LESSER PRAIRIE-CHICKEN REPRODUCTIVE SUCCESS, HABITAT SELECTION, AND RESPONSE TO TREES

by

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Abstract

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie grouse native to the southwest Great Plains. Population declines and threats to populations of lesser prairie-chickens led U.S. Fish and Wildlife Service to list the species as “threatened” under the protection of the Endangered Species Act in May 2014. Lesser prairie-chickens are found within three distinct ecoregions of Kansas and Colorado and portions of the species’ range are affected by tree encroachment into grasslands. The effect of trees on lesser prairie-chickens is poorly understood. I evaluated habitat selection and reproductive success and across the northern portion of the species’ range. I captured female lesser prairie-chickens within the three different ecoregions in Kansas and Colorado to track nest and brood survival and measure nest and brood habitat. My findings show that there are regional and annual variations in nest and brood survival. Mean nest survival during 2013 and 2014 was estimated to be 0.388 (95% CI = 0.343 – 0.433) for a 35-day exposure period. Brood survival during 2013 and 2014 was estimated to be 0.316 (95% CI = 0.184 – 0.457) for 56 days. Chick survival was the lowest during the first week of life and is probably a limiting factor for population growth. Chick and brood survival decreased as Julian hatch date increased. Across the northern portion of the species’ range, females consistently select visual obstruction between 2-3 dm. Vegetation at the nest changes between regions and years to reflect environmental and regional conditions. Broods consistently selected habitats with greater percent cover of forbs than was expected at random across all study sites. Broods also selected against areas of bare ground. The threshold of lesser prairie-chicken use was 2 trees/ha throughout the year. No nests were located within areas with greater densities. Lesser prairie-chickens had a greater probability of use at greater distances from trees and at lower tree densities. To provide adequate nesting habitat managers should provide 2-3 dm of

visual obstruction. Providing forb cover with visual obstruction between 2.5-5 dm near nesting habitat should provide adequate habitat for broods. Removing trees in core habitats and expand removal efforts outward should expand potential habitat for lesser prairie-chickens.

Table of Contents

List of Figures

List of Tables

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Chapter 1 - **INTRODUCTION**

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie grouse native to North America and found within the Southern Great Plains region of New Mexico, Texas, Oklahoma, Colorado, and Kansas. Since the late 1800s, the population and range of the lesser prairie-chicken has declined by >90% (Taylor and Guthery 1980, Hagen et al. 2004). The population decline has mostly been attributed to conversion of native grassland for agricultural uses (Hagen et al. 2004). Other factors contributing to the decline include: energy exploration and development (e.g., oil, natural gas, and ethanol); mismanaged grazing lands; shrub and tree encroachment; planting of invasive and exotic grasses; and urban development (Hagen et al. 2004). The lesser prairie-chicken population peaked most recently in the mid-1980s, but continued to decline thereafter (Garton et al. 2015). Recent range-wide surveys indicate populations were reduced by ~45%, between 2012 and 2013, most likely due to intensive drought conditions throughout the species' range (McDonald et al. 2014). Continuing population declines, range-wide drought conditions (2011-2013), and anticipated anthropogenic impacts led the U.S. Fish and Wildlife Service to list the lesser prairie-chicken as a threatened species under the Endangered Species Act in May 2014 (USFWS 2014).

Lesser prairie-chickens are found within 3 distinct habitat types forming disjunct populations within Kansas and eastern Colorado: sand sagebrush (*Artemisia filifolia*) prairie of southwest Kansas and southeast Colorado, mixed-grass prairie in south-central Kansas, and short-grass/CRP mosaic prairie in northwest Kansas (Figure 1.1; McDonald et al. 2014). Southwest Kansas and southeastern Colorado was a former stronghold of lesser prairie-chickens (Haukos et al. 2015). However, lek surveys indicate that this population has dramatically declined within the past decade (Haukos et al. 2015). Recent drought (2011 – 2013) further reduced populations within this region (McDonald et al. 2014). This area is characterized by sandy to sandy-loam soils and sand sagebrush interspersed with native grasses. Row-crop agriculture is interspersed throughout the region, with center pivot agriculture being one of the dominant types of agriculture within the ecoregion. Other land uses include livestock grazing and CRP grasslands. Oil and gas wells are active within the ecoregion.

South-central Kansas falls within the mixed-grass prairie ecoregion (Figure 1.1; McDonald et al. 2014). Spring lek surveys indicate lesser prairie-chicken populations have remained relatively stable within the mixed-grass prairie, including south-central Kansas, in recent decades (Wolfe et al. 2015); however, severe drought conditions during 2011 and 2012 have resulted in a recent decline (McDonald et al. 2014). This region is characterized by a mixture of native grasses on loamy soils and large, intact grasslands. Land use within the ecoregion is primarily livestock grazing, with row-crop agriculture along waterways and some dry land farms on hilltops. Oil and gas infrastructure is present throughout the ecoregion. The mixed-grass prairie ecoregion is threatened by tree encroachment, with the eastern red cedar (*Juniperus virginiana*) being the primary concern, and has been implicated as a source of habitat loss and fragmentation for lesser prairie-chickens (Fuhlendorf et al. 2002).

Northwest Kansas has experienced an increase in lesser prairie-chicken population size and occupied range since the mid-1990s (Dahlgren et al. 2015). Northwest Kansas was characterized by a mixture of U.S. Department of Agriculture Conservation Reserve Program (CRP) fields, row-crop agriculture, and short-grass prairie intermixed with mixed-grass prairie on silt loam soils. Much of the short-grass prairie in the ecoregion is grazed by livestock. There are active oil and gas wells within the region. Comparing reproduction success, population recruitment, and habitat use among the three different regions will allow insights into factors affecting populations and facilitate conservation planning by identifying management needs on a regional scale.

Lesser prairie-chickens have habitat requirements that need to be met throughout each ecoregion. Additionally, the lesser prairie-chicken's habitat requirements vary temporally during the year. During the lekking season, lesser prairie-chickens require short vegetation within open areas (Hagen and Giesen 2005). During nesting, lesser prairie-chickens generally use sites with greater cover including bunch grasses and shrubs (e.g., Haukos and Smith 1989, Pitman et al. 2005, Grisham et al. 2013). Brood rearing often occurs in habitats with greater cover of forbs, which is linked with invertebrate biomass (Hagen et al. 2005). During the fall and winter, lesser prairie-chickens typically require grasslands for foraging and loafing and are often observed foraging in crop fields or in shrub thickets (Taylor and Guthery 1980, Hagen et al. 2004, Hagen and Giesen 2005). General habitat requirements for lesser prairie-chicken populations include relatively large blocks of contiguous grassland (e.g., ≥ 2,000 ha) containing all the habitats required during different life stages (Hagen et al. 2004). Evaluating habitat requirements among regions will provide managers the information needed to provide habitat for each life stage within each ecoregion.

Habitat requirements and demographic trends are linked to the unique biology of the species. The lesser prairie-chicken is a lekking species (Hagen and Giesen 2005). A lek is an aggregation of displaying males at a distinct location (Hoglund and Alatalo 1995). Females attend leks for the purpose of selecting a mate from late March – early May (Hoglund and Alatalo 1995; Hagen and Giesen 2005). Following mating, females lay one egg per day until the clutch is complete. A typical lesser prairie-chicken clutch size ranges from 10-12 eggs, but is often reduced for renesting attempts (Hagen and Giesen 2005). Females begin incubation when the penultimate egg is laid, so that all eggs will hatch on the same day. Nests are typically initiated in mid-April – mid-May (Hagen and Giesen 2005). Female lesser prairie-chickens place nests on the ground in areas of greater cover and greater visual obstruction than would be expected at random (Hagen et al. 2004). Nests have been documented in shrubs, such as sand sagebrush, and in grasses, such as little bluestem (*Schizachyrium scoparium*) (e.g., Pitman et al. 2005, Grisham et al. 2013). The nest is a small depression on the ground, shaped like a bowl and lined with feathers and dried grass (Hagen and Giesen 2005). Female lesser prairie-chickens are solely responsible for nesting and chick rearing (Hagen and Giesen 2005). If a nest is unsuccessful, females will often attempt to renest (Pitman et al. 2006a, Grisham et al. 2013). The lesser prairie-chicken is considered a boom-bust species (Hagen et al. 2008), with reproductive success varying annually and regionally (e.g., Fields et al. 2006, Pitman et al. 2006a, Grisham 2012).

Lesser prairie-chickens have precocial young (i.e., nidifugous). By having precocial chicks, females can immediately move all chicks (collectively the chicks form a brood) from the nest site to foraging areas. Movement reduces the risk of the entire brood being lost to predation. It is likely that only one or two chicks will be lost in a predation event compared to species with altricial (i.e., parental care at the nest until fledging) young, as the chicks are capable of scattering at an early age (Ehrlich et al. 1988, Sandercock 1994). Broods typically stay with the female until chicks are between 85-128 days old (Pitman et al. 2006b). Invertebrates have been identified as the primary source of food for chicks (Sumlinski 1977, Davis et al. 1980). Broods in Kansas use habitat with greater percent cover of forbs than would be expected at random, which has been linked to increased biomass of invertebrates (Hagen et al. 2005, Fields et al. 2006).

Factors affecting reproductive success are linked to population growth in prairie grouse ecology (Bergerud 1988, Peterson and Silvy 1996, Wisdom and Mills 1997, Hagen 2003). By investigating reproductive success of lesser prairie-chickens simultaneously among populations of Kansas and eastern Colorado, relative differences in nest success, brood survival, nest site selection, and brood site selection can be evaluated. Nest success and brood survival may be two of the driving vital rates affecting population trends within Kansas and eastern Colorado (Hagen et al. 2008, McNew et al. 2012). By gaining a better knowledge of nest success and brood survival, management strategies can be targeted for this life stage in an effort to increase population recruitment.

Nest survival is most often measured to estimate reproductive success of lesser prairie-chickens. Most female lesser prairie-chickens (i.e., 81-100% of radio-marked females) attempt at least one nest (Hagen et al. 2004). Often, if the initial clutch is lost, female lesser prairie-chickens will attempt to renest (Giesen 1994, Pitman et al. 2006b). In 10 telemetry studies, nest survival averaged 28% for the ~25-day incubation period (Hagen and Giesen 2005); however, there is considerable annual variation in nest success in response to environmental conditions (Grisham et al. 2013). Drought conditions reduced nest attempts and nest survival in Texas (Grisham et al. 2013).

Estimating chick and brood survival provides further insight into reproductive success. Chick and brood survival have been identified as critical demographic drivers of prairie grouse populations, including the lesser prairie-chicken (Wisdom and Mills 1997, Park et al. 2001, Hagen et al. 2008). Chick survival is highly variable across the lesser prairie-chicken range, averaging 39% over 60 days (Hagen et al. 2004). Unfortunately, small sample sizes have hindered efforts to characterize the relative influence of brood and chick survival on population demography of lesser prairie-chickens.

Measuring nest and brood habitat among regions and years will provide better understanding of regional and annual trends of habitat use. It will also give managers regional guidelines for management and conservation planning. Nest habitat characteristics can provide managers additional information to target nesting habitat in each region. Understanding brood habitat can provide managers with guidelines for providing adequate habitat for brood rearing. Investigating brood habitat in each region will provide further insight into trends in habitat use.

Grassland habitats, especially within the southeastern portion of the lesser prairie-chicken range in south-central Kansas and Oklahoma, have experienced severe tree encroachment. Tree encroachment, especially eastern red cedar (*Juniperus virginiana*), has been implicated as a cause of the lesser prairie-chicken decline (Fuhlendorf et al. 2002). However, the lesser prairie-chicken response to the presence of trees is poorly understood. Investigating the lesser prairie-chicken response to trees will provide valuable insight into habitat quality and habitat fragmentation due to tree encroachment in grasslands. Additionally, investigating nesting success in areas with tree encroachment will provide information on reproductive output in relation to trees. Managers can use this information to shape management goals in relation to tree encroachment.

The goals of my research were to investigate reproductive success and habitat of nests and broods concurrently within three different ecoregions and evaluate the response to trees by lesser prairie-chickens. The first objective, discussed in Chapter 2, was to concurrently evaluate nesting survival within three different ecoregions in Kansas and Colorado, compare nesting habitat and nest site selection between ecoregions and years, and investigate the influence of anthropogenic features on nest survival and nest site selection. The second objective of this study was to estimate lesser prairie-chicken brood and chick survival in the northern portion of the lesser prairie-chicken range, compare regional trends in chick and brood survival, and provide insight into brood habitat selection and provide management recommendations, discussed in Chapter 3. My last objectives were to measure lesser prairie-chicken habitat selection and reproductive response to trees and tree removal, discussed in Chapter 4.

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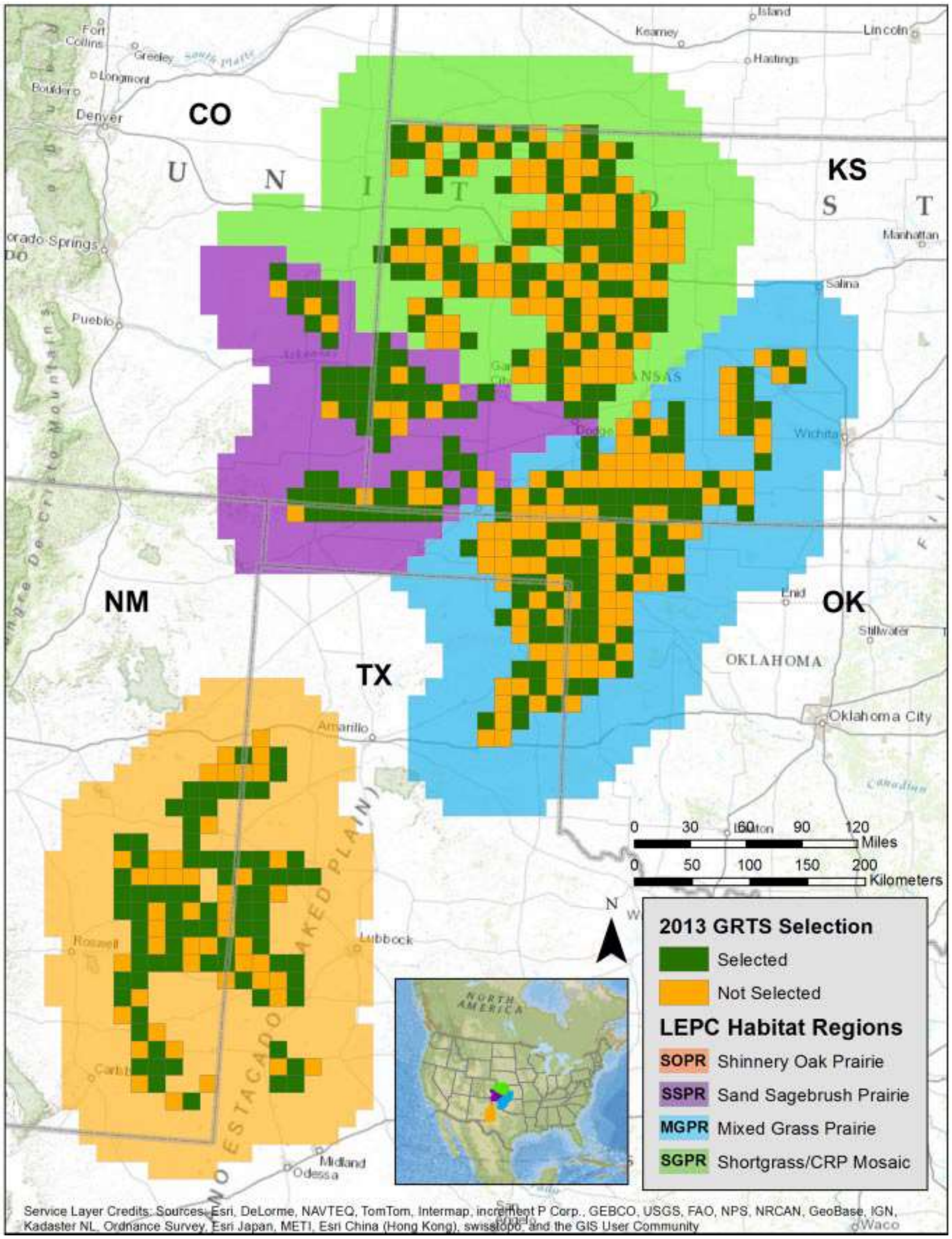
Figure 1.1 Lesser prairie-chicken range occurs in four distinct regions: shinnery oak prairie, sand sagebrush prairie, mixed-grass prairie, and short-grass/CRP mosaic. Figure taken from McDonald et al. (2014).



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Chapter 2 - **HABITAT SELECTION AND NEST SURVIVAL FOR NESTS OF LESSER PRAIRIE-CHICKENS IN KANSAS AND COLORADO**

Introduction

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie grouse native to North America and found within the Southern Great Plains of New Mexico, Texas, Oklahoma, Colorado, and Kansas. Since the late 1800s, the population size and range of the lesser prairie-chicken have declined by >90% (Taylor and Guthery 1980, Hagen et al. 2004). In May of 2014, the lesser prairie-chicken was listed as threatened under the Endangered Species Act (USFWS 2014). The population decline has been primarily attributed to conversion of native grassland for agricultural uses (Hagen et al. 2004). Other factors contributing to the decline include: energy exploration and development (e.g. oil, natural gas, ethanol, biofuels, and wind); mismanaged grazing lands; shrub and tree encroachment; invasive and exotic grasses; and urban development (Hagen et al. 2004).

Lesser prairie-chickens are found within 3 distinct ecotypes forming disjunct populations depending upon unique habitat types within Kansas and eastern Colorado: sand sagebrush (*Artemisia filiafolia*) prairie ecoregion of southwest Kansas and southeast Colorado, mixed-grass prairie ecoregion in south-central Kansas, and short-grass/CRP mosaic prairie ecoregion in northwest Kansas (Figure 1.1; McDonald et al. 2014). The sand sagebrush prairie ecoregion of southwest Kansas and southeastern Colorado was the former stronghold of lesser prairie-chickens (Haukos et al. 2015). However, lek surveys indicate that this population has dramatically declined within the past decade (Haukos et al. 2015). This ecoregion is characterized by sandy to sandy-loam soils and sand sagebrush interspersed with native grasses.

Spring lek surveys indicate lesser prairie-chicken populations have remained relatively stable within the mixed-grass prairie ecoregion including south-central Kansas in recent decades (Wolfe et al. 2015); however, severe drought conditions during 2011 and 2012 have resulted in a recent population decline (McDonald et al. 2014). This ecoregion is characterized by a mixture of native grasses on loamy soils. The short-grass/CRP mosaic prairie ecoregion of northwest Kansas has experienced an increase in lesser prairie-chicken population size and occupied range since the mid-1990s (Dahlgren et al. 2015). This ecoregion is characterized by a mixture of U.S. Department of Agriculture Conservation Reserve Program (CRP) fields, row-crop agriculture, and short-grass prairie intermixed with mixed-grass prairie on silt loam soils. Comparing reproduction success, population recruitment, and habitat use among the different ecoregions will facilitate conservation planning by identifying management needs on a regional scale.

Reproductive success is essential to the persistence of prairie grouse populations, including the lesser prairie-chicken (Peterson and Silvy 1996, Wisdom and Mills 1997, Hagen 2003, McNew et al. 2012). Nest survival makes up one component of lesser prairie-chicken reproductive success. Hagen et al. (2008) identified reproduction as having the greatest influence on lesser prairie-chicken population growth. Most lesser prairie-chicken females (i.e., 81-100%) will annually attempt at least one nesting effort (Hagen et al. 2004). If the initial clutch is lost, females will attempt 1-2 renest attempts (Giesen 1994, Pitman et al. 2006). Across 10 telemetry studies, nest survival averaged 28% for the ~25-day incubation period (Hagen and Giesen 2005); however, there is considerable annual variation in nest survival in response to environmental conditions (Merchant 1982, Lyons et al. 2011, Grisham et al. 2013). Studying nest survival and nest site selection concurrently among different ecoregions will provide new insights into population trends and regional differences among lesser prairie-chickens.

Nest site selection and survival differ among ecoregions. Within the sand shinnery oak (*Quercus havardii*) prairie ecoregion of eastern New Mexico and west Texas, lesser prairie-chickens select areas of greater grass cover, less bare ground, taller vegetation, and greater visual obstruction for nest locations (Sell 1979, Davis et al. 1979, Haukos and Smith 1989, Riley et al. 1992, Lyons et al. 2011, Grisham et al. 2013). Shrub cover is also important, especially as precipitation is less reliable in the New Mexico and west Texas. Shrub cover, shrub height, and visual obstruction are greater at nest sites than at random points (Wilson 1982, Davis 2009, Grisham et al. 2013). Nest survival within Texas was estimated to be 0.43 for 28 days during 2008 – 2011 (Grisham et al. 2014).

Within the sand sagebrush prairie ecoregion, nest site selection and nesting success vary from the sand shinnery oak prairie of New Mexico and Texas. Nests are typically located in areas with greater grass and shrub cover and denser vegetation, where the shrubs being used were primarily sand sagebrush (Bent 1963, Copelin 1963, Giesen 1994, Lyons et al. 2011, Pitman et al. 2005). Overall, nest survival was observed to be 26% for a study from 1997-2002 in Finney County, Kansas (Pitman et al. 2005).

For the mixed-grass prairie ecoregion, in the Red Hills region of Oklahoma, 67 nests of which 28 were successful during 1999-2003 (42% apparent nest success; Wolfe et al. 2003). Nests were placed as follows: 30 (46.2%) within native grassland, 25 (38.5%) nests in CRP fields, 9 (13.8%) in fallow fields, and 1 (1.5%) in an alfalfa field (Wolfe et al. 2003). Plant height was five times taller at nests (53.5 cm at successful nest vs. 47.0 cm at failed nest) than at random vegetation points (11.1 cm; Wolfe et al. 2003). In Texas, there was a difference in apparent nest survival between two different regions within Texas (Lyons et al. 2011). In the southwestern panhandle (sand shinnery oak prairie), nest survival was observed at 38%, whereas nest survival in the northeastern panhandle (mixed-grass prairie ecoregion) was found to be 67% for 21 nests. Vegetation VOR was greater at nest sites than at paired random points at both sites (Lyons et al. 2011). Vegetation height at nests in the southwestern site was greater than at the paired random sites; vegetation height did not differ between nest and random sites within the northeastern site (Lyons et al. 2011).

Within the short-grass/CRP mosaic prairie ecoregion of northwest Kansas, 49% apparent nest survival was observed (Fields et al. 2006). Daily survival rates decreased as nests aged, nesting season progressed, and temperatures increased (Fields 2004, Fields et al. 2006). Female lesser prairie-chickens were found to primarily use CRP grasslands for nest sites; however, this did not appear to influence nest survival (Fields et al. 2006).

Nest-site selection of lesser prairie-chickens is also influenced by the distance to anthropogenic structures. Areas of sand sagebrush habitat near anthropogenic features are avoided by nesting females; however, distances to anthropogenic features does not appear to influence nest survival (Pitman et al. 2005). Lesser prairie-chickens have been known to exhibit avoidance behavior in response to nearby anthropogenic structures such as power lines, roads, wells, and buildings (Hagen et al. 2011). Additionally, nest locations have been linked with leks in most studies. Most studies recommend that land managers target management activities within 3.5 km of leks, as most nests are located within this radius (Giesen 1998, Hagen et al. 2004, Pitman et al. 2006).

My objectives for this study were threefold: (1) investigate the influence of anthropogenic features on nest survival and nest site selection; (2) compare nesting habitat and nest site selection among ecoregions and years; and (3) estimate nest survival concurrently among three different ecoregions in Kansas and Colorado. I hypothesized that (1) nest selection would be negatively related with proximity to infrastructure; (2) lesser prairie-chickens would have a positive relationship between daily survival rate and visual obstruction; and (3) nest survival will vary regionally.

Methods

Study Area

Three study sites were located within Kansas and Colorado: Kiowa, Comanche, and Clark counties within south-central Kansas; Gove and Logan counties within northwest Kansas; and Baca and Prowers counties within eastern Colorado (Figure 2.1). The south-central Kansas site was located on private lands in Kiowa and Comanche counties within the Red Hills region. The Red Hills region consisted of mixed-grass prairie on loamy soils. The region was primarily used for ranching/pastureland with row-crop agriculture interspersed throughout the region. Dominant vegetation within the region includes: little bluestem (*Schizachyrium scoparium*), blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), sideoats grama (*B. curtipendula*), buffalograss (*Buchloe dactyloides*), sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludiviciana*), western ragweed (*Ambrosia psilostachya*), sand sagebrush, and eastern red cedar (*Juniperus virginiana*; Lauver et al. 1999).

The Clark County site within south-central Kansas was located along the ecotone of the mixed-grass and sand sagebrush prairie ecoregions. Land use in the region was dominated by livestock grazing and row-crop agriculture. In addition to the mixed-grass and sand sagebrush prairie, 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* sp.), kochia (*Kochia scoparium*), annual sunflower (*Helianthus annuus*), and sand sagebrush (Lauver et al. 1999).

In northwest Kansas, study sites were located on private lands and The Smoky Valley Ranch, within Logan and Gove counties. The Smoky Valley Ranch is a property owned and managed by The Nature Conservancy in Logan County, Kansas. This area was a mosaic of short-grass and mixed-grass prairies, CRP grasslands, and row-crop agriculture on silt loam soils. The dominant land uses in this region were livestock grazing, row-crop agriculture, CRP, and rural towns. Dominant vegetation in the region includes: blue grama, hairy grama, buffalograss, little bluestem, side oats grama, 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 planted within the CRP fields include: little bluestem, sideoats grama, big bluestem, switchgrass (*Panicum virgatum*), blue grama, buffalograss, and Indian grass (*Sorghastrum nutans*) (Fields et al. 2006). After original planting, some of the fields were inter-seeded with forbs 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.

Within eastern Colorado, the study sites were located on private lands in Baca, Cheyenne, and Prowers counties. All study sites were within the sand sagebrush ecoregion (Figure 1.1). Land use within the study site included ranching/pastureland, row-crop agriculture, and CRP grasslands. Dominate vegetation in the region included: blue grama, hairy grama, sideoats grama, little bluestem, sand sagebrush, kochia, and Russian thistle. Major crops within the region included wheat, sorghum, and corn.

Field Methods

Capture

In order to find and monitor nests we captured lesser prairie-chicken females at leks using walk-in traps (Haukos et al. 1990, Schroeder and Braun 1991) and drop nets (Silvy et al. 1990). Leks were trapped through the ~2-month lekking season (~10 March-15 May). Captured lesser prairie-chickens were sexed and aged using plumage characteristics (Copelin 1963). Females were fitted with either a satellite transmitter (platform transmitting terminals or PTT) or a VHF radio transmitter, which allowed us to track females to nests. Each PTT contained sensors to transmit calibrated indices for unit temperature and motion, which were used to determine if the bird was alive. The PTTs were mounted on the rump using leg harnesses made of Teflon ribbon (Dzialak et al. 2011); each unit weighed 22 g and had a solar battery charging component (Microwave Telemetry, Columbia, Maryland, USA). The VHF radio transmitters were equipped with a 12-hr mortality switch. VHF radio transmitters were 12-g bib/collar attachment style, with an average lifespan of 350 days (Advanced Telemetry System, Isanti, Minnesota, USA). Captured individuals were released within 10 – 20 minutes on-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 scientific collection license numbers 13TRb2053 and 14TRb2053.

