From:	Wiechman, Lief
To:	Dawn Davis; Pat Deibert; Jesse D"Elia
Subject:	Fwd: Power line manuscript
Date:	Wednesday, May 27, 2015 1:41:48 PM
Attachments:	Influence of power lines on sage-grouse_5_25_15.docx

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All,

Dan's power line draft manuscript.
He's asked for a CLOSE-HOLD as they're submitting for publication. Please to not share.

LW

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---------- Forwarded message ----------
From: (b) (6) >
Date: Tue, May 26, 2015 at 12:14 PM
Subject: Power line manuscript
To: "Wiechman, Lief" <lief_wiechman@fws.gov>

Hey Lief,

Just wanted to reach out and send you a placeholder for the FG power line manuscript that I have been working on the last few months. It's getting pretty close to completion, but still needs a few more eyes to look over it before it enters review as I am sure there are still a fair number of typos, unclarities, or inconsistencies. As it has not entered review yet, I'd suggest to forward it to a limited number of people (e.g., Pat). Feel free to send any suggestions my way!

Cheers!

-Dan

Running Head: Influence of power lines on sage-grouse

Effects of transmission lines on demography and population dynamics of greater sage-grouse (*Centrocercus urophasianus*)

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ABSTRACT

Energy infrastructure has been associated with altering wildlife community dynamics by influencing survival, reproduction, and movements of individuals. Power lines, specifically, may indirectly impact habitat selection, beyond the immediate footprint of the corridor, through avoidance behaviors related to increased harassment of predators that are positively associated with elevated structures. In addition to avoidance responses, power lines may indirectly suppress various vital rates for certain species as a function of increased predator abundance or predator foraging performance along power line corridors. Greater sage-grouse (*Centrocercus urophasianus*), a species of conservation concern across western North America, have been suspected to be indirectly affected by power lines related to changes in predator dynamics associated with power lines. Previous studies, however, have failed to provide evidence regarding the causal mechanism directly influencing vital rates, nor have they controlled for variation in demographic rates related to environmental heterogeneity. Here, our primary objective was to assessing the influence of power lines on multiple sage-grouse vital rates, based on Greater sage-grouse and Common raven (*Corvus corax*) demographic data collected from 2003-2012 in central Nevada, that accounted for various sources of underlying environmental heterogeneity. We focused primarily on a single transmission line that was constructed at the beginning of our monitoring efforts, however, we also determined if similar patterns were observed with all other nearby power lines. We found that numerous demographic rates (e.g., nest site selection, nest survival, recruitment, and population growth) were indirectly affected by power lines, and that these negative effects were predominantly explained by variation in Common raven abundance or distribution. More importantly, we found that latent environmental heterogeneity in this system, if unaccounted for, could either mask or exacerbate the negative

effects attributed to power lines for half of the analyses considered, highlighting the importance of both study and analytical design.

Keywords: power lines, indirect anthropogenic effects, sage-grouse, common ravens, elevated structures, environmental heterogeneity

INTRODUCTION

Energy infrastructure has been associated with altering wildlife population dynamics by influencing survival, reproduction, and habitat use, as well as the spread of invasive species and acerbating habitat fragmentation (Naugle et al. 2011a, Northrup and Wittemyer 2013). Overhead power lines, specifically, can negatively influence wildlife populations directly through the immediate loss of habitat (i.e., the physical footprint of power line towers and line rights of way; Jones et al. 2015) or increased mortality (e.g., bird collisions with guy wires, towers, or lines; Bevanger 1998, Janss 2000, Bevanger and Broseth 2001, Loss et al. 2014). Power line towers, however, may also enhance habitat for some organisms by creating nesting (Steenhof et al. 1993, Howe et al. 2014) and perching habitat for bird species, such as raptors and ravens (Coates et al. 2014b). Additionally, construction and tower footprints can disturb the underlying soil and vegetation, promoting the spread of non-native species (Lathrop and Archbold 1980). Although less studied, power lines are hypothesized to indirectly impact habitat selection through avoidance behaviors beyond the physical footprint of the structure potentially related to the increased presence of electromagnetic fields (Balmori and Hallberg 2007), avoidance of elevated structures, or increased harassment of predators associated with elevated structures (Pruett et al. 2009, Silva et al. 2010).

In addition to avoidance responses, power lines may indirectly suppress various vital rates [e.g., nest success (DeGregorio et al. 2014); adult survival (Hovick et al. 2014)] for certain species as a function of increased predator abundance or predator foraging behavior (Plumpton and Andersen 1997) along power line corridors. Beyond species-specific susceptibilities, the overall impact of power lines on wildlife populations may be influenced by surrounding environmental characteristics. For example, relative to woodlands, transmission lines may have a

85 greater effect in open habitats (e.g., shrub- or grasslands), which may be related to differences in
86 flight behavior (Rollan et al. 2010), power line visibility (Benitez-Lopez et al. 2010), or changes
87 in local predator densities (Howe et al. 2014).

88 Placement of power lines on the landscape is not random, as it is influenced by local
89 topography and geology (Vajjhala and Fischbeck 2007). In the absence of conservation
90 constraints utility corridors are typically placed along least cost routes, which usually minimize
91 changes in slope and elevation (Bagli et al. 2011). This non-random distribution of power lines
92 across a landscape, results in covariance between proximity to, or density of, power lines and
93 other environmental features (e.g., elevation, slope, hydrology) that may influence the structure
94 of surrounding habitat, thereby complicating assessment of impacts of power lines themselves.
95 For example, changes in demographic rates in proximity to a power line could result from a
96 gradient in habitat features, rather than an impact of the line itself but such potential covariances
97 between environmental conditions and anthropogenic disturbances are often ignored.

98 Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are of
99 conservation concern that have been negatively influenced by anthropogenic disturbances,
100 including energy development and its supporting infrastructure (Naugle et al. 2011b, Hovick et
101 al. 2014). Sage-grouse are endemic to sagebrush (*Artemisia spp*.) ecosystems of western North
102 America (Connelly et al. 2011), which are characterized by large expanses of woody shrubs,
103 with trees occurring in either low densities or localized patches. In these systems, anthropogenic
104 structures including utility lines can provide novel perches or nest sites otherwise unavailable in
105 the local landscape (Steenhof et al. 1993, Coates et al. 2014b, Howe et al. 2014).

106 Although sage-grouse, like other Galliformes, are susceptible to fatal collisions with
107 power lines (Borell 1939, Bevanger 1998), numerous telemetry based studies (Connelly et al.

2000, Beck et al. 2006, Blomberg et al. 2013a, Dinkins et al. 2014b) have reported low numbers of bird strikes of radio-marked individuals, which suggest this source of mortality is unlikely to be meaningful at the population level. Site-specific mortality may be appreciable, however, if elevated structures are placed perpendicular to a corridor of high sage-grouse use during crepuscular periods (Stevens et al. 2011). Recent work has suggested that indirect effects of elevated structures, such as either causing avoidance of habitat near lines (Doherty et al. 2008, Dinkins et al. 2014b), or lower vital rates due to increased predation (Ellis 1984, Bui et al. 2010), may important at the population level. Sage-grouse and other grouse species have been reported to avoid habitat near elevated structures, primarily other types of energy infrastructure (Doherty et al. 2008, Pruett et al. 2009, Silva et al. 2010, Hovick et al. 2014, Lebeau et al. 2014). Authors have speculated that the perceived threat of predation associated near power lines may explain this potential avoidance of habitat (Hall and Haney 1997, Braun 1998, Holloran et al. 2015).

Common ravens (*Corvus corax;* hereafter, raven) are important predators of sage-grouse nests and chicks throughout the species range (Coates et al. 2008, Hagen 2011, Lockyer et al. 2013). Raven populations have steadily increased across western North America over the last 50 years, associated with increases in anthropogenic subsidies (Bui et al. 2010, Webb et al. 2011). Power poles, and other elevated structures have increased nesting substrate in shrublands and grasslands where nest sites are typically less abundant (Steenhof et al. 1993, Howe et al. 2014). Consequently, raven densities are higher near elevated structures compared to the surrounding landscape (Knight and Kawashima 1993, Coates et al. 2014b). Therefore, we expect that effects of power lines on sage-grouse habitat use or reproductive success should depend on raven abundance near power lines.

Relatively few studies have addressed impacts of elevated structures on sage-grouse (e.g.; Johnson et al. 2011, Dinkins et al. 2014a) , in contrast to the case of oil and gas development (e.g.; Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2010, Naugle et al. 2011a, Fedy et al. 2015, Holloran et al. 2015). Effects of oil and gas development cannot be extrapolated to those of utility lines because the former is often associated with substantial human activity and noise (Blickley et al. 2012) and the infrastructure differs between the two kinds of disturbance (Copeland et al. 2011). Although some studies have reported negative effects of distances from elevated structures on individual vital rates (e.g., adult survival, nest success, brood survival; Dinkins et al. 2014, Lebeau et al. 2014), these studies have not generally controlled for confounding effects of variation in habitat. Additionally, no studies have causally linked utility lines, predator abundance and behavior, with sage-grouse demography and population trajectories (Hagan et al. 2011). Furthermore, large-scale patterns in population dynamics in relation to utility lines are not consistent (Johnson et al. 2011, Wisdom et al. 2011).

