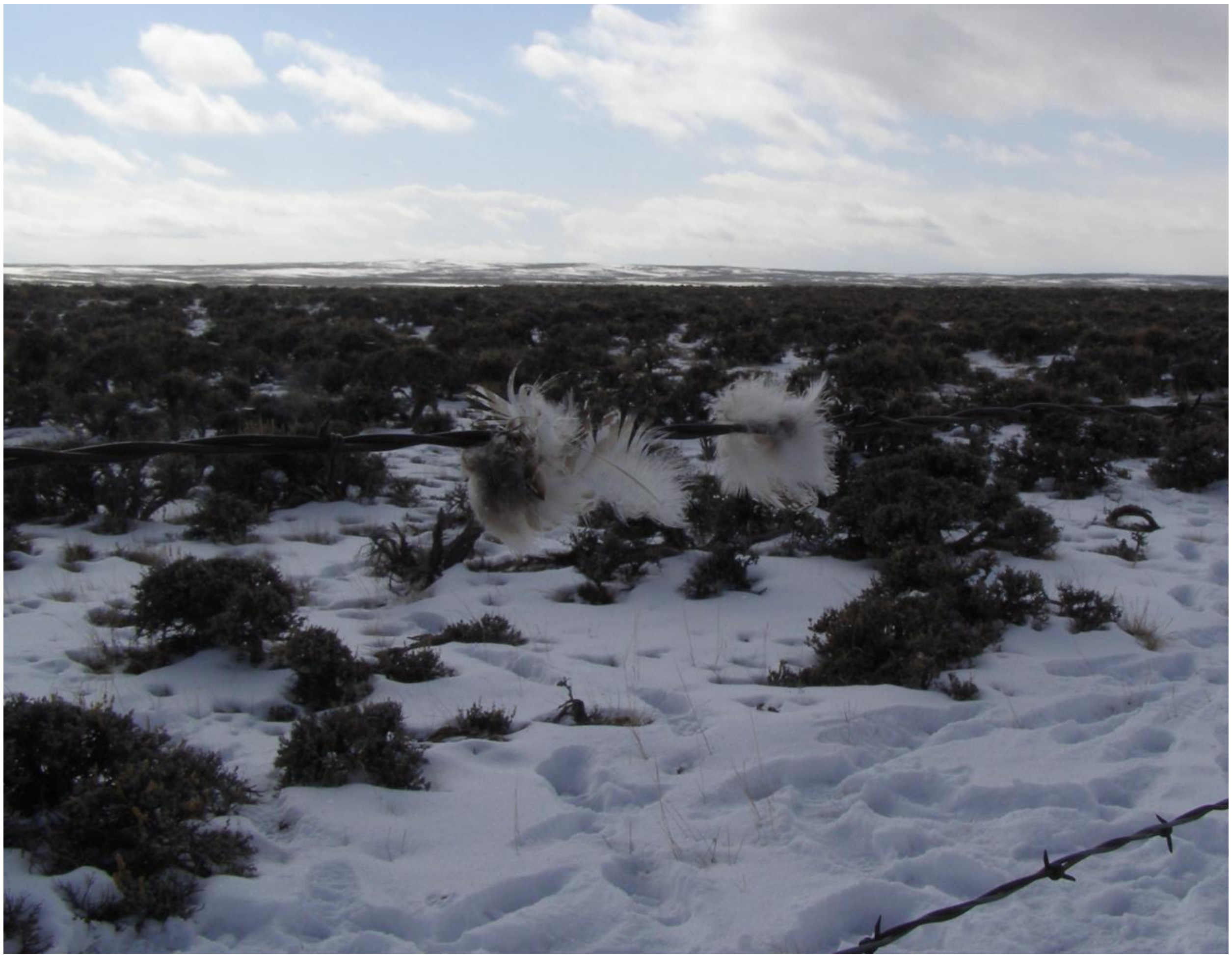
Evaluating Efficacy of Fence Markers in Reducing Greater Sage-Grouse Collisions With Fencing
Final Report



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Bird Conservancy of the Rockies
14500 Lark Bunting Lane
Brighton, CO 80603
303.659.4348
www.birdconservancy.org
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The Bird Conservancy of the Rockies

Connecting people, birds and land

Mission: Conserving birds and their habitats through science, education and land stewardship

Vision: Native bird populations are sustained in healthy ecosystems

Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education and land stewardship. Our work radiates from the Rockies to the Great Plains, Mexico and beyond. Our mission is advanced through sound science, achieved through empowering people, realized through stewardship and sustained through partnerships. Together, we are improving native bird populations, the land and the lives of people.

Core Values:
1. **Science** provides the foundation for effective bird conservation.
2. **Education** is critical to the success of bird conservation.
3. **Stewardship** of birds and their habitats is a shared responsibility.

Goals
1. Guide conservation action where it is needed most by conducting scientifically rigorous monitoring and research on birds and their habitats within the context of their full annual cycle.
2. Inspire conservation action in people by developing relationships through community outreach and science-based, experiential education programs.
3. Contribute to bird population viability and help sustain working lands by partnering with landowners and managers to enhance wildlife habitat.
4. Promote conservation and inform land management decisions by disseminating scientific knowledge and developing tools and recommendations.

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Cover Photos:
Greater Sage-grouse feathers found in fence (Photo by Nick Van Lanen)

Contact Information:
Nick Van Lanen
nick.vanlanen@birdconservancy.org
Bird Conservancy of the Rockies
230 Cherry St.
Fort Collins, CO 80521
(970) 482-1707 ext. 28

EXECUTIVE SUMMARY

Greater sage-grouse (*Centrocercus urophasianus*; GRSG) populations have declined substantially over the last several decades, resulting in extirpation from nearly half of the species' range. Much of these losses are attributed to habitat loss and fragmentation due to a wide variety of causes, including energy development, urbanization, rural development, the spread of invasive grasses and the corresponding altered wildfire regimes, improper grazing regimes, encroaching conifers, and agricultural cultivation. In addition to habitat loss, anthropogenic features on the landscape may degrade GRSG habitat by increasing the risk of predation and the frequency of collisions with power lines, fences, and other structures. The density of fences and other anthropogenic structures has increased dramatically in sagebrush habitats over the last 50 years and there is reason to believe these structures negatively impact GRSG. A number of studies have found evidence that GRSG do collide with anthropogenic structures, and fences are routinely marked to reduce these collisions. However, there is little empirical evidence on fence characteristics and the surrounding landscape to influence the probability or abundance of collisions. Additionally, there is no research on the efficacy of different styles of fence markers in minimizing collision risk. We developed a multi-scale occupancy model to evaluate a previously created collision risk model for GRSG, estimate how factors at landscape and local scales impact the probability of collisions, and to determine the most cost-effective marking options to reduce GRSG collisions. We found evidence for 64 confirmed fence collisions by GRSG during the two-year study, with 15 detected in 2014 and 49 detected in 2015. Over 60% of sites (16 of 26) and 26% of fence segments (27 of 104) contained evidence of one or more collisions. We found little evidence for differences in collision risk within our study area between areas defined as "high" or "moderate" risk in a pre-existing collision risk map. We also found substantial evidence for the ability of markers to reduce collision probabilities (~58% reduction), though there was little difference between the three marker types investigated. We found strong evidence for lower occupancy probabilities at fences with wood posts and those farther from leks. Our results also indicate a negative relationship between occupancy probabilities and the difference between fence and vegetation heights. Collision probabilities were lower at unmarked fences with wood posts than at marked fences with wood and t-posts. We recommend that, when possible, markers be placed on fences close to leks, on fencing with t-posts, and/or in areas with shorter vegetation. Furthermore, we recommend the use of the least expensive, vinyl without reflective tape, marker in future fence marking efforts.

