

Influence of transmission line construction on winter sage-grouse habitat use in southern Utah

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Abstract: The construction and operation of electric power transmission lines (“power lines”) and their associated infrastructure has been identified as a conservation threat to the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse). The conservation buffer zones recommended by state and federal agencies to avoid potential impacts on breeding populations differ because information regarding the effects of power lines on sage-grouse is lacking. Little information is available regarding sage-grouse responses to power lines placed in winter habitat. Hence, we evaluated sage-grouse habitat use before and after construction of the Sigurd-Red Butte (SRB) 345-kilovolt (kV) transmission line in winter habitat. The SRB line was constructed in the fall of 2014, and was sited parallel to a pre-existing 500-kV transmission line through salt-desert habitat on the western edge of what is now the Bald Hills Sage-Grouse Management Area (SGMA) in southern Utah. We deployed Global Positioning System (GPS) transmitters on 2 female and 16 male sage-grouse from 2014–2016 and compared collected locations to data independently acquired in the winter of 2011–2012 to determine if the construction of the SRB transmission line altered sage-grouse winter habitat use. Using the 2014–2016 data, we developed a resource selection function (RSF) model to quantify the influence of transmission line presence on sage-grouse movements while accounting for low-quality habitat (salt-desert) near the transmission line. Post-construction data were compared to the 2011–2012 data to evaluate whether RSF-predicted changes in relative probability of use were reflected in actual shifts in habitat use before and after construction. The top RSF model contained a significant negative interaction between distance to transmission line and average salt-desert coverage within a 1-km² moving window. Although a comparison of pre- and post-construction mapped RSFs predicted a decreased probability of winter habitat use in the vicinity of the transmission line corridor as a result of the new line, we did not detect increased avoidance by sage-grouse when comparing spatial distributions between winters using minimum convex polygons. This suggests that immediate negative effects of new transmission line construction can be eliminated by implementing best management practices such as co-locating the transmission line in a preexisting energy corridor where impacts on habitat selection have already occurred, and siting the line in poor-quality habitat that does not fragment existing habitat. However, we caution that there may be other long-term influences of transmission line installation that are outside the scope of our 2-year post-construction study design, and more research is required to assess the influence of transmission lines on sage-grouse winter habitat use over longer timescales.

Key words: anthropogenic infrastructure, *Centrocercus urophasianus*, electric power transmission lines, habitat quality, resource selection function, sage-grouse, Utah

THE U.S. FISH AND WILDLIFE SERVICE (USFWS) attributed the historical range wide declines observed in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) to continued loss and fragmentation of the sagebrush (*Artemesia* spp.) ecosystem in their 2010 decision to list the species as a candidate for protection under the Endangered Species Act of 1973 (USFWS 2010). The sagebrush ecosystem on which sage-grouse depend has undergone extensive alteration since European settlement in the early 1900s as a result of habitat conversion,

degradation, and fragmentation (Connelly et al. 2000, Schroeder et al. 2004). Connelly et al. (2004) suggested that tall structures associated with energy production and transmission may functionally fragment sage-grouse habitat, and thus could have indirect impacts that are more pronounced than direct habitat loss. Tall structures are typically defined as power lines, communication towers, wind turbines, and other similar installations (USFWS 2010, Utah Wildlife in Need® 2010, Messmer et al. 2013).

The best management practices for mitigating

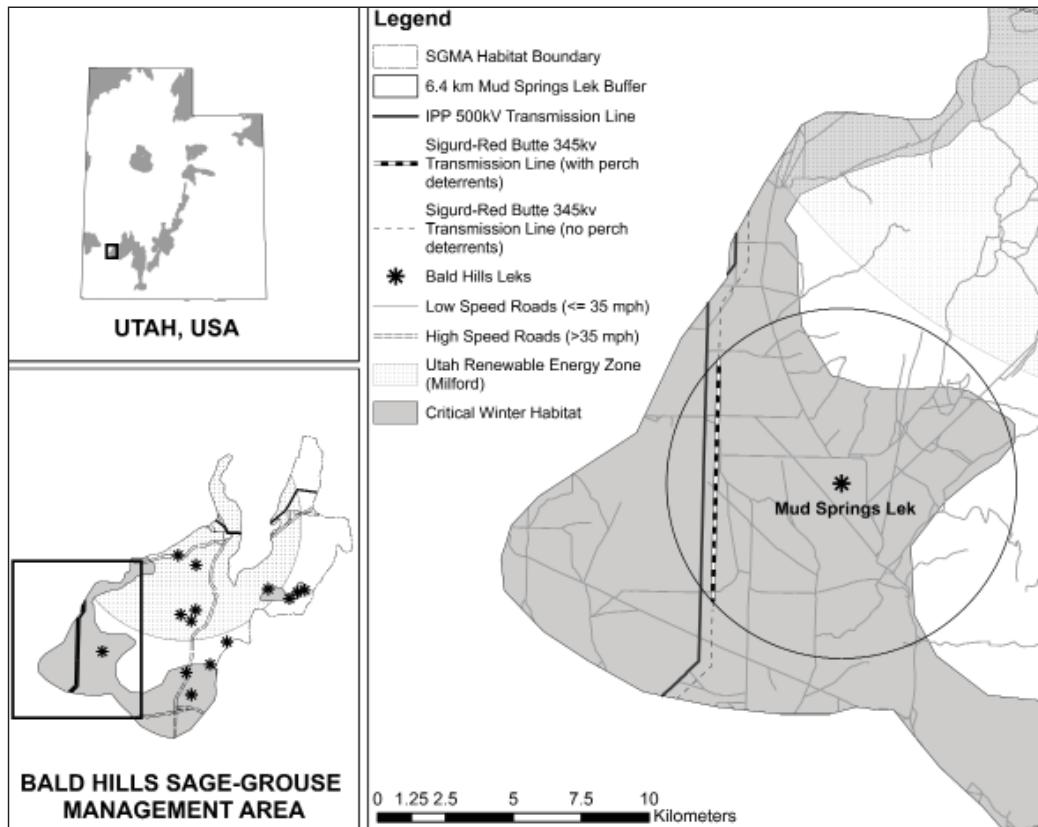


Figure 1. Transmission lines west of the Mud Springs lek in the Bald Hills Sage-Grouse Management Area, southern Utah. The Intermountain Power Project (IPP) 500-kV transmission line (pre-existing) and Sigurd-Red Butte (SRB) 345-kV transmission line (constructed fall 2014) both passed through a 6.4-km no-disturbance buffer surrounding the lek. SRB towers that were within the Mud Springs lek buffer were fitted with perch deterrents. The SRB line, upon completion, was located 4.7 km from the lek at its closest point. The area within the lek buffer was also used heavily by sage-grouse during the winter months.

the impacts of tall structures are largely based on the reasoning that introducing new vertical features and associated infrastructure in a sagebrush landscape where those features are typically rare may increase perching by avian predators, fragment sage-grouse habitat, or promote human traffic in otherwise undisturbed areas (Messmer et al. 2013). However, the extent of these impacts is not well understood (Utah Wildlife in Need® 2010, Walters et al. 2014). Conservation buffer zones recommended by state and federal agencies to avoid potential effects on breeding sage-grouse populations differ throughout the species' range because information is lacking regarding the influence of power lines on sage-grouse (Messmer et al. 2013, Manier et al. 2014).