As avoidance of habitat near power lines is the most consistently reported effect, the lack of evidence for negative effects of power lines on vital rates may be may be related to reduced statistical power owing to low numbers of individuals using habitat near power lines (Kirol et al. 2014). A corollary is that potential negative effects of power lines are partially mediated by sage-grouse behavior, and the absolute cost of power lines on the landscape is related to the extent of avoidance. Interpreting previously reported patterns in habitat use or reproductive success related to power lines are complicated by the fact that earlier studies did not control for potential confounding habitat effects. Therefore, we cannot be certain that negative effects of power lines are not an artifact of an association between location of utility lines and habitat quality (see Fig. 1 for a reconstruction analysis of data originally presented in Hall and Haney 1997) or spatial

153 autocorrelation (e.g., including multiple individuals from a single breeding area; Gillan et al.
154 2013).

155 Here, we define transmission line as any overhead structure that is capable of transmitting
156 voltages > 69 kV (Hamilton and Schwann 1995), and overheard structures transmitting < 69 kV
157 as subtransmission and distribution lines. We use the term 'power line' to refer to all elevated
158 energy transmission structures (i.e., transmission, subtransmission, and distribution lines)
159 regardless of voltage. Our primary objective was to assess the influence of power lines on
160 multiple sage-grouse demographic rates after accounting for other sources of environmental
161 heterogeneity in demography. Our goal was to provide as complete an assessment as possible of
162 influences of utility lines on population dynamics of sage-grouse. We used ten years of data on
163 sage-grouse demography following construction of a 345 kilovolt transmission line in central
164 Nevada in our assessment. Because recent studies have indicated that impacts of utility lines on
165 grouse may occur largely through the association of avian predators with such lines (Doherty et
166 al. 2008, Lebeau et al. 2014, Fedy et al. 2015, Holloran et al. 2015), we also determined if
167 variation in sage-grouse reproductive success was related to raven abundance or distribution.

168 **STUDY AREA**

169 The study site was located in east central Nevada within Eureka County (Fig. 2). The
170 study area encompasses approximately 7000 km^2 of sagebrush steppe and pinyon-juniper
171 mountain ranges. Within this system, sage-grouse occur in habitat that varies along an elevation
172 gradient. At lower elevations (< 2000m), the shrub community is dominated by Wyoming big
173 sagebrush (*Artemisa tridentata wyomingensis*), with localized patches of black sagebrush (*A.*
174 *nova*) and basin big sagebrush (*A. tridentata tridentata*). Rubber rabbitbrush (*Chrysothamnus*
175 *nauseosus*), greasewood (*Sarcobatus vermiculatus*), and scattered Utah juniper (*Juniperus*

176 *osteosperma*) were also relatively common. At higher elevations (> ~2000m), the dominant
177 shrub community is a mixture of mountain big sagebrush (*A. tridentata vaseyana*) and low
178 sagebrush (*A. arbuscula*), with some intermixed common snowberry (*Symphoricarpos albus*),
179 western serviceberry (*Amelanchier alnifolia*), and bitterbrush (*Purshia tridentata*). Large
180 expanses of singleleaf pinyon (*Pinus monophylla*)/Utah Juniper forest often occurs at mid-
181 elevation sites between the low and high elevation sagebrush communities. Structure and
182 composition of understory vegetation, primarily grasses and forbs (e.g., richness and biomass)
183 was also positively correlated with elevation (Gibson et al. in review-a). Common annual and
184 perennial forb taxa included phlox (*Phlox* spp.), lupine (*Lupinus* spp.), mustard (*Descurainia*
185 spp.), and vetch (*Astragalus* spp.). Common grasses consisted of blue grass (*Poa* spp.),
186 cheatgrass (*Bromus tectorum*), crested wheat (*Agropyron cristatum*), Indian rice grass
187 (*Achnatherum hymenoides*), and squirrel tail (*Elymus elymoides*). Patterns in seasonal habitat use
188 (Atamian et al. 2010) and genetic structure (Jahner et al. in review) indicate that sage-grouse in
189 our study system can be classified into at least two distinct populations: individuals associated
190 with the Cortez mountains or the Roberts Creek Mountain (hereafter Cortez or Roberts).

191 *Falcon-Gondor transmission line*

192 In fall 2003, Sierra Pacific Power Company (now NV Energy) began construction of a
193 345 kilovolt transmission line between the Falcon and Gondor (hereafter FG transmission line)
194 substations located in White Pine and Lander Counties, respectively, in Nevada, U.S.A.
195 Construction of the FG transmission line was completed in the spring of 2004 and was energized
196 in May of that year. The completed FG transmission line was approximately 299km long and
197 consisted of 734 towers that varied in height (23-40m), and design (2-pole H-frame or 3-pole
198 guyed angle-transposition towers; Fig. 3), depending on topography and projection. Towers in

areas of historic or active sage-grouse habitat were fit with experimental perch deterrents that were fixed on sections of towers where avian predators were most likely to perch. Deterrents consisted of 16-gauge steel in an inverted-Y design fit on horizontal tower arms, and steel plate deterrents fit on the tops of vertical tower arms and crossarms (Lammers and Collopy 2007).

The FG transmission line runs through the middle Eureka County's prime sage-grouse habitat (M. Podborny, NDOW, personal communication). We defined our study area as anything within a 10km buffer surrounding the minimum convex-hull polygon that encompassed all female sage-grouse telemetry locations from 2003–2012 (Fig. 2). The study area includes 134km of the FG transmission line and focuses primarily on individuals associated with 13 leks at various distances from the FG transmission line. Six study leks were within 5km of the Falcon-Gondor transmission line, and ten study leks were within 10km of the Falcon-Gondor transmission line.

Study lek descriptions

We monitored 10 to 13 breeding areas, or leks located within 20 km of the Falcon-Gondor transmission line (see below) from 2003-2012. Male sage-grouse establish territories within these leks and attempt to attract potential mates with a mating display (Wiley 1973). Lek activity began in late February and ceased in mid-May, with male lek attendance peaking in both early and late April associated with high female attendance (Blomberg et al. *unpublished data*). Leks were selected by evaluating previously collected data from the Bureau of Land Management (BLM) and the Nevada Department of Wildlife (NDOW). Five leks were monitored by NDOW and BLM over the past thirty years. Long term data show male lek attendance at these leks has declined over the last five decades (NDOW *unpublished data*). Although long term lek monitoring suggested that populations stabilized during the 1990's, the

abundance of sage-grouse within this system declined over the course of this study (Gibson et al. 2014), similar to population trends across the southern Great Basin (Garton et al. 2011, Garton et al. 2015).

Other anthropogenic disturbances

Other power lines

The study area also included approximately 243km of additional power lines, of which 42km were associated with a second transmission line, and 201km were either subtransmission or distribution lines. The other transmission line, which runs east-west through the southern portion of the study system, was substantially older (~circa 1980), but of similar design and structure to the FG transmission line. Subtransmission and distribution lines were similarly older, and were typically one- or two-pole structures that facilitated transmission to mines, ranches, and residences. Eight study leks were within 5km of any power line.

Highways and roads

The study area included two major paved roads, which were both two lane state highways that intersected in the southeast portion of the study area, and combined were 162km in length. Four study leks were within 5km of a highway. There was an additional 430km of maintained gravel or dirt roads, and 3,500km of unmaintained single-lane dirt access roads (two-tracks). All study leks were within 5km of a maintained or unmaintained road. In this system, each transmission line corridor ran parallel (although not always immediately adjacent to) one of the two previously established highways, creating spatial correlation between highways and transmission lines.

Mining

Mineral extraction (primarily gold or other rare earth metals) is common throughout northern Nevada. Approximately 46,000 ha (~6.6%) of the study system was currently, or had recently been, within the physical footprint of mining activities (Nevada Department of Wildlife, *unpublished data*). The level of disturbance associated with mining is spatially heterogeneous, and ranges from complete loss of functional habitat (e.g., creation of open pit mines) to minor disturbances (e.g., increased noise; Blickley et al. 2012). However, it was unclear what percentage of the study area was comprised of actual surface disturbance, versus less intrusive activities (e.g., prospecting) or previously mined areas with no current disturbance. Additionally, the area associated with mining was not completely additive to other forms of disturbance, as the acreage associated with mining typically included roads, power lines, and/or recent wildfire.

Wildfire

Wildfires have disturbed approximately 85,000 ha (~12.1%) of our study system since 1999, with 90% of this disturbance occurring before the onset of this study. Burned areas were primarily colonized by exotic grasses, predominantly cheatgrass, but also planted crested wheatgrass. Exotic grasslands typically suppress the suppresses establishment of native vegetation (Miller et al. 2011), and are negatively associated with sage-grouse population trajectories (Blomberg et al. 2012).

Ranching and agricultural use

The majority (88%; ~619,000 ha) of the study system was federal lands that were primarily managed by the BLM. Livestock grazing (primarily cattle and to a lesser extent sheep) were prevalent on BLM managed lands. Of the ~ 82,500 ha of study system under private ownership, approximately 10,500 ha (1.5% of total study area) had been converted to cropland

agriculture, primarily irrigated fields planted with alfalfa (*Medicago sativa* cv.) or grass hay. These areas were generally located in the southeastern portion of the system. Alfalfa fields that bordered by sagebrush were used as early brood rearing habitat, however radio-marked sage-grouse were never observed in the interior of fields (D. Gibson et al., *unpublished data*). The remaining private land holdings were primarily in a checkboard pattern intermixed with BLM land localized in the northern portion of the study system, or were associated with mesic, lower elevation sites scattered throughout the system, often associated with grazing operations.