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ACKNOWLEDGMENTS

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INTRODUCTION

The greater sage-grouse (*Centrocercus urophasianus*) (GRSG) once occurred across more than 290 million acres of sagebrush habitat prior to 19th century European settlement of the western United States. Historically, the GRSG range spanned an area that would now include 13 states and 3 Canadian provinces (Connelly and Braun 1997, Schroeder et al. 1999, Schroeder et al. 2004). Today, GRSG occupy just 56% of their historic range (Schroeder et al. 2004), with more than 98% located in the United States (Knick et al. 2011). GRSG have been extirpated from Nebraska, British Columbia, and possibly Arizona. Additionally, the range of the GRSG has been significantly reduced across the 11 states and 2 provinces they still occupy (California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming, Alberta and Saskatchewan) (Schroeder et al. 1999,Schroeder et al. 2004). In 2010, the U.S. Fish and Wildlife Service (USFWS) listed the GRSG as a candidate species for protection under the Endangered Species Act, citing an 80 to 90% population decline from pre-colonial times; a 30% decline since 1985; and ongoing threats from habitat destruction, degradation, and fragmentation (USFWS 2010). In 2015 the USFWS reviewed that decision and concluded the species was “not warranted” based on conservation plans currently being implemented (USFWS 2015) despite the possibility that populations may be continuing long-term declines.

The primary driver of reduced GRSG populations is thought to be the loss, fragmentation, and degradation of sagebrush habitat (Schroeder et al. 2004, Knick and Connelly 2011). Currently, energy development, urbanization, rural development, the spread of invasive grasses and the corresponding altered wildfire regimes, improper grazing regimes, encroaching conifers, and agricultural cultivation are all thought to contribute to the loss and degradation of sagebrush ecosystems that provide GRSG habitat (Yocom 1956, Swenson et al. 1987, Miller and Tausch 2001, Kuvlesky et al. 2007, Knick et al. 2011). In addition, anthropogenic features on the landscape may degrade GRSG habitat by increasing the risk of predation and the frequency of collisions with power lines, fences, and other structures (Beck et al. 2006).

Collision mortality has been widespread and well documented in *tetraonid* species. In North America, Wolfe et al. (2007) found that 39.8% of lesser prairie-chicken (*Tympanuchus pallidicinc tus*) mortality was caused by collision with fences and Patten et al. (2005) observed elevated mortality rates for female lesser prairie-chickens where habitats were fragmented by fences, power lines, and roads in Oklahoma. In Europe, collisions with fences and power lines has been observed for the capercaillie (*Tetrao urogallus*), black grouse (*Tetrao tetrix*), red grouse (*Lagopus lagopus scoticus*), and ptarmigan (*Lagopus spp*.) (Bevanger 1990, Bevanger 1995, Baines and Summers 1997). How collision-associated mortality affects populations is not particularly well understood; however, there is some evidence indicating this source of mortality may contribute substantially to population declines in some species (Bevanger 1995, Moss et al. 2000, Smith and Dwyer 2016).

The density of fences and other anthropogenic structures has increased dramatically in sagebrush habitats over the last 50 years and there is reason to believe these structures negatively impact GRSG (Braun 1998, Connelly et al. 2000, Johnson et al. 2011, Knick et al. 2011). A number of studies have found evidence that GRSG do collide with anthropogenic structures. Beck et al. (2006) found that 33% of juvenile radio-marked GRSG mortality at an Idaho site was due to power-line collisions. An ongoing study in western Wyoming located 146 GRSG collisions along a 4.7 mile stretch of fence between April 15, 2005 and Nov. 16, 2007 (Christiansen 2009). Following these findings, Stevens et al. (2012a) conducted a study to explicitly investigate the risk of GRSG collisions with fencing. Their work in Idaho suggests that fence collision risk is influenced by a variety of factors, including time of the year, fence structure, fence density, topographical ruggedness, and distance to the nearest lek. Based on findings, Stevens et al. (2013) developed a spatial model predicting areas of high, moderate, and low-risk fencing throughout the GRSG range.

Marking human infrastructure to increase its visibility is a common practice for reducing collisions for a variety of avian species (Luzenski et al. 2016). Stevens et al. (2012b) evaluated the effectiveness of fence markers in reducing GRSG collisions and found marked fences reduced GRSG collisions by 83% in high risk areas during the breeding season. Another study demonstrated fence markers reduced GRSG collisions by 61% (Christiansen 2009). These studies demonstrating the effectiveness of markers in reducing collisions have spurred a large-scale marking and fence-moving effort throughout significant portions of the GRSG range. The Sage Grouse Initiative 2015 annual report states that 350 miles of high-risk fence have been marked or moved since its inception (NRCS 2015).

Although fence markers are widely touted for their effectiveness in preventing GRSG collisions, there is only a single peer-reviewed study evaluating marker effectiveness to date (Stevens et al. 2012b). Additionally, although several marker styles are currently being deployed on the landscape, the work by Stevens et al. tested the effectiveness of a single marker style (white markers with reflective tape). Lastly, the collision risk map for the GRSG range was based on data collected in Idaho alone (Stevens et al. 2013). Therefore, in this study we attempted to (1) validate the efficacy of the GRSG collision risk map in predicting collision risk in high and moderate-risk areas of our study area in Sublette County, Wyoming, (2) investigate how local and landscape features impact the relative risk of GRSG collisions, and (3) test the efficacy of three different types of fence markers in reducing collisions. We attempted to explicitly test the following hypotheses: (1) collision risk will be greater along fence segments with higher proportions of the fencing falling within high risk areas of our study site as designated by the collision risk map created by Stevens et al. (2013), (2) collision risk will be higher along fencing with a larger number of occupied leks within 4km, (3) collision risk will be higher along fencing near leks with larger numbers of greater sage-grouse counted during lek counts, (4) collision risk will be higher along fencing with a larger "exposure angle" (i.e., the angle created by the triangle between the ends of the fence segment and the associated lek), (5) collision risk will be greater along fencing in close proximity to an active lek, (6) collision risk will be greater along fencing with a larger amount of fencing extending above the vegetation, (7) collision risk will be greater along fencing with t-posts than along fencing with wooden posts, (8) collision risk will be greater along un-marked fencing compared to fencing with any variety of fence markers installed, (9) among marked fencing, collision risk would be minimized along fence segments outfitted with Fly Safe markers, intermediate along fence segments outfitted with white markers with reflective tape, and greatest along fence segments outfitted with white markers without reflective tape.

METHODS

Study Area

Our study occurred on both private and public lands within Sublette County, Wyoming. Sublette County contains some of the highest GRSG population indices within the occupied range (USFWS 2010). It lies within Management Zone II as identified by Stiver et al. (2006). The county covers approximately 3.2 million acres, of which, 80 percent is publicly owned. Elevations within Sublette County range from 6,280 feet to 13,400 feet (Wyoming State Historical Society 2016). Lower elevations are largely characterized as sagebrush steppe habitat with riparian corridors along the Green River and its tributaries. Dominant vegetation within the lower elevation sagebrush steppe largely consists of Wyoming big sagebrush (*Artemesia tridentata ssp. wyomingensis*) and basin big sagebrush (*Artemesia tridentate ssp. tridentata*).