Wisdom et al. (2011) compared multiple variables between current and extirpated sage-grouse habitat. They found that, among other factors, distance to transmission lines and distance to cellular towers were strongly

associated with sage-grouse extirpation. However, they concluded that the mechanism of this relationship was unknown at a regional scale. Similarly, Gillian et al. (2013) showed that sage-grouse in Idaho avoided transmission lines by 600 m when comparing telemetry locations to a null model. However, Johnson et al. (2011) did not detect an effect of power lines on sage-grouse lek trends between 1997 and 2007 across the species' range.

An empirical study conducted by Messmer et al. (2013) concluded that much of the available research addressing the impacts of tall structures on sage-grouse was related to oil and gas development, only quantified cumulative effects, or did not implicate tall structures themselves as causal agents of negative impacts. Specifically, the mechanism of avoidance and the timescale over which it may occur are not well understood (Utah Wildlife in Need® 2010, Messmer et al. 2013, Walters et al. 2014). One long-term study (Nonne et al. 2013)

directly addressed the impact of transmission line presence on sage-grouse population demographics. They reported that distance to transmission line had no effect on nest site selection and female nesting propensity, a weak effect on male survival, and a strong effect on nest survival and female survival. Little information is available regarding sage-grouse responses to power lines placed in winter habitat.

In 2013, Utah published a state-wide plan (Plan; State of Utah 2013) to facilitate sage-grouse conservation by protecting all seasonal habitats (USFWS 2010, Dahlgren et al. 2016). Because sage-grouse use large landscapes, there is a need to understand seasonal movements and how these movements may be affected by anthropogenic land use such as the construction of power lines in winter range. Hence, we quantified how the addition of a new transmission line to an existing energy corridor influenced sage-grouse winter habitat use before and after construction.

Study area

The Bald Hills Sage-Grouse Management Area (SGMA; study area) was 1 of 11 designated sage-grouse management areas within the state of Utah (State of Utah 2013). The Bald Hills SGMA consisted of 1,343 km² and spanned across Beaver and Iron counties in the southwestern portion of the state. It was located at the southern periphery of the sage-grouse distribution in North America (State of Utah 2013, UDWR 2014; Figure 1). The SGMA included land managed by the Bureau of Land Management (BLM) as well as private stakeholders and state agencies (State of Utah 2013). In 2015, a total maximum count of 148 male sage-grouse was obtained at 14 active leks (J. Nicholes, UDWR, unpublished data).

The Bald Hills SGMA was a mountainous area ranging from 1596 m elevation in the southwest corner, at the Mud Springs lek, to 2314 m elevation in the northwest portion. The average annual precipitation was 26 cm. The study area was located in the Great Basin sagebrush ecosystem (West and Young 2000), which was generally arid and desert-like. Specifically, shrubs were shorter (generally <1 m in height) than those in sagebrush-steppe, were less densely spaced, and were

interspersed with loamy surface soils, microphytic crusts, and sparsely distributed grasses (West and Young 2000). Sagebrush species in the Bald Hills consisted of mountain big sagebrush (*Artemisia tridentata vaseyana*) at upper elevations, black sagebrush (*A. nova*) at lower elevations, and Wyoming big sagebrush (*A. tridentata wyomingensis*) present at moderate elevations (Burnett 2013). Sand sagebrush (*A. filifolia*) was also present in small quantities in the northwestern portion of the study area. The study area also contained significant patches of mixed pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) forest; salt-desert shrub (dominant species included *Artiplex confertifolia*, *Krascheninnikovia lanata*, and *Salicornia* sp.); agricultural fields consisting of alfalfa (*Medicago sativa*) and corn (*Zea* sp.); and disturbed areas that were characterized by both native and non-native forbs and grasses.

The study area contained multiple sources of anthropogenic landscape disturbance (Figure 1). Domestic cattle (*Bos* spp.) and sheep (*Ovis* spp.) grazing were common, and agricultural development was present in the northern portion of the study area near the town of Minersville (population 907, U.S. Census Bureau 2012) and the unincorporated community of Greenville. Two 2-lane, paved highways bisected the study area in the north-south and east-west directions. Additionally, many maintained and unmaintained dirt roads were present throughout the study area. The Bald Hills SGMA also overlapped the Milford Renewable Energy Development Zone, designated by the Utah Renewable Energy Task Force as a region that had high potential for wind and solar development (Black and Veatch Corporation 2010).

The West-Wide Energy Corridor crossed the study site west of the Mud Springs lek (BLM 2012a). West-Wide Energy Corridors were designated under the Energy Policy Act of 2005 to delineate appropriate regions on federal land for the development of multiple oil, gas, and hydrogen pipelines and electricity transmission and distribution facilities (Barton 2005). At the start of the study in spring 2014, the corridor contained the 500-kV Intermountain Power Project (IPP) transmission line. In August 2014, construction of the Sigurd-Red Butte (SRB) 345-kV transmission line was initiated, and



Figure 2. Typical H-frame tower with installed perch deterrents which comprised the Sigurd-Red Butte 345-kV transmission line, constructed fall 2014. (Photo by E. Hansen)

construction was completed in fall of 2014. At the initiation of the scoping process for the SRB line, the proposed location was sited outside of the SGMA boundary. In 2010, however, the Mud Springs lek was discovered, and the SGMA boundary was subsequently adjusted. The lek discovery and boundary adjustment late in the scoping process caused the SRB line to violate a 6.4-km designated buffer of no disturbance around the Mud Springs lek, and pass through 18.8 km of designated sage-grouse habitat within the SGMA (BLM 2012b). The SRB line was located to the east of the IPP line, with a separation distance of approximately 457 m (BLM 2012a; Figure 1). The Mud Springs lek was located 4.7 km from the SRB line at its closest point. The access road under the SRB line was reseeded to promote vegetation growth and to discourage access by recreational vehicles (Figure 2). An established dirt road under the original IPP line was active throughout the study. SRB transmission line towers that were located within the 6.4-km buffer surrounding the Mud Springs lek were fitted with perch deterrents (Figure 2). This corridor was a likely zone for siting additional transmission lines or pipelines in the region in future years.

Methods

Sage-grouse capture and data collection

We deployed Global Positioning System (GPS)/Platform Transmitting Terminal (PTT) transmitters on male and female sage-grouse in the springs of 2014 and 2015 (22-g Model PTT-100, Microwave Telemetry Inc., Columbia, MD, USA). Transmitters were programmed to record 4 GPS locations/day for download once weekly through the Argos satellite data collection system (Argos System, CLS America, Lanham, MD, USA). Locations were recorded at 0200, 0700, 1300, and 2100 daily, local time, to ensure habitat use was accurately represented throughout each 24-hour period. Sage-grouse were captured using standard spotlight methodology (Wakkinen et al. 1992). Individuals were captured in the vicinity of the Mud Springs lek and the Little Horse Valley lek complex. These 2 areas had the highest numbers of breeding individuals within the study area (J. Nicholes, UDWR, unpublished data), and were the 2 closest lekking areas to the West-Wide Energy Corridor containing the SRB and IPP transmission lines. The PTT-100 transmitters used in this study recorded GPS locations as well as additional locations derived from the position of the transmitter in relation to the Argos receiving satellites (Microwave Telemetry 2016). The Argos location data were qualified by an assigned location class indicating the reliability of each data point. The highest quality locations were assigned a value of LC3, which indicated that the location was accurate to \pm 250 m (Collecte Localisation Satellites 2014). Visual examination of these locations in comparison to GPS location data collected at similar times indicated that this error radius was typically much smaller than 250 m. Thus, the GPS data for an individual was supplemented with the highest-quality Argos data (LC3) for analysis in the rare event of a GPS component malfunction.