METHODS

Field Methods

Mark-Capture

We captured male and female sage-grouse on, or near, 10 to 13 leks during the mating season (March-May) from 2003–2012 and in seasonal high-elevation habitat during the fall from 2005–2011. Upon capture, birds were aged, sexed, weighed, and a series of morphological measurements were taken (i.e., length of 1st primary, 5th primary, wing chord, tarsus, foot, and number of tail feathers). Each female was banded with a size 14 National Band and Tag metal band, and most females were equipped with either a 22g or 12g radio with necklace-style attachment (A4060, A3950, Advanced Telemetry Systems, Isanti, MN). Radios were equipped with a mortality sensor that doubled the signal pulse rate if the transmitter remained motionless for >8 h. Each male was banded with a size 16 National Band and Tag metal band, and all adults and those young that were large enough were banded with a colored plastic tarsal band engraved with a unique three character alpha-numeric code for re-sighting during lek observations (described below). Individually marked male sage-grouse were re-encountered by recapture, re-

sightings of tarsal bands during morning lek observations, or from images of tarsal bands recorded by trail cameras placed on leks (Gibson et al. 2013).

Lek observations

Each study lek was observed approximately once weekly during the mating season (March- May) from 2003–2012. Observers arrived on the leks 1/2 hour before morning nautical twilight, and remained until strutting activity ceased or birds dispersed. During these periods, observers monitored leks from trucks or mobile blinds with spotting scopes and binoculars. We occasionally included a mobile observation tower to facilitate band reading where terrain permitted and vegetation characteristics required it. Observers counted the number of males and females, marked and unmarked, on leks every 30 minutes during each observation period. Observers also recorded individual tarsal band codes (resights) and behavioral interactions with potential predators. Observers recorded all disturbances at the lek, which included sage-grouse reaction, time of day, number of birds affected, and type of predator/disturbance (e.g., visual or audible detection of a mammalian or avian predator).

Female monitoring

Radio-marked females were located at least once weekly during the nesting season (end March – mid June) from 2003–2012 using a handheld receiver and YAGI antenna. Once nesting was confirmed, observers visited nests approximately twice a week until the nest hatched or failed. Our full nest monitoring protocols are described in (Gibson et al. 2015). From 2005–2012, we continued to monitor females that successfully hatched a nest to assess brood status and habitat use. We assessed brood foraging habitat by locating brood-rearing females weekly during diurnal hours (i.e., 700–1700). We monitored each female's current brood status through weekly

brood flush counts conducted the morning after the diurnal location. We performed weekly flush counts until 42 days after hatch (hereafter, pre-fledging period) or after two weeks of consecutive counts of zero chicks, which ever occurred first. Our full brood monitoring protocols are described in (Gibson et al. in review-b). After all radio-collared females had fledged young or failed, we continued to monitor survival of radio-marked females approximately once a month using fixed-wing aircraft.

Vegetation surveys

We measured vegetation at each nest site, weekly diurnal brood locations, and at random points temporally associated with the nesting and brood rearing periods, which all followed similar protocols. We measured nest vegetation at all monitored nest sites within 3 days of either the predicted or actual date of hatch. Nest site vegetation was sampled along 10m intersecting transects centered at the nest bowl (Gregg et al. 1994), using the line-intercept (Canfield 1941) and Daubenmire (1959) frame methods. The line-intercept method was used to estimate total shrub cover, sagebrush shrub cover, and non-sagebrush shrub cover. We used Daubenmire frames placed along each transect to classify ground cover of grass, forbs, and total cover (grass, forb, and shrub). See Gibson et al. (2015) for detailed nest vegetation protocols. We also measured vegetation at each weekly diurnal brood location, which were conducted approximately one week after the initial brood location, and centered approximately (± 5 m) where the brood was located the week prior. Brood vegetation surveys followed the same protocols as nest vegetation surveys, however from 2008–2012, brood vegetation surveys were sampled along 20m intersecting transects. See Gibson et al. (in review-b) for detailed brood vegetation protocols. Lastly, we randomly selected four points each year for each monitored study lek that were generated within a 5 km buffer around each study lek. We began random

vegetation surveys after the first predicted hatch date in a given year, and completed them haphazardly throughout the nesting and brood rearing seasons to coincide with sampling at nest and brood locations.

Raven monitoring

During March-May from 2003–2012, we performed avian point counts along three transects (i.e., south, central, north) that paralleled the Falcon-Gondor transmission line corridor. The average distance between two points within a single transect was 3.36 km (sd = 0.70 km). The north and central transects had 9 points, and the south transect had 5 points. The nearest points in the central and north transects were 10.9 km apart, and the nearest points in the the central and south transects were 20.2 km apart. Observers attempted to survey each transect once every 10 days from March - May. We alternated transect start times (between 1 hour after sunrise and at 13:00 hrs), and survey start point (between northernmost and southernmost point of a transect). Surveys were not conducted if there was precipitation, fog, or if wind speeds exceeded 19 km/hr. Observers spent 10 minutes at each point, identified all observed raptor and corvid species, number of individuals, and whether the observed individual was within 400m of the line or beyond.

Quantitative Methods

Sage-grouse demographic processes

We estimated the following demographic rates from radio-telemetered female sage-grouse data: 1) nesting propensity; 2) re-nesting propensity; 3) nest site selection; 4) nest success; 5) brood site selection; 6) pre-fledging chick survival; and 7) adult female survival. We estimated the following demographic rates from capture-mark-recapture data of male sage-

grouse: 1) adult male survival; 2) male lek movements; 3) per capita recruitment; and 4) population growth. Each analysis is outlined in detail within the Demographic Analyses sub-section.

Approach to inference

The underlying hypothesis for each analysis was that a particular demographic rate (e.g., nest success, female survival) was not influenced by an individual's proximity to either the FG transmission line or any other power line. Environmental impact studies often employ a Before-After-Control-Impact (BACI) study design to account for correlations between various temporal or spatial variables and the potential disturbance. Such an experimental design presumably accounts for factors that may otherwise mask or inflate impacts. Although BACI study designs are ideal for disentangling variables that are spatially confounded (Green 1993), the pace at which disturbances occur, even those of anthropogenic origin, often occur prior to sufficient data collection, which precludes BACI approaches. In such cases, post-disturbance data sampled across sufficient spatial and temporal scales represent the only viable approach to assessing disturbance (Johnson et al. 2005).

We developed a two stage approach for assessing impacts of power lines on sage-grouse habitat use and demography. First, we developed functional relationships between habitat variables (e.g., elevation, shrub cover, etc.) and the response variable of interest (e.g., daily nest survival), which allowed us to establish a predictive surface for each response variable for the entire study area based entirely on features of the natural environment. We refer to values from this surface as reference values, as they represent estimates of demographic rates based solely on features of the natural environment. Second, we compared the predicted value of each response variable to the estimated value, including effects of distance to anthropogenic features in models.

The second set of models allowed us to assess the impact of anthropogenic features on potential demographic rates, while controlling for habitat and other environmental effects. Spatial correlation between anthropogenic features and habitat variables has the potential to render our approach conservative but the approach we adopted produces less biased assessments of the impacts of anthropogenic disturbance than approaches that do not account for effects of habitat.

For this study, a BACI study design was not possible because the period between permitting and construction of the FG transmission line did not allow for adequate collection of pre-construction data. Additionally, other anthropogenic disturbances (e.g., highways, other transmission lines), as well as other natural environmental variation (e.g., elevation, Fig. 4), were associated with the location of power lines. Therefore, our modeling approach had to account for potential correlations between an individual's distance from all power lines and other confounding sources of variation. Although modeling interactions between covariates can be an appropriate method for accounting for correlations in models with a few covariates, complex models with numerous parameters and multiple interactions are both difficult to interpret and are sensitive to sparse or outlier data (Zuur et al. 2010).

Accounting for confounding sources of variance in demographic data

Our approach to account for demographic heterogeneity among individuals, while minimizing the number of estimated parameters and interactions among parameters, was to use the parameter coefficients from the most competitive model structure that did not consider the distance from the FG transmission line covariate, to create a reference value, and use this value as a weighting factor. This reference value represented the predicted demographic probability (e.g., survival) for an individual, given the characteristics of the individual and its environmental (e.g. associated habitat), in the absence of any transmission line effects. Reference values were

401 then used as an individual covariate in a second analysis where we considered a series of models
402 designed to evaluate whether an individual's proximity to a utility line influenced their
403 demographic rates, while explicitly accounting for the individual's underlying demographic
404 state.

405 Demographic analyses used to generate reference values were conducted in the Program
406 MARK (White and Burnham 1999) or in R (R Core Team 2012) using generalized linear mixed
407 effects models with the lme4 package (Bates and Maechler 2009). We primarily developed
408 analysis-specific reference values from ecological relationships based on analyses previously
409 conducted in this study system (Blomberg et al. 2012, Blomberg et al. 2013a, Gibson et al. 2014,
410 Gibson et al. 2015, Gibson et al. in review-a;b, Gibson et al. in review-c). However, we modified
411 some analyses by considering additional environmental variables that were not included in the
412 original publications. We were not able to use a uniform suite of environmental variables across
413 all analyses because spatial (e.g., landscape- versus local-scale), organizational (e.g., individual-
414 versus lek-specific) and temporal resolution (e.g., daily versus annual time-steps) varied among
415 analyses. See supplemental material for all covariates considered (Table S1) for each reference
416 value analysis.

