavaleta 2015). More contemporary forms of spatial heterogeneity such as anthropogenic-induced fragmentation of habitat for row-crop agriculture has drastically impacted the landscapes that lesser prairie-chickens inhabit with 98.5% of remaining fragments of grassland being <486 ha in size with 95.44% of patches in Kansas being <10 ha in size (USFWS 2014, Spencer 2014). I hypothesized that increased spatial distribution of resources, as a result of fragmentation, on the landscape would increase the amount of movement and space use needed to obtain them. Results from this study support this hypothesis as average daily movement varied among study sites with females in northwest Kansas exhibiting approximately 10 – 49 % greater movement depending on the study site being compared. The northwest Kansas landscape also had the highest degree of fragmentation compared to the landscapes at the other study sites. However, space use did not follow the same trend as average breeding season home range size did not differ among sites. Interestingly, birds move at greater daily rates in more fragmented landscapes compared to more contiguous landscapes but use similar amounts of space. There are two potential explanations for this: 1) female lesser prairie-chickens have a maximum amount of space that they can use during the breeding season because of intrinsic and extrinsic pressures and the patchy distribution of resources resulting from increased landscape fragmentation requires increased movement among fragmented patches to secure necessary resources, and/or 2) the more fragmented landscapes have not reached a threshold at which inter-patch movement affects could increase home-range sizes because of the high mobility potential of lesser prairie-chickens. For example, as the distance between juxtaposed patches increases, females may continue to move interchangeably among these patches in light of these increased distances as a result of their mobile capability. However, at a certain point the distances between these patches will either outweigh the benefit of reaching them or females may no longer perceive the available habitat.

Habitat alteration and fragmentation may unduly influence an organism's movements, either by restricting them or by forcing the organism to move further to acquire distributed resources (McNab 1963, Herfindal et al. 2005). Physical habitat loss that sculpted current landscapes in the northern extent of the specie's range has not occurred in the last two decades (Spencer 2014). However, it has been becoming increasingly evident that prairie-grouse, including the lesser prairie-chicken, avoid anthropogenic features, which could potentially limit movement through the landscape (Pruett 2009, Hagen et al. 2011, Chapter 3). Behavioral avoidance can result in functional habitat loss and further fragment remaining habitat patches on the landscape (Robel et al. 2004). Because anthropogenic features such as power lines can limit the amount of movement across them (Pruett et al. 2009), it is possible that in already fragmented landscapes increased anthropogenic density of anthropogenic features surrounding remaining habitat patches could restrict inter-patch movement. Thus, females within that habitat patch would need to move more to find limited resources but be restricted to that amount of space. Another possibility is that female movement may not be completely halted but because of their behavioral avoidance may have to move further around these barriers to avoid them (McNab 1963, Herfindal et al. 2005). Managers should limit the amount of anthropogenic structures in and around patches of grassland; especially those between high quality habitat patches to facilitate inter-patch movement (Chapter 3).

Variability in precipitation is the primary ecological driver of grassland productivity because of its limited availability, thus, lesser prairie-chickens have evolved with recurring drought in the Great Plains (Grisham et al. 2015). Drought naturally reduces the availability of resources, such as forage and cover, by limiting vegetative productivity. The Southern Great Plains experienced the worst drought on record from 2011 to May of 2014. Vegetative cover in western Kansas and Colorado was greatly reduced from lack of precipitation and continued grazing. South-central Kansas was under drought conditions but received 43% more precipitation than the western portion of the state in 2013. Habitat used during the initial portion of the breeding season (March – May) is driven by the vegetative productivity from the previous year. If females perceive habitat on the surrounding landscape as poor, it is possible that in an effort to reduce the energetic costs of searching for limited resources, females may find the highest quality habitat available and reside within that habitat until conditions improve, reducing their movements. In northwest Kansas, habitat conditions remained in poor condition until May of 2014 (R. Plumb, personal observation) and I saw no difference in movement between years. However, movement increased 32% in south-central Kansas from 2013 to 2014 suggesting that females may have perceived the surrounding habitat as more suitable and subsequently increased movement to utilize newly available resources. I would predict that with increased precipitation in northwest Kansas, female movements in northwest Kansas should increase from 2014 to the 2015 breeding season.

Annual differences between home-range sizes were shown for lesser prairie-chickens in New Mexico when comparing between normal and drought years (Merchant 1982; Table 1.2). Merchant (1982) hypothesized that in New Mexico lesser prairie-chicken home-range size increased from an average precipitation year to a drought year as a result of drought conditions limiting food abundance. My results do not support this hypothesis as female home ranges did not increase during a drought year (2013) compared to a normal year (2014) but my breeding season home range estimates were consistent with his drought year estimates. A potential explanation is that vegetation used during the initial portion of the breeding season is a result from the previous year's productivity. I suspect that because of the delay between precipitation and productivity, my home range estimates for 2013 and 2014 reflect drought year estimates as the northern extent of the species range did not receive drought relieving rain until late May and June of 2014. The potential for home range estimates reflecting drought years is further supported by the 15% reduction in the post-breeding period home range size from 2013 to 2014 as the habitat began to respond to increased precipitation. I hypothesize that breeding season home range size will decrease from 2014 to 2015 as a result of the vegetative response to increased precipitation in 2014.

Females move in general to locate specific resources needed to complete different stages of their life history whether it is escape cover, nesting cover, food resources, mates, etc. In their quest to find and obtain these resources, both positive and negative tradeoffs exist as a result of movement such as energy expenditure and predator risk. As females move through the landscape, they may become more apparent to potential predators. Increasing the amount of exposure events from increased movement or space use may result in reduced survival of females, which would reduce the potential breeding cohort of the population (Patten et al. 2011). My data and other research from this study support this prediction as mortality was greatest in northwest Kansas, which also exhibited the greatest amount of movement (Chapter 2).

The home-range, or the amount of physical space an individual needs to fulfill its life history, is a fundamental aspect of species ecology and crucial to understanding its place in the ecosystem (Patten et al. 2011). This project was the first study to report breeding season home range sizes that included only birds that survived the whole breeding season. My estimate indicates that a female in the northern extent of their range needs at least 340 ha of habitat during the breeding season is consistent with estimates from other parts of their range (Merchant 1982, Toole 2005, Borsdorf 2013; Table 1.2). Unfortunately, an estimated 98.5% of remaining fragments of grassland are <486 ha in size (USFWS 2014). Therefore, managers should focus on prioritizing the remnant large tracts of intact grassland for management. Though space use did not vary between the nesting, brooding, or post-breeding period of the breeding season, it did provide insight into how females need differing patches of habitat within their home range for different periods of the breeding season; especially when females are most vulnerable during the nesting and brooding periods.

Movement by individuals determines the scale at which patchiness and spatial heterogeneity affect a species (Fahrig and Paloheimo 1988, Gardner et al. 1991, Harris and Silva-Lopez 1992). Future research needs to explicitly test how fragmentation of habitat patches affect movement and space use patterns of lesser prairie-chickens and determine the scale at which impact of fragmentation is perceived by females during the breeding season. Linkages among amount and type of fragmentation, movement, and demographic rates need to be explicitly investigated to determine the potential negative effects of increased movement and how that might influence population viability. Additionally, research needs to focus on investigating how density of, type of, and scale at which anthropogenic features impact movement and space use in an effort to understand the resistance of the landscape to movement.

Management Implications

Breeding season movement of female lesser prairie-chickens was dynamic between regional populations suggesting that management recommendations are best constructed as ecoregion specific. Managers need to prioritize conservation of remaining large contiguous habitat patches that have no or limited amounts of anthropogenic features on or surrounding them within 1.9 km of a known lek (Giesen 1994, Hagen et al. 2013, Lautenbach 2014, Chapter 3). On average a single female needs 340 ha of habitat within the area surrounding a lek. At the home range scale, each female needs heterogeneous mix of habitat patches that meet all requirements for her breeding season life history; most importantly the nesting (138 ha ± 14.4 [SE]) and brooding (85 ha ± 14.7) periods. Nesting and brooding habitat should be <1.5 km from a known lek with at least 34% of that area as nesting and 21% as brooding habitat. Brooding habitat needs to be located within relatively close proximity to nesting habitat (<754 m). Nesting females need habitat between 1.5 and 2.5 dm of 75% visual obstruction with increased litter depth (Lautenbach 2014). Brooding habitat should not be as thick as nesting habitat with 2-5 dm of 50% visual obstruction and contain ~ 20% forb cover (Lautenbach 2014). Managers should use a rotational grazing system in tandem with reserving 34% of the area around a lek that meet the minimum requirements for nesting and 21% that meet the requirements for brooding habitats. Nesting habitat should be assessed at the end of the growing season the year before the nesting period being managed for. Reducing the distance from nest to brood habitat may help reduce brood mortality especially during extreme weather events such as drought, which is one of the limiting factors of population growth for lesser prairie-chickens (Hagen et al. 2008). Future research needs to determine the amount of home range overlap, the maximum capacity of nests that a specific area of habitat will facilitate, the overlap in habitat requirements from the nesting to the brooding period, and grazing methods to optimize lesser prairie-chicken productivity. Additionally, research needs to explicitly address the effect of fragmentation on inter- and intra-patch movement, the scale at which female lesser prairie-chickens perceive fragmentation on the landscape, the functional resistance of anthropogenic features to movement and space use, the effect of different grazing strategies to movement and space use, as well as the effects of increased movement and space use on demographic parameters.

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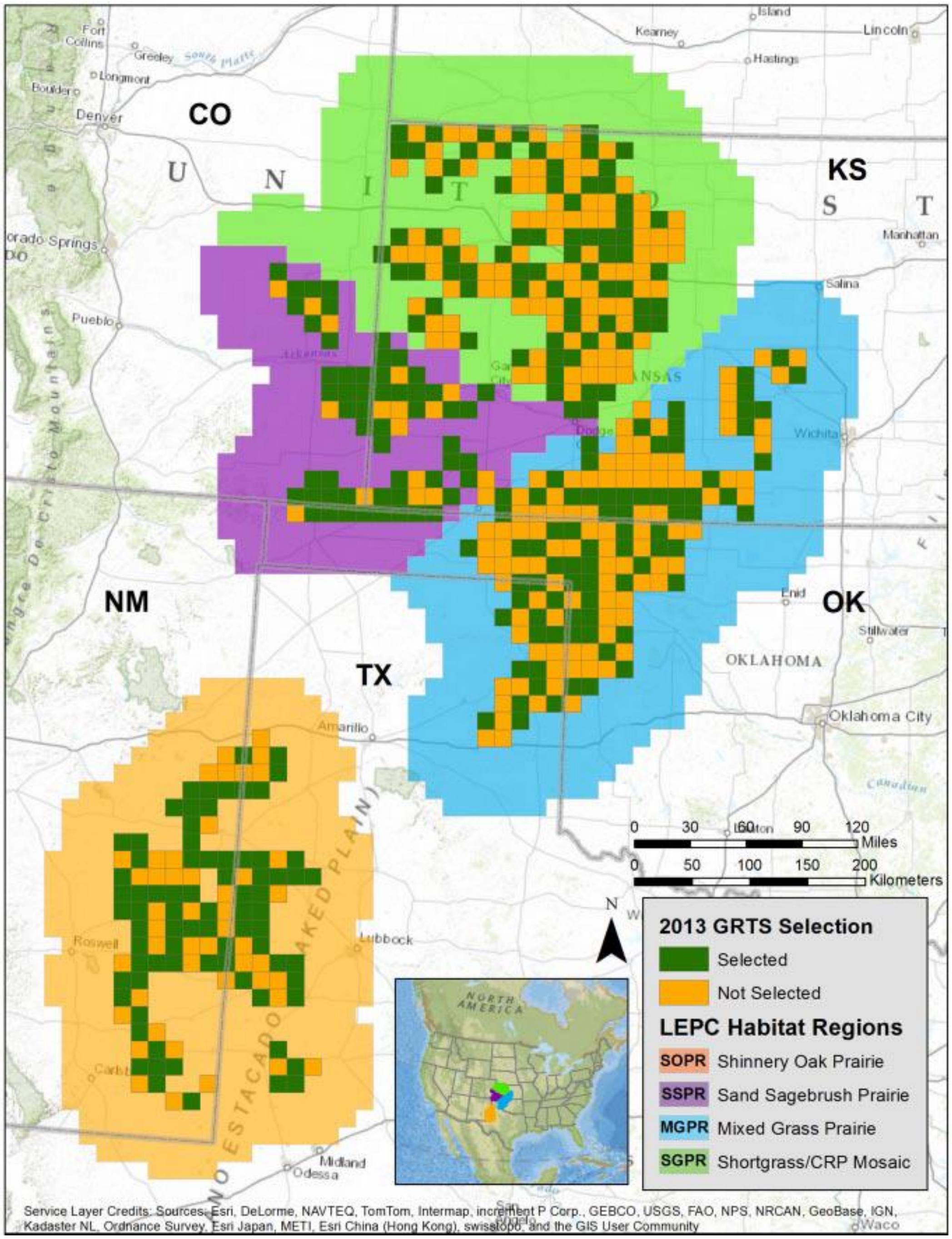
Figure 1.1 The lesser prairie-chicken range occurs across the Southern Great Plains in four distinct ecoregions: Sand Shinnery Oak Prairie, Sand Sagebrush Prairie, Mixed-Grass Prairie, and Shortgrass/CRP Mosaic Prairie (McDonald et al. 2014).



Service Layer Credits: Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure 1.2 Study area locations where lesser prairie-chickens were researched in 2013 and 2014 in Kansas and eastern Colorado. Light blue shading indicates the northern extent of the lesser prairie-chicken range

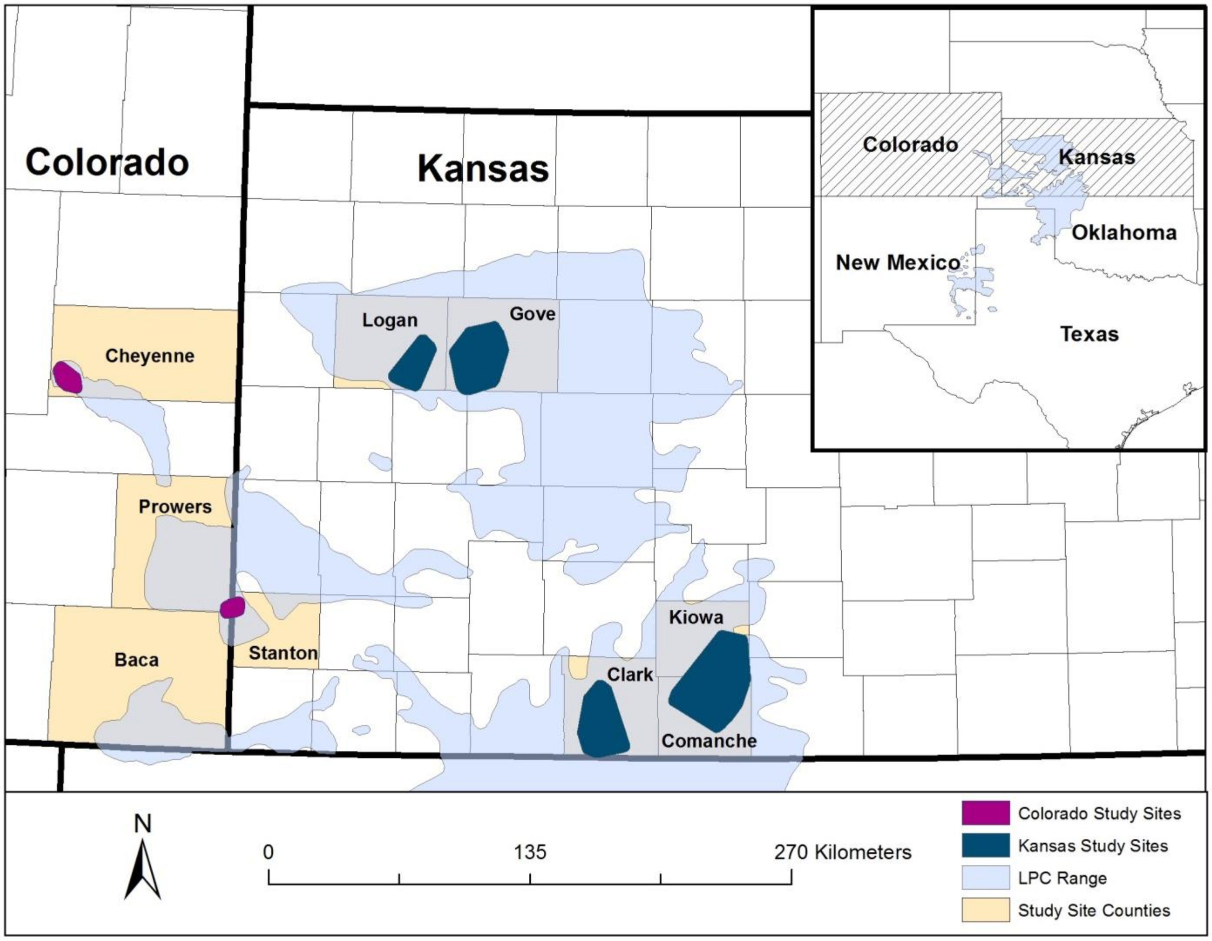


Figure 1.3 Distribution of monthly precipitation totals (cm) for the western portion of Kansas, Colorado, and south-central Kansas for 2012, 2013, and 2014 (Kansas Mesonet 2014).

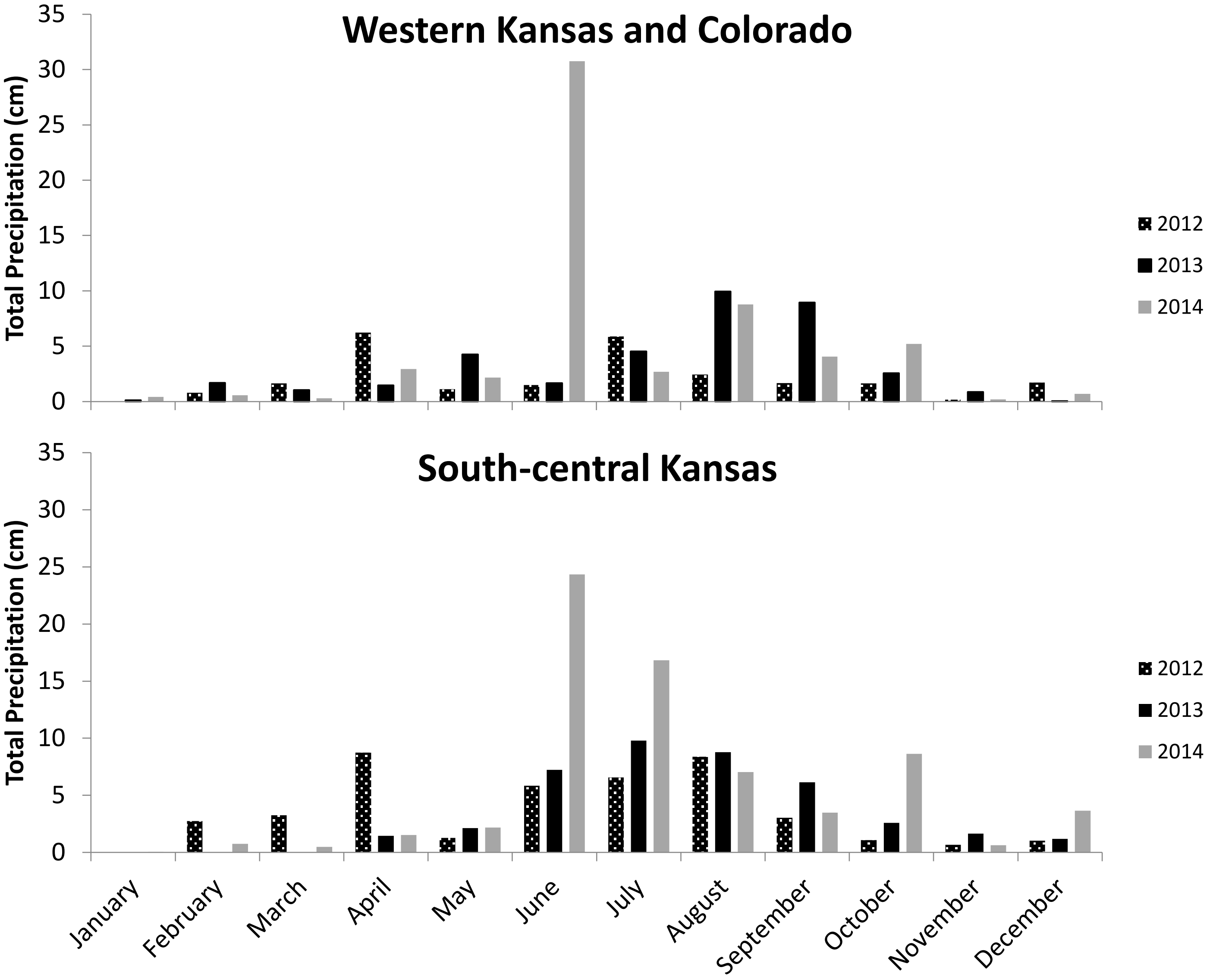


Figure 1.4 **Conceptual diagram illustrating the successional progression and overlap of biological periods through time for female Lesser Prairie-Chickens during the breeding season (15 March – 15 September).**

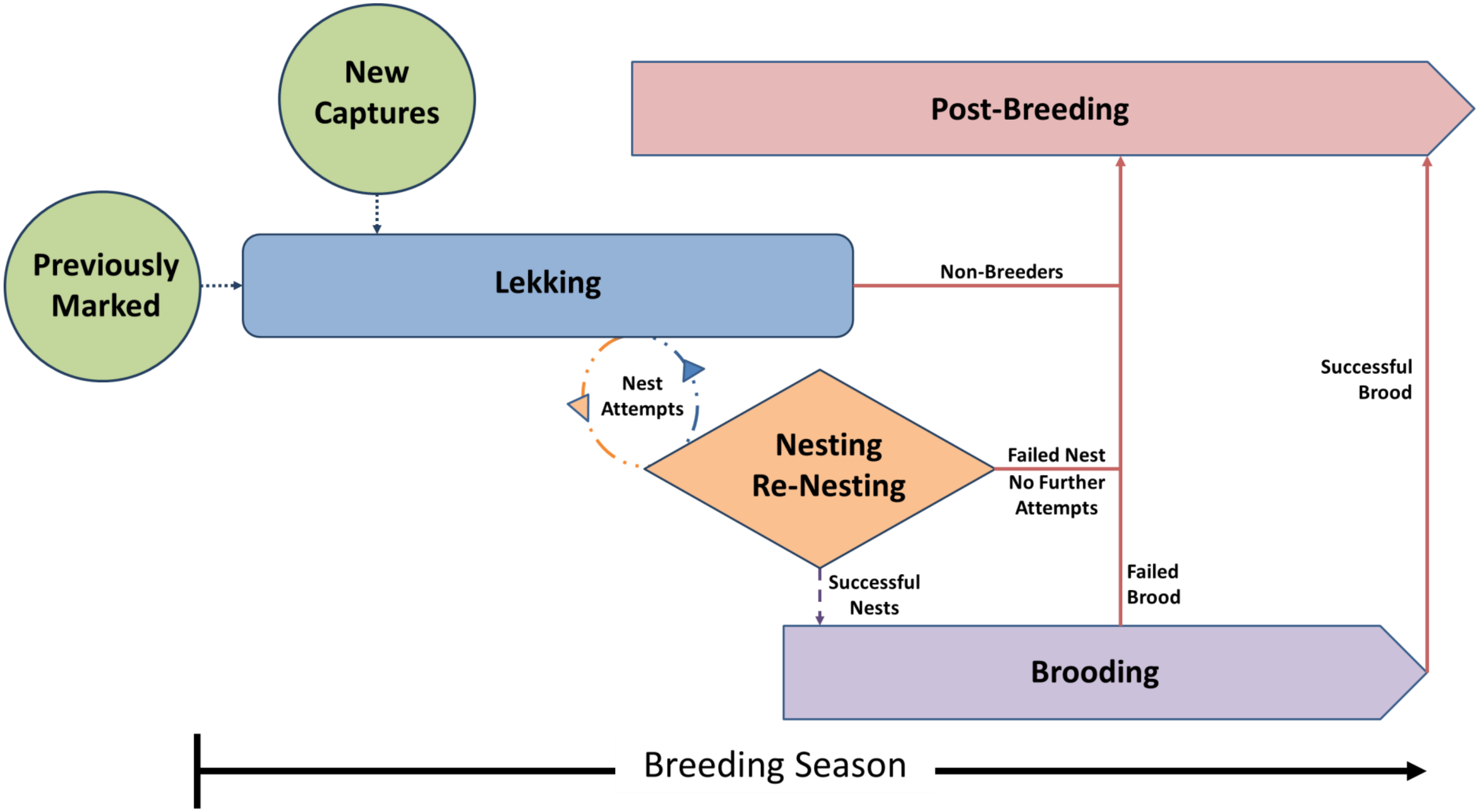


Figure 1.5 Landscape metrics indicating the degree of fragmentation for each of the lesser prairie-chicken study regions in Kansas (northwest [NW], south-central [SC], and Ashland [ASH]) and eastern Colorado, specifically the number of patches, mean patch area (ha; [±SE]), total patch edge (km), and contagion (patch aggregation).