Locations

In 2013 and 2014, female lesser prairie-chickens fitted with VHF radio transmitters were located (3+ times/week) via triangulation 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) to record telemetry locations via triangulation based on a minimum of three bearings (Cochran and Lord 1963). A maximum of 20-min time interval between bearings was used to minimize error from lesser prairie-chicken movement. Location of a Signal software (Ecological Software Solutions, Florida, USA) was used to obtain Universal Transverse Mercator (UTM) coordinates from VHF data collected in the field. For lesser prairie-chickens fitted with PTTs, the duty cycle for Global Positioning System (GPS) fixes was: one data point taken every 2 hours from 0400-2200 (~8-10 points/day) with a data transmission cycle of 8 hours on and 50 hours off. Potential location error using PTT transmitters was ≤18 m.

Nest locations were identified by approaching females marked with VHF transmitters using homing once a female had been recorded in the same location for three or more consecutive days (Pitman et al. 2005). For females with PTTs, we waited until GPS locations indicated the female had begun incubation used the GPS locations to initially locate the nest. The UTM coordinates of nest locations were recorded using a hand-held GPS unit (Garmin eTrex 30). When the nest was approached, rubber boots and latex gloves were worn to reduce scent and scent trails around the nests. We attempted to spend as little time as possible at the nest (<5 minutes) and avoided leaving “dead end” scent trails at the nest (Grisham 2012). Thereafter, nests were monitored remotely by radio signal. If telemetry or GPS fixes indicated the female was off the nest, we approached to assess nest fate (Pitman et al. 2005). Nests were considered successful if ≥1 egg successfully hatched and produced a chick that left the nest.

Nest Timing

At each nest site, I counted number of eggs present at the initial flush. We floated eggs to estimate the nest incubation date, nest initiation date, and predicted hatch date (Coats 1955, Pitman et al. 2006, Grisham 2012). At the visit to identify fate, each nest was categorized as successful (≥1 egg hatching) or unsuccessful (depredated, destroyed, or abandoned). A nest was considered abandoned if the nest is left unattended for ≥ 3 consecutive days. A nest was considered successful if we found pipped eggshells in the nest. We recorded the number of hatched eggs in the clutch.

Nest Placement

We measured the distance from each nest to a number of nearest anthropogenic features (e.g., roads, power lines, fences, oil and gas infrastructure) using ARCGIS 10 (ESRI Inc., 2011, Redlands, CA). We used the roads layers (included improved and unimproved roads) from Kansas GIS and Data and Support Center (http://www.kansasgis.org/), Kansas distribution lines (which included the Kansas transmission lines) shapefile from the Kansas Corporation Commission (http://www.kcc.state.ks.us/), the oil and gas wells available from the Kansas GIS Data and Support Center (http://www.kansasgis.org/), and fence shapefiles that were hand digitized using ArcGIS 10 and ground truthed.

Nest Vegetation

We conducted a standardized vegetation survey at each nest bowl and each nest site within three days after the fate was identified using protocols adopted by the NRCS Lesser Prairie-Chicken Initiative and Lesser Prairie-Chicken Interstate Working Group as sampling strategies for standardization among field studies (Pitman et al. 2005, Grisham 2012). Vegetation variables at both scales were compared between years and among regions. Additionally, we compared vegetation at the nest bowl to random points across each study site and the nest site to random points distributed across each study site. We estimated percent canopy cover of shrubs, forbs, grasses, bare ground, and litter using a 60 x 60 centimeter (cm) Daubenmire frame

(Daubenmire 1959) at the nest bowl and 4-m from the point center to the north (N), south (S), east (E), and west (W) of the nest bowl, which represented the nest site. We estimated a visual obstruction reading (VOR) using Robel pole at the point center from a distance of 4 m and a height of 1 m (Robel et al. 1970). We measured litter depth from the point center out to 4 m N, S, E, and W of the nest bowl at 0.5-m intervals (Davis et al. 1979). We averaged across all litter depth measurements to get an average litter depth for the nest site. We measured vegetation at a paired random point at a random distance within 360 m from the nest in a random direction, following the same techniques used at the nest. Additionally, the same vegetation measurements techniques were used at random points distributed throughout each study site.

Statistical Analyses

I used the nest survival procedure within Program MARK to estimate daily nest survival (White and Burnham 1999, Dinsmore et al. 2002). I developed 23 potential models *a priori*, using my hypotheses to guide model construction. Nest survival models tested included combinations of region, year, nest vegetation variables, initiation date, date during the nesting season, and transmitter type. I used Akaike's Information Criterion, corrected for a small sample size (AIC_c) to rank models (Burnham and Anderson 2002).

I used an information theoretic approach to rank models and logistic regression to identify the best visual obstruction for nest use (Burnham and Anderson 2002, Manly et al. 2002). I used logistic regression to determine nest site selection, where I compared both the nest bowl and nest sites (used) separately to random points distributed across each study site (unused) (Manly et al. 2002). I compared nest vegetation variables (e.g., visual obstruction; percent cover of litter, grass, forbs, bare ground, and shrubs; mean litter depth) and distance to nearest anthropogenic features (e.g., roads, power lines, oil and gas infrastructure, and fences) between used and random sites. Program R. To identify the probability of use, I used the following logistic regression function:

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

to generate probability of use curves. I used the beta coefficients from the model, within the logistic regression function. Program R (R core development team, version 3.0.1, 2013, Vienna, Austria) and SAS (SAS Institute Inc., 2013. version 9.4, Cary, North Carolina) were used for all statistical analyses.

Results

During 2013 and 2014, we located and monitored a total of 185 nests (63 in 2013, 122 in 2014) in Kansas and Colorado. Within the Kansas Red Hills, we monitored 22 and 41 nests in 2013 and 2014, respectively. Within Clark County, Kansas, 27 nests were monitored in 2014. Within northwest Kansas, we monitored 37 nests in 2013 and 51 nests in 2014. In eastern Colorado, 4 nests were monitored in 2013 and 2 in 2014. All nests (100%) in the Kansas Red Hills and Clark County, Kansas were in grassland. In northwest Kansas, 33% (29) of nests were in CRP, 1% (1) of nests were in wheat fields, and 66% (58) nests were in grasslands. In Colorado, 50% (3) nests were in grasslands, 33% (2) of nests were in CRP, and 17% (1) of nests were in wheat fields. Fate of all nests across all years and regions was: 26.5% hatched, 58.4% nests were depredated, 1.6% nests were trampled, 1.6% nests were lost due to the female being killed off the nest, 8.7% were abandoned, and for 3.2% of nests the cause of failure could not be identified (Table 2.1).

Nests were found to be an average of 1,632 m (SE = 153) from leks across all regions. Within the Red Hills, nests were an average of 1,093 m (SE = 115) from leks. Nests within northwest Kansas were 1,723 m (SE = 195) from leks. Colorado nests were located an average of

1,807 m (SE = 852) from leks. Last, nests in Clark County, Kansas averaged 2,542 m (SE = 738) from leks.

Mean clutch size of first nest attempts was 10.4 (SE = 0.3) eggs in 2013 and 10.6 (SE = 0.3) eggs in 2014 (Table 2.2). Clutch size differed between nest attempts ($F_{3, 149}$ = 12.91 P < 0.001) and renests contained 3 eggs less than first nest attempts on average (Table 2.2). Renest attempts had a mean clutch size of 7.3 (SE = 1.0) eggs in 2013 and 7.80 (SE = 0.5) eggs in 2014 (Table 2.2). There was no difference in clutch size among regions ($F_{3, 146}$ = 2.50 P = 0.06) or between years ($F_{1, 146}$ = 2.10, P = 0.15; Table 2.2).

Nest Site vs. Random Site

Visual obstruction at the nest bowl was 1 decimeter (dm) greater than at paired random points when compared across all regions (t_{268} = 12.21; *P* < 0.001; Table 2.3). Percent cover of litter and shrubs were 20% (t_{268} = 2.02, *P* = 0.04) and 320% (t_{327} = 2.10, *P* = 0.04) greater at the nest bowl than at paired random points across all regions, respectively (Table 2.3). There was no difference between percent cover of forbs (t_{312} = -0.33, *P* = 0.74) and grass (t_{275} = 1.64, *P* = 0.10) at the nest bowl across all regions when compared to paired random points (Table 2.3). Percent cover of bare ground was 66% less at the nest bowl than at paired random points (t_{157} = -5.10, *P* < 0.001; Table 2.4). Mean litter depth was 0.9 cm greater at nest sites compared to paired random points (t_{300} = 4.28, *P* < 0.001; Table 2.3).

There were regional differences for vegetation between paired random and nest bowls. Within the Red Hills, visual obstruction was 1.3 dm greater at nests (t_{80} = 6.26, *P* < 0.001; Table 2.3). Nests within the Red Hills had 73% less bare ground at nests than paired random points (t_{55} = -2.21, *P* = 0.03; Table 2.3). In Clark County, Kansas, the only differences between nest bowls and paired random points were visual obstruction (1.25 dm greater at nests; t_{43} = 5.68, *P* < 0.001) and percent cover of bare ground (70% less bare ground at nests; $t_{25} = -2.60$, P = 0.02; Table 2.4). Northwest Kansas had visual obstruction ~0.6 dm greater at nest bowls ($t_{73} = 6.43$, $P < 0.01$; Table 2.3). In addition, bare ground was 57% less at nests ($t_{54} = -2.16$, $P = 0.04$) and percent cover of shrubs was 6 times greater at nest sites ($t_{142} = 2.38$, $P = 0.02$; Table 2.3).

Nest Site Selection

The visual obstruction reading that best explained habitat selection was 75% visual obstruction (Table 2.4). The top model for explaining habitat selection for use in regards to 75% visual obstruction was a quadratic function of visual obstruction (Table 2.4). 75% visual obstruction was used to build all models when it was used as a component of habitat selection models.

When compared to random points across all study sites, the model that best explained nest bowl selection was an additive model of percent cover of bare ground, visual obstruction, and a quadratic function of visual obstruction (Table 2.5). There was a negative relationship with percent cover of bare ground, a positive relationship with visual obstruction, and a negative relationship with the quadratic function of visual obstruction, indicating a concave quadratic relationship (Table 2.5). The relationship with visual obstruction across all regions indicates that the probability of use peaks between 2 – 3 dm of vegetation cover (Figure 2.2). Within the Red Hills and northwest Kansas, the model that best explained nest-site selection was an additive model of percent cover of bare ground, visual obstruction, and a quadratic function of visual obstruction (Tables 2.3, 2.4). Again, each of the relationships within the Red Hills and Northwest the probability of use peaks between 2.5 – 3.5 dm and 1.5 – 3 dm, respectively (Figures 2.3, 2.4). Within Clark County, Kansas, there were two competing models. Each competing model contained a concave quadratic component of visual obstruction along with a negative relationship with percent cover of forbs and a negative relationship with percent cover of bare ground (Table 2.5). The relationship with visual obstruction indicates a peak area of use for visual obstruction of 2.0 – 3.5 dm (Figure 2.5).

Nest-site selection at the scale of 4-m interval surrounding the nest at all study areas indicated that, similar to nest-bowl selection, visual obstruction was a key component of selection, as the top model included an additive model including percent cover of litter, visual obstruction, and a quadratic function of visual obstruction (Table 2.9). Nest sites at the 4-m scale within the Red Hills had the same top ranked model as was found across all sites (Table 2.10). In northwest Kansas, the top model was an additive model that contained a negative relationship with percent cover of bare ground and a concave relationship for a quadratic visual obstruction component (Table 2.11). Within Clark County, Kansas, there were 6 competing top ranked at the 4-m scale of nest-site selection (Table 2.12). The top-ranked models all contained a quadratic, concave relationship with visual obstruction (Table 2.12). There was a negative relationship with percent cover of shrubs and bare ground, while there was a positive relationship with percent cover of litter, forbs, and grass (Table 2.12).

Lesser prairie-chicken nest-site placement in relation to anthropogenic features indicates that nests were placed closer to roads (included improved and unimproved roads) than expected at random (Table 2.13). Nests had positive relationships with both power lines and fences than expected at random (Table 2.13). While there was no significant trend for distance to nearest anthropogenic feature (i.e., measuring the distance to the nearest feature regardless of what type: Table 2.13), the probability of use increased linearly with increasing distance to nearest anthropogenic feature (Figure 2.6).

Nest Survival

Nest survival varied among regions and between years, with estimates greatest in the Red Hills in 2013 and northwest Kansas in 2014 (Figure 2.7). While not the top-ranked model, one of the objectives was to evaluate nest survival concurrently across all regions and years (Table 2.14). Colorado had the highest nest survival in 2014; however, there was a sample size of 2 nests, making conclusions difficult. We observed regional variation among years. For instance, nest survival decreased by 64% between 2013 and 2014 in the Red Hills, but doubled in northwest Kansas between 2013 and 2014 (Figure 2.7). Apparent nest survival for the duration of the study and across all regions was estimated to be 0.388 (95% CI = 0.343 – 0.433). Nest survival across all regions was estimated to be 0.416 (95% CI = 0.340 – 0.440) during 2013 and 0.373 (95% CI = 0.317 – 0.428) during 2014. Across years, the regional nest survival estimates for the Red Hills, Colorado, northwest Kansas, and Clark County were 0.376 (95% CI = 0.300 – 0.451), 0.576 (95% CI = 0.294 – 0.781), 0.299 (95% CI = 0.192 – 0.415), and 0.409 (95% CI = 0.344 – 0.473), respectively.

Variation in daily nest survival was best explained by quadratic model of date during the nesting season (Table 2.14). Daily nest survival decreased as the nesting season progressed, but began to increase later in the nesting season, which corresponded to the renesting period (Figure 2.8). The habitat variable that best explained variation in nest survival was an additive model of visual obstruction and a quadratic function of visual obstruction (Table 2.14). Visual obstruction had a positive relationship with nest survival. While visual obstruction varied regionally and yearly (Table 2.3), the trend followed a quadratic function, where at low visual obstructions there was a decrease in daily nest survival (e.g., 0.5 – 1.1 dm; daily survival rate decreases by 0.01), daily nest survival then bottoms out (e.g., 1.1 – 2.1 dm; daily survival rate = 0.97), and then daily survival rate increases until it reaches 5.75 dm (daily survival rate increases 0.02). The relationship with visual obstruction was consistent among years and regions (Figure 2.9). Nest survival did not differ between PTT and VHF transmitters (Figure 2.10). Models using variables of percent cover at the nest (litter, grass, and forbs) performed poorly (Table 2.14). When variables with percent cover at nests were combined with visual obstruction, these models were ranked higher; however all these models were competitive when compared to each other (Table 2.14). Nest survival increased with increasing distance away from nearest anthropogenic feature (Figure 2.11).

Discussion

My findings indicate (1) clutch size does not vary regionally and annually, while nest survival does vary regionally and annually, (2) nest survival declines during the breeding season and increased with visual obstruction (3) there are differences between nests and paired random points (4) nest habitat selection is relatively consistent across the northern portion of lesser prairie-chicken range. Providing nesting habitat with 2 - 3 dm of visual obstruction away from anthropogenic structures would provide reliable nesting habitat for lesser prairie-chickens.

Lesser prairie-chicken clutch size was consistent between years and among regions, indicating that clutch size is consistent across the northern portion of the lesser prairie-chickens range. While consistent between years, there is seasonal variation in clutch size in relation to nesting attempt, which indicates a smaller clutch size with renest attempts. Within the southern portion of the lesser prairie-chicken’s range, clutch size is 2 – 3 eggs fewer than the northern portion of the range, on average (Haukos 1988, Holt 2012, Grisham et al. 2014). In Kansas, first nest attempts contained 3 eggs more than renest attempts, which is consistent with previous work (Pitman el al. 2005). Additionally, within northwest Kansas and Oklahoma, clutch sizes were similar to my findings (Copelin 1963, Fields 2004, Wolfe et al. 2003). It appears that clutch size within the northern portion of the species' range is typically larger than the southern portion of the species' range.

I observed regional and annual differences in nest survival. Annual and regional variation of lesser prairie-chicken nest survival could be attributed to patterns related to environmental conditions of climate and weather. For instance, in 2013 northwest Kansas was considered to be in extreme drought and nest survival was low. By 2014, northwest Kansas came out of the drought and nest survival improved. Within Finney County, Kansas there was no inter-annual variation in nest survival (Pitman et al. 2005). Lyons et al. (2011) observed similar patterns in lesser prairie-chicken populations in the Texas panhandle, with nest survival being lower during drought conditions. Grisham et al. (2014) observed inter-annual variation in nest initiation date and the percent of females incubating and concluded that weather patterns promoting greater grass growth affected lesser prairie-chicken reproduction. By reducing stocking rates of livestock during drought conditions, managers can reduce the impacts on grasslands and maintaining some nesting cover.

Nest survival was greatly influenced by the date within the nesting period. Daily survival decreased as the nesting season progressed and then increased around June 12. I hypothesize that early in the nesting season, there are fewer nests and females are not spending as much time incubating. However, as incubation time increases, females spend more time at the nest and this may allow for easier detection of nests by mammalian predators due to increased concentration of scent, visual indicators of presence, or improved search pattern capacity of nest predators. Additionally, as the number of nests increases, so does the probability of a predator discovering a nest. Later in the nesting season, the more robust females are attempting renests and the number of nests declines, perhaps decreasing the odds of a predator discovering a nest. Willow ptarmigan

(*Lagopus lagopus*) were observed to follow the same pattern and it was hypothesized that predators began to cue in on nests as the season progressed and nests were more abundant until the number of nests declined and it was no longer beneficial for predators to seek out nests (Wilson et al. 2007). Grant et al. (2005) hypothesized that nest survival decreased due to increased predator movement as the nesting season progressed. Unfortunately, this is difficult to manage, if not impossible.

Nest survival and nest-site selection results indicate that vertical visual obstruction was the most important habitat characteristic for lesser prairie-chickens when selecting a nest site. Across all regions, lesser prairie-chickens had a greater probability of using 1.5 – 3.5 dm of visual obstruction; this appeared to be the optimal range for nest selection. There was a general trend within each region where there was an optimal range for nest site selection. These findings are consistent with greater prairie-chickens, where there appears to be an optimal range for nest placement in relation to visual obstruction (*Tympanuchus cupido*; McNew et al. 2014). Another species of grouse, the white-tailed ptarmigan (*Lagopus leucurus*), exhibited a tradeoff between cover and predation risk: too much cover and the female could not escape predation events, too little cover and the eggs were exposed (Wiebe and Martin 1998).

The type of cover at the nest was less important than having adequate structure to establish a nest. There was a consistent avoidance of bare ground and selection of greater visual obstruction; however, no nests were located in visual obstruction greater than 5 dm. The importance of vertical visual obstruction for nest establishment is consistent with other studies across the range of the lesser prairie-chicken. A meta-analysis of lesser prairie-chicken nesting studies revealed that selected nest sites had greater visual obstruction and lower bare ground in the sand sagebrush prairie and the sand shinnery oak prairie ecoregions than available (Hagen et al. 2013). Nest survival in relation to visual obstruction followed the opposite trend, where there was a decrease in nest survival from 1.1 – 2.1 dm. As the major cause of nest failure was predation (58%), perhaps predators are more likely to search within grass heights in optimal lesser prairie-chicken nesting and therefore predators have a greater probability of encountering a nest.

Nest site selection for both nest bowls and nest sites were similar in that both had a quadratic relationship with visual obstruction. There was an optimal range or availability of visual obstruction selected by lesser prairie-chickens which was 2 – 3 dm. There was a negative relationship with percent cover of bare ground, indicating it was avoided. Greater visual obstruction will generally lead to lower percent cover of bare ground. Percent cover of litter was consistently selected at the nest site scale, indicating that residual cover was important for nest site selection. Providing litter is potentially difficult for managers, as amount of litter is linked with amount of residual cover remaining from previous growing seasons and dependent on the amount of precipitation received in previous years, grazing intensity, and time since disturbance (e.g., fire, mowing).

Differences in regional habitat composition alter lesser prairie-chicken nest site selection across their range. Shrub cover is more important for nesting in the sand sagebrush prairie and sand shinnery oak ecoregions than in mixed-grass prairie ecoregion (Hagen et al. 2013); indicating lesser prairie-chickens alter habitat use by region to maximize visual obstruction. Fields (2004) observed lesser prairie-chickens using nest sites with greater grass cover than forb cover in northwest Kansas, but shrub cover at nests was not observed during the study, despite shrubs being present on the study site at very low densities. As precipitation becomes more reliable in the eastern portion of their range, lesser prairie-chickens increase use of grass for nest cover.

Nest survival increased with increasing distance from the nearest anthropogenic feature and in general nests were placed further from anthropogenic features than expected at random. However, roads were an exception. Most roads on the study sites were in areas were unimproved roads with very little traffic use (J. Lautenbach, unpublished data). Females could place nests nearer to unimproved roads as a way to move chicks once a nest hatches. Perhaps females find suitable nesting habitat close to unimproved roads, so when the nest hatches, females only need to move their brood a short distance through thick vegetation. Once the brood makes it to the unimproved road, females could use unimproved roads as a travel corridor to move broods to appropriate brood rearing habitats.

I observed avoidance of power lines and fences, but no avoidance of oil and gas infrastructure. Power lines and fences provide additional perch sites for raptors, and therefore lesser prairie-chickens avoid nesting near these areas as a response to reduce potential avian predation of nests. Oil and gas infrastructure does not provide adequate perching sites, and therefore, lesser prairie-chickens do not need to avoid them. Pitman et al. (2005) observed that distances to anthropogenic features did not affect nest survival and lesser prairie-chickens avoided habitat surrounding anthropogenic features.

Management Implications

Providing habitat with visual obstruction between 1.5 and 2.5 dm will provide adequate habitat for nesting. The type of cover is not as important as ensuring cover is available for lesser prairie-chickens to nest. Ensuring there is cover available during weather and climate variation will help to reduce annual reproductive variability, this could include reducing livestock stocking rates during droughts. Reducing the number of anthropogenic features in grasslands can increase the amount of area available for nesting lesser prairie-chickens. Preventing further development within core lesser prairie-chicken habitats will provide areas that have a greater probability of being selected. Managers should also focus habitat management in areas with low densities of anthropogenic features.

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Table 2.1 Summary of lesser prairie-chicken nest fates across Kansas and Colorado during 2013 and 2013. Kiowa and Comanche counties (Red Hills) are located within south-central Kansas, Clark County (Clark) is located with south-central Kansas, Gove and Logan counties (Northwest) are located with Northwest Kansas, and Baca, Cheyenne, and Prowers counties (Colorado) are located in eastern Colorado.

Site	Year	Hatch	Predator	Trampled	Female Depredated	Abandoned	Unknown	Total
Red Hills	2013	8	11	1	0	2	0	22
	2014	7	30	0	3	1	0	41
Clark	2014	7	18	0	0	0	2	27
Northwest	2013	6	22	2	0	4	3	37
	2014	18	24	0	0	9	1	52
Colorado	2013	1	3	0	0	0	0	4
	2014	2	0	0	0	0	0	2
Total	-	49	108	3	3	16	6	185

Table 2.2 Comparisons between regions, years, and nesting attempts in average clutch size of lesser prairie-chickens during 2013 and 2014 in Clark County, Kansas (Clark), Kiowa and Comanche counties, Kansas (Red Hills), Gove and Logan counties, Kansas (Northwest), and Baca and Prowers counties, Colorado.

	2013				2014			
Region	First Nest Attempts	SE	Renest Attempts	SE	First Nest Attempts	SE	Renest Attempts	SE
Red Hills	11.39A*	0.40	10.50B	0.50	10.48A	0.49	8.00B	0.47
Colorado	9.00A	1.53	N/A	N/A	7.50A	2.50	N/A	N/A
NW KS	10.50A	0.47	6.00B	0.71	9.93A	0.52	6.67B	1.33
Clark, KS	N/A	N/A	N/A	N/A	10.94A	0.36	8.50B	0.99
Total	10.61A	0.34	7.29B	0.97	10.38A	0.26	7.80B	0.46

* Means with the same uppercase letter did not differ ($P < 0.05$) between years or regions

Table 2.3 Comparisons of habitat variables between nest site and paired random site using a Student's *t*-test across all regions, within Clark County, Kansas, Gove and Logan counties (Northwest Kansas), and Kiowa and Comanche counties (Red Hills, Kansas) during 2013 and 2014. Mean, standard error, *t* statistic, and *P*-values shown.

Region	Habitat	Nest	SE	Paired	SE	*t*	*P* ≤
All Regions	VOR (dm)	1.98	0.06	0.96	0.07	12.21	0.001
	% Litter	24.48	1.39	20.48	1.48	2.02	0.04
	% Grass	57.64	2.17	52.38	2.51	1.63	0.10
	% Forbs	13.34	1.44	13.97	1.35	-0.33	0.74
	% Bare Ground	4.30	0.52	12.82	1.59	-5.10	0.001
	% Shrub	3.54	0.98	1.10	0.73	2.10	0.04
	Litter Depth (cm)	2.70	0.15	1.80	0.16	4.28	0.001
Clark, Kansas	VOR (dm)	2.28	0.15	0.99	0.17	5.68	0.001
	% Litter	15.91	2.17	13.78	2.73	0.62	0.54
	% Grass	64.70	4.84	54.43	7.91	1.11	0.28
	% Forbs	6.57	1.35	13.78	3.99	-1.72	0.10
	% Bare Ground	6.17	1.41	20.04	5.15	-2.60	0.02
	% Shrub	4.96	2.73	5.39	4.02	-0.09	0.93
	Litter Depth (cm)	2.83	0.56	2.13	0.43	0.99	0.33
Northwest Kansas	VOR (dm)	1.71	0.07	0.90	0.11	6.43	0.001`
	% Litter	25.34	1.99	20.75	2.56	1.46	0.15
	% Grass	63.46	2.77	64.31	3.57	-0.19	0.85
	% Forbs	8.90	1.85	6.23	1.27	1.30	0.20
	% Bare Ground	4.63	0.81	10.81	2.71	-2.16	0.04
	% Shrub	2.55	0.85	0.40	0.33	2.38	0.02
	Litter Depth (cm)	3.37	0.22	2.67	0.31	1.91	0.06
Red Hills, Kansas	VOR (dm)	2.30	0.09	1.00	0.09	6.26	0.001
	% Litter	25.95	2.62	22.88	2.18	1.11	0.37
	% Grass	45.10	3.88	41.88	3.02	-0.34	0.51
	% Forbs	24.52	2.69	20.34	1.98	1.38	0.21
	% Bare Ground	3.15	0.78	11.64	1.73	-2.21	0.03
	% Shrub	2.60	1.59	0.00	0.00	1.76	0.11
	Litter Depth (cm)	1.33	0.97	0.96	0.06	1.62	0.11

Table 2.4 Model ranking for visual obstruction readings (VOR) for determining the VOR that best explains nest use within Kansas and Colorado during 2013 and 2014.

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
75% VOR as Quadratic	1175.9	3	0.0[e]	1
50% VOR as Quadratic	1368.4	3	17.6	<0.001
100% VOR as Quadratic	1222.4	3	46.5	<0.001
25% VOR as Quadratic	1243.4	3	67.5	<0.001
0% VOR as Quadratic	1300.3	3	124.4	<0.001
50% VOR	1368.4	2	190.5	<0.001
25% VOR	1369.8	2	191.9	<0.001
75% VOR	1370.5	2	192.6	<0.001
100% VOR	1392.9	2	214.9	<0.001
0% VOR	1412.9	2	235.0	<0.001
Null[f]	1440.3	1	260.4	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. Minimum AIC_c = 1181.9
f. Compares used points to available with no covariates.