417 *Description of primary disturbance covariates*

418 We were primarily interested in assessing if sage-grouse demographic rates varied as a
419 function of their distance from the FG transmission line. We digitized the FG transmission line
420 corridor from UTM coordinates of all tower locations in our study system, and created a spatial
421 surface that represented the Euclidian distance each pixel was from the FG transmission line
422 using the spatial analyst toolbox in ArcMap 10.0 (Environmental Systems Research Institute,
423 Redlands, CA). We used this surface to assign individuals a distance from FG transmission line

value, where assignment depended on temporal resolution of each analysis. We were also interested in whether individuals responded to a new transmission line differently than previously existing power lines, and thus we considered two power line covariates for each analysis; 1) distance from the FG transmission line; and 2) distance from any power line. We digitized all known power lines from satellite imagery, and created a spatial surface of Euclidian distances from any power line for our study system, which was assigned to each individual in each analysis. We also allowed for diminishing effects on demographic rates of distance to a power line by considering models containing both linear and quadratic effects of distance from utility lines.

Lastly, as an important hypothesis underlying the influence of power lines on sage-grouse demography is that power lines positively influence sage-grouse predators (e.g., reproductive success, foraging efficiency), we used estimates of raven abundance and raven disturbance (see below) as covariates to investigate the linkage between utility lines, the distribution and abundance of avian predators, and sage-grouse.

Raven abundance

We used a modified robust design N-mixture model in a Bayesian hierarchical framework (Kery and Schaub 2012) in JAGS accessed through program R using the rjags package (Plummer 2013) to estimate raven abundance (n), finite rate of increase (*r*), and detection (*p*) from avian point count data collected along the FG transmission line corridor from 2003–2012. We summarized point count data to represent the maximum number of ravens observed within 400m of the FG transmission line per transect survey. Each survey was assigned to a transect group (i.e., north, central, south), and to a 10-day secondary occasion based on the ordinal date of the survey (OD: 61–140; no. secondary occasions = 8) within each year, and a

primary occasion based on year (no. primary occasions = 10). For this analysis, we allowed raven populations to be open among years (primary occasions), but closed within primary occasions; however, as raven territory behavior is heterogeneous, and individuals range along a continuum from permanent residents to seasonal transients (Webb et al. 2011). We, therefore, acknowledge that we likely violated the assumption of population closure inherent to the secondary occasions of the robust design, because some counted individuals were most likely transients and thus not available for detection during all secondary occasions within a primary occasion. However, we suggest that the violation of this assumption results in our estimates of raven abundance nevertheless represent the superpopulation size, or the total number of ravens that were available for detection at least once during a single year near the FG transmission line (Kéry and Schaub 2012). Furthermore, even though the overall estimate of raven abundance shifts as a function of a models constraints on population closure, patterns in population trajectories across years (e.g., lambda), which we were primarily interested in, should remain unaffected. We report the mean and standard errors for each parameter. The model code and specifications can be found in Supplemental Material B.

Raven disturbance

We used a site-dynamic occupancy model in a Bayesian hierarchical framework (Kéry and Schaub 2012) in JAGS accessed through program R using the rjags package, based on raven observation data collected during morning sage-grouse lek observations from 2003–2012 to estimate the following: probability 1) of a lek being visited by a raven (ψ_{Dis}) in year$_t$; 2) that a lek not visited by a raven in year$_t$ would be visited in year$_{t+1}$ (γ_{Dis}); 3) that a lek visited by a raven in year$_t$ would not be visited in year$_{t+1}$ (φ_{Dis}), and 4) of detecting of a raven visitation (p_{Dis}). We summarized raven visitations recorded during lek observations as a Bournoulli

(presence or absence) response variable describing whether a lek was disturbed at least once by a raven during a morning lek observation. Each study lek was considered to be independent (no. leks = 13), and each lek observation was assigned to a to a 20-day secondary occasion based on the ordinal date of the survey (OD: 61–140; no. secondary occasions = 4) within each year, and a primary occasion based on year (no. primary occasion = 10). We used 20-day lengths for secondary periods to both increase the probability that at least one full survey per lek was completed per occasion (e.g., not cancelled due to weather) and decrease the absolute variation in survey observation length. Although both raven analysis share an assumption of closure among secondary occasions, this analysis was less sensitive to violations of this assumption, because it was highly likely that each lek was available to be visited by at least one raven during each secondary occasion. We report the mean and standard errors for each parameter. The model code and specifications can be found in Supplemental Material C

Model selection - maximum likelihood

We used an information theoretic approach to evaluate support for competitive models preformed in a maximum-likelihood framework (Burnham and Anderson 2002), and considered covariate effects to be meaningful if 85% confidence intervals of β coefficients did not overlap 0.0 (Arnold 2010). For generation of the reference values, we used an iterative process in model creation whereby we applied individual covariates to assess various potential sources of heterogeneity in each demographic rate. Covariates were added to a model one covariate at time, and those that improved model fit were retained in the model structure. Covariates that were correlated with each other (Pearson's r >0.50) were not included simultaneously in models. We then performed backwards model selection; each covariate in the current model structure was removed singularly to assess its influence on model performance in the presence of other

493 covariates. If exclusion of a single covariate improved model performance, that covariate was
494 removed from consideration. All covariates in all analyses were z-standardized (mean = 0.0, SD
495 = 1.0; White and Burnham 1999).

496 *Model selection – Bayesian hierarchical model*

497 The appropriate methods for model selection in Bayesian hierarchical model framework
498 are still under debate (Hooten and Hobbs 2015). However, we were not interested in assessing
499 model support for explanatory variables in either Bayesian analysis, but instead only interested in
500 developing less-biased estimates of raven abundance and spatial distribution. Therefore, it was
501 only necessary that our models were both realistic and reached convergence. As such, we
502 developed a series of models of increasing prior parameter complexity, and derived demographic
503 estimates from the most complex model that was both biologically reasonable and converged
504 based on Gelman's diagnostic (Brooks and Gelman 1998).

505 *Modeling power line covariates*

506 For each analysis, we considered linear effects of distance from the FG transmission line
507 and any power line. Additionally, if the underlying data was sufficient we considered the effect
508 of distance from either any power line or FG transmission line, specifically, as a non-linear
509 relationship (i.e., quadratic) or allowed for interactions between the reference valueand each
510 distance variable. Post-hoc, we report the inflection point for all supported non-linear effects of
511 distance from a power line or FG transmission line to provide an estimate of the distance at
512 which an effect began to dissipate. For analyses that measured metrics of reproductive success
513 (e.g., nesting propensity, nest success, population growth), we also considered linear and
514 quadratic effects of estimated maximum raven population size and raven disturbance as well as

interactions between raven population size or disturbance and distance from power lines. Lastly, post-hoc, for the nest site selection and nest survival models, we considered models that allowed for full annual variation in the effects of distance from the FG transmission line to assess if female nesting behavior or hatching success was influenced by annual shifts in raven population size. We considered disturbance effects to be meaningful if 85% confidence intervals of β coefficients did not overlap 0.0 (Arnold 2010).

Demographic Analyses

Nesting propensity

We used spring (April 1s –May 31st) locations from radio-marked female sage-grouse from 2003–2012 in multi-state framework in Program MARK to assess the influence of power lines on probabilities of nest initiation. We formatted encounter histories and model state specifications following methods outlined in Gibson et al. (in review-c), which used the recorded nesting state from each check of a radio-marked female to generate an encounter history for each female in each study year. In this analysis, year-specific nesting states were defined as a female not yet observed on a nest (PreNest), a female observed on her first nest ($Nest_1$), a female observed not on a nest following failure of a first nest (PostNest), and a female observed on a second nest ($Nest_2$). We were primarily interested in estimating the probabilities of transitioning (ψ_{Nest}) among nesting states, which can be used to derive an overall probability of nest initiation and re-nest initiation conditioned on failure of a first nest. We developed the reference value variable (NP) for nest initiation as an occasion specific covariate (30 2-day occasions) and included the following variables (and direction of effect): 1) male population size (-); 2) minimum female age (+); 3) minimum female age^2 (-), and 4) a quadratic time trend. The reference value variable (RNP) for re-nest initiation was modeled with no temporal variation

within years and included the following variables (and direction of effect): 1) male population size (-); and 2) total precipitation recorded for the previous year (August-July). See (Gibson et al. in review-c) for methods, parameter estimates, and model results for the reference value analysis.

For the power line component of this analysis, we calculated the average distance to the closest power line or the FG transmission line, for all unique locations for each female (i.e. a single nest was only considered once, and not for every visit) during each spring. We used these values as a covariates for both the nest and re-nest initiation parameters. We also assigned each individual a covariate that represented the estimate raven population size for that year, as well as a covariate that represented the average probability of raven disturbance associated with the study lek that a female was most often closest to each spring.