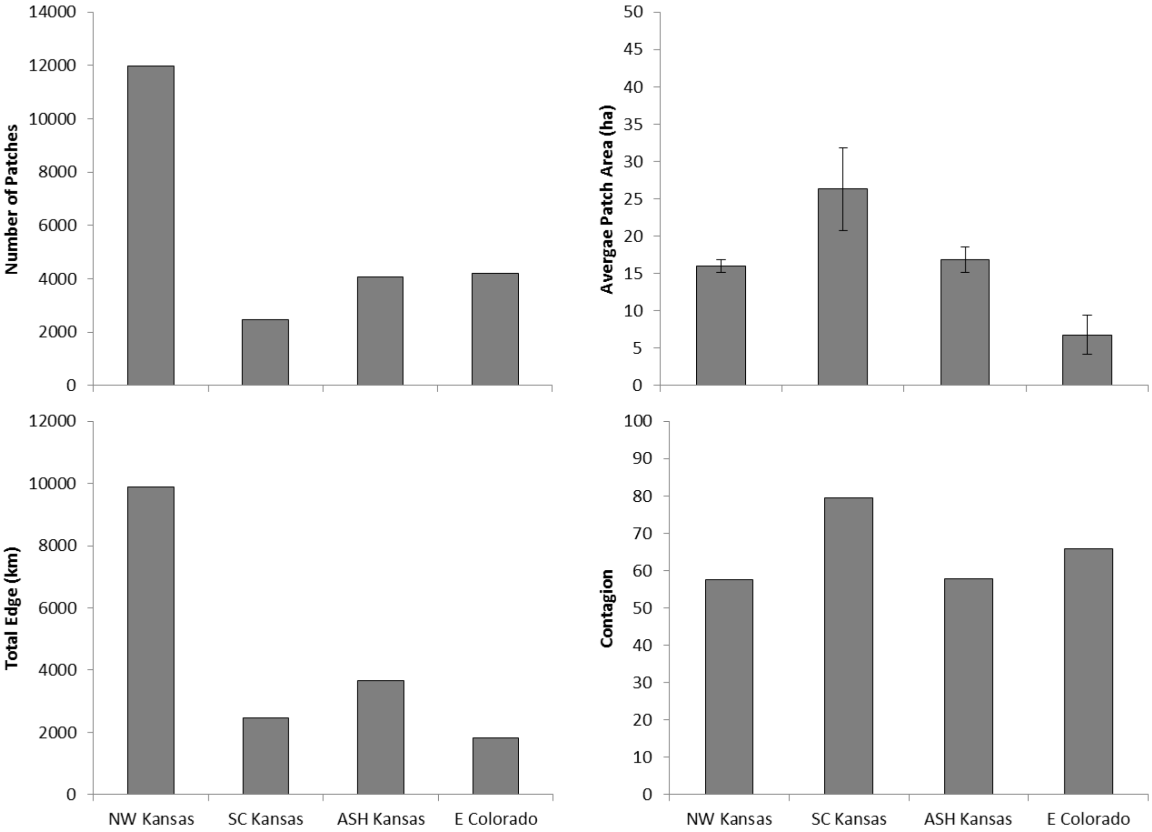


Figure 1.6 Average daily movements (m; [SE]) of female lesser prairie-chickens during each biological period for the 2013 and 2014 breeding season in all regions of Kansas (northwest [NW], south-central [SC], and Ashland [ASH]) and Colorado. Colorado was not represented in 2014 because no data were available. The Ashland, Kansas, field site was established during the spring of 2014 and has no associated 2013 data.

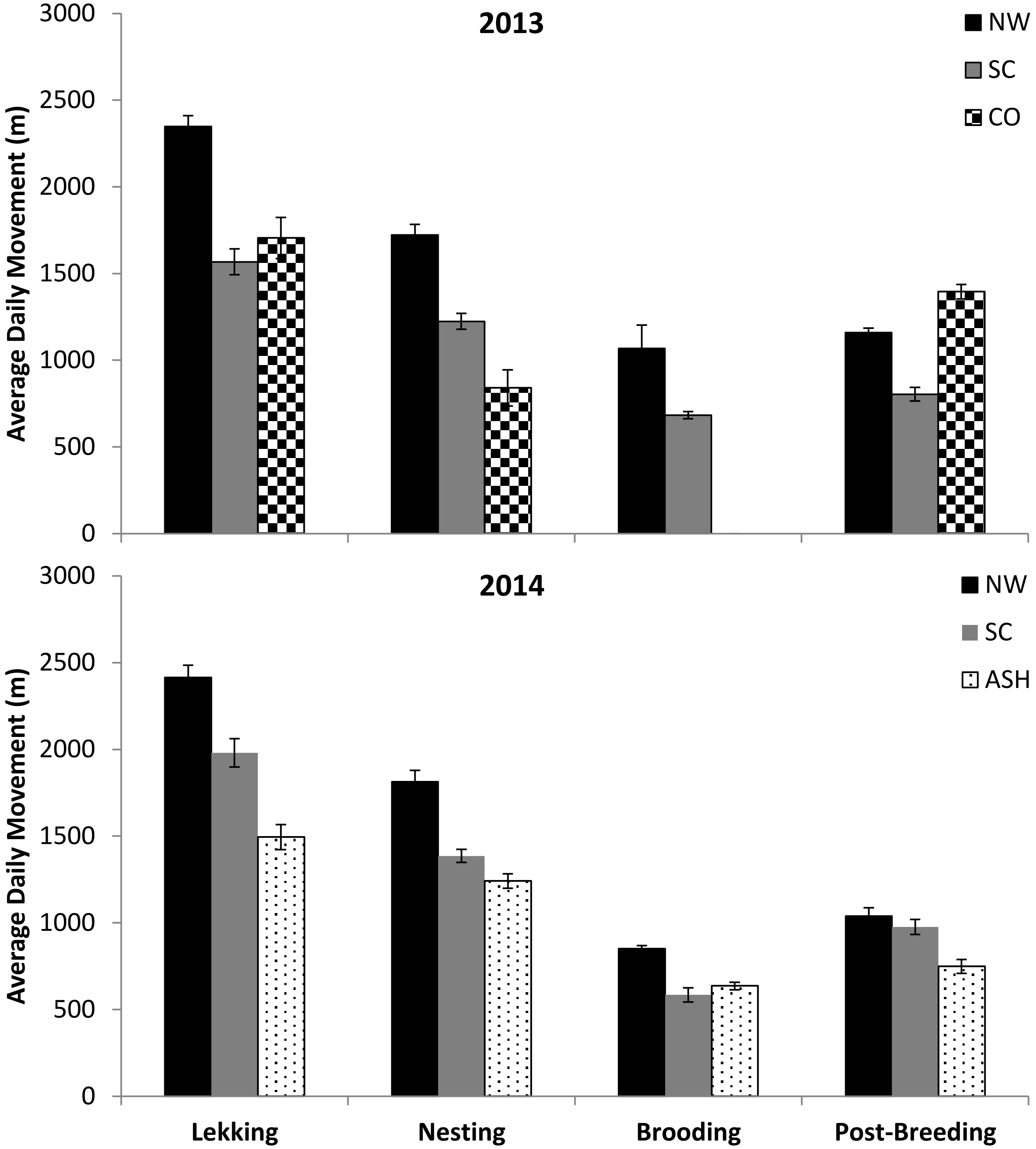


Figure 1.7 Average 95% home-range size (ha; [SE]) of female lesser prairie-chickens during each biological period and for the entire 6-month breeding season (Entire BS) for the 2013 and 2014 breeding seasons in all regions of Kansas (northwest [NW], south-central [SC], and Ashland [ASH])and Colorado. Colorado was not represented in 2014 because no data were available. The Ashland Kansas field site was established during the spring of 2014 and has no associated 2013 data.

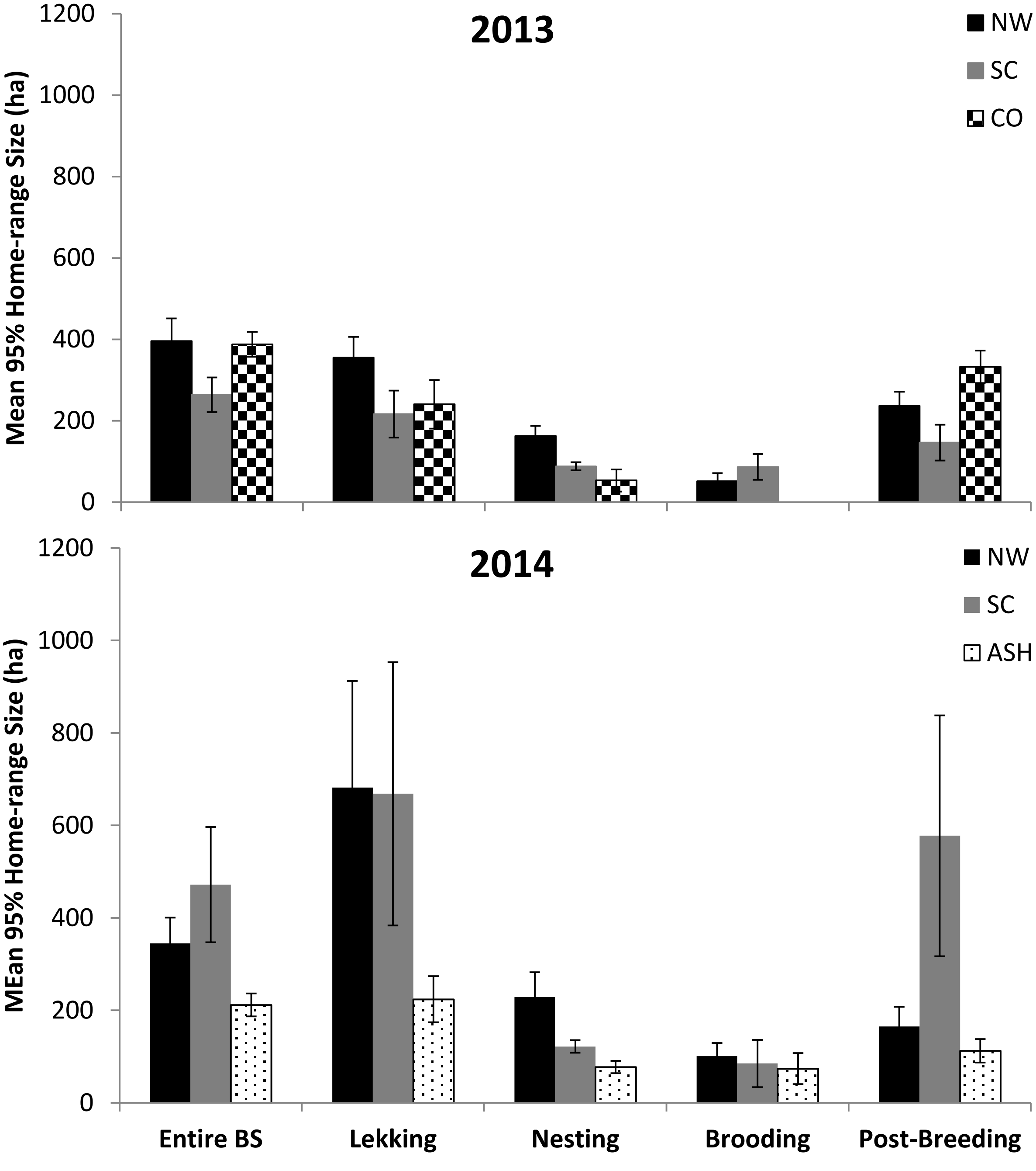


Figure 1.8 Google Earth image of a nesting GPS marked female Lesser Prairie-Chicken visually illustrating the foraging movements to and from the nest site during the spring of 2014.

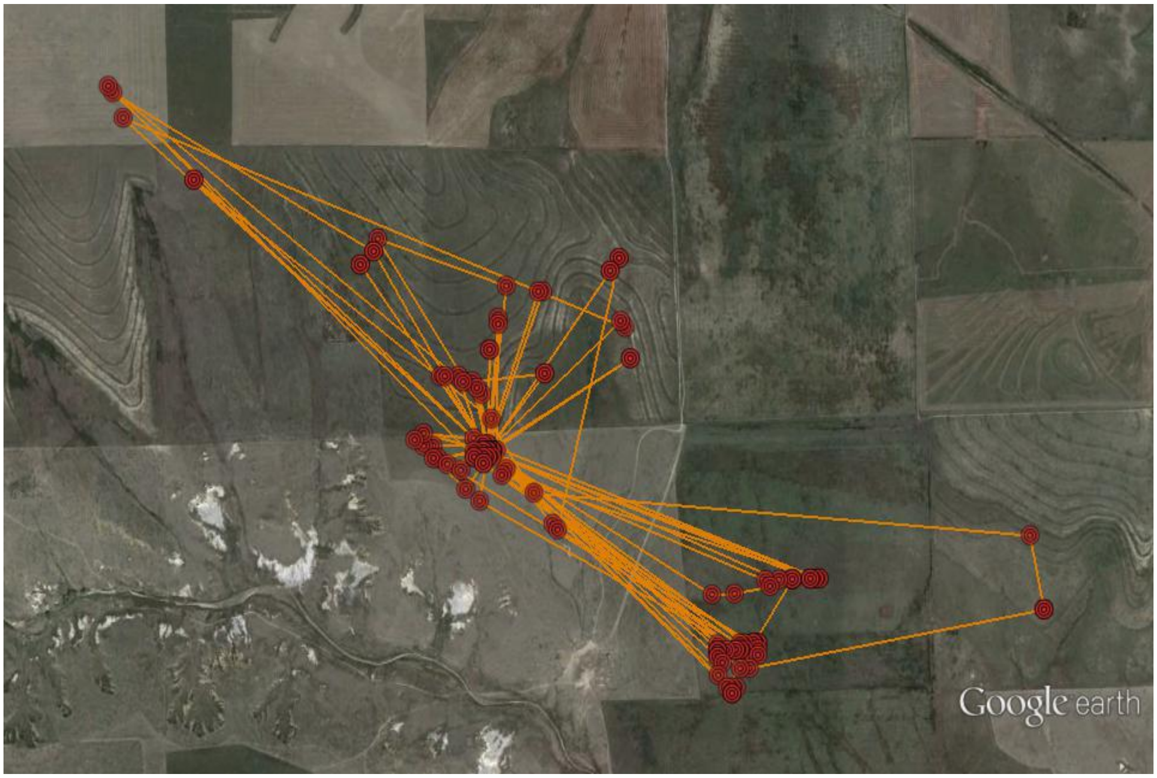


Table 1.1 All known breeding season movement estimates for female lesser prairie-chickens throughout its range of Kansas, New Mexico, Colorado, Oklahoma, and Texas.

Source	Location	Habitat	Date	N	Type	Movement Estimates
Ahlborn 1980	NM	SSO	1979	16	Brooding females	1148 ± 107.6 ha average max. distance moved
Candelaria 1979	NM	SSO	1976-1978	23	Breeding Season Period	0.39 ± 0.23km/day pre-nesting 0.25 ± 0.11 km/day nesting 0.28 ± 0.55 km/day post-nesting
Leonard 2008	TX	SSO	2006-2007	18	Breeding Season	1,197 ± 148 m mean movement
Riley et al. 1994	TX	SSO and SSB	1976-1978	40 12 3 19	Breeding Season Period	390 ± 117.3 m/day pre-nesting 250 m/day nesting 280 ± 280 m/day brooding 220 ± 71.4 m/day post-nesting

Table 1.2 All known breeding season home-range estimates for female lesser prairie-chickens throughout its range of Kansas, New Mexico, Colorado, Oklahoma, and Texas.

Study	Location	Habitat	Date	N	Type	Home Range Estimates
Borsdorf 2013	TX	SSO	2008-2012	38	Breeding Season	671.4 ± 538 ha, 95% LSCV
						471.2 ± 327 ha, 95% Plug in
						415.1 ± 306 ha, 100% MCP
Candelaria 1979	NM	SSO	1976-1978	23	Breeding Season Periods	230.75 ± 80.25 ha pre-nesting
						92.02 ± 18.36 ha nesting
						118.94 ± 458.92 ha post-nesting
Leonard 2008	TX	SSO	2006-2007	18	Breeding Season	265 ± 76 ha
Merchant 1982	NM	SSO	1979-1980	8,18	Breeding Season	62.7 ha, 121.8 ha pre-nesting
				10,11		14.2 ha, 8.5 ha nesting
				7,9		66.4 ha, 240 ha post-nesting
				7,8		174.4 ha, 463.8 ha Entire
Riley et al. 1994	TX	SSO and SSB	1976-1978	40	Breeding Season Periods	231 ± 40.9 ha pre-nesting
				12		92 ± 2.7 ha nesting
				3		119 ha brooding
				19		73 ± 15.2 ha post-nesting
Toole 2005	TX	SSO and SSB	2001 -2002	18	Breeding Season	236 ± 52 ha

Table 1.3 Capture and marking results for lesser prairie-chickens in Kansas (northwest [NW], south-central [SC], and Ashland [ASH]) and Colorado during the spring lekking season of 2013 and 2014.

		2013				2014			
	Total No. Captured	No. Males Captured	No. Females Captured	No. GPS Units	No. VHF Units	No. Males Captured	No. Females Captured	No. GPS Units	No. VHF Units
NW Kansas	275	110	63	33	29	59	43	23	19
SC Kansas	113	27	30	15	15	30	26	15	11
E Colorado	38	23	6	6	0	7	2	2	0
ASH Kansas	87	-[a]	-	-	-	56	31	20	8

[a] Data were not present for that site during that year

Table 1.4 Mean daily movement (m) of female lesser prairie-chickens marked with GPS satellite transmitters for each study region in Kansas (northwest [NW], south-central [SC], and Ashland [ASH]) and eastern Colorado during 2013 and 2014.

	2013			2014			Between Years[c]	
Regions	N[a]	$\bar{x}$	SE	N[a]	$\bar{x}$	SE	*F*	*P*
NW Kansas	2323	1555.81^{A*}	26.09	2821	1506.14^{E}	27.42	$1.67_{1, 5142}$	0.20
SC Kansas	1377	1032.79^{B}	25.35	1886	1362.37^{F}	31.14	$60.43_{1,3261}$	<0.001
E Colorado	642	1396.11^{C}	41.99	–[b]	–	–	–	–
ASH Kansas	–[b]	–	–	1578	1027.09^{G}	22.06	–	–

[a] Total number of daily movement observations used to estimate mean daily movement

[b] Data were not present for that site during that year

[c] Means between years for each region do not differ if P > 0.05

* Regional means followed by the same capital letter within year do not differ (P > 0.05)

Table 1.5 Mean daily movement (m) of female lesser prairie-chickens marked with GPS satellite transmitters for each biological period and study site in Kansas and Colorado (NW = northwest Kansas, SC = south-central Kansas, CO = Colorado, ASH = Ashland Kansas) pooled across years (2013, 2014).

	NW			SC			CO			ASH		
Periods	*N*	$\bar{x}$	SE	*N*	$\bar{x}$	SE	*N*	$\bar{x}$	SE	*N*	$\bar{x}$	SE
Lekking	1194	2384.69^{Aa}	48.10	726	1853.20^{Ab}	61.69	153	1704.58^{Abc}	118.49	265	1494.44^{Ac}	72.60
Nesting	1176	1773.11^{Ba}	45.93	1039	1322.42^{Bb}	29.04	84	839.91^{Bc}	104.51	546	1241.00^{Bb}	41.07
Brooding	575	858.44^{Ca}	17.17	310	654.74^{Cb}	19.32	–[1]	–	–	242	636.39^{Cb}	21.86
Post-Breeding	2199	1108.17^{Da}	19.06	1188	899.99^{Db}	30.14	405	1394.94^{Cc}	41.55	525	748.82^{Cd}	40.78

[1] No data available

*Means followed by the same uppercase letter and same lowercase letter do not differ ($P > 0.05$) among periods within region and among regions for each period, respectively.

Table 1.6 Mean daily movement (m) for each biological period during the breeding season for 2013 and 2014 pooled across regions for female lesser prairie-chickens marked with GPS satellite transmitters.

	2013			2014			Between Years[b]	
Periods	N[a]	$\bar{x}$	SE	N	$\bar{x}$	SE	*F*	*P*
Lekking	905	2046.74[A*]	47.53	1433	2091.61[A]	46.33	$0.42_{1,2336}$	0.52
Nesting	1013	1448.85[B]	38.61	1832	1495.42[B]	30.23	$0.88_{1,2843}$	0.35
Brooding	237	710.90[C]	22.82	890	766.40[C]	13.49	$3.75_{1,1125}$	0.05
Post-Breeding	2187	1117.57[D]	19.32	2130	948.36[D]	19.84	$37.36_{1,4315}$	<0.001

[a] Total number of daily movement observations used to estimate mean daily movement

[b] Means between years for each period do not differ if $P > 0.05$

*Means followed by the same uppercase letter do not differ ($P > 0.05$) among periods within years.

Table 1.7 Entire breeding season estimates of mean 95% home-range size (ha) of female Lesser Prairie-Chickens for 2013 and 2014 in Kansas and Colorado (NW = northwest Kansas, SC = south-central Kansas, CO = Colorado, ASH = Ashland, Kansas).

	2013			2014			Between Years[b]	
Regions	N[a]	$\bar{x}$	SE	N	$\bar{x}$	SE	*F*	*P*
NW Kansas	13	395.39^{A}	56.09	13	345.00^{A}	55.42	$0.41_{1,24}$	0.53
SC Kansas	8	263.88^{A}	42.66	9	472.00^{A}	124.58	$3.14_{1,12}$	0.10
CO Kansas	–[1]	-	-	9	211.56^{A}	25.00	-	-
ASH Kansas	4	387.75^{A}	30.33	-	-	-	-	-

[a] Total number of daily movement observations used to estimate mean daily movement

[b] Means between years for each period do not differ if P > 0.05

[1] No data available

*Means followed by the same uppercase letter do not differ (*P* > 0.05) among sites within years.

Table 1.8 Breeding season period estimates of mean 95%home-range size (ha) of female lesser prairie-chickens marked with GPS satellite transmitters for 2013 and 2014 in Kansas and Colorado (NW = northwest Kansas, SC = south-central Kansas, CO = Colorado, ASH = Ashland, Kansas).

	2013			2014		
Region/Period	N^{a}	$\bar{x}$	SE	N	$\bar{x}$	SE
NW Kansas						
Lekking	26	355.12^{Aa*}	51.00	18	681.94^{Aa}	230.56
Nesting	19	162.68^{Bb}	24.53	22	228.59^{Bb}	53.56
Brooding	2	51.50^{Cc}	19.50	7	101.14^{Cc}	28.08
Post-Breeding	14	237.07^{Dd}	34.46	9	164.78^{Dd}	42.64
SC Kansas						
Lekking	11	216.55^{Aa}	57.65	19	668.21^{Aa}	284.82
Nesting	13	88.08^{Bb}	10.15	24	121.54^{Bb}	13.60
Brooding	3	86.33^{Cc}	31.52	3	85.00^{Cc}	51.26
Post-Breeding	6	146.33^{Dd}	44.20	9	577.56^{Dd}	260.38
Colorado						
Lekking	6	240.33^{A}	59.79	-	-	-
Nesting	4	53.25^{B}	27.03	-	-	-
Brooding	-	-	-	-	-	-
Post-Breeding	4	332.50^{D}	39.63	-	-	-
ASH Kansas						
Lekking	-	-	-	17	223.94^{A}	50.09
Nesting	-	-	-	18	77.33^{B}	13.56
Brooding	-	-	-	4	73.75^{C}	33.56
Post-Breeding	-	-	-	7	112.29^{D}	25.48

[a] Total number of 95% home ranges used to estimate mean daily movement

*Means followed by the same uppercase letter and same lower case letter do not differ ($P > 0.05$) among periods within year and between year within period.

