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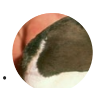

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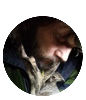

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Research Article

Lesser Prairie-Chicken Fence Collision Risk Across Its Northern Distribution

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ABSTRACT Livestock fences have been hypothesized to significantly contribute to mortality of lesser prairie-chickens (*Tympanuchus pallidicinctus*); however, quantification of mortality due to fence collisions is lacking across their current distribution. Variation in fence density, landscape composition and configuration, and land use could influence collision risk of lesser prairie-chickens. We monitored fences within 3 km of known leks during spring and fall and surveyed for signs of collision occurrence within 20 m of fences in 6 study sites in Kansas and Colorado, USA during 2013 and 2014. We assessed mortality locations of radio-tagged birds ($n = 286$) for evidence of fence collisions and compared distance to fence relative to random points. Additionally, we quantified locations, propensity, and frequency of fences crossed by lesser prairie-chickens. We tested for landscape and vegetative characteristics that influenced fence-cross propensity and frequency of global positioning system (GPS)-marked birds. A minimum of 12,706 fence crossings occurred by GPS-marked lesser prairie-chickens. We found 3 carcasses and 12 additional possible instances of evidence of collision during >2,800 km of surveyed fences. We found evidence for a single suspected collision based on carcass evidence for 148 mortalities of transmittered birds. Mortality locations of transmittered birds were located at distances from fences 15% farther than expected at random. Our data suggested minimal biological significance and indicated that propensity and frequency of fence crossings were random processes. Lesser prairie-chickens do not appear to be experiencing significant mortality risk due to fence collisions in Kansas and Colorado. Focusing resources on other limiting factors (i.e., habitat quality) has greater potential for impact on population demography than fence marking and removal.

KEY WORDS Colorado, fences, Kansas, lesser prairie-chicken, management, mortality, *Tympanuchus pallidicinctus*.

Conservation strategies to reduce mortality and abate population declines are fundamental to maintain or recover vulnerable species (Tuttle 1979, Weimerskirch et al. 1997, Battin 2004). However, identifying definitive factors that threaten population growth can be difficult. Further, the relative impacts of identified factors may vary among sub-populations, requiring a multi-scale threat assessment (Frank and Wissel 1998, Margules and Pressey 2000, Stevens et al. 2013). Assuming uniformity of potential limiting factors across a species distribution can result in misguided application of management actions, and may hinder conservation efforts for imperiled species (Stem et al. 2005). If management actions are not targeted effectively, declining populations will remain on current downward trajectories.

The lesser prairie-chicken (*Tympanuchus pallidicinctus*), a species of prairie-grouse in the Southern Great Plains, has experienced severe population declines since the early 1900s. Several studies have sought to identify risk factors to the species (Woodward et al. 2001, Fuhlendorf et al. 2002, Patten et al. 2005, Haukos and Boal 2016). Range-wide declines have been associated with the loss of habitat quantity and quality resulting from conversion of native prairie to cropland, energy development, invasive species,

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and unmanaged grazing (Crawford and Bolen 1976, Taylor and Guthery 1980, Hagen et al. 2004). The current legal status of the lesser prairie-chicken is uncertain given that the May 2014 listing of the species as threatened under the Endangered Species Act was vacated by a federal judge in September 2015 on procedural grounds (U.S. Fish and Wildlife Service 2014; Permian Basin Petroleum Association et al. v. Department of Interior, U.S. Fish and Wildlife Service, [Case 7:14-cv-00050-RAJ, U.S. District Court, Western District of Texas, Midland-Odessa Division]). However, threats to population persistence continue, necessitating identification of factors influencing population demography of lesser prairie-chickens.

A factor suggested as posing a substantial risk to lesser prairie-chicken populations is collisions with livestock fences (Patten et al. 2005; Wolfe et al. 2007, 2009). Lesser prairie-chickens are a relatively low flying bird and have the potential to collide with fences, especially when birds are flushed or chased by predators. Wolfe et al. (2007) attributed high proportions of mortality to fence collisions in Oklahoma (39.8%) and New Mexico (26.5%). The majority of the mortalities attributed to collision were within 30 m of a fence (Wolfe et al. 2009). However, other studies identifying cause-specific mortality concluded that fence collisions by lesser prairie-chickens are a rare event. A study in Kansas attributed 4% of mortalities to collision, but these were collisions confounded with power lines (Hagen et al. 2007). Additionally, other studies in Texas (Haukos 1988, Kukal 2010, Pirius 2011, Holt 2012, Grisham and Boal 2015), New Mexico (Campbell 1972, Merchant 1982), Kansas (Jamison 2000, Fields 2004), and Oklahoma (Copelin 1963) attributed no mortalities to collisions with fences. The only other published account of significant mortality due to wire collisions was by Ligon (1951) who related an anecdotal account of prairie-chicken mortalities due to telegraph lines along railroad tracks in the mid-1800s.

The concern for lesser prairie-chicken fence collisions is not unfounded because the risk associated with fences has been well documented for multiple species of grouse. Deer fences, which are typically taller than livestock fences, were determined to be an important cause of mortality for red grouse (*Lagopus lagopus scotica*), black grouse (*Lyrurus tetrix*), and capercaillie (*Tetrao urogallus*; Catt et al. 1994, Baines and Andrew 2003). Research on the greater sage-grouse (*Centrocercus urophasianus*) indicated that fence collisions can be an influential cause of mortality, with areas of high mortality localized near leks (Connelly et al. 2000; Stevens et al. 2011, 2013). However, other studies on greater sage-grouse have conflicting findings, with one study reporting only a single possible collision mortality of a transmittered bird (Blomberg et al. 2013). In studies where fence collisions were considered a significant source of mortality for prairie-grouse, increased risk of fence-related mortality appears to be associated with decreased distance to lek, greater fence density, and areas of heavy use, such as greater elevation and decreased topographic ruggedness (Wolfe et al. 2007; Stevens et al. 2012*a*,*b*). Therefore, assessing the variation in collision risk for lesser prairie-chickens in relation to specific risk factors is needed to facilitate prioritization of fences and targeting of mitigation efforts in high risk areas, maximizing the return on expended resources (Stevens et al. 2013).

Currently, population-level effects of fence collisions on lesser prairie-chicken are unknown. Understanding the spatial variation of fence collisions by lesser prairie-chickens is needed to inform conservation efforts on the relative influence of potential sources of mortality. We hypothesized that fence collision risk to lesser prairie-chickens varies over broad spatial scales. We assessed the occurrence of fence-related mortality of lesser prairie-chickens at 5 study sites of varying landscape characteristics and bird density in the northern portion of the species range in Kansas and Colorado, USA to determine the relative risk of mortality from livestock fences. Our goal was to determine the occurrence, frequency, and distribution of lesser prairie-chicken mortality to identify high-risk fence-collision areas. Our specific objectives were to 1) quantify occurrence of fence-related mortalities, 2) test spatial distribution of mortality locations, 3) quantify fence-cross occurrence as a proxy for collision risk, and 4) determine landscape characteristics influencing fence-cross location and frequency.

STUDY AREA

We quantified evidence for lesser prairie-chicken collisions with livestock fences across 8 counties in 3 study areas, comprised of 6 study sites in Kansas and Colorado (Fig. 1). One study area was located in northwest Kansas (Northwest). One study area was in south-central Kansas (Red Hills and Clark County) and another study area in Colorado was comprised of sites in Prowers, Baca, and Cheyenne counties, Colorado. Temperatures averaged 12°C among all areas and seasons (KState Research and Extension 2015). These study areas cumulatively encompassed 254,727 ha, within which we identified 52 leks. The mean elevation among all study areas was 749 m and ranged from 551 m to 973 m. Our study areas were located in 3 of the 4 lesser prairie-chicken ecoregions: Short-Grass Prairie/Conservation Program Mosaic, Mixed-Grass Prairie, and Sand Sagebrush Prairie (McDonald et al. 2014). Fence density and lek density varied among the study sites (Table 1). Dominant plants included blue grama (*Bouteloua gracilis*), little bluestem (*Schizachyrium scoparium*), side oats grama (*B. curtipendula*), sand dropseed (*Sporobolus cryptandrus*), western ragweed (*Ambrosia psilostachya*), and sand sagebrush (*Artemisia filiafolia*). The primary land uses in all study areas were livestock grazing, oil and gas extraction, Conservation Reserve Program (CRP) grasslands, and irrigated and dryland row-crop agriculture.

The Northwest study area was comprised of 2 study sites in adjoining Logan and Gove counties in Kansas. The Gove County site was approximately 87,000 ha and located entirely on private lands. The Logan county site was approximately 50,000 ha and located on private lands, including the Smoky Valley Ranch, owned and managed by The Nature Conservancy. Leks at these study sites included lesser and

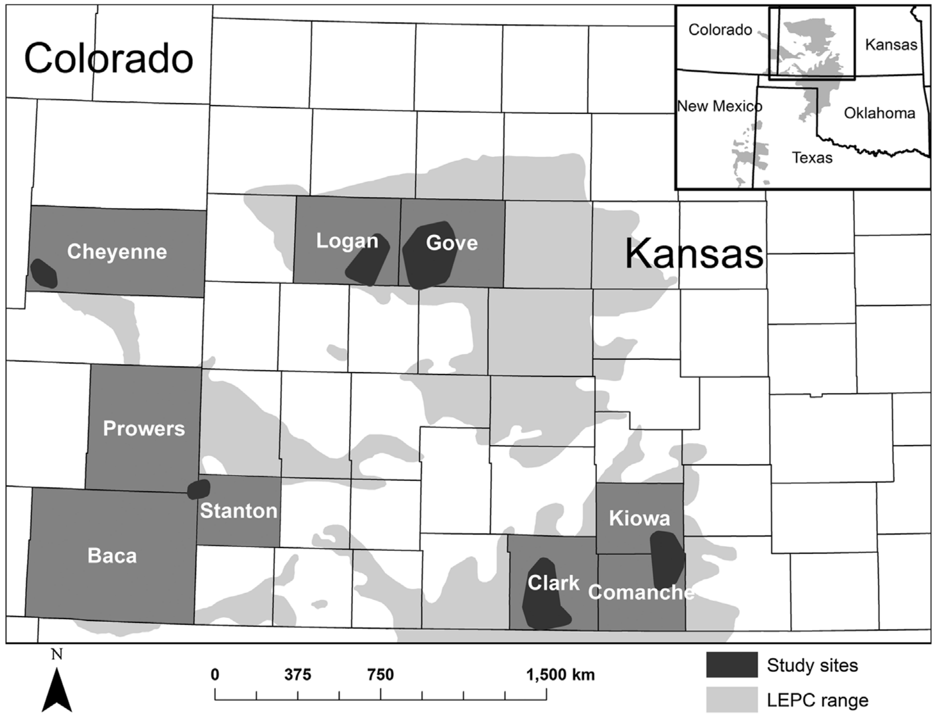

Figure 1. Study sites in Kansas and Colorado, USA in which we walked fences and trapped and monitored lesser prairie-chickens (LEPC) to document collisions during spring 2013 and 2014. Study areas in Kansas included Northwest, with 2 sites in Logan and Gove counties, and South-Central, with 2 sites: Red Hills in Kiowa and Comanche counties and Clark in Clark County. The study area in Colorado contained 2 sites, 1 located in Cheyenne County and another in Prowers and Cheyenne counties, Colorado and Stanton County, Kansas.

greater prairie-chickens (*Tympanuchus cupido*) and a low density of lesser prairie-chicken × greater prairie-chicken hybrids (Bain 2002, McDonald et al. 2014). The South-Central study area was comprised of the Red Hills and Clark County study sites. The Red Hills study site was located on private lands in Kiowa and Comanche counties, Kansas. This study site was approximately 49,000 ha. The Clark County study site was located on private lands in Clark County, Kansas. This study site was approximately 47,500 ha. The study sites in Colorado were primarily located on roughly 28,000 ha of private lands in Cheyenne and Prowers counties and adjacent Stanton County, Kansas but also included portions of the United States Department of Agriculture, Forest Service, Comanche National Grasslands in Baca County, Colorado.

Table 1. Total area, fence density, lek density, number of fence crossings, and number of mortalities of 158 lesser prairie-chickens marked with satellite transmitter attributed to fence collisions for the 4 study sites used to assess mortality due to fence collisions in western Kansas and eastern Colorado, USA, 2013–2014.

Study area	Lek density (no. leks/1,000 ha)	Fence density (km/km^2)	Fence crossings[a]	Fence-related mortalities
Northwest	0.2	1.69	6,696	0
Red Hills	0.2	1.76	2,367	0
Clark County	0.5	1.53	3,578	0
Colorado	0.15	0.81	67	1

[a] Determined by number of successive locations of lesser prairie-chickens tagged by global positioning system satellite transmitters, indicating that a fence was crossed during the movement.

METHODS

Field Methods

Fence surveys.—We delineated and ground-truthed fences in all study sites by hand in ArcGIS 10.0 (Environmental Systems Research Institute, Inc., Redlands, CA, USA). We walked alongside 2-, 3-, 4-, 5-, and 6-strand livestock fences to search for carcasses of birds and other evidence of prairie-chicken collisions 3–4 times each week during spring lekking season (15 Mar–1 Jun) and fall juvenile dispersal and lekking season (15 Aug–1 Nov) in 2013 and 2014. This regimen of fence walking occurred frequently enough to detect most carcasses before removal by scavengers; past studies recommended surveys at intervals of >1/week (Stevens et al. 2011). One or 2 observers walked within 5 m of fences, at a distance of up to 3 km from known leks in each study area. We surveyed each side of the fence visually out to roughly 20 m. We classified observations from fence walking as either evidence of collision or carcass. We considered prairie-chicken feathers on the fence or on the ground within 20 m of the fence evidence of a potential collision. We considered large feather piles or other bird remains on or within 20 m of the fence to be carcasses.

Radio-telemetry.—We trapped lesser prairie-chickens at leks in spring (Mar–May) during 2013 and 2014 using walk-in drift traps (Haukos et al. 1990, Schroeder and Braun 1991), magnetic drop-nets, and rope-trigger drop-nets (Silvy et al. 1990). We marked each individual with a unique band combination using size-4 color bands (Avinet, Dryden, NY, USA) and individually numbered butt-end aluminum bands

(National Band and Tag Company, Newport, KY, USA). We primarily identified the sex of individuals using the presence of air sacs and greater pinnae length in males but also used tail feather color, with females having barred tail feathers and male prairie-chickens having mainly black tail feathers (Copelin 1963).

We tagged female lesser prairie-chickens with 15-g bib-style very-high-frequency (VHF) transmitters (A3960, Advanced Telemetry System, Isanti, MN, USA) or a rump-mounted 22-g satellite platform transmitting terminal (PTT) global positioning system (GPS) transmitter (PTT-100, Microwave Telemetry, Columbia, MD, USA). The VHF transmitters were equipped with a mortality switch, which activated after being motionless for ≥8 hours. We tagged a smaller sample of male lesser prairie-chickens with PTT-GPS transmitters opportunistically after females had stopped attending leks or during fall lek trapping. All capture and handling procedures were approved by the Kansas State University Institutional Animal Care and Use Committee protocol (3241), Kansas Department of Wildlife, Parks and Tourism scientific collection permits (SC-042-2013 and SC-079-2014), and Colorado Parks and Wildlife scientific collection licenses (13TRb2053 and 14TRb2053).

Female lesser prairie-chickens outfitted with VHF transmitters were located via triangulation 3–4 times/week. If individuals could no longer be located because of dispersal from the study area, we attempted to locate them using a fixed-wing Cessna aircraft (Cessna, Wichita, KS, USA). If we heard a mortality signal, we used homing to locate the bird and determine its fate. Birds outfitted with a satellite-PTT transmitter recorded up to 10 GPS positions a day (PTT-GPS) with ±18-m accuracy between the hours of 0600 and 2200. We downloaded points weekly from the Argos satellite system (CLS America, Largo, MD, USA) for locations and mortality assessments. Potential mortalities for birds with PTT-GPS transmitters were based on lack of movement for >1 day, static activity sensor, and temperature sensor readings that fluctuated with ambient conditions. If a bird was determined to have died based on satellite data, we searched within the 50 m area surrounding the indicated point of mortality until we located the transmitter and carcass.

We recovered carcasses of transmittered birds as soon as possible following indication of a mortality. We evaluated the specific cause of mortality. We examined all carcasses for evidence of collision following Wolfe et al. (2007). Once we located the carcass or transmitter, we measured the distance from each mortality to the nearest fence.

Fence-cross estimation.—We estimated the minimum number of fence crosses by transmittered birds using all PTT-GPS-marked lesser prairie-chickens from March 2013 to March 2015. We used only GPS locations because these had the greatest temporal resolution and degree of accuracy. We generated movement tracks using the convert.pointtolines tool in Geospatial Modeling Environment (Beyer 2012), creating a movement track for each bird in the dataset and a line segment for each pair of sequential points within the bird's movement track. We imported movement tracks into ArcGIS 10.0 and overlaid tracks with a delineated fence layer. We considered line segments of the movement tracks that intersected fence lines to have been crossed and selected. We generated intersection locations between line segments of the movement track and delineated fences using the isectfeatures tool in Geospatial Modeling Environment (Beyer 2012). We then summed the number of cross locations for each study area and pooled them across all study areas.

We generated cross locations from straight line trajectories between 2 consecutive locations. Biological organisms, more often than not, do not move in straight-line trajectories. Therefore, we accounted for this error by splitting delineated fences at 100-m intervals. We selected the 100-m interval distance because it was at least double the potential error associated with a point fix of a PTT-GPS transmitter unit (±18 m) and accounted for the variation in cross location that may have occurred during the 2-hr period between locations. We then buffered all cross locations by a 500-m radius. We considered 500 m as the perceived maximum distance a lesser prairie-chicken could decide whether or not to cross a section of fence and where to cross; it was the average distance moved between 2 consecutive locations generated from all PTT-GPS-marked lesser prairie-chickens (R. T. Plumb, Kansas State University, unpublished data). We clipped all 100-m fence sections within the buffer from the original fence layer for each study site. We considered the selected fence sections to be the available fence to cross in any direction. We then determined if the available fence sections were crossed (1) or not (0) and quantified the frequency of crosses within each 100-m fence section.

We collected biological (i.e., distance to nearest lek and cover type) and topographical characteristics at the midpoint of each 100-m fence section in each study site. We calculated the Euclidean distance to nearest lek using the Near tool in ArcGIS 10.0. Because livestock fences often occur on the boundaries of grazed grassland, different cover types sometimes occur on either side, especially in more fragmented and disturbed landscapes. Differences between cover types along fences may be a factor influencing an animal's propensity to cross a fence. For example, lesser prairie-chickens feed in agriculture fields (Crawford and Bolen 1976) and may cross fences between grassland and crop fields as they move from roost to feeding sites. Therefore, we categorized each fence section mid-point into 6 different cover type categories: grass–grass ($n = 1{,}714$), grass-CRP ($n = 318$), grass–crop ($n = 831$), CRP–CRP ($n = 17$), CRP-crop ($n = 8$), and crop–crop ($n = 21$). We used the Playa Lakes Joint Venture landcover classification layer to assign fence section mid-points into the proper cover type category (Playa Lakes Joint Venture 2009). We extracted topographical data (e.g., slope [%], elevation [m]) from a digital elevation model (DEM) accessed from the Kansas Data Access and Service Center (retrieved 26 Jul 2015) and the United States Geological Survey's National Map website (retrieved 23 Sep 2015). We measured topographic heterogeneity using the terrain ruggedness index (Riley et al.

1999, Stevens et al. 2012*a*) calculated from the 30-m DEMs. We tested for multicollinearity among numeric variables using condition indices and variance decomposition rates as described by Belsley et al. (1980) where condition indices ≥30 coupled with ≥2 variables with variance decomposition proportions >50% indicate that those variables may be causing collinearity problems. If collinearity was indicated between variables, we investigated further and removed redundant variables when necessary.

Statistical Methods

We distributed an average of 250 random points within each study area and measured the distance from each random point to the nearest fence. Four points occurred in water in the Northwest study area and we removed them from the data set. We considered the average distance from random points to a fence to be expected if mortalities occurred at random in the landscape. We compared the average distance to fence for observed mortalities of transmittered lesser prairie-chickens to the average of random points within and across study areas with a 1-sample *t*-test. We used a *Z*-test to compare the proportions of random and mortality points at 20 m and 50 m from a fence. We used a Kolmogorov–Smirnov test to compare the distributions of the distance from fence for random points versus mortality locations in all study areas. We performed *Z*-tests and Kolmogorov–Smirnov tests in SAS 9.3 (SAS Institute, Cary, NC, USA).

We used a modified used-available study design within a resource selection framework to determine if specific biological and topographical variables were related to the 100-m section of fence that was crossed by lesser prairie-chickens (Manly et al. 1992, Boyce et al. 2002). We used logistic regression to compare crossed sections of a fence ($n = 2{,}909$) to uncrossed fence sections ($n = 7{,}152$; Manly et al. 1992). We assessed the fit of our model using a 2-step approach. First, we tested whether our saturated model fit better than an empty model (null) using the likelihood (or deviance) ratio goodness-of-fit statistic (Simonoff 1998, Boyce et al. 2002, Smyth 2003). Additionally, we assessed how well the a priori selected parameters improved upon the prediction of the null model using McFadden's pseudo-R^2 (Allison 2012).

It was logical to assume that as the frequency of crosses in a particular section of fence increased, the probability of a collision and resulting mortality would subsequently increase. Thus, to determine if cross frequency was explained by our specific biological and topographical characteristics, we used a multiple linear regression with the number of crosses as our response variable (*y*). We used only fence sections that had a cross for this analysis ($n = 2{,}909$). To meet the assumption of a normal distribution for a multiple linear regression, we $\log_e$ transformed cross frequencies (Kitchens 1998). We tested our model including all parameters that we hypothesized a priori to influence cross frequency (i.e., distance to nearest lek [m], elevation [m], slope [%], terrain ruggedness index, cover type category) against the null model using the *F*-statistic to determine if the included parameters increased model fit (Kitchens 1998). Further, we examined the adjusted R^2 to assess how well the selected parameters improved the ability of each model to explain the variation in the response variable. We conducted fence cross analyses using the generalized linear model (glm) and linear model (lm) functions in Program R (R Core Team 2013).

RESULTS

Fence Surveys

We surveyed >2,800 km of fence equating to >600 person hours during the 2 years of fence searching for carcasses and evidence of fence collisions by lesser prairie-chickens (Table 2). We recorded evidence for 15 potential fence collisions. We found 12 suspected collision locations (e.g., feathers) and 3 carcasses. We found all carcasses at the Clark County, Kansas, study site in the spring of 2014. Of the remains found, we detected one during the initial survey and it appeared to be feathers from a nearby depredated nest from the previous spring. We found another feather pile 4 m from a fence line and it showed signs of a recent avian depredation. The remains of the third carcass detected were located at a fence corner, with feathers present on either side of the fence and coyote (*Canis latrans*) scat nearby. Overall, evidence of potential collision from feather evidence was 1 collision/187 km of fence surveyed. Assuming the 3 carcasses discovered were the result of fence collision, then the carcass recovery rate was 1 carcass/935 km of fence. However, we were unable to conclusively document mortality of any lesser prairie-chicken due to a fence collision during fence surveys.

Table 2. Survey effort for carcasses and evidence of collision of lesser prairie-chickens with permanent livestock fences for each study site in Kansas (Clark County, Northwest, and Red Hills) and Colorado, USA by season, 2013 and 2014.

Study site	Year	Season	Distance walked (km)	Time (min)	Evidence of collision	Carcasses found
Colorado	2013	Spring	46.4	840	0	0
Clark County	2014	Spring	403.0	6,096	1	3
Clark County	2014	Fall	85.6	2,124	0	0
Northwest	2013	Spring	308.5	2,404	1	0
Northwest	2013	Fall	296.4	5,344	0	0
Northwest	2014	Spring	730.2	6,212	7	0
Northwest	2014	Fall	502.8	4,261	3	0
Red Hills	2013	Spring	119.3	2,446	0	0
Red Hills	2013	Fall	45.8	1,070	0	0
Red Hills	2014	Spring	156.8	3,693	0	0
Red Hills	2014	Fall	110.4	2,278	0	0
Total			2,805.2	36,768	12	3

Radio-Telemetry

We captured and equipped 268 individual lesser prairie-chickens with transmitters (Table 3). We documented at least 12,706 fence crosses by GPS-PTT-transmittered individuals based on movement tracks (Table 1). We recorded 146 mortalities of all transmittered birds in 2013 and 2014. Only 1 mortality (0.7%) was conclusively determined to be due to a fence collision by a transmittered bird, a male on Comanche National Grassland in Colorado during 2013 (Table 3). Causes of mortality for the remaining carcasses were mainly attributed to mammalian (33.3%) and avian (33.3%) predators, with 2 mortalities (3.3%) attributed to snakes, and 2 mortalities (3.3%) corresponding with tilling of agricultural fields during nesting. We could not assign cause-specific mortality to 25% of mortalities that we located. The inability to assign cause-specific mortality was due to several reasons that arise when monitoring prairie-chickens, such as only finding the transmitter of the bird, scavenging before discovery, and conflicting pieces of evidence that point to multiple potential causes of mortality (e.g., both mammalian and avian).

Spatial Distribution of Mortality

For transmittered lesser prairie-chickens, we found that mean carcass distance from fences was statistically similar to that of random points across all study sites, but the observed mean was 15% farther from fences than the random mean (Fig. 2). The pattern of observed mortality distance occurring farther than random but lacking statistical significance at the 95% level was evident for all study sites at varying effect sizes: 43.7% for Colorado ($t_{18} = 1.66$, $P = 0.11$), 24.6% for Northwest Kansas ($t_{74} = 1.52$, $P = 0.13$), 22.5% in the Red Hills, Kansas ($t_{41} = 1.52$, $P = 0.14$) and 5.5% in Clark County, Kansas ($t_9 = 0.23$, $P = 0.82$; Fig. 2).

The proportion of carcasses within 20 m of a fence ($Z = -0.96$, $P = 0.34$) and 50 m of a fence ($Z = -0.54$, $P = 0.59$) did not differ from random. Across all study areas, the random distribution of points indicated that 4.6% of points (46/996) were within 20 m of fence and 13.1% (130/996) of points were within 50 m of a fence. For the mortalities of transmittered birds, 6.8% (10/146) were within 20 m of a fence and 15.1% (22/146) were within 50 m of a fence. The cumulative distribution of mortality locations for lesser prairie-chickens did not differ across all study sites ($K = 0.02$, $P = 1.00$; Fig. 3).

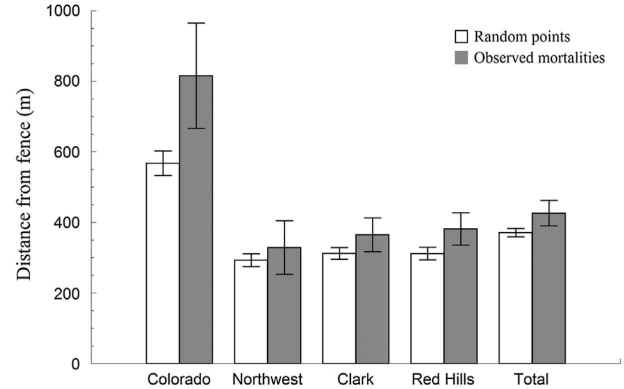

Figure 2. Comparison of distance ($\bar{x} \pm$ SE) from livestock fences for 1,000 random points and recovered mortalities of lesser prairie-chickens marked with satellite and radio transmitters in 3 study areas in Kansas (Northwest, $n = 75$ mortalities; Clark, $n = 10$ mortalities; and Red Hills, $n = 42$ mortalities) and 1 in southeast Colorado, USA ($n = 19$ mortalities) during 2013–2014. There were no differences ($P > 0.05$) between random and observed distances for any study site or combined total.

Fence-Cross Estimation

We found large variance decomposition proportions between slope and terrain ruggedness index; however, the condition index did not meet the suggested threshold ($\geq$30) to suggest collinearity problems. All hypothesized variables were retained in the modeling process. Distance to lek and elevation were significant predictors of fence-cross occurrence in the logistic regression model set, with the number of fence sections being crossed decreasing with increasing distance from lek ($\beta = -0.00018$; 95% CI $= -0.00016$, -0.00021) and increasing with increasing elevation ($\beta = 0.00072$; 95% CI $= 0.00036$, 0.00104). For each 1-m increase away from a lek, the odds of a cross occurring decreased from 1.0 to 0.9998 ($=e^{-0.00018}$; Table 4). Additionally, for every 1 m increase in elevation, the odds of a cross increased from 1.0 to 1.0007 ($=e^{0.00070}$; Table 4). Land cover category influenced cross occurrence with transitions of CRP–CRP, grass-CRP, and grass–grass differing from the reference category crop–crop. The odds of a lesser prairie-chicken crossing a fence was 2.94 and 1.68 times greater for fence sections that transitioned between CRP–CRP and grass-CRP than compared to crop–crop sections, respectively. Model fit statistics indicated the saturated model was better supported by data than an intercept only model ($\chi^2_9 = 303.07$; $P < 0.001$). Our model

Table 3. Number of captured lesser prairie-chickens, mortalities, and mortalities attributed to fence collision categorized by study sites in Kansas and Colorado, USA during 2013 and 2014. Captures are categorized by type of transmitter.

	Transmitter type[a] (no.)				
Site	Satellite	VHF	Total	No. mortalities	No. suspected collisions based on carcass evidence
Colorado	24	0	24	10	0
Clark County	19	18	37	19	1
Red Hills	41	39	80	42	0
Northwest	74	53	127	75	0
Total	158	110	268	146	1

[a] Satellite = satellite platform transmitting terminal (PTT) global positioning system transmitter; VHF = very high frequency.

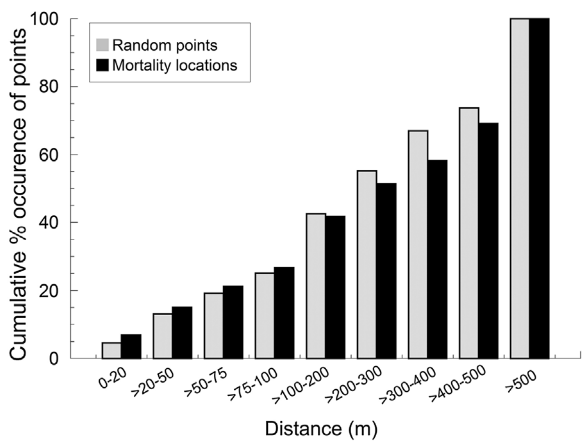

Figure 3. Cumulative distribution comparing distance of random points and mortality locations for lesser prairie-chickens in all study sites in Kansas and Colorado, USA during 2013 and 2014.

performed better than the null model, but the McFadden's pseudo-R^2 suggested that the predictive power was low and the saturated model increased the R^2 only 2.5% from the null model (Table 4).

Multiple linear regression analysis indicated that distance to lek was a significant predictor of fence-cross frequency, with the number of crosses decreasing with increasing distance from lek (β = −0.00007; 95% CI = −0.00009, −0.00005; Table 5). Contrary to our logistic regression results, elevation was not a significant predictor of fence-cross frequency (β = −0.00015; 95% CI = −0.00014, 0.00043; Table 5). Vegetation categories influenced cross frequency, with categories grass–crop, grass-CRP, and grass–grass differing from the reference category crop–crop. Our model fit the data better than the null model ($F_{9,2899} = 11.68$, $P < 0.001$); however, the adjusted R^2 was low, explaining only 3.2% of the variation in the response variable.

DISCUSSION

We found little evidence to suggest that collision with livestock fences is an influential mortality factor for lesser prairie-chickens in Kansas and Colorado. Using both indirect (fence survey) and direct (radio-marked birds) methods, we found minimal fence-collision risk, contrary to previous work in Oklahoma (Wolfe et al. 2007). Wolfe et al. (2007) attributed all mortalities within 20 m of a fence to be a collision, but our evidence indicated that mortalities close to fences were just as likely from predation. Assuming all mortalities within a certain distance to fence are directly related to fence collisions negates the necessity to correctly identify mortality causes, which could be related

Table 4. Logistic regression analysis of fence characteristics hypothesized to influence fence-cross propensity by marked lesser prairie-chickens in Kansas (Northwest, Red Hills, and Clark County) and Colorado from 2013 to 2015. We compared crossed fence sections ($n = 2{,}909$) to available ($n = 7{,}152$) sections.

Predictor	β	Lower 95% CI	Upper 95% CI	P	Odds ratio
Constant (crop–crop)	−1.21	−1.76	−0.70	<0.001*	
Distance to lek	−0.0002	−0.0002	−0.0002	<0.001*	0.99
Slope	0.0065	−0.058	0.074	0.66	1.00
Terrain Ruggedness Index	−0.19	−0.49	0.037	0.10	0.82
Elevation	0.0007	0.0004	0.0010	<0.001*	1.00
CRP-crop[a]	−0.63	−1.56	0.23	0.17	0.53
CRP–CRP	1.079	0.29	1.87	0.007*	2.94
Grass–crop	0.37	−0.097	0.89	0.055	1.45
Grass-CRP	0.52	0.032	1.042	0.016*	1.68
Grass–grass	0.46	−0.0042	0.98	0.062	1.59

* Signifies statistically significant β parameters ($P < 0.05$).
[a] Cover type category of each fence section. CRP = Conservation Reserve Program.

Table 5. Multiple linear regression analysis of fence-cross characteristics hypothesized to influence cross frequency of fence sections by marked lesser prairie-chickens in Kansas (Northwest, Red Hills, and Clark County) and Colorado, USA from 2013 to 2015. We used only fence sections that were crossed for this analysis ($n = 2{,}909$).

Predictor	β	Lower 95% CI	Upper 95% CI	P
Constant	0.47	0.032	0.92	0.04*
Distance to lek	−0.0001	−0.0001	−0.0001	<0.001*
Slope	0.0084	−0.040	0.057	0.76
Terrain Ruggedness Index	−0.14	−0.33	0.058	0.17
Elevation	0.0001	−0.0001	0.0004	0.32
CRP-crop[a]	−0.29	−1.07	0.48	0.46
CRP–CRP	0.18	−0.43	0.79	0.56
Grass–crop	0.45	0.037	0.86	0.03*
Grass-CRP	0.65	0.23	1.079	0.003*
Grass–grass	0.45	0.037	0.86	0.03*

* Signifies statistically significant β parameters ($P < 0.05$).
[a] Cover type category of each fence section. CRP = Conservation Reserve Program.

to predators that use fence-lines for perches or movement corridors. Furthermore, we concluded that although we found statistically significant predictors (i.e., distance to lek) of occurrence and frequency of fence crossings, the biological significance was negligible, because of the low predictability and little variation in the data by the tested independent variables.

Results from transmittered birds across our study sites indicated that mortality locations were distributed at distances to fences similar to that which would be expected at random. We documented only a single mortality from a fence collision, which was a male in Colorado. Thus, we documented only 1 collision mortality for >12,700 fence crosses. The Colorado study site was characterized by the lowest lek and fence densities compared to the other study sites. With mortality locations randomly dispersed across the landscape, we could find no evidence to conclude that collision with fences is influential to lesser prairie-chicken mortality in areas with low to moderate fence density in Kansas or Colorado.

Other than Patten et al. (2005) and Wolfe et al. (2007) for Oklahoma and New Mexico, there are no other studies that have documented fence collisions by lesser prairie-chickens as anything other than an exceedingly rare event for Texas (Haukos 1988, Kukal 2010, Pirius 2011, Holt 2012, Grisham and Boal 2015), New Mexico (Campbell 1972, Merchant 1982), Kansas (Jamison 2000, Fields 2004), and Oklahoma (Copelin 1963). If collisions were detected, they were generally confounded with power lines (Jamison 2000, Hagen et al. 2007). Our documented collision rates contrast with the evidence in Oklahoma, for which 39.8% of mortalities were attributed to collision (Wolfe et al. 2007). Fence densities in Oklahoma (3.8 km of fence/km^2) are more than double those in Kansas, which could explain discrepancies between studies, and this difference was used to explain the difference in collision frequency in Oklahoma in comparison to New Mexico (Wolfe et al. 2007, 2009). Therefore, management to reduce fence collisions (e.g., fence marking, fence removal; Wolfe et al. 2009) may be effective only where fence density exceeds some threshold.

Fence collisions have been associated with increased mortality risk and population-level impacts for greater sage-grouse (Connelly et al. 2000, Stevens et al. 2011). Differences in body size, flight behavior, and vegetative characteristics of occupied habitat could explain differences in collision occurrence and rates between these species. Fence collision mortality has not been quantified for the more closely related sharp-tailed grouse (*Tympanuchus phasianellus*) or greater prairie-chickens (Hovick et al. 2014). There is evidence that collision from fences is an influential cause of mortality in European woodland grouse (Catt et al. 1994, Baines and Andrew 2003). However, the majority of these fence collisions occur with deer fences that are more than twice the typical height of livestock fences across the lesser prairie-chicken range.

We did not use a detectability survey with placed carcasses; however, if we used a detection rate of 0.53 from a study on greater sage-grouse (Stevens et al. 2011), we would have effectively doubled the amount of possible collisions detected on our surveys. Doubling the collisions detected would have increased actual collisions documented per unit effort (1 carcass/468 km of fence), especially with the frequency and scale with which we conducted fence surveys. We believe that our detection rates were greater than Stevens et al. (2011) because our habitats surveyed contained less vertical structure and less shrub cover than greater sage-grouse habitat.

To more accurately estimate the risk associated with fences, documenting the extent to which lesser prairie-chickens cross fences is required. This information was not previously accessible, because VHF transmitter data are not collected frequently enough to accurately determine fence-cross location and frequency. Using high accuracy, fine temporal-scale data from GPS transmitters, we were able to quantify the number of fence crossings by marked lesser prairie-chickens. Across all study areas, this resulted in a single mortality. On average, our GPS-marked birds crossed fences 94.9 (SD = 9.27) times; if fences were a significant risk factor to lesser prairie-chickens, we would have attributed many more mortalities due to fence collisions.

Similar to results reported by Stevens et al. (2013), distance to lek was a significant predictor of fence-cross occurrence and cross frequency for this study; however, the distance to lek predictor, though statistically significant, contributed little to the predictability of both models. Contrary to Stevens et al. (2013), terrain ruggedness was not a significant predictor of fence-cross propensity or frequency. Non-significance of terrain ruggedness is likely a product of the landscapes that lesser prairie-chickens inhabit, which, for the most part, have minimal topographical variation. However, we did find that the propensity to cross a fence section did increase with increasing elevation. This finding was not surprising because lesser prairie-chickens mainly place leks in areas with higher elevation than the surrounding landscape (Hagen et al. 2004) and exhibit a high degree of site fidelity to leks (Fuhlendorf et al. 2002). We found evidence that vegetation cover type influenced the propensity of a lesser prairie-chicken crossing a fence and the frequency of crosses with fences between grass cover types incurred the greatest potential risk of collision. This result is intuitive as the majority of a lesser prairie-chicken's life cycle is spent within large contiguous grassland patches (Fuhlendorf et al. 2002). Unfortunately, our models had low predictability and accounted for little variation in the data set. Thus, the biological significance was negligible and fence-cross propensity and frequency appear to be random processes.

Current management recommendations for prairie-grouse, based on perceived increased mortality risk, include marking of fences to increase fence visibility or complete removal of fences. Because of the current science (Wolfe et al. 2007; Stevens et al. 2012*a*,*b*), federal agencies have mandated and provided incentives to mark fences when funding conservation actions. Fence marking is recommended for reducing avian-infrastructure collisions (Baines and Andrew 2003; Wolfe et al. 2007; Stevens et al. 2012*a*,*b*). Unfortunately, fence marking and removal can require significant staff time.

As a result, targeting high-risk collision areas have focused mitigation efforts for greater sage-grouse to fences that occur closer to leks and in flatter terrain (Stevens et al. 2013). However, selective targeting of fences in low fence density areas for marking to mitigate mortality for lesser prairie-chickens is not possible based on our results, and even in high-density areas, the effectiveness of fence marking is unknown.

Fence markers are designed to increase visibility of fences to flying birds (Wolfe et al. 2009). Greater sage-grouse collisions decreased by 83% when fences were marked (Stevens et al. 2012*b*) and European grouse collisions decreased by 70% (Baines and Andrew 2003). However, there has not been an assessment of the effectiveness of fence markers relative to reducing mortality of lesser prairie-chickens. Our results indicate that despite high collision risk (i.e., number of estimated fence crosses) there is little evidence that livestock fences are a significant mortality source. From a population-level effect, it would appear that fence marking would have little impact for the northern extent of the species' range. If the presence of fences is related to greater rates of mortality for lesser prairie-chickens, it is more likely to be an indirect association with increased predator abundance rather than direct mortality due to collision (Taylor et al. 2012, Robinson 2015). Predation is likely to occur close to edges, and on these landscapes, fences may frequently create edge habitats, for which there is greater predator density (Wilcove et al. 1986, Andrén and Angelstam 1988).

MANAGEMENT IMPLICATIONS

Given the low occurrence of fence collision, marking of fences in areas with a fence density <2 km/km^2 will likely not improve survival of lesser prairie-chickens. Marking of areas of low-density fences expends resources that could be used more effectively to improve the quality and quantity of available habitat. Furthermore, the effectiveness of fence marking in areas of low fence density remains elusive and more monitoring is necessary. Land managers should seek range management strategies that maintain low fence densities to avoid increasing risk to lesser prairie-chickens, such as what is found in Oklahoma.

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