Table 2.5 Resource selection functions of lesser prairie-chicken nest bowl placement in relation to habitat features among all study sites in Kansas during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Bare (-)[e] + VOR (+) + VOR^2 (-)	1111.7	4	0.0[f]	1
% Litter (+) + VOR (+) + VOR^2 (-)	1140.9	4	29.1	<0.001
% Forbs (-) + VOR (+) + VOR^2 (-)	1149.0	4	37.3	<0.001
% Grass (+) + VOR (+) + VOR^2 (-)	1149.3	4	37.6	<0.001
% Shrub (+) + VOR (+) + VOR^2 (-)	1157.8	4	46.1	<0.001
VOR (+) + VOR^2 (-)	1175.9	3	62.1	<0.001
% Bare (-)	1296.5	2	180.7	<0.001
VOR (+)	1368.4	2	254.7	<0.001
% Grass (+)	1394.3	2	278.5	<0.001
% Shrub (+)	1411.0	2	295.2	<0.001
% Litter (+)	1411.7	2	295.9	<0.001
% Forbs (N)	1421.7	2	306.0	<0.001
Null[g]	1440.3	1	322.5	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum AIC_c = 1119.7
g. Compares used points to available with no covariates.

Table 2.6 Resource selection functions of lesser prairie-chicken nest bowl placement in relation to habitat features among all study sites in Kiowa and Comanche counties, Kansas, during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Bare (-)[e] + VOR (+) + VOR^2 (-)	329.1	4	0.0[f]	0.994
% Litter (+) + VOR (+) + VOR^2 (-)	340.0	4	10.2	0.006
% Grass (+) + VOR (+) + VOR^2 (-)	350.9	4	21.1	<0.001
VOR (+) + VOR^2 (-)	359.3	3	27.5	<0.001
% Forbs (N) + VOR (+) + VOR^2 (-)	365.8	4	28.0	<0.001
% Shrub (N) + VOR (+) + VOR^2 (-)	359.3	4	29.5	<0.001
% Bare (-)	415.5	2	81.6	<0.001
VOR (+)	440.9	2	107.0	<0.001
% Litter (+)	451.7	2	117.8	<0.001
% Forbs (+)	459.3	2	125.4	<0.001
Null	462.6	1	126.8	<0.001
% Grass (N)	461.5	2	127.5	<0.001
% Shrub (N)	461.6	2	127.7	<0.001

a. Deviance

b. Number of parameters

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

d. Akaike weights

e. (-) negative relationship, (+) positive trend, (N) indicates no trend

f. Minimum $\text{AIC}_c = 337.8$

Table 2.7 Resource selection functions of lesser prairie-chicken nest bowl placement in relation to habitat features among all study sites in Gove and Logan counties, Kansas, during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Bare (-)[e] + VOR (+) + VOR^2 (-)	524.4	4	0.0[f]	0.851
% Shrub (N) + VOR (+) + VOR^2 (-)	528.6	4	4.2	0.104
% Litter (N) + VOR (+) + VOR^2 (-)	532.3	4	7.9	0.0162
% Grass (+) + VOR (+) + VOR^2 (-)	532.5	4	8.1	0.015
% Forbs (N) + VOR (+) + VOR^2 (-)	533.0	4	8.6	0.012
VOR (+) + VOR^2 (-)	538.1	3	11.7	0.002
% Bare (-)	637.1	2	108.7	<0.001
VOR (+)	642.2	2	113.8	<0.001
% Grass (+)	666.9	2	138.4	<0.001
% Shrub (+)	670.8	2	142.4	<0.001
% Litter (N)	676.0	2	147.6	<0.001
% Forbs (N)	676.8	2	148.4	<0.001
Null	691.6	1	161.1	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum AIC_c = 532.4

Table 2.8 Resource selection functions of lesser prairie-chicken nest bowl placement in relation to habitat features among all study sites in Clark County, Kansas, during 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Forbs (-)[e] + VOR (+) + VOR^2 (-)	143.7	4	0.0[f]	0.613
% Bare (-) + VOR (+) + VOR^2 (-)	145.7	4	2.0	0.230
% Litter (+) + VOR (+) + VOR^2 (-)	155.7	4	3.9	0.086
VOR (+) + VOR^2 (-)	151.8	3	6.0	0.030
% Grass (N) + VOR (+) + VOR^2 (-)	150.1	4	6.4	0.025
% Shrub (N) + VOR (+) + VOR^2 (-)	151.1	4	7.3	0.016
% Bare (-)	182.2	2	34.4	<0.001
VOR (+)	190.1	2	42.3	<0.001
% Grass (+)	191.8	2	44.0	<0.001
% Forbs (-)	192.5	2	44.7	<0.001
Null	200.3	1	50.5	<0.001
% Shrub (N)	198.7	2	50.9	<0.001
% Litter (N)	199.4	2	51.6	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum $AIC_c = 151.7$

Table 2.9 Resource selection functions of lesser prairie-chicken nest site (i.e., 4-m radius surrounding nest) placement in relation to habitat features among all study sites in Kansas during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Litter (+)[e] + VOR (+) + VOR^2 (-)	1105.6	4	0.0[f]	1.000
% Bare (-) + VOR (+) + VOR^2 (-)	1125.3	4	19.7	<0.001
% Forbs (-) + VOR (+) + VOR^2 (-)	1144.4	4	38.8	<0.001
% Grass (+) + VOR (+) + VOR^2 (-)	1158.3	4	52.7	<0.001
VOR (+) + VOR^2 (-)	1175.9	3	68.3	<0.001
% Shrub (-) + VOR (+) + VOR^2 (-)	1174.0	4	68.4	<0.001
Litter Depth (+)	1317.9	2	208.2	<0.001
% Bare (-)	1319.0	2	209.3	<0.001
VOR (+)	1368.4	2	260.9	<0.001
% Grass (+)	1412.8	2	282.0	<0.001
% Litter (+)	1391.6	2	303.1	<0.001
% Forbs (-)	1428.5	2	318.9	<0.001
% Shrub (N)	1433.9	2	324.2	<0.001
Null	1440.3	1	328.7	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum AIC_c = 1113.6

Table 2.10 Resource selection functions of lesser prairie-chicken nest site (i.e., 4-m radius surrounding nest) placement in relation to habitat features between all study sites in Kiowa and Comanche counties, Kansas, during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Bare (-)[e] + VOR (+) + VOR^2 (-)	335.7	4	0.0[f]	0.995
% Litter (+) + VOR (+) + VOR^2 (-)	329.2	4	12.0	0.002
VOR (+) + VOR^2 (-)	359.3	3	13.8	0.001
% Shrub (+) + VOR (+) + VOR^2 (-)	350.2	4	14.1	<0.001
% Forbs (-) + VOR (+) + VOR^2 (-)	355.0	4	14.9	<0.001
% Grass (N) + VOR (+) + VOR^2 (-)	348.7	4	15.7	<0.001
Litter Depth (+)	415.8	2	95.1	<0.001
% Bare (-)	424.0	2	105.2	<0.001
VOR (+)	440.9	2	115.8	<0.001
% Grass (+)	461.9	2	153.5	<0.001
% Litter (+)	445.7	2	155.4	<0.001
% Shrub (+)	460.5	2	155.8	<0.001
% Forbs (N)	460.3	2	158.7	<0.001
Null	462.6	1	163.1	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum AIC_c = 343.8

Table 2.11 Resource selection functions of lesser prairie-chicken nest site (i.e., 4-m radius surrounding nest) placement in relation to habitat features between all study sites in Gove and Logan counties, Kansas, during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
% Bare (-)[e] + VOR (+) + VOR^2 (-)	522.4	4	0.0[f]	0.995
% Litter (+) + VOR (+) + VOR^2 (-)	534.4	4	12.0	0.002
VOR (+) + VOR^2 (-)	538.1	3	13.8	0.001
% Shrub (+) + VOR (+) + VOR^2 (-)	536.4	4	14.1	<0.001
% Forbs (-) + VOR (+) + VOR^2 (-)	537.3	4	14.9	<0.001
% Grass (N) + VOR (+) + VOR^2 (-)	538.0	4	15.7	<0.001
Litter Depth (+)	621.5	2	95.1	<0.001
% Bare (-)	631.6	2	105.2	<0.001
VOR (+)	642.2	2	115.8	<0.001
% Grass (+)	679.9	2	153.5	<0.001
% Litter (+)	681.8	2	155.4	<0.001
% Shrub (+)	682.2	2	155.8	<0.001
% Forbs (N)	685.1	2	158.7	<0.001
Null	691.6	1	163.1	<0.001

a. Deviance

b. Number of parameters

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

d. Akaike weights

e. (-) negative relationship, (+) positive trend, (N) indicates no trend

f. Minimum AIC_c = 530.4

Table 2.12 Resource selection functions of lesser prairie-chicken nest site (i.e., 4-m radius surrounding nest) placement in relation to habitat features between all study sites in Clark County, Kansas, during 2013 and 2014. Variables included percent cover of litter (% Litter), percent cover of grass (% Grass), percent cover of forbs (% Forbs), percent cover of bare ground (% Bare), percent cover of shrubs (% Shrub), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), and a model with no variables included (Null).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
VOR (+)[e] + VOR^2 (-)	151.8	3	0.0[f]	0.240
% Shrub (-) + VOR (+) + VOR^2 (-)	150.0	4	0.2	0.210
% Litter (N) + VOR (+) + VOR^2 (-)	150.7	4	0.9	0.150
% Forbs (N) + VOR (+) + VOR^2 (-)	150.7	4	0.9	0.150
% Grass (N) + VOR (+) + VOR^2 (-)	150.9	4	1.1	0.130
% Bare (-) + VOR (+) + VOR^2 (-)	151.2	4	1.4	0.120
VOR (+)	190.1	2	36.2	<0.001
Litter Depth (+)	191.4	2	37.5	<0.001
% Bare (-)	194.8	2	41.0	<0.001
% Grass (+)	195.6	2	42.7	<0.001
Null	200.3	1	44.5	<0.001
% Forbs (-)	199.9	2	46.0	<0.001
% Shrub (N)	200.3	2	46.5	<0.001
% Litter (N)	200.3	2	46.5	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum AIC_c = 157.8

Table 2.13 Resource selection functions of lesser prairie-chicken nest site placement in relation to anthropogenic features among all study sites in Kansas during 2013 and 2014.

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
Dist. to Roads (-)[e]	906.3	2	0.0[f]	0.456
Dist. to Power lines (+)	875.2	2	1.5	0.212
Dist. to Fence (+)	876.2	2	2.8	0.112
Dist. to Oil (-)	907.3	2	4.2	0.056
Dist to Nearest Anthropogenic (N)	880.1	2	4.6	0.045

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. (-) negative relationship, (+) positive trend, (N) indicates no trend
f. Minimum $AIC_c = 910.3$

Table 2.14 Model ranking for lesser prairie-chicken nest survival using the nest survival model in Program MARK to estimate daily survival. Models compared included variable combinations of region (different study sites; Colorado, Red Hills, Kansas, northwest Kansas, and Clark, Kansas), year (2013, 2014), visual obstruction reading (VOR), a quadratic function of VOR (VOR^2), percent cover of litter (Litter), percent cover of grass (Grass), percent cover of forbs (Forbs), nest initiation date (Initiation), a quadratic function of nest initiation date ($Initiation^2$), distance to nearest anthropogenic feature (Anthropogenic), a quadratic function of distance to nearest anthropogenic feature ($Anthropogenic^2$), a constant model (Constant), date during the nesting season (Date), and a quadratic function of date during the nesting season ($Date^2$).

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
Date + $Date^2$	2087.6	3	0.0[e]	0.999
Date	2103.5	2	13.9	0.001
Region + Year + VOR + VOR^2	2118.3	8	40.8	0.000
Region + Year + VOR	2123.7	7	44.1	0.000
VOR + VOR^2 + Forbs	2130.0	4	44.4	0.000
VOR + VOR^2	2132.1	3	44.5	0.000
VOR + VOR^2 + Grass + Litter + Forbs	2126.3	6	44.8	0.000
VOR + VOR^2 + Litter	2132.1	4	46.5	0.000
VOR + VOR^2 + Grass	2132.1	4	46.5	0.000
VOR	2139.7	2	50.1	0.000
Region + Year	2131.7	7	52.1	0.000
Forbs	2144.0	2	54.5	0.000
Initiation	2144.5	2	54.9	0.000
Constant	2146.9	1	55.3	0.000
Anthropogenic	2145.7	2	56.1	0.000
Initiation + $Initiation^2$	2144.0	3	56.4	0.000
Year	2146.0	2	56.5	0.000
Region	2142.1	4	56.5	0.000
Litter	2146.9	2	57.1	0.000
Grass	2145.7	2	57.3	0.000
Anthropogenic + $Anthropogenic^2$	2478.7	3	58.1	0.000
VHF	2478.7	2	389.1	0.000
Satellite	2482.3	2	392.7	0.000

[a] Deviance
[b] Number of parameters
[c] Difference in Akaike's Information Criterion, corrected for a small sample size
d Akaike weights
e Minimum AIC_c = 2093.6

Figure 2.1 Study sites for the lesser prairie-chicken research during 2013 and 2014 across Kansas and Colorado. Courtesy of S. Robinson.

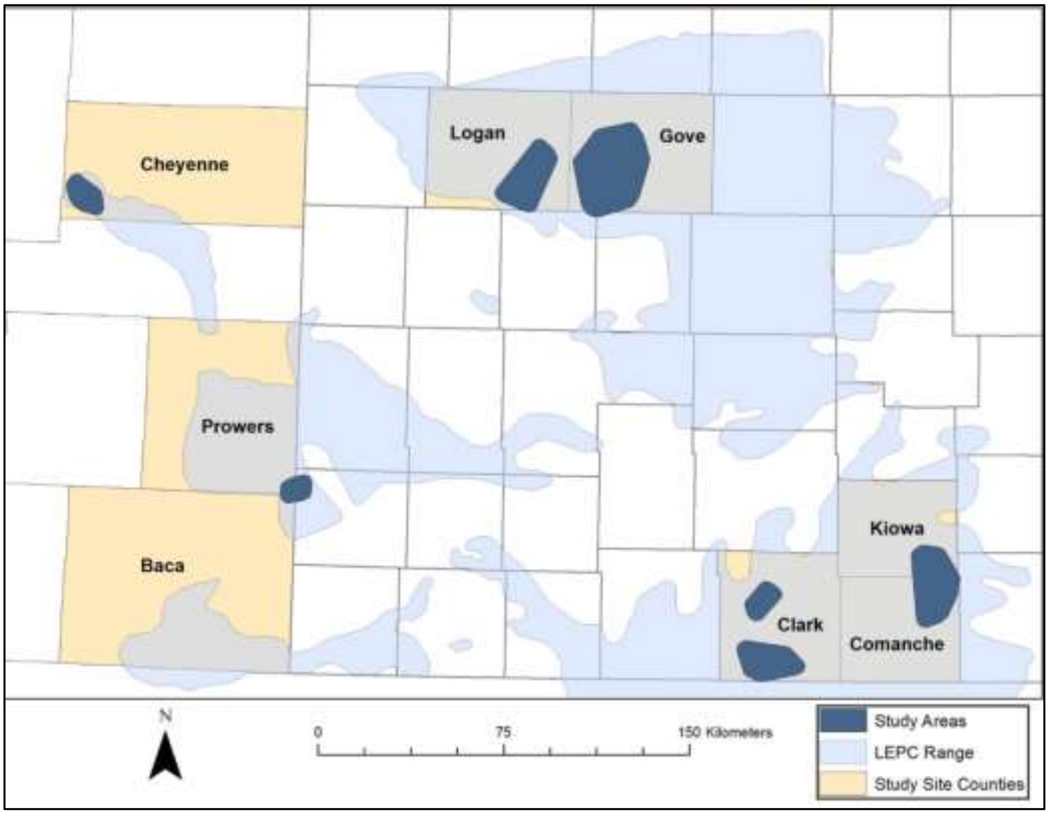


Figure 2.2 Probability of use for 75% visual obstruction for all regions of Kansas for 2013 and 2014. Shown with 95% confidence intervals.

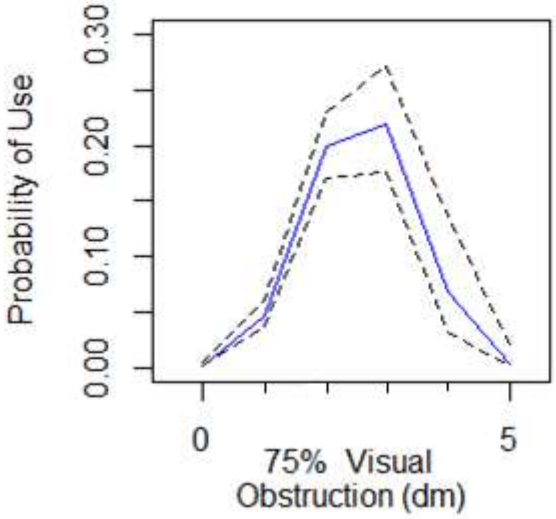


Figure 2.3 Probability of use for 75% visual obstruction for the Red Hills region of Kansas during 2013 and 2014. Shown with 95% confidence intervals.

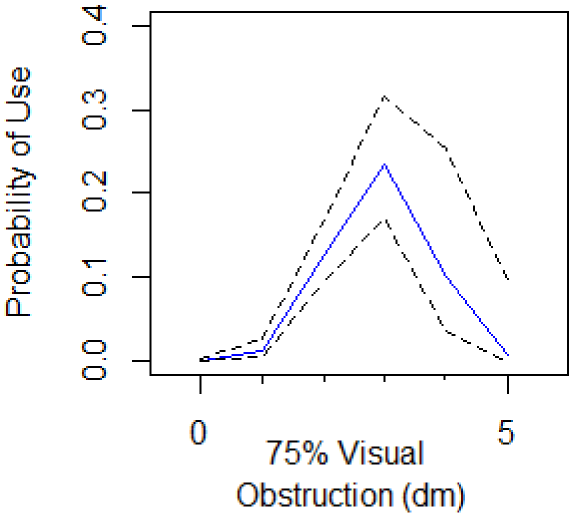


Figure 2.4 Probability of use for 75% visual obstruction for the High Plains region of northwest Kansas during 2013 and 2014. Shown with 95% confidence intervals.

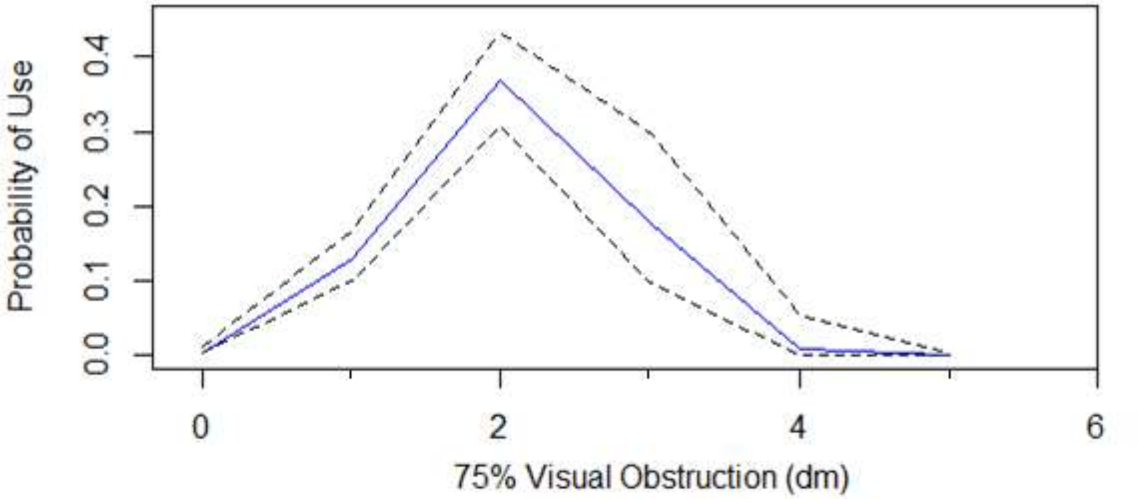


Figure 2.5 Probability of use for 75% visual obstruction for Clark County within south-central Kansas during 2014. Shown with 95% confidence intervals.

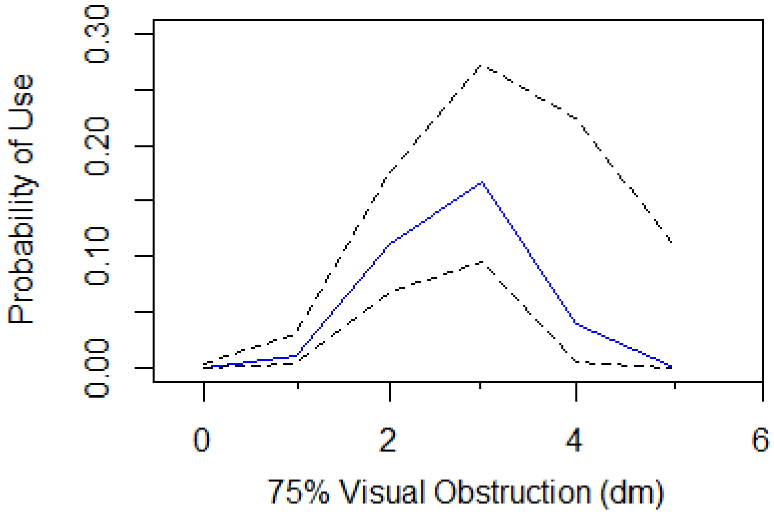


Figure 2.6 Probability of use of a nesting site for lesser prairie-chickens in relation to the nearest anthropogenic feature (i.e., roads, fences, oil and gas structures, and power lines) in Kansas during 2013 and 2014.

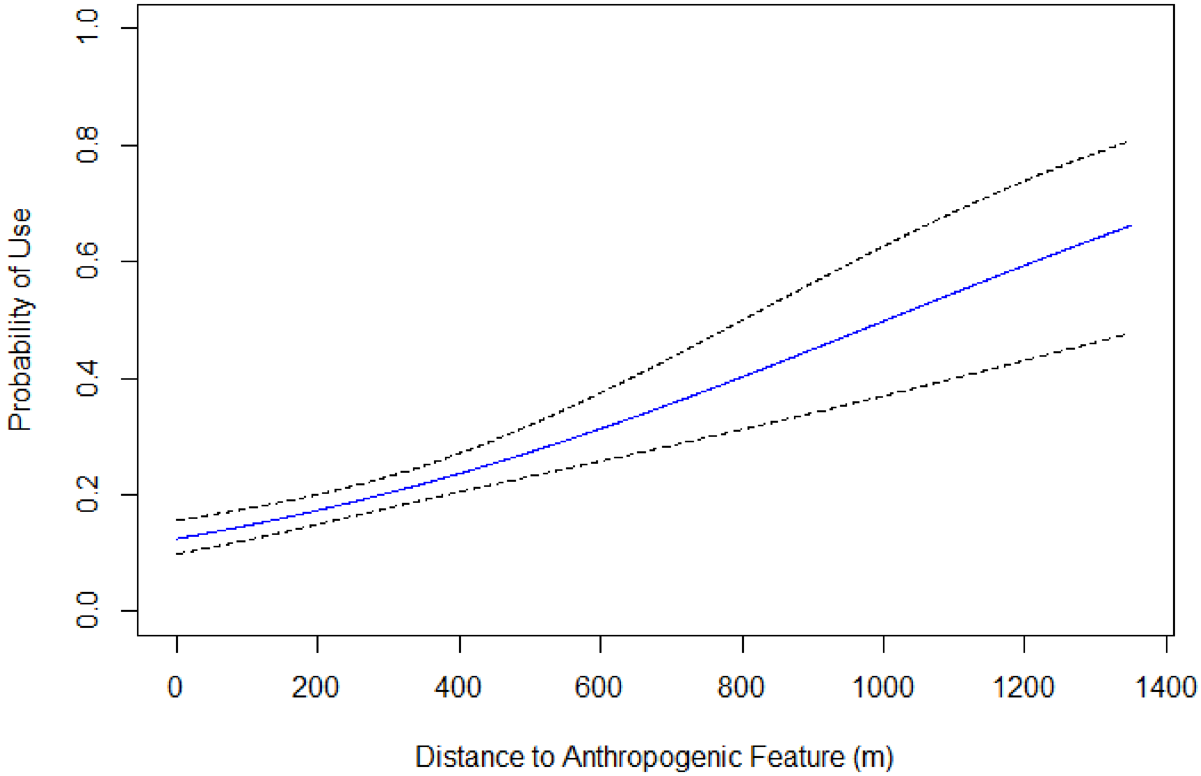


Figure 2.7 Nest survival estimates over a 35-day exposure period for lesser prairie-chickens within Kansas and Colorado during 2013 and 2014. Red Hills encompasses Kiowa and Comanche counties, Kansas. Colorado encompasses Prowers and Cheyenne counties. Clark is Clark County, Kansas. NW Kansas encompasses Gove and Logan counties, Kansas. Estimates from nest survival model in Program MARK, using model containing region + year.

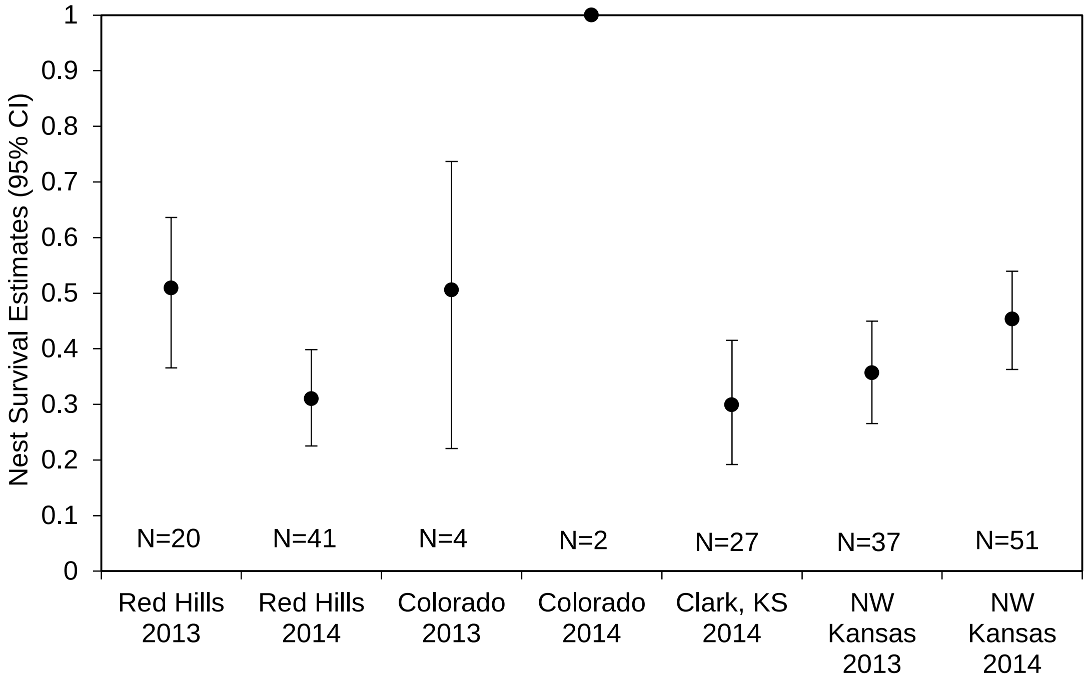


Figure 2.8 Daily nest survival rates of lesser prairie-chickens through time during the nesting period in Kansas and Colorado during 2013 and 2014. Estimates generated in the nest survival model in Program MARK using the model containing Date + Date^2.