Table 1.9 Breeding season period estimates of mean 95% home-range size (ha) of female Lesser Prairie-Chickens marked with GPS satellite transmitters pooled across years (2013, 2014) in Kansas and Colorado.

Period	N^a	$\bar{x}$	SE
Lekking	97	431.29^A	73.76
Nesting	100	137.87^B	14.36
Brooding	19	85.26^B	14.68
Post-Breeding	49	265.18^{AB}	52.89

[a] Total number of daily movement observations used to estimate mean daily movement

*Means followed by the same uppercase letter do not differ (P > 0.05) among periods within year

Appendix A - Core Area Home Range

Table A-1 Entire breeding season estimates of mean 50%home-range core area size (ha) of female Lesser Prairie-Chickens for 2013 and 2014 in Kansas and Colorado (NW = northwest Kansas, SC = south-central Kansas, CO = Colorado, ASH = Ashland, Kansas).

	2013			2014		
Region	N[a]	$\bar{x}$	SE	N	$\bar{x}$	SE
NW Kansas	13	51.85	6.98	13	45.46	4.91
SC Kansas	8	34.13	7.09	9	59.17	16.64
E Colorado	4	63.25	8.16	–	–	–
ASH Kansas	–[b]	–	–	7	29.11	2.64

[a] Total number of core home-range estimates

[b] Data was not present for that site during that year

Chapter 2 - Breeding Season Survival of Female Lesser Prairie-Chickens in Kansas and Colorado

Introduction

The largest vegetative biome in North American was the native prairie ecosystem. Grass species inhabit the continent in greater abundance than any comparable group of plants (Samson and Knopf 1994, Knopf 1994). Since European settlement in the 19th century and the advent of John Deere's steel plow, the estimated loss of grassland ecosystems in North America has exceeded 80% (Samson and Knopf 1994, Knopf 1994). Continental population declines and range contractions of North America's grassland avifauna have been well documented in scientific literature with habitat loss as the primary culprit (Brennan and Kuvlesky 2005). Coupled with more contemporary impacts to prairie landscapes such as habitat degradation, continued fragmentation, intrusion of woody vegetation, unmanaged grazing, and energy development (e.g., wind farms, oil and gas extraction), continued declines in native avifauna are on track to be one of the greatest conservation crises of the 21st Century (Brennan and Kuvlesky 2005).

Grassland obligate prairie grouse have been shown to be extremely sensitive to prairie ecosystem health and many species have been designated as at risk (Hagen et al. 2007). The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a prairie grouse species once widely distributed across the southern Great Plains of Texas, New Mexico, Oklahoma, Kansas, and Colorado in North America. Their occupied range and population size have been reduced by an estimated 90% since European settlement in the 1800s (Taylor and Guthery 1980, Hagen et al. 2004). More recent and continued range-wide population declines prompted the U.S. Fish and Wildlife Service (USFWS) to list the lesser prairie-chicken as a threatened species under the

Endangered Species Act in May of 2014 (USFWS 2014). With the increased concern for the viability of the species, further research on lesser prairie-chicken ecology is needed to fill current gaps in lesser prairie-chicken ecology and provide more recent and robust demographic information for conservation planning and management of the species.

The rate at which animals survive is one of several demographic parameters that directly affects population growth rate and is critical to the viability of wildlife populations (Pollock et al. 1990, White and Garrott 1990). Reproductive success (i.e., nest and brood survival) of grouse species has been shown on multiple occasions to be one of the most important demographic rates for the persistence of their populations (Bergerud 1988, Hagen et al. 2009). Females of promiscuous grouse species, such as the lesser prairie-chicken, provide sole parental care of nests and broods (Bergerud 1988). The ability for a nest and brood to survive is a product of the female making choices to maximize her, as well as her progeny's, survival indicating that female survival crucial to reproductive success. Female lesser prairie-chicken survival can be affected by environmental variability such as drought events, differences among populations, habitat quality, and biological season (Merchant 1982, Patten et al. 2005, Hagen et al. 2007, Lyons 2008, Grisham 2012).

Survival of lesser prairie-chickens has frequently been estimated by researchers throughout much of the specie's range with the vast majority focusing on the southern portion of Texas, Oklahoma, and New Mexico (Campbell 1972, Merchant 1982, Haukos et al. 1989, Toole 2005, Leonard 2008, Lyons et al. 2009, Jones 2009, Pirius 2011, Holt 2012, Grisham 2012). However, relatively few studies have estimated lesser prairie-chicken survival in the northern extent of the species range of Kansas and Colorado, which has recently shown to hold roughly two-thirds of the remaining range-wide population (McDonald et al. 2014). Lesser prairie-chickens are found within three distinct ecoregions forming disjunct populations within Kansas and Colorado: the Mixed-Grass Prairie Ecoregion in south-central Kansas, Short-Grass/CRP Mosaic Prairie Ecoregion in northwest Kansas, and Sand Sagebrush (*Artemisia filifolia*) Prairie Ecoregion of southwest Kansas and eastern Colorado (Figure 1.1; McDonald et al. 2014).

Three of the four studies that have estimated lesser prairie-chicken survival in the northern extent of the species range has occurred within the southwest population in Kansas in the Sand Sagebrush Prairie Ecoregion; the former stronghold of lesser prairie-chickens in Kansas (Jamison 2000, Pitman 2003, Hagen et al. 2007, Haukos et al. 2015). Hagen et al. (2007) is the only study to report seasonal variation in female survival estimates for the breeding season in Kansas with female lesser prairie-chickens having the lowest survival during the nesting and brooding periods. Only one study has estimated female survival in the northwestern population of the Short-Grass/CRP Mosaic Prairie Ecoregion and found that female survival during the breeding season was a function of precipitation with females having a 62% chance of surviving the entire breeding period (Fields 2004). No studies have estimated survival rates for lesser prairie-chickens in the Mixed-Grass Prairie Ecoregion of Kansas or estimated survival for multiple populations simultaneously. Furthermore, only Hagen et al. (2007) explicitly evaluated probable causes of mortality for females during the breeding season in Kansas. Probable causes of mortality for populations in northwest Kansas and south-central Kansas have yet to be investigated. Therefore, more recent and robust survival estimates and specific cause of mortality will provide information necessary to characterize the current status of the population as well as a critical parameters for population models that will aid in future conservation planning.

Understanding seasonal variation in survival estimates of female lesser prairie-chickens during the breeding season is critical for a species of conservation concern. Increased rates of female mortality during the reproductive periods of the breeding season could have detrimental effects for recruitment to the next year’s population. For example, losses in recruitment would not only occur from direct mortality of females, but also indirectly from the loss of potential nests and broods associated with depredated hens. Therefore, managing habitat, such as nesting, in a manner that would reduce breeding season mortality could benefit population recruitment both directly and indirectly (Hagen et al. 2007).

Survival estimates are important for conservation and management of a species as they are an essential component for development of demographic models. Unbiased survival estimation from known-fate data requires meeting several assumptions, most of which are addressed with the appropriate research design or statistical models. However, the need for more detailed information on the lesser prairie-chicken ecology and the continued technological advances in the field of biotelemetry has led to the increased interest in using reliable, light weight, solar powered, Global Positioning System (GPS) transmitters (Bedrosian and Craighead 2007).

To date, the most common method for attaching transmitters to prairie grouse species has been the necklace style attachment with a very high frequency (VHF) transmitter (Amstrup 1980, Haukos et al. 1989, Bedrosian and Craighead 2007, Patten et al. 2011). The necklace style attachment with VHF transmitters has been shown to not impact survival of lesser prairie-chickens (Hagen et al. 2006). Unfortunately, the necklace style attachment cannot be used for solar powered GPS transmitters because of weight and size constraints. GPS transmitters need to be fitted dorsally because of the solar panel placement on the transmitter (Bedrosian and

Craighead 2007). A rump-mount method was explored by Bedrosian and Craighead (2007) on greater sage-grouse (*Centrocercus urophasianus*) and they showed that survival rates did not differ between the rump-mounted attachment and the widely used necklace style attachment. On the contrary, Caudill (2011) concluded that dorsal marking of juvenile sage-grouse with sutured on backpack transmitters negatively affect survival, though no statistically significant differences between backpack-style or necklace style transmitters were estimated. Ruffed grouse (*Bonasa umbellus)* have been reported to need a longer acclimation period using a harness style attachment with some individuals not accepting the marking package. Survival of individuals with harness style backpack transmitters was slightly lower than those fitted with poncho style transmitters; but attributed the lighter weight of the poncho transmitter as the cause of the difference (Small and Rusch 1985). Prairie falcons (*Falco mexicanus*) also showed decreased survival from dorsal marking in southwest Idaho (Steenhof et al. 2006). Survival rates of both male and female spotted owls (*Strix occidentalis)* were not affected by backpack-style transmitters compared to color leg banding methods (Foster et al. 1992). Conflicting results between multiple avian species suggests that effects of dorsal marking with transmitters may be species specific and needs to be tested over multiple species to meet the fifth assumption of survival models in which the techniques themselves do not impact survival of marked individuals (Winterstein et al. 2001).

My objectives were to 1) estimate breeding season survival rates for each population in the northern extent of the species range, 2) examine variation in survival between defined biological periods of the breeding season (i.e., lekking, nesting, post-nesting), 3) investigate probable causes of female mortality, and 4) determine if survival of marked individuals differs between transmitter types. Lesser prairie-chicken populations inhabit three distinct ecoregions of

Kansas and Colorado that are characterized by different vegetative communities as a result of a west to east precipitation gradient (Grisham et al. 2015). Furthermore, landscapes within these ecoregions are impacted by differing anthropogenic land uses. Regional populations of lesser prairie-chickens in the northern extent of their range have experienced differing population trajectories over the past two decades (Garton et al. 2015). I hypothesized that female lesser prairie-chicken survival would vary by ecoregion. I predicted that 1) females in northwest Kansas would exhibit greater survival rates than the other two regional populations because the northwest Kansas population is the only population that has recently increased in size and range. Survival of female lesser prairie-chickens in the Sand Sagebrush Prairie Ecoregion has been shown to vary annually with females experiencing lower survival rates during the late spring and summer months; which coincides with nesting and brooding (Hagen et al. 2007). I hypothesized that survival of females would vary annually among all ecoregions and predicted that survival would be 2) lowest during the nesting period of the breeding season. This study is the first to use solar powered GPS transmitter with a rump-mounted harness on female lesser prairie-chickens. Conflicting evidence from previous literature suggests that transmitter effects on survival may be species specific. Female and yearling greater sage-grouse marked with GPS transmitters using a rump-mounted harness did not experience increased mortality when compared to the more conventional VHF necklace style attachment. I hypothesized that female lesser prairie-chickens would experience similar results and that survival rates of female lesser prairie-chickens would be similar between transmitter types.

Study Area

Study sites were located in Kiowa, Comanche, and Clark counties within south-central Kansas; Gove and Logan counties within northwest Kansas; and Cheyenne, Baca and Prowers counties within eastern Colorado (Figure 1.2). The northwest (NW) Kansas study area encompassed two separated sites; one located in Gove County and one in Logan County. Research in the Gove County area was conducted solely on private lands within the Short-Grass/CRP Mosaic Ecoregion (McDonald et al. 2014; Figure 1.1, 1.2). Research in Logan County was centered on The Smoky Valley Ranch owned and managed by The Nature Conservancy, as well as private lands surrounding the ranch. As a whole, the northwest study site was a mosaic of short-grass and mixed-grass prairies, land enrolled in the Conservation Reserve Program (CRP) of the U.S. Department of Agriculture, and row-crop agriculture on silt loam soils. The dominant land uses in this region were livestock grazing, row-crop agriculture, CRP, oil and gas exploration and extraction, and rural towns. Dominant vegetation in the region included: blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), buffalograss (*Buchloe dactyloides*), little bluestem (*Schizachyrium scoparium*), side oats grama (*B. curtipendula*), big bluestem (*Andropogon gerardii*), Illinois bundleflower (*Desmanthus illinoensis*), prairie sunflower (*Helianthus petiolaris*), annual buckwheat (*Eriogonum annum*), sand milkweed (*Asclepias arenaria*), nine-anther dalea (*Dalea enneandra*), and western ragweed (*Ambrosia psilostachya*; Lauver et al. 1999). Some of the grass species planted within the CRP fields included: little bluestem, side oats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*; Fields et al. 2006). After original planting in the mid-late 1980s, some CRP fields were interseeded with forbs in the mid-1990s including: white sweet clover (*Melilotus alba*), yellow sweet clover (*Melilotus officinalis*), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower, purple prairie clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*; Fields et al. 2006). Wheat

(*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*) were the major crops in the region.

The south-central Kansas study area encompassed two sites located in 1) Kiowa and Comanche counties and 2) Clark County within the Mixed-Grass Prairie Ecoregion (McDonald et al. 2014; Figures 1.1, 1.2). Research was conducted solely on private lands. This region was characterized by large intact tracts of native mixed-grass prairie with minimal row crop agriculture. The region was primarily used for livestock grazing, oil exploration and extraction, with row-crop agriculture interspersed throughout the region located principally in bottomlands or adjacent to riparian areas. Dominant vegetation within the region included: little bluestem, blue grama, hairy grama, side oats grama, buffalograss, sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludiviciana*), annual sunflower (*Helianthus annuus*), western ragweed, sand sagebrush (*A. filifolia*), alkali sacaton (*Sporobolous airoides*), Russian thistle (*Salsola kali*), kochia (*Kochia scoparium*), eastern red cedar (*Juniperus virginiana*), and sand sagebrush (Lauver et al. 1999).

Within eastern Colorado, study sites were located on private lands in Cheyenne, Baca, and Prowers counties (Figure 1.2). The study area was within the Sand Sagebrush Prairie Ecoregion as defined by McDonald et al. (2014; Figure 1.1). Land use within the Cheyenne County study site included mainly livestock grazing with relatively little row-crop agriculture or energy exploitation. The study site located between Baca and Prowers counties was a mosaic of livestock grazing, row-crop agriculture, previously cultivated lands enrolled in the CRP, and minimal oil and gas development. Dominant vegetation for the region was comprised of: blue grama, hairy grama, side oats grama, buffalograss, little bluestem, big bluestem, sand sagebrush, kochia, and Russian thistle. Major crops within the region included wheat, sorghum, and corn (D. Sullins unpublished data).

Highly variable environmental conditions were experienced across all the study areas during 2013 and 2014. Much of the western portion of Kansas and eastern Colorado was in moderate to extreme drought conditions from 2012 to 2014, according the Palmer Drought Severity Index (Index Value = -2.00 to -4.00 or below; NOAA 2014). The long-term average annual precipitation for western Kansas and eastern Colorado is ~47 cm (HPRCC 2013). During 2012, the region received a total of ~ 25 cm of precipitation; increasing slightly in 2013 to 31 cm (Kansas Mesonet 2014). Coupled with the lack of rain, most areas grazed by livestock were in poor range condition. The vegetative growth was highly suppressed and resulted in CRP fields being emergency hayed, a policy allowed under emergency drought conditions in CRP as declared by the USDA Farm Service Agency for individual counties (R. Plumb, personal observation). Drought-relieving precipitation began in mid-May through early August 2014, with an approximate total precipitation of 35 cm between 1 January – 31 August, 20.5 cm of which fell between 15 May – 15 July (Kansas Mesonet2014; Figure 1.3). Prairie ecosystems responded positively to precipitation and stable temperatures with robust vegetation growth in summer of 2014 (R. Plumb, personal observation).

Environmental conditions in south-central Kansas were slightly better compared to the more western region of the state and eastern Colorado. The Palmer Drought Severity Index placed south-central Kansas under moderate – severe drought conditions during 2012 and early 2013 (Palmer Index Value = -2.00 to - 3.99; NOAA 2014). The long-term annual average precipitation for south-central Kansas is ~ 70.7 cm (HPRCC 2013). The region received an approximate total of 42.5 cm of precipitation during 2012 and 55 cm in 2013. South-central

Kansas received weekly precipitation events from mid-March to mid-June in 2013 and received roughly 43% more precipitation than northwest Kansas and Colorado (Kansas Mesonet 2014). Although this region received greater precipitation than other portions of the lesser prairie-chicken range in Kansas and Colorado in 2013, it was approximately 22% less than the average precipitation for this area. The drought continued into 2014 with very dry conditions persisting until late May. The drought continued in early summer when the region received approximately 53 cm of precipitation from 1 January – 31 August with ~ 77% from 1 June – 31 July (Kansas Mesonet 2014; Figure 1.3). Increased vegetation growth was witnessed during 2014 (Lautenbach 2014). The Ashland, Kansas, study area was established in 2014 and environmental conditions were similar to the rest of the south-central portion of Kansas (D. Sullins, personal communication).

Methods and Materials

Capture and Marking

Lesser prairie-chickens were captured using walk-in drift traps (Haukos et al. 1990) and drop nets during the spring lekking period; March – mid May. Immediately upon capture, lesser prairie-chickens were sexed, aged (Copelin 1963) and females were fitted with either a 22-g (<3% body weight), solar-powered, satellite-received transmitter (Wegge et al. 2007) or a 15-g, very-high-frequency radio transmitter (VHF; Hagen et al. 2005). In Kansas, I used model 100 GPS Platform Transmitting Terminals (PTT) by Microwave Telemetry Inc. (Columbia, Maryland, USA) and in Colorado we used model 22 GPS PTT by NorthStar Science and Technology, LLC (King George, Virginia, USA) with a modified rump-mount harness (Bedrosian and Craighead 2007). Each PTT contained sensors to transmit calibrated indices for unit temperature and motion, which were used to determine if the bird was alive. The VHF radio transmitters weighed 12 g, equipped with a 12-hr mortality switch, and attached using a bib/collar attachment (Amstrup 1980). Transmitters had an average lifespan of 350 days (Advanced Telemetry System, Isanti, Minnesota, USA). Females were given either a VHF or GPS transmitter in an every-other sequence in an effort to obtain an unbiased sample that would allow us to compare transmitter effects on survival. Captured individuals were released within 60 min at the capture site. All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee under protocol # 3241, the Kansas Department of Wildlife, Parks, and Tourism scientific collection permit numbers SC-042-2013 and SC-079-2014, and the Colorado Parks and Wildlife permit numbers 13TRb2053 and 14TRb20153.

Tracking

Satellite-marked birds were tracked using GPS/Argos system. GPS locations were taken every 2 hours from 0400 – 2200 hours resulting in approximately 10 locations per day. This varied based on the daily solar charge. Locations were uploaded every 3-4 days when the likelihood of a satellite pass was greatest. Microprocessor controlled battery charge management allows the PTT to charge during the day, collect data, and transmit at night. Temperature readings and movement between locations were used to determine mortality events. I assumed a mortality occurred if temperature signatures of the bird fluctuated similar to the ambient temperature of the surrounding environment and consecutive locations were taken at the same point. On occasion, transmitters would stop transmitting from being buried or flipped over and could not charge. I would investigate all potential mortalities at the last location given and retrieve the GPS transmitter if possible. Positions were downloaded on a 7-day cycle, which made determining cause of mortality difficult. The longer the carcass was present on the landscape, the greater the potential for confounding evidence from multiple predators at the mortality site as a product of scavenging (Bumann and Stauffer 2002, Hagen et al. 2007). Therefore, causes of mortalities were only classified for those within 7 days since the mortality event; every attempt was made to get to the mortality as soon as possible.

I regularly located VHF-marked individuals (i.e., 3+ times/week) using a three-piece, hand-held Yagi antenna, along with a radio receiver (Advanced Telemetry Systems, Isanti, Minnesota, USA and Communication Specialists, Inc. Orange, California, USA). When a mortality switch had been activated on a VHF transmitter, I homed in and retrieved the radio collar as soon as it was possible. When birds were lost or emigrated from the immediate study area, fixed-wing aircraft were used to conduct aerial surveys to find lost transmitters. If significant time had passed since relocation attempts (>3 days), I estimated the mortality date as the median date between the date that the bird was successfully located as alive and the date at which the mortality signal was heard.

Probable Causes of Mortality

When kill sites and/or carcasses were located, they were classified as either mammal, avian, snake, accidental, or unknown. Bite marks, tracks in the soil, a cached carcass, scat, or chewed and feathers stuck together from saliva indicated mammal predation and was classified accordingly. Potential mammalian predators observed at the field sites included American badger (*Taxidea taxus)*, coyote (*Canis latrans*), swift fox (*Vulpes velox*) and bobcat (*Lynx rufus*). Avian predation was classified if there were no apparent tooth marks on the transmitter or harness, the carcass had been decapitated, a feather pile was present with no apparent chewing of the feathers, the breast muscle had been cleaned, bird feces, and/or placement of colored leg bands in a pile next to the carcass. Red-tailed hawk (*Buteo jamaicensis*), golden eagle (*Aquila* *chrysaetos*), ferruginous hawk (*B. regalis*), rough-legged hawk (*B. lagopus*), northern harrier (*Circus cyaneus*), prairie falcon (*Falco mexicanus*), peregrine falcon (*Falco peregrinus)* and great-horned owl (*Bubo virginianus*) were potential avian predators of lesser prairie-chickens (Hagen et al. 2007). Lesser prairie-chickens that were suspected of death from collision with anthropogenic features or farm machinery were considered accidental mortality. Collisions were suspected when a carcass was found near an anthropogenic feature with no indications of death from a predator or indications of impact such as feathers on a barbed wire fence. Mortality from farm equipment was suspected when a female was using an agriculture field and death happened soon after harvest or the carcass was plowed under ground from farm machinery. Unknown mortalities were those that we were unable to get to within 7 days or had multiple forms of evidence clouding my ability to determine cause of mortality (Jamison 2000). In the event that I recovered a carcass intact, it was classified as unknown.

Data Analysis

Survival Modeling

I estimated breeding season survival (15 March – 15 September) using known-fate models in Program Mark 7.1 (Cooch and White 2012). Encounter histories were developed where each estimation period was a weekly time-step and coded as either live, dead, or censored. I developed 11 *a priori* survival models using my hypotheses and objectives as my modeling framework. I examined the effects of the covariates of ecoregion, year, and period on survival where region and year were coded as groups and period as the time-dependent variation in the breeding season data. Biological periods were defined as temporal categories: lekking, nesting and brooding, and post-nesting. I characterized the lekking period as the beginning of the breeding season (15 March) to the median laying date (i.e., nest initiation; 23 April) of all first nest attempts. The nesting and brooding period was defined as the time from the median laying date of all initial nesting attempts to the median last-date active (i.e., hatch or fail; 22 June) for all re-nest attempts. Last, the post-nesting period was characterized as the time between the last-date-active for all re-nest attempts to the end of the breeding period (15 September). I was not able to discern the brooding period from the nesting period using this approach because transitions between nesting and brooding periods are based on the individual. The transition from one period to the other is not a linear progression through time as females can shift back and forth depending on the fate of the nest (Figure 1.4). Therefore, I recognize that the "nesting period" as I have defined it in this chapter, will incorporate females that had successful nests and are in the brooding period of the breeding season. Regardless, females have been shown to have heightened vulnerability to predation during these periods so overlap in biological periods should not affect my results (Hagen et al. 2007).

Estimates of period survival indicating the probability of surviving each period from the beginning of the period to the end were calculated using the weekly parameter estimate for that period and raising it to the power of the number of weeks within the period. The lekking period began 15 March and ended 22 April, the nesting and brooding period began 23 April and ended 22 June, and the post-nestng period began 23 June and ended 15 September. I used the Delta method to calculate the variance associated with each derived estimate to get the standard error and 95% confidence intervals (Powell 2007).

To determine if transmitter type affected female survival, I estimated survival rates using the staggered entry Kaplan-Meier survival method (White and Garott 1990) with the package Survival (Therneau 2014) in program R (R core development team, version 3.1.2, 2014, Vienna, Austria). I compared estimated survival rates for females with VHF and GPS transmitters during the breeding season for each region and between years. Statistically significant differences were survival estimates that had non-overlapping 95% confidence intervals at the end of breeding season. Birds that were right censored as a result of emigrating from the study area or had transmitter failure could have survived till the end of the breeding season. Therefore, I also adjusted all right-censored VHF encounter histories to having survived the entire period and compared that VHF survival estimate to that of the GPS marked birds.