Nest site and brood site selection

We used vegetation and location data collected from nest sites, brood sites, and random locations from 2004–2012 (nest site selection) and 2005–2012 (brood site selection) to assess the influence of power lines on probabilities of habitat use during the nesting and brood rearing periods at multiple scales using resource selection functions implemented with methods described by Boyce and McDonald (1999) and Hebblewhite and Merrill (2008). We performed two separate resource selection analyses based on the spatial scale of the habitat characteristics considered for the both nesting and brood rearing periods. The local scale selection analyses considered predictor variables derived from fine-scale vegetation surveys, and the landscape scale selection analyses used predictor variables derived from more broad-scale Geographic Information Systems data. We performed each resource selection function analysis in a generalized linear mixed model framework (Zuur et al. 2009) using the lme4 package (Bates and Maechler 2010) in R. The reference value variable (Landscape Nest Site Selection) for nest site

561 selection at the landscape scale included the following variables (and direction of effect): 1) nest
562 site elevation (+); 2) slope (+); 3) slope * elevation (-); 4) amount of habitat classified as
563 sagebrush with 1000m (+); 5) distance from nearest lek (-); 6) amount of habitat classified as
564 sagebrush * distance to lek (-); 7) amount of habitat classified as pinyon-juniper woodlands (+);
565 8) amount of habitat classified as pinyon-juniper woodlands^2 (-); 9) distance from nearest water
566 source (-); and 10) distance from nearest water source^2 (-).The reference value variable (Local
567 Nest Site Selection) for nest site selection at the local scale included the following variables (and
568 direction of effect): 1) sagebrush shrub cover (+); 2) non-sagebrush shrub cover (+); 3)
569 sagebrush shrub cover * non-sagebrush shrub cover (+); 4) forb cover (+); 5) forb height (+); 6)
570 forb cover * forb height (+); 7) forb taxa richness (+); 8) live grass height (+); 9) residual grass
571 height (+); and 10) shrub height (-). See (Gibson et al. in review-a) for methods, parameter
572 estimates, and model results for the nest site selection analyses used to generate reference values.

573 The reference value variable (Landscape Brood Site Selection) for brood site selection at
574 the landscape scale included the following variables (and direction of effect): 1) nest site
575 elevation (+); and 2) slope (-). The reference value variable (Local Brood Site Selection) for
576 brood site selection at the local scale included the following variables (and direction of effect): 1)
577 non-sagebrush shrub cover (-); 2) total vegetation cover (+); 3) forb height (+); 4) forb taxa
578 richness (+); 5) live grass height (+); and 6) residual grass height (+). See Supplemental Material
579 (Tables S4-6) for parameter estimates and model results for the brood site selection analyses
580 used to generate reference values.

581 For each of power line components of these analyses, we used the distance each nest,
582 brood location, or a random location was from any power line and the FG transmission line as
583 covariates. Additionally, for the brood rearing habitat selection models, we allowed the effect of

distance from either power line covariate to vary as a function of survey date to assess if habitat selection varied as a function of brood age. Landscape brood-rearing selection models allowed for weekly variation, however we only allowed local brood-rearing selection models to vary by early and late brood-rearing, which was delineated by the median survey date. Post hoc, we estimated the effect of distance to FG transmission line variable to estimate independently for each year of the study in the landscape-level nest site selection analysis to assess how patterns in nest site selection changed over time. We only considered a year by distance from FG interaction for the landscape nest site selection analysis due to data limitations in other analyses.

Nest survival

We used the 'nest survival' module in Program MARK to model the influence of power lines on daily nest survival probabilities based on data collected from nests monitored from 2004–2012. We did not censor research related abandonments for this analysis, which biased our estimates of overall nest survival low (~0.07; Gibson et al. 2015), however, this bias should not substantially influence observed covariate relationships. The reference value variable (Success) for nest survival analysis included the following variables (and the direction of the effect): 1) percent non-sagebrush shrub cover (+); 2) percent forb cover (+); 3) average shrub height (+); 4) the amount of surrounding habitat classified as pinyon–juniper woodlands (+); and 5) the population the female was associated with [i.e. Roberts (+) or Cortez (-)]. See Supplemental material (Tables S2-3) for parameter estimates and model results for the reference value analysis.

For the power line component, we used the distance each nest was from either a power line or the FG transmission line as covariates. Post hoc, we also allowed the distance to FG transmission line variable to be estimated independently for each year of the study to assess how patterns in nest survival changed over time. We also assigned each nest a covariate that

607 represented the estimated raven population size for that year, as well as a covariate that
608 represented the average probability of raven disturbance associated with the study lek nearest to
609 the nest.

610 *Pre-fledging chick survival*

611 We used the Lukacs young survival of marked adults module (Lukacs-survival; Lukacs et
612 al. 2004)) in Program MARK to assess the influence of power lines on the pre-fledging chick
613 survival based on brood flush count and brood-site vegetation survey data collected from 2005–
614 2012. Lukacs's et al. (2004) model uses repeated counts of unmarked individuals (i.e., chicks)
615 that are completely associated with a marked individual (i.e., radio-marked female) who is
616 available for detection, to estimate apparent offspring survival (φ) accounting for imperfect
617 detection (p) of offspring. We modeled the reference value variable ($Survival_{chick}$) for the pre-
618 fledging chick survival analysis as a weekly time-varying covariate (no. weeks = 6) and included
619 the following variables (and the direction of the effect): 1) total percent vegetative cover (+); 2)
620 average grass height (-); 3) distance from spring or water source (+); 4) distance brood moved
621 during previous week (-); 5) mean maximum summer temperature (-); 6) nest site quality (+);
622 and 7) a quadratic effect (+) of minimum female age (+). Each weekly value for $Survival_{chick}$,
623 which is an interval-specific survival probability, was estimated using habitat characteristics
624 from the previous weeks brood location, as well as additive terms for current week (i.e., chick
625 age) and year. See Gibson et al. (in review-b) for methods, parameter estimates, and model
626 results for the reference value component for this analysis.

627 For the power line component, we calculated the distance a female and her brood was
628 located from either the nearest power line or FG transmission line at the beginning each week,
629 and used each of these values as a weekly time-varying covariate. Additionally, we also assigned

each brood a covariate that represented the estimated raven abundance for that year. We did not use probability of raven disturbance as a covariate in this analysis as broods tended to congregate, and were not spatially associated with leks, which together reduced variation in possible covariate values.

Adult Female survival

We used the 'nest survival' module in Program MARK to assess the influence of proximity to power lines on monthly female survival probabilities (*S*) based on year round telemetry data collected from radio-marked females from 2003–2012. We used nest survival models as they more appropriately assign timing of mortality when telemetry data is collected at irregular intervals (Dinsmore et al. 2002, Mong and Sandercock 2007, Blomberg et al. 2014). Individual encounter histories were 12 intervals (months) long, beginning March 1st in $year_t$, and terminating February 28/29th in $year_{t+1}$. Each year ($n_{years} = 10$) was defined as a group; females that were monitored across multiple years had a unique 12-occasion encounter history for each year they were monitored. We modeled the reference value variable ($Survival_{female}$) for the female survival analysis as a monthly time-varying covariate during the months we had ground-based telemetry locations (March–August; $n_{month} = 6$), and included the following variables (and the direction of the effect): 1) average monthly elevation (-); 2) minimum female age (-); 3) nest success (- ; a binomial variable (yes/no) modeled on June-July survival); and 4) brood success (- ; a binomial variable (yes/no) modeled on August survival). Elevation was the average monthly value from all telemetry locations during each monthly occasion. The reference value model also consisted of additive terms for the current season [i.e., spring (Mar-May); summer (June-July); fall (August)]. The reference value covariate was based on results published in (Blomberg et al. 2013b), but see Supplemental Material (Table S7) for model modifications.

For the power line component, we calculated the average distance a female was located from either the nearest power line or FG transmission line based on all ground-based telemetry locations collected for each female during a given month (March–August), and used each of these values as a monthly time-varying covariate. We did not assess the influence of distance from a power line or FG transmission line from the beginning of September to the end of February because we lacked precise location data for these months during all study years. Additionally, we did not use either metric of raven abundance in this analysis, as ravens are not known predators of adult sage-grouse.

Male survival and movement rates

We used the multistate robust design model in Program MARK to assess the influence of proximity to power lines on annual male survival (φ_{male}) and male lek-lek movement rates ($\psi_{movement}$) based on mark-recapture data collected from 2003–2012 during trapping events on leks (captures/recaptures) and during lek observations (resights). Encounter histories were generated from physical recaptures and band resights, and used in a two state, multistate robust design framework, where males were grouped together by lek of capture ($n_{leks} = 13$). As in Gibson et al. (2014), state transition probabilities represented the annual probability of a male moving to a lek different from it's lek of original capture. To fit criteria necessary for robust design analyses, we defined primary occasions as an annual breeding season, and subdivided each breeding season into two 35-day secondary occasions. The reference value variable ($Survival_{male}$) for the male survival analysis was based on spatial covariate values at the lek-scale (as opposed to individual), and should be interpreted as the average annual male survival for each lek. The variables in $Survival_{male}$ (and the direction of the effect) included the following: 1) lek elevation (+); 2) population the lek was associated with [(Roberts (+); Cortez (-)]; and 3) the

676 total precipitation recorded for the year prior (+). We did not calculate a reference value variable
677 for $\psi_{movement}$ as the data were too sparse to reliably assess model structures more complicated
678 than the intercept-only model. See Gibson et al. (2014) for methods, parameter estimates, and
679 model results of the reference value component of this analysis.

680 We assigned each male was assigned annual time-varying covariates that represented the
681 distance between the lek he attended in year$_t$ and the nearest power line or FG transmission line
682 to assess the influence of power lines on either φ_{male} or $\psi_{movement}$ from year$_t$ to year$_{t+1.}$ We did
683 not use either metrics of raven abundance on either φ_{male} or $\psi_{movement}$ for this analysis as ravens
684 are not known predators of adult sage-grouse.