Spatial and temporal extents of analysis

Sage-grouse locations collected from the winters of 2014–2015 (first season after construction of the SRB line) and 2015–2016

(second season after construction of the SRB line) were used for model development. This was supplemented with Very High-Frequency (VHF) sage-grouse location data collected independently from the winter of 2011–2012 (pre-construction; Burnett 2013) for validation. Individuals from the 2011–2012 study were caught across all active leks in the Bald Hills. We assumed that potential avoidance of the transmission line was likely to occur within sage-grouse seasonal winter range (third-order selection, Johnson 1980), because sage-grouse exhibit strong seasonal site fidelity (Connelly et al. 2004). We believed that it was unlikely that construction of the new transmission line would result in dramatic shifts of winter home range placement within the SGMA as a whole (second-order selection) because the IPP line was already present. We defined the winter season as November 15 to February 25 for all years. These seasonal dates were chosen because they reflected seasonal movements to winter habitat (i.e., the last bird arrived in winter habitat just prior to November 15 and birds began lekking after February 25).

We generated a 99% kernel density estimate (KDE) around all pooled 2014–2015 and 2015–2016 winter sage-grouse locations to delineate seasonally available habitat using package *adehabitatHR* in program R (R version 3.1.3, <<http://www.r-project.org>>, accessed December 12, 2015). We used a smoothing parameter of 0.8 times the reference bandwidth (h_{ref}), because the commonly used least-squares cross validation (h_{lscv}) bandwidth has been shown to be unreliable for the large numbers of clustered locations present in GPS data sets (Hemson et al. 2005), and 0.8 was the smallest multiplier of h_{ref} that still resulted in a single, continuous polygon (Kie 2013). A small portion of the KDE polygon extended outside delineated SGMA habitat boundaries into non-habitat, and no presence points were located in this area. To avoid including non-habitat in our assessment of availability, we clipped this portion of the KDE by the SGMA habitat boundary in ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, CA, USA). This resulted in 355 km² of available winter habitat within the SGMA boundary. The final winter habitat polygon included >95% of all VHF locations collected from the

2011–2012 winter, and thus was determined to be a suitable delineation of available winter habitat for the pre-construction season as well.

Predictor variables

We derived candidate predictor variables (Table 1) shown to be strongly associated with winter sage-grouse habitat selection (Carpenter et al. 2010, Burnett 2013, Smith et al. 2014). Variables were divided into 3 categories: (1) vegetation, (2) topographic, and (3) anthropogenic.

Vegetation. Vegetation covariates were derived from Landfire 2012 existing vegetation type and existing vegetation height data (LANDFIRE 2012) and assessed within a 1-km² (564-m) radius moving window because selection at this scale was detected in other studies of sage-grouse habitat use (e.g., Aldridge and Boyce 2007, Carpenter et al. 2010, Fedy et al. 2015). For sagebrush covariates, we extracted both mean and standard deviation of coverage within the 1-km² window, with the assumption that areas with a high standard deviation had more spatial heterogeneity or patchiness (Aldridge and Boyce 2007).

Topographic. We obtained 10-m Digital Elevation Model data (DEM; Utah Automated Geographic Reference Center [AGRC], <<http://www.gis.utah.gov>>, accessed February 1, 2016) and used it to derive slope (degrees), aspect (categorical, 8 categories) and topographic wetness index (TWI) layers in ArcGIS. TWI was calculated using Topography Tools for ArcGIS 10.3 and earlier (Dilts 2015), and is a steady-state wetness index based on upslope topography. TWI values for flat areas were rare, but extremely large, so TWI was capped at 2500; all values larger than 2500 (<5% of the total area) were reclassified as 2500 to assist with model convergence and increase ease of variable interpretation.

Anthropogenic. We included distance to roads (Road Centerlines; Utah AGRC, accessed March 16, 2014) because this was a strong predictor of winter sage-grouse habitat use in a previous study of this population (Burnett 2013). Roads were categorized into 2 classes; high-speed and low-speed. High-speed roads were roads with posted speeds >56 km/hr, and included paved 2-lane highways. Low-speed roads were roads with posted speeds ≤56 km/hr, and included

single-lane paved roads, dirt roads, and 2-tracks. We also derived an exponential decay covariate for distance to development (LANDFIRE 2012). Exponential decay was calculated as a function ($e^{-(d/\alpha)}$) where d was the distance to a feature and α was set to the radii for the chosen scale of selection (Smith et al. 2014). The value for α was set to 564 m, because that was the scale of selection chosen for other covariates included in the model. Assessing distance to development using an exponential decay function captured a non-linear relationship between the outcome and the predictor, where the predictor (i.e., effect of development) decreased to almost zero after a specified distance (Leu et al. 2011). An exponential decay function was used for distance to development because much of the development within the winter seasonal KDE was low-impact (water troughs, shoulders of dirt roads, and areas in the periphery of agricultural fields), and we assumed a linear distance measurement would likely overestimate the spatial influence of these features on the landscape. We anticipated that avoidance would occur at a localized scale with the influence of these features eventually decreasing to almost zero.

Because the scale at which the transmission line could influence habitat use was unknown, we developed multiple covariates describing distance to transmission line with varying strengths of exponential decay. Values chosen for α were 564 m, 1,000 m, and 6,400 m. These values were chosen because they were (1) the 564-m radius assessed for other covariates (Aldridge and Boyce 2007), (2) the 1000-m literature minimum recommended lek buffer radius for minimizing impacts of tall structures on sage-grouse based on observed effects (Howe et al. 2014, Manier et al. 2014), and (3) the radius of the full 6,400-m lek buffer distance applied to the Mud Springs lek (BLM 2012b).

Model development

We used a resource selection function (RSF) framework to compare third-order selection (Johnson 1980) of habitat used by sage-grouse during the winters of 2014–2015 and 2015–2016 to available habitat within a 99% winter seasonal KDE under a used-available design (Manly et al. 2002). To ensure that small changes in the predicted probability of use

with the construction of the new transmission line were appropriately captured, we randomly generated points to characterize available habitat at a rate of 100 points/km² within the winter habitat boundary, resulting in a total of 35,500 available points. RSF models were estimated using logistic regression to approximate relative probability of use within a specified area (Manly et al. 2002, Hosmer et al. 2013). We included a random intercept for individual in the model structure to accommodate potential spatial autocorrelation from high numbers of locations within an individual (Gillies et al. 2006). The final RSF took the form of a generalized linear mixed-model (GLMM; Bolker et al. 2009). We used a multi-step modeling approach to select a top model from all biologically relevant candidate covariates.

All continuous predictor variables were standardized ($\bar{x} = 0.0$, $SD = 1$) prior to analysis. Univariate analysis was conducted on each predictor individually to confirm predictive strength against a null model and to investigate the potential for including a quadratic term to accommodate nonlinearities. We then identified a top model in each of the 3 predictor categories using Akaike's Information Criterion corrected for small sample sizes (AICc) to select between any competing models (Hurvich and Tsai 1989, Burnham and Anderson 2002). No variables that were highly correlated (Pearson's correlation coefficient ≥ 0.70) were included in the same model at any stage. Because distance to transmission line was selected for inclusion a priori, it was excluded from covariate selection within the anthropogenic model, and only incorporated in the final step of the modeling process. The top models for each category were combined (i.e. anthropogenic + vegetation + topographic). The full model was compared against models for individual categories and a null model using AICc to select the best possible suite of covariates for predicting sage-grouse habitat selection within available winter habitat. Variables that became non-significant when top anthropogenic, vegetation, and topographic models were combined were removed if this improved model fit ($> 2 \Delta AICc$).