Results

We captured and fitted a total of 201 (114 GPS and 82 VHF) female lesser prairie chickens in Kansas and Colorado with transmitters (Table 1.3). I right censored 14 marked females: 12 VHF and 2 GPS. Right censoring for VHF birds was primarily caused from losing radio signals as a result of failure or emigration. Only two GPS-marked females were right censored in my survival analysis; one bird slipped its harness and the other had a faulty transmitter.

Survival for female lesser prairie-chickens during the 6-month breeding season and across all regions and combined transmitter type was estimated to be 0.455 (S_{constant}; 95% CI = 0.38 – 0.53). Survival of female lesser prairie-chickens varied between years and among regions with the greatest regional survival rates in south-central Kansas and eastern Colorado (Figure 2.1). Across years, regional female survival estimates for south-central Kansas, northwest Kansas, and Colorado were 0.55 (S_{region}; 95% CI = 0.42 – 0.66), 0.39 (S_{region}; 95% CI = 0.29 – 0.48), 0.49 (S_{region}; 95% CI = 0.11 – 0.80), respectively (Figure 2.2). Female survival across all regions was lowest in 2013 with an estimate of 0.42 (S_{year}; 95% CI = 0.31 – 0.52). The probability of surviving the entire breeding season increased in 2014 by 14.3% to 0.48 (S_{year}; 95% CI = 0.38 – 0.58). Regional variation in survival among years was observed with the northwest Kansas increasing approximately 32.5% from 0.34 (95% CI 0.21 – 0.46) to 0.44 (95% CI 0.30 – 0.58) from 2013 to 2014. Annual survival for south-central Kansas decreased 10.9% from 0.59% (95% CI 00.35 – 0.77) in 2013 to 0.53% (95% CI 0.38 – 0.66) in 2014. Survival in Colorado decreased 39.5% from 0.55% (95% CI 0.09 – 0.86) in 2013 to 0.33% (95% CI 0.00 – 0.86) in 2014, however the sample size was low in both years (2013 N = 6; 2014 N = 2; Figure 2.1)

Period within breeding seasons was an important structure within all top-ranked models (Table 2.1). The weekly survival rates for each period were 0.98 (S_{period}; 95% CI = 0.96 – 0.99) for the lekking period, 0.96 (S_{period}; 95% CI = 0.94 – 0.97) for the nesting and brooding period, and 0.98 (S_{period}; 95% CI = 0.97 – 0.99) for the post-nesting period. The time-dependent variation in survival was explained by period with the nesting period (23 April – 22 June) having the lowest probability survival compare to the other two periods (Figure 2.3). The probabilities of female lesser prairie-chickens surviving the lekking, nesting, and post-nesting periods were 0.89 (S_{period}; 95% CI = 0.79 – 0.94), 0.67 (S_{period}; 95% CI = 0.60? – 0.74), and 0.82 (S_{period}; 95% CI = 0.74 – 0.88), respectively. The nesting period contained the majority (59.5%) of all observed mortalities during the breeding season with 30.4% of all observed mortalities occurring within the first 3 weeks (21 April – 11 May). Variation in breeding season survival was best explained by a year and period interaction as the only parsimonious model ($\Delta\text{AIC}_c \leq 2$) in the model set (Table 2.1). The pattern of survival through the breeding season periods was consistent across years and regions but from 2013 to 2014, survival decreased 15.2% during the lekking period, increased 22.5% during the nesting period, and decreased slightly (6.2%) during the post-nesting period (Figure 2.4). Period survival estimates varied by region with Colorado having the highest probability of survival during the lekking and post-nesting period. South-central Kansas had the highest probability of female survival during the nesting period but the lowest during the lekking period. Northwest Kansas had the lowest probability of survival during the post-nesting period (Figure 2.4).

A total of 69 mortality events were confirmed across all study regions; however, only 35 of those were investigated within the 7-day post-mortality criteria. The majority of mortality was attributed to avian predation (45.7%). Mammals accounted for 34.3% of the breeding season mortality. Two mortalities (5.7%) were thought to be caused by snake because both females were incubating and the carcass was found near the nest with no indication of damage from a weather event or predation. One had a peculiar brown liquid emanating from the mouth. The cause of mortality was not determined for 5 mortality events (14.3%) because of confounding evidence or the sites were plowed under before investigation. Out of all 69 confirmed mortalities, five (7.2%) were possibly caused by accidental situations such as fence collisions or agriculture equipment. Two of the 5 mortalities (2.9%) were in agricultural fields that coincide with tilling of agricultural fields. At both, kill sites and transmitters were plowed under before we could retrieve them and assess the probable cause of mortality. Fence collisions were infrequent but 3 mortalities (4.3%) were found within close proximity to barb wire fence lines. We witnessed no evidence of collision (e.g., feathers stuck to the fence, blood on barbs, ripped skin, etc.) with the fence itself and each site had confounding indicators such as mammal track, bird scat, or no carcass with the transmitter completely intact. The causes of these mortalities were uncertain and did not fall within the required 7 day window for inclusion into my analysis.

Survival estimates pooled across regions and years did not differ between transmitter types (Figure 2.5). The probability of surviving from the beginning to the end of the breeding season was 0.48 (95% CI = 0.39 – 0.58) for GPS-marked individuals and 0.50 (95% CI = 0.38 – 0.64) for VHF-marked birds. I did observe some annual variation between survival estimates for transmitter type with the difference between survival estimates being greater during 2013 than 2014 (Figures 2.6, 2.7). In 2013, birds marked with a VHF transmitter were more likely to survive the entire breeding season than birds marked with GPS transmitters, but the difference in survival estimates was not statistically significant (GPS: 0.45 95% CI 0.33 – 0.62; VHF: 0.55 95% CI 0.42 – 0.74). Differences in survival estimates became non-existent in 2014 with females that were marked with a GPS transmitter having a slightly higher probability of surviving the breeding season (0.51 95% CI 0.40 – 0.65) compared to a VHF transmitter (0.50 95% CI 0.36 – 0.69).

To investigate the plausibility that the differences in survival estimates between GPS- and VHF-marked birds were masked by right censoring of lost VHF marked birds or radio failure, I adjusted the analysis to have all right censored VHF marked individuals survive the entire breeding season. The adjusted survival probabilities were 0.56 (95% CI 0.43-0.74) for 2013, 0.56 (95% CI 0.43-0.74) for 2014, and 0.54 (95% CI 0.42-0.68) when pooled across years (Figure 2.8). I witnessed negligible increases in survival estimates of VHF marked birds with survival estimates increasing 2% in 2013, 12% in 2014, and 8% when pooled across years. These small increases in survival of VHF birds remained statistically insignificant when compared to GPS marked birds (Figure 2.8).

Discussion

Consistent with my hypothesis and prediction, breeding season survival was best explained by variation in survival among seasonal periods, with the nesting and brooding period having the lowest probability of survival. This was consistent across years and regions. Females in the Sand Sagebrush Prairie Ecoregion of southwestern Kansas showed consistently the same pattern of survival from 1998 – 2002 with survival being highly associated with mortality rates of incubating females on nests (Hagen et al. 2007). Similar results were found for New Mexico, Oklahoma, and Texas where mortality of lesser prairie-chickens peak during the breeding season (Patten et al. 2005, Lyons et al. 2009).

Predation had a considerable effect on female lesser prairie-chickens during the breeding season with ~60% of all observed mortalities occurring during the nesting and brooding period. Hagen et al. (2007) reported similar intensities of predation during the nesting period of the breeding season in the southwestern region of Kansas with mammals being suspected as the major predator. However, contrary to their findings, we found that avian predation was the dominant form of mortality for the regional populations investigated by this study. Avian predators were suspected of causing over half of all mortality events across all ecoregions. My results were consistent with a study in the southern portion of the Mixed-Grass Prairie Ecoregion in Oklahoma, where avian predation caused the most mortality (Wolfe et al. 2007). Mammals were still an important predator of females, causing 34.2% of all observed mortalities. It is possible that mammalian predation was the dominate form witnessed in the Sand Sagebrush Prairie Ecoregion of southwestern region of Kansas because the shrub-dominated habitat provided adequate overhead cover for concealment from avian predators, but did not hinder scent-oriented mammalian predators (Hagen et al. 2007). I hypothesize that heightened avian predation in grassland landscapes may be a result of reduced overhead nesting cover from drought conditions and intensive grazing. Evidence from 2013 supports this hypothesis as the raptor migration northward was delayed from a late spring. Based on open source information from eBird, indicated that avian predator occurrence peaked in tandem with the peak in female mortality distribution; which coincided with the nesting period of the breeding season (eBrid, accessed 12/10/13, http://ebird.org/ebird/summaryLocation.form; Figure 2.9). Therefore, managing habitats in grassland dominated landscapes that promotes overhead cover and moderate mid-level cover may help reduce both dominate forms of mortality.

Collisions with fences and other anthropogenic features have been shown to be a substantial form of mortality for lesser prairie-chickens in Oklahoma (Wolfe et al. 2007). Hagen et al. (2007) found some evidence of collisions with power lines in southwestern Kansas but concluded that the losses were relatively small. No mortalities were attributed to collisions with power lines during this study; however, only three mortality events (4.3%) were potentially caused by collisions with fences; 2 in northwest Kansas and 1 in Colorado. Results were inconclusive as the sites were not reached within the 7-day criteria and scavenging was apparent. Regardless, fence collision appears to be a minor type of mortality for my study.

Previous estimates of survival probabilities for the breeding season in Kansas from Fields (2004) and Hagen et al. (2007) range from 0.62 – 0.76 and were ~35% greater than the estimate reported here (0.46), respectively. I hypothesize that reduced breeding season survival rates of female lesser prairie-chickens for the northern portion of the species range compared to previous estimates are a product of a prolonged drought that started in 2011, peaked in 2012, and lasted through 2014 (Grisham 2012, Hoerling et al. 2013). Lower survival rates coinciding with one of the most severe droughts on record, rivaling the Dust Bowl of the 1930s (Hoerling et al. 2013), suggests that survival rates are negatively affected by drought. In northwest Kansas, Fields (2004) found that weekly survival estimates were related to precipitation. Precipitation is the primary ecological driver of vegetative productivity among the ecoregions of the southern Great Plains because of its erratic availability (Grisham et al. 2015). The relationship between drought and survival is most likely a product of reduced vegetative growth especially for periods that exhibit heightened sensitivity to predation such as the nesting period (Merchant 1982, Peterson and Silvy 1994, Fields 2004, Grisham 2012).

During the initial portion of the breeding season (lekking and nesting), females are selecting habitats that are a result of residual growth from the previous year. Reductions in habitat quality and/or availability as a result of either reductions in precipitation from drought or disruptions in the timing of precipitation outside of the peak growing season could affect breeding season survival rates. Breeding season survival of female lesser prairie-chickens increased 16.3% from 2013 to 2014; most likely as a result from a 22.5% increase in survival during the nesting period. Increased 6-month breeding season survival may have been caused by increased precipitation during the summer months of 2013 resulting in increased vegetative structure during the spring of 2014 (J. Lautenbach and R. Plumb, personal observation; Figure 1.3); although the total amounts were below the annual average. Furthermore, survival of female lesser prairie-chickens is highly dependent on their ability to use their cryptic plumage and the available habitat to avoid predators (Hagen et al. 2007). Reduction in vegetative structure during the breeding season, as a function of drought, may reduce the effectiveness of their plumage and potentially make them more visible to avian predators. My results indicated that avian predators were the largest form of breeding season mortality further corroborating the relationship between precipitation, vegetative cover, and female survival.

Precipitation is a phenomenon that occurs heterogeneously across the northern extent of the lesser prairie-chicken's range because of a precipitation gradient where precipitation increases from west to east (Grisham et al. 2015). Vegetation and survival likely respond in a similar fashion. In support of my hypothesis, female lesser prairie-chicken survival varied between study regions and between years. Contrary to my prediction however, the northwest Kanas region had the lowest female survival whereas the south-central region consistently had greater female survival. Survival estimates from Colorado were similar to south-central Kansas; however, Colorado had high uncertainty in the estimates mainly due to a low sample size (n = 8). The probability of females in south-central Kansas surviving the entire breeding season in 2013 was 77% greater than females in northwest Kansas. Differences in survival estimates coincides with south-central Kansas receiving 72.4% more precipitation than northwest Kansas in 2012. Northwest Kansas received 50.4 % more precipitation in 2013 than 2012. Subsequently, survival increased 32.5% from 2013 to 2014. This trend however did not hold for south-central Kansas as precipitation increased 31.3% from 2012 to 2013 but survival decreased 10.9% from 2013 to 2014. The decrease in survival in south-central Kansas in the presence of increased precipitation may be indicating a threshold at which precipitation on the landscape no longer aids in increased survival because of the physical growth capacity of the plant community itself. Another possibility is that other drivers influencing plant growth such as grazing may mask the positive effect of precipitation (Milchunas et al. 1994). It is reasonable to assume that as plant production increases, ranchers may increase their herds which would in turn limit the vegetative structure and potentially mask the effects of precipitation on survival. Regardless, the variability between precipitation/vegetation relationships and potential survival responses is unique in that it indicates that ecoregions are dynamic from one another either from the amount of precipitation it receives, the physical constraints of the plant community, and/or the differences in anthropogenic landuses. Thus, conservation decisions may need to be made based on the ecoregion under question to adequately manage for the lesser prairie-chicken populations.

Lesser prairie-chickens have evolved on landscapes that regularly experience drought and have thus far shown resilience in their ability to rebound within relatively short time-frames (Crawford and Bolen 1976, Merchant 1982, Grisham 2012). The climate of the Great Plains is projected to change with decreased precipitation, increased temperatures, and increased drought events becoming more prevalent (Grisham et al. 2015). The 2012 drought was one of the most extreme drought events on record, resulting in lower breeding season survival rates than compared to the southern portion of their range (Merchant 1982, Haukos et al. 1989, Jones 2009, Toole 2005, Grisham 2012, Holt 2012). From 2012 to 2013, the northwest Kansas ecoregion was considered to be in extreme drought and received only 52% of its long-term annual average precipitation (HPRCC 2013), and subsequently had the lowest breeding season survival estimates ever recorded for lesser prairie-chickens; females had a 33.5% chance of surviving the entire breeding season. Survival rates reported here in association with extreme drought conditions reveal a glimpse of potential demographic rates that may occur more frequently in the future. I would predict that increased frequencies or prolonged drought events would increase the time it would take a population to rebound from a drought event. If the time it took to recover from a drought was longer than the time span between reoccurring droughts, continued low survival rates could have compounded effects on the population and be detrimental to population persistence. Furthermore, the effect of drought could be exacerbated by fragmentation, changing landuse practices, as well as functional habitat loss from anthropogenic structures (Grisham et al. 2015). Understanding the relationships and thresholds between environmental conditions, anthropogenic impacts, and lesser prairie-chicken demographic rates will be of vital importance for long-term conservation planning.

Estimates of survival are important for conservation and management of a species as survival is a dominant component needed for development of demographic models to guide conservation and management efforts. Additionally, survival estimates need to be unbiased and meet the fifth assumption of survival models where the methods of extracting survival data does not impact the survival of the individuals (i.e. tracking methods should not affect survival; Winterstein et al. 2001). This study is the first study to attach GPS transmitters using a rump mounted harness on lesser prairie-chickens. Consistent with my hypothesis that survival rates would be similar between transmitter type, I found no differences in breeding season survival between transmitter type overall; even after adjusting right-censored VHF birds. My results are consistent with studies that have used rump-mounted GPS transmitters on greater sage grouse in Wyoming (Bedrosian and Craighead 2010). Hagen et al. (2006) indicated that radio marking male lesser prairie-chickens did not affect their survival. The research presented here adds to this conclusion, indicating that two different forms of radio marking do not impact female lesser prairie-chicken survival during the breeding season.

I did witness some annual variation in survival estimates with VHF marked birds having greater survival in 2013 than GPS marked birds. Differences between transmitter types changes in 2014 with GPS marked birds having slightly greater survival than VHF marked birds. Given the evidence that my survival research has produced, I would hypothesized that survival of GPS marked birds may decrease during drought years as overhead vegetation is reduced from stunted growth and continued grazing pressure. It is possible that increase detectability by avian predators during times of reduced overhead vegetative cover could be a product of dorsal marking; which is a current requirement of solar powered transmitters (Haukos et al. 1989).

Management Implications

Female mortality was greatest during the nesting and brooding period of the breeding season but varied between regions and years. Management guidelines should be implemented based on the ecoregion under question and focused on creating suitable nesting habitat that minimizes female loss during the breeding season. Management should focus on providing suitable nesting habitat that minimizes avian and mammalian predation. In ecoregions dominated by grasses, managers should ensure that a minimum of 1.5 – 2.5 dm of 75% visual obstruction with increased litter depth is available during the breeding season (Lautenbach 2014). Nesting habitat in shrub dominated communities should be managed for moderate vertical structure with 15-20% of canopy cover (Hagen et al. 2007). Managing habitat in accordance with these recommendations and for specific vegetative communities will likely increase female survivorship during the nesting period. Precipitation plays an important role in survival as it dictates vegetative growth and extreme reductions in precipitation may have detrimental effects to breeding season survival. Predicting drought earlier than 6 months is difficult if not impossible because of the annual variation in the Southern Oscillation in the Pacific Ocean (Grisham et al. 2015). Management options in such situations would be limited to proactive measures and should focus on providing adequate nesting habitat year round by reducing livestock grazing when minimum nesting habitat conditions have been met (Hagen et al. 2004). Residual vegetative structure should be assessed after the growing season of the year prior to the nesting season of interest. Managing grasslands in this manner will not only benefit nesting females and ultimately population growth, maintain pasture integrity for cattle producers, but buffer against potential drought that will provide habitat for lesser prairie-chickens and also a reserve stand of forage for cattle (Holechek et al. 1998). Furthermore, future research should explicitly test immediate and delayed impacts of precipitation at regional scales, and the effect of different grazing management plans and stocking rates on female survival,.

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Figure 2.1 Female lesser prairie-chicken probabilities of surviving the 27-week breeding season (15 March – 15 September) for each region (northwest Kansas, south-central Kansas, and Colorado) and year (2013, 2014). Estimates were generated using weekly survival estimates from Known-Fate Models in Program MARK and extrapolating those by the number of weeks within the breeding season. The 95% CIs were calculated using the Delta Method.

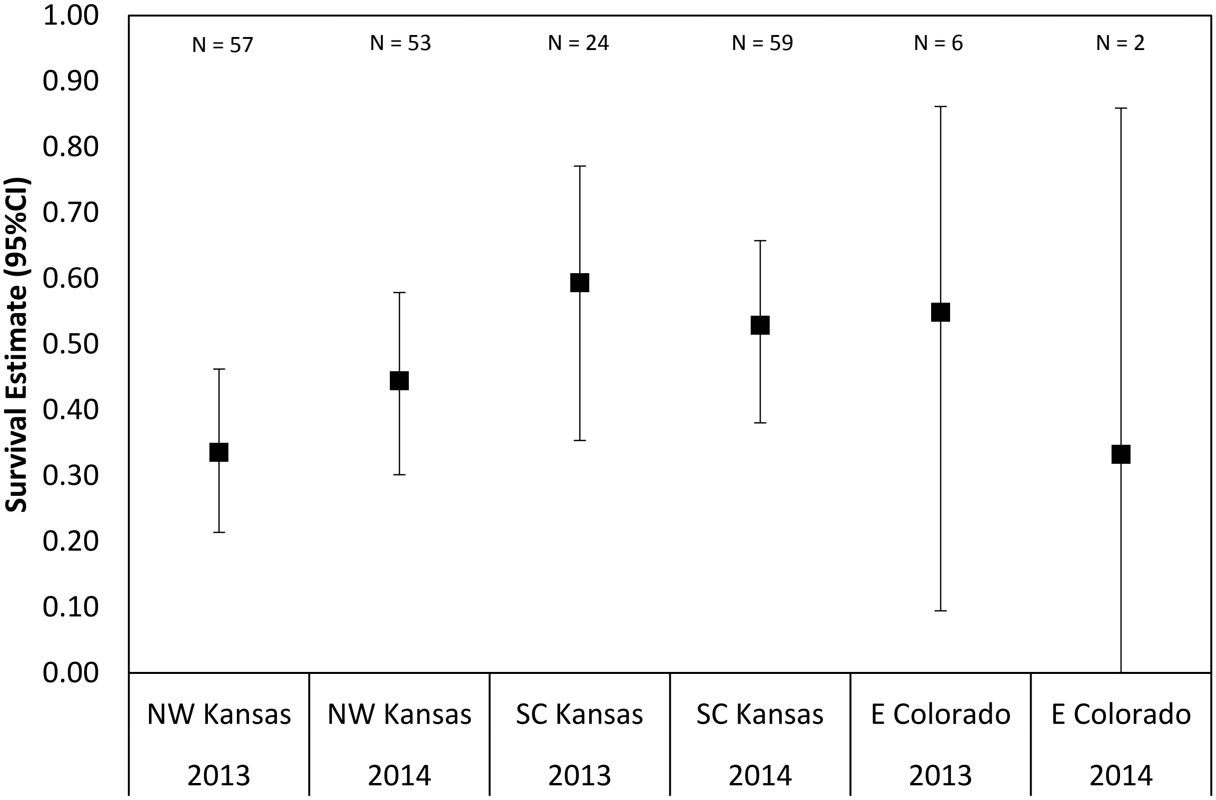

Figure 2.2 Female lesser prairie-chicken probabilities of surviving the 27-week breeding season (15 March – 15 September) for each region pooled across years (2013, 2014). Estimates were generated using weekly survival estimates from Known-Fate Models in Program MARK and extrapolating those by the number of weeks. The 95% CIs were calculated using the Delta Method.

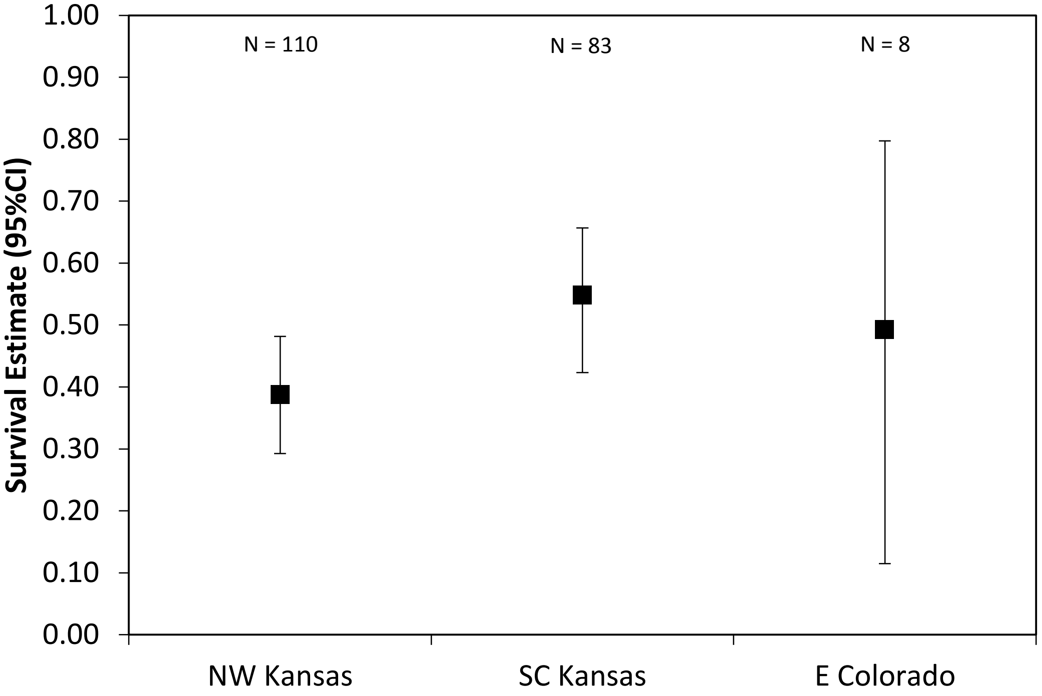

Figure 2.3 Female lesser prairie-chicken probabilities of surviving each period within the breeding season across all regions (northwest Kansas, south-central Kansas, Colorado) and years (2013, 2014). Breeding season periods are characterized as the lekking (15 March – 22 April), nesting and brooding (23 April – 22 June), and post-nesting (23 June – 15 September). Estimates were generated using weekly survival estimates from Known-Fate Models in Program MARK and extrapolating those by the number of weeks within each period (Lekking = 6, Nesting = 9, Post-nesting = 12). The 95% CIs were calculated using the Delta Method.