685 *Recruitment and population growth*

686 We used robust design Pradel models in the Program MARK to assess the influence of
687 proximity to power lines on lek-specific population growth (λ) and recruitment rates (f) based on
688 male encounters from 2003–2012 during trapping events on leks. Encounter histories were
689 generated from only physical captures of males at leks that were monitored from the entire
690 length of the study (n_{leks} = 11). Similar to the multistate robust design analysis, we defined
691 primary occasions as an annual breeding season, and subdivided each breeding season into two
692 35-day secondary occasions. Additionally, both the reference value variables for λ (PopGrowth)
693 and f (Recruit) were based on spatial covariate values at the lek-scale, and should be interpreted
694 as the average demographic rate for each lek. The variables in PopGrowth (and the direction of
695 effect) included the following: 1) lek elevation (+); 2) total precipitation recorded for the year
696 prior (+); and 3) proportion of surrounding habitat converted to exotic grasslands (-). The
697 variables in Recruit (and direction of effect) included the following: 1) lek elevation (+); 2) total
698 precipitation recorded for the year prior (+); 3) proportion of surrounding habitat converted to

699 exotic grasslands (-); 4) an interaction between precipitation and exotic grasslands (-); and 5)
700 average percent vegetation cover from all random vegetation surveys performed within 5km of a
701 lek (+). The reference value models were based on results published in Blomberg et al. (2012),
702 but see Supplemental Material (Tables S8-9) for model modifications.

703 Each male was assigned annual time-varying covariates that represented the distance
704 between the lek he attended in year$_t$ and the nearest power line or FG transmission line to assess
705 the influence of power lines on λ or f between years t and $t+1$. We also assigned each male a
706 time-varying covariate that represented the estimated raven population size for that year, as well
707 as a covariate that represented the average probability of raven disturbance at the study lek each
708 male was associated with to assess whether variation in raven abundance influenced sage-grouse
709 recruitment and population trajectories.

710 **RESULTS**

711 **Descriptive Results**

712 We captured and radio-marked 361 female sage-grouse and captured and banded 988
713 male sage-grouse over the course of the study (Table 1). Over the ten year period, we did not
714 attribute any mortalities of radio-marked individuals to a collision with a power line or pole. We
715 discovered and monitored 427 nests from 249 unique females from 2003-2012, of which 138
716 nests from 116 unique females were successful. We classified 355 of the nests as first nests, 66
717 as second nests, and 6 as third nest attempts. Adults initiated 312 of the nests, juveniles initiated
718 96, and 19 nests were from unknown-age females. We monitored 120 broods after hatch from 99
719 unique females, and observed 862 chicks at hatch, of which 163 chicks were associated with
720 their mothers at approximately 6 weeks after hatch. We completed 1364 vegetation surveys, of

721 which 423 were associated with nests, 452 were associated with brood locations, and 488 were at
722 random sites. We completed 1067 lek observations at our 13 study leks ($\bar{x}$ = 8.73 observations
723 per lek per year).

724 **Quantitative Results**

725 *Raven abundance*

726 The most complex model we considered that converged allowed n (raven abundance) and
727 *r* (within-year growth rate) to vary independently among transects and years, and *p* (detection) to
728 vary independently among transects and secondary occasions, but constrained *p* to be constant
729 among years (Table 2). Raven populations in Eureka County, NV, have increased approximately
730 5-fold since the construction of the FG transmission line in 2004 (range: 69.50 – 318.39; Fig.
731 4A). On average, the annual rate of increase was 22.7 ravens/year, however this represents the
732 increase in the superpopulation of ravens, which relative to a geographic area we cannot spatially
733 delineate. Annual estimates of raven population size were used in subsequent models to assess
734 the influence of changes in common raven abundance on various sage-grouse demographic rates.

735 *Raven occupancy*

736 We had sufficient data to estimate probability of raven disturbance at 12 of the 13
737 monitored leks. After censoring data from the lek that failed to converge (i.e., Pony Express), the
738 most complex model that converged allowed ψ_{Dis} to vary independently among leks and years,
739 where γ_{Dis}, φ_{Dis}, p_{Dis} were allowed to vary independently among years, but were constrained to
740 be similar among secondary occasions and leks (Table 3). We found that, across all leks, annual
741 probabilities of raven disturbances generally increased from 2003-2012, and were positively
742 associated with our annual estimates of raven abundance (Fig. 4B; $\beta_{Abun\text{-}Occ}$ = 0.73; 85% C.I.:

743 0.38 – 1.08). Lek-specific probabilities of raven disturbances were variable across space, and
744 negatively covaried with distance from a power line or FG transmission line (Fig. 5). These
745 relationships, however, were based on limited data and were not well supported ($\beta_{Occ\text{-}Power}$ = -
746 0.046; 85% C.I.: -0.098 – 0.005; $\beta_{Occ\text{-}FG}$ = -0.044; 85% C.I.: -0.096 – 0.007) (Table Sx).
747 Nevertheless, the overall synchrony between our independently generated estimates of raven
748 abundance (i.e., abundance and disturbance rates) through time supported the use of these
749 metrics as variables in subsequent analyses.

750 *Nesting propensity*

751 Reference value variables for the nesting propensity analyses were predictive for both
752 probabilities of nest initiation (β_{NP} = 0.86; 85% C.I.: 0.76 – 0.93) and re-nest initiation (β_{RNP} =
753 0.33; 85% C.I.: 0.09 – 0.56). We found that an individual's distance from either the FG
754 transmission line or any power line did not influence her nesting propensity (Table 4); however
755 we found that probabilities of re-nesting (conditioned on initial failure) were highest in areas
756 most proximate to the FG transmission line (Fig. 6A). Annual estimated raven population size
757 was positively associated with re-nesting propensity but not nesting propensity (Fig.6B; Table 5).
758 We also found that the estimated probability of raven disturbance at the lek nearest to an
759 individual female was positively associated with nesting propensity, but was negatively
760 associated with re-nesting propensity (Fig. 6C).

761 *Nest site selection*

762 The reference value variables for the nest site selection analyses were predictive at both
763 the landscape ($\beta_{landscape}$ = 1.22; 85% C.I.: 1.13 – 1.30) and local (β_{local} = 1.24; 85% C.I.: 1.07 –
764 1.42) scales. Contrary to our hypothesis, at the landscape scale, we found support for a positive

765 linear effect of distance to any power line on nest site selection (Fig. 7A; Tables 6, 7), indicative
766 of avoidance. We also found support for a quadratic effect of distance from the FG transmission
767 line, which suggested that avoidance of the FG transmission line begins to dissipate, based on the
768 inflection point of the non-linear function, at approximately 10.5km from the line. At the local
769 scale, we found the most support for a positive linear effect of the FG transmission line on nest
770 site selection (Fig. 7B; Tables 8, 9), also indicative of avoidance behavior. We also found
771 support for a quadratic effect of distance from any power line, which suggested that avoidance of
772 power lines, based on the inflection point of the function, began to dissipate approximately
773 11.6km from the line.

774 Post hoc, we assessed whether the magnitude of the effects of distance from the FG
775 transmission line on nest site selection at the landscape scale was dependent on the current raven
776 population by developing a model that allowed for year-specific estimates of distance from the
777 FG transmission line. We found that year-specific parameter estimates for distance from the FG
778 transmission line on nest site selection positively covaried with estimated raven abundance (Fig.
779 8). This result indicates that females were more likely to nest further away from the line in years
780 with greater numbers of ravens present in the study landscape.

781 *Nest survival*

782 The reference value variable for the nest survival analysis was predictive of nest success
783 ($\beta_{success}$ = 0.27; 85% C.I.: 0.19 – 0.36). The best supported models included a quadratic effect of
784 distance from the FG transmission line on nest survival (Fig. 9; Tables 10, 11), which suggested
785 nests within 9.2km of the FG transmission line had reduced probabilities of hatching. We also
786 found support for a positive linear effect of distance from any power line on nest survival, which
787 suggested that nests distant from any elevated structures had higher probabilities of hatching. We

did not find support for a non-linear effect of distance to any power line, which is most likely related to the limited amount of habitat, and therefore nests, that were sufficiently distant from all power lines to observe a threshold. We did not find that, individually, annual raven abundance influenced nest survival, however we found support for an interaction (β_{FG}^2-$_{RavenAbun}$ = 0.21; 85% C.I.: 0.11 – 0.31) between a non-linear effect of distance to FG transmission line (β_{FG} = 0.13; 85% C.I.: 0.01 – 0.25; β_{FG}^2 = -0.17; 85% C.I.: -0.01 – -0.35) and raven abundance ($\beta_{RavenAbun}$ = -0.13; 85% C.I.: -0.27 – 0.01), which suggested nest survival near the FG transmission line was decreased when raven abundance was higher.

Post hoc, we further assessed whether the magnitude of the effects of a nest's distance from the FG transmission line was dependent on the current raven population size by developing a model that allowed for year-specific estimates of nest distance from the FG transmission line. Similar to results from the nest site selection analysis, we found that year-specific parameter estimates for distance effects nest survival positively covaried with estimated raven abundance (Fig. 8). This suggests that either the reduction in nest survival, or the distance from the FG transmission line in which nest survival was reduced, was positively correlated with annual raven abundance.

