Original Article

Greater Sage-Grouse and Fences: Does Marking Reduce Collisions?

BRYAN S. STEVENS,[1] *Departments of Fish and Wildlife Resources and Statistics, P.O. Box 441136, University of Idaho, Moscow, ID 83844, USA*

KERRY P. REESE, *Department of Fish and Wildlife Resources, P.O. Box 441136, University of Idaho, Moscow, ID 83844, USA*

JOHN W. CONNELLY, *Idaho Department of Fish and Game, 1345 Barton Road, Pocatello, ID 83204, USA*

DAVID D. MUSIL, *Idaho Department of Fish and Game, 324 South 417 E Suite 1, Jerome, ID 83338, USA*

ABSTRACT Collision with infrastructure such as fences is widespread and common for many species of grouse. Greater sage-grouse (*Centrocercus urophasianus*) fence-collision has been documented and fence-marking methods have been recommended for mitigating prairie-grouse collision in rangeland habitats. We tested a marking method in greater sage-grouse breeding habitat and modeled collision as a function of fence marking and control covariates, in Idaho (USA) in 2010. Our results suggested collision risk decreased with fence marking, increased with lek-count indices of local abundance, and decreased with increasing distance from lek. We found an approximate 83% reduction in collision rates at marked fences relative to unmarked fences. Our results also suggested marking may not be necessary on all fences, and mitigation should focus on areas with locally abundant grouse populations and fence segments <2 km from known leks. Nonetheless, collision still occurred at marked fences <500 m from large leks and moving or removing fences may be necessary in some areas if management is to eliminate collision. © 2012 The Wildlife Society.

KEY WORDS avian collision, *Centrocercus urophasianus*, collision mitigation, fence management, greater sage-grouse, Idaho, infrastructure marking, prairie-grouse.

Collision with anthropogenic infrastructure is widespread and common for grouse species across Europe (Catt et al. 1994, Bevanger 1995, Baines and Summers 1997), and limited research in North America suggested grouse–infrastructure collision may be a threat in some areas (Patten et al. 2005, Beck et al. 2006, Wolfe et al. 2007). Although tetraonid fence-collision is common, magnitude of collision risk and population-level consequences appear to vary by species and region. In Scotland, fence-collision was common for red grouse (*Lagopus lagopus scoticus*), capercaillie (*Tetrao urogallus*), and black grouse (*Tetrao tetrix*), and likely contributed to long-term capercaillie population declines (Baines and Summers 1997, Moss et al. 2000, Moss 2001). Population impacts of tetraonid collision in Norway are not well-understood, but losses may exceed harvest in some areas (Bevanger 1995, Bevanger and Brøseth 2004). Wolfe et al. (2007) found 39.8% and 26.5% of all lesser prairie-chicken (*Tympanuchus pallidicinctus*) mortality in Oklahoma and New Mexico (USA) was caused by fence-collision, and collision was greatest for adult females and peaked during the breeding season (Patten et al. 2005, Wolfe et al. 2007). Further, 33% of mortality for radiomarked juvenile greater sage-grouse (hereafter, sage-grouse; *Centrocercus urophasianus*) on an Idaho (USA) site was caused by collision with power lines (Beck et al. 2006).

Reducing collision through infrastructure marking is a commonly suggested mitigation method (Bevanger 1994, Baines and Andrew 2003). Most research on infrastructure marking focused on static ground wires of power lines (Morkill and Anderson 1991, Bevanger 1994, Brown and Drewien 1995), and research evaluating fence-marking mitigation is less common. However, Baines and Andrew (2003) reported that orange-barrier netting reduced woodland grouse fence-collision in Scotland.

Recent concerns over declining populations of sage-grouse generated speculation on effects of infrastructure on this species (Braun 1998, Johnson et al. 2011, Knick et al. 2011). That sage-grouse occasionally collide with fences has been known since at least the 1940s (Scott 1942); however, this phenomenon has never been systematically studied. Moreover, fence-marking methods have been developed for reducing prairie-grouse collision in rangeland habitats (Wolfe et al. 2009), but no studies have tested their effectiveness. Marking fences in sage-grouse habitats may be a desired management option, but it is necessary to determine effectiveness of fence marking prior to widespread application. Therefore, we tested effectiveness of a fence-marking method to reduce collision in high-risk sage-grouse breeding habitats.

STUDY AREA

We conducted a field experiment on 8 sites across south-central and southeast Idaho, with sites located in Blaine, Butte, Clark, Jefferson, and Twin Falls counties. We selected

study sites independent of sage-grouse lek locations and counts. However, regional lek count totals during this study indicated similar relative abundances for all but one site, where counts for the Twin Falls County site suggested reduced relative abundance (Stevens 2011). Common vegetation types observed on study sites included little sagebrush (*Artemisia arbuscula*), black sagebrush (*A. nova*), three-tip sagebrush (*A. tripartita*), and big sagebrush (*A. tridentata*) communities with some grassland habitats and bare ground interspersed as a result of previous fires. Elevations on study sites ranged from approximately 1,580 m to 1,900 m.

METHODS

Field Methods

We found spatially aggregated collisions (≥2 collisions/km) during preliminary sampling in spring 2009 (Stevens 2011) and replicated our marking study on 8 of these areas. We used sites with ≥2 collisions/km in 2009 because high-risk sites were necessary to obtain adequate sample sizes (i.e., adequate no. of collisions), and spatial aggregation of collision suggests areas of high risk. Thus, inferences from this study are limited to high-risk areas; however, this is appropriate because fence markers are likely not necessary at low-risk sites. We used the 3-km fence segment around each collision aggregation, and we divided each segment into 6 500-m fence segments that served as experimental units. We used 3 km of fence to accommodate the broader area at each site. Pilot data from 2009 were used to identify high-risk sites, so we believed it possible that specific locations for collision aggregations may vary between years. Thus, we speculated 3 km was sufficiently large to accommodate spatial–temporal variation in collision locations within sites while also allowing us to sample in a timely manner. However, 500-m fence segments were arbitrarily used as experimental units for simplicity in setting up the study and conducting fieldwork. Moreover, Baines and Andrew (2003) suggested fence-marker assessments could become biased if unmarked segments are directly adjacent to marked segments and birds adjust their flight paths laterally along the fence to avoid marked segments. Under these circumstances, birds could strike unmarked fences simply by avoiding marked segments and thus artificially increase collision rates in unmarked areas (Baines and Andrew 2003). Therefore, we placed 50 m of buffer fence between each 500-m segment to prevent artificially increasing collision rates in unmarked areas (Baines and Andrew 2003). We randomly selected 3 500-m segments at each site for fence marking, with the remaining 3 segments used as unmarked controls. This design resulted in 24 marked and 24 unmarked 500-m fence segments on 8 sites across south-central and southeast Idaho.

We constructed fence markers using vinyl-siding undersill (Wolfe et al. 2009), and we added reflective metallic tape (Reflectix, Inc., Markleville, IN) to both sides of each marker to increase visibility under low-light conditions and on snow-covered landscapes. We placed markers on the top strand of fence at 1-m intervals to approximate the wingspan of sage-grouse. Wolfe et al. (2009) staggered markers on first and third strands of fence in mixed-grass prairie; however, we did not believe this was necessary because observational studies suggested birds rarely attempt to fly under marked infrastructure (Brown and Drewien 1995, Savereno et al. 1996). Moreover, marking only one fence strand reduces the number of markers necessary and is more cost-effective. We completed marker construction and marking activities in February 2010.

We sampled study fences during the sage-grouse breeding season at approximate 2-week intervals (range = 11–16 days) from 17 March to 26 May 2010, and all sites were sampled on 5 occasions. Observers walked each side of the fence while searching for sage-grouse carcasses or feather sign on the ground and feathers stuck on fence strands. During surveys, observers walked approximately 1–3 m from the fence and monitored the area up to approximately 15 m from the fence for carcasses or collision evidence. We defined a collision as detection of a whole carcass or a feather pile (>5 feathers) within 15 m of the fence, feathers stuck on the fence, or a combination of these (Stevens 2011). We were cautious when only feather sign was detected, and if a likely raptor perch or plucking post was present, we did not use data from the site. Plucking posts were common in some areas (primarily for passerine prey) and were usually located at wooden fence posts, with the resulting feathers scattered from the post in the prevailing wind direction. In contrast, sites deemed collisions based solely on feather-pile evidence commonly contained feathers scattered in the prevailing wind direction from under the fence itself, or very close to the fence (typically <1 m). Feather piles were counted as collisions with no knowledge of fate of collision victims; therefore, counts are number of collisions present at the time of sampling, not of collision mortalities. We removed all collision evidence (feathers and carcasses) at each sampling occasion to prevent double-counting. We used feather characteristics to identify sage-grouse remains (Dalke et al. 1963), and we sent evidence from unknown species to the Feather Identification Laboratory at the Smithsonian Institution, who used whole-feather (Sabo and Laybourne 1994, Woodman et al. 2005) and microscopic feather characteristics (Dove and Koch 2010) and DNA barcoding (Dove et al. 2007) to identify individual collision victims to species. Lastly, we measured microsite shrub height at collision locations and at 1 m in each cardinal direction to correct counts for the influence of local vegetation on detection probability (Stevens et al. 2011).

Traditional experimental design assumes homogenous experimental units to prevent erroneous inference in the presence of confounding variables. Randomization helps alleviate systematic bias caused by confounding variables; however, control covariates can allow for a more precise evaluation of treatment effects by accounting for specific sources of variation in the response not due to treatments. All fence-segment units were not identical with respect to biological or technical factors; therefore, we collected data on attributes of fences and covariates potentially influencing collision at each segment. We used 1-in-5 systematic sampling (Scheaffer et al. 2006) of individual fence sections (i.e., length of fence

between 2 subsequent posts) to quantify technical attributes of each 500-m fence segment. We collected covariate data including fence type (e.g., 4-strand barbed-wire, woven-wire), fence height, and number of markers per fence section. Number of fence markers/500 m was not constant because 500-m fence segments had variable lengths for individual sections (i.e., lengths of fence between subsequent posts) and therefore variable numbers of fence posts. Because there was no need to put fence markers on the posts, this resulted in fewer markers for 500-m segments with shorter section lengths and more markers for 500-m segments with longer section lengths and fewer fence posts.

Sage-grouse exhibit a lek mating strategy with traditional lek sites often used for many years (Patterson 1952, Dalke et al. 1963). We calculated an index to sage-grouse abundance with maximum lek count at the nearest lek, and calculated distance to nearest lek from the midpoint of each 500-m segment in ArcMap 9.3. Using fence-segment midpoints for distance to lek measurements is an obvious simplification that ignores distance to lek from each portion of the 500-m segment. However, fence segments were the experimental units for analyses; thus, a representative measure of distance to lek was necessary for each 500-m segment. We believed using fence-segment midpoints resulted in the most representative measure of distance to lek because length of fence in either direction was equal. Standard methodology for annual sage-grouse lek-count surveys followed Connelly et al. (2003). Moreover, because all sites were in areas sampled annually by Idaho Department of Fish and Game (hereafter, IDFG), all lek count and location data were provided by IDFG from surveys conducted in 2010.

Statistical Methods

We summed collision counts over the lekking season for each 500-m segment to evaluate effects of fence marking on expected collision counts. Each collision represented $1/P$ corrected collisions, where P was detection probability estimated from the logistic-regression model with only an intercept and a term for mean microsite shrub height (Stevens et al. 2011). Stevens et al. (2011) found little evidence that distance from fence (0–15 m) influenced detectability of hypothetical collision evidence; therefore, we did not include distance from fence as a covariate when correcting collision counts for detectability. Moreover, because most collisions included evidence <1 m from the fence (Results), distance of collision evidence from study fences did not appear to influence detection. Furthermore, we assumed perfect detection for collisions whose evidence included feathers stuck on the fence because visibility was high and did not appear influenced by vegetation. We summed corrected counts over the lekking season for each fence segment and rounded counts to the nearest whole number. We did not correct counts for collision sign-removal bias because we were unable to measure sign longevity at each site (Stevens et al. 2011).

Due to many zero counts we used zero-inflated Poisson regression (hereafter, ZIP) to model corrected counts as a function of marking and control covariates (Lambert 1992, Welsh et al. 1996, Martin et al. 2005). We constructed ZIP models using a priori hypothesized treatment effects and potential control covariates, and we used model-selection methods to facilitate comparison of nonnested models (Burnham and Anderson 2002). Covariates used in the count segment of ZIP models included fence-marking treatment, size of nearest lek (i.e., lek count), and distance to nearest lek. Due to limited samples sizes with count data pooled over time ($n = 48$) we used intercept-only models for the binomial mixture probabilities. To evaluate evidence for additional overdispersion not accounted for by ZIP models, we also fit the best covariate combinations ($\Delta AIC_c \leq 2$) using zero-inflated negative binomial models. We hypothesized that fence-marking effect sizes may vary with values of the control covariates distance to lek and lek size. For example, if collision risk varied by lek proximity, then estimated marking effects could be stronger for fences closer to leks. Thus, we included 4 plausible interactions (treatment × distance, treatment × lek size, lek size × distance, and treatment × lek size × distance), and added these terms individually to the top model. We compared 10 models representing covariate combinations and the intercept-only model using the pscl package in the R statistical computing language (R Core Development Team 2006, Zeileis et al. 2008).

We evaluated goodness-of-fit and prediction success for the top model with parametric bootstrap and cross-validation procedures (Efron and Tibshirani 1994). We used 1,000 parametric bootstrap samples of the Pearson χ^2 statistic to test the null hypothesis that the top model fit the data, and we used 1,000 parametric bootstraps to estimate 95% confidence intervals on expected collision counts for the top model. We used leave-one-out cross-validation and root-mean-squared error to evaluate prediction success, calculating the square root of average squared error between predicted and observed collision counts for each model in R (R Core Development Team 2006).

RESULTS

We recorded 60 avian collisions during spring 2010, of which 56 were sage-grouse. We found evidence for temporal variation in collision within the lekking season and spatial variation among sites (Fig. 1). A collision peak occurred from mid-March to mid-April, with reduced but stable collision risk through the end of the season (Fig. 1). Sage-grouse collisions were spatially aggregated near leks; approximately 73% ($n = 41$) of collisions were <500 m from a lek, 14% ($n = 8$) were from 500 m to 1,000 m from a lek, 13% ($n = 7$) were >1,000 m, and 2% ($n = 1$) were >1,500 m from a lek. Composition of collision evidence was dominated by feather piles (75%, $n = 42$), with smaller numbers of feather piles and feathers lodged in the fence (23%, $n = 13$), only feathers in the fence (5%, $n = 3$), and intact carcasses (2%, $n = 1$). Distance from fence to the closest collision evidence averaged 0.18 m, and ranged from 0 m to 1.6 m. We were able to determine sex from approximately 43% of sage-grouse collision remains ($n = 24$), resulting in 22 male and 2 female known-sex collisions.
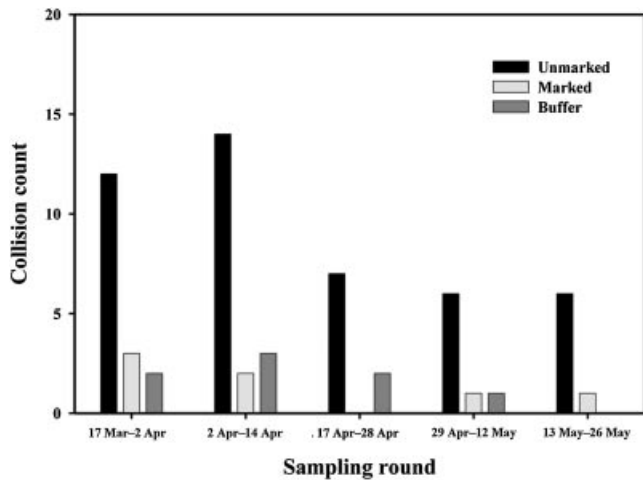
Figure 1. Total number of avian collisions located per treatment type and time period during fence-marking studies in southern Idaho, USA, during spring 2010.

Uncorrected sage-grouse fence-collision counts pooled across sites and time were 6 times greater in unmarked segments (3.5 strikes/km; unmarked: $n = 42$, buffer: $n = 7$) than marked segments (0.6 strikes/km; $n = 7$); an approximate 83% reduction in uncorrected collision rates at marked fences. Corrected collision counts pooled across sites and time were approximately 5.7 times greater in unmarked segments (4.9 strikes/km; $n = 58.6$) than in marked segments (0.9 strikes/km, $n = 10.2$); again resulting in an approximate 83% reduction in detection-bias-corrected collision at marked fences.

The average estimated number of markers per 500-m segment was 479.3 (SD = 42.2, $n = 24$, range = 370.5–578.1), and fence types were dominated by 4-strand ($\bar{x} = 0.58$, SD = 0.46, $n = 48$) and 3-strand ($\bar{x} = 0.32$, SD = 0.45, $n = 48$) barbed wire. Lesser amounts of 5-strand ($\bar{x} = 0.07$, SD = 0.23, $n = 48$), woven-wire ($\bar{x} = 0.02$, SD = 0.12, $n = 48$), 6-strand ($\bar{x} = 0.001$, SD = 0.008, $n = 48$), and 2-strand ($\bar{x} = 0.003$, SD =

0.014, $n = 48$) fence were also present. The average estimated mean fence height per 500-m segment was 110.5 cm (SD = 9.7, $n = 48$, range = 84.5–131.8). Covariate data used in regression modeling had mean lek size of 47.1 birds (SD = 44.3, range = 1–127, $n = 48$), and mean distance from midpoint of a fence segment to lek of 1,364.4 m (SD = 1194.9, range = 104–4,650, $n = 48$).

Zero-inflated regression modeling identified fence marking, lek size, and distance to lek effects on expected collision counts ($\Delta AIC_c = 0$, $w_i = 0.383$; Table 1). However, we also found support for an interaction between marking and distance to lek ($\Delta AIC_c = 0.365$, $w_i = 0.319$; Table 1). The top model suggested reduced collision counts with fence marking ($\beta = -1.35$, 95% CI $= -2.2$ to -0.5; Fig. 2) and increasing distance from lek ($\beta = -0.001$, 95% CI $= -0.001$ to -0.0008; Fig. 2), increased collision frequency with lek size ($\beta = 0.017$, 95% CI $= 0.010$–0.023; Fig. 2) and a binomial mixture probability of 0.62. Graphical representation of the top model shows a predicted nonlinear increase in expected collision frequency as lek size increases and distance to lek decreases (Fig. 2). Maximum and minimum observed values of lek size and distance to lek (i.e., lek size = 127 and distance to lek = 104 m) resulted in high expected collision counts per 500 m over the lekking season for unmarked ($\hat{y} = 8.33$, 95% CI $= 8.14$–8.51) and marked fences ($\hat{y} = 2.17$, 95% CI $= 2.10$–2.23). Goodness-of-fit testing failed to reject the hypothesis that the top model fit the data ($P = 0.31$), and cross-validation suggested top models performed relatively similar in terms of prediction error (range $= 1.774$–2.164, $n = 5$; Table 1). The second-best model including the treatment × distance interaction predicted a slightly stronger fence-marking treatment effect ($\beta = -2.07$, 95% CI $= -3.3$ to -0.8), and similar lek size ($\beta = 0.017$, 95% CI $= 0.010$ to 0.024) and distance to lek effects ($\beta = -0.001$, 95% CI $= -0.001$ to -0.0001); however, the interaction eliminated distance to lek effects for marked fences only ($\beta = 0.001$, 95% CI $= -0.00005$ to -0.002).

Table 1. Top zero-inflated regression models of greater sage-grouse collision counts for marked and unmarked fence segments on 8 breeding areas of southern Idaho, USA, during spring 2010. Covariates were marking treatment (Trt), lek count at the nearest lek (Lsize), distance to nearest lek (Dist), and intercept only (Null). Models were zero-inflated Poisson models unless otherwise indicated, and all models were fit with an intercept-only binomial mixture probability. We ranked models using Akaike's Information Criteria corrected for small sample sizes (AIC_c) and normalized Akaike model weights (w_i; Burnham and Anderson 2002).

Model[a,b]	K[c]	AIC_c	ΔAIC_c	w_i	$-2LL$[d]	Prediction error[e]
Trt + Lsize + Dist	5	111.775	0.000	0.383	100.346	1.871
Trt + Lsize + Dist + Trt × Dist	6	112.140	0.365	0.319	98.092	1.774
Trt + Lsize + Dist + Trt × Lsize	6	114.324	2.549	0.107	100.276	1.898
Trt + Lsize + Dist NB[f]	6	114.397	2.622	0.103	100.348	1.863
Trt + Lsize	4	114.700	2.925	0.089	105.770	2.164
Trt	3	140.031	28.256	0.000	133.485	2.836
Null	2	159.756	47.981	0.000	155.489	2.997

[a] Model form is $\log(\lambda) = \beta_0 + \beta_1(X_1) + \ldots \beta_k(X_k)|\text{logit}(p) = \gamma_0$, where λ is the expected collision count and p is the binomial mixture probability.
[b] The following models were attempted but could not be fitted because they did not converge: (Trt + Lsize + Dist + Lsize × Dist); (Trt + Lsize + Dist + Trt × Lsize × Dist); (Trt + Lsize + Dist + Trt × Dist NB).
[c] K = no. of model parameters.
[d] $-2LL = -2 \times$ maximized log-likelihood for the model of interest.
[e] Prediction error = root-mean-squared error calculated via leave-one-out cross-validation.
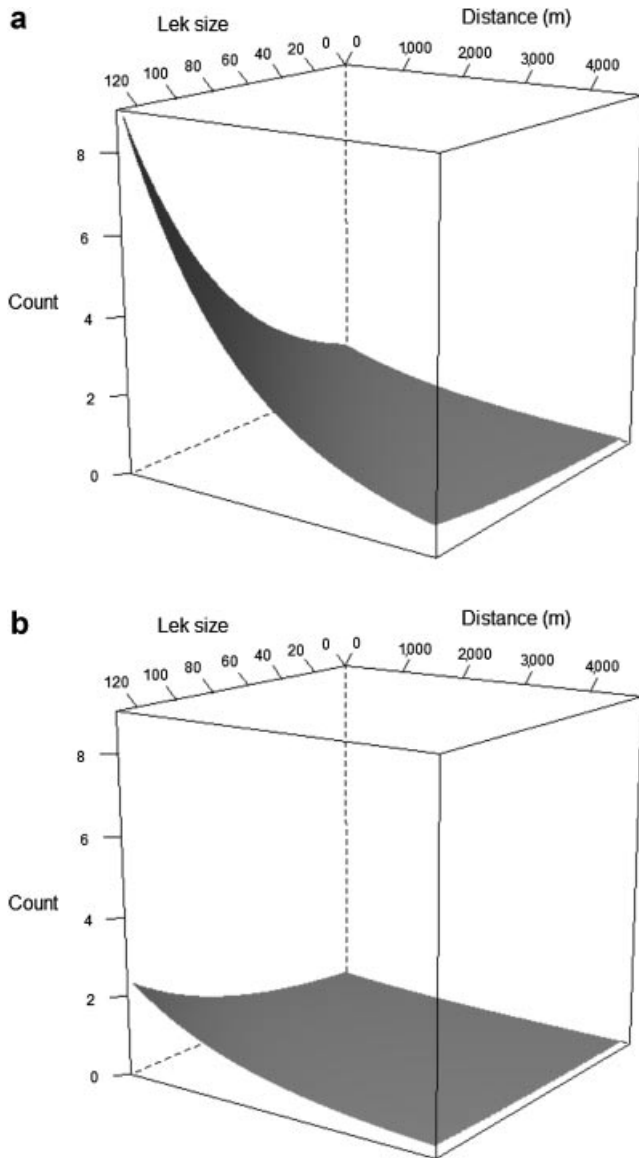[f] NB = zero-inflated negative binomial regression model.

Figure 2. Plots of expected greater sage-grouse collision count/500 m/ lekking season on southern Idaho, USA, during spring 2010, from the top zero-inflated Poisson regression model. a: Collision count as a function of size of nearest lek (i.e., lek count) and distance to lek for unmarked fence segments. b: Collision count as a function of size of nearest lek and distance to lek for marked fence segments.

DISCUSSION

We found that fence marking reduced sage-grouse collision frequency by approximately 83%. Wolfe et al. (2009) provided anecdotal evidence for reduced prairie-chicken collision after marking; however, they did not explicitly test fence-marker effectiveness. Baines and Andrew (2003) marked deer fences in Scotland with orange-barrier netting and reported approximately 84% fewer woodland–grouse collisions on marked fences using uncorrected data, results similar to ours (83% reduction). However, fence marking did not eliminate collision in high-risk areas (Baines and Andrew 2003), which is consistent with our results despite different fence-marking methodology. Although biological, technical, and methodological differences preclude meaning-

ful comparison of fence and power-line marker effectiveness, power-line marking has also generally been successful at reducing avian collision (Morkill and Anderson 1991, Brown and Drewien 1995, Savereno et al. 1996, Barrientos et al. 2011).

In addition to collision variation caused by fence marking, we observed spatial variation in sage-grouse collision that appeared influenced by lek size and lek proximity to fences. Spatial variation is common in avian-collision studies across a range of species and infrastructure types (Baines and Summers 1997, Bevanger and Brøseth 2000, Janss and Ferrer 2000, Barrios and Rodríguez 2004, Shaw et al. 2010). Leks are focal points for sage-grouse breeding activities, thus a relationship between collision and lek proximity is likely a function of breeding season space use (Patterson 1952, Gibson 1996, Holloran and Anderson 2005). Scott (1942) found 4 dead male sage-grouse collision victims along a fence bisecting a lekking area in Wyoming, USA, and observed a fifth male collide with a fence. Lek-mating strategies have been hypothesized to influence collision for birds and bats (Bevanger 1994, Baines and Summers 1997, Cryan 2008), and we provided a quantifiable link between lek location and infrastructure collision. We are not aware of previous studies that quantify the relationship between infrastructure-lek proximity and collision risk, however, several studies found collision to vary with habitat use (Baines and Summers 1997, Smallwood et al. 2007, Rollan et al. 2010, Shaw et al. 2010). Although distance to lek effects on fence-collision during the lekking season is an intuitive result, the regression coefficients for this effect and the marking-by-distance interaction were close to zero, possibly suggesting little biological effect (Arnold 2010). The small regression coefficients in this case were a function of measurement scale of the predictor variable distance to lek (i.e., measured in meters), and changing the scale to km would increase the absolute values of estimated effect sizes and their confidence intervals. Moreover, the effect of distance on collision was illustrated clearly via effect plots (Fig. 2). However, the interaction effect appeared to be estimated imprecisely and thus should be interpreted cautiously.

Spatial variability in collision was also related to size of the nearest lek, and risk increased with indices of local sage-grouse abundance. Similarly, Baines and Andrew (2003) reported collision rates correlated with counts of displaying male black grouse in Scotland ($r = 0.60$). Anderson (1978) found power-line-collision counts in Illinois, USA, were correlated with counts of mallard (*Anas platyrhynchos*) and blue-winged teal (*Anas discors*) using the area. Increasing abundance likely increases collision by increasing the number of flights over an infrastructure segment (Janss and Ferrer 2000). Although this result is biologically intuitive and expected, we are not aware of previous research linking prairie-grouse collision to local abundance.

Methodological limitations prevented us from correcting collision counts for evidence-removal bias, which may have occurred by removal of collision evidence via scavenging or weather between sampling occasions (Smallwood 2007, Smallwood et al. 2010, Stevens et al. 2011). Research sug-

gested spatial variability in persistence of collision evidence was common at broad spatial scales (Smallwood 2007, Stevens et al. 2011), and this may have introduced error in our modeling results. We minimized this error by conducting repeated sampling with a minimum possible interval length (approx. 2 weeks; Stevens et al. 2011); however, we did not have resources to conduct carcass-removal experiments on all sites. Moreover, our sampling intensity was greater than many published studies that sampled at ≥1-month intervals (Baines and Summers 1997, Bevanger and Brøseth 2000, Janss and Ferrer 2000, Baines and Andrew 2003, Smallwood et al. 2007). Thus, despite correcting for the influence of vegetation on detection probability, our collision counts may be conservative.

In addition to inferential limitations regarding sampling methodology, our study scope was limited to high-risk areas for only one breeding season; thus, sample sizes were limited. It is necessary to use high-risk sites in infrastructure-marker assessments to obtain adequate numbers of collisions to estimate marker effectiveness; however, focusing on high-risk sites may provide a biased view of sage-grouse fence-collision risk in general, and does not indicate what proportion of the landscape may be considered high risk. Moreover, our results and inference are limited to the breeding season and provide no evidence of marker effectiveness in other seasonal habitats (e.g., winter range) or during other environmental conditions (e.g., snow). Further, no research has addressed how collisions affect prairie-grouse demography, and it remains unclear whether collision mortality is additive or compensatory to natural mortality for sage-grouse. Population-level impacts of collision likely depend on relative numbers of male and female fatalities. Our results suggested male sage-grouse may collide with fences more frequently than females. However, identification of male sage-grouse was greatly facilitated by presence of air-sac and filoplume feathers (Dalke et al. 1963), and observed sex-composition was likely male-biased. Fence-marking mitigation will likely focus on high-risk areas despite these inferential limitations. Thus, our fence-marker assessment should remain valid under breeding-season conditions where it will be applied.

MANAGEMENT IMPLICATIONS

Our data indicated a reduction in fence-collision with reflective markers placed in high-risk areas. Our data also suggested previous recommendations to mark fences within 1 km of prairie-grouse leks (Wolfe et al. 2007) may be insufficient for sage-grouse, and we recommend marking fences within about 2 km of leks at high-risk sites. However, some level of collision should still be expected in circumstances with fences close to large leks, and moving or removing fences may be a desired alternative to marking in these circumstances if management objectives are to eliminate collision risk.

ACKNOWLEDGMENTS

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