Sampling Design

We developed the sampling frame for Sublette County, Wyoming, using the 3km-radius collision risk polygons (Stevens et al. 2013) for GRSG leks represented in the Wyoming Game and Fish Department lek database (Christianson et al. 2012). We reclassified the high and moderate risk zones into a single

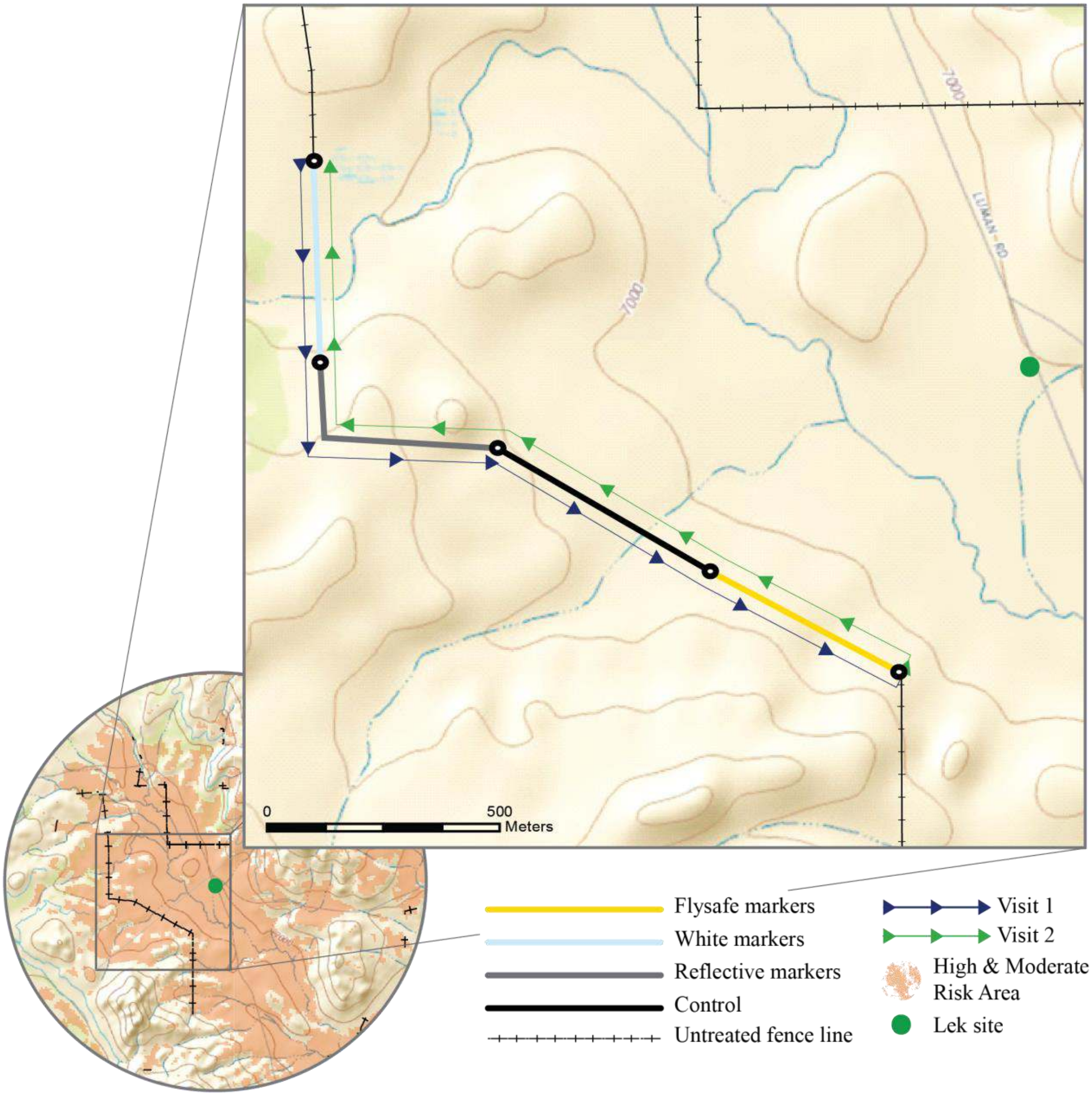

Figure 1. Illustration of four treated segments of fence-line associated with a focal lek.

collision risk category and omitted the low risk zone for each of the 308 lek polygons in Sublette County (Figure 1) using a Geographic Information System (GIS, ArcGIS Version 10.0, Environmental Systems Research Institute, Redlands, CA). Next, we intersected the combined high and moderate risk zone for the lek polygons with the Bureau of Land Management fence database (D. Woolwine personal communication). The sampling frame consisted of 77 lek polygons containing a minimum of 2km of fence within the combined high and moderate risk zone of the lek polygons. We defined the sampling unit as the lek, which was represented by the 3km-radius collision risk polygon (Stevens et al. 2013).

We selected a spatially balanced sample of 26 lek polygons using Generalized Random Tessellation Stratification (GRTS, Stevens and Olsen 2004). We determined land ownership from the Sublette County Assessor's Office and requested permission to access the sampling units in the rank order of the GRTS sample selection. When landowners denied permission, we selected the next highest rank order of the GRTS sample selection. A useful feature of the GRTS design is the spatially balanced property of the sample was maintained when private landowners denied permission to access the sampling units (Stevens and Olsen 2004).

Treatments

Treatments were randomly applied to 500m stretches of fencing nearest the lek within selected sample units. Treatments were defined as control (no marker), white (approximately 3" long piece of white vinyl siding), reflective (white markers with a 3" X 0.5" long strip of yellow reflective tape applied to each side), and Fly Safe markers (http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_040072.pdf, http://www.flysafellc.com/). For the 500m stretches receiving the white, reflective, or Fly Safe treatments, markers were spaced approximately 1m from fence-posts and other markers on the top wire of the fencing to be consistent with fence marking recommendations (USDA 2016).

Sampling Methods

Observers trained in GRSG feather identification and possessing extensive biological survey experience conducted field work. Surveyors were intensively trained to ensure they possessed a complete understanding of field protocols, a sufficient ability to identify collision events, and could positively identify GRSG remains.

Observers conducted fence-line collision surveys following protocol established by Bird Conservancy of the Rockies with input from Tom Christiansen of the Wyoming Game and Fish Department. Surveys were conducted approximately biweekly in March and April of 2014 and 2015. A survey of a site entailed either two or four visits. The first visit consisted of an observer walking along the site's fence while scanning for evidence of animal collisions. The observer then crossed the fence and conducted the second visit by doubling back and walking to the starting point of the first visit (Figure 1). A survey consisted of four visits when a second observer, surveying separately from the first observer, visited the same site on the same day. For these surveys the two observers each independently conducted two visits as described above, for a total of four visits. Observers did not discuss findings during the course of the surveys in order to avoid influencing detection rates.

Observers maintained a distance of 1-2m from the fence during each visit. While surveying, observers primarily searched the wires of the fence for signs of a collision; typically, this consisted of feathers stuck between strands or on a barb of the fencing. Additionally, observers scanned the bushes and ground approximately 10m out from either side of the fence. Observers recorded ocular estimates of average snow and cloud cover estimates during the course of each survey.