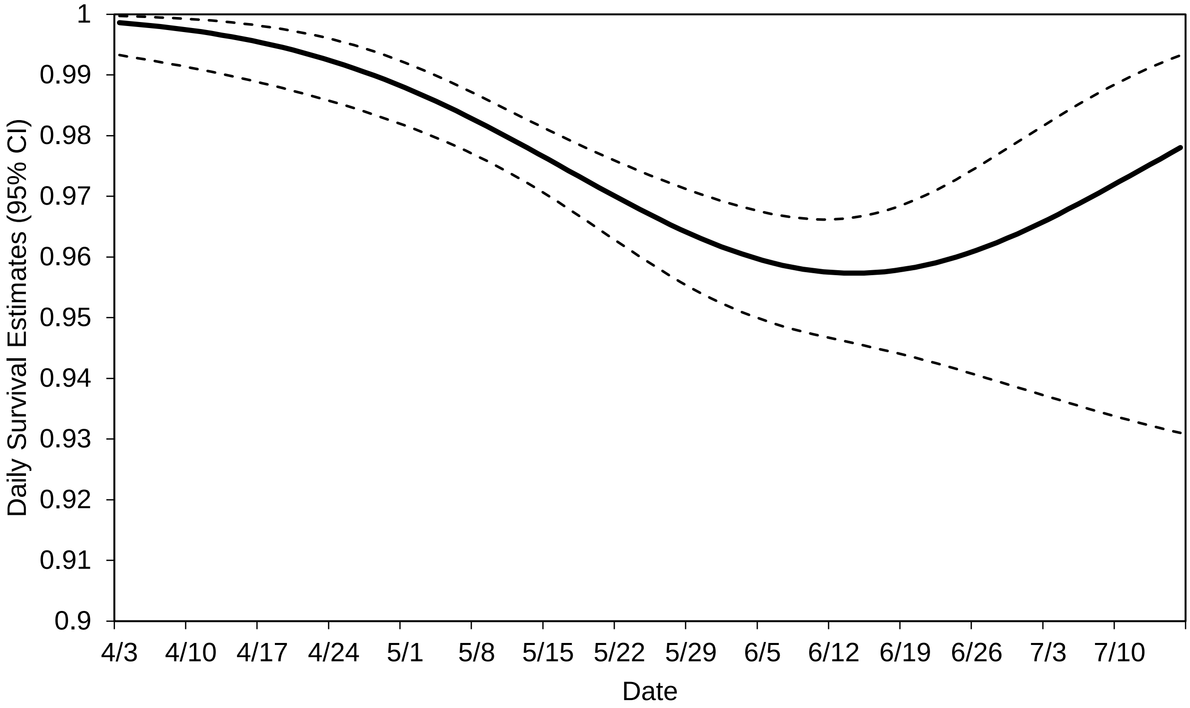


Figure 2.9 Daily nest survival rates of lesser prairie-chickens in relation to 75% visual obstruction readings in Kansas and Colorado pooled over 2013 and 2014. Estimates generated from nest survival model Program MARK, using the model containing VOR + VOR^2.

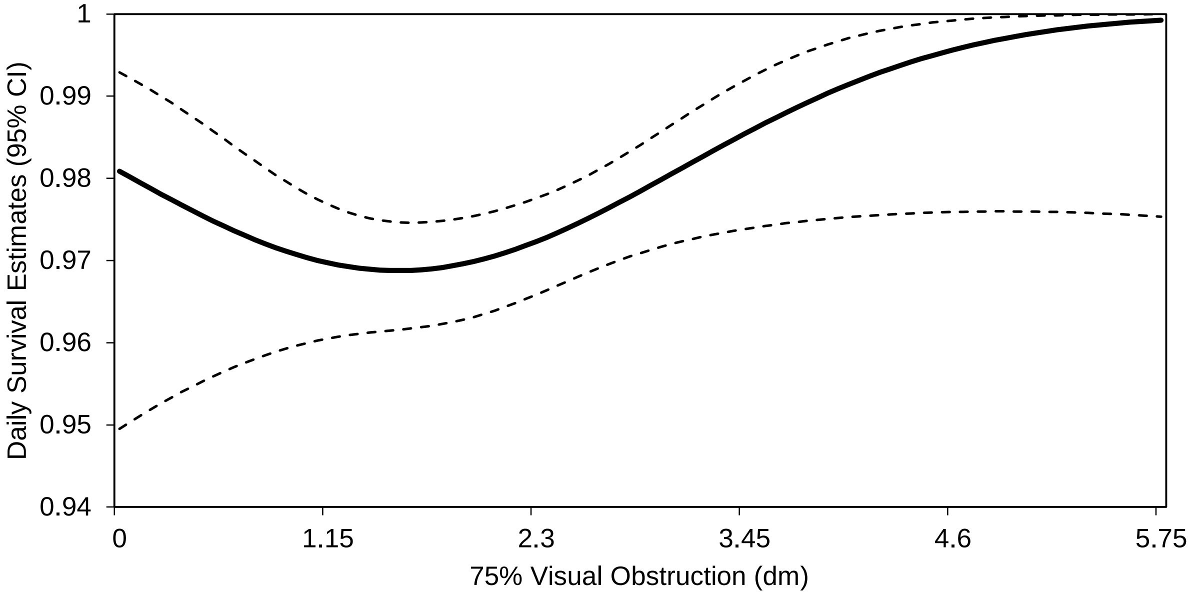


Figure 2.10 Nest survival rates for a 35-day exposure of lesser prairie-chickens marked with VHF radio transmitters and satellite GPS transmitters in Kansas and Colorado during 2013 and 2014. Estimates generated using the nest survival model in Program MARK.

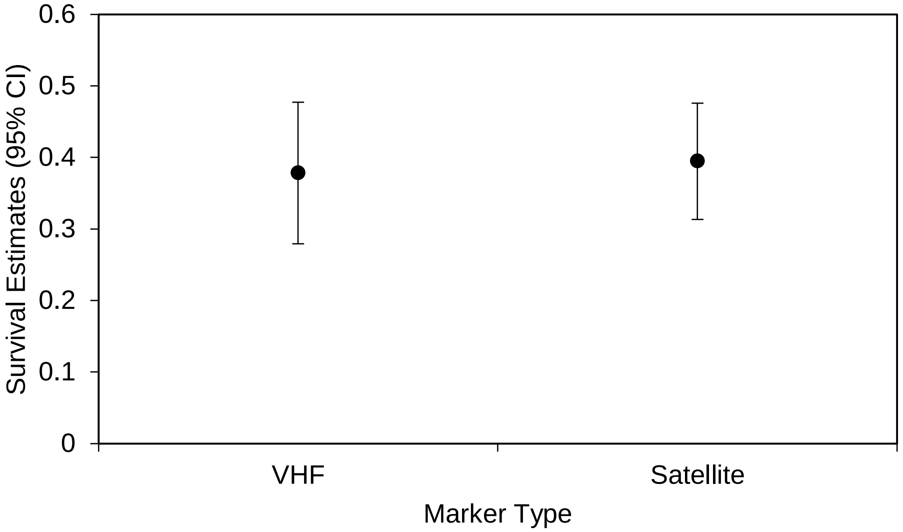
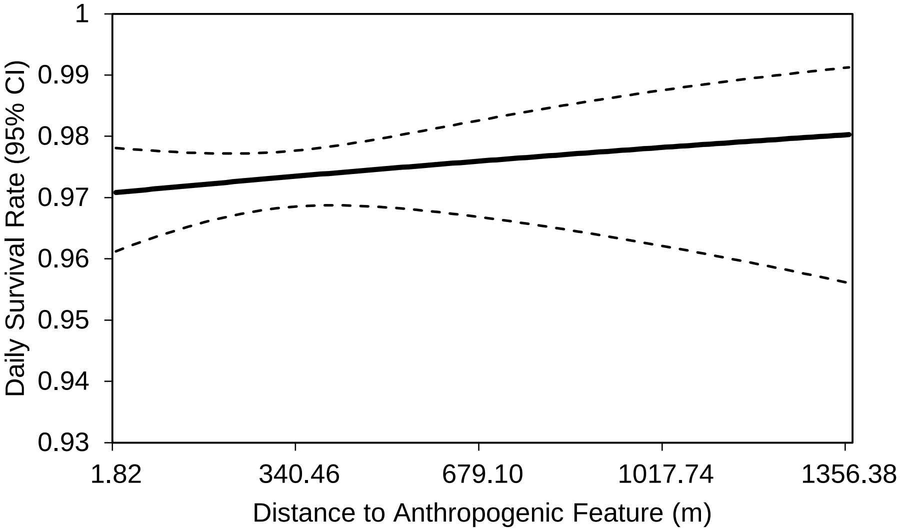


Figure 2.11 Daily nest survival rates of lesser prairie-chickens in relation to the distance to the nearest anthropogenic feature (i.e., roads, fences, oil and gas structures, and power lines) in Kansas and Colorado during 2013 and 2014. Estimates generated in Program MARK with the nest survival model.



Chapter 3 - **HABITAT SELECTION AND BROOD SURVIVAL OF LESSER PRAIRIE-CHICKENS IN KANSAS AND COLORADO**

Introduction

The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie grouse native to North America and found within the Southern Great Plains of New Mexico, Texas, Oklahoma, Colorado, and Kansas. Since the late 1800s, the population size and range of the lesser prairie-chicken have declined by >90% (Taylor and Guthery 1980, Hagen et al. 2004). In May of 2014, the lesser prairie-chicken was listed as threatened under the Endangered Species Act (USFWS 2014). The population decline has been primarily attributed to conversion of native grassland for agricultural uses (Hagen et al. 2004). Other factors contributing to the decline include: energy (e.g. oil, natural gas, ethanol, biofuels, and wind) exploration and development; mismanaged grazing lands; shrub and tree encroachment; invasive and exotic grasses; and urban development (Hagen et al. 2004).

Lesser prairie-chickens are found within 3 distinct ecoregions forming disjunct populations associated with discrete habitat types within Kansas and eastern Colorado: sand sagebrush (*Artemisia filifolia*) prairie ecoregion of southwest Kansas and southeast Colorado; mixed-grass prairie ecoregion in south-central Kansas; and a mosaic of short-grass prairie, U.S. Department of Agriculture Conservation Reserve Program (CRP), and row-crop agriculture (short-grass/CRP mosaic ecoregion) in northwest Kansas and eastern Colorado (Figure 1.1; McDonald et al. 2014). Southwest Kansas and southeastern Colorado was the former stronghold of lesser prairie-chickens (Haukos et al. 2015). However, lek surveys indicate that this population has dramatically declined within the past decade (Haukos et al. 2015). This ecoregion is characterized by sandy to sandy-loam soils and sand sagebrush interspersed with native grasses. Spring lek surveys indicate lesser prairie-chicken populations have remained relatively stable within the mixed-grass prairie ecoregion including south-central Kansas in recent decades (Wolfe et al. 2015); however, severe drought conditions during 2011 and 2012 resulted in a recent decline (McDonald et al. 2014). This region is characterized by a mixture of native grasses on loamy soils. Northwest Kansas has experienced an increase in lesser prairie-chicken population size and occupied range since the mid-1990s (Dahlgren et al. 2015). Comparing reproduction success, population recruitment, and habitat use among the different ecoregions will allow insight into factors affecting regional population trends of lesser prairie-chickens and facilitate conservation planning by identifying management needs on a regional scale.

Reproductive success is essential to the persistence of prairie grouse populations, including the lesser prairie-chicken (Peterson and Silvy 1996, Wisdom and Mills 1997, Hagen 2003). A sensitivity analysis identified recruitment as more important to lesser prairie-chicken population growth than adult survival (Hagen et al. 2008). Nest survival makes up one component of lesser prairie-chicken reproductive success. Most female lesser prairie-chickens (i.e., 81-100%) will annually attempt at least one nesting effort (Hagen et al. 2004). Often, if the initial clutch is lost, females will attempt 1-2 renest attempts (Giesen 1994, Pitman et al. 2006). In 10 telemetry studies, nest survival averaged 28% for the ~ 25-day incubation period (Hagen and Giesen 2005); however, there is considerable annual variation in nest success in response to environmental conditions (e.g., Grisham et al. 2013).

Following nest success, the next component of lesser prairie-chicken reproductive success and eventual recruitment is chick and brood survival. The survival of chicks was identified as the most important driver of demography and primary contributor to inter-annual fluctuations in lesser prairie-chicken populations (Hagen et al. 2008). Despite its importance, chick and brood survival have been little studied, with most studies plagued by small sample sizes. Previous studies indicate that chick survival is highly variable across the lesser prairie-chicken range, averaging 39% over 60 days (Hagen et al. 2004). Most chick mortality occurs within the first 14 days post-hatch (Pitman 2003). In the sand sagebrush prairie ecoregion within Kansas, Jamison (2000) estimated daily survival rates of 0.941 for chicks 0 - 14 days and 0.983 from 14 - 60 days (0.194 survival for 60 days). Daily survival estimates of chicks within the sand sagebrush prairie ecoregion ranged from 0.971 – 1.000 from 14 – 60 days and did not differ significantly among years (Pitman 2003). Chick survival for 60 days was estimated to be 0.433 in northwest Kansas (Fields 2004). Nest success and brood survival were correlated and reflective of environmental conditions in the mixed-grass prairie of Oklahoma (Wolfe et al. 2003). In northwest Kansas, overall brood survival decreased as the brooding period progressed, but individual brood survival increased with increasing chick age (Fields et al. 2006). Brood survival increased with percentage of forbs and decreased with increased temperatures (Fields et al. 2006). In Texas, zero chicks out of 15 successful nests surviving to 60 days post hatch from 2008 – 2011 (Grisham 2012). Additionally, 11 of 15 broods did not make it to 14 days post hatch (Grisham 2012).

Habitat selection by female lesser prairie-chickens with broods is related to vegetation, invertebrate availability, and ease of locomotion. Vegetative composition and structure used by broods varies across the lesser prairie-chicken range, but generally broods use areas with lower grass cover, greater forb cover, and greater shrub cover compared to random points (Copelin 1963, Jones 1963, Davis et al. 1979, Ahlborn 1980, Riley and Davis 1993, Hagen et al. 2005). In the southwestern portion of lesser prairie-chicken range, broods were more likely to select areas of sand shinnery oak (*Quercus havardii*), taller plant heights, and more overhead cover when temperatures exceeded 26.4ºC (Bell et al. 2010). Brood site canopy cover did not differ from random locations in sand shinnery oak prairie (Grisham 2012). Likewise, visual obstruction readings (VOR) did not differ between brood sites and paired random locations (Grisham 2012). The primary food source for chicks is invertebrates, comprising 98 – 100% of chick's diets during from ages 1 – 10 weeks post hatch (Suminski 1977, Davis et al. 1980). Invertebrate biomass was greater at points used by broods than non-used points (Hagen et al. 2005). Invertebrate biomass is correlated with greater percent cover of forbs and lower densities of sand sagebrush (Jamison et al. 2002, Hagen et al. 2005). Travel corridors are important within brood habitat to allow for ease locomotion of grouse chicks (Muessehl 1963). Energy expenditure is greater in self-fed chicks than in parent-fed chicks (Schekkerman and Visser 2001). Female lesser prairie-chickens might select habitats to reduce energy expenditure of chicks.

Understanding trends and factors influencing chick survival among ecoregions will provide baseline information for regional populations and recommendations to guide lesser prairie-chicken conservation efforts. Hagen et al. (2008) identified chick survival as an important driver of lesser prairie-chicken demography and understanding drivers of chick survival and habitat selection are important for guiding conservation efforts of the species. Investigating and comparing reproductive success of lesser prairie-chickens simultaneously among populations of Kansas and eastern Colorado will give insight into the relationship between brood habitat selection and survival across the northern portion of the species' range. Further, quantifying selection and use patterns by female lesser prairie-chickens with broods can provide additional information for designing conservation and management plans for the species. Lesser prairie-chicken chick survival is poorly understood and this research will fill a void in the knowledge of the species' conservation by investigating the most limiting factor of lesser prairie-chicken demography.

My research objectives were to (1) estimate lesser prairie-chicken brood and chick survival and evaluate factors influencing survival, (2) test for habitat selection by females with broods, and (3) evaluate potential factors influencing brood habitat in the northern portion of the lesser prairie-chicken range. I hypothesized that: (1) brood survival would differ between regions and (2) females with broods would select areas with greater percent forb cover (~ 15%).

Methods

Study Area

Three study sites were located within Kansas and Colorado: Kiowa, Comanche, and Clark counties within south-central Kansas; Gove and Logan counties within northwest Kansas; and Baca and Prowers counties within eastern Colorado (Figure 1.2). The south-central Kansas site was located on private lands of the Red Hills region. The Red Hills region consisted of mixed-grass prairie on loamy soils. The region was primarily used for livestock grazing with row-crop agriculture interspersed throughout the region, principally bottomlands or adjacent to riparian areas. Dominant vegetation within the region included: little bluestem (*Schizachyrium scoparium*), blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), side oats grama (*B. curtipendula*), buffalograss (*Buchloe dactyloides*), sand dropseed (*Sporobolus cryptandrus*), Louisiana sagewort (*Artemisia ludiviciana*), western ragweed (*Ambrosia psilostachya*), sand sagebrush, and eastern red cedar (*Juniperus virginiana*; Lauver et al. 1999).

The northwest Kansas study site was located on private lands and The Smoky Valley Ranch. The Smoky Valley Ranch was owned and managed by The Nature Conservancy in Logan County, Kansas. This area was a mosaic of short-grass and mixed-grass prairies, CRP grasslands, and row-crop agriculture on silt loam soils. The dominant land uses in this region were livestock grazing, row-crop agriculture, CRP, and rural towns. Dominant vegetation in the region included: blue grama, hairy grama, buffalograss, little bluestem, side oats grama, big bluestem, Illinois bundleflower, prairie sunflower (*Helianthus petiolaris*), annual buckwheat (*Eriogonum annum*), sand milkweed (*Asclepias arenaria*), nine-anther dalea (*Dalea enneandra*), and western ragweed (Lauver et al. 1999). 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, some CRP fields were interseeded with forbs 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 Clark County site within south-central Kansas was located on the ecotone of the mixed-grass prairie and sand sagebrush prairie. Land use in the region was dominated by livestock grazing and row-crop agriculture. In addition to the mixed-grass and sand sagebrush prairie, the study site had considerable alkali flats in 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 scoparium*), annual sunflower (*Helianthus annuus*), and sand sagebrush.

Within eastern Colorado, the study sites were located on private lands in Cheyenne, Baca, and Prowers counties. The study site was within the sand sagebrush prairie ecoregion (Figure 1.1). Land use within the study site included livestock grazing, row-crop agriculture, and CRP grasslands. Dominate 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.

Environmental conditions were highly variable during the study. In 2013, northwest Kansas and eastern Colorado remained under extreme drought conditions that originated during 2011. Many CRP fields within the region were cut for hay during emergency haying operations or grazed as allowed under drought rules in CRP contracts. Most areas grazed by livestock were in poor range condition. The long term average annual precipitation is 47 cm (High Plains Regional Climate Center, accessed 1/23/2013, http://www.hprcc.unl.edu/index.php). During 2012, the region received an approximate total of 24.7 cm of precipitation. Total approximate precipitation during 2013 was 31 cm (Kansas Mesonet, retrieved 11/26/14, http://mesonet.k-state.edu/weather/historical/#!). Vegetative growth was suppressed. The extreme drought continued within northwest Kansas and eastern Colorado into the beginning of 2014. However, starting in mid-May, and through early August, the drought broke, with an approximate total precipitation of 35 cm between 1 January – 31 August (with 20.5 cm of precipitation between 15 May – 15 July) (Kansas Mesonet, retrieved 11/26/14, http://mesonet.k-state.edu/weather/historical/#!). Vegetation positively responded to the precipitation and vegetation growth was robust.

During 2013, south-central Kansas was under a moderate drought that had originated during 2012. The region received an approximate total of 42.5 cm during 2012 (Kansas Mesonet, retrieved 11/26/14, http://mesonet.k-state.edu/weather/historical/#!). The region received ~ 55 cm of precipitation during 2013, with a weekly precipitation event from mid-March – mid-June (Kansas Mesonet, retrieved 11/26/14, http://mesonet.k-state.edu/weather/historical/#!). The long term average precipitation is 70.7 cm of annual precipitation (High Plains Regional Climate Center, accessed 1/23/2013, http://www.hprcc.unl.edu/index.php). Vegetation growth was much greater than northwest Kansas. The drought continued into 2014, with very dry conditions into late May. However, during June and July 2014 the drought broke. The region received ~ 53 cm of precipitation from 1 January – 31 August (~ 41 cm of precipitation from 1 June – 31 July; Kansas Mesonet, retrieved 11/26/14, http://mesonet.k-state.edu/weather/historical/#!). Vegetation growth was robust in 2014.

Field Methods

Capture

Lesser prairie-chickens were trapped on leks using walk-in traps (Haukos et al. 1990, Schroeder and Braun 1991) and drop nets (Silvy et al. 1990) during spring 2013 and 2014 in order to monitor reproductive success. Leks were trapped during the 2-month lekking season (~10 March - 15 May). Captured lesser prairie-chickens were sexed and aged using plumage characteristics (Copelin 1963). Females were fitted with either a satellite transmitter (platform transmitting terminals or PTT) or a very-high-frequency (VHF) radio transmitter. Each PTT contained sensors to transmit calibrated indices for unit temperature and lesser prairie-chicken motion, which were used to determine if the bird was alive. The PTTs were mounted on the rump using Teflon ribbon (Dzialak et al. 2011); each unit weighed 22 g and had a solar charging component that allowed for the battery to be recharged (Microwave Telemetry, Columbia, Maryland, USA). The VHF radio transmitters were equipped with a 12-hr mortality switch. VHF radio transmitters were 12-g bib/collar attachment style, with an average lifespan of 350 days (Advanced Telemetry System, Isanti, Minnesota, USA). 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 scientific collection license numbers 13TRb2053 and 14TRb2053.

Locations

In 2013 and 2014, female lesser prairie-chickens fitted with VHF radio transmitters were regularly (i.e., 3+ times/week) located via triangulation 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) to record telemetry locations via triangulation based on a minimum of three bearings (Cochran and Lord 1963). A maximum of 20-min time interval between bearings was used to minimize error from lesser prairie-chicken movement. Location of a Signal software (Ecological Software Solutions, Florida, USA) was used to obtain Universal Transverse Mercator (UTM) coordinates from VHF data collected in the field. For lesser prairie-chickens fitted with PTTs, the duty cycle for Global Positioning System (GPS) fixes was one data point taken every other hour from 0400-2200 with a data transmission cycle of 8 hours on and 50 hours off. Potential location error using these transmitters was ≤18 m.

We assumed that the female was incubating if the telemetry bearings and PTT GPS fixes remained relatively constant without a mortality signal. Nest locations were identified by approaching females marked with VHF transmitters using homing once a female had been recorded in the same location for three or more consecutive days (Pitman et al. 2005). If GPS fixes indicated that a female was incubating (i.e., female at/returning the same location), WE approached the location indicated by the GPS fixes and searched the area to locate the nest.

When the nest was approached, rubber boots and latex gloves were worn to reduce scent and scent trails around the nests. We attempted to spend as little time as possible at the nest (<5 minutes) and avoided leaving "dead end" scent trails at the nest (Grisham 2012). The UTM coordinates of nest locations were recorded using a hand-held GPS unit (Garmin eTrex 30). Following the initial visit, nests were monitored remotely until fate could be determined. The nest location was not revisited until the female was determined to be off the nest, via VHF or PTT GPS fixes (Pitman et al. 2005). When the female was determined to be off of the nest, we returned to the nest site and assessed nest fate. If we found ≥1 pipped eggshell in the nest, we considered the nest successful.

If nests were successful, marked females were flushed and we captured or counted as many chicks as we could visually find 1-5 days post-hatch to obtain accurate counts for verification of the number of hatched eggs counted when evaluating nest fate. Additionally, brood flushes were conducted when chicks were approximately 14, 21, 28, 35, 42, 48, and 56 days old given suitable weather conditions and available locations for satellite-tagged females. Brood flushes were conducted at or before sunrise because females were brooding the chicks, making the chicks easier to locate (Schole et al. 2011). Each brood flush location was marked using a handheld GPS unit. Broods were monitored until the chicks dispersed from the female, or there were no chicks encountered on two consecutive brood flushes. In addition to brood flushes, WE tracked females with broods equipped with VHF transmitter to estimate brood locations. If a female with a brood was equipped with a PTT, we used GPS fixes for brood locations.

Brood Vegetation

Vegetation was measured at two brood locations per week for each brood. We used brood flush locations for one location and we randomly selected one of the locations collected through telemetry and GPS fixes. All vegetation measurements were taken within one week of the location. We estimated percent canopy cover of shrubs, forbs, grasses, bare ground, and litter using a 60 x 60 centimeter (cm) Daubenmire frame (Daubenmire 1959) at the point center and at a 4-m radius north (N) , south (S) , east (E), and west (W) of the point center. We estimated a visual obstruction reading (VOR) using Robel pole at the point center from a distance of 4 m and a height of 1 m (Robel et al. 1970). We measured litter depth from the point center out to 4 m N, S, E, and W of the flush or location point at 0.5-m intervals (Davis et al. 1979). We measured vegetation at a paired random point/area at a random distance within 360 m from the nest in a random direction, with the same techniques used at the point center to test for habitat selection. Additionally, the same vegetation measurements techniques were used at random points distributed throughout each study site to compare brood locations to random points within the study site. These protocols were used in previous studies (Pitman et al. 2005, Grisham 2012) and have been adopted by the NRCS Lesser Prairie-Chicken Initiative and Lesser Prairie-Chicken Interstate Working Group as sampling strategies for standardization among studies.

Statistical Analyses

I used the nest survival model in Program MARK to estimate daily survival of broods (White and Burnham 1999, Dinsmore et al. 2002). To estimate chick survival, I used the Lukacs young survival from a marked adult model within Program MARK (White and Burnham 1999, Lukacs et al. 2004). Models for both analyses were selected *a priori* and tested covariates included region, a time interval, year, and Julian Hatch date. I used an information theoretic approach to rank models (Burnham and Anderson 2002).

I used a use/non-use design within a resource selection framework to identify habitat selection by females with broods (Boyce et al. 2002, Manly et al. 2002). I compared measured vegetation variables between points where I observed broods and random points within the same habitat patch where we did not observe broods. Logistic regression was used to identify vegetation characteristics that best explained habitat selection. All analyses were conducted in Program R (Program R, version 3.0.1). I identified the VOR measure (i.e., height of 0, 25, 50, 75, or 100% obstruction) that had the greatest influence on habitat selection using logistic regression and AIC_c to rank models (Burnham and Anderson 2002). The highest ranked VOR measure was used in combination with percent cover to identify vegetative characteristics that influenced lesser prairie-chicken brood habitat. In addition to logistic regression, I used analysis of variance (ANOVA) to identify differences in percent cover and visual obstruction between brood, paired, and random points to allow me to compare my results with other studies. I used SAS for ANOVA analyses (SAS Institute Inc., 2013. version 9.4, Cary, North Carolina).