Once an overall top model was selected from all candidate models, the covariates describing distance to transmission line were included

Table 1. Biologically relevant predictor variables considered for resource selection function modeling.

Variable	Type (resolution)	Description (units)
Vegetation ^a		
<i>shrubheight_avg</i>	Continuous (30 m)	Average shrub height within 1-km ² moving window, derived from Landfire existing vegetation height layer (cm)
<i>shrubheight_sd</i>	Continuous (30 m)	Standard deviation of shrub height within 1-km ² moving window, derived from Landfire existing vegetation height layer (cm)
<i>sageall_avg</i>	Continuous (30 m)	Average coverage of all sagebrush within 1-km ² moving window ¹ (%)
<i>sageall_sd</i>	Continuous (30 m)	Standard deviation of all sagebrush within 1-km ² moving window ¹
<i>sagebig_avg</i>	Continuous (30 m)	Average coverage of big sagebrush within 1-km ² moving window ¹ (%)
<i>sagebig_sd</i>	Continuous (30 m)	Standard deviation of big sagebrush within 1-km ² moving window ¹
<i>sagelow_avg</i>	Continuous (30 m)	Average coverage of low sagebrush within 1-km ² moving window ¹ (%)
<i>sagelow_sd</i>	Continuous (30 m)	Standard deviation of low sagebrush within 1-km ² moving window ¹
<i>juniper_avg</i>	Continuous (30 m)	Average coverage of pinyon-juniper forest within 1-km ² moving window ¹ (%)
<i>saltdesert_avg</i>	Continuous (30 m)	Average coverage of salt-desert within 1-km ² moving window ¹ (%)
Topographic		
<i>asp.f^b</i>	Categorical (10 m)	Aspect calculated from 10 m DEM (km)
<i>slope</i>	Continuous (10 m)	Slope calculated from 10 m DEM (degrees)
<i>dem</i>	Continuous (10 m)	Elevation derived from 10 m DEM (km)
<i>twi</i>	Continuous (10 m)	Topographic wetness index
Anthropogenic		
<i>dist_rdlow</i>	Euclidean distance (30 m)	Distance to ≤56 km/hr (≤35 mph) roads (km)
<i>dist_rdhi</i>	Euclidean distance (30 m)	Distance to >56 km/hr (>35 mph) roads (km)
<i>dist_develop</i>	Exponential decay (30 m)	Distance to development ¹ defined by an exponential decay function with $a = 564$ m
Transmission line		
<i>SRBIPP_564</i>	Exponential decay (10 m)	Distance to SRB and IPP transmission lines defined by an exponential decay function with $a = 564$ m
<i>SRBIPP_1000</i>	Exponential decay (10 m)	Distance to SRB and IPP transmission lines defined by an exponential decay function with $a = 1,000$ m
<i>SRBIPP_6400</i>	Exponential decay (10 m)	Distance to SRB and IPP transmission lines defined by an exponential decay function with $a = 6,400$ m
<i>IPP_564</i>	Exponential decay (10 m)	Distance to IPP transmission line defined by an exponential decay function with $a = 564$ m

^a Derived from 2012 Landfire existing vegetation type data

^b Aspect categories represented the compass direction of the downslope topography, segmented by direction to include north (337.5°–22.5°), northeast (22.5°–67.5°), east (67.5°–112.5°), southeast (112.5°–157.5°), south (157.5°–202.5°), southwest (202.5°–247.5°), west (247.5°–292.5°), and northwest (292.5°–337.5°)

Table 2. Final models selected to represent topographic and anthropogenic categories for winter sage-grouse habitat selection.

Model	Structure
<i>anth_final</i>	<i>develop_564 + roadlow_km + roadlow_km² + roadhi_km</i>
<i>topo_final</i>	<i>twi + twi² + asp.f + dem + dem² + slope + slope²</i>

Table 3. Akaike Information Criterion (corrected for small sample size, AICc) ranked vegetation models for winter sage-grouse habitat selection in the Bald Hills Sage-Grouse Management Area (SGMA), Southern Utah.

Model	Structure	AICc	ΔAICc	ω_i
<i>vg_final</i>	<i>sagelow_avg + sagelow_avg² + sagebig_avg + sagebig_avg² + sageall_sd + shrubheight_sd + saltdesert_avg + juniper_avg</i>	32935	0.0	1.00
<i>vg4</i>	<i>sagelow_avg + sagelow_avg² + sagebig_avg + sagebig_avg² + sageall_sd + saltdesert_avg + juniper_avg</i>	32956	21.3	≤ 0.001
<i>vg2</i>	<i>sagelow_sd + sagelow_sd² + sagebig_sd + sagebig_sd² + sageall_avg + sageall_avg² + shrubheight_sd + saltdesert_avg + juniper_avg</i>	33235	300.4	≤ 0.001
<i>vg5</i>	<i>sagelow_sd + sagelow_sd² + sagebig_sd + sagebig_sd² + sageall_avg + sageall_avg² + saltdesrt_avg + juniper_avg</i>	33277	342.3	≤ 0.001
<i>vg3</i>	<i>sagelow_avg + sagelow_avg² + shrubheight_avg + shrubheight_sd + saltdesert_avg + juniper_avg</i>	33538	602.6	≤ 0.001
<i>vg8</i>	<i>sagelow_avg + sagelow_avg² + sagebig_avg + sagebig_avg² + saltdesert_avg + juniper_avg</i>	33672	737.2	≤ 0.001
<i>vg7</i>	<i>sageall_avg + sageall_avg² + saltdesert_avg + juniper_avg</i>	34234	1299.0	≤ 0.001
<i>vg6</i>	<i>shrubheight_avg + saltdesert_avg + juniper_avg</i>	34789	1853.6	≤ 0.001

at each scale of decay strength (*SRBIPP_564*, *SRBIPP_1000*, *SRBIPP_6400*) to determine which best described sage-grouse habitat use. Finally, because we suspected that any avoidance of the transmission line corridor may have been influenced by its placement in low-quality habitat (salt-desert) on the western side of the Bald Hills, we included an interaction between distance to transmission line and average salt-desert coverage (*SRBIPP*saltdesert_avg*) for each strength of transmission line decay to evaluate whether this improved model fit.

Model validation

The ultimate test for the suitability of an RSF is how well it predicts species use of landscapes across space and time (Johnson et al. 2006). To assess model fit, the final RSF was validated both internally through k-fold cross-validation (Boyce et al. 2002), and externally by mapping the RSF across a pre-construction landscape

and validating with independently collected data from the winter of 2011–2012 (Burnett 2013). For k-fold validation, we divided the individuals from the main (2014–2015) data set into 5 randomly assigned folds. The top RSF model was then refit 5 times, each time withholding a different fold of test data. The refit RSFs were mapped across available habitat within the 99% winter KDE and divided into 10 quantiles (equal-area bins) of increasing rank (1 = low quality habitat, 10 = high quality habitat). We extracted the frequency of test fold data points that fell in each bin for all 5 refit RSF models and calculated Spearman rank correlations for each test fold to quantify the relationship between frequency of use by test locations and increasing bin ranks of habitat quality (Boyce et al. 2002, Aldridge and Boyce 2007). We expected that as bin rank increased, frequency of use should also increase.