We considered a collision to have occurred when GRSG feathers were observed in the wires or barbs of a fence. Collisions were recorded on each visit during which they were observed. In the event that feathers were found on the fence at multiple locations within a panel, the evidence was considered a single collision unless the largest gap between feathers on the wire was greater than 40" (GRSG wingspans average 38" for males and 33" for females (Sibley 2000)), or unless the animal remains were indicative of multiple individuals.

Observers thoroughly documented all collisions found through use of a camera and written notes. Observers recorded collision locations with a hand-held Global Positioning System (GPS) unit. Additionally, observers recorded the following information pertaining to the collision evidence: the distance from the evidence on the fence to the nearest fence-post, the distance from the evidence on the fence to the nearest marker, the distance from the ground (or top of the snow layer, when applicable) to the highest evidence on the fence, and the strand of wire containing the collision evidence. Finally, the observers collected the following data to describe the collision site: the distance between the two fence-posts for the panel containing the evidence, the mean height of the vegetation along the fence panel containing the collision evidence, and the number of strands of wire on the panel of fencing containing the evidence. Observers recorded the species associated with the collision evidence when known. Collision events were only identified to species when diagnostic feathers were found; otherwise the species associated with the collision event was considered unknown.

Occasionally feathers in the fence were thought to be associated with possible perching or predation events. Possible perching events were characterized by a very small amount of down lightly stuck on the fence wire with no other evidence in close proximity. Possible predation events were characterized by (1) GRSG remains being very lightly stuck or draped over a fence wire located immediately under, or adjacent to, a fence-post or (2) feathers concentrated around a fence-post and not along the fence wire. In all cases, data resulting from a possible perching or predation event were removed from analyses.

Observers did record instances in which flight feathers and/or a substantial clump of body feathers were observed near the fence if there were no feathers adhered to the fence itself. These observations were classified as either “Likely” or “Possible”. The minimal evidence required to categorize an event as “Likely” consisted of the presence of a significant amount of flight and/or body feathers localized around the wire or leading from the wire; however, “likely” collision events were frequently characterized by significant portions of a GRSG carcass laying on the ground/or in the bushes. “Possible” strikes were characterized by a significant amount of body feathers (but <20), bones on the ground, or a smaller amount of body feathers (<10) in conjunction with 1 or 2 flight feathers. The “Possible” strike classification was also used for evidence that appeared to be very old or was less heavily concentrated around the wire. A small amount of body feathers and one or two flight feather were not considered a “Likely” or “Possible” collision because this loss of feathers may have resulted from preening behavior or been carried on the wind, for example. In total, 96 unique instances of “Likely” or “Possible” collisions were recorded. “Likely” and “Possible” collision data were excluded from data analyses because we were uncertain if the evidence was the result of a collision with fencing.

Covariate Data Collection

We estimated the average height of woody vegetation and measured the height of the top strand of fencing in centimeters between fence-posts (two fence-posts and fencing in between is hereafter referred to as a “panel”). We then subtracted the height of the woody vegetation from the height of the top wire of fencing to obtain a value of “fence exposure” in centimeters for the panel. We measured these values for six panels within each 500m stretch of fencing at 100m intervals. The fence exposure values for each of the six panels per stretch were then averaged to derive a single mean fence exposure value for the stretch.

Using ArcGIS 10.0 (ESRI) we calculated the number of occupied GRSG leks within 4km of the lek the sum of lek count mean values in 2014 and 2015 for all leks within 4km radius of the fence segment midpoint, the distance from the midpoint of each fence segment to the nearest occupied GRSG lek, the proportion of each fence segment that fell within the high risk category of the collision risk map (Stevens et al. 2013), and the angle of exposure for each segment of fence (i.e., the angle created by the triangle between the ends of the fence segment and the associated lek).

Lastly, observers estimated cloud cover to the nearest 10% during each survey and percent of the ground covered by snow. In 2014 observers recorded a single value for the average snow cover values surrounding each of the four fence segments during a survey. In 2015 observers recorded a separate value for average percentage of snow cover along each fence segment. For analyses purposes we calculated the mean of the 2015 values for each survey to produce a single snow cover value for the analyses.

Statistical Analyses
We developed a multiscale occupancy model (Nichols et al. 2008, Mordecai et al. 2011, Pavlacky et al. 2012) to estimate occupancy probabilities of collision evidence, and the factors influencing them at site- and fence-segment levels. The model allowed estimation of three parameters that corresponded to each level in the nested sampling design. Replicate visits nested within each survey associated with a fence segment were used to estimate detection and small-scale occupancy, and surveys nested within a site (i.e., lek) were used to estimate large-scale occupancy of all fence segments associated with a lek. All analyses were conducted using Program MARK (version 8.0, White and Burnham 1999) via RMARK (version 2.1.14 Laake 2013). We defined our three general parameters as: (1) the probability that evidence of $\geq$1 new GRSG collision was present on $\geq$1 fence segment at site i during any of the surveys, ψ_i, (2) the probability that evidence of $\geq$1 new collision was present at a fence segment during survey j, θ_{ij}, and (3) the probability that a new collision was detected on visit k, given the fence segment was occupied during survey j, p_{ijk}. We assumed fence segments were closed to changes in occupancy during each survey and that new collisions were accurately identified and recorded. This model also assumes that detections are independent; however, observers conducted the second visit on the opposite side of the fence immediately after the first visit. We attempted to account for this potential lack of independence by estimating separate detection probabilities for the first and second visits by the same observer during a survey period along with whether a collision was detected during the first visit.

Model Set
To investigate our hypotheses regarding the factors influencing large- and small-scale occupancy and detection, the models in our model set consisted of various combinations of covariates on each parameter. These covariates included: (1) fixed year effects, (2) the number of occupied leks within 4km of the focal lek, and (3) the sum of the lek counts for leks within 4km of the focal lek for large-scale occupancy (ψ); (1) fixed year effects, (2) treatment effects (for each marker type), (3) marker effects (marked vs. control), (4) fence exposure angle, (5) the distance (km) between the midpoint of the fence segment and the nearest lek, (6) fence exposure (i.e., the mean value of fence height minus vegetation height recorded at the six locations along fence segments), (7) the proportion of the fence segment in high risk areas (based on the collision risk map created by Stevens et al. (2013)), (8) post type (i.e., wood, t-post-, or both), and (9) fixed survey effects for small-scale occupancy (θ); and (1) fixed visit effects, (2) fixed survey effects, (3) fixed observer effects, (4) "trap effects" for the 2nd and 4th visits (to account for potential lack of independence between visits by the same observer), (5) "trap effects" accounting for whether a collision was detected or not on the 1st visit, (6) cloud cover, and (7) snow cover for detection (p). Because the model set was very large when considering all possible combinations of covariates, we used a sequential approach to model selection. Using a general model structure, including additive effects for all covariates, for large- (ψ) and small-scale (θ) occupancy, we fit models that included all possible additive combinations of factors thought to influence detection probability. Then, using the most parsimonious detection structure(s), we tested our hypotheses related to large-scale occupancy. Retaining the best large-scale occupancy model structure(s), we fit models that included all possible additive combinations of factors thought to influence small-scale occupancy. Large-scale occupancy had two covariates that were different measures of the same hypothesis: (1) the number of occupied leks within 4km of the focal lek and (2) the sum of the lek counts for leks within 4km of the focal lek. We did not include both covariates in the same model. Therefore, we included the global model structure on ψ for each of the covariates when performing the stepwise model selection on detection probabilities, which doubled the number of models fit during this step in the model selection process.