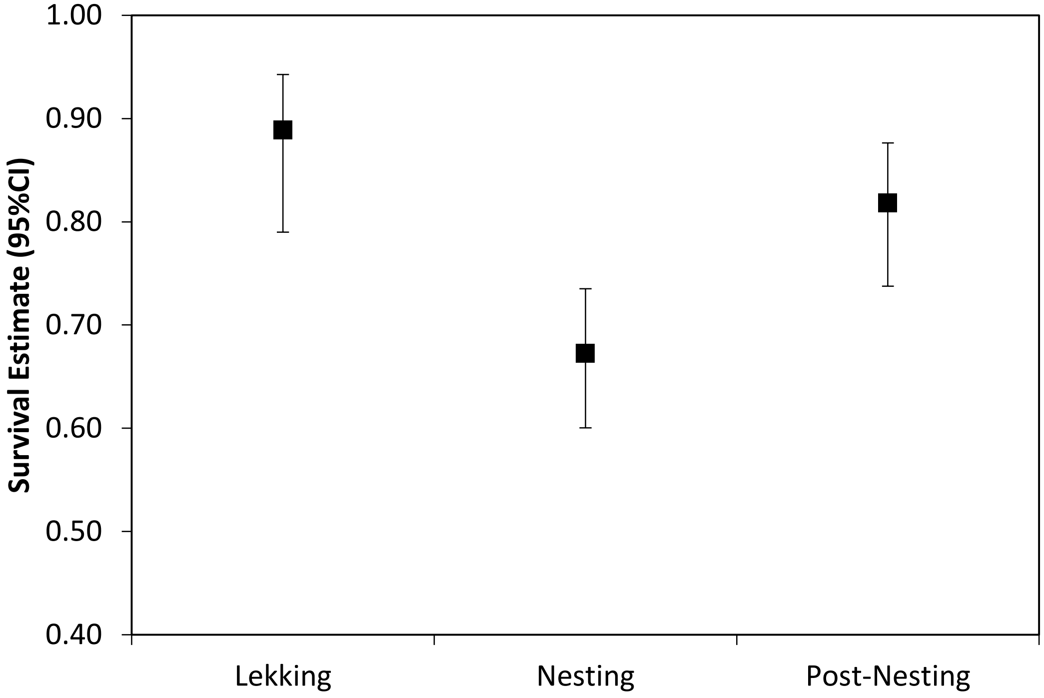

Figure 2.4 Female lesser prairie-chicken probabilities of surviving each period within the breeding season. Breeding season periods are characterized as the lekking (15 March – 22 April), nesting and brooding (23 April – 22 June), and post-nesting (23 June – 15 September). Chart A represents each region (northwest Kansas, south-central Kansas, Colorado) pooled across years (2013, 2014) and chart B represent differences in years across regions. Estimates were generated using weekly survival estimates from Known-Fate Models in Program MARK and extrapolating those by the number of weeks within each period (Lekking = 6, Nesting = 9, Post-nesting = 12; CIs were omitted for clarity).

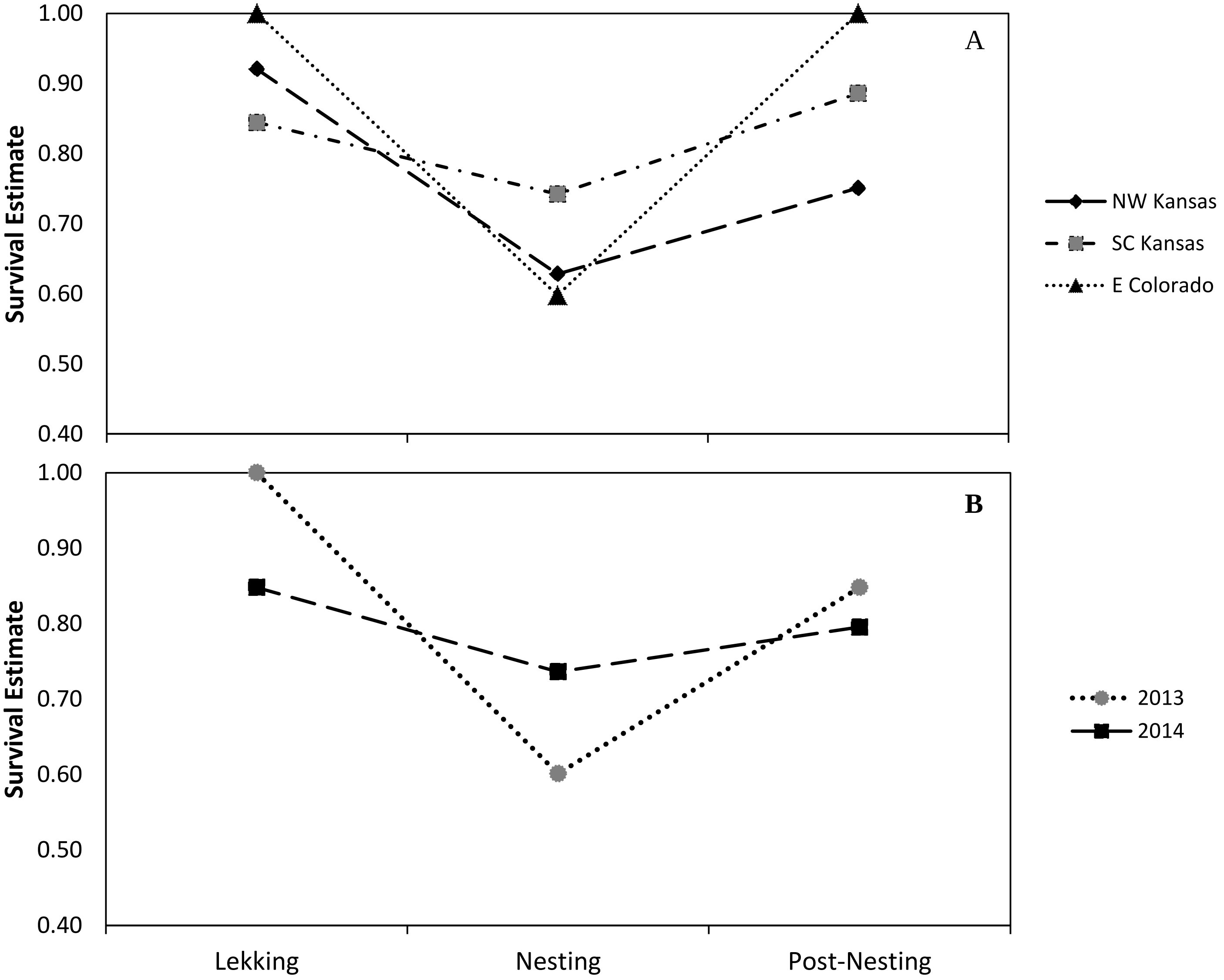

Figure 2.5 Comparison of female lesser-prairie chicken survival rates (Kaplan-Meier) for birds marked with either necklace style VHF transmitter (15-g, N = 87) or a rump-mounted GPS transmitter (22-g, N = 114) during a 27-week breeding season (15 March – 15 September) in Kansas and Colorado for 2013 and 2014 (CIs were omitted for clarity).

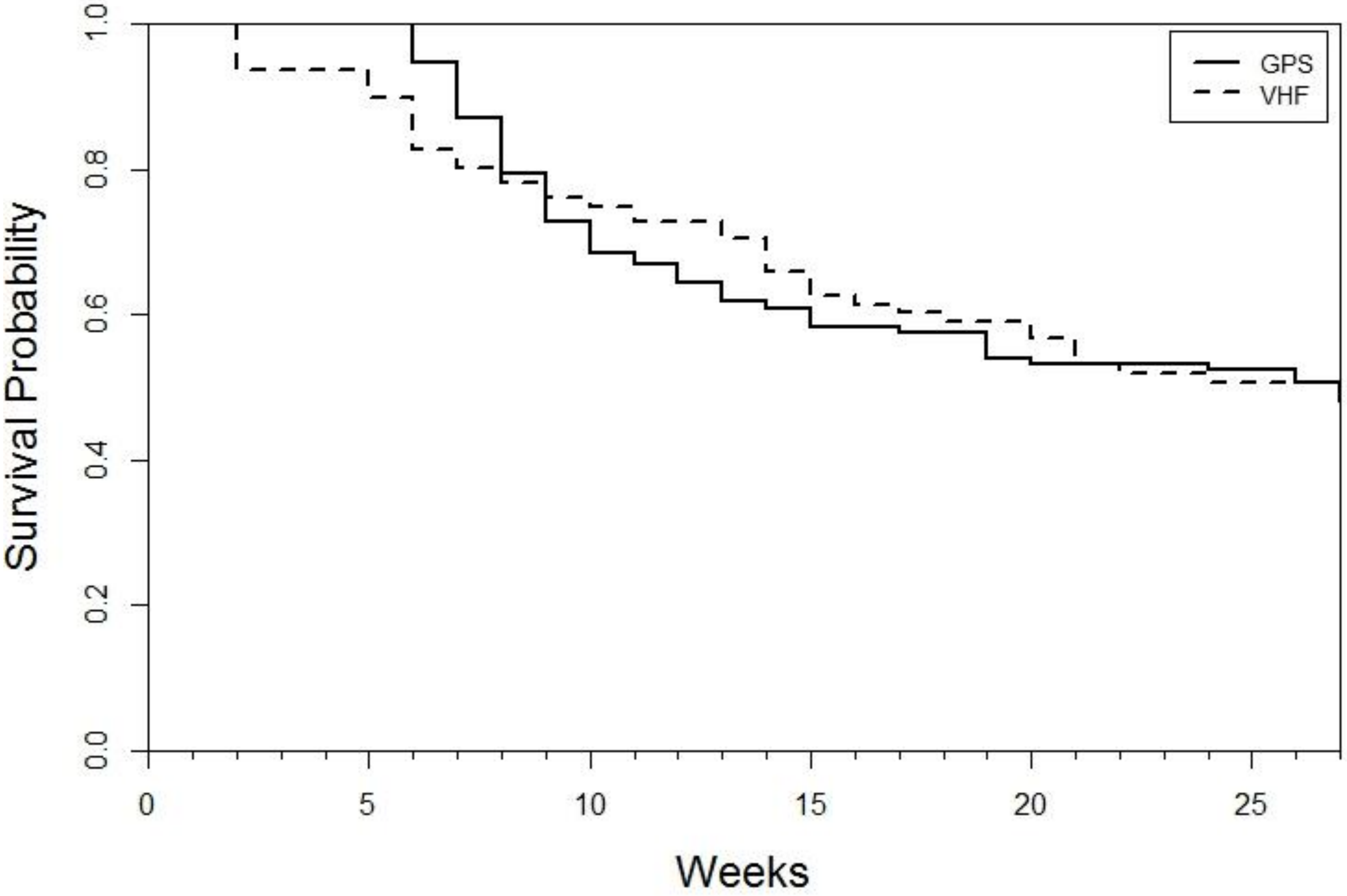

Figure 2.6 Comparison of female lesser-prairie chicken survival rates (Kaplan-Meier) for birds marked with either necklace style VHF transmitter (15-g, N = 39) or a rump mounted GPS transmitter (22-g, N = 48) during a 27-week breeding season (15 March – 15 September) in Kansas and Colorado, 2013 (CIs were omitted for clarity).

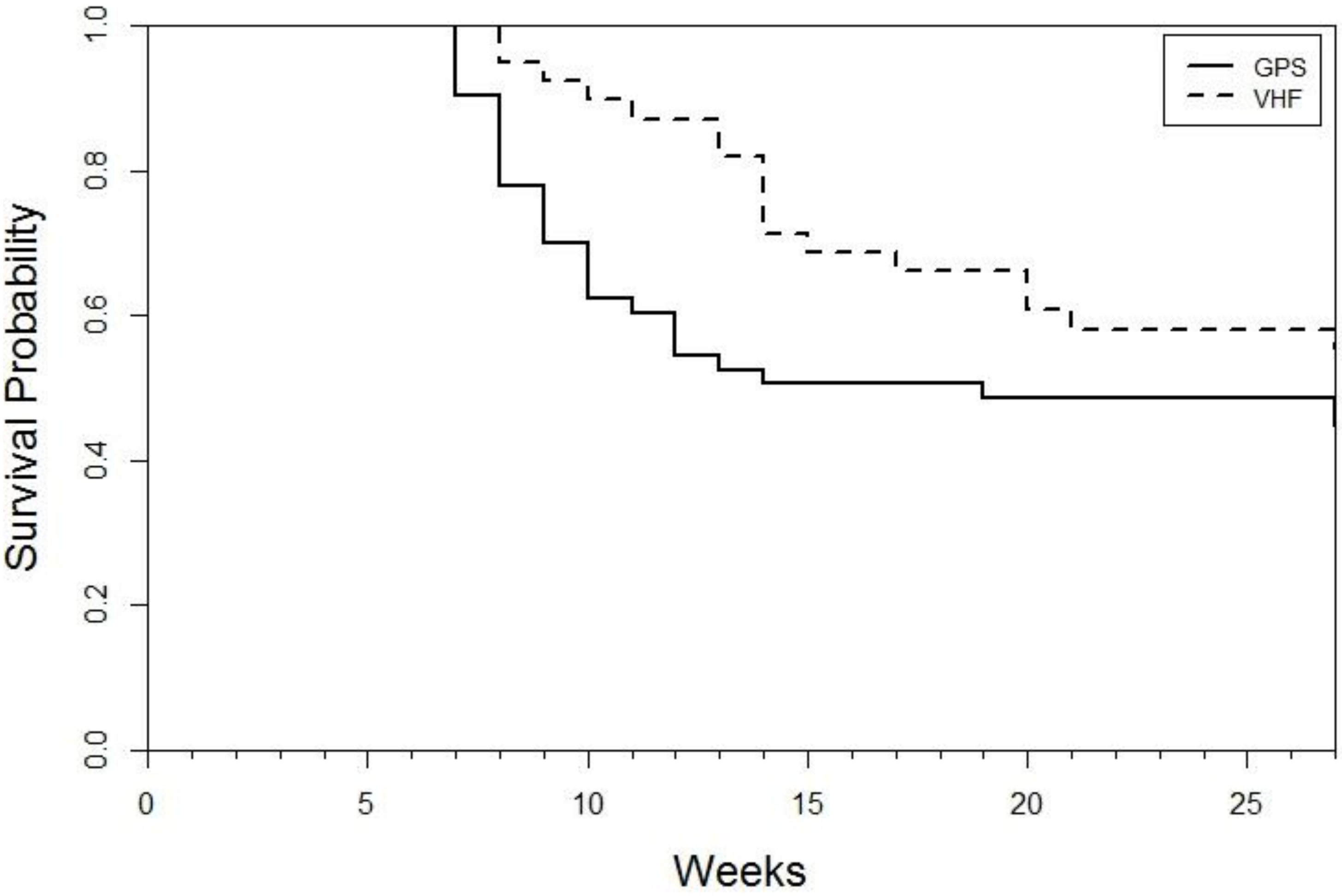

Figure 2.7 Comparison of female lesser-prairie chicken survival rates (Kaplan-Meier) for birds marked with either necklace style VHF transmitter (15-g, N = 48) or a rump mounted GPS transmitter (22-g, N = 66) during a 27-week breeding season (15 March – 15 September) in Kansas and Colorado, 2014 (CIs were omitted for clarity).

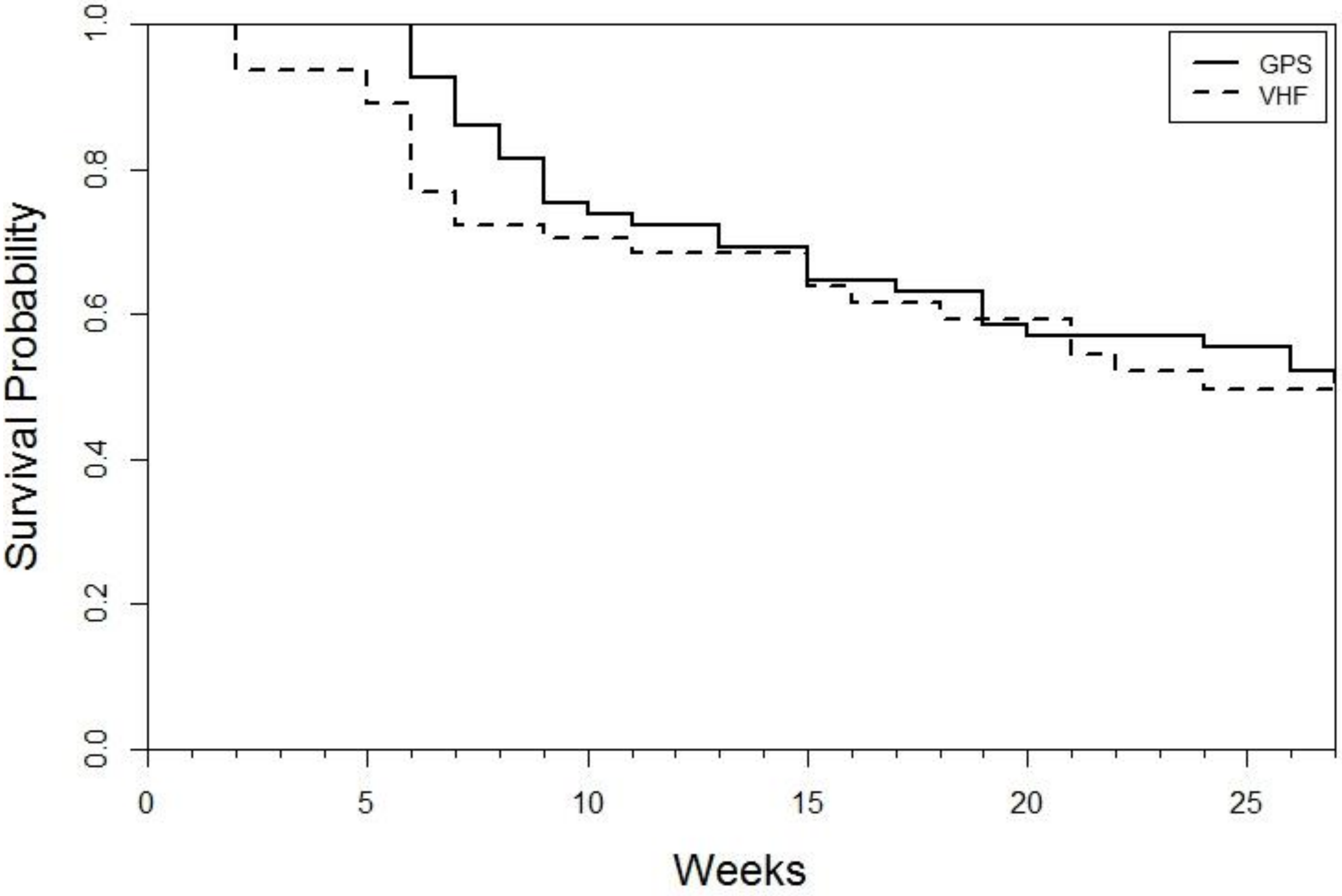

Figure 2.8 Comparison of female lesser-prairie chicken survival rates (Kaplan-Meier) for birds marked with either necklace style VHF transmitter (15-g, N = 87) or a rump mounted GPS transmitter (22-g, N = 114) during a 27-week breeding season in Kansas and Colorado for 2013 (A), 2014 (B), and Pooled (C). VHF adj., represents survival estimates after coding right censored birds to alive.

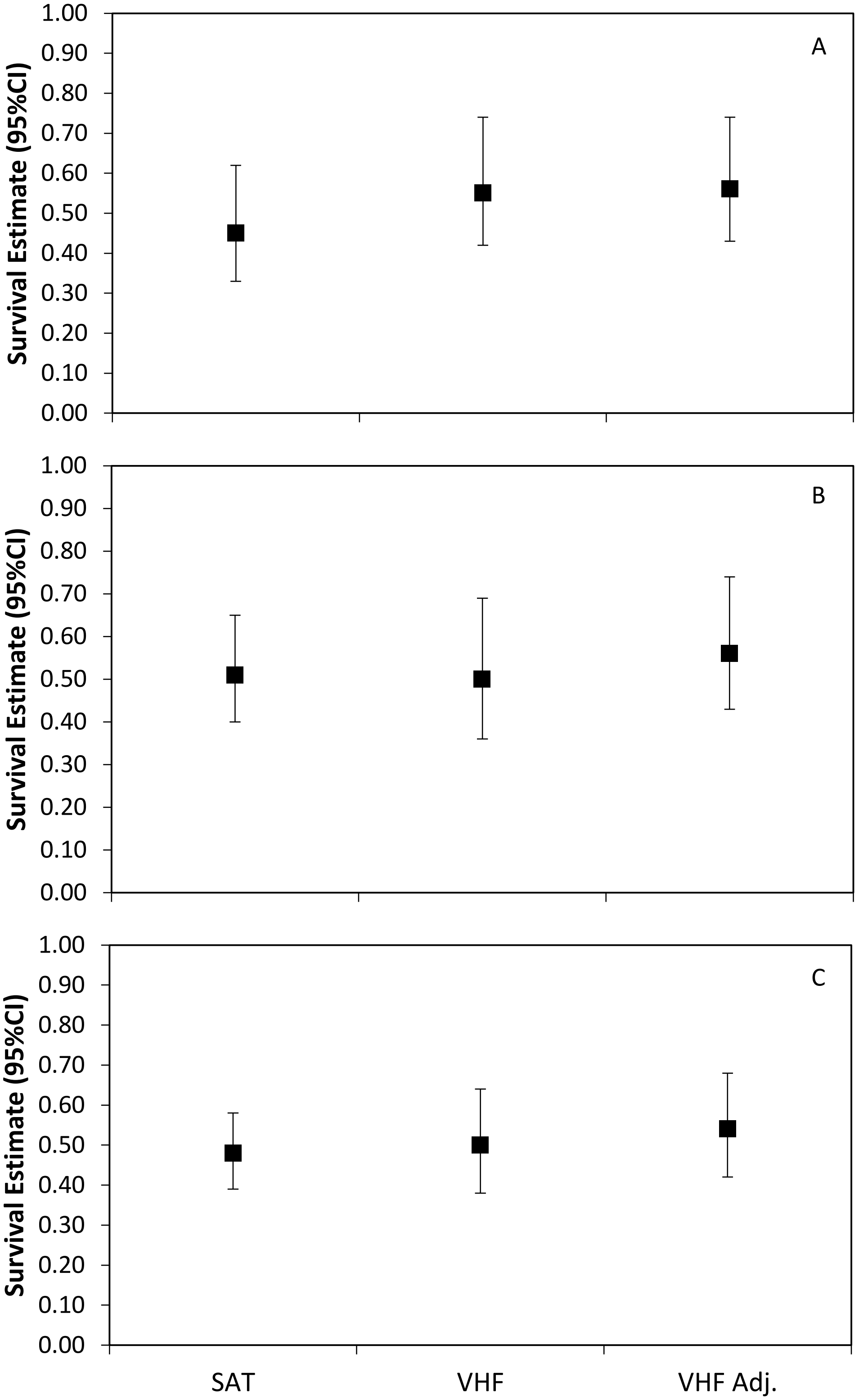

Figure 2.9 Comparison of weekly female lesser prairie-chicken mortality distribution for each ecoregion (NW = Northwest Kansas, SC = South-central Kansas, and CO = Colorado) through the breeding season (15 March – 15 September) of 2013 in Kansas and Colorado with the number of birding reports containing a potential avian predator (Northern Harrier, Ferruginous Hawk, Golden Eagle, Prairie Falcon, Red-tailed Hawk, and Swainson's Hawk) from the open source data site E-Bird.