Although internal validation of an RSF

provides insight on its effectiveness, the best test of an RSF is independent validation with an external data set (Boyce et al. 2002). Because a previous study (Burnett 2013) had collected winter VHF data on sage-grouse locations from the winter of 2011–2012, this allowed us to evaluate model fit across years and compare how RSF-predicted habitat quality in the vicinity of the West-Wide Energy Corridor differed before and after construction of the SRB line. To ensure that temporally dynamic covariates were appropriately applied to this map, we used an input for distance to transmission line that included only the IPP line because only that line was present in the West-Wide Energy Corridor at the time those locations were collected. We also updated vegetation predictor variables using Landfire 2010 data (LANDFIRE 2010) to more accurately represent vegetation available during the winter of 2011–2012. For external validation, the RSF was mapped across the pre-construction landscape within the same 99% winter seasonal KDE, divided into 10 equal-area bins, and frequencies of use were compared to bin rank using Spearman-rank correlations in a similar fashion as the validation for the post-construction RSF model.

Comparisons of pre- and post-construction data

The development of pre- and post-construction RSF models for winter habitat allowed us to compare how predicted habitat use may have changed with the construction of a new transmission line. This offered the most conservative estimate of differences between pre- and post-construction landscapes, because it assumed that the construction of the new SRB line did not change the strength of avoidance of the West-Wide Energy Corridor (β coefficient), only the spatial orientation of transmission lines on the landscape (i.e., the corridor was composed of 2 lines in the post-construction model and 1 line in the pre-construction model). If the addition of the new line was multiplicative (e.g., doubled a negative effect), then the pre-construction map we derived would underestimate the probability of use near the single, original transmission line and the change in RSF value would actually be greater than is reported here. However, because the effects of adding a new transmission line to a pre-existing transmission line corridor are

not well documented, and the original patterns of habitat use prior to the construction of any transmission lines in the Bald Hills SGMA were unknown, we chose to estimate changes on the landscape in the most conservative manner possible.

We compared changes in RSF-predicted probability of habitat use and differences in the spatial distribution of sage-grouse locations within the vicinity of the transmission line corridor between the pre- and post-construction data sets. We focused on these changes for winter habitat inside the 6.4-km Mud Springs lek buffer, because sage-grouse used this area heavily in the winter months and it was at a high risk of being negatively influenced by the construction of the new transmission line due to its close proximity. We quantified changes in RSF-predicted habitat use by calculating the difference between the pre- and post-construction mapped RSFs ($RSF_{post} - RSF_{pre} = \Delta RSF$). This resulted in a map layer that showed decreased RSF scores from pre-to post-construction as negative values, and increased RSF scores as positive values. To compare sage-grouse spatial distributions between winters, we generated minimum convex polygons (MCPs) for sage-grouse locations within the Mud Springs lek buffer for each winter (2011–2012, 2014–2015, and 2015–2016) and calculated the centroid for each MCP. We anticipated that if the RSF-predicted relative probability of use decreased within the boundaries of the lek buffer after the addition of the new transmission line, this would be reflected by a corresponding shift in MCP centroids further from the transmission line corridor in the 2 post-construction seasons.

Results

Sage-grouse capture and data collection

The GPS data set for the winters of 2014–2015 and 2015–2016 included locations from 18 individual sage-grouse (2 females, 16 males) and included 7,534 locations. Sexes were pooled because male and female sage-grouse can occupy mixed-sex flocks in the winter months (Swanson et al. 2013) and examination of GPS locations indicated this was the case in our study area for the time periods included in our analysis. Birds caught from both the

Table 4. Akaike Information Criterion (corrected for small sample size, AICc) ranked final models for winter sage-grouse habitat selection in the Bald Hills Sage-Grouse Management Area (SGMA), Southern Utah.

Model	Structure	AICc	ΔAICc	ω_i
rsf_final (SR-BIPP564_int)	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f + SRBIPP_564 + (SRBIPP_564*saltdesert_avg)</i>	23175	0.0	1.00
SRBIPP564	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f + SRBIPP_564</i>	23242	66.6	≤0.001
SRBIPP1000_int	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f + SRBIPP_1000 + (SRBIPP_1000*saltdesert_avg)</i>	23253	77.4	≤0.001
SRBIPP1000	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f + SRBIPP_1000</i>	23440	265.2	≤0.001
SRBIPP6400_int	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f + SRBIPP_6400 + (SRBIPP_6400*saltdesert_avg)</i>	23604	429.0	≤0.001
veg_topo_anthro	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f</i>	23661	486.0	≤0.001
SRBIPP6400	<i>dist_develop + dist_rdlow + dist_rdlow² + dist_rdhi + juniper_avg + sagebig_avg + sagebig_avg² + sagelow_avg + sagelow_avg² + sageall_sd + saltdesert_avg + twi + slope + slope² + dem + dem² + asp.f + SRBIPP_6400</i>	23666	490.8	≤0.001
anth_final	<i>develop_564 + roadlow_km + roadlow_km² + roadhi_km</i>	31905	8729.4	≤0.001
vg_final	<i>sagelow_avg + sagelow_avg² + sagebig_avg + sagebig_avg² + sageall_sd + shrubheight_sd + saltdesert_avg + juniper_avg</i>	32935	9760.3	≤0.001
topo_final	<i>twi + twi² + asp.f + dem + dem² + slope + slope²</i>	35558	12382.9	≤0.001
null	—	38043	14867.9	≤0.001

Mud Springs and Little Horse Valley leks moved frequently between these 2 locations during the spring, and thus were assumed to be part of the same breeding population. Malfunction of transmitter GPS components occurred on 2 individuals during the study, and consequently their location data were supplemented with the highest quality Argos location data (class LC3). Number of locations per bird ranged from 54–802, depending on the length of transmitter deployment for that particular bird. The VHF data set from 2011–

2012 used in external validations contained 85 locations from 19 sage-grouse (11 males, 8 females).

Resource selection function modeling

Global models for the topographic and anthropogenic categories indicated that all a priori selected predictors contributed significantly ($P \leq 0.05$) and no variables were collinear, so all predictors were included in the final model for each of those groups (Table 2). Because many of the vegetation predictors

Table 5. Beta coefficients (β_i) and standard errors (SE) for the final selected RSF model (rsf_{final}) for winter sage-grouse habitat selection within the Bald Hills Sage-Grouse Management Area, Southern Utah. Non-significant coefficients ($P > 0.05$) are designated with a dash (-).