We used an information-theoretic approach for model selection and used Akaike's Information Criterion (AIC) adjusted for sample size (AIC_c) for model comparison (Burnham and Anderson 2002). We used Akaike weights, w_i, as a measure of the relative amount of evidence for each model and used cumulative weights $[w_+(j)]$ to determine the relative importance of our covariates. Cumulative weights rely on a balanced model set, so we only calculated them for covariates influencing small-scale occupancy.

RESULTS

We found evidence of 64 confirmed fence collisions by GRSG during the study, with 15 detected in 2014 and 49 detected in 2015. Additionally, we observed 96 instances of possible or likely collisions which were not included in analyses. Over 60% of sites (16 of 26) and 26% of fence segments (27 of 104) contained evidence of $\geq$1 confirmed collision. Only two fence segments were constructed using t-posts exclusively, and no collisions were detected at those segments; therefore, we fixed small-scale occupancy (θ) of those segments to zero to assist with numerical convergence.

Our most general models included year and either the number of nearby occupied leks or the sum of the lek counts at those leks effects on large-scale occupancy, ψ (year + occ.leks) or ψ (year + sum.leks); year, survey, treatment, distance to nearest lek, fence angle to lek, proportion in high risk areas, fence exposure, and post type effects on small-scale occupancy, θ (year + surv + trt + dist + angle + risk + fence.exp + post.type); and observer, cloud cover, snow cover, and visit effects on detection, p (obs + cloud + snow + visit) (Appendix A).

Detection probabilities

Using these two global models, we explored 40 other detection structures, representing simplifications of our general detection structure (Table 1, Appendix A). The most parsimonious model included a constant detection probability (w = 0.51), as did the 2nd best model, cumulatively accounting for 76.4% of the weight; thus we retained this detection structure, p (.), in our subsequent models. We estimated the probability of detecting $\geq$1 collision at 0.935 (SE=0.026).

Large-scale occupancy

Large-scale occupancy of collisions increased as the sum of nearby lek counts increased and was higher in 2015. However, the 95% confidence intervals for both of these effects included zero. Because of this uncertainty, the most parsimonious model for ψ was the constant model, which accounted for a majority of the AIC_c weight (w = 0.71) (Table 2, Appendix A). On average, large-scale occupancy was estimated to be 0.750 (SE = 0.123).

Small-scale occupancy

We found strong evidence for effects of post type and distance to the nearest lek on small-scale occupancy [w_+(post.type) = 0.999, w_+(dist) = 0.995]. Year [w_+(year) = 0.767], whether a fence was marked or not [w_+(mark) = 0.722], fence exposure [w_+(fence.exp) = 0.697], and survey [w_+(survey) = 0.541] were less, but still substantially, influential, and risk [w_+(risk) = 0.280], fence angle to lek [w_+(angle) = 0.144], and separate treatment effects [w_+(trt) = 0.023] had little support (Table 3, Appendix A). Consistent with our hypotheses, fence marking and distance to nearest lek resulted in lower collision occupancy probabilities (Figure 2); any type of marker reduced the probability of $\geq$1 collision by 58.3% compared to an unmarked fence, and a 940m increase in distance between a fence and a lek resulted in a 64.2%

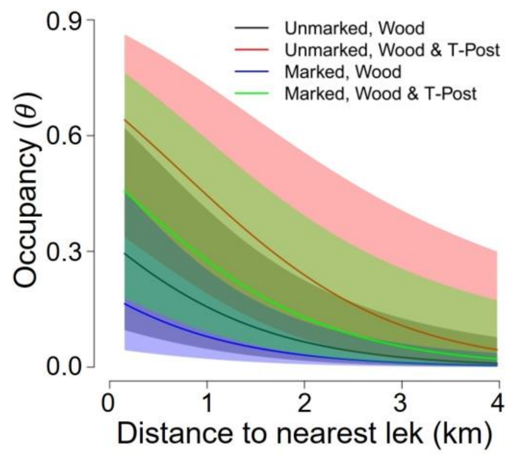

Figure 2. Collision probability and associated 95% confidence intervals at various distances from a lek for marked and unmarked segments of fence with wooden posts only and both wood and T-posts.

reduction in occupancy probabilities. A 15cm increase in fence exposure resulted in a 39.1% increase in collision occupancy probabilities (Figure 3). Occupancy probabilities were higher in 2015 and during the 1st survey but were fairly consistent for all other surveys. All marker types performed similarly, with reflective ($\beta = -0.990$, SE = 0.478, 95% CI = -1.927, -0.053) and white ($\beta = -0.880$, SE = 0.460, 95% CI = -1.782, 0.022) reducing occupancy probabilities slightly more than the Fly Safe markers ($\beta = -0.693$, SE = 0.458, 95% CI = -1.591, 0.205). Only three leks were visited during survey 7 and no collisions were detected resulting in poor estimation of the coefficient for that survey.

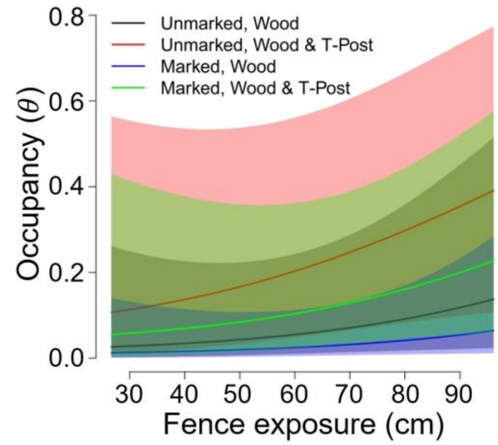

Figure 3. Collision probability and associated 95% confidence intervals with different amounts of exposed fencing for marked and unmarked segments of fence with wooden posts only and both wood and T-posts.

DISCUSSION

The continuing decline of GRSG is of major concern to land managers and producers throughout the western United States. Increases in anthropogenic disturbance have been shown to have negative impacts on GRSG. Because the SGI prescribed grazing practices often require considerable cross fencing, a rigorous evaluation of the efficacy of fence markers for reducing GRSG collision mortality is needed (USFWS 2010).

We adapted the multi-scale occupancy framework to investigate landscape- and local-level factors influencing the probability of fence collision, and our results support the anecdotal and limited empirical evidence for the threat of fences to GRSG (Scott 1942, Flake et al. 2010, Christiansen 2009, Stevens et al. 2012a,b). We also provided insight into the factors influencing fence collisions at two spatial scales by using the multiscale occupancy model. This approach also allowed us to account for the potential lack of independence between fence segments associated with a particular lek (Nichols et al. 2008, Pavlacky et al. 2012).

We found the proximity of a fence segment to a lek influenced the probability of a collision; the average occupancy probability decreased by 50% between distances of 153m (i.e., smallest distance observed) to 1km. This is consistent with the findings of Stevens et al. (2012a,b). This relationship is likely due to increased encounters between birds and fences when a fence is closer to an area where birds congregate, such as a lek. Unlike Stevens and colleagues, we found little evidence for an effect of the number of birds using nearby leks on collision probabilities. This may be due to a lack of power of occupancy models to detect differences among leks of various sizes, such that the probability of $\geq$1 collision is high for a fence near even a smaller lek. Lek counts have been criticized for their inability to accurately reflect abundance of GRSG (Beck and Braun 1980, Walsh et al. 2004, Johnson and Rowland 2007) but have been shown to be a reasonable index of the population of breeding males when standard survey protocols are followed (Jenni and Harzler 978, Emmons and Vraun 1984, Walsh et al. 2004, Johnson and Rowland 2007). However, lek counts may not accurately represent the number of birds in the area surrounding a lek, and therefore, may be a poor indicator of the likelihood of a collision.