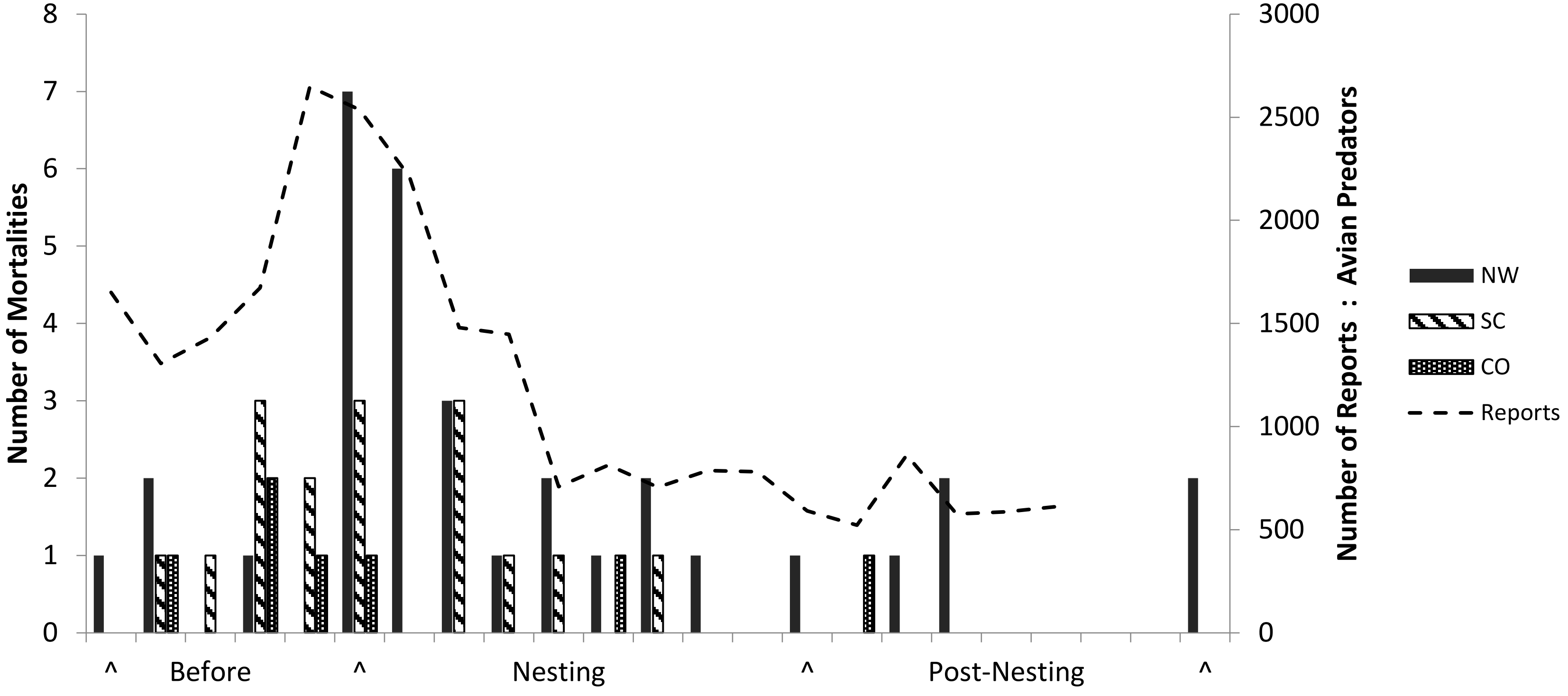

Table 2.1 Candidate models and model statistics for period survival over a twenty-seven week breeding season (15 March – 15 September) for female lesser prairie-chickens in Kansas and Colorado. Models compared include combinations of region (study regions: northwest Kansas, south-central Kansas, and Colorado, year (2013, 2014), and seasonal period (lekking, nesting and brooding, post-nesting).

	Model Statistic[a]			
Model Structure	Dev	K	Δ AIC$_c$	w_i
$S_{\text{year x period}}$	111.76	6	0.00[b]	0.740
S_{period}	121.58	3	3.80	0.111
$S_{\text{region + period}}$	117.78	5	4.01	0.100
$S_{\text{region x period}}$	112.01	9	6.27	0.032
$S_{\text{region + year + period}}$	116.53	8	8.78	0.009
$S_{\text{year + period}}$	120.99	6	9.23	0.007
$S_{\text{region + year x period}}$	102.62	18	15.05	0.000
S_{region}	135.95	3	18.16	0.000
S_{constant}	140.21	1	18.42	0.000
S_{year}	139.41	2	19.62	0.000
$S_{\text{region + year}}$	134.22	6	22.46	0.000

[a] Model fit is described by deviance (Dev), the number of parameters (K), the difference in Akaike's Information Criterion corrected for small sample size (ΔAIC$_c$), and the AIC$_c$ weight (w_i).

[b] AIC$_c$ = 799.73 for the best fit model.

Chapter 3 - Lesser Prairie-Chicken Space Use in Response to Anthropogenic Structures

Introduction

The Great Plains was once an expansive sea of grassland from horizon to horizon prior to settlement by European descendants. Grasslands are now one of the most threatened ecosystems on the planet. Since the mid-1800s, it has been estimated that ~95% of North American grasslands have been lost; due in large to the advent of the steel plow and conversion to agriculture (Knopf 1994, Brennan and Kuvlesky 2005). Remaining reduced tracts of native grassland are nestled within an agriculture-dominated landscape. Endemic grassland fauna such as the lesser prairie-chicken (*Tympanuchus pallidicinctus*) have experienced drastic declines in population and occupied range as a result of grassland conversion and other anthropogenic impacts (Hagen et al. 2004). More recent and continued declines in lesser prairie-chicken populations prompted the U.S. Fish and Wildlife Service to list the endemic prairie grouse as a threatened species under the Endangered Species Act of 1973 in May 2014 (USFWS 2014).

Global demand for energy is projected to increase by 40% in the next 20 years (International Energy Agency 2009) with fossil fuels likely remaining the largest source of energy worldwide. As a result, demand for domestic energy sources, specifically oil, natural gas, and wind energy, has spurred increased anthropogenic disturbance in the Great Plains (Pruett et al. 2009a, Hagen et al. 2011). Energy development can have broad impacts on wildlife by direct and indirect avenues such as 1) fragmentation associated with the development of infrastructure needed for exploration, development, or extraction such as road networks, pipelines, and power lines, 2) direct habitat loss from the development footprint, 3) behavioral responses of wildlife as a result of development-related activities, 4) direct mortalities caused from collisions with structures or vehicles, 5) exacerbation of fragmentation and other effects by providing access to further development, and/or 6) providing travel corridors and perching sites for mammalian and avian predators (Naugle et al. 2011, Northrup and Wittemyer 2012). Unfortunately, these potential negative effects could be exacerbated for species in danger of extinction within the remaining prairie fragments such as the lesser prairie-chicken.

Lesser prairie-chicken populations reside within the southwestern Great Plains of Texas, New Mexico, Oklahoma, Kansas, and Colorado. An estimated two-thirds of the remaining range-wide population of lesser prairie-chickens occurs within the states of Kansas and Colorado; with the majority residing in Kansas (McDonald et al. 2014). Protection of the lesser prairie-chicken and its habitat has caused contention among conservationists and industry as much of the lesser prairie-chicken's range is rich with energy resources and widely used for fossil fuel exploration and extraction (Hagen and Giesen 2005). Large-scale modifications of habitat associated with energy development may alter habitat use and/or vital rates of sensitive wildlife species (Walker et al. 2007). Research on multiple species of prairie grouse, including the lesser prairie-chicken, has demonstrated that these species are sensitive to anthropogenic disturbance on the landscape. Lesser prairie-chickens have exhibited reduced lek abundance near development areas, negative demographic consequences, loss of nesting habitat, and avoidance behavior (Robel et al. 2004, Pitman 2005, Walker et al. 2007, Pruett et al. 2009a, Hagen et al. 2011, Naugle et al. 2011, Northrup and Wittmeyer 2012, Winder et al. 2014). Negative consequences from anthropogenic development suggest that a larger ecological footprint associated with energy development exists outside of the immediate disturbed area. Unfortunately, shortfalls in the ability of conservationists to evaluate the impacts of energy development on already strained lesser prairie-chicken populations, at a rate consistent with the development itself, has created new challenges for lesser prairie-chicken conservation (Hagen et al. 2011).

Anthropogenic features were indicated as having an overall negative effect on Tetraonid (grouse species) displacement behavior and survival; especially in the presence of oil and gas structures (Horvick et al. 2014)   However, quantitative information on the spatial ecology of lesser prairie-chickens in relation to anthropogenic features is limited. Most work has focused on nesting and lek locations (Robel et al. 2004, Pitman et al. 2005, Pruett et al. 2009b) with only two studies investigating space use avoidance and quantifying avoidance distances (Pruett et al. 2009b, Hagen et al. 2011). Pruett et al. (2009a) investigated the effects of roads and power lines on home-range placement and whether they act as functional barriers to movement for lesser prairie-chickens in Oklahoma. Lesser prairie-chickens were shown to avoided paved highways and power lines with the majority of marked birds placing home-ranges away from these structures. Home-ranges that did overlap power lines and paved roads had significantly less overlap of the higher use areas within the home-range (50-75% isopleths) suggesting that they are using space away from them. Pruett et al. (2009a) did not however investigate other anthropogenic features such as oil wells or more prevalent gravel county roads. Hagen et al. (2011) conducted their study within the southwestern portion of Kansas known for its production of natural gas (Kansas Geological Survey http://www.kgs.ku.edu/PRS/County/def/finney.html). Results from Hagen et al. (2011) indicated that lesser prairie-chickens avoid power lines, paved roads, buildings, and wells; adding to the growing evidence that energy development negatively affects prairie grouse.   However, their study sites occupied an already fragmented landscape and they concluded that the inference of their results was restricted to populations that occupy fragmented landscapes. Hagen et al. (2011) called for additional measurements to be gathered from other populations to gain a better understanding of true sensitivity of lesser prairie-chickens to the presence of anthropogenic structures.

Previous studies investigating avoidance of anthropogenic features specifically tested proximity to structures but did not explicitly investigate the effect of density of features on use; density was acknowledged as being of future research interest (Hagen et al. 2011, Pitman et al. 2005, Pruett et al. 2009b, Robel et al. 2004). Density is a metric of number of features per unit area and two things need to be considered: 1) the spatial scale at which a lesser prairie-chicken perceives density of anthropogenic features and 2) the density of features within that area. For successful management of landscapes that balance anthropogenic utility of resources and yet minimize impacts to populations of lesser prairie-chickens, quantifying thresholds at which suitable habitat (i.e., habitat that we perceive as suitable for lesser prairie-chickens) becomes unsuitable needs to be established to better guide conservation efforts and appropriate mitigation (Hagen et al. 2011).

Relating anthropogenic disturbance to demographic rates is vitally important in understanding potential negative population consequences and directing accurate mitigation efforts. As female prairie-chickens biologically progress through the breeding season, they transition in and out of multiple behavioral states as a result of the life history stages they enter and exit. Therefore, it is logical that female space use requirements and behavioral avoidance will change through the breeding season as a result. Hagen et al. (2008) concluded in a sensitivity analysis that nest and brood success were the two most important demographic parameters of population growth. Female lesser prairie-chickens provide sole parental care to the nest and brood during the breeding season (Bergerud 1988). If the goal of the female is to maximize survival of the nest, brood, and herself, then she would select the most optimal habitat available. However, if female space use responses are more sensitive to anthropogenic features during those biological periods of the breeding season, the perception of suitable nesting and brooding habitat by the female maybe even more constrained than previously thought. Reduced perception of adequate habitat could have severe negative impacts when coupled with an already fragmented landscape because it could equate to functional habitat loss. Alternatively, females prefer suitable habitat near anthropogenic features (e.g., oil wells), which results in failed nests, broods, and/or increased female mortality, then the habitat would become an ecological trap (Aldridge and Boyce 2007). Therefore, understanding whether increased sensitivity to anthropogenic features exists in these different behavioral states is extremely important when determining potential demographic consequences.

Hagen et al. (2011) recommended that future research investigate additional topics (e.g., density of features, relationship with landscape fragmentation). My study expands on previous work by addressing such topics. Distances reported herein were calculated using similar techniques (see Methods below) for direct comparison among studies. My objectives were to 1) assess the effect of anthropogenic features on space use of female lesser prairie-chickens from different ecoregions and provide distance recommendations for buffering effects of these features for conservation and mitigation guidelines, 2) investigate if effects of anthropogenic features on space use vary as females transition through the different behavioral states of the breeding season, 3) quantify the scale at which lesser prairie-chickens respond to oil well density, and 4) determine the relationship between density of oil wells and space use. I hypothesized that female lesser prairie-chickens would exhibit behavioral avoidance of anthropogenic features. I predicted that females would show heightened avoidance during the nesting and brooding periods of the breeding season. I also predicted that the female lesser prairie-chickens would select areas with lower well densities than available and that the spatial scale at which prairie-chickens respond to well density will be larger in populations occupying relatively unfragmented landscapes.

Study Area

Lesser prairie-chickens are found within 3 distinct ecoregions in Kansas and Colorado forming disjunct populations associated with discrete habitat types. These regional populations occur within the Sand Sagebrush (*Artemisia filifolia*) Prairie Ecoregion of southwest Kansas and southeast Colorado, the Mixed-Grass Prairie Ecoregion in south-central Kansas, and the Short-Grass Prairie/CRP Mosaic Ecoregion in northwest Kansas (McDonald et al. 2014; Figure 1.1). My research was conducted within two of the three ecoregions of the northern range - the Short-Grass Prairie/CRP Mosaic Ecoregion (i.e., northwest Kansas) and Mixed-Grass Prairie Ecoregion (i.e., south-central Kansas) (McDonald et al. 2014; Figure 1.1)

Two field sites were established in each ecoregion. The northwest Kansas study area encompassed sites located in Gove and Logan counties (Figure 1.2). Research in the Gove County area was conducted solely on private lands. Research in Logan County was centered on The Smoky Valley Ranch owned and managed by The Nature Conservancy as well as private lands surrounding the ranch. As a whole, the northwest study site was a mosaic of short-grass and mixed-grass prairies, land enrolled in the Conservation Reserve Program (CRP) with the U.S. Department of Agriculture, and row-crop agriculture. Dominant vegetation in the region included: blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), buffalograss (*Buchloe dactyloides*), little bluestem (*Schizachyrium scoparium*), side oats grama (*B. curtipendula*), big bluestem (*Andropogon gerardii*), Illinois bundleflower (*Desmanthus illinoensis*), prairie sunflower (*Helianthus petiolaris*), annual buckwheat (*Eriogonum annum*), sand milkweed

(*Asclepias arenaria*), nine-anther dalea (*Dalea enneandra*), and western ragweed (Lauver et al. 1999). Some of the grass species originally planted within the CRP fields included: little bluestem, side oats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*; Fields et al. 2006). After original planting in the mid-late 1980s, some CRP fields were interseeded with forbs in the mid-1990s including: white sweet clover (*Melilotus alba*), yellow sweet clover (*Melilotus officinalis*), Maximillian sunflower (*Helianthus maximiliani*), Illinois bundleflower, purple prairie clover (*Dalea purpurea*), and prairie coneflower (*Ratibida columnifera*; Fields et al. 2006). Wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), and corn (*Zea mays*) were the major crops in the region. The dominant land uses in this region were rotational and season-long livestock grazing, row-crop agriculture, CRP, oil exploration and extraction (Kansas Geological Survey http://www.kgs.ku.edu/PRS/petro/interactive.html), electrical distribution, and rural towns (R. Plumb, personal observation).

The south-central Kansas study area encompassed sites located between Kiowa and Comanche counties and in Clark County (Figure 1.2). Research was conducted solely on private lands. This region was characterized by large intact tracks of native mixed-grass prairie with minimal row-crop agriculture. The region was primarily used for livestock grazing, oil exploration and extraction, with row-crop agriculture interspersed throughout the region, principally bottomlands or adjacent to riparian areas. Dominant vegetation within the region included: little bluestem, blue grama , hairy grama, side oats grama, buffalograss, sand dropseed *(Sporobolus cryptandrus)*, Louisiana sagewort *(Artemisia ludiviciana)*, annual sunflower (*Helianthus annuus*), western ragweed, sand sagebrush (*Artemisia filifolia*), alkali sacaton

(*Sporobolous airoides*), Russian thistle (*Salsola kali*), kochia (*Kochia scoparium*) and eastern red cedar (*Juniperus virginiana*) (Lauver et al. 1999).

Landscape fragmentation was present on both study areas but the degree of fragmentation for each study area differed with northwest Kansas having a greater degree of fragmentation compared to south-central Kansas. Northwest Kansas had the greatest number of patches, the greatest amount of total edge, the lowest mean patch size, and the lowest contagion value (Figure 1.5).

Methods and Materials

Capture and Marking

Lesser prairie-chickens were captured using walk-in drift traps and drop nets during the spring lekking period; March – mid May (Haukos et al. 1990). Immediately upon capture, lesser prairie-chickens were sexed, aged, and females fitted with a 22-g (<3% body weight), solar-powered, satellite-received transmitter (Wegge et al. 2007). We used model 100 GPS Platform Transmitting Terminals (PTT) (Microwave Telemetry Inc., Columbia, Maryland, USA) with a modified rump-mounting harness (Bedrosian and Craighead 2007). Females and males both received a color leg band combination to indicate year of capture, lek of capture, and individual identity (Sell 1979). Males received an individually numbered aluminum leg band (Hagen et al. 2007). Captured individuals were released within 60 min of initial capture at the capture site. All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee under protocol #3241 and Kansas Department of Wildlife, Parks, and Tourism scientific collection permit numbers SC-042-2013 and SC-079-2014.

Tracking

Satellite-marked birds were tracked using GPS/Argos system. GPS locations were taken every 2 hours from 0400 – 2200 hours resulting in approximately 10 locations per day. This varied depending on the solar charge the device gets for that day. Locations were uploaded every 3-4 days when the likelihood of a satellite pass was greatest. Microprocessor controlled battery charge management allowed the PTTs to charge during the day, collect data, and transmit at night.

Biological Periods

Space use of individuals can vary depending on the behavioral state that the individual is in (Nathan et al. 2008). The sensitivity of the individual to anthropogenic impacts can also vary in relation to these behavioral states. For example, a nesting female lesser prairie-chicken trying to maximize her survival as well as the her nest’s survival may avoid roads, or power lines, or oil wells at a greater degree than during a different state because they may act as travel corridors or perching sites for predators (Hagen et al. 2011).

Succession of breeding season behavioral states through time is not linear. The transition between these behavioral states is individually dynamic as individuals can enter and exit different states at the same point in time (Figure 1.4). Females individually transition through four biologically-relevant periods during the breeding season. These behavioral states were defined as: lekking, nesting, brooding, and post-breeding. I defined the lekking period as the time from capture or start of the breeding season (15 March) to the start of nest initiation and the time between a failed nest and nest initiation of a renest attempt (Riley et al. 1994). The nesting period was pooled across all nest attempts and began at the start of nest initiation until the fate of the nest was determined. At this juncture, females could either enter the brooding period only if the nest was successful, back into the lekking period for another breeding attempt, or omit breeding and enter the post-breeding period (Figure 1.4). Females that had successful nests entered the brooding period until the fate of the brood was determined by brood flushes. If a brood failed between brood flushes, the median date was used as the transition from the brooding period into the post-breeding period. The end of the breeding season was determined as the average date of brood break up (September 15). Females could either end the breeding season in the brooding period as the brood would be leaving the hen or in the post-breeding period from omitting breeding during that year, failed nest or nesting attempts, or a failed brood.

Space Use Predictors

I was interested in assessing the potential impact of anthropogenic features to lesser prairie-chicken space use ecology. Four anthropogenic space use predictors were hypothesized *a priori* to influentially impact female lesser prairie-chicken space use: oil and gas wells (hereafter wells), distribution power lines (hereafter power lines), larger transmission power lines (hereafter transmission lines), and roads (county gravel and paved). Distance to nearest lek was also included in this analysis as leks, or communal breeding grounds, have been shown to be an important driver of space use for female prairie grouse during the breeding season (Giesen 1994, Winder et al. 2014). Road layers did not include ranch roads (two-tracks) as these have relatively low frequency of vehicle traffic. Differences between road types (paved or gravel) or between power sources for well pumping units were not distinguished and all were included in the analysis as either well or road (Hagen et al. 2011). Active oil/gas well and road layers were collected from the Kansas GIS and Data and Support Center (http://www.kansasgis.org/).

In this study, I was limited to areas that already had established anthropogenic features such as transmission lines. The opportunity for a Before-After-Control-Impact (BACI) research design was not present. Additionally, large transmission lines were not spread across the study area in a manner that allowed for consistent interaction with marked birds. It was difficult to determine whether differential space use was a product of the transmission lines on the landscape or other confounding factors between the area used and the transmission line; especially as distance from transmission lines increased. Recent analysis showed that, on average, an individual female lesser prairie-chicken will move ~ 4.5 km (linear distance) from her first location since marking to her last location within the breeding season (R. Plumb, unpublished data). Moreover, current recommendations by the U.S. Fish and Wildlife Service suggest an 8 km buffer for tall vertical structures such as wind turbines (Manville 2004). Therefore, I buffered transmission lines by 5 and 8 km and included only individuals that had $\geq$50% of their estimated locations and $\geq$50% of their 99% use polygon within these buffers (N = 10 and 29). Distribution and transmission line feature layers were collected from the Kansas Cooperation Commission (http://www.kcc.state.ks.us/).

Distance rasters were generated from all anthropogenic layers for each study region using the Euclidean Distance tool in ArcMap 10.0 (ESRI Inc., 2011, Redlands, CA). Because oil and gas exploration and extraction includes infrastructure such as roads and power lines, it is logical to assume that these variables would be spatially correlated. Variables exhibiting multicollinearity can be problematic for coefficients in linear regression models and it is beneficial to test variables for multicollinearity. I tested anthropogenic variables across all study areas at two different scales: the landscape scale and the home range scale. At the landscape scale, I created a 500 x 500 m sampling point grid across the all study areas and extracted distance-to-anthropogenic feature values from the central location of each cell. The relationships of distances from each cell location to all anthropogenic variables were tested using a Pearson’s

Correlation coefficient in Program R (R core development team, version 3.1.2, 2014, Vienna, Austria). The greatest correlation coefficient (r) was 0.51 between distance to power line and distance to transmission line indicating some collinearity. Additionally, I tested the collinearity of anthropogenic variables at the home range scale using multiple linear regression with a variance inflation factor (VIF) in Program R (R core development team, version 3.1.2, 2014, Vienna, Austria). I regressed use values from the center of each 30 x 30m grid cell in each bird's utilization distribution (hereafter UD) that were used in my analysis against distance-to-anthropogenic-feature values. The greatest VIF value was 1.59 for distance to road and corroborates the Pearson's output suggesting that predictor variables have moderate collinearity (VIF $\leq$ 5) but not enough to indicate redundant variables.

Much of the northern extent of the lesser prairie-chicken range has been subjected to energy exploration. The current energy regulations for Kansas restrict well density to 1 well per 10 acres (4.05 ha; http://www.kcc.state.ks.us/conservation/cons_rr_092413.pdf). However, the scale and density at which oil/gas wells occur on the landscape and effect lesser prairie-chicken use has yet to be investigated (Hagen 2011). To approach this, density surfaces of wells were created in ArcMap 10.0 (ESRI Inc., 2011, Redlands, CA) at twelve different spatial scales starting at 100 ha and increasing to 500 ha at 50 ha increments. I included the 4.05 ha (10 acres) spatial scale that is currently allowed by the state of Kansas. Density values were the total number of wells within the specified area. All raster layers were created with a 30 m X 30 m resolution to mirror the resolution at which space use values were quantified.

Data Analysis

Utilization Distributions

Anthropogenic influences on space use were investigated at two different temporal scales; the overall effect of anthropogenic disturbances on breeding season space use and differential impacts of disturbances within each biological period of the breeding season. It has yet to be determined how many satellite locations are needed to accurately represent the entirety of breeding season space use for female lesser prairie-chickens. Girard et al. (2002) estimated that 100-300 locations were necessary to accurately estimate annual space use for moose (*Alces alces)*. However, location number could be species specific as the amount of space used is dependent on the mobility and life history requirements of the organism under investigation. Therefore, I limited my sample to only females that had >90 locations (~10 days). Females that did not meet the location requirement were removed from the sample. Segments of the animal track that had starting and ending locations with elapsed time between them >2880 minutes were not used in the space use calculation. The biotelemetry error was estimated as 1 standard deviation from the average linear error calculated from the beacon test (5.7 m; Nielson et al. 2012)

Estimates of space use were based on utilization distributions (UD) of GPS marked females estimated using the Brownian Bridge Movement Model (BBMM; Horne et al. 2007) with the BBMM function in the BBMM package (Nielson et al. 2012) of the statistical program R (R core development team, version 3.1.2, 2014, Vienna, Austria). The BBMM is a continuous–time stochastic model of movement in which the probability of being in a specific space at a given time is conditioned on starting and ending locations, the time elapsed between those two locations, the error associated with the transmitter, and the mobility of the organism (Horne et al. 2007). This methodology explicitly makes use of auto-correlated telemetry data and is well suited for GPS data (Bullard 1991, Walter et al. 2011).