Results

In 2013 (14 broods) and 2014 (29 broods), 43 broods were monitored across Kansas and Colorado. I monitored 13 broods in Kiowa and Comanche counties, Kansas; 3 broods in Baca and Prowers counties, Colorado; 22 broods in Gove and Logan counties, Kansas; and 5 broods in Clark County, Kansas. Mean number of chicks/brood was 11.1, ranging from 1 – 14 chicks/brood at hatch. I conducted brood vegetation surveys at 86 brood locations, 86 paired locations, and 1017 random locations in 2013, and at 157 brood locations, 157 paired locations, and 2716 random locations in 2014.

Brood Survival

There were two competing models from the nest survival procedure for estimating brood survival; both competing models were additive models that contained region, year, and Julian hatch date (Table 3.1). The top ranked model also contained a quadratic function of Julian hatch date (Table 3.1). I used the top ranked model to estimate brood survival. Brood survival varied by region and year, with estimates greatest in the Red Hills in 2013 but in Clark County for 2014 (Figure 3.1). I observed regional variation between years. For instance, brood survival increased 35 percentage points from 2013 to 2014 in northwest Kansas and eastern Colorado, but decreased ~ 56% from 2013 to 2014 in the Red Hills (Figure 3.1). Variation in brood survival was best explained by an additive model of region, year, and Julian hatch date, which carried 58% of the model weight (Table 3.1). However, there was a competing top model that also included a quadratic function of Julian hatch date, which carried 41% of the model weight (Table 3.1). Brood survival decreased as Julian hatch date increased, which was a general trend across all study sites ($\beta_{\text{Julian hatch date}} = -0.051$, SE = 0.014) with a mean daily survival rate of 0.990 (SE = 0.003) for hatch dates between May 19 – June 6, a mean daily survival of 0.973(SE = 0.005) for hatch dates between June 7 to June 25, and a mean daily survival rate of 0.936 (SE = 0.020) for a hatch date between June 26 and July 14 (Figure 3.2).

Chick Survival

Chick survival was best explained by a combination of year ($\beta = -0.70$, SE = 0.25), weekly time step ($\beta_{T1} = -65.99$, SE = 69.97, $\beta_{T2} = 34.81$, SE = 1315.01, $\beta_{T3} = -65.986$, SE = 69.97, $\beta_{T4} = -62.99$, SE = 69.99, $\beta_{T5} = -62.71$, SE = 69.99, $\beta_{T6} = 23.51$, SE = 9389.96, β_{T7} = --29.84, SE = 2148.96) and Julian hatch date ($\beta = -0.51$, SE = 0.22), and a quadratic function of Julian hatch date (β = 0.13E-3, SE = 0.64E-3; Table 3.2). Chicks had the lowest survival probability estimates during the first week following hatch (0.161 in 2013, 0.289 in 2014 probability of survival to 7 days post-hatch); however, after the first week, weekly chick survival probabilities increased by a factor of 5 and remained relatively stable with small fluctuations (i.e., weekly survival decreased by as much as 0.17 at 5 weeks post-hatch in 2013 and 0.06 at 5 weeks post-hatch in 2014) in weekly survival until chicks reached 56 days (Figures 3.3, 3.4). Chick survival probabilities doubled during the first week between 2014 and 2013, however, patterns in chick survival were similar in 2013 and 2014 (Figures 3.3, 3.4). Probability of survival of chicks decreased from 0.69 to ~ 0.10 as Julian hatch date increased (Figure 3.5). Detection of chicks during brood flushes is important for estimating chick survival. Detection rates of chicks at brood flushes were similar between 2013 and 2014 (2013 = 0.949, SE = 0.023; 2014 = 0.984, SE = 0.004).

Habitat Selection

The highest ranked visual obstruction reading for brood habitat selection was a quadratic function of the 50% obscured visual obstruction (Table 3.3). There were no competing models and the top-ranked model had 65.8% of the weight of all models tested. The model indicated that there was a concave relationship with visual obstruction across all study sites ($\beta_{50\%} = 0.132$, $SE_{50\%} = 0.020$; $\beta_{50\%2} = -0.002$, $SE_{50\%2} = 0.0003$). The 50% visual obstruction as a quadratic function was then used as the visual obstruction component for all other models investigating habitat selection. The generated probability of use indicates that lesser prairie-chickens have the greatest probability of use between 3 and 5 dm for 50% visual obstruction (Figure 3.6). In general, visual obstruction was 0.40 dm greater at used points than at random sites distributed across each study site (Figure 3.6). This trend held within the Red Hills region, where visual obstruction was 0.87 dm greater at used points that at random points ($t_{1701} = 51.23$, P < 0.001 $P < 0.001$; Figure 3.6) . In northwest Kansas, broods used sites with 0.46 dm greater visual obstruction than at random sites distributed across the study site (Figure 3.7). However, within Clark County, Kansas, there was no difference ($F_{2, 1103} = 1.50$, $P = 0.22$) between used points and paired random points or random points distributed across the study site.

Across all regions, the top-ranked model for brood habitat selection was a combination of a quadratic function of visual obstruction reading and percent forb cover (Table 3.4). There were no other top ranked models and the top ranked model carried 100% of the weight (Table 3.4). There was a positive relationship with percent cover of forbs (β_{forb} = 2.111, SE = 0.375). Mean percent cover of forbs was 6 percentage points greater at points used by broods than at random points (t = 65.68, $P < 0.001$; Figure 3.8).

In the Kansas Red Hills, brood habitat use was best explained by a model that included a quadratic function of visual obstruction and percent shrub cover (Table 3.5). There were no other competing models and the top ranked model carried 91.3% of the weight. There was a negative relationship with percent cover of shrubs (β = -0.141, SE = 0.042). In the Kansas Red Hills, broods used points with 6 percentage points greater forb cover (t_{1698} = 67.62, P = 0.01) and 5 percentage points less shrub cover (t_{1698} = 5.33, P = 0.02) than random points distributed throughout the study site (Figure 3.9).

In the High Plains region of northwest Kansas, the top-ranked model for brood habitat selection was percent cover of bare ground and a quadratic function of 50% visual obstruction (Table 3.6). There were no competing models and the top ranked model had 91.6% of the model weights (Table 3.6). The proportion of bare ground was 7 percentage points greater at random points distributed across the study site than at used points (t_{1252} = 8.27, $P < 0.01$; Figure 3.10). In addition, the proportion of forbs was 12 percentage points greater at used points than was found at random points distributed across the study site (t_{1252} = 8.76, $P < 0.01$; Figure 3.10).

In Clark County, Kansas, the null model was the highest ranked model, but all potential models were competitive and none of the tested covariates were related to habitat selection by lesser prairie-chicken broods (Table 3.7). There was no trend with any of the variables measured between used brood points, paired random points, and random points distributed across the study site (Figure 3.11).

Discussion

My findings indicate (1) brood and chick survival varied spatially and temporally, (2) chick and brood survival decrease as Julian hatch date increases over the breeding season, (3) chick survival increases with increasing time-since-hatch, (4) visual obstruction at brood points follows a quadratic relationship indicating an optimal habitat, (5) females with broods select habitat with greater percent cover of forbs across Kansas, and (6) brood habitat selection varies between regions. This study, with a relatively large sample of chicks and broods, provides much needed information about chicks and broods for managers.

Spatial and temporal differences in brood survival reflect regional and yearly differences in environmental conditions. I observed large differences in reproductive success between years within the same region, where the region shifted from drought conditions to average conditions; the differences in environmental conditions likely resulted in an increase in chick and brood survival. For instance, during 2013, a drought year, in northwest Kansas I observed estimates of brood survival close to zero. However, in 2014 the drought broke in northwest Kansas and estimates of brood survival to 56 days increased from to 0.31. Fluctuating environmental conditions have been attributed to annual variations in reproductive success (Wolfe et al. 2003, Grisham et al. 2013). In general, differing environmental conditions will influence chick and brood survival, which has the potential to annually drive population trends within a portion of the lesser prairie-chicken range (Hagen et al. 2008).

Within a single year, brood survival and chick survival decrease if a nest hatches later in the season. Survival of chicks in northwest Kansas exhibited similar trends (Fields et al. 2006) reported a similar trend to what I observed. Typically, environmental conditions for chick survival are more favorable in May and early June and ambient temperatures are less likely to reach extremes, which increases the probability of chicks dying of exposure. This trend has consequences for renest attempts. Chicks from renest attempts that are initiated later in the season have a much lower probability of surviving to 56 days. Renests that hatch late in the season (i.e., late June or July) probably contribute little to population growth.

Chick survival was related to time since hatch, with individual chicks having lowest survival during the first week post-hatch and survival increasing thereafter. Grouse chicks are poor thermoregulators until they are ~8 days old (Erikstad and Spidso 1982, Goddard and Dawson 2009). If extreme temperatures occur during those first 8 days post-hatch, lesser prairie-chickens are more likely to die of exposure. Additionally, lesser prairie-chickens are unable to fly until they are ~ 10 – 14 days old (Hagen and Giesen 2005). Without flight, chicks are less likely to escape a predation event. Once chicks are better able to thermoregulate and fly, chick survival increases. My findings are consistent with other studies across the range of lesser prairie-chickens (Jamison 2000, Fields et al. 2006). Grisham (2012) hypothesized that chick survival from days 1 – 14 was a limiting factor of lesser prairie-chicken populations in Texas, as 11 of 15 broods failed to reach 14 days. During the first 7 days post-hatch is when chicks are most susceptible to mortality and chick survival during the first 7 days post-hatch is a limiting population factor.

There is a quadratic relationship with visual obstruction at points selected by broods. The relationship indicates that there is an optimal range of visual obstruction for broods. This trend was consistent across all regions. The mean visual obstruction at sites used by broods in Kansas fell within the optimal range for the northern portion of lesser prairie-chicken range (Hagen et al.

2005). However, in Texas mean visual obstruction fell outside the optimal range of visual obstruction (Grisham 2012). Because the Texas study was in a different region, the optimal range and quadratic trend might not hold true. Having an optimal range of use could provide managers a valuable tool.

Females with broods consistently selected areas with greater percent cover of forbs across Kansas. Brood survival has been positively linked with increasing forb cover (Fields et al. 2006). Invertebrates are a major source of food for lesser prairie-chicken chicks (Suminski 1977, Davis et al. 1980) and forbs also have been linked to greater invertebrate biomass (Hagen et al. 2005). Greater cover of forbs may provide travel corridors for chicks, which reduces energy expenditure for locomotion. Herbaceous cover has been noted for greater travel corridors at brood locations for other grouse (Muessehl 1963). Forb cover can provide a food source for chicks and reduce energy expenditures during movements. Providing habitat with forbs for broods could improve survival of chicks by providing a more invertebrates.

There was less bare ground at brood sites than would be expected at random points distributed across the study site. Bare ground has the potential to expose chicks to predators and heat. Brood locations used by broods of other grouse have also used less bare ground than would be expected at random; the avoidance was attributed to less exposure to predators (Muessehl 1963). Bare ground increases the chances of chicks of dying of exposure, as there is less protection from temperature extremes. Bell et al. (2010) reported that lesser prairie-chicken broods moved into areas with taller plants, greater overhead cover, and areas with more sand shinnery oak when temperatures exceeded 26.4 ºC. This indicates that broods avoid areas with more bare ground during high temperatures, perhaps to reduce the risk of exposure to chicks.

Bare ground increases the risk of predation and exposure; therefore, females with broods are less likely to use areas with greater cover of bare ground.

At all sites, there were no differences in percent cover of vegetation between brood points and paired random points. This indicates that female lesser prairie-chickens with broods move broods into habitat patches that are similar in structure throughout the patch. Females with broods select habitat at a patch scale, rather than at the scale of an individual point.

Brood selection across all ecoregions is consistent within each ecoregion. In the Kansas Red Hills and northwest Kansas, females with broods selected areas with greater forbs and less bare ground than was available at random points. Females with broods tended to avoid habitats with greater percent cover of bare ground and moved broods into grasslands with a greater percent cover of forbs (J. Lautenbach, J. Kraft, and R. Plumb, unpublished data).

Within Clark County, Kansas, I observed no differences in percent cover and visual obstruction among used, paired random points, and random points distributed across the study site. These data suggest that the lack of differences among brood points, paired random, and random points distributed across the study site is a result of a relatively homogenous landscape within the Clark County, Kansas site. Selection of different habitats was not possible for females with broods. This finding is consistent with a study in west Texas, where there were no differences among brood locations and random locations (Grisham 2012). A homogenous landscape would reduce the risk of traveling to get to adequate habitat for brood rearing. If the habitat meets the needs of brood-rearing habitat (e.g., food, cover) this could positively influence brood survival, which appeared to be the case at the Clark County site. However, if the homogenous landscape does not meet the requirements of brood-rearing habitat, the population could suffer with low population recruitment.

Management Implications

Understanding brood survival and habitat selection will provide guidelines for conservation efforts for lesser prairie-chickens, as chick survival has been identified as the most important driver of lesser prairie-chicken populations (Hagen et al. 2008). Providing forb cover (~20%) near nesting habitat will ensure lesser prairie-chicken broods have forage, because insects that have been identified as a major source of a chick's diet are associated with forbs. Having greater forb cover with 50% visual obstruction readings ranging between 2-5 dm would have a greater probability of being used by females with broods. Burning portions of grasslands can provide needed nesting cover and greater forb cover in areas one year post-fire adjacent to nesting cover (Fuhlendorf and Engle 2004). Providing brood-rearing habitat within 1 km of nesting cover would reduce the need for broods to move long distances. I suggest 1 km from nesting cover because mean brood movement weekly brood movement ranges from 585 m (SE = 40) in in the Red Hills to 1068 m (SE = 134) in northwest Kansas (R. Plumb, unpublished data). During drought conditions, reductions in stocking rates of livestock in grasslands would prolong habitat quality for broods. Providing good nesting cover earlier in the season will help to increase the success of first nesting attempts, which will improve the probability of chicks surviving to 56-days and improve population recruitment, although managers have no control over nest initiation.

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Table 3.1 Model ranking for lesser prairie-chicken brood survival using the nest survival model in Program MARK to estimate survival. Models compared included variable combinations of region (Red Hills, Northwest, Clark County, Kansas and Colorado), year (2013, 2014), hatch date (Hatch, a quadratic function of hatch date (Hatch^2), and constant.

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
Region + Year + Hatch	129.8	9	0.0[e]	0.583
Region + Year + Hatch + Hatch^2	128.5	8	0.7	0.411
Hatch	151.9	2	10.0	0.004
Hatch+Hatch^2	151.9	3	12.0	0.001
Region + Year	144.8	7	12.9	0.001
Region + Hatch + Hatch^2	165.8	6	14.8	<0.001
Constant	164.7	1	21.5	<0.001
Year	164.4	2	23.5	<0.001
Region	161.4	4	23.5	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. Minimum AIC_c = 145.9

Table 3.2 Model rankings of lesser prairie-chicken chick survival in Kansas and Colorado in 2013 and 2014 using Lukacs young survival from a marked adult and unmarked young model. Tested variables included year, time-since-hatch (time), Julian hatch date (hatch), and Julian date as a quadratic function (hatch^2).

Model	Dev.^{a}	K^b	$\Delta\text{AIC}_c{}^c$	$w_i{}^d$
e^d(Year+Time+Hatch+Hatch^2) p^f(Year+Hatch+Hatch^2)	492.6	15	0.0^g	0.994
Φ(Year+Time+Hatch) p(Year+Hatch)	508.2	13	10.5	0.005
Φ(Year*Time+Hatch+Hatch^2) p(Year+Time+Hatch+Hatch^2)	466.0	29	14.3	0.001
Φ(Year*Time) p(Year*Time)	508.3	19	26.3	0.000
Φ(Year*Time) p(Year)	526.1	13	28.4	0.000
Φ(Year*Time) p(Year+Time)	519.1	18	34.4	0.000
Φ(Year*Time) p(Time)	521.1	18	36.4	0.000
Φ(Year+Time) p(Year*Time)	527.7	17	40.4	0.000
Φ(Year+Time) p(Time)	542.9	13	45.2	0.000
Φ(Year+Time) p(Year)	549.3	11	46.7	0.000
Φ(Year+Time) p(Year+Time)	538.7	16	48.6	0.000
Φ(Time) p(Year*Time)	540.7	16	50.7	0.000
Φ(Time) p(Year)	559.4	10	54.4	0.000
Φ(Time) p(Year+Time)	547.5	15	64.4	0.000
Φ(Time) p(Time)	555.5	12	65.4	0.000
Φ(Year+Hatch+Hatch2) p(Year+Hatch+Hatch^2)	744.8	8	235.2	0.000
Φ(Year) p(Year+Time)	755.1	9	247.8	0.000
Φ(Year) p(Year*Time)	748.2	12	248.1	0.000
Φ(Year) p(Time)	763.0	8	253.4	0.000
Φ(Hatch+Hatch2) p(Hatch+Hatch^2)	797.4	5	281.2	0.000
Φ(Year) p(Year)	836.1	4	360.2	0.000

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. ϕ is apparent survival
f. p is the detection probability
g. Minimum AIC_c = 526.7

Table 3.3 Ranking of logistic regression models testing Visual Obstruction Readings (VOR) measured as dm between used-brood points and random points for lesser prairie-chickens in Kansas in 2013 and 2014.

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
50% VOR as Quadratic	1599.8	3	0.0[e]	0.62
75% VOR as Quadratic	1602.2	3	2.3	0.19
25% VOR as Quadratic	1602.3	3	2.5	0.18
100% VOR as Quadratic	1619.5	3	19.7	<0.001
50% VOR	1650.2	2	48.4	<0.001
75% VOR	1650.2	2	48.7	<0.001
25% VOR	1654.9	2	53.1	<0.001
100% VOR	1658.4	2	56.6	<0.001
0% VOR	1676.0	2	74.2	<0.001
0% VOR as Quadratic	1676.0	3	76.1	<0.001
Null[f]	1707.8	1	104	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. Minimum AIC_c = 1578.6
f. Null model compared used to unused points with no covariates

Table 3.4 Model and rankings developed for evaluating lesser prairie-chicken brood habitat selection comparing used brood points to paired random points and random points distributed across all study sites within Kansas during 2013 and 2014. Ranked models included combinations of 50% Visual Obstruction Reading (VOR); a quadratic function of 50% VOR (VOR^2); percent cover of litter, grass, forbs, bare ground, and shrubs; and mean litter depth.

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
VOR + VOR^2 + Forb Cover	1570.6	4	0.0[e]	1
VOR + VOR^2 + Grass Cover	1589.7	4	19.2	<0.001
VOR + VOR^2 + Shrub Cover	1592.0	4	21.4	<0.001
VOR + VOR^2 + Litter Depth	1596.4	4	25.9	<0.001
VOR + VOR^2 + Litter Cover	1598.8	4	28.2	<0.001
VOR + VOR^2 + Bare Ground Cover	1599.8	4	29.2	<0.001
Forb Cover	1621.9	2	47.4	<0.001
VOR	1650.2	2	75.7	<0.001
Grass Cover	1668.3	2	93.8	<0.001
Shrub Cover	1671.7	2	97.2	<0.001
Litter Cover	1672.4	2	97.8	<0.001
Bare Ground Cover	1671.2	3	98.6	<0.001
Litter Depth	1676.2	2	101.6	<0.001
Null[f]	1707.8	1	131.2	<0.001

a. Deviance

b. Number of parameters

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

d. Akaike weights

e. Minimum AIC_c = 1578.6

f. Null model compared used to unused points with no covariates

Table 3.5 Model rankings for evaluating lesser prairie-chicken brood habitat selection, comparing used brood points to paired random points and random points distributed across the study site within Kiowa and Comanche counties within the Red Hills region of south-central Kansas during 2013 and 2014. Models combined the following variables: 50% Visual Obstruction Reading (VOR); a quadratic function of 50% VOR (VOR^2); percent cover of litter, grass, forbs, bare ground, and shrubs; and mean litter depth.

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
VOR + VOR^2 + Shrub Cover	714.3	4	0.0[e]	0.913
VOR + VOR^2 + Forb Cover	722.3	4	4.7	0.086
VOR + VOR^2 + Litter Depth	734.7	4	16.2	<0.001
VOR + VOR^2+ Grass Cover	737.0	4	18.1	<0.001
VOR + VOR^2 + Litter Cover	737.9	4	19.4	<0.001
VOR + VOR^2 + Bare Ground Cover	739.4	4	20.8	<0.001
Forb Cover	793.3	2	64.5	<0.001
VOR	814.3	2	83.1	<0.001
Grass Cover	837.3	2	105.4	<0.001
Bare Ground Cover	845.7	3	108.3	<0.001
Shrub Cover	841.7	2	109.8	<0.001
Null[f]	850.1	1	115.2	<0.001
Litter Cover	848.9	2	116.1	<0.001
Litter Depth	849.2	2	116.3	<0.001

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. Null model compared used to unused points with no covariates
f. Minimum AIC$_c$ = 722.3

Table 3.6 Model rankings for evaluating lesser prairie-chicken brood habitat selection comparing used brood points to paired random points and random points distributed across the study site within Gove and Logan counties within the High Plains region of northwest Kansas during 2013 and 2014. Models combined the following variables: 50% Visual Obstruction Reading (VOR); a quadratic function of 50% VOR (VOR^2); percent cover of litter, grass, forbs, bare ground, and shrubs; and mean litter depth.

Model	Dev.[a]	K[b]	ΔAICc[c]	w_i[d]
Bare Ground Cover	278.6	3	0.0[e]	0.916
Litter Depth	287.7	2	6.0	0.045
VOR + VOR^2 + Litter Depth	283.1	4	8.5	0.013
VOR + VOR^2 + Bare Ground Cover	276.3	4	9.1	0.010
VOR + VOR^2 + Litter Cover	254.7	4	9.7	0.010
Litter Cover	262.4	2	11.2	0.003
VOR + VOR^2 + Forb Cover	279.1	4	12.3	0.002
Forb Cover	284.4	2	13.6	0.001
VOR + VOR^2 + Grass Cover	277.9	4	14.0	<0.001
VOR	289.6	2	14.4	<0.001
Grass Cover	280.7	2	14.8	<0.001
VOR + VOR^2 + Shrub Cover	284.2	4	14.9	<0.001
Shrub Cover	291.7	2	17.1	<0.001
Null	319.2	1	50.9	<0.001

a. Deviance

b. Number of parameters

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

d. Akaike weights

e. Null model compared used to unused points with no covariates

f. Minimum AIC_c = 282.6

Table 3.7 Model rankings for lesser prairie-chicken brood habitat selection, comparing used brood points to paired random points and random points distributed across the study site within Clark County south-central Kansas during 2014. Models combined the following variables: 50% Visual Obstruction Reading (VOR); a quadratic function of 50% VOR (VOR^2); percent cover of litter, grass, forbs, bare ground, and shrubs; and mean litter depth.

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
Null[e]	417.4	1	0.0[f]	0.125
Bare Ground Cover	415.8	3	0.2	0.113
VOR + VOR^2 + Bare Ground Cover	411.1	4	0.2	0.113
VOR + VOR^2 + Grass Cover	411.4	4	0.5	0.096
Litter Depth	416.5	2	1.0	0.075
VOR + VOR^2 + Litter Depth	412.1	4	1.1	0.073
Grass Cover	420.5	2	1.2	0.07
VOR	416.8	2	1.5	0.059
VOR + VOR2 + Forb Cover	412.8	4	1.8	0.05
Forb Cover	417.3	2	1.8	0.05
Shrub Cover	417.4	2	1.9	0.047
Litter Cover	417.4	2	2.0	0.046
VOR + VOR^2 + Shrub Cover	421.1	4	2.1	0.043
VOR + VOR^2 + Litter Cover	413.2	4	2.2	0.042

a. Deviance
b. Number of parameters
c. Difference in Akaike's Information Criterion, corrected for a small sample size
d. Akaike weights
e. Null model compared used to unused points with no covariates
f. Minimum AIC_c = 419.4

Figure 3.1 Estimates of brood survival in Kansas (Red Hills, northwest [NW], and Clark County) and Colorado in 2013 and 2014 for 56-day exposure period. Survival estimates generated using the nest survival model in Program MARK using the Lukacs young survival from an marked female. Survival estimates shown with 95% confidence intervals.

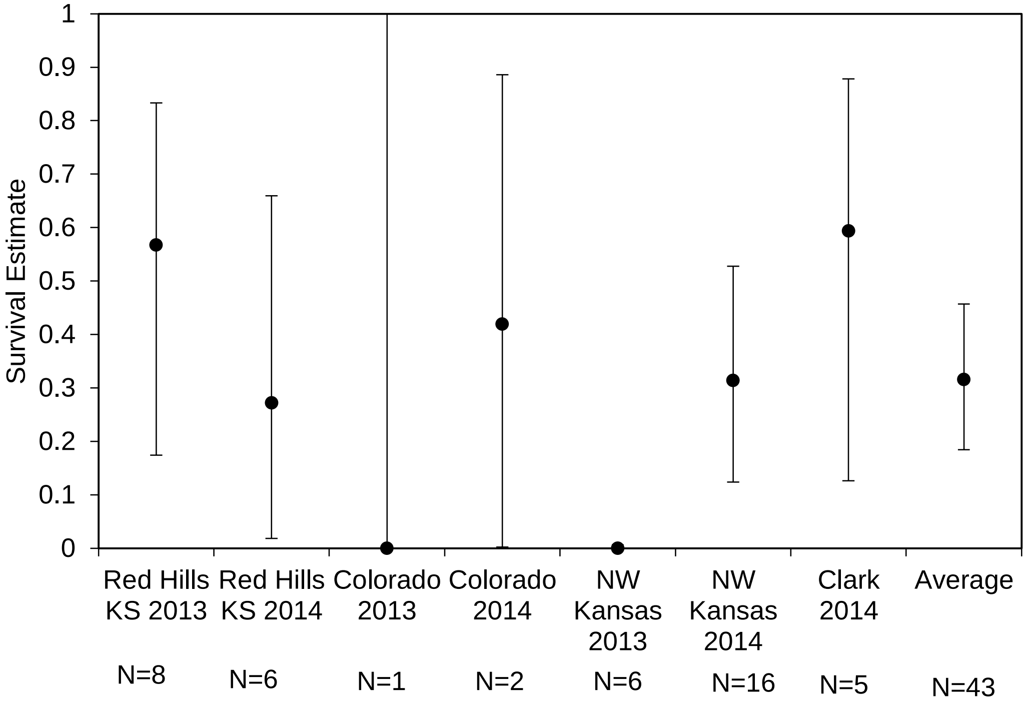


Figure 3.2 Estimates of daily brood survival for lesser prairie-chickens in Kansas and Colorado in 2013 and 2014 in relation to hatch date. Survival estimates generated using the nest survival model in Program MARK. Survival estimates shown with 95% confidence intervals.