Predictor	β_i	SE
Vegetation		
<i>sageall_sd</i>	0.296	0.026
<i>sagebig_avg</i>	-0.960	0.030
<i>sagebig_avg²</i>	0.706	0.039
<i>sagelow_avg</i>	1.957	0.056
<i>sagelow_avg²</i>	-0.733	0.026
<i>juniper_avg</i>	-2.501	0.070
<i>saltdesert_avg</i>	-	-
Topographic		
<i>asp.Flat</i>	-	-
<i>asp.North</i>	0.854	0.111
<i>asp.Northeast</i>	-	-
<i>asp.Southeast</i>	0.479	0.088
<i>asp.South</i>	0.303	0.086
<i>asp.Southwest</i>	0.557	0.086
<i>asp.West</i>	0.384	0.087
<i>asp.Northwest</i>	-0.222	0.103
<i>slope</i>	-0.495	0.043
<i>slope²</i>	-0.047	0.018
<i>dem</i>	1.805	0.047
<i>dem²</i>	0.661	0.028
<i>twi</i>	0.076	0.021
Anthropogenic		
<i>dist_rdlow</i>	0.639	0.029
<i>dist_rdlow²</i>	-0.319	0.016
<i>dist_rdhi</i>	1.259	0.025
<i>dist_develop</i>	0.392	0.021
Transmission line		
<i>SRBIPP_564</i>	-1.407	0.350
<i>SRBIPP_564*saltdesert_avg</i>	-2.440	0.302

were collinear (Pearson's correlation coefficient ≥ 0.70), a set of candidate models for the vegetation category was developed post priori and a top model was selected using AICc (Table 3). Once top models for anthropogenic ($anth_{final}$), vegetation (vg_{final}), and topographic ($topo_{final}$) categories

Table 6. Spearman-rank correlations (r_s) for k-fold cross-validation of post-construction resource selection function (RSF) model and external validation of pre-construction RSF model using 2011–2012 data collected within the Bald Hills Sage-Grouse Management Area.

Test fold	r_s	P
1	1.00	≤ 0.001
2	0.92	≤ 0.001
3	0.96	≤ 0.001
4	0.64	0.054
5	0.97	≤ 0.001
Mean r_s across folds	0.90	-
External 2011–2012 validation	0.86	0.001

were selected, these models were combined and compared against the individual top models as well as a null model (Table 4) to determine which best described winter habitat use in the Bald Hills. Variables that became non-significant ($P > 0.05$) when the models were combined (*twi2* and *shrubheight_sd*) were dropped because removing them significantly improved model fit ($> 2 \Delta\text{AICc}$; Burnham and Anderson 2002).

After confirming a combination of top anthropogenic, topographic, and vegetation models outperformed any individual model, we investigated which scale of exponential decay function best described habitat use in relation to the West-Wide Energy Corridor, and whether an interaction between distance to transmission line and average salt-desert coverage within a 1-km² moving window improved model fit. The top model (rsf_{final} ; Table 4) included the smallest scale of decay for distance to transmission line (*SRBIPP_564*) as well as an interaction between distance to transmission line and average coverage of salt-desert (*SRBIPP_564*saltdesert_avg*). The final RSF model included multiple topographic, anthropogenic, and vegetation covariates (Table 5). Distances to low-speed roads and high-speed roads were classified as linear functions, thus the direction of their coefficients needs to be reversed when interpreting selection or avoidance. For example, $\beta_{dist_rdhi} = 1.259$ indicated sage-grouse avoid areas near high-speed roads. Covariates that also

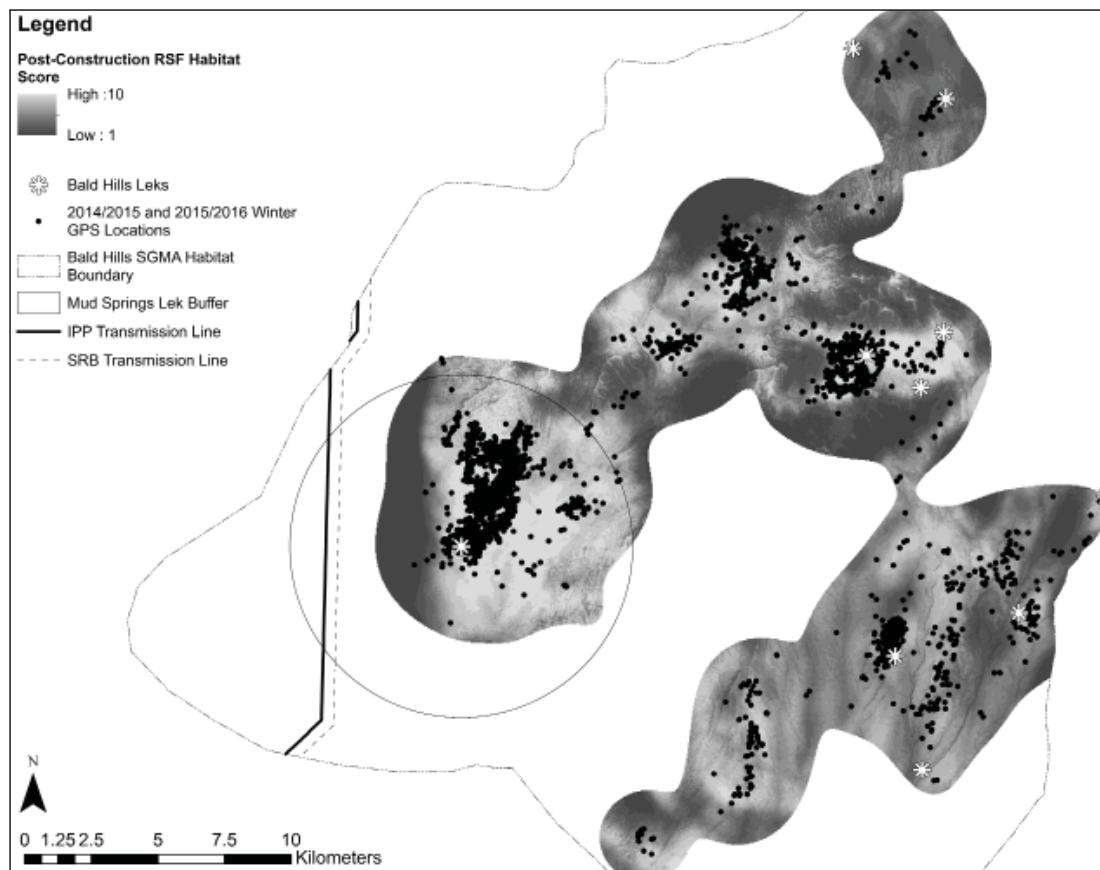


Figure 3. Resource selection function (RSF) predicted relative probability of presence (ranked in 10 equal area bins, 1 = low through 10 = high) for winter habitat after the installation of the Sigurd-Red Butte 345-kV transmission line (post-construction). All GPS locations collected for both the 2014–2015 and 2015–2016 winters are shown in black.

included a squared term indicated a non-linear relationship to the response variable (i.e., $slope + slope^2$ indicated sage-grouse selected for moderately steep slopes). The interaction between salt-desert coverage and proximity to transmission line ($SRBIPP_564*saltdesert_avg$) negatively influenced predicted probability of habitat use.

Model validation

The model performed well in both internal and external validation (Table 6). The average Spearman rank correlation coefficient (r_s) for k-fold cross-validation was 0.90 across all 5 folds. Four of the 5 iterations of k-fold validation exhibited excellent predictive capacity ($r_s = 0.92$ to 1.00), but 1 fold (Fold 4; Table 6) had a much lower predictive success ($r_s = 0.64$, $P = 0.054$), which lowered the average overall. Correlations were also high for the 2011–2012 external validation with $r_s = 0.86$ ($P = 0.001$), which suggested good predictive capacities for

the model across years. Visual examination of RSFs mapped for both timeframes indicated good model fit across available winter habitat within the Bald Hills SGMA (Figures 3 and 4).