Brood site selection

The reference value variables for the brood site selection analyses were predictive at both the landscape ($\beta_{broodlandscape}$ = 0.70; 85% C.I.: 0.62 – 0.77) and local ($\beta_{broodlocal}$ = 1.40; 85% C.I.: 1.20 – 1.60) scales. At the landscape scale, we found the most support for an interaction between brood age and a quadratic effect of distance from any power line on brood site selection (Tables 12, 13), which suggested avoidance of habitat near power lines when chicks were very young. The magnitude of effect of power lines, however, declined as chicks aged (Fig. 10). We

did not find that distance from the Falcon-Gondor transmission line influenced site selection at the landscape scale. However, at the local scale, we found strong support for an interaction between chick age and a quadratic effect of distance from the FG transmission line, as well as interaction between chick age and a linear effect of distance from any power line (Fig. 11). Both effects suggested early avoidance of power lines, and that this effect dissipated as broods aged.

Pre-fledging chick survival

The reference value variable for the pre-fledging chick survival analysis was predictive of pre-fledging chick survival ($\beta_{survival\text{-}chick}$ = 0.41; 85% C.I.: 0.34 – 0.48). We found that early pre-fledging chick survival (i.e., first two weeks) was reduced near the FG transmission line (Table 14, 15). Furthermore, the effect of the FG transmission line on brood survival was greater in in habitats associated with higher probabilities of chick survival than on broods in lower quality habitat. We did not find that pre-fledging survival in later weeks (i.e., 3-6 weeks after hatch) was substantially influenced by distance from the FG transmission line. Support for an effect of distance to any power line on pre-fledging chick survival was marginal during both the early and late pre-fledging period. We did find that chick survival during the first two weeks after hatch was negatively impacted by raven abundance ($\beta_{RavenChickEarly}$ = -0.46; 85% C.I.: -0.63 – -0.28), however chick survival during subsequent weeks was positively associated with raven abundance ($\beta_{RavenChickLate}$ = 0.23; 85% C.I.: 0.07 – 0.39). We also found support for an interaction ($\beta_{Raven*FG}$ = 0.26; 85% C.I.: 0.11 – 0.41) between raven abundance ($\beta_{RavenAbundance}$ = -0.65; 85% C.I.: -0.90 – -0.41) and a non-linear effect of distance from the FG transmission line ($\beta_{FGChick}$ = 0.00; 85% C.I.: -0.12 – 0.12; $\beta_{FGChick}^{2}$ = -0.35; 85% C.I.: -0.45 – -0.25) (Fig. 12). This suggests that when raven abundance was high, chick survival was low regardless of brood location relative to the FG transmission line. However, during years of average or low raven abundances,

834 chicks further from the FG transmission line survived at substantially higher rates than chicks
835 located near the FG transmission line.

836 *Female survival*

837 The reference value variable for the female survival analysis was predictive of monthly
838 female survival ($\beta_{survival\text{-}female}$ = 0.59; 85% C.I.: 0.47 – 0.71). We found evidence of a weak
839 quadratic effect of distance from any power line on survival, however, in general, we found little
840 support for an influence of distance to the FG transmission line or any power line on female
841 survival (Fig. 13; Tables 16, 17).

842 *Male survival and lek movement rates*

843 The reference value variable for the male survival analysis was predictive of annual male
844 survival ($\beta_{survival\text{-}male}$ = 0.41; 85% C.I.: 0.25 – 0.57). We did not find that distance to FG
845 transmission line or any power line influenced male survival (Fig. 14; Tables 18, 19). Due to
846 rarity of observed movements among leks (Gibson et al. 2014), we did not estimate a reference
847 value variable for the male lek movement parameter. We found support for a marginal quadratic
848 effect of distance to any power line on male movement rates, which suggested that males
849 originally captured on leks closer to the transmission line were more likely to move to a different
850 lek than individuals from leks further away from transmission lines (Fig. 15). Overall, we did not
851 find that a lek's distance to the FG transmission line influenced male movement rates.

852 *Lek-specific recruitment and population growth rates*

853 The reference value variable for the population growth analysis ($\beta_{PopGrowth}$ = 0.42; 85%
854 C.I.: 0.35 – 0.48) was predictive of population change within our study system. After accounting
855 for the effect of surrounding habitat quality on population growth, we found leks more distant

from either the FG transmission line or any power line had higher population growth rates (Fig 16A; Tables 20, 21). The reference value variable for the recruitment analysis ($\beta_{Recruit}$ = 0.45; 85% C.I.: 0.36 – 0.54) was predictive of per capita recruitment. Overall, we found similar patterns between the recruitment and population growth analyses. After accounting for environmental conditions that influence recruitment, we found per capita recruitment was substantially higher at leks more distance from any power line (Figs 16A; Tables 22, 23). Alternatively, we did not find conclusive support for a relationship between distance of the FG transmission line and per capita recruitment.

Our findings indicated that among year estimates of population growth and recruitment were negatively influenced by annual raven abundance, and lek-specific estimates of population growth and recruitment were negatively influenced by the probability of raven disturbance at each lek (Fig. 16B). Models that included an interaction between distance from either the FG transmission line or any power line and a non-linear effect of raven abundance were supported in both analyses. Additionally, parameter estimates for distance from line variables in these interaction models were reduced, relative to the additive model, and were not supported. However, the raven abundance terms as well as the interaction between distance from line and raven abundance term were consistently supported, which suggests the negative effect of power lines on sage-grouse demographic rates were associated with raven population abundance and spatial distribution.

Influence of latent environmental heterogeneity on detection of power line effects

Numerous analyses demonstrated substantial differences in parameter estimates for distance from line covariates between models that accounted for environmental heterogeneity and those that did not. The direction of effect switched signs for a third of the analyses that

879 considered linear effects of distance to the FG transmission line (i.e., landscape-scale nest site
880 selection, nest survival, recruitment, population growth) between models that did, or did not,
881 include the reference value variable (Figs. 17, 18A,B). Additionally, confidence intervals
882 between estimates did not overlap for multiple analyses (i.e., recruitment, pre-fledging chick
883 survival, population growth, landscape-scale nest site selection). Similar inconsistencies were
884 also observed between models assessing the linear influence of distance to any power line in the
885 nest survival, recruitment, and population growth analyses. The effect of inclusion of the
886 reference value variable, however, was not consistent across all analyses, as it reduced the
887 observed negative effects of proximity to power lines (e.g., local nest site and brood selection),
888 as well as, negated support for an effect (e.g., female survival), but also suggested the existence
889 of a cryptic negative effect (e.g., nest survival, recruitment, population growth). As an example,
890 predicted nest survival based on habitat conditions were suggested, on average, to be higher near
891 power lines (Fig. 19A, B), which inhibited more simple model designs from detecting a
892 deleterious effect of utility lines (Fig. 17, 18A,B).

893 **DISCUSSION**

894 We found contrary to our initial hypotheses, that many demographic processes were
895 negatively influenced by an individual's proximity to either the FG transmission line or any
896 power line. However across the 10 year study period, we did not attribute a single mortality
897 event of a radio-marked individual to a direct collision with a power line, pole, or guy wire.
898 Although collisions between Galliformes and power lines have been suggested to be
899 disproportionately high relative to other birds (Bevanger 1998). The observed lack of mortality
900 was consistent with other long term studies that have recorded low numbers of mortalities
901 associated with power lines, relative to other sources, of radio-marked sage-grouse (Connelly et

al. 2000, Beck et al. 2006, Dinkins et al. 2014b) or other North American Galliformes (Pruett et al. 2009). Thus, effect of power lines on sage-grouse population dynamics was associated with indirect mechanisms, such as avoidance of habitat or suppressed vital rates, near power lines.

Avoidance of Habitat near Utility Lines

We found consistent support across spatial scales and seasonal habitat requirements that female sage-grouse selected habitat more distant from power lines. That is, we found that areas proximate to either the FG transmission line or any power line, which were otherwise predicted to be appropriate habitats for either nesting or brood-rearing, were less likely to used by female sage-grouse. Most notably, we found that the extent of avoidance during the nesting period was positively associated with annual raven abundance. This novel result suggests that changes in predator distribution across the landscape is the direct mechanism driving the avoidance of nesting in habitat near power lines. Raven populations have been positively associated with power lines (Knight and Kawashima 1993, Knight et al. 1995, Coates et al. 2014a, Howe et al. 2014), and sage-grouse have been found to avoid nesting in areas with high densities of avian nest predators (Dinkins et al. 2012). To our knowledge this is the first study that both demonstrates that sage-grouse avoid nesting near power lines, and that the magnitude of the avoidance is related to abundance of nest predators.

Avoidance of habitat near power lines during the nesting period was greater than during the brood-rearing period (Fig. 17). As selection for nesting habitat occurs before selection of brood rearing habitat, and support for avoidance of power lines during the brood rearing period dissipated as a function of chick age, it is likely that avoidance of power lines during the early brood rearing period was an artifact of avoidance of nesting near power lines. That is, we expect that reduced nest initiation and lower nest success near power lines would result in a distribution

of initial brood locations across a landscape that appear to reflect avoidance of power lines. We clearly cannot separate effects of lower nesting and nest success near lines from the potential that females avoided using habitats near utility lines during early brood rearing. Regardless, even in the absence of true avoidance behaviors during the brood rearing period, the combined effects of avoidance during nesting and or reduced reproductive performance near power lines results in a reduction in 'quality' of brood rearing habitat near power lines as brood rearing habitat is only functional if it is physically accessible (i.e., near successful nests) by broods (Gibson et al. in review-b) . Furthermore, as seasonal brood rearing habitat in our study system was rare (Atamian et al. 2010), and its abundance and condition influence sage-grouse chick survival (Guttery et al. 2013), which strongly influences population growth (Blomberg et al. 2012), relatively small losses of existing functional brood rearing habitat may result in substantial reductions in recruitment and population growth.