Our study design was largely based off the collision risk map developed by Stevens et al. (2013) which predicted high risk of collisions in areas close to leks and with little topography. The authors acknowledged their range-wide model was created using data collected within a relatively small geographic area in Idaho. As such, they recommended additional validation efforts be conducted.

Unfortunately, our study in Sublette County, Wyoming did not support the assertion that the high and moderate collision zones were an accurate predictor of collision risk. In contrast, our study indicated similar collision rates in the high and moderate risk zones. Because we attempted to select fence-line segments within the high and moderate risk areas of this map, much of the fence-line included in our study did fall within either high or moderate risk areas according to the collision prediction map. Therefore, we did not collect large amounts of data across the entire spectrum of collision risks (low risk areas were not represented in our study) which precluded an evaluation of the low risk areas of the risk map. We recommend further investigation of the efficacy of the collision risk map in predicting collision risk; particularly to determine if greater slopes associated with topography does indeed impact collision risk and to determine if low risk areas on the collision risk map do indeed have a lower number of associated fence collisions. Until the collision risk map can be evaluated further, we recommend that managers seeking to reduce collisions focus their fence-marking efforts on fence-lines in both the high and moderate risk zones which are both close to leks and possess local site characteristics which have been shown to increase collision risk in our study and/or by Stevens et al. (2012b).

Our results suggest that all three types of fence markers employed in our research were effective at reducing collision probabilities. Stevens et al. (2012b) saw an 83% reduction in collisions using reflective markers. Reflective markers were the most effective marker type in our study, but we only found a 63% reduction in collision probability. The smaller effect observed in our study may be due in part to less resolution to detect covariate effects when using occupancy models compared to abundance measures because counts are summarized to presence or absence. In addition, the smaller effect observed in our study may be partially related to accounting for incomplete detection of GRSG collisions. The estimated detection rate was 0.94 which suggested a false absence rate of 6% in the raw collision data. Despite the lack of resolution, and accounting for incomplete detection, we still found strong effects of markers on reducing collisions. Unlike Stevens et al. (2012b), we were able to test the effectiveness of several marker types. We found little difference in the effectiveness of the three marker types, as models with a marker effect (for any marker type) had substantially more cumulative AIC_c weight than models with effects for all marker types individually. However, contrary to our hypothesis, Fly Safe markers were slightly less effective than both white and reflective markers. We estimated average per marker costs of white markers at $0.14, reflective markers at $0.71, and Fly Safe markers at $0.40. Therefore, we recommend using the plain white markers without reflective tape, as they were more effective and less expensive than the Fly Safe markers and nearly as effective as the more expensive reflective markers.

As in Stevens et al. (2012a), our results suggest that fence-post type has the largest effect on the occupancy probability of GRSG collisions, with the lowest occupancy probabilities for fence segments with wooden posts. Only two fence segments in our study had t-posts exclusively and neither of those segments had evidence of a collision on them; therefore, we were unable to estimate occupancy probabilities for segments with only t-posts. Unmarked fence segments with wooden posts had lower occupancy probabilities than segments with both wooden and t-posts and any of the fence markers. This suggests that preferentially marking fencing with t-posts could maximize the reduction in potential GRSG collisions with fencing.

Finally, we found a small effect of the amount of exposed fencing on collision risk. As vegetation height near a fence decreased, the probability of a collision increased. GRSG generally fly above the vegetation and are, therefore, less likely to collide with a fences when the vegetation approaches the top strand of wire. Though this relationship was weak, areas with short vegetation may benefit more from the use of markers by making the fence more visible to GRSG. Similarly, we suggest that taller "elk fences" may increase collision risk beyond that of standard fencing due to the additional fencing projecting above the vegetation. This idea was not explicitly tested in our study and represents an area for future research.

LITERATURE CITED

Baines, D. and Andrew, M. 2003. Marking of deer fences to reduce frequency of collisions by woodland grouse. Biological conservation, 110(2): 169-176.

Beck, J.L., Reese, K.P., Connelly, J.W. and Lucia, M.B., 2006. Movements and survival of juvenile greater sage-grouse in southeastern Idaho. Wildlife Society Bulletin, 34(4): 1070-1078.

Bevanger, K., 1995. Estimates and population consequences of tetraonid mortality caused by collisions with high tension power lines in Norway. Journal of Applied Ecology, 32: 745-753.

Bevanger, K. and Brøseth, H., 2001. Bird collisions with power lines—an experiment with ptarmigan (*Lagopus spp.*). Biological Conservation, 99(3): 341-346.

Braun, C. E. 1998. Sage Grouse declines in western North America: what are the problems? Proc. West. Assoc. State Fish and Wildl. Agencies, 78:139-156.

Christiansen, T. 2009. Fence marking to reduce greater sage-grouse (*Centrocercus urophasianus*) collisions and mortality near Farson, Wyoming – summary of interim results. Wyoming Game and Fish Department.

Christiansen, T. 2012. Chapter 12: sage grouse (*Centrocercus urophasianus*). Pages 1 - 55 in S. A. Tessmann, and J. R. Bohne, editors. Handbook of biological techniques. Third edition. Wyoming Game and Fish Department, Cheyenne, Wyoming, USA.

Connelly, J. W. and C. E. Braun. 1997. Long-term changes in Sage Grouse (*Centrocercus urophasianus*) populations in western North America. Wildlife Biology, 3:229-234.

Connelly, J.W., M.A. Schroeder, A.R. Sands, and C.E. Braun. 2000. Guidelines for management of sage grouse populations and habitat. Wildlife Society Bulletin, 28:967-985.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming.

Crawford, J.A., Olson, R.A., West, N.E., Mosley, J.C., Schroeder, M.A., Whitson, T.D., Miller, R.F., Gregg, M.A. and Boyd, C.S., 2004. Ecology and management of sage-grouse and sage-grouse habitat. Rangeland Ecology & Management, 57(1): 2-19.

Flake, L.D., J.W. Connelly, T.R. Kirschenmann, and A.J. Lindbloom. 2010. Grouse of plains and mountains: the South Dakota story. South Dakota Department of Game, Fish, and Parks, Pierre, South Dakota, USA.

Knick, S.T., and J.W. Connelly. 2011. Greater sage-grouse and sagebrush: An introduction to the landscape. Introduction in S.T. Knick, and J.W. Connelly, eds. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology. 38th. University of California Press, Berkeley, USA. Pp. 24

Kuvlesky, W.P. Jr, L.A. Brennan, M.L. Morrison, K.K. Boydston, B.M. Ballard, and F.C. Bryant. 2007. Wind energy development and wildlife conservation: challenges and opportunities. Journal of Wildlife Management, 71: 2487-2498.

Johnson, D. H., M. J. Holloran, J. W. Connelly, S. E. Hanser, C. L. Amundson, and S. T. Knick. 2011. Influences of environmental and anthropogenic features on greater sage-grouse populations, 1997-2007. Pages 407—450 in S. T. Knick and J. W. Connelly, editors. Greater sage grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology Series, Volume 38, University of California Press, Berkeley, USA.