Comparisons of pre- and post-construction data

Comparisons of the pre- and post-construction RSF maps indicated a decrease in predicted probability of use for winter habitat in the vicinity of the West-Wide Energy Corridor after the addition of the SRB line (Figure 5). The mean Δ RSF score for available winter habitat within the 6.4-km Mud Springs lek buffer was -0.03, or an overall 3% decrease in predicted probability of winter habitat use within that area. However, this change did not result in detectable changes in sage-grouse avoidance of the transmission line corridor between the pre- and post-construction winters when comparing sage-grouse spatial distributions across years. The MCP centroid farthest from

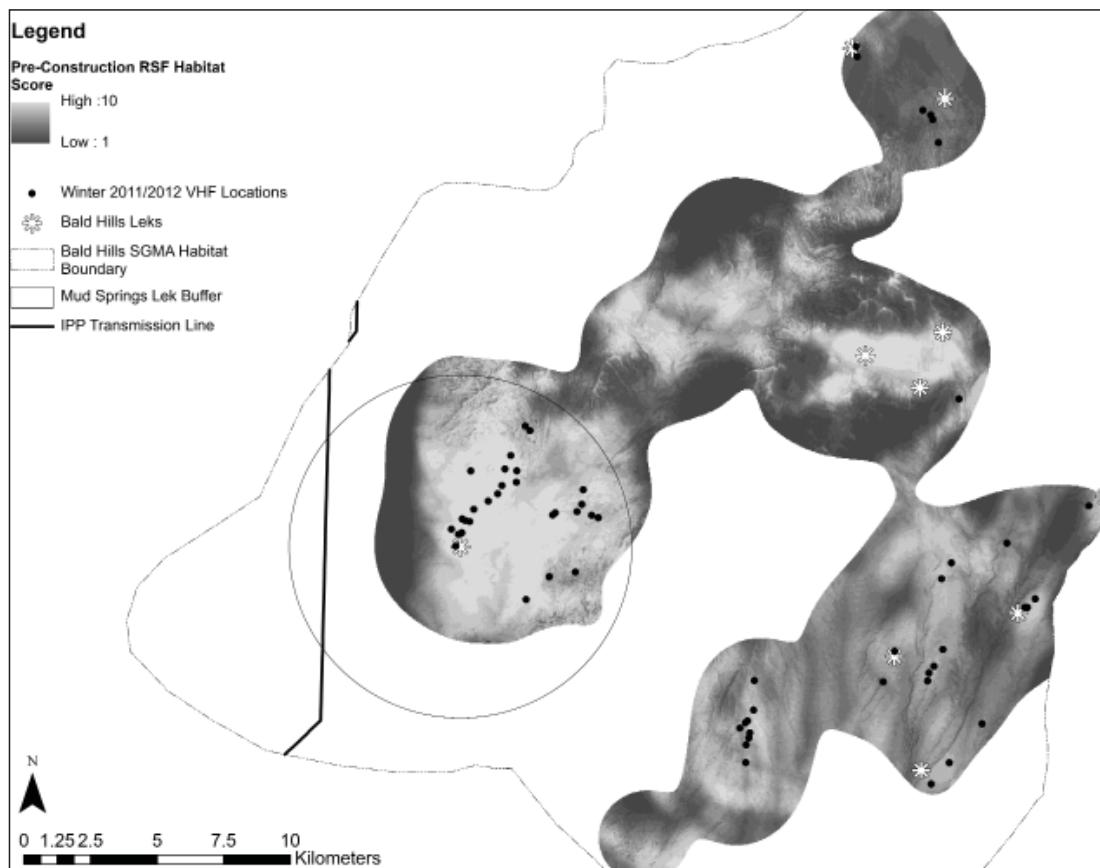


Figure 4. Resource selection function (RSF) predicted relative probability of presence (ranked in 10 equal area bins, 1 = low through 10 = high) for winter habitat prior to construction of the Sigurd-Red Butte (SRB) transmission line. All validation locations for the pre-construction (2011–2012) winter are shown in black.

the transmission line corridor occurred in the pre-construction season and was located 7.4 km from the IPP transmission line. MCP centroids for both post-construction seasons were located 6.4 km from the SRB line and were closer to a transmission line than the pre-construction season. The MCP centroids for all 3 seasons were located <1 km from each other (Figure 5).

Discussion

This project was initiated because the new transmission line was located in designated winter habitat, which is considered lacking in Utah (State of Utah 2013). We confirmed that transmission line presence negatively influenced probability of sage-grouse winter habitat use through RSF modeling. The interaction between *saltdesert_avg* and *SRBIPP_564* indicated that with greater coverage of salt-desert, the effect of transmission line proximity on probability of use grew increasingly negative. Thus, sage-grouse avoided areas of high salt-desert

coverage near transmission lines more strongly than would be expected when each effect was included in the model independently. Although the final RSF model predicted a 3% decrease in probability of use within the lek buffer due to the construction of the new transmission line, we did not observe any detectable shifts in habitat used by sage-grouse near the transmission line corridor when comparing MCPs. The closest sage-grouse location to a transmission line recorded after construction was 2.9 km from the SRB line, while the closest location recorded prior to construction was 4.9 km from the original IPP transmission line. Visual examination of both sets of locations overall did not suggest any avoidance induced by the construction of the new line, as evidenced by the close placement of MCP centroids for all 3 winters considered in the analysis. A failure to document any differences in avoidance of the transmission line corridor before and after construction, in spite of a negative interaction

between *saltdesert_avg* and *SRBIPP_564* in the modeled RSF, could arise from multiple sources.

Efforts to minimize project footprint, implement best management practices, and reclaim habitat after construction may have lessened impacts of the project on sage-grouse habitat use (BLM 2012b, APLIC 2015, Fedy et al. 2015). The area within the seasonal winter KDE that was located near the transmission line corridor had a low probability of use in both pre- and post-construction maps. Thus, the area closest to the West-Wide Energy Corridor was avoided by sage-grouse in the winter prior to the addition of the SRB line. The habitat to the west of the energy corridor was not considered high-quality sage-grouse winter habitat; therefore, sage-grouse use of this area was not anticipated. No birds crossed the West-Wide Energy Corridor during the course of our entire study in either the pre- or post-construction time periods (2011–2013, 2014–2016; Burnett 2013, Hansen 2016). The placement of the SRB 345-kV transmission line, in an area of low predicted probability of use that was located on the western periphery of the SGMA, likely reflects a best-case scenario for minimizing direct impacts to winter habitat use or movement patterns.

It is also possible that the presence of the new transmission line did negatively influence habitat suitability, but that the change was not dramatic enough to override the strong site-fidelity of sage-grouse (e.g., Fischer et al. 1993, Holloran and Anderson 2005), or that site fidelity could cause sage-grouse to continue to use this habitat for multiple years before adjusting movement patterns (Harju et al. 2010). Time lag delays for negative impacts of energy development on male lek attendance in Wyoming have been suggested to range from 2–10 years (Walker et al. 2007, Harju et al. 2010). Although little information is available regarding time lag delays on winter habitat selection or response to transmission line development, our study only included 2 years of post-construction data and thus may not cover a sufficient temporal scale for this impact to detectably alter spatial distributions of sage-grouse that overwinter in the area.

Alternatively, the influence of the transmission line corridor on habitat use as detected by the

RSF may not have been a function of direct avoidance of a tall structure on the landscape, but rather by some associated, indirect impact. These effects may not manifest immediately after construction because they require a longer time period for the negative change to occur, and could include increased traffic due to the addition of ancillary roads, or changes in avian predator abundance as a result of increased perching substrate. It is unlikely that the installation of the access road under the SRB line would result in future increased avoidance by sage-grouse during the winter months. This is because the new road under the SRB line was revegetated to discourage non project-related use of the right-of-way (ROW), and vehicular access to the area in the winter months is difficult given its remote location (Hansen 2016).

Increased perching substrate for avian predators of sage-grouse is also a major concern related to power line development (Messmer et al. 2013), and we were not able to incorporate avian predator presence into our RSF model. The portion of the SRB transmission line that passed through the 6.4-km lek buffer around the Mud Springs lek was fitted with perch deterrents, but the effectiveness of these can vary widely (Prather and Messmer 2010, Slater and Smith 2010, Dwyer and Doloughan 2014), and historic perching locations were still available on the original IPP transmission line (Hansen 2016). Avian predator species that had winter ranges that overlapped the study area included golden eagles (*Aquila chrysaetos*; Kochert et al. 2002) and ferruginous hawks (*Buteo regalis*; Bechard and Schmutz 1995), both of which were observed nesting on the original IPP towers during the breeding season in 2014 and 2015 (Hansen 2016). An assessment of overwintering avian predator presence along the transmission line across years would provide more information about the indirect consequences of energy corridor expansion located adjacent to sage-grouse critical winter habitat.

Within the 2-year post-construction temporal scale covered by our study, we did not observe increased avoidance of the West-Wide Energy Corridor by sage-grouse. This is likely because the SRB line was sited outside of utilized winter habitat, adjacent to an area of low predicted

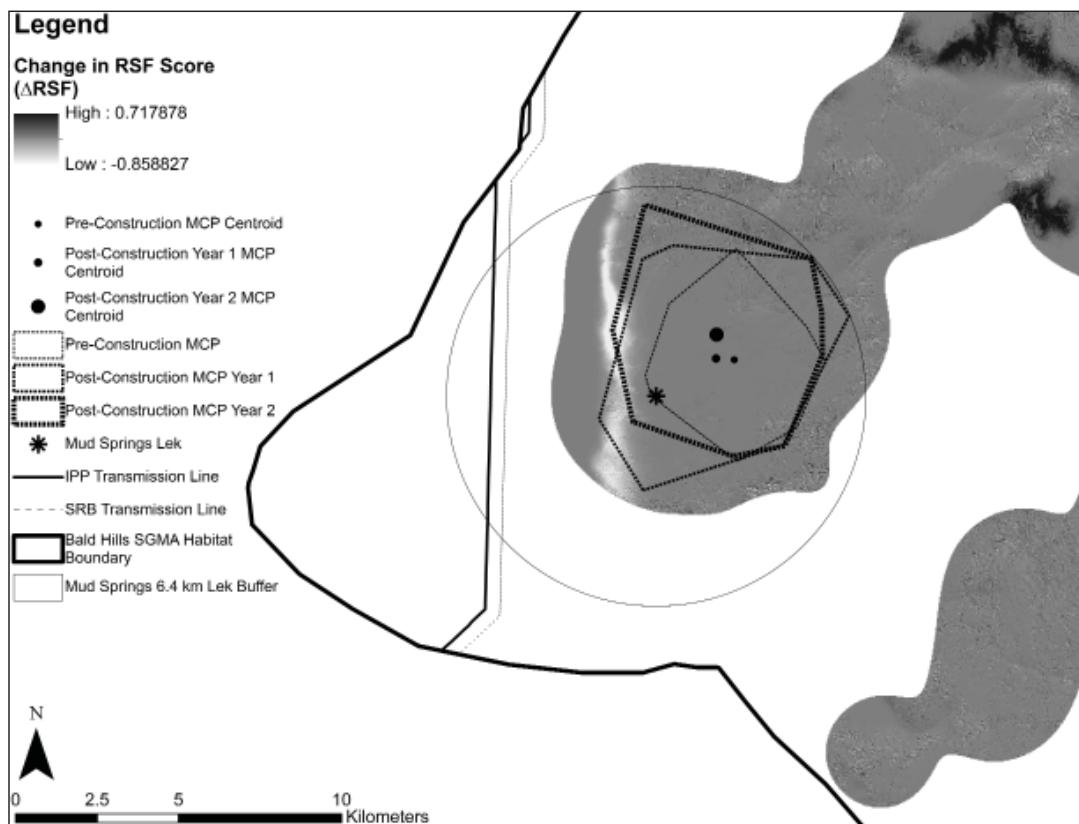


Figure 5. Changes in probability of use predicted by the final resource selection function (RSF) model in the vicinity of the Mud Springs lek between pre- and post-construction maps (ΔRSF), and minimum convex polygons (MCPs) for sage-grouse locations within the Mud Springs lek buffer for one pre-construction and 2 post-construction winters. Negative ΔRSF values (lighter regions) indicate a decrease in predicted probability of use from pre- to post-construction maps, while positive values (darker regions) indicate an increase. Because RSF probabilities of use range from 0 to 1, ΔRSF values were constrained between -1 and 1, with values of 0 indicating no change (grey regions). Placement of MCPs and corresponding centroids does not indicate increased avoidance after construction, with the furthest MCP centroid from the transmission line corridor occurring in the pre-construction data set.

probability of use, and was located within an existing energy corridor. This suggests that the co-location of new transmission lines with those that are already in place is an effective technique for mitigating the short-term impacts of transmission line construction on sage-grouse habitat use. The interaction between average coverage of salt-desert and transmission line proximity included in the final model also indicated that sage-grouse spatial response to transmission lines in the winter can be influenced by the type of habitat surrounding the ROW. This should be addressed in development plans when assessing the potential for either increased avoidance or increased fragmentation of movement patterns within existing habitat. For example, siting a new transmission line in an existing corridor that is located in low-quality winter habitat (and thus potentially

already avoided by sage-grouse) may reduce negative effects on overwintering populations, provided that avoidance of the corridor does not fragment existing habitat use. Continued monitoring of spatial distributions for sage-grouse that overwinter in the Mud Springs area, as well as collection of relevant demographic parameters, would yield additional information about this sage-grouse population in the long-term.

Management implications

Utah's sage-grouse conservation plan calls for the avoidance and minimization of disturbance in winter habitat (State of Utah 2013). When disturbance cannot be avoided or minimized, mitigation is required. These results provide a quantitative assessment of winter sage-grouse habitat use in relation to the West-Wide Energy Corridor. We did not observe increased

avoidance of the transmission line corridor by sage-grouse as distance to transmission line changed after the addition of a new line. Siting the line in an area of poor-quality habitat (salt-desert) on the periphery of the SGMA represents a best-case scenario for reducing the influence of new energy development projects. Our results suggest that existing transmission line corridors located in poor-quality winter habitat are likely already avoided by sage-grouse, and co-locating additional lines within these corridors may dampen the effects of new tall structures on the landscape in the years immediately following construction. We emphasize that more data collection is required to determine if this technique also minimizes impacts to habitat use across long-term time scales. Because future indirect disturbances are still possible in the project area, we suggest monitoring of avian predator presence along the transmission line corridor, as well as management actions that protect and increase winter habitat. Management actions should include maintaining ≥10% sagebrush cover, maintaining ≤5% tree cover in and adjacent to currently used winter habitat, and protecting designated winter habitat from wildfire (State of Utah 2013).

Acknowledgments

Funding for this research was provided by Rocky Mountain Power. We thank the many volunteers who assisted with sage-grouse trapping and transmitter deployment. We appreciate assistance and support provided by the Utah State University Quinney College of Natural Resources.

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