The spatial extent of space use by female lesser prairie-chicken was defined by the 99% isopleth of the BBMM UD boundary; which contains 99% of the volume of the probability density distribution for an individual's movement (Kertson and Marzluff 2011, Winder et al. 2014). A raster surface with 30 X 30 m cells was created within the 99% volume contour of the utilization distribution. Use values, bounded from 1 to 99, were assigned to each cell based on the relative volume (height) of the utilization distributions of that cell (Kertson and Marzluff 2011). Space use data were $\log_e$-transformed to meet the assumptions of linear multiple regression models (Winder et al. 2014).

Anthropogenic Influence

Resource Utilization Functions (hereafter RUF) in the RUF.fit package (Hancock 2007) for Program R were used to relate the effect that anthropogenic structures has on female lesser prairie-chicken space use. RUFs are based on relative space use where the unit of study is the individual utilization distribution. An RUF correlates the intensity of use expressed as the height of the three dimensional UD to resource values on a cell-by-cell basis in a multiple linear regression framework to obtain standardized beta (β) coefficients. These coefficients indicate the importance or influence of each variable to the variation in the UD (Marzluff et al. 2004, Kertson and Marzluff 2011).

Biological inferences were developed by calculating the mean standardized β coefficient for each predictor and pooling across ecoregions, by each ecoregion, and by biological period (Winder et al. 2014). Variables that significantly influenced space use were those with coefficients that had 95% confidence intervals that did not overlap zero. If the influence of a specific variable was significantly different than zero, I inferred that the influence of that variable was greater (+) or less (-) than expected based on the availability (i.e., distance from) of that variable within the home-range (Marzluff et al. 2004, Winder et al. 2014). For example, a negative (-) mean β indicates that on average, female lesser prairie chickens are exhibiting behavioral attraction towards the predictor as space use increases with decreasing distance. The opposite is true for positive mean β. The relative influence of anthropogenic variables on space use was ranked using the absolute value of their mean standardized β coefficients (Winder et al. 2014). Because anthropogenic features are permanent relative to the life span of a lesser prairie-chicken, I assumed that the effect of these features did not vary between years. Estimates were subdivided by ecoregion and breeding season period to evaluate differences between ecoregional populations and determine if the influence of predictors change relative to the breeding season behavioral state of individuals.

Well Density

I used a use/non-use design within a resource selection framework to determine the impact of well density on female lesser prairie-chicken space use (Manly et al. 1992, Boyce et al. 2002). Use points were generated from marked females that were tracked with GPS transmitters. Unused points were randomly generated within the area considered to be available using ArcMap 10.0 (ESRI Inc., 2011, Redlands, CA). Availability was characterized using the average linear distance from the first location since marking to last location within the breeding season. All breeding season home-ranges were then buffered by the calculated 4.5 km to derive a sampling area that was potentially available to all marked females for the entire breeding season. I used logistic regression in Program R (R core development team, version 3.1.2, 2014, Vienna, Austria) to identify oil well densities that best explained selection (Manly et al. 1992). Probability of use was estimated using the following logistic regression function:

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

in Program R (R core development team, version 3.1.2, 2014, Vienna, Austria). I identified the spatial scale that had the greatest influence on well density selection by ranking the logistical regression models using Akaike's Information Criterion (AIC) in Program R (Burnham and Anderson 2002).

Distance to Anthropogenic Features

Distances to anthropogenic features were characterized by using the observed locations of marked individuals. I used the near tool in ArcMap 10.0 (ESRI Inc., 2011, Redlands, CA) to measure the nearest linear distance between locations and anthropogenic features. Because anthropogenic features are not equally distributed across the landscape, distance metrics that are averaged across all individuals may give spurious results as the distances are not true representations of avoidance. To characterized distances for conservation guidelines, I used the lower 10th percentile of the distribution of observed distances because its represents the portion of the study population that occurred closest to the anthropogenic features. Furthermore, the lower tenth percentile is not too extreme as to be subject to excessive random variation in its estimation (Hagen et al. 2011). All means were reported with their associated standard error (SE) unless otherwise noted.

Results

A total of 193 female lesser prairie-chickens were captured in northwest and south-central Kansas during the springs of 2013 and 2014, resulting in a total of 106 GPS transmitters being deployed. UDs were successfully created from 100 of the 106 females marked. Across both regions, the strongest significant predictors of space use were distance to lek and distance to power line. Females, on average, used space at greater magnitudes within their home range closer to leks and further away from power lines (Mean $\beta = -0.11 \pm 0.03$[SE], 95% CI = -0.18, -

0.05; Mean β = 0.15 ± 0.05, 95% CI = 0.05, 0.25; Figure 3.1). Females resided on average 1852 m ± 9.4 and 2352 m ± 4.1from the nearest known lek and nearest power line. Distance to road, distance to oil well, and distance to transmission line within 5 km and 8 km were not significant predictors of female space use when pooled across ecoregions (Figure 3.1).

Significant predictors of space use varied by region with females in northwest Kansas showing avoidance behavior of power lines (Mean β = 0.16 + 0.06, 95% CI = 0.05, 0.28). In contrast, space use of females in south-central Kansas showed behavioral attraction to leks and roads (Mean β = -0.18 ± 0.06, 95% CI = -0.29, -0.07; Mean β = -0.17 ± 0.08, 95% CI = -0.34, -0.01; Figure 3.2) indicating that females used space at greater magnitudes closer to leks and roads within their home ranges. Increased avoidance behavior was not observed during the nesting or brooding periods of the breeding season. Females in northwest Kansas showed avoidance behavior of power lines during the lekking and nesting periods of the breeding season (Mean β = 0.19 ± 0.05, 95% CI = 0.09, 0.29; Mean β = 0.15 ± 0.05, 95% CI = 0.06, 0.24; Figure 3.2). Counterintuitively, females used space within their home range closer to oil wells during the nesting period (Mean β = -0.23 ± 0.1, 95% CI = -0.04, -0.42; Figure 3.3). Space use during the brooding and post-breeding periods was not related to any hypothesized predictors suggesting that space use was equal in proportion to distances to predictors within their home-range. In contrast, distance to lek was the only significant predictor for females in south central Kansas. Distance to lek was a significant predictor of female space use for the lekking, nesting, and post breeding periods. Similar to northwest Kansas, no predictors were significant during the brooding period (Figure 3.3).

Though the majority of the anthropogenic predictors were not significant factors in female space use, females did reside at greater distances away from features than would be expected at random (Table 3.1). The lowest 10th percentile of locations, as described by Hagen et al. (2011), represents the portion of the population that tended to come closest to anthropogenic features. For all observed female locations, distances away from transmission lines and distribution power lines were larger than the other anthropogenic features (4888 m, 716 m). Roads and wells were not significant predictors of female space use but the lowest 10th percentile distances did suggest that females tended to avoid these features (378 m and 504 m, respectively).

To determine the spatial scale that densities of oil/gas wells are most influential to female lesser prairie-chicken use, 12 single covariate logistic regression models comparing density of wells at used and random point locations were ranked using Akaike's Information Criterion. The scale at which density of oil wells best explained the data varied by region. The highest ranked model for the northwest study area was the density of oil wells at a 100-ha scale (Table 3.2). The largest spatial scale investigated in this study was the highest ranked model for the south-central study area of Kansas, which was 5 times larger than northwest Kansas (500 ha; Table 3.3). To compare probability of use between regions, data were pooled to determine the highest ranked spatial scale across both regional populations. The spatial scale at which density of oil wells best explained use for both populations was 250 ha (Table 3.4).

Significant negative slope coefficients for both the northwest and south-central populations indicate that female lesser prairie-chickens use habitats that have a lower well density than available. Across both regions, the probability of use by a female lesser prairie-chicken decreased with increasing well density (Figure 3.4). In northwest Kansas, female lesser prairie-chickens were five times more likely to use areas that had no wells than areas with 15 wells/100ha (Figure 3.5). Similar to the northwest population, females in the south-central population were five time more likely to use areas with no wells than areas with 15 wells/500 ha; however the scale of use was five times greater in south-central Kansas; suggesting a heightened sensitivity (Figure 3.6). Compared together at the same scale, the sensitivity of females in the south-central region becomes apparent. The probability of use for females in northwest Kansas was 3 times greater in areas with 5 wells/250ha, than for females in the south-central Kansas (Figure 3.7).

Discussion

Although loss of habitat in the northern extent of the lesser prairie-chicken range has not occurred in the last two decades, current populations have continued to decline despite stable amounts of grassland habitats available on the landscape (Spencer 2014). Avoidance behavior exhibited by prairie grouse to anthropogenic features on the landscape may result in functional elimination of habitat (Robel et al. 2004) and further exacerbate effects of previous habitat loss and fragmentation; especially in already highly fragmented landscapes. My results add to the growing evidence that species of prairie grouse show sensitivity to anthropogenic features and that these features may act as functional obstructions to otherwise suitable habitats (Robel et al. 2004, Pitman et al. 2005, Pruett et al. 2009a, Hagen et al. 2011, Naugle et al. 2011, Winder et al. 2014). This study is the first to investigate space use behavior within the home-range in relation to anthropogenic features using an RUF framework, the impact of oil well density, and at what scale the density of oil wells explain space use of female lesser prairie-chickens during the breeding season. Furthermore, it is the first to investigate differences in avoidance among regional populations and between the differing behavioral states that females transition through during the breeding season. The results indicated that 1) power lines and leks were significant drivers of space use, 2) these drivers were regionally independent, 3) anthropogenic features did not influence space use more during the nesting and brooding periods of the reproductive period, 4) females selected areas with lower well densities, and 5) females will cease use at a specific well density.

I used RUFs to test for potential effects of anthropogenic features such as roads, oil/gas wells, power lines, and transmission lines as well as natural features such as leks on the spatial ecology of lesser prairie-chickens. Across both regions, the best predictors of space use were distance to power line and distance to lek. Distance to lek and power line were regionally variable however, with distance to lek being a significant predictor for the south-central region and distance to power line being a significant predictor for the northwest region of Kansas.

Power lines and transmission lines have been implicated as barriers to prairie grouse movement, nest site selection, and general habitat use (Pitman et al. 2005, Pruett et al. 2009b, Hagen et al. 2011, Lautenbach 2014). Behavioral avoidance and minimum avoidance distance of power lines (712 m) were similar to those observed by other studies on prairie-grouse species (Braun 1998, Pruett et al. 2009b, Hagen et al. 2011). Though not a significant space use predictor, female lesser prairie-chickens avoided transmission lines by ~ 5km. My finding is the first to indicate a difference in avoidance distances from small distribution power lines and larger transmission lines. Avoidance of both types of power lines suggest that they act as potential barriers to habitat use and may further fragment what is perceived as available high quality habitat. Prairie chickens have been shown to move across power lines in Oklahoma but transience between power lines was low in relation to normal movement behavior (Pruett et al. 2009b). Continued functional fragmentation of remaining habitat patches from power lines in already fragmented landscapes may compound negative effects on lesser prairie-chicken movement and population connectivity.

General behavioral avoidance of tall structures such as power lines may be a product of increased predation attempts or perceived predation presence associated with these features. In prairie landscapes, raptors use power lines as perching structures to scan for potential prey and may use power line structures preferentially compared to an oil or gas well (Ellis 1984, Steenhof et al. 1993). Increased raptor abundance adjacent to readily used lesser prairie-chicken habitats may increase raptor-induced mortality at levels greater than naturally expected (Ellis 1984, Coates 2007). Other research from this project indicates that an estimated 40% of breeding season mortality was a result of avian predation and avian abundances peak in relation to the peak breeding season motility distributions (Chapter 2). Raptor mortality in northwest Kansas and south-central Kansas were twice as high as estimates in southwestern Kansas (Hagen et al. 2007). Avian-induced mortality for this study (Chapter 2) was greater but more comparable to those reported in Oklahoma and New Mexico with >30% of mortalities resulting from avian predation (Wolfe et al. 2007). Female lesser prairie-chickens have also been shown to collide on occasion with power lines causing roughly 3-5% of mortalities observed in Oklahoma and southwestern Kansas (Wolfe et al. 2007, Pruett et al. 2009b, Hagen et al. 2011). I witnessed no direct mortalities associated with power lines suggesting that power lines were not a direct threat to female survival but a potential catalyst to increased indirect mortality.

Leks and associated habitats have been shown to be highly important for breeding female lesser prairie-chickens with nest sites usually residing within 1.5 km and females observed locations within 1.7 – 2.4 km of known leks (Giesen 1994, Hagen et al. 2013, Kukal 2010, Pirius et al. 2013). Results from this study were similar with females showing behavioral attraction towards lek sites and the average distance from known lek being 1852 m ± 9.4 (SE) for observed female locations across both regional populations. My results add continuing evidence that lek sites and habitats within ~2 km of leks are highly important to breeding female lesser prairie-chickens and population viability.

Contrary to my hypothesis, I witnessed no increased avoidance of anthropogenic features during the nesting or brooding periods of the breeding season. Interestingly, during the nesting period in the northwest Kansas region, females used areas closer to well sites than expected. The average nesting period home range for female lesser prairie-chickens during this study was roughly 50% greater (138 ha ± 14) than previously reported in the literature (92.02 ha ± 18.36, 92 ha ± 2.7; Candelaria 1979, Riley et al. 1994). During egg laying, females attend the nest site for a few hours during the day to lay an egg and then continue with regular daily activities away from the nest (Candelaria 1979, Hagen and Giesen 2005). In addition, females early in incubation make regular trips off of the nest to forage in both crop and native prairie habitats adjacent to nest sites; activity off nest slows as incubation progresses (Candelaria 1979, Riley et al. 1994). If, for example, females forage away from high intensity use areas such as nest sites the resulting UD is increased in size with more low use values further away from wells than high use nest sites. These foraging bouts may artificially increase the "behavior" of attraction toward the well because larger low use areas (foraging areas) are further away from well sites than high use areas (nest sites) resulting in a significant negative β (attraction). Enough significant negative β's will result in a significant negative mean β and thus indicate a population response towards well sites. Lowest 10th percentile distances did indicate that females do avoid wells site with observed locations being located further away than would be expected at random. Furthermore, other results from this study indicated that females place nest sites further away from wells than is available at random (Lautenbach 2014).

Impacts of other anthropogenic features across both regions were not clear. Space use within the female home range was not significantly influenced by road, well, or transmission lines. Lowest 10th percentile distances did however suggest that lesser prairie-chickens do avoid these features at varying degrees depending on feature type. Nonsignificant results of space use predictors within home range indicate that the differential use of habitats at distances away from features are used in equal proportion to what is available within the home range (Winder et al. 2014). Nonsignificance could be a product of prior placement of the home-range away from anthropogenic features at distances that females no longer perceive these features as threats. Therefore, future research using a 3rd order statistic, such as an RUF, should use samples of females that interact readily with features thereby increasing perception of these structures and potential avoidance responses; this is especially true for features that are not uniformly distributed across the landscape. A Before-After-Control-Impact (BACI) study design would be the best case scenario to investigate how differential space use is affected by anthropogenic features because initial space use references (use without the feature) would allow for more robust comparisons between before and after construction space use (Winder et al. 2014). Differing results between the RUF and 10th percentile measurement indicates that the scale at which avoidance is measured may play a role into our interpretation of female avoidance of anthropogenic features. Because situations allowing for a BACI design are rare and that results may differ depending on scale, I would suggest using a 2nd order statistic such as a logistic regression in tandem with a 3rd order selection function such as a resource utilization function to investigate how space was used within home-ranges but also how home ranges or space was used in relation to what is available on the landscape.

Densities of oil and gas wells have been shown to affect habitat use by wildlife species (Sawyer et al. 2006, Walker et al. 2007, Doherty et al. 2008, Hagen et al. 2011). Pitman et al. (2005) indicated that the number of wells affected habitat and nest site selection. My research corroborates these findings as the probability of use by female lesser prairie-chickens decreases with increasing well density. This trend was consistent across regional populations; however, the spatial scale that best described the variability in the data varied between regions. Data from the south-central region were best described by a 500 ha scale whereas the northwest population was best described by a 100 ha scale. Differences in spatial scales suggests that female lesser prairie-chickens inhabiting fairly intact tracts of native grassland landscapes, such as south-central Kansas, may exhibit higher sensitivity to well densities than females in more fragmented and impacted landscapes such as northwestern or southwestern Kansas (Hagen et al. 2011).

Increasing densities of oil wells could have profound effects on population viability. My results indicate that when densities reach roughly 25 wells/250 ha (617.8 acres), the probability of a female lesser prairie-chicken using that space would be nonexistent. If well densities are increased in or close to suitable grassland habitats, females may be displaced from these otherwise functional grassland patches. Functional habitat loss from increased well density could prove detrimental to demographic rates (Holloran 2005, Doherty et al. 2008). If females chose to use habitat with increased well density for reproduction, such decisions may lead to increased nest, brood, or female mortality outside of natural variability and the grassland habitat would become an ecological trap (Aldridge and Boyce 2007). Furthermore, if productivity of the habitat is affected by displacement or a resulting ecological trap, the persistence of leks and/or the occupancy of these patches may diminish over time (Hagen et al. 2011) and lead to decreases in local populations. Unfortunately, demographic relationships have yet to relate density of anthropogenic features to adult survival, nest success, or brood success of female lesser prairie-chickens. Future research should relate demographic parameters to anthropogenic features on the landscape, further investigate densities of other anthropogenic features such as roads, power lines, or buildings to use of female lesser prairie-chickens, evaluate ways to reduce impacts of anthropogenic features especially for energy development, and determine if combinations of anthropogenic features in relation to one another create an additive avoidance response to lesser prairie-chicken space use.

Management Implications

Continuing evidence suggests that areas within 2 km of leks are important for breeding female lesser prairie-chickens. Habitats within this radius should be protected from any initial or further anthropogenic disturbances. Lesser prairie-chickens avoid anthropogenic structures at varying degrees depending on feature type. Existing high quality lesser prairie-chicken habitat should be protected from development of anthropogenic features whenever possible. If constructing anthropogenic features are necessary, efforts to reduce impact such as clustering them together on the periphery of habitat patches or near already compromised areas such as heavily trafficked or paved roads, current standing structures, or agricultural fields. Power lines should be installed underground, especially those leading to cattle operations at the center of pastures. Mitigation guideline boundaries should include boundary distance of: power lines $\geq$ 700 m, wells $\geq$ 500 m, roads $\geq$ 400 m, and transmission lines $\geq$ 5000 m. The standard drilling unit in the state of Kansas as described in KAR 82-3-103 (http://www.kcc.state.ks.us/conservation/cons_rr_092413.pdf) is 1 well/10 acres unless exceptions are granted. The current well density regulation would result in a probability of 0% of use by female lesser prairie-chickens if exploited to its full potential. The density of oil wells per 640 acres (section) should not exceed 11 wells / section (~ 1 well / 60 acres) for a 10% probability of use. However, because the affect that density of wells has on demographic rates has yet to be determined, densities in or adjacent to grassland patches should be minimized as much as possible. Areas with minimal anthropogenic features that were evaluated here should be given preference for conservation action in an effort to maintain their condition.

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Figure 3.1 Mean standardized β coefficients (95% CI) for female lesser prairie-chicken resource utilization functions pooled across regions in Kansas during 2013 and 2014. Estimates represent all birds marked and tracked pooled across region regardless of fate. Asterisks denote a significant response at the population level; 95% CI of β's do not overlap zero. Transmission line estimates represent estimates for a subset of the sample that had $\geq$50% of their home range within a 5 and 8 km buffer from current transmission lines.

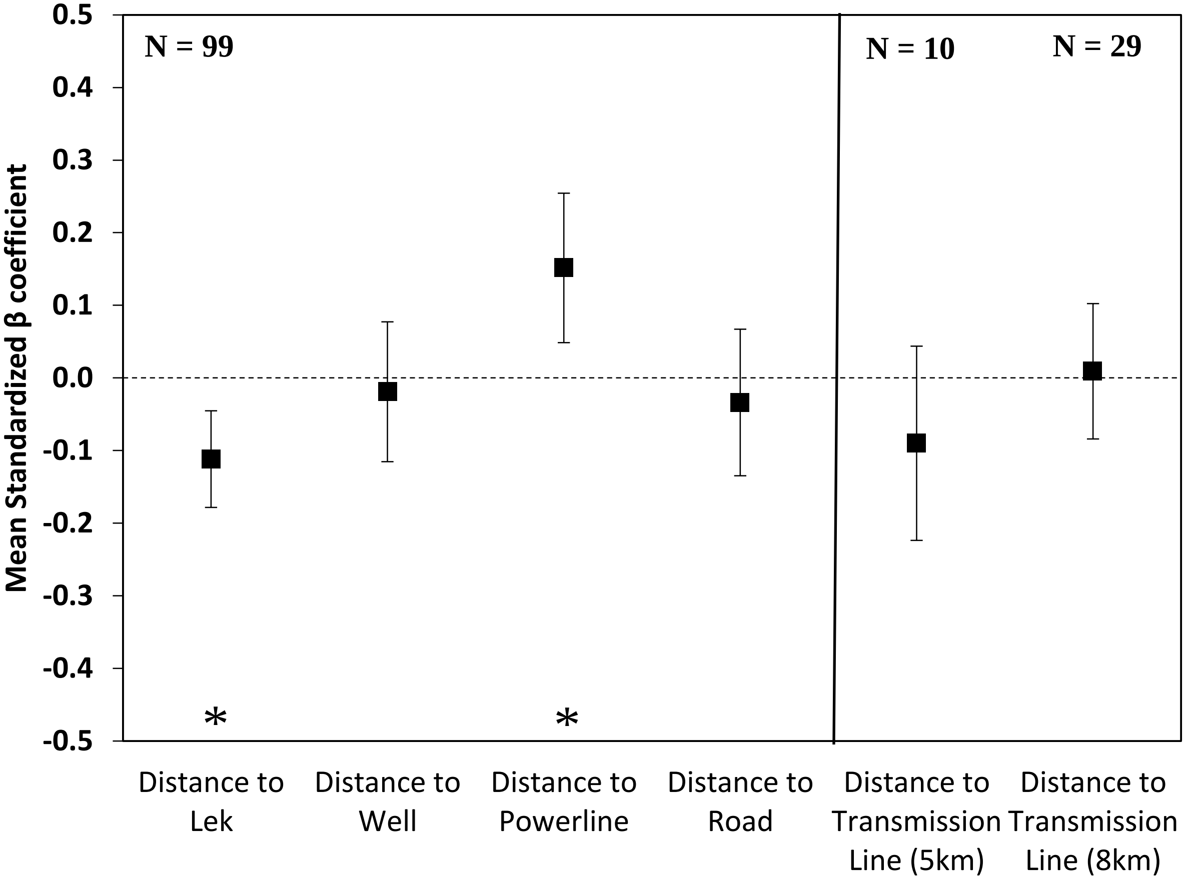

Figure 3.2 Mean standardized β coefficients (95% CI) for female lesser prairie-chicken resource utilization functions within each study region (northwest and south-central Kansas) in 2013 and 2014. Estimates represent all birds marked within each region regardless of fate. Asterisks denote a significant response at the population level; 95% CI of β's that do not overlap zero.