Luzenski,J., C. E. Rocca, R. E. Harness, J. L. Cummings, D. D. Austin, M. A. Landon and J. F. Dwyer. 2016. Collision avoidance by migrating raptors encountering a new electric power transmission line The Condor 118:402-410.

Miller, R.F. and Tausch, R.J., 2000, November. The role of fire in pinyon and juniper woodlands: a descriptive analysis. In Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species. Fire conference, pp. 15-30.

Miller, R.F. and R.J. Tausch. 2001. The role of fire in juniper and pinyon woodlands: a descriptive analysis, p. 15–30. In: K.E.M. Galley and T.P. Wilson (eds.) Proc. Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Misc. Pub. No. 11, Tall Timbers Res. Sta. Tallahassee, Fla.

Moss, R., Picozzi, N., R.W. Summers. and D. Baines. 2000. Capercaillie Tetrao urogallus in Scotland-demography of a declining population. Ibis, 142(2): 259-267.

Natural Resources Conservation Service (NRCS). 2015. Outcomes in Conservation: Sage Grouse Initiative. <http://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=stelprdb1270408&ext=pdf > (accessed 02.16)

Nichols, J.D., L.L. Bailey, A.F. O'Connell, Jr., N.W. Talancy, E.H.C. Grant, A.T. Gilbert, E.M. Annand, T.P. Husband, and J.E. Hines. 2008. Multi-scale occupancy estimation and modelling using multiple detection methods. Journal of Applied Ecology, 45: 1321-1329.

Patten, M.A., Wolfe, D.H., Shochat, E. and Sherrod, S.K., 2005. Effects of microhabitat and microclimate selection on adult survivorship of the lesser prairie-chicken. Journal of Wildlife Management, 69(3): 1270-1278.

Pavlacky, D.C., Jr., J.A. Blakesley, G.C. White, D.J. Hanni, and P.M. Lukacs. 2012. Hierarchical multi-scale occupancy estimation for monitoring wildlife populations. Journal of Wildlife Management, 76: 154-162.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (Centrocercus urophasianus). in A. Poole and F. Gill (eds.) The birds of North America, No. 425. The Birds of North America, Inc. Philadelphia, Pennsylvania.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S. J. Stiver. 2004. Distribution of sage-grouse in North America. Condor 106: 363-376.

Scott, J.W. 1942. Mating behavior of the sage-grouse. Auk, 59, 477-498.

Sibley, D.A. 2000. The Sibley Guide to Birds. Alfred A. Knopf, New York, NY.

Smith, J. A. and J. F. Dwyer. 2016. Avian interactions with renewable energy infrastructure: An update The Condor 118:411-423.

Stevens, B.S., J.W. Connelly, and K.P. Reese. 2012a. Multi-scale assessment of greater sage-grouse fence collision as a function of site and broad scale factors. The Journal of Wildlife Management, 76(7): 1370-1380.

Stevens, D. L., Jr., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99: 262-278.

Stevens, B.S., K.P. Reese, J.W. Connelly, and D.D. Musil. 2012b. Greater sage-grouse and fences: does marking reduce collisions? Wildlife Society Bulletin, 36(2): 297-303.

Stevens, B.S., D.E. Naugle, J.W. Connelly, T. Griffiths, and K.P. Reese. 2013. Mapping sage-grouse fence-collision risk: spatially explicit models for targeting conservation implementation. Wildlife Society Bulletin, 37(2): 409-415.

Stiver, S.J., A.D. Apa, J.R. Bohne, S.D. Bunnell, P.A. Deibert, S.C. Gardner, M.A. Hilliard, C.W. McCarthy, and M.A. Schroeder. 2006. Greater Sage-grouse Comprehensive Conservation Strategy. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming.

Swenson, J.E., Simmons, C.A. and Eustace, C.D. 1987. Decrease of sage grouse *Centrocerus urophasianus* after ploughing of sagebrush steppe. Biological Conservation, 41(2):125-132.

United States Department of Agriculture (USDA). 2015. Release No. 0238.15. http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2015/08/0238.xml&printable=true&contentidonly=true (accessed 03.16).

United States Department of Agriculture (USDA). 2016. How To Make and Install Fence Markers For Sage-grouse. http://www.sagegrouseinitiative.com/wp-content/uploads/2013/07/NRCD-SGI_FenceMarker_Instructions.pdf (accessed 06.16).

United States Fish and Wildlife Service (USFWS). 2010. Endangered and threatened wildlife and plants; 12-Month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered. 50 CFR Part 17.

United States Fish and Wildlife Service (USFWS). 2010. Conference report for the Natural Resources Conservation Service Sage-grouse Initiative (SGI). U. S. Department of Agriculture, Natural Resources Conservation Service and U. S. Department of Interior, Fish and Wildlife Service, Washington D.C., USA.

United States Fish and Wildlife Service (USFWS). 2015. Endangered and threatened wildlife and plants; 12-month findings for petition to list greater sage-grouse (Centrocercus urophasianus) as an endangered or threatened species. 50 CFR Part 17.

Wolfe, D.H., Patten, M.A., Shochat, E., Pruett, C.L. and Sherrod, S.K., 2007. Causes and patterns of mortality in lesser prairie-chickens Tympanuchus pallidicinctus and implications for management. Wildlife Biology, 13(1): 95-104.

Wyoming State Historical Society. Accessed 3/8/2016. http://www.wyohistory.org/encyclopedia/sublette-county-wyoming

Yocom, C. N. 1956. The sage hen in Washington State. Auk 73:540-550.

APPENDIX A

Table 1. Model set for models explaining variation in detection probabilities (p) of Greater Sage-Grouse fence collisions in Wyoming, 2014-2015. We fit models using the most general small- (θ) and large-scale (ψ) occupancy probability model structures. Because two covariates on each occupancy probability were different measures of similar hypotheses, we included both model structures on each of those parameters. Covariates included to explain variation in detection probabilities included: fixed visit effects (time), fixed survey effects (surv), fixed observer effects (obs), "trap effects" for the 2nd and 4th visits (trap), "trap effects" accounting for whether a collision was detected or not on the 1st visit (trap.2), cloud cover (cloud), and snow cover (snow). Model structures on small-scale occupancy included: distance to nearest lek, fence exposure, wood post or t-post, proportion of fence segment in high risk areas, angle of fence in relation to lek , year, biweekly (primary) period plus either marker type (trt) or marked vs. unmarked (mark; indicated in θ column). Model structures on large-scale occupancy included: year and either the sum of lek counts at nearby leks (sum.lek) or the number of nearby occupied leks (occ.leks; indicated in ψ column). The number of parameters (npar), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference between a model's AICc value and the minimum AICc value (ΔAIC_c), and AIC_c weights are also shown for models with a $\Delta AIC_c \leq 10$.