Lastly, we found support for a marginal effect of distance a lek was from any power line on the probability a breeding-aged male would move to a new lek the following year. Confidence intervals associated with these estimates were wide due to the rarity of observed lek movements within this system (Gibson et al. 2014), which also prevented us from developing more sophisticated models that could partition the direction of lek movements (e.g., towards or away from a power line) from absolute movements. Although these relationships indicate that power lines may, over time, lead to lek abandonments through habitat avoidance alone, it is far more likely extirpation of a lek would be a function of reduced recruitment of new individuals and reduced survival of adults in addition to greater male lek movement rates (Wisdom et al. 2011, Hess and Beck 2012).

Suppression of Individual Vital Rates

948 We found variable support for reductions of vital rates as a function of distance from
949 power lines. Some vital rates (e.g., nesting propensity, male survival) were not influenced by an
950 individual's distance from either FG transmission line or any power line. We found marginal
951 support for greater re-nesting rates near the FG transmission line, which was not observed with
952 other power lines. This relationship was not directly related to reduced nest survival near the FG
953 transmission line, as our model's estimates of re-nesting propensity were conditional on nest
954 failure, and as such, did not directly increase as a function of increased nest failure. However,
955 increased nest predation may result in more nests failing earlier in the nesting season, which
956 could indirectly increase re-nesting propensity as the average unsuccessful female would have
957 more time to attempt a second nest, or be in better body condition for such an attempt. Although
958 sage-grouse nesting propensity has been found to be negatively influenced by other
959 anthropogenic disturbances (e.g., oil development; Lyon and Anderson 2003), these estimates
960 were reported as apparent nesting propensity and are not directly comparable with our results
961 (Gibson et al. in review-c).

962 Nest survival, on the other hand, was negatively impacted by proximity to both the FG
963 transmission line and any power line. Similar to the pattern of avoidance of habitats near utility
964 lines for nesting, the effect of the distance to FG transmission line covariate in the nest survival
965 analysis positively covaried with annual raven abundance. Together, these results suggests that
966 females selected nesting habitat more distant from power lines, because nesting near power lines
967 resulted in reduced nest survival. Additionally, both the reduction in nest survival and the
968 amount of habitat avoided was correlated with temporal changes in raven abundance, which to
969 the best of our knowledge are the first results to also demonstrate a negative relationship between
970 raven abundance and sage-grouse reproductive success. Furthermore, we observed a sharp

971 increase in raven abundance associated with the FG transmission line corridor following its
972 construction and an increasing trend in raven abundance during our study. Having only one year
973 of pre-construction data limits our ability to draw inferences regarding raven responses to utility
974 lines but the patterns we observed are consistent with hypothesized responses of ravens to
975 elevated structures or other anthropogenic features (Knight et al. 1995, Kristan and Boarman
976 2003, Howe et al. 2014).

977 We also found reduced chick survival near the FG transmission line during the first two
978 weeks after hatch and the extent of the reduction varied as a function of raven abundance. Chick
979 survival was lower when raven abundance was higher, potentially related to increased predation.
980 Raven densities have been reported to be greater near sage-grouse brood rearing areas (Bui et al.
981 2010), indicative of increased predation pressure. However, female sage-grouse have also
982 exhibited avoidance of brood rearing habitat associated with greater raven densities (Dinkins et
983 al. 2012), which suggests behavioral mechanisms exist that reduce predation pressure.
984 Furthermore, and counterintuitively, we also found that chick survival during the end of the pre-
985 fledging period positively covaried with raven abundance, which we suspect may be related to
986 shared covariance between ravens and young-of-year sage-grouse with respect to how various
987 environmental conditions (e.g., forage conditions) affect productivity.

988 Similar to Dinkins et al. (2014a), we found a slight reduction in adult female survival for
989 females that occupied habitat associated with power lines, however we found no support for an
990 influence of power lines on adult male survival. We did not have sufficient data to estimate
991 variation in the abundances of predators of adult sage-grouse (e.g., raptors, coyotes, badgers)
992 within this system, therefore we could not design more targeted models related to adult survival.
993 Raptor abundances, however, were generally low and did not appear to increase following the

994 construction of the FG transmission line (Lammers and Collopy 2007, Gibson et al. unpublished
995 data)

996 *Did Power Lines Lead To Population-Level Effects?*

997 Although increased raven density or abundance has been associated with reduced nest
998 survival across many taxa (Andren 1992, Kurki et al. 1997, Klausen et al. 2010), overall, support
999 is lacking for population-level effects of ravens on avian population trajectories in general
1000 (Madden et al. 2015). We found that both habitat use (e.g., nest and brood site selection) and
1001 reproductive success (e.g., nest survival, chick survival) were reduced for female sage-grouse
1002 within ~10km of any power line, and this effect was clearly linked to raven abundance. Most
1003 importantly, our male-centered analyses suggested that these negative relationships observed in
1004 the female-centered analyses led to observable reductions in both recruitment of individuals into
1005 the breeding population and population growth. We found lek-specific recruitment and overall
1006 population growth rates were reduced near all power lines, and similar to results from the female
1007 analyses, these relationships were primarily associated with raven abundance or distribution.
1008 Although, we did not find the same level of support for reductions in lek-specific recruitment and
1009 overall population growth rates as a function of distance from the FG transmission line compared
1010 to distance from any power line, the patterns were consistent. Additionally, our ability to
1011 observe a correlation between sage-grouse population trajectories and distance from the FG
1012 transmission line was reduced, as leks more distant (>10km) from the FG transmission line
1013 predominantly remained within 10 km of, and therefore negatively influenced by, other power
1014 lines (Figs. 2, 6).

1015 In summary, we found that multiple vital rates estimated from independent data sources
1016 had the same general pattern; in that vital rates were reduced near utility lines. However, support

for the distance from power line parameters waned when models also considered interactions with raven abundance or distribution. Together, these analyses indicated utility lines indirectly influenced various sage-grouse vital rates, and ultimately population growth, through the positive association of ravens with utility lines. In other words, utility lines create an artificial selection pressure on sage-grouse, which have instilled behavioral responses in sage-grouse (e.g., avoidance), however the long term consequences of this selective pressure are currently unclear.

Importance of Accounting for Environmental Conditions

Our results highlight the importance of considering the underlying, latent environmental variability when assessing the influence of anthropogenic (or other) features. Here, we observed inconsistencies in the effect size or direction of the influence of either the distance from the FG line or any utility line. Over half of the analyses supported an effect of utility lines only with the inclusion of a reference value parameter that represented variation in environmental conditions. That is, we were substantially less likely to detect impacts of utility lines when we did not control for other environmental variables. In our study, these patterns resulted from the fact that the FG transmission line (and other lines) was placed in habitats that, would otherwise, be of high quality for sage-grouse. Additionally, support for models that included interactions between environmental conditions (e.g., shrub cover) and distance from power lines suggest complex relationships exist, in which certain individuals, or individuals associated with certain environmental conditions are more, or less, affected by their proximity to a power line. Furthermore, accounting for environmental heterogeneity produced different effects across demographic analyses, even within analyses based on similar data (e.g., landscape versus local scale nest site selection), as environmental heterogeneity was observed to both mask and exacerbate effects ultimately assigned to proximity to power lines.

We suspect inconsistencies related to environmental heterogeneity were driven primarily by two mechanisms; 1) study design (i.e., sampling variance), and 2) covariance among environmental conditions (i.e., process covariance). First, contrary to the reference models assessing the influence of distance to the FG transmission line at the landscape scale, models that did not consider the reference value variable suggested individuals selected habitat closer to the FG transmission line. This, however, was most likely an artifact of study design as this study was primarily developed to assess the effects of the FG transmission line on sage-grouse demographic rates. As such, study leks were selected (and therefore females were captured) as a function of their proximity the FG line corridor relative to available area within the study system. However, if leks nearest to the FG line were over represented as study leks relative to leks more distant from the FG line (Fig 14), then regardless of the true effect of the FG transmission line on nest site selection, models based on these data would inherently suggest females were attracted to the FG line corridor (Fig 17). Alternatively, if leks had not been selected relative to their proximity to power lines, we would have expected the bias in nest site selection (tending to be nearer the line) would have disappeared. Inclusion of the reference value variable, which was based on our earlier work using widely accessible environmental data allowed us to parsimoniously account for this source of sampling variance associated with study design, and provide less biased estimates of nest site selection.

Second, we suspect covariance among distance from either the FG transmission line or any power line variables and other environmental variables both obfuscated and exacerbated the true relationships between a vital rate and distance from a power line. For example, we have illustrated that distance from power lines was correlated with site elevation (Fig. 2; Fig. 4), and that elevation was correlated with habitat characteristics that influenced certain sage-grouse

demographic rates (Gibson et al. in review-a*;* Figure S6), and therefore, was correlated with those demographic