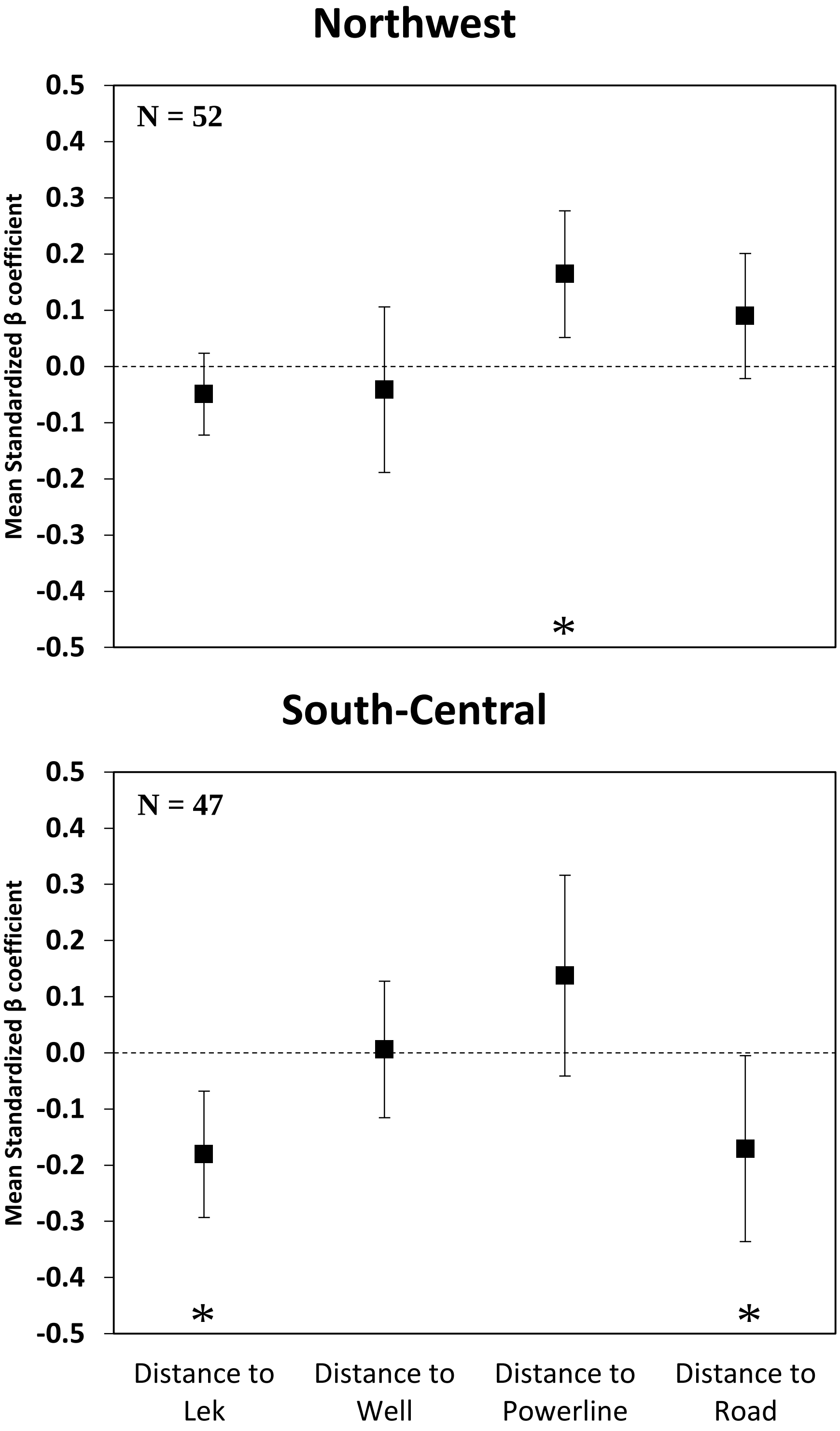

Figure 3.3 Mean standardized β coefficients (95% CI) for female Lesser Prairie-Chicken resource utilization functions within each study population (northwest and south-central Kansas) during 2013 and 2014. Estimates are for the each biological period defined for the breeding season. Asterisks denote a significant response at the population level; 95% CI of β's that do not overlap zero.

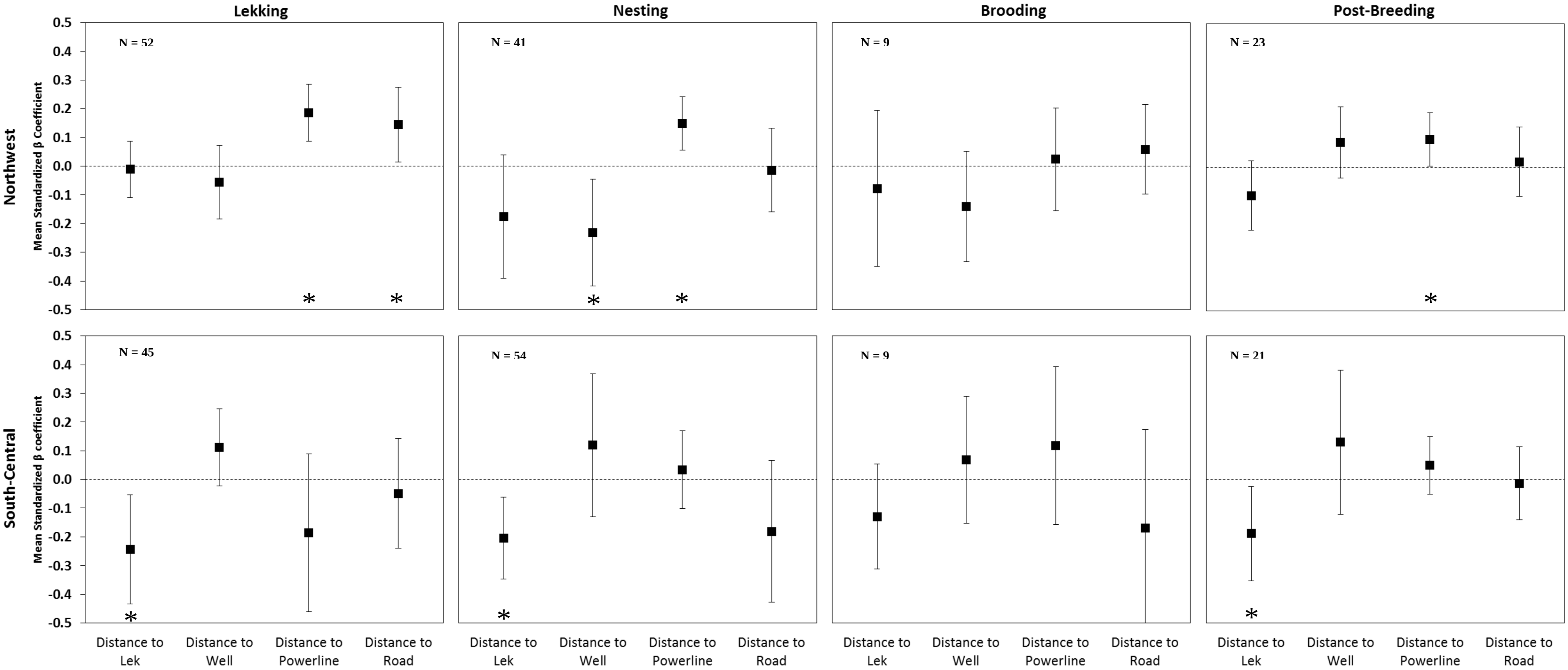

Figure 3.4 Probability of use for female lesser prairie-chickens in relation to oil/gas well densities (wells/250 ha) across both northwest and south-central regional populations in Kansas during 2013 and 2014. Dashed lines represent the 95% CIs. Use does not reach 100% because not all habitats within the available area are being used as it may not be suitable habitat (i.e., agricultural fields).

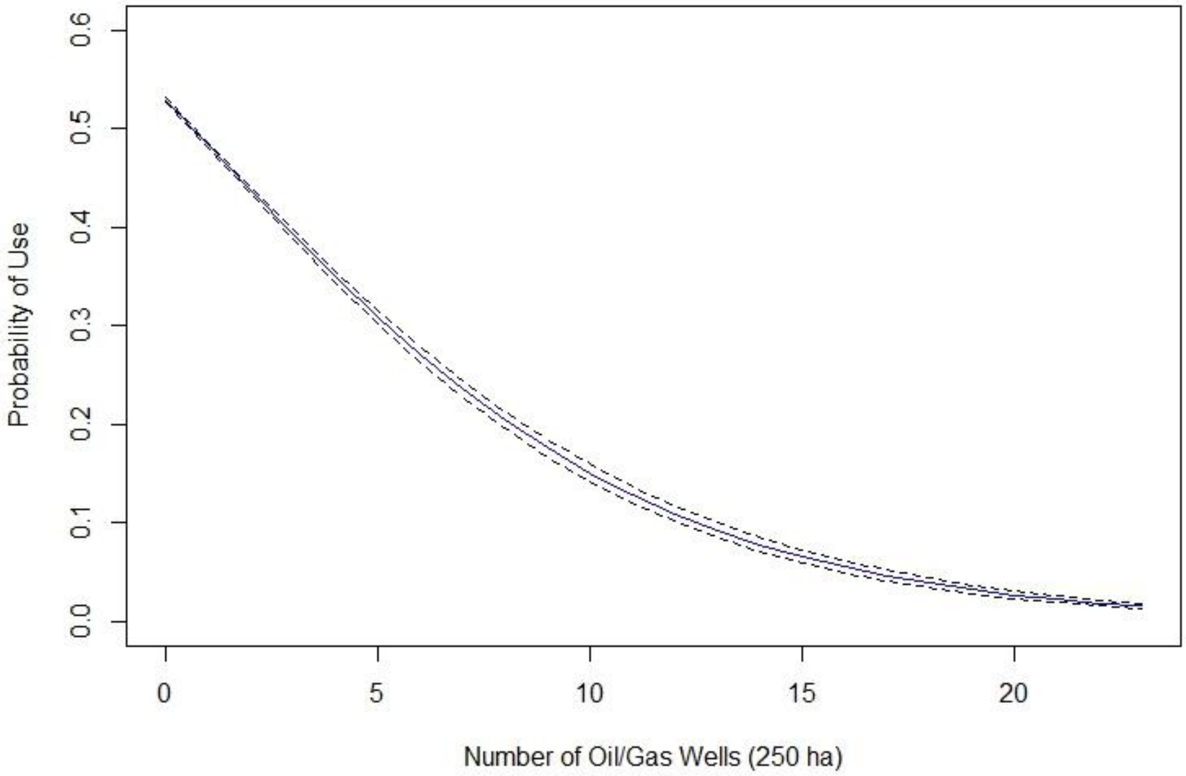

Figure 3.5 Probability of use for female lesser prairie-chickens in relation to oil/gas well densities (wells/100 ha) for Gove and Logan counties of the northwest regional population in Kansas during 2013 and 2014. Dashed lines represent the 95% CIs. Use does not reach 100% because not all habitats within the available area are being used as it may not be suitable habitat (i.e., agricultural fields).

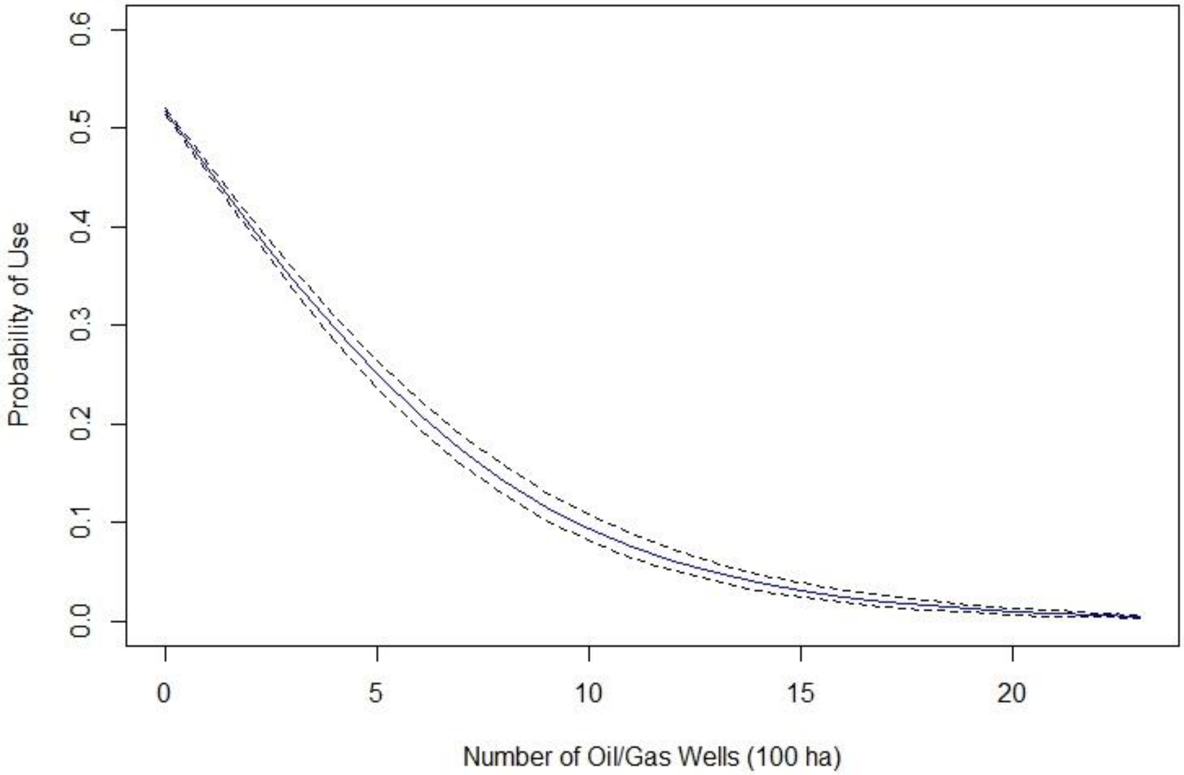

Figure 3.6 Probability of use for female lesser prairie-chickens in relation to oil/gas well densities (wells/500 ha) for Kiowa, Comanche, and Clark counties of the south-central regional population in Kansas during 2013 and 2014. Dashed lines represent the 95% CIs. Use does not reach 100% because not all habitats within the available area are being used as it may not be suitable habitat (i.e., agricultural fields).

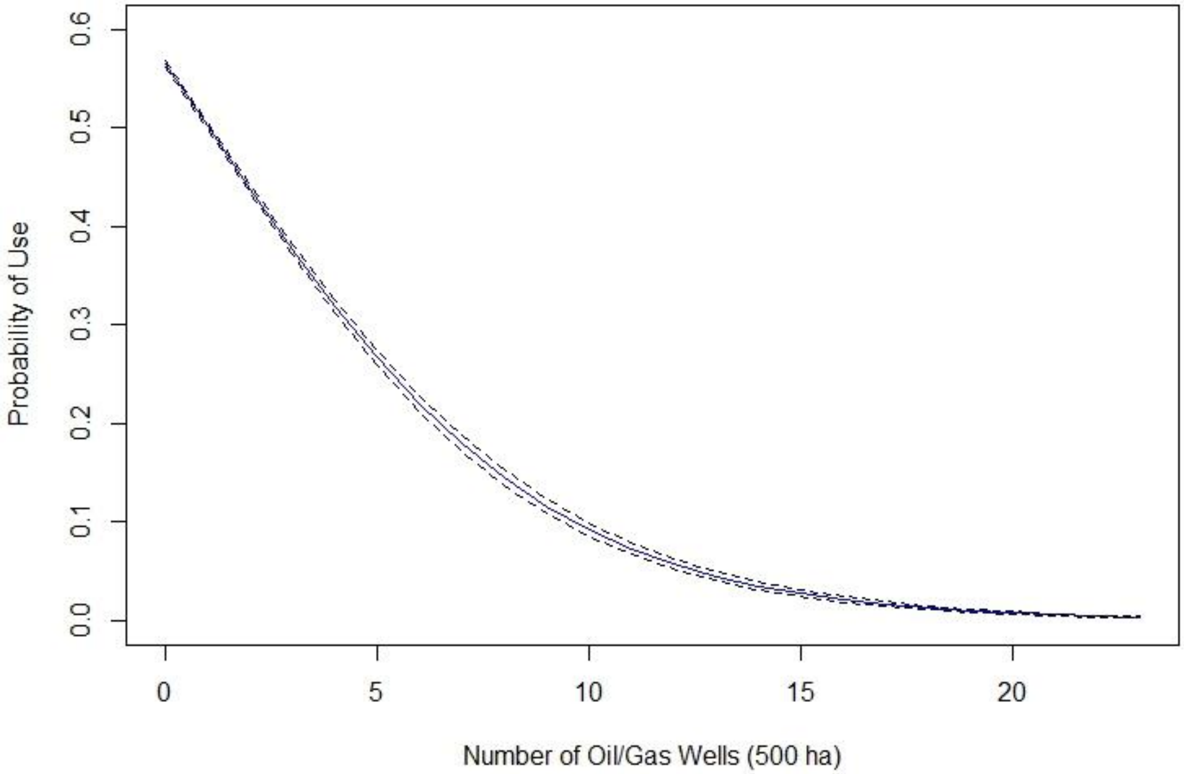

Figure 3.7 Probability of use for female lesser prairie-chickens in relation to oil/gas well densities (wells/250 ha) across both northwest and south-central regional populations in Kansas during 2013 and 2014. Dashed lines represent the 95% CIs. Use does not reach 100% because not all habitats within the available area are being used as it may not be suitable habitat (i.e., agricultural fields).

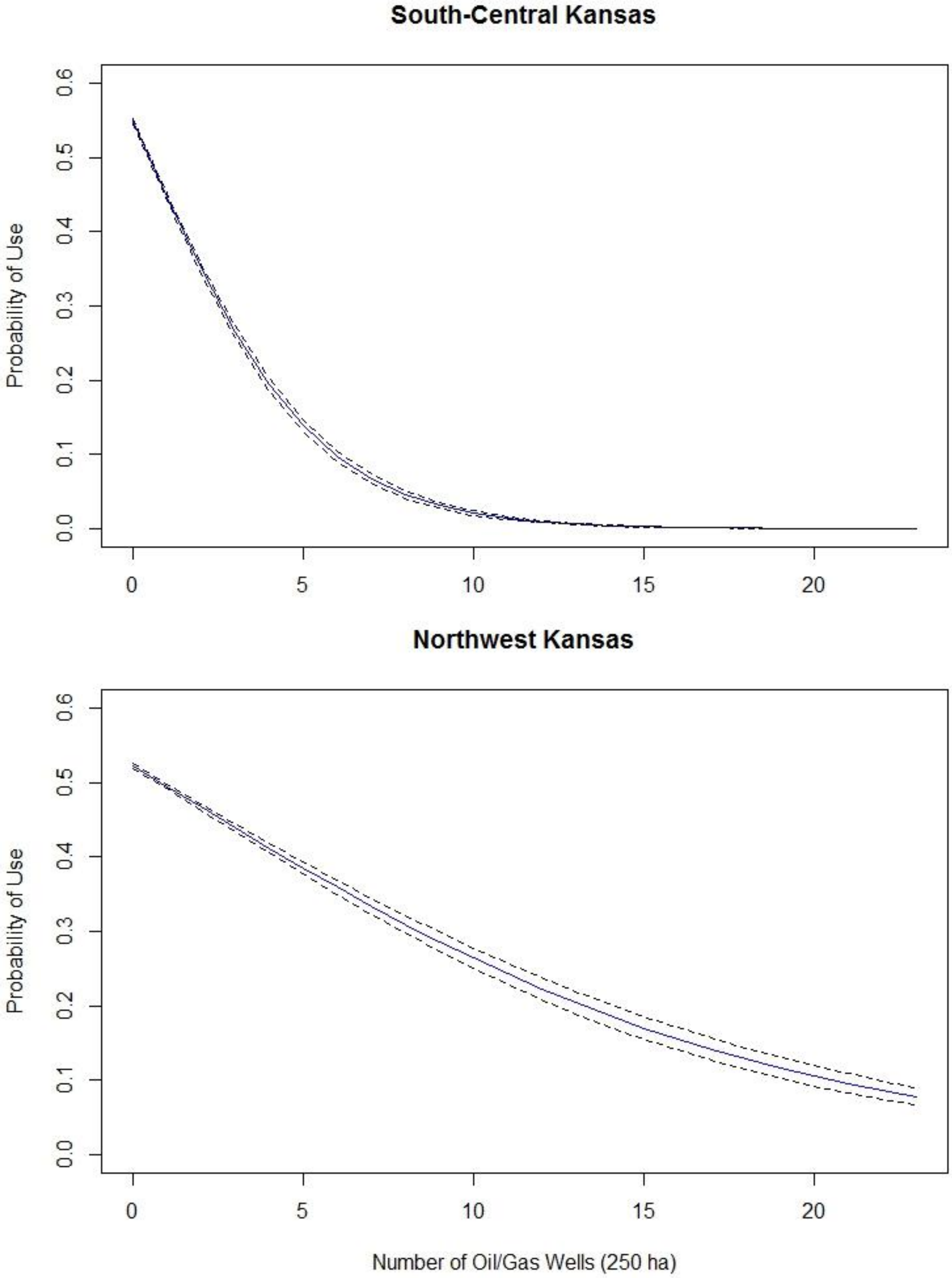

Table 3.1 Summary statistics representing the average linear distance (m), standard error (SE), and the maximum distance of the nearest 10^{th} percentile (10th *P*) from each anthropogenic feature to all observed bird locations and random locations for northwest Kansas (N = 47,587), south-central Kansas (N= 47,011), and pooled across regions (N= 94,598). Sample sizes for random locations were equal to observed locations.

	Pooled			NW Kansas			SC Kansas		
Type/Feature	$\bar{x}$	SE	10th *P*	$\bar{x}$	SE	10th *P*	$\bar{x}$	SE	10th *P*
Observed									
Lek	1852.80	9.40	404.75	2045.59	12.38	439.07	1657.64	14.11	386.00
Wells	1709.93	3.15	504.24	1563.09	4.61	413.38	1858.57	4.18	632.82
Roads	1630.71	3.77	378.21	1256.91	3.49	339.87	2009.09	6.24	456.38
Power Line	2351.79	4.06	716.04	1835.93	4.44	585.76	2873.98	5.93	935.63
Transmission Lines	11002.44	15.98	4888.26	12781.46	25.68	2991.75	9201.61	14.89	5378.40
Random									
Lek	5143.33	12.61	1370.45	5317.07	17.05	1441.45	4967.46	18.56	1304.57
Wells	1554.64	3.71	374.96	1624.35	5.40	368.80	1484.08	5.06	380.33
Roads	975.59	3.84	89.49	728.17	3.07	88.91	1226.05	6.90	90.32
Power Lines	1434.94	4.86	158.45	1178.25	4.87	147.15	1694.78	8.28	172.13
Transmission Lines	9204.30	20.89	1648.89	10727.61	33.38	1686.84	7662.33	22.91	1620.72

Table 3.2 Rank order of models compared to identify the appropriate scale for evaluation of the relationship between oil well densities (wells/ha) and female lesser prairie-chicken space use in Gove and Logan counties of the northwest Kansas during 2013 and 2014.

Grid Size	Dev.[a]	K[b]	Δ AIC[c]	w_i[d]
100 ha	130900	2	0	0.995
250 ha	130900	2	10.6	0.005
500 ha	131400	2	441.8	<0.001
450 ha	131500	2	534	<0.001
200 ha	131500	2	558.2	<0.001
350 ha	131500	2	593.3	<0.001
300 ha	131700	2	717.2	<0.001
150 ha	131700	2	753.6	<0.001
4.27 ha[e]	131800	2	844.9	<0.001
Null[f]	131900	1	1003.5	<0.001

[a] Dev = Deviance

[b] K = Number of parameters

[c] Differences in Akaike's Information Criterion

[d] Akaike's weights.

[e] Current area/well regulation in Kansas

[f] Null model compared used and random location with no covariates

Table 3.3 Rank order of models compared to identify the appropriate scale for evaluation of the relationship between oil well densities (wells/ha) and female lesser prairie-chicken space use in Kiowa, Comanche, and Clark counties of south-central Kansas during 2013 and 2014.

Grid Size	Dev.[a]	K[b]	Δ AIC[c]	w_i[d]
500 ha	126600	2	0	1
250 ha	126900	2	360.4	<0.001
350 ha	127000	2	458.2	<0.001
450 ha	127700	2	1139	<0.001
200 ha	127800	2	1191.4	<0.001
150 ha	127900	2	1346.4	<0.001
100 ha	128400	2	1843.5	<0.001
300 ha	128500	2	1877.5	<0.001
4.27 ha[e]	129900	2	3280.3	<0.001
Null[f]	130300	1	3756.5	<0.001

[a] Dev = Deviance

[b] K = Number of parameters

[c] Differences in Akaike's Information Criterion

[d] Akaike's weights.

[e] Current area/well regulation in Kansas

[f] Null model compared used and random location with no covariates

Table 3.4 Rank order of models compared to identify the appropriate scale for evaluation of the relationship between oil well densities (wells/ha) and female lesser prairie-chicken space use in both northwest and south-central Kansas during 2013 and 2014.

Grid Size	Dev.[a]	K[b]	Δ AIC[c]	w_i[d]
250 ha	259200	2	0	1
100 ha	259800	2	617.4	<0.001
500 ha	260000	2	818.9	<0.001
350 ha	260400	2	1225.8	<0.001
200 ha	260400	2	1264.6	<0.001
450 ha	260400	2	1290.2	<0.001
150 ha	260900	2	1725.2	<0.001
300 ha	260900	2	1786.8	<0.001
4.27 ha[e]	261800	2	2621.4	<0.001
Null[f]	262300	1	3120.0	<0.001

[a] Dev = Deviance

[b] K = Number of parameters

[c] Differences in Akaike's Information Criterion

[d] Akaike's weights.

[e] Current area/well regulation in Kansas

[f] Null model compared used and random location with no covariates