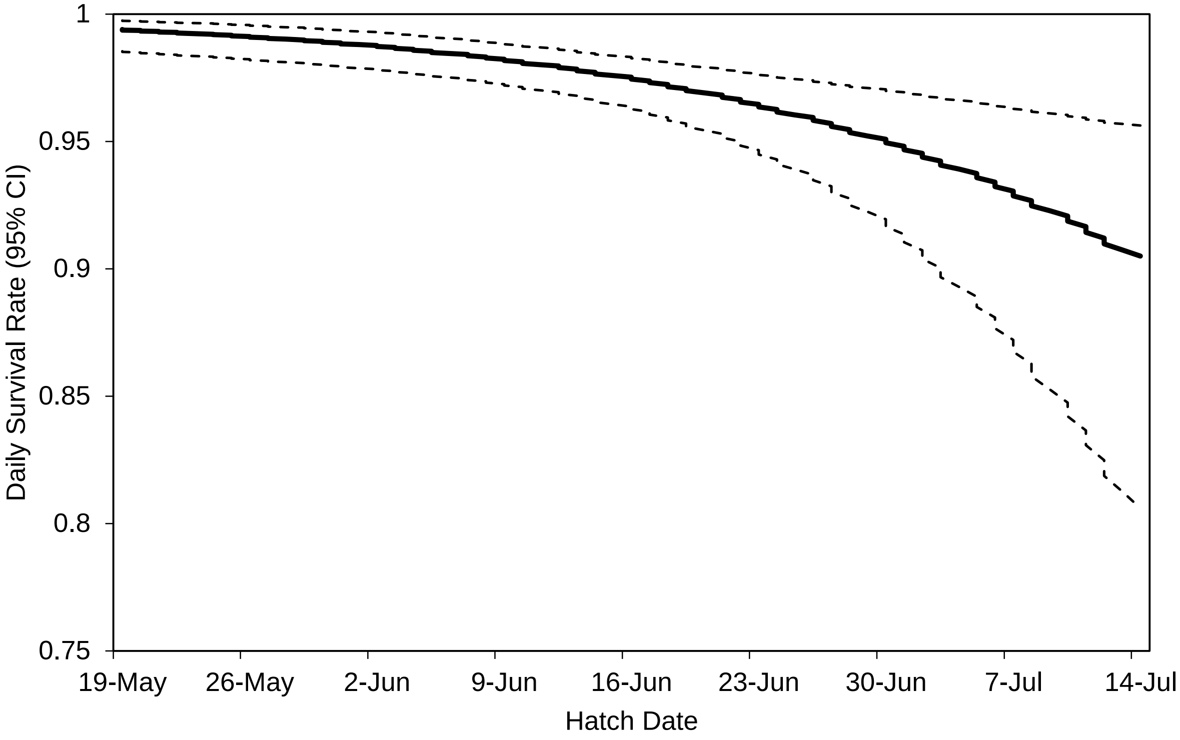


Figure 3.3 Weekly survival estimates for lesser prairie-chicken chicks in 2013 across Kansas and Colorado using the top model generated from Lukacs young survival from a marked adult model within Program MARK. Survival estimates shown with 95% confidence intervals.

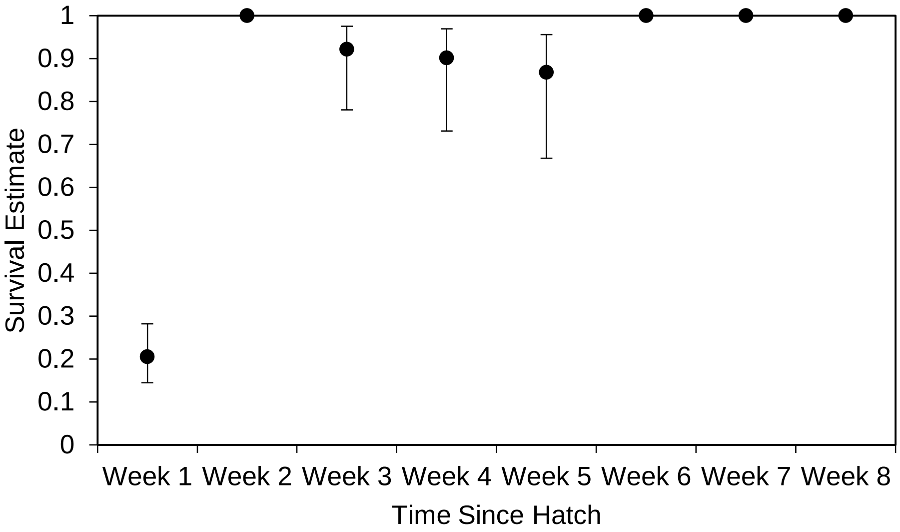


Figure 3.4 Weekly survival estimates for lesser prairie-chicken chicks in 2014 across Kansas and Colorado using the top model generated from Lukacs young survival from a marked adult model within Program MARK. Survival estimates shown with 95% confidence intervals.

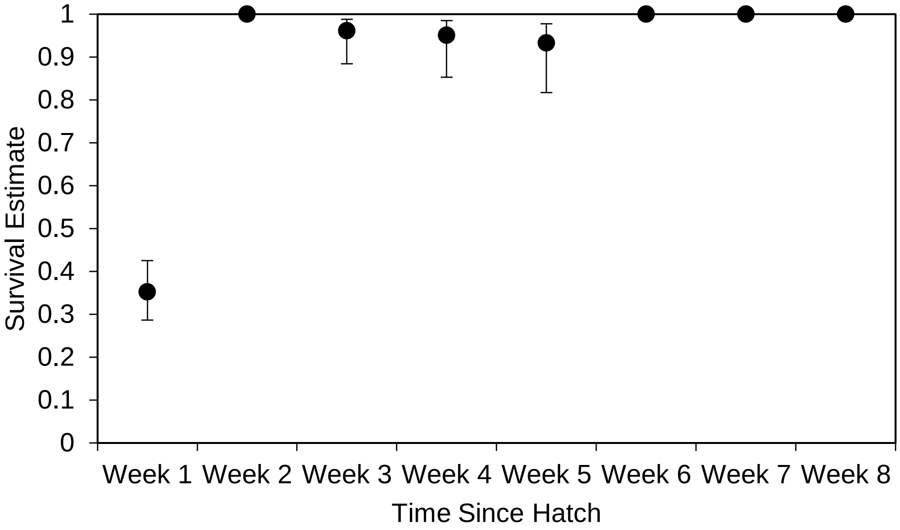


Figure 3.5 Probability of chick survival over 56 days for lesser prairie-chickens in Kansas and Colorado in 2013 and 2014 in relation to hatch date. Survival estimates generated using the Lukacs survival of young from a marked adult model. Survival estimates shown with 95% confidence intervals.

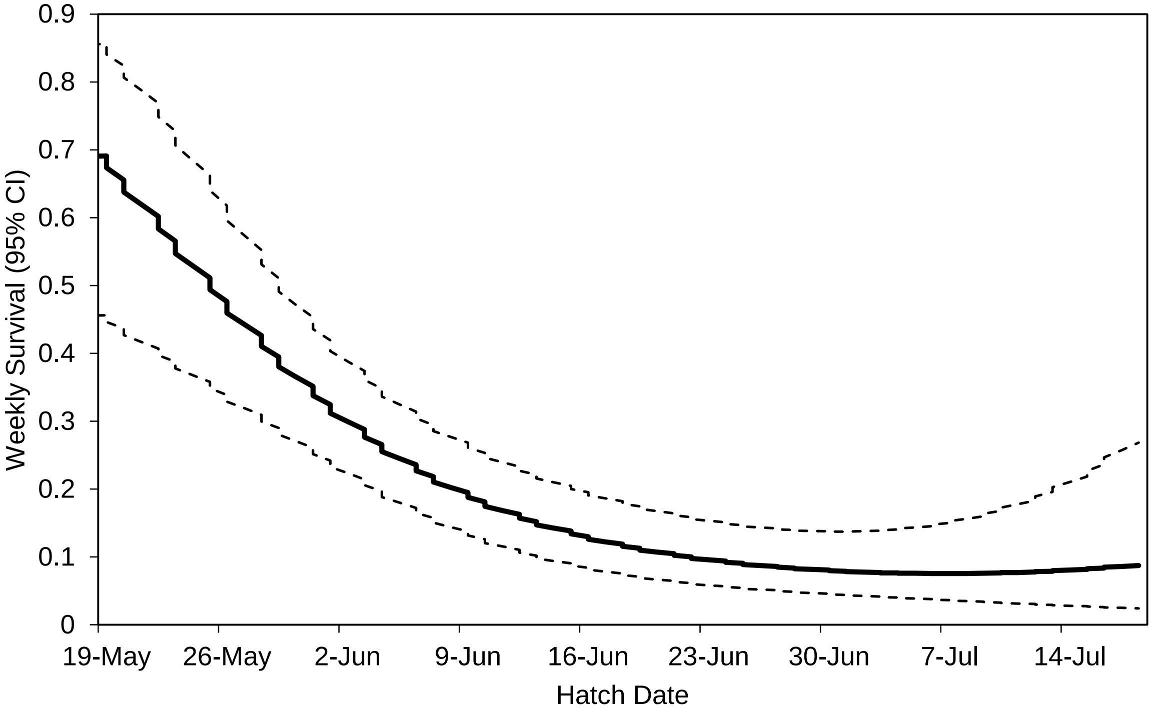


Figure 3.6 Probability of use of 50% visual obstruction for female lesser prairie-chickens with broods in Kansas during 2013 and 2014. Shown with 95% confidence intervals.

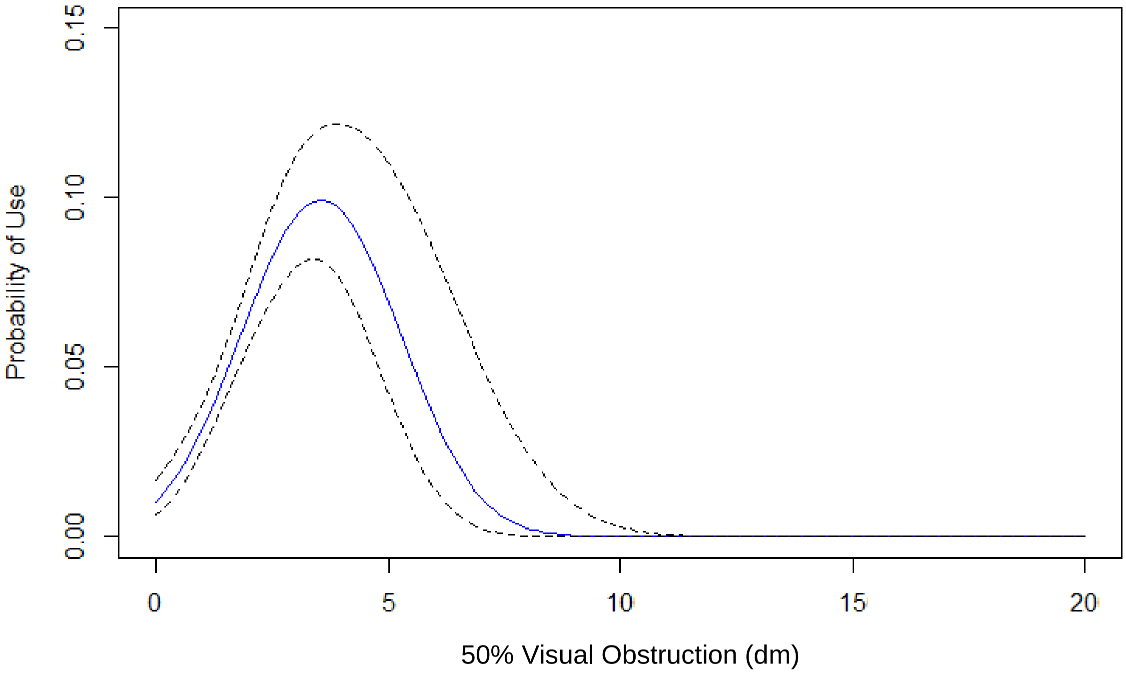


Figure 3.7 Comparison of 50% visual obstruction readings at points used by broods, paired random points, and random points among all of study sites (Red Hills (Kiowa and Comanche counties, Kansas), Northwest (Gove and Logan counties, Kansas), and Clark County, Kansas) during 2013 and 2014.

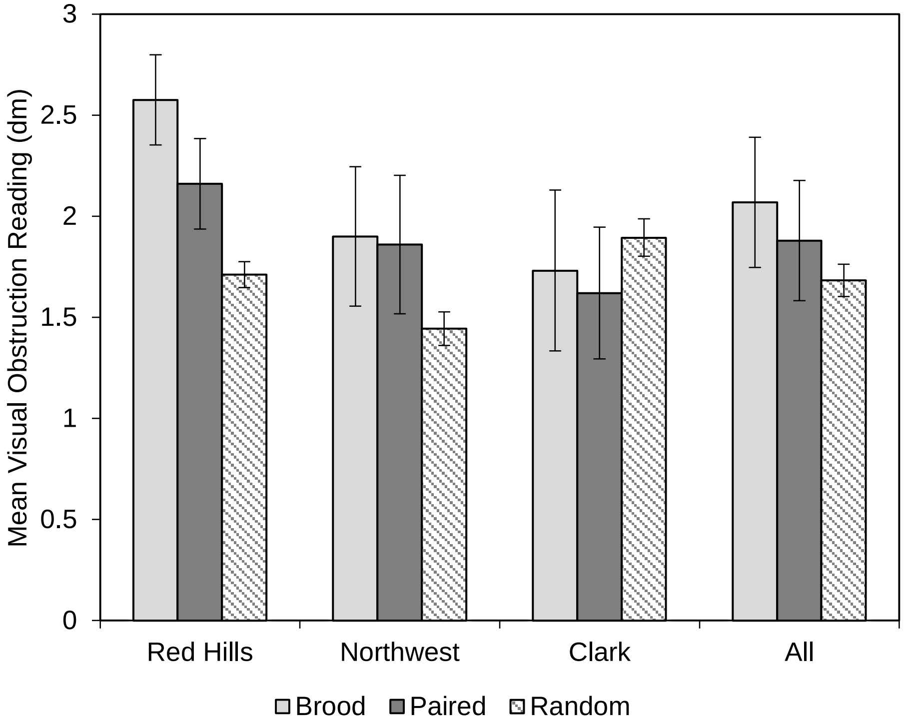


Figure 3.8 Comparison of percent cover of vegetation functional groups between points used by broods, paired random points, and random points distributed across all study sites (Kiowa, Comanche, Gove, Logan, and Clark counties) during 2013 and 2014.

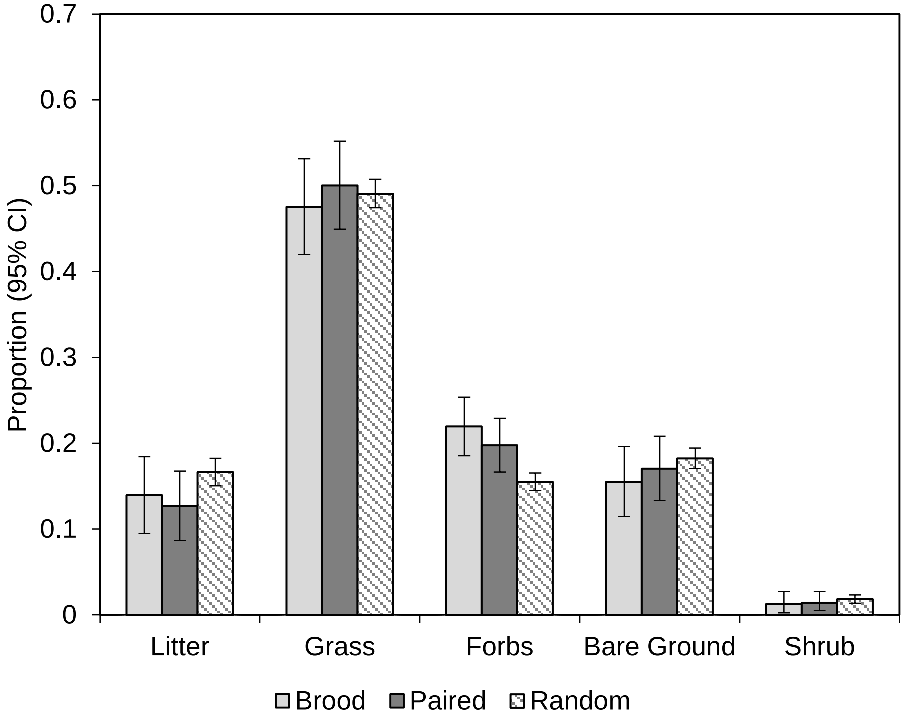


Figure 3.9 Comparison of percent cover of vegetation functional groups between points used by broods, paired random points, and random points distributed across Kiowa and Comanche counties within the Red Hills region of south-central Kansas during 2013 and 2014.

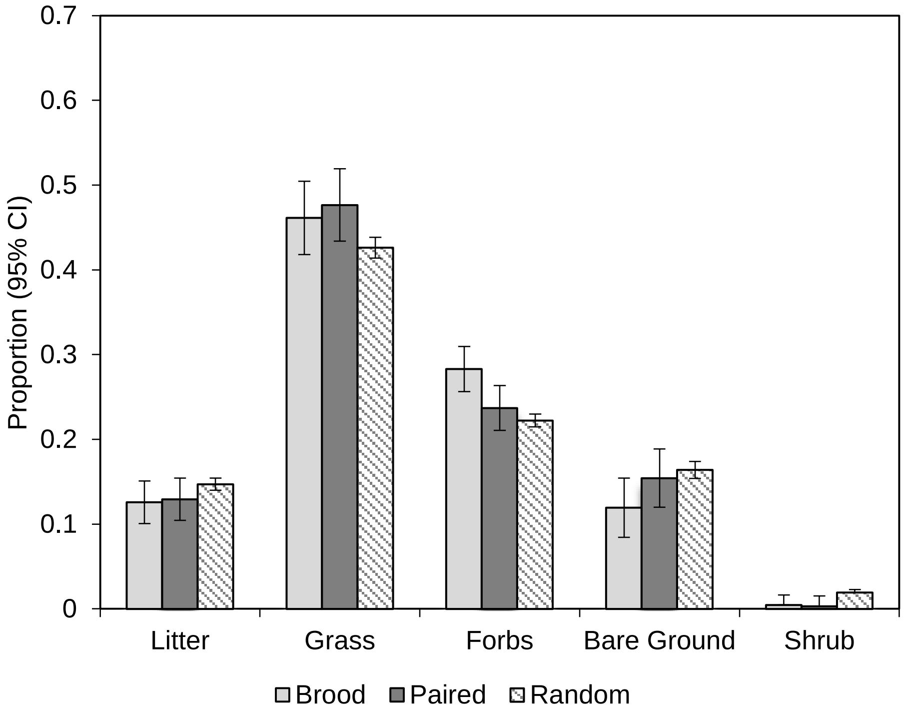


Figure 3.10 Comparison of percent cover of vegetation functional groups between points used by broods, paired random points, and random points distributed across Gove and Logan counties within the High Plains region of northwest Kansas during 2013 and 2014.

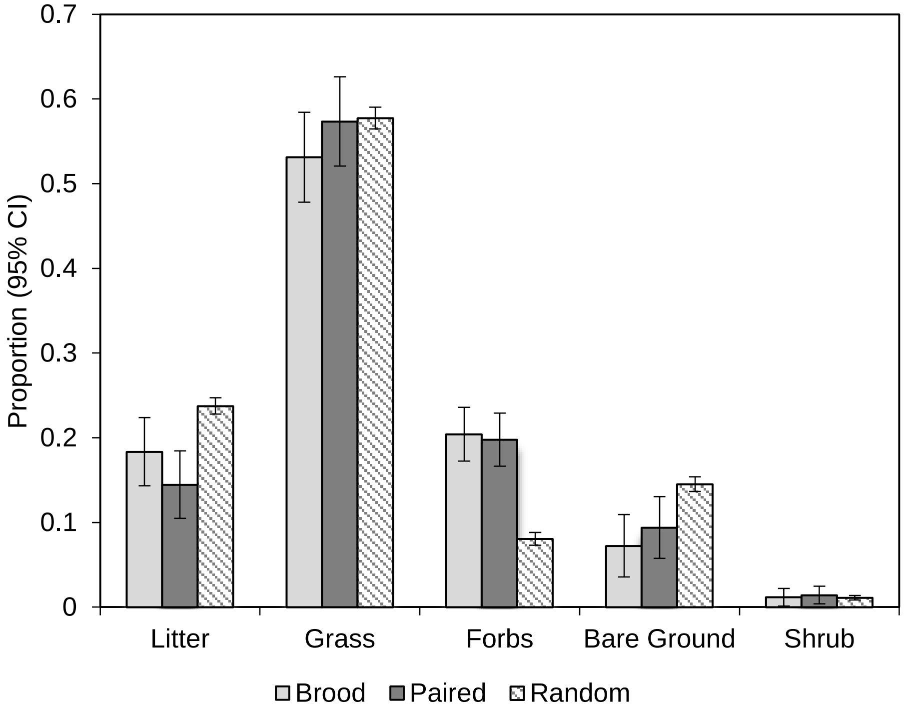
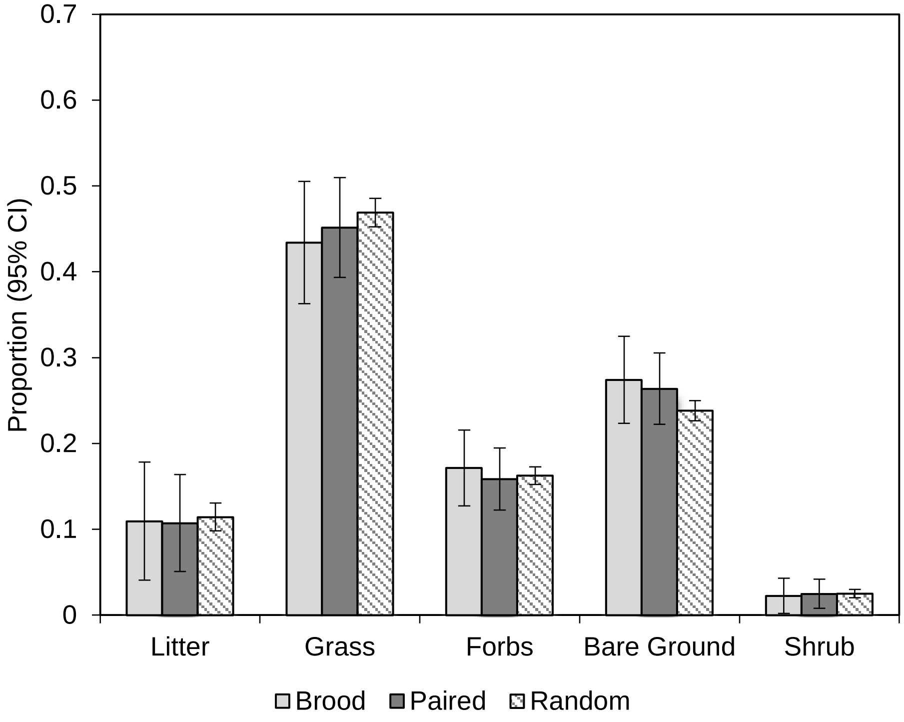


Figure 3.11 Comparison of percent cover of vegetation functional groups between points used by broods, paired random points, and random points distributed across Clark County in south-central Kansas during 2013 and 2014.



Chapter 4 - **LESSER PRAIRIE-CHICKEN RESPONSE TO TREES IN A GRASSLAND LANDSCAPE**

Introduction

Great Plains grasslands have become one of the most threatened ecosystems in North America (Cully et al. 2003, Samson et al. 2004). Grasslands have experienced the greatest reduction in occurrence of any North American ecosystem (Samson and Knopf 1994). Conversion of grasslands to row-crop agriculture has been the major cause for grassland loss (White et al. 2000). In addition, mismanaged livestock grazing has reduced the quality and diversity of many intact grassland ecosystems (O'Connor et al. 2010). Exotic and invasive grasses alter remaining grasslands further (Cully et al. 2003). A loss of ecological drivers, such as fire and large herbivore grazing, has resulted in tree encroachment into grasslands (Samson et al. 2004, Engle et al. 2008). Tallgrass prairie loss has been estimated to be 86.6% within North America (Samson et al. 2004). ~ 29.1% of mixed-grass prairie remains intact today (Samson et al. 2004). Short-grass prairie has seen the least amount of loss. However, ~ 48.2% of short-grass prairie has been lost (Samson et al. 2004).

Grasslands provide important ecological goods and services for society. Grasslands have the ability to act as carbon banks, which is beneficial with global climate change (Samson and Knopf 1994). The biodiversity and heritage within grassland ecosystems in unique and worth preserving. For instance, grassland birds are one of the fastest declining groups in North America (Peterjohn and Sauer 1999). Grasslands are important agricultural landscapes (e.g., livestock grazing) throughout the world and continued degradation will reduce the quality of grasslands for livestock production. Continued degradation and loss of grasslands will negatively affect human societies.

Within the southern Great Plains, woody plant encroachment in grasslands has become a major conservation and management issue and has replaced conversion of grassland to row-crop agriculture as the major cause of grassland fragmentation and degradation (Bragg and Hulbert 1976; Coppedge et al. 2001a,b; Engle et al. 2008). Fire suppression has resulted in the spread and encroachment of woody plants into grasslands and eliminated a critical driver of grassland quality (Bragg and Hulbert 1976, Blewett 1986). Trees, such as junipers (*Juniperus* spp.), mesquite (*Proposis* spp.), salt cedar (*Tamarix* spp.), and oaks (*Quercus* spp.) are woody plants that are especially concerning in the southern Great Plains. Trees alter plant communities, reduce grassland production, and alter animal communities. In addition to fire suppression, historical conservation plantings by agencies have contributed to the problem of woody plant encroachment (Ganguli et al. 2008). For instance, numerous trees such as eastern red cedar (*Juniperus virginiana*) have been planted as wind breaks to control erosion and provide wildlife habitat (Capel 1988). Historically, eastern red cedars were limited to areas with shallow or poor soils where there were inadequate fuels to support fires. Eastern red cedars are able to grow in a wide variety of soil types and climatic conditions, thus allowing for expansion into many grassland habitat types when disturbance factors limiting cedar occurrence are reduced (Schmidt and Wardle 2002). Consequently, eastern red cedar has become a major concern for grassland managers in the southern Great Plains (Engle et al. 2008).

Tree encroachment has altered grassland habitats by reducing herbaceous cover within grassland ecosystems. Herbaceous biomass and diversity decreases as eastern red cedar canopy cover increased (Briggs et al. 2002, Limb et al. 2010). Herbaceous biomass underneath tree canopies was reduced by 83% in the presence of eastern red cedar; the biomass reduction may have been as a result of a reduction 85% reduction of light and an 11.5% reduction in soil water availability (Smith and Stubbendieck 1990). In addition, eastern red cedars alter plant communities causing composition of grasslands to shift from warm season (C4) grasses towards cool season (C3) grasses (Gehring and Bragg 1992, but see Limb et al. 2010). Shading caused by eastern red cedars reduces fuel loads reducing fire intensity and frequency. The reduced fire intensity creates a positive feedback loop that prevents fires from killing eastern red cedars and other woody plants (Reich et al. 2001). In addition, evidence from aerial photographs suggests that tall-grass prairie can convert from prairie to closed canopy eastern red cedar forest in as little as 40 years (Briggs et al. 2002). The spread of trees is a grassland management concern, which needs to be addressed by managers.

Once trees become established in grasslands, removal must occur to restore grasslands. There are four ways to remove trees from prairie habitats: prescribed fire, herbicide, manual cutting, and individual tree ignition (Ortmann et al. 1998). The most cost effective method to reduce and/or control trees on grassland sites is using regular prescribed fire (Ortmann et al. 1998). Prescribed fire was observed to kill trees 88% of trees < 1 m, 60% of trees 1-2 m, 35% of trees 2-3 m and 10% of trees > 3 m (Ortmann et al. 1998). Prescribed fire is relatively inexpensive and efficient (Ortmann et al. 1998). Herbicide, individual tree ignition, and manual cutting are more time and labor intensive (Ortmann et al. 1998). However, once trees reach a threshold size (> 2-3 m), prescribed fire will not effectively kill or control trees, forcing land managers to use the more expensive methods to control trees (Ortmann et al. 1998). Once trees such as eastern red cedar are removed, herbaceous plant diversity increased and plant composition returned to plant composition expected in areas without trees within three to four years (Pierce and Reich 2010, Alford et al. 2012). In addition, after eastern red cedar removal, mammal communities shift towards those found in native grass communities (Alford et al. 2012).

Bird and mammal communities have been shown to be affected by trees (Coppedge et al. 2001b, Alford et al. 2012). However, how trees affect lesser prairie-chickens is poorly understood. The lesser prairie-chicken (*Tympanuchus pallidicinctus*) is a species of prairie grouse native to the southern Great Plains. Lesser prairie-chickens have experienced population declines and range contraction since the early 1900s (Taylor and Guthery 1980, Hagen et al. 2004). In addition, the lesser prairie-chicken was listed as a threatened species in May 2014 under the Endangered Species Act (USFWS 2014). Primary causes for the lesser prairie-chicken decline include conversion of native grasslands to row-crop agriculture, energy development, mismanaged grazing lands, and woody plant encroachment into native grasslands (Hagen et al. 2004). Prairie grouse, including the lesser prairie-chicken, are surrogate species for grasslands because they require large blocks of grassland habitat (Svedarsky et al. 2000, Poiani et al. 2001, Hagen et al. 2004, Pruett et al. 2009b). Increases in relative cover of native shrubs (e.g., sand shinnery oak [*Quercus havardii*]) and sand sagebrush [*Artemisia filifolia*]) and other woody vegetation (e.g., eastern red cedar) is reducing the amount of available grassland habitat throughout the range of the lesser prairie-chicken. However, sand shinnery oak and sand sagebrush are important sources of cover in the western range of the lesser prairie-chicken. For instance, lesser prairie-chickens were more likely to nest in sand shinnery oak if there was intense grazing (Haukos and Smith 1989). In the eastern portion of the lesser prairie-chicken’s range, increasing presence of eastern red cedar is believed to cause avoidance of surrounding available habitat by lesser prairie-chickens due to occurrence of an unnatural vertical structure on the landscape (Fuhlendorf et al. 2002). However, much remains unclear regarding the influence of eastern red cedar and other trees on lesser prairie-chicken populations including density thresholds, avoidance patterns, and response to removal.

The response of lesser prairie-chickens to shrub and tree removal in the eastern portion of the species' range is poorly understood. Fuhlendorf et al. (2002) used aerial photographs and population data from 1959-1996 to attribute lesser prairie-chicken population declines to habitat loss and eastern red cedar encroachment. Eastern red cedar encroachment could be reducing the available habitat for lesser prairie-chickens through habitat conversion and fragmentation, altering habitat structure, or through lesser prairie-chicken avoidance behavior. The presence of trees could be impacting population demography, including nest success. Waterfowl, ground-nesting birds in grassland ecosystems, showed decreased nest success in areas of woody plant encroachment (Thompson et al. 2012). Grassland nesting songbirds were more susceptible to predation in areas of woody vegetation (Klug et al. 2010). Lesser prairie-chickens may also experience reduced nest success in areas of woody vegetation because tree encroachment may also alter the habitat to benefit potential predators by providing perches for raptors and travel corridors for mesocarnivores including: raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and coyotes (*Canis latrans*).

Currently, the U.S. Departments of Agriculture and Interior have conservation programs and applied practices that include woody vegetation removal to benefit grassland wildlife species (e.g., manual cutting, use of herbicides, prescribed fire). The Natural Resources Conservation Service (NRCS) initiated the Lesser prairie-chicken Conservation Initiative (LPCI) in 2011 (NRCS 2012a). The LPCI uses current Farm Bill and Farm Service Agency (FSA) programs such as Environmental Quality Incentives Program (EQIP) and Conservation Reserve Program (CRP) to target management for lesser prairie-chicken habitat. One of the programs of the LPCI is targeted at removing trees, such as eastern red cedar, from grasslands to improve lesser prairie-chicken habitat (NRCS 2012b). The Partners for Fish and Wildlife program, a US Fish and Wildlife Service program, works with private landowners to improve fish and wildlife habitat on private lands (USFWS 2011). One aspect of the Partners for Fish and Wildlife program targets the removal of trees from grasslands. However, little information is available to guide conservation efforts involving management of woody vegetation. If the programs and practices elicit a positive response (i.e., based upon use patterns), benefits to lesser prairie-chicken populations could be quantified and additional recommendations provided to continue and improve these programs. In addition, current government programs targeted for lesser prairie-chicken conservation incentivize tree removal in grasslands. Tree removal allows for evaluation and need for the programs targeted at lesser prairie-chickens.

Due to their habitat requirements, role as a surrogate species for grasslands, and the current conservation needs of this declining grassland bird, the lesser prairie-chicken serves as an ideal candidate to measure impacts of tree encroachment on grassland species. The goal of my research was to assess potential responses by lesser prairie-chickens to a grassland invaded by eastern red cedars. My objectives were to measure lesser prairie-chicken habitat use and reproductive response to trees. I hypothesized that (1) lesser prairie-chickens would avoid areas with high tree densities, (2) lesser prairie-chickens use would cease at a certain threshold of tree density, and (3) lesser prairie-chickens would place nests in areas of lower tree density and further from tree cover than expected at random. Results from this research could be used to provide managers a better understanding of the impacts trees have on lesser prairie-chickens and help shape future management objectives and decisions.

Methods

Study Site

The study site was in south-central Kansas on ~14,000 ha of private land within Kiowa and Comanche counties (Figure 1.2). The study site was primarily mixed-grass prairie on loamy and limy soils within the Red Hills region of Kansas. The land use within the region was primarily livestock grazing with pockets of row-crop agriculture. The region mean high temperature near the study sites was 20.8º C. The mean low temperature for the study period was 6.6ºC. The area received a total of 109 cm of precipitation during the study, with 55.8 cm falling from1 January – 31 December 2013 and 53.2 cm falling from 1 January – 31 August (Kansas Mesonet, accessed 11/30/2014, http://mesonet.k-state.edu/weather/historical/#!). The region's average annual temperature is 13.7ºC with an average 70.7 cm of annual precipitation. The average low temperature in January is -6.8º C. The average high temperature in July is 34.4ºC (High Plains Regional Climate Center, accessed 1/23/2013, http://www.hprcc.unl.edu/index.php). Most of the precipitation falls from April to late July.

Dominant grasses within the region include: little bluestem (*Schizachyrium scoparium*), blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsute*), side oats grama (*B. curtipendula*), buffalo grass (*Buchloë dactyloides*), and tall dropseed (*Sporobolus compositus*; Lauver et al. 1999). Other dominant vegetation within the region include: sand sagebrush, purple poppy mallow (*Callirhoe involucrate*), heath aster (*Aster ericoides*), evening primrose (*Oenothera macrocarpa*), broom snakeweed (*Gutierrezia sarothrae*), sand plum (*Prunus angustifolia*), and smooth sumac (*Rhus glabra*; Lauver et al. 1999). Trees prevalent in the region include: eastern red cedar, eastern cottonwood (*Populous deltoides*), Siberian elm (*Ulmus pumila*), and hackberry (*Celtis occidentalis*).

Tree removal has been prevalent at the study site for the past 30 years. However, tree encroachment continues across the study site and region. Eastern cottonwoods and other hardwoods are typically restricted to lowlands and along drainages, where adequate moisture is available. Eastern red cedars have encroached into upland habitats in addition to drainages. Eastern red cedars are the dominant tree species on the study site and within the region and the most likely to impact lesser prairie-chicken habitat use.

Capture

Lesser prairie-chickens were trapped at leks using walk-in traps (Haukos et al. 1990, Schroeder and Braun 1991) and drop nets (Silvy et al. 1990). Leks were trapped continuously through the lekking season (~ 10 March-15 May). Captured lesser prairie-chickens were sexed and aged using plumage characteristics (Copelin 1963). Females were fitted with either a satellite transmitter (platform transmitting terminals or PTT) or a VHF radio transmitter. Each PTT contained sensors to transmit calibrated indices for unit temperature and lesser prairie-chicken motion, which were used to determine if the bird was alive. The PTTs were mounted on the rump using Teflon ribbon (Dzialak et al. 2011); each unit weighed 22 g and had a solar charging component that allowed for the battery to be recharged (Microwave Telemetry, Columbia, Maryland, USA). The VHF radio transmitters were equipped with a 12-hr mortality switch. VHF radio transmitters were 12 g bib/collar attachment style, with an average lifespan of 350 days (Advanced Telemetry System, Isanti, Minnesota, USA). Captured individuals were released at the capture site. All capture and handling procedures approved by the Kansas State University Institutional Animal Care and Use Committee under protocol # 3241 and the Kansas Department of Wildlife, Parks, and Tourism scientific collection permit numbers SC-042-2013 and SC-079-2014.

Locations

In 2013 and 2014, female lesser prairie-chickens fitted with VHF radio transmitters were regularly (i.e., 3+ times/week) monitored via triangulation 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) to record telemetry locations via triangulation based on a minimum of three bearings (Cochran and Lord Jr 1963). A maximum of 20-min time interval between bearings was used to minimize error from lesser prairie-chicken movement. Location of a Signal (Ecological Software Solutions, Florida, USA) was used to obtain Universal Transverse Mercator (UTM) coordinates from VHF data collected in the field. For lesser prairie-chickens fitted with PTTs, the duty cycle for Global Positioning System (GPS) fixes was: one data point taken every other hour from 0400-2200 with a data transmission cycle of 8 hours on and 50 hours off. Potential location error using these transmitters was ≤18 m.

Nest locations were identified by approaching females marked with VHF transmitters using homing once a female had been recorded in the same location for three or more consecutive days (Pitman et al. 2005). I assumed that the female was incubating if the telemetry bearings and PTT GPS fixes remained relatively constant without a mortality signal. The nest location was not revisited until the female was determined to be off the nest, via telemetry or PTT GPS fixes (Pitman et al. 2005). When the female was determined to be off of the nest, I returned to the nest site and assessed nest fate. The UTM coordinates of nest locations were recorded using a hand-held GPS unit (Garmin eTrex 30). When the nest was approached, rubber boots and latex gloves were worn to reduce scent and scent trails around the nests. I attempted to spend as little time as possible at the nest (<5 minutes) and avoided leaving “dead end” scent trails at the nest (Grisham 2012).

Spatial Analysis

Individual trees within the study area were digitized and mapped by hand using the National Agricultural Imagery Program (NAIP) 1 m resolution imagery using ArcGIS 10 (ESRI 2011. ArcGIS 10. Environmental Systems Research Institute, Redlands, CA) and were ground truthed. All trees, regardless of species, were classified under the same category, because I hypothesized that lesser prairie-chickens would behave similarly to the presence of any tree, regardless of species. Digitized trees ranged in height from 1 m – 20 m. Once all trees were digitized, 10 grids ranging from 1 ha to 100 ha were established to avoid selecting an arbitrary scale to investigate the effect of trees and tree density on the pattern of use by lesser prairie-chickens. Once I developed the grids, I used ArcGIS to count the number of individual trees within each grid cell and then used the count information to generate a density in trees/ha for each cell at each scale.

I used lesser prairie-chicken locations collected through telemetry and satellite GPS data points to assess habitat use relative to the presence and density of trees. Movements allowed me to determine if lesser prairie-chickens use areas relative to the occurrence and density of trees. Locations from females equipped with both VHF and PTT transmitters were uploaded into ArcGIS 10. All locations collected while a female was incubating on the nest were removed from analysis of habitat use, as a separate analysis was conducted using nest locations. In addition, I removed the points one week post-capture to allow for acclimation to transmitters and one week pre-mortality.

I imported all lesser prairie-chicken use points into ArcGIS 10 and then measured the Euclidean distance from each point to the nearest tree (m). In addition, I extracted the value of tree density (trees/ha) from the grid for each point. The elevation (m) and slope (%) for each used point were extracted from a Digital Elevation Model (DEM) accessed from the Kansas Data

Access and Service Center (retrieved July 15, 2014). In addition, the same information was collected at nest locations to identify trends in nest placement in relation to distance to tree, tree densities, elevation, and slope. I selected elevation and slope as potentially important variables because trees tended to be located in drainages and on slopes and I wanted to determine if lesser prairie-chickens were avoiding areas based upon trees or differentially selecting areas with relatively higher elevations and more level slopes.

Statistical Analyses

I used ArcGIS 10 to generate 30,192 random points distributed across the study site to serve as a reference for what was available for use by lesser prairie-chickens. I used 30,192 random points because this was the total number of used points by lesser prairie-chickens before I removed points. I used a *t*-test to compare distance to nearest tree between random points and used points and between random points and nest locations.

To identify the appropriate spatial scale relevant to the lesser prairie-chicken used points and nests in relation to tree densities, I used an information theoretic approach (e.g., AIC_c) to select the scale that is best supported by the data (Boyce 2006). I used the tree densities from different scaled grids to model lesser prairie-chicken use and selected the model with the lowest AIC_c rank and weight (Burnham and Anderson 2002). This prevented me from using an arbitrary scale and allowed use of a scale that was more biologically relevant to lesser prairie-chickens. I evaluated used points and nest sites separately, as I hypothesized nests might be placed using a different scale by female lesser prairie-chickens than would ordinary use.

I used a used/available study design within a resource selection framework to test for habitat selection (Manly et al. 1992, Boyce et al. 2002). To avoid any potential correlation issues among tree location, elevation, and slope, I standardized all points by taking the value, subtracting the mean, and dividing by the standard deviation for all values in the data set (i.e. *z*-score; Allred et al. 2011). I used a logistic regression to compare used points to available points, using the standardized values for each variable (Manly et al. 2002, Allred et al. 2011). I used models developed *a priori* and based upon the initial hypotheses relating to distance to trees (m), tree density (trees/ha), a quadratic tree density function (density^2), elevation (m), and slope (%). I tested a global model that included all of the covariates (i.e., distance to tree, tree density, a quadratic tree density function, elevation, and slope). Last, I tested a null model where no covariates were tested. I did not evaluate distances to other structures and microhabitat characteristics because I was interested in exploring lesser prairie-chicken use strictly in relation to trees and tree densities. All statistical analyses were conducted using Program R (R core development team, version 3.0.1, 2013, Vienna, Austria).

To identify the threshold of use, I used the following logistic regression function:

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

to generate probability of use curves. Where use was approximately equal to zero I assigned as the threshold where use ceased for density and distance to nearest tree. I used the same function for nesting and use points.

To detect if the factors of interest affected nest survival, I used the nest survival model within Program MARK to estimate daily nest survival (White and Burnham 1999, Dinsmore et al. 2002). I used tree density (trees/ha), distance to tree (m), slope (%), and elevation (m) as individual covariates.

Results

I captured 58 female lesser prairie-chickens in the Kansas Red Hills during the springs of 2013 and 2014. Combining the VHF data and the PTT data, I had >30,000 points available for analysis; however, I removed locations while females were at the nest and one week post-capture and one week pre-mortality for a total of 28,702 locations. Used points were located at distances ~ twice as far from trees than random points (use: 282.5 m ± SE 0.96, random: 128.9 m ± 0.77, $t_{57401} = 296.6$, $P < 0.0001$). I located and monitored 60 nests over the two years of the study. In addition, I found 3 destroyed nests and included these nests in the nest location analysis, but were excluded from nest survival analyses (total nest N = 63). Nests were monitored at greater than twice the distance from trees than were randomly generated points (nest: 292.7 m ± SE 0.96, random point: 131.8 m ± 0.77, $t_{736} = 30.13$, $P < 0.0001$). The scale with the lowest AIC_c value selected for tree density in relation to lesser prairie-chicken use points was 400 m x 400 m (16 ha grid cells; Table 4.1). In contrast to the lesser prairie-chicken used points, factors influencing nest sites were best analyzed at a scale using 600 m x 600 m grid cells (36 ha; Table 4.2).

I used 15 models to test my hypotheses in relation to tree density, distance to nearest tree, elevation, and slope. The highest ranked model that fit the location data was the global model for both used points and nest sites (Tables 4.3, 4.4). The global model included distance to nearest tree, tree density, a quadratic function of tree density, elevation, and slope. The ranking of the models for both used points and nest sites indicated that tree density and distance to the nearest tree are important factors in lesser prairie-chicken habitat selection (Tables 4.3 and 4.4).

The beta estimates for coefficients for the global model indicate relative influence of probability of habitat use. The sign (±) of the coefficient beta estimates indicate positive or negative relationships with habitat factors (Allred et al. 2011). Lesser prairie-chicken use patterns showed a strong negative relationship with tree densities than available (Table 4.4, Figure 4.2). Lesser prairie-chickens are six times more likely to use habitats with tree densities of

0 trees/ha, than habitats with 5 trees/ha (Figure 4.3). Lesser prairie-chickens were more likely to use areas as distance to nearest tree increased (Table 4.4). Probability of use indicates lesser prairie-chickens are five times more likely to use habitats 600 m from the nearest tree when compared to using habitats 0 m from the nearest tree (Figure 4.4). Lesser prairie-chicken use had a positive relationship with elevation (Table 4.4). Slope did not influence lesser prairie-chicken habitat selection (Table 4.4).

Lesser prairie-chickens did not place nests within habitats with >2 trees/ha (Figure 4.5, Table 4.5). Nests had a strong negative relationship with tree density (Table 4.6). The probability of a lesser prairie-chicken placing a nest habitat with 0 trees/ha was seven times greater than placing a nest in habitats with 2 trees/ha (Figure 4.6). Nests had a positive relationship with increasing distance to tree (Table 4.6). The probability of lesser prairie-chickens placing nests 1200 m away from the nearest nest was two times greater than a nest being placed 400 m from the nearest tree (Figure 4.7). Nests had positive relationship with elevation (Table 4.6). Slope was not an important predictor of nest sites (Table 4.6).

With the covariates tested for nest survival, there were 7 competing models, indicating that there was no clear cut predictor of nest survival among the factors investigated (Table 4.7). The best predictor of nest survival (of the covariates tested) was elevation, followed by slope (Table 4.7). Nest survival increased with increasing slope (β_{Slope} = 0.067, SE = 0.081); whereas nest survival decreased with increasing elevation ($\beta_{\text{Elevation}}$ = -0.020, SE = 0.016). Nest survival was not impacted by tree density at the low densities where lesser prairie-chickens nested (β_{Density} = 0.096, SE = 0.452; Figure 4.8). Additionally, distance to tree did not have an effect on nest survival ($\beta_{\text{Distance to tree}}$ = -0.413E-3, SE = 0.991E-3).

Discussion

My research indicated that (1) trees are located farther from use points and nest sites than would be expected at random and lesser prairie-chickens avoided trees within the landscape, (2) nest sites are selected to avoid trees and nest survival was not affected by tree densities and distance to nearest tree, and (3) there is a threshold where lesser prairie-chicken cease use and will not place nests. Trees within grassland landscapes within the Southern Great Plains affect lesser prairie-chicken habitat use and this has conservation implications for the species. Given that lesser prairie-chickens are listed as threatened and management actions are being taken, this research has positive implications for grassland conservation.

Lesser prairie-chickens avoided trees. The probability of use increases as tree densities decreased. In addition, the probability of use increases as distance from the nearest tree increased. A negative relationship with trees has consequences for lesser prairie-chicken habitat. Tree encroachment has been implicated as a source of habitat loss and fragmentation for lesser prairie-chickens (Fuhlendorf et al. 2002). The findings of this research confirm that lesser prairie-chickens avoid trees and trees are a source of habitat loss and fragmentation, especially within the Red Hills region of Kansas and Oklahoma. Tree encroachment, especially by junipers, has been implicated in population declines and habitat loss for another lek-mating species of grouse. Greater sage-grouse (*Centrocercus urophasianus*) lek activity has been shown to decline with increasing juniper canopy cover, which has reduced the amount of shrub-land available to greater sage-grouse (Baruch-Mordo et al. 2013). The configuration of the juniper stands had a negative effect on lek placement and lek persistence; where junipers were more clustered, leks were more likely to persist (Baruch-Mordo et al. 2013). Trees reduce habitat for lesser prairie-chickens because they select habitats with lower tree densities.

Lesser prairie-chicken nests were placed at greater distances from trees than would be expected at random and female lesser prairie-chickens selected nesting sites with lower tree densities. Nest site selection follows the same pattern as use, however at a different scale. Nest sites were selected at a larger scale than used points. The difference in scale between nest locations and used locations indicates that nest sites are selected based on landscape characteristics at larger scales than normal activities. Nest sites and used points exhibited similar patterns aside from the differences in scale for tree densities. Because lesser prairie-chicken females spend a great deal of time at the nest (~ 25 days of incubation) and reproductive success is an important demographic driver for prairie grouse (Bergerud 1988). Nest sites may be selected to reduce the risk of predation by selecting landscapes with tree densities ≤ 2 trees/ha at a larger scale than their normal activities. Nest survival was not affected by tree densities ≤ 2 trees/ha. Nest survival could not be affected by tree densities ≥ 2 trees/ha, because nests were not found in habitats with ≥ 2 trees/ha. The threshold where lesser prairie-chickens no longer nest is 2 trees/ha.

One potential reason for avoidance of trees is predator avoidance. When trees encroach into grasslands, new trees provide additional perches for raptors (Reinert 1984, Widén 1994); lesser prairie-chickens could alter their behavior in response to additional perch sites for raptors. In addition to avian predators, lesser prairie-chickens also have mammalian predators, such as coyotes. In two separate studies in southwest Oklahoma and northeast Colorado, coyotes were observed more often than would be expected in pinyon-juniper forests and savannah-type habitats, but less than expected in open grassland habitats (Litvaitis and Shaw 1980, Gese et al. 1988). Lesser prairie-chickens could be avoiding habitats with tree encroachment to avoid predation by avian and mammalian predators that are more likely to use tree encroached areas.

Lesser prairie-chickens could simply be avoiding foreign vertical structures that are present on the landscape. Avoidance of non-tree structure has also been observed in grouse species. Lesser prairie-chickens have shown avoidance of power lines (Pruett et al. 2009a). Additionally, greater prairie-chickens (*Tympanuchus pallidicintus*) have altered home ranges in relation to wind power development and showed avoidance behavior around wind turbines (Winder et al. 2014). Avoidance of trees could be a behavioral response by lesser prairie-chickens in relation to foreign vertical structure within grasslands.

Trees in grasslands alter lesser prairie-chicken habitat and avoidance of trees may be a response to a reduction in habitat quality. Trees alter the composition from warm season (C4) grasses to cool season grasses (C3) and finally in a closed canopy or directly below trees (Gehring and Bragg 1992). Trees, specifically eastern red cedar, reduce the canopy biomass by 83% (Smith and Stubbendieck 1990). Lesser prairie-chickens require cover for nests and forb cover for brood rearing (Hagen et al. 2004). However, given that lesser prairie-chickens are selecting areas at such great distances from trees on average, it seems unlikely that trees are altering habitat at the same scale as lesser prairie-chickens are selecting habitat.

Because prairie grouse, including the lesser prairie-chicken, have been identified as a surrogate species for grasslands (Svedarsky et al. 2000, Poiani et al. 2001, Pruett et al. 2009a), tree removal will have additional benefits for other grassland obligate species. The “threatened” status of lesser prairie-chickens (USFWS 2014) provides an unique opportunity to use management, funding, and conservation actions to restore grasslands through tree removal.

Removing trees would have additional benefits for grassland systems and landowners. For instance, removing trees will increase forage available to cattle, as canopy biomass is reduced by 83% in the presence of eastern red cedar (Smith and Subbendieck 1990). Increasing available forage could increase beef production. Removing trees from grasslands increases the amount of water flowing into streams and ponds. The increase in trees within the southern Great Plains has decreased water flows as tree encroachment has continued over past decades (Wilcox and Thurow 2006, Wilcox et al. 2008). Increasing stream flow is desirable, as water is a scarce resource in many regions in the southern Great Plains.

In addition to benefits to humans, removing trees will have many positive effects on grassland species. For instance, in Oklahoma plant and small mammal communities shifted toward grassland communities following tree removal (Alford et al. 2012). Grassland songbirds have experienced large declines since the 1960s (Peterjohn and Sauer 1999, Brennan and Kuvlesky 2005). One threat to grassland birds is tree encroachment. Birds associated with grassland habitats decrease in abundance with increasing juniper canopy cover (Chapman et al. 2004). In addition, overwintering communities in juniper encroached areas shift towards forest dwelling species (Coppedge et al. 2001b). Removing trees, especially junipers like eastern red cedars can benefit many grassland birds, in addition to benefitting the threatened lesser prairie-chicken. Removing trees can begin the restoration of grasslands and the associated communities and benefit landowners in the process.

Management Implications

Given the current threatened status of lesser prairie-chickens (USFWS 2014), trees and tree removal should have implications for lesser prairie-chicken conservation efforts. Targeting tree removal efforts in regions already occupied by lesser prairie-chickens should improve habitat quality and increase habitat occupancy for lesser prairie-chickens over time. Expanding tree removal from core lesser prairie-chicken habitats will allow for dispersal into unoccupied habitats. Removing trees at larger scales to improve and restore grasslands for lesser prairie-chickens. Hagen et al. (2004) suggest that lesser prairie-chickens require ≥2,000 ha of continuous grassland habitats. Removing trees at larger scales around already established populations will allow for persistence and expansion of current lesser prairie-chicken populations. Prescribed fire can be used as a tool to keep trees from grasslands and prevent young trees from taking hold.

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Table 4.1 Rank order of models compared to identify the appropriate scale for evaluation of the relationship between tree densities (trees/ha) and female lesser prairie-chicken used points in Kiowa and Comanche counties in the Red Hills region of south-central Kansas during 2013 and 2014 based on grids established using 100 m x 100 m cells (1 ha), 200 m x 200 m (4 ha), up to 1000 m x 1000 m (100 ha).

Grid Size	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
16 ha	64576	2	0.0[e]	1
36 ha	65440	2	864.2	<0.001
9 ha	65973	2	1396.3	<0.001
25 ha	66161	2	1585	<0.001
1 ha	66483	2	1906.7	<0.001
64 ha	68981	2	4404.3	<0.001
49 ha	69211	2	4634.5	<0.001
100 ha	69483	2	4906.9	<0.001
81 ha	69493	2	4916.9	<0.001
4 ha	70098	2	5521.3	<0.001
Null[f]	83710	2	19131.7	<0.001

a. Deviance
b. Number of parameters
c. Differences in Akaike's Information Criterion, corrected for a small sample size.
d. Akaike weights.
e. Minimum AIC_c =
f. Null model compared used and random locations with no covariates.

Table 4.2 Rank order of models compared to identify the appropriate scale for evaluation of the relationship of tree densities (trees/ha) to female lesser prairie-chicken nest points in Kiowa and Comanche counties in the Red Hills region of south-central Kansas during 2013 and 2014 based on grids established using 100 m x 100 m cells (1 ha), 200 m x 200 m (4 ha), up to 1000 m x 1000 m (100 ha).

Grid Size	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
36 ha	799.4	2	0[e]	1
100 ha	815.6	2	16.2	<0.001
25 ha	817.3	2	17.9	<0.001
9 ha	820.2	2	20.8	<0.001
49 ha	823.7	2	24.3	<0.001
16 ha	825.4	2	26	<0.001
64 ha	833.6	2	34.2	<0.001
81 ha	837.1	2	37.7	<0.001
1 ha	854.8	2	55.3	<0.001
4 ha	861.2	2	67.8	<0.001
Null[f]	903.8	2	102.4	<0.001

a. Deviance
b. Number of parameters
c. Differences in Akaike's Information Criterion, corrected for a small sample size.
d. Akaike weights.
e. Minimum AIC_c = 803.4
f. Null model compared used and random locations with no covariates.

Table 4.3 Rankings of models to test relative influence of factors (tree density (trees/ha; using previously selected scale (16 ha)), distance to nearest tree (Dist. Tree; m), elevation above sea level (Elevation; m), and slope (%)) in determining use patterns for female lesser prairie-chickens in Kansas during 2013 and 2014.

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
Global[e]	159079	6	0	1[f]
Density + Dist. Tree	166940	3	2250.5	<0.001
Density + Slope + Elevation	159557	4	5767.7	<0.001
Density + Elevation	165246	3	5875.8	<0.001
Density + Slope	160258	3	9346.5	<0.001
Density + Density squared	168680	3	9382.8	<0.001
Density	168758	2	9732.5	<0.001
Dist. Tree + Elevation	178645	3	12081.2	<0.001
Dist. Tree + Slope + Elevation	173739	4	12081.5	<0.001
Dist. Tree + Slope	173746	3	14397.3	<0.001
Dist. Tree	178941	2	14421.1	<0.001
Slope + Elevation	174903	3	23364.1	<0.001
Elevation	179009	2	23627.3	<0.001
Slope	175091	2	28156.2	<0.001
Null[g]	179117	1	28839.3	<0.001

a. Deviance

b. Number of parameters

c. Differences in Akaike's Information Criterion, corrected for a small sample size.

d. Akaike weights.

e. Global model included Density, a quadratic function of Density, Dist. Tree, slope, and elevation.

f. Minimum AIC_c = 159091

g. Null model compared used and random locations with no covariates.

Table 4.4 Estimates of resource selection function beta estimates, standard errors, *z* values, and probabilities for the top model (global model) selected using AIC$_c$ to rank models for female lesser prairie-chicken use patterns in Kansas during 2013 and 2014. Coefficients included tree density (trees/ha), a quadratic function of tree density ((Density)^2), distance to nearest tree (m), elevation (m), and slope (%).

Coefficients	Estimate	Standard Error	z value	Pr >|z|
Intercept	-0.81279	0.02079	-39.09	<0.001
Density	-5.01564	0.07916	-63.359	<0.001
(Density)^2	2.64188	0.05575	47.392	<0.001
Dist. Tree	0.92939	0.01397	66.515	<0.001
Elevation	0.53415	0.01244	42.927	<0.001
Slope	0.01155	0.01102	1.048	0.295

Table 4.5 Rankings of models to test relative influence of factors (tree density (trees/ha; using previously selected scale (36 ha)), distance to nearest tree (Dist. Tree; m), elevation above sea level (Elevation; m), and slope (%)) in determining nesting patterns for female lesser prairie-chickens in Kansas during 2013 and 2014.

Model	Dev.[a]	K[b]	ΔAIC_c[c]	w_i[d]
Global[e]	713.4	6	0[f]	0.953
Density + Density squared	725.4	3	6.0	0.047
Density + Dist. Tree	760.3	4	40.8	<0.001
Density + Elevation	782.4	3	63.0	<0.001
Density + Slope + Elevation	781.9	3	64.5	<0.001
Density	799.4	3	78.0	<0.001
Density + Slope	797.5	2	78.1	<0.001
Dist. Tree + Elevation	836.2	3	116.8	<0.001
Dist. Tree + Slope + Elevation	844.2	4	118.8	<0.001
Dist. Tree	846.7	3	125.3	<0.001
Dist. Tree + Slope	846.5	2	127.0	<0.001
Elevation	884.0	3	162.6	<0.001
Slope + Elevation	882.7	2	163.2	<0.001
Slope	900.5	2	179.0	<0.001
Null[g]	903.8	1	180.4	<0.001

a. Deviance

b. Number of parameters

c. Differences in Akaike's Information Criterion, corrected for a small sample size.

d. Akaike weights.

e. Global model included Density, a quadratic function of Density, Dist. Tree, slope, and elevation.

f. Minimum AIC_c = 725.4

g. Null model compared used and random locations with no covariates.

Table 4.6 Estimates of resource selection function beta estimates, standard errors, *z* values, and probabilities for the top model selected using AIC_c to rank models for female lesser prairie-chicken nest location patterns in Kansas during 2013 and 2014. Coefficients included tree density (trees/ha), a quadratic function of tree density ($(\text{Density})^2$), distance to nearest tree (m), elevation (m), and slope (%).

Coefficients	Estimate	Standard Error	z value	Pr >|z|
Intercept	-40.29205	11.52701	-3.495	<0.001
Density	-10.22321	2.12843	-4.803	<0.001
$(\text{Density})^2$	-122.94848	47.92187	-2.566	0.010
Dist. Tree	0.22850	0.08293	2.756	<0.001
Elevation	0.35988	0.18178	1.980	0.048
Slope	0.06224	0.14802	0.420	0.674

Table 4.7 Model ranking for nest survival models using the covariates of elevation (m), slope (%), distance to nearest to tree (m), and tree density (trees/ha) for breeding female lesser prairie-chickens in Kansas during 2013 and 2014.

Model	ΔAIC_c	K	w_i
Elevation	0.0000	2	0.18307
Slope	0.8757	2	0.11816
Distance to Tree	1.416	2	0.09019
Density	1.5426	2	0.08465
Elevation + Slope	1.6849	3	0.07884
Distance to Tree + Elevation	1.7687	3	0.07561
Density + Elevation	1.8772	3	0.07161
Distance to Tree + Quadratic Distance to Tree	2.1559	3	0.0623
Distance to Tree + Slope	2.847	3	0.0441
Density + Slope	2.8541	3	0.04394
Density + Quadratic Density	2.9584	3	0.04171
Distance to Tree + Density	3.3985	3	0.03347
Elevation + Slope + Distance to Tree	3.5825	4	0.03053
Elevation + Slope + Density	3.6001	4	0.03026
Elevation + Slope + Distance to Tree + Density	5.5229	5	0.01157

a. Differences in Akaike’s Information Criterion, corrected for a small sample size.

b. Number of parameters

c. Akaike weights.

Figure 4.1 Study site location for evaluating the response of lesser prairie-chickens to the occurrence of trees in Kiowa and Comanche counties within the Red Hills region of south-central Kansas during 2013 and 2014.

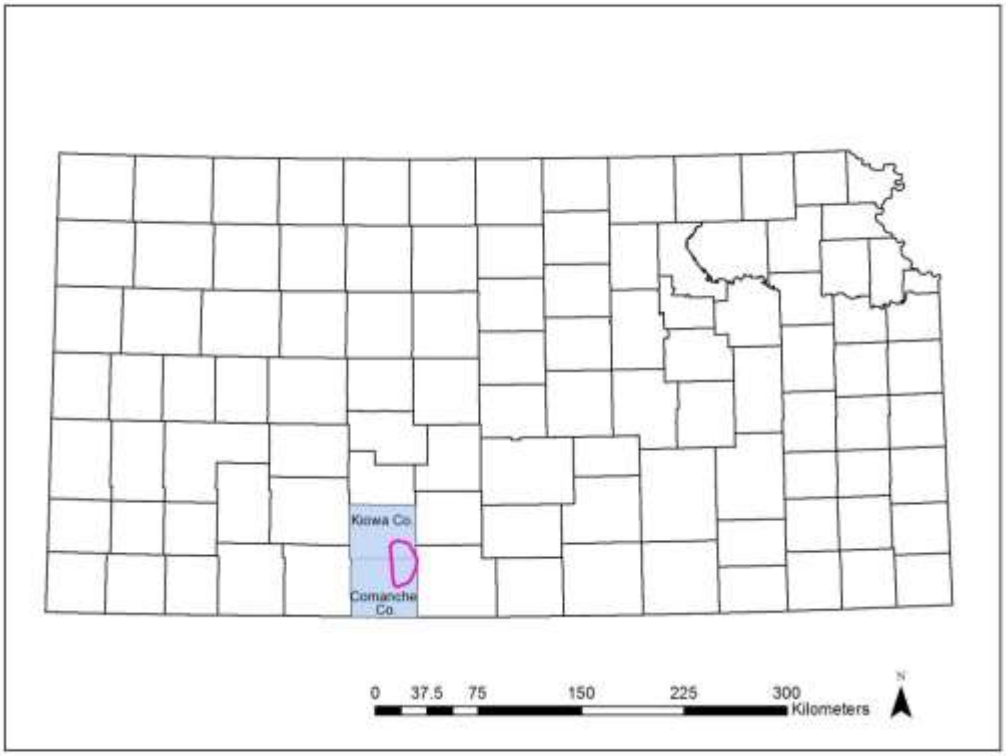

Figure 4.2 Comparison of the proportion of used points of lesser prairie-chicken females against the proportion of available tree densities at the scale of 16 ha in Kiowa and Comanche counties within the Red Hills region in south-central Kansas during 2013 and 2014.

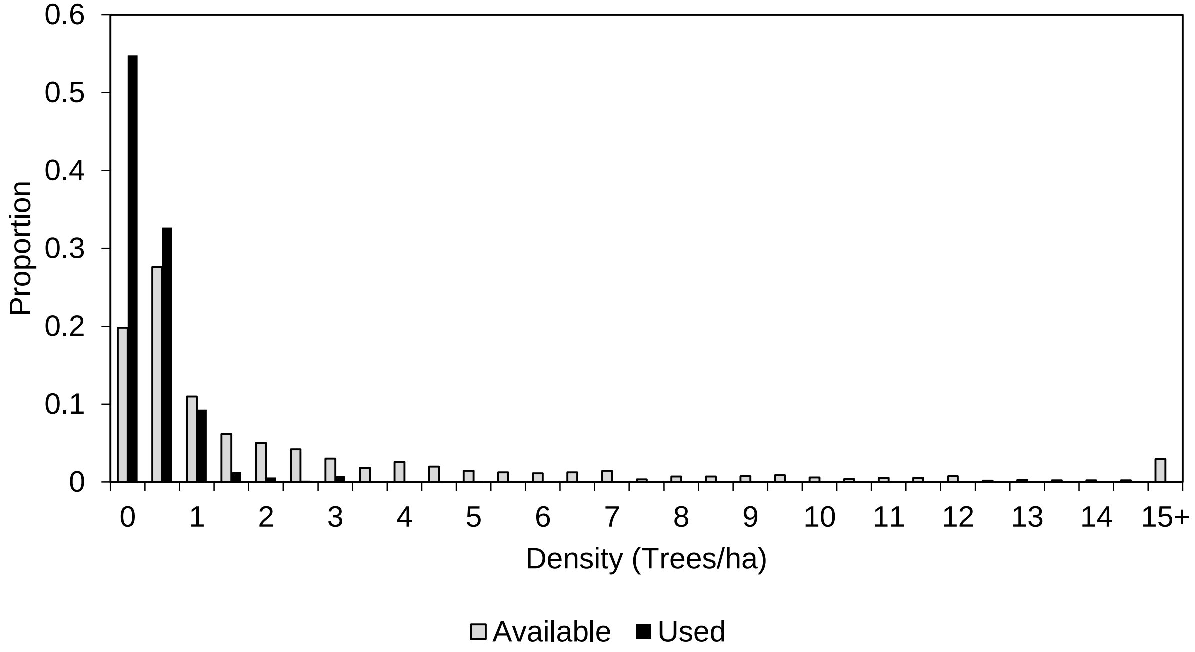

Figure 4.3 Probability of use for lesser prairie-chickens in relation to tree densities (trees/ha) in the Red Hills region of south-central Kansas during 2013 and 2014. Shown with 95% confidence intervals.

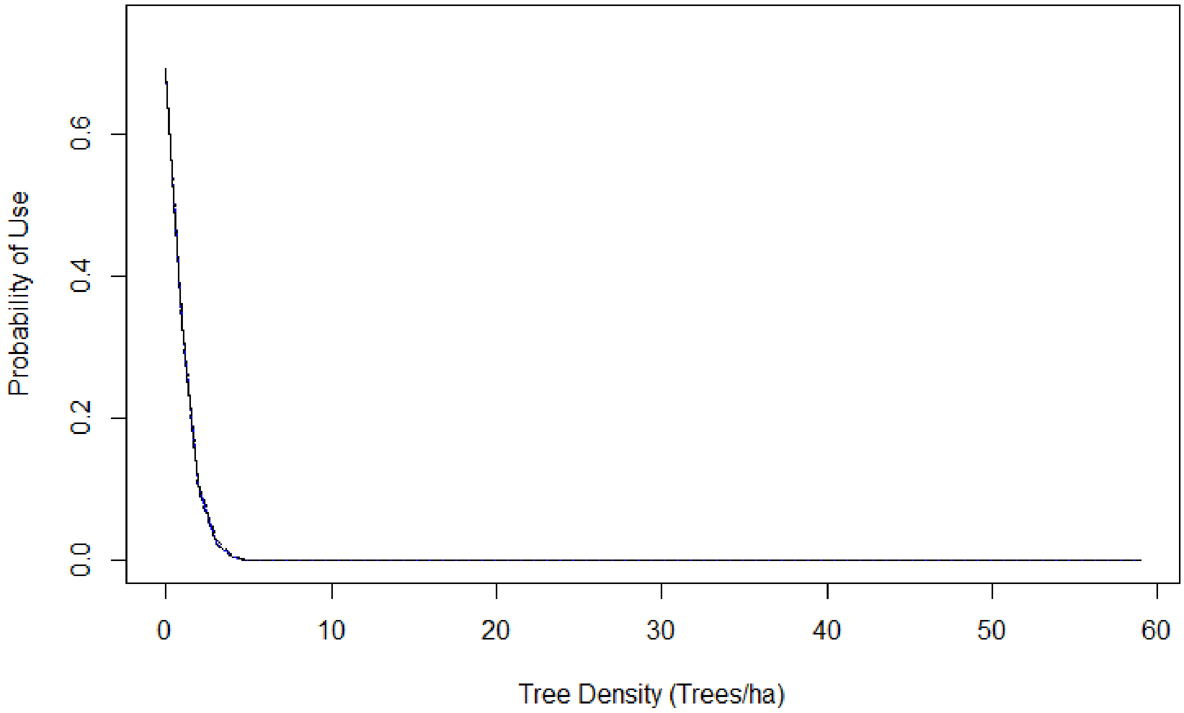

Figure 4.4 Probability of use for lesser prairie-chickens in relation to distance to the nearest tree (m) in the Red Hills region of south-central Kansas during 2013 and 2014. Shown with 95% confidence intervals.

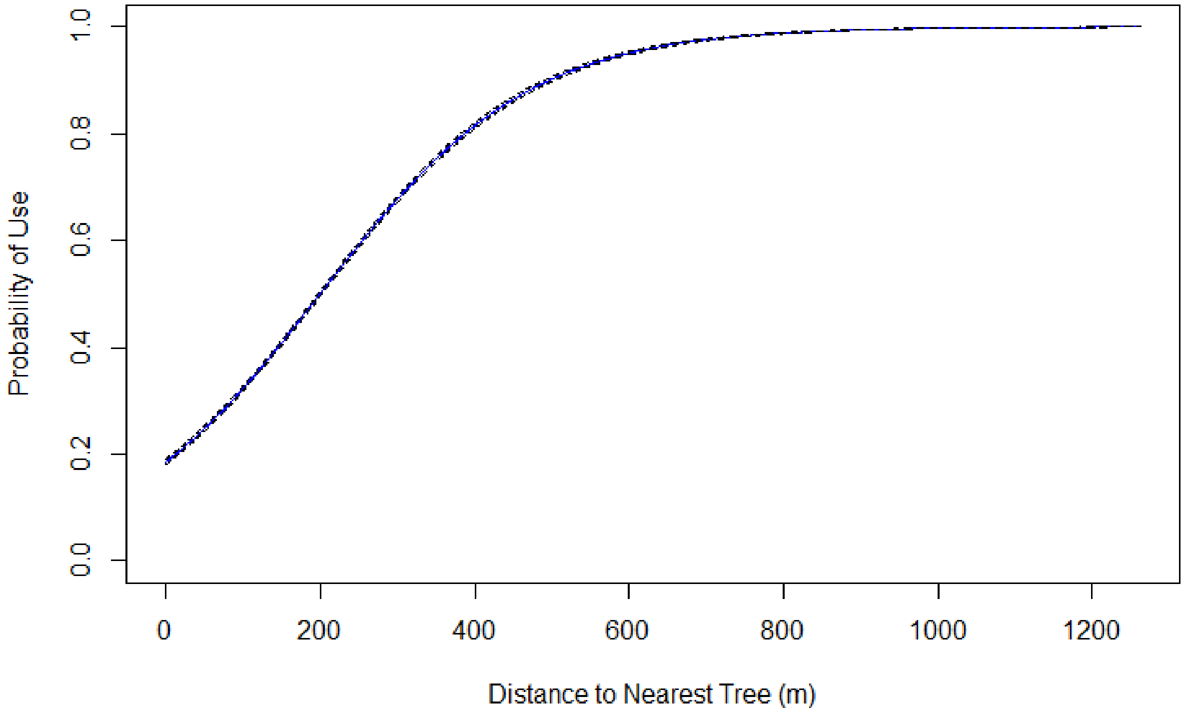

Figure 4.5 Comparison of the proportion of nest locations of lesser prairie-chickens against the proportion of available tree densities at the scale of 36 ha in Kiowa and Comanche counties within the Red Hills region in south-central Kansas during 2013 and 2014.

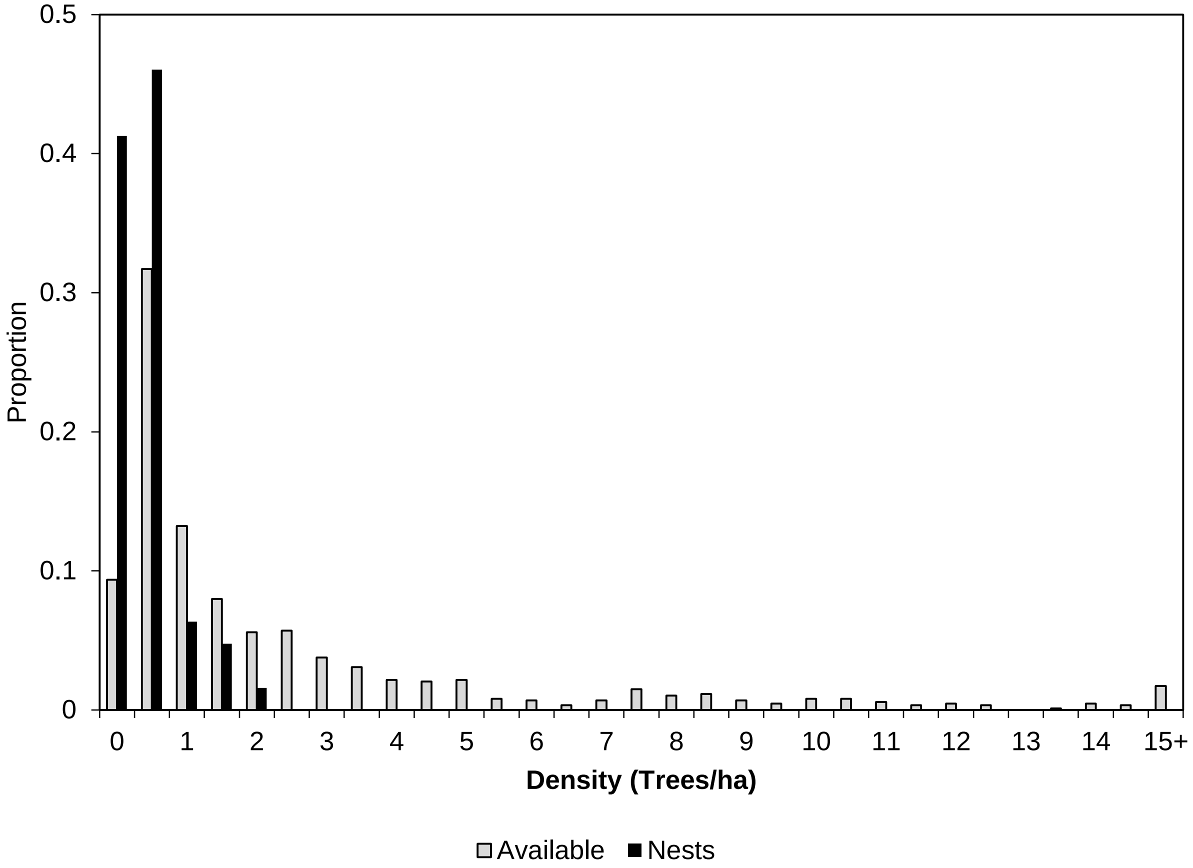

Figure 4.6 Probability of use for nests of lesser prairie-chicken in relation to tree densities (trees/ha) within Kiowa and Comanche counties within the Red Hills region in south-central Kansas during 2013 and 2014. Shown with 95% confidence intervals.

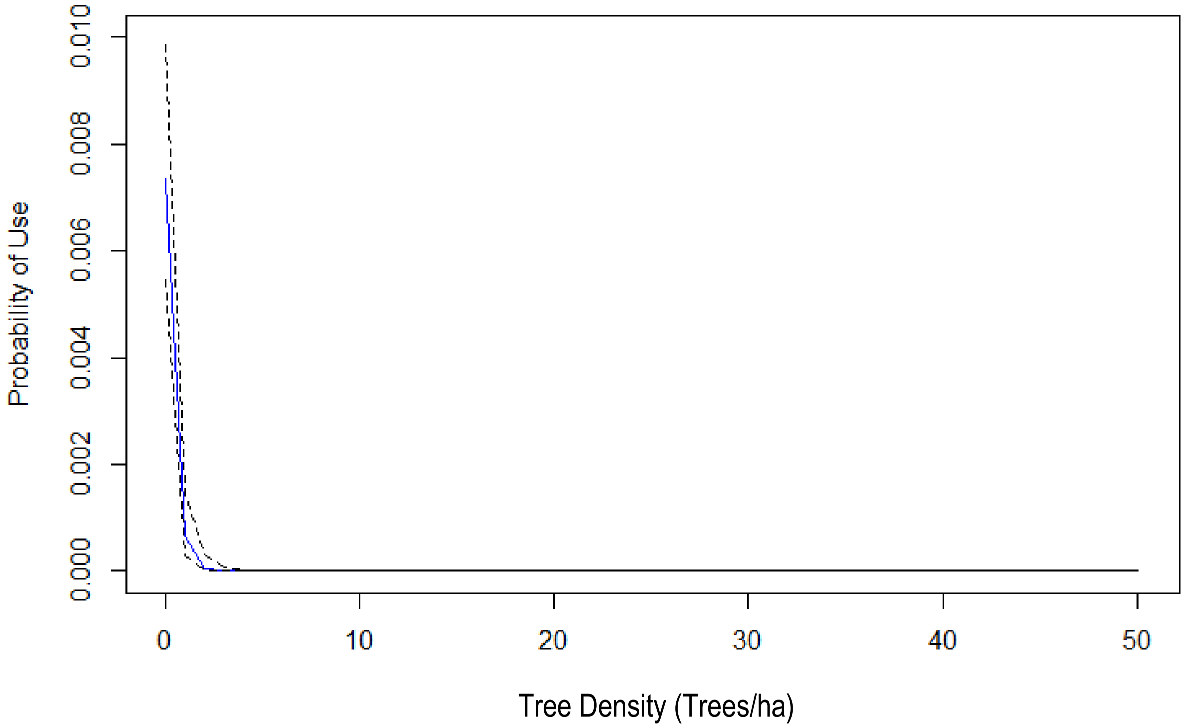

Figure 4.7 Probability of use for nests of lesser prairie-chicken in relation to the distance to the nearest tree (m) within Kiowa and Comanche counties within the Red Hills region in south-central Kansas during 2013 and 2014. Shown with 95% confidence intervals.

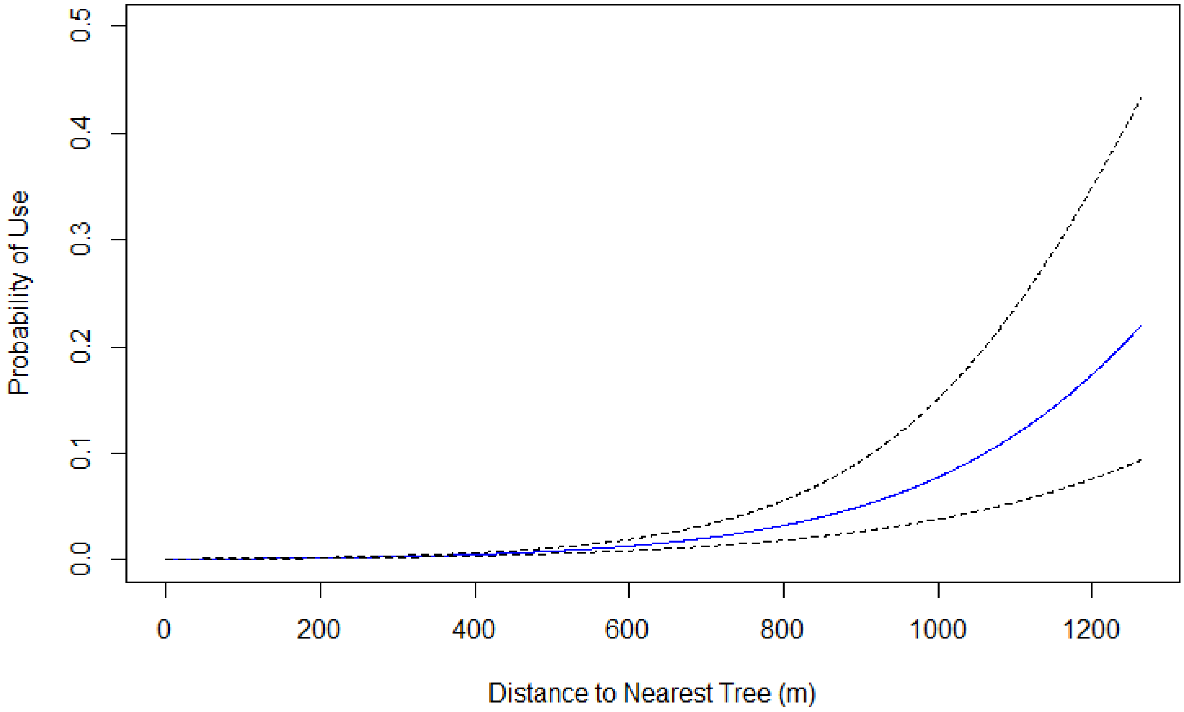

Figure 4.8 Daily survival of lesser prairie-chicken nests in relation to tree density (95% confidence intervals displayed) in Kiowa and Comanche counties, within the Red Hills region of south-central Kansas during 2013 and 2014. From the nest survival model from Program MARK.