ψ	θ	*p*	npar	AIC_c	ΔAIC_c	weight
sum.lek	mark	null	19	374.95	0.00	0.51
occ.leks	mark	null	19	376.39	1.44	0.25
sum.lek	mark	snow	20	379.97	5.02	0.04
sum.lek	mark	surv	20	380.24	5.29	0.04
sum.lek	mark	cloud	20	380.43	5.48	0.03
sum.lek	mark	trap.2	20	380.43	5.48	0.03
occ.leks	mark	snow	20	381.41	6.46	0.02
occ.leks	mark	surv	20	381.68	6.73	0.02
occ.leks	mark	cloud	20	381.87	6.91	0.02
occ.leks	mark	trap.2	20	381.87	6.92	0.02

Table 2. Model set for models explaining variation in large-scale occupancy probabilities (ψ) of Greater Sage-Grouse fence collisions in Wyoming, 2014-2015.We fit models using the most parsimonious model on detection probabilities (i.e., null) and the most general model structure on small-scale occupancy probabilities (θ). Model structures on large-scale occupancy included: year and either the sum of lek counts at nearby leks (sum.lek) or the number of nearby occupied leks (occ.leks; indicated in ψ column). Because two covariates on small-scale occupancy probabilities were different measures of a similar hypothesis, we included both model structures on each of those parameters. Model structures on small-scale occupancy included: distance to nearest lek, fence exposure, wood post or t-post, proportion of fence segment in high risk areas, angle of fence in relation to lek , year, biweekly (primary) period plus either marker type (trt) or marked vs. unmarked (mark; indicated in θ column). The number of parameters (npar), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference between a model's AICc value and the minimum AICc value (ΔAIC_c), and AIC_c weights are also shown for models with a $\Delta AIC_c \leq 10$.

ψ	θ	npar	AIC_c	ΔAIC_c	weight
null	mark	17	367.09	0.00	0.71
sum.lek	mark	18	370.94	3.85	0.10
year	mark	18	371.40	4.31	0.08
occ.leks	mark	18	371.63	4.54	0.07
year + sum.lek	mark	19	374.95	7.86	0.01
year + occ.leks	mark	19	376.39	9.30	0.01
null	trt	19	376.63	9.54	0.01

Table 3. Model set for models explaining variation in small-scale occupancy probabilities (θ) of Greater Sage-Grouse fence collisions in Wyoming, 2014-2015.We fit models using the most parsimonious model on detection probabilities (i.e., null) and large-scale occupancy probabilities (i.e., null). Model structures on small-scale occupancy included: distance to nearest lek (min.dist), fence exposure (fnc.exp), wood post or t-post (post.type), proportion of fence segment in high risk areas (risk), angle of fence in relation to lek (angle), marker type (trt), marked vs. unmarked fence (mark), year (year), and biweekly (primary) period (biweek). The number of parameters (npar), Akaike's Information Criterion adjusted for small sample size (AIC_c), difference between a model's AICc value and the minimum AICc value (ΔAIC_c), and AIC_c weights are also shown for models with a $\Delta AIC_c \leq 10$.

θ	npar	AIC_c	ΔAIC_c	weight
min.dist + fnc.exp + post.type + mark + year + biweek	14	355.94	0.00	0.15
min.dist + fnc.exp + post.type + mark + year	8	356.32	0.38	0.12
min.dist + post.type + mark + year + biweek	13	357.60	1.65	0.06
min.dist + fnc.exp + post.type + risk + mark + year	9	357.69	1.74	0.06
min.dist + post.type + year + biweek	12	357.92	1.98	0.05
min.dist + fnc.exp + post.type + mark + biweek	13	358.26	2.32	0.05
min.dist + fnc.exp + post.type + risk + mark + year + biweek	15	358.48	2.54	0.04
min.dist + fnc.exp + post.type + mark	7	358.64	2.70	0.04
min.dist + fnc.exp + post.type + year	7	359.00	3.05	0.03
min.dist + fnc.exp + post.type + angle + mark + year	9	359.11	3.17	0.03
min.dist + post.type + mark + year	7	359.54	3.59	0.02
min.dist + fnc.exp + post.type + risk + mark	8	359.61	3.66	0.02
min.dist + fnc.exp + post.type + risk + year + biweek	14	359.97	4.02	0.02
min.dist + post.type + risk + mark + year + biweek	14	360.12	4.17	0.02
min.dist + post.type + risk + year + biweek	13	360.21	4.27	0.02
min.dist + fnc.exp + post.type + risk + mark + biweek	14	360.32	4.38	0.02
min.dist + fnc.exp + post.type + risk + year	8	360.42	4.48	0.02
min.dist + post.type + mark + biweek	12	360.60	4.66	0.01
min.dist + post.type + year	6	360.79	4.85	0.01
min.dist + fnc.exp + post.type + biweek	12	360.94	4.99	0.01
min.dist + post.type + angle + year + biweek	13	360.97	5.03	0.01
min.dist + post.type + risk + mark + year	8	361.09	5.14	0.01
min.dist + fnc.exp + post.type + angle + year + biweek	14	361.27	5.32	0.01
min.dist + fnc.exp + post.type + angle + mark	8	361.31	5.37	0.01
min.dist + post.type + angle + mark + year + biweek	14	361.32	5.38	0.01
min.dist + fnc.exp + post.type + year + biweek	14	361.37	5.43	0.01
min.dist + fnc.exp + post.type + angle + year	8	361.80	5.85	0.01
min.dist + fnc.exp + post.type + angle + mark + biweek	14	362.06	6.12	0.01
min.dist + fnc.exp + post.type + trt + year	10	362.07	6.13	0.01
min.dist + post.type + biweek	11	362.13	6.19	0.01
min.dist + fnc.exp + post.type + risk + angle + mark	9	362.13	6.19	0.01
min.dist + post.type + risk + year	7	362.24	6.30	0.01
min.dist + post.type + angle + mark + year	8	362.32	6.38	0.01

θ	npar	AIC_c	ΔAIC_c	weight
min.dist + fnc.exp + post.type	6	362.35	6.41	0.01
min.dist + post.type + mark	6	362.49	6.54	0.01
min.dist + post.type + risk + mark + biweek	13	362.91	6.97	0.00
min.dist + fnc.exp + post.type + risk + biweek	13	362.96	7.02	0.00
min.dist + post.type + angle + year	7	363.08	7.14	0.00
min.dist + fnc.exp + post.type + risk + angle + year	9	363.38	7.44	0.00
min.dist + fnc.exp + post.type + risk	7	363.47	7.52	0.00
min.dist + fnc.exp + post.type + risk + angle + mark + year	11	363.64	7.70	0.00
min.dist + post.type + risk + angle + year + biweek	14	363.67	7.73	0.00
min.dist + fnc.exp + post.type + trt + year + biweek	16	363.81	7.87	0.00
min.dist + post.type + risk + mark	7	363.91	7.96	0.00
min.dist + post.type + risk + angle + mark + year	9	364.05	8.10	0.00
min.dist + post.type + angle + mark + biweek	13	364.06	8.11	0.00
min.dist + fnc.exp + post.type + trt	9	364.07	8.13	0.00
min.dist + post.type + risk + angle + mark + year + biweek	15	364.14	8.20	0.00
min.dist + fnc.exp + post.type + angle + mark + year + biweek	16	364.22	8.28	0.00
min.dist + post.type + risk + biweek	12	364.25	8.30	0.00
min.dist + fnc.exp + post.type + angle + biweek	13	364.27	8.33	0.00
min.dist + post.type + angle + biweek	12	364.58	8.64	0.00
min.dist + post.type + risk + angle + year	8	364.81	8.87	0.00
min.dist + fnc.exp + post.type + angle	7	364.96	9.02	0.00
min.dist + post.type + angle + mark	7	365.12	9.17	0.00
min.dist + post.type + trt + year	9	365.25	9.31	0.00
min.dist + post.type + trt + year + biweek	15	365.33	9.38	0.00
min.dist + fnc.exp + post.type + risk + trt	10	365.50	9.55	0.00
min.dist + fnc.exp + post.type + trt + biweek	15	365.59	9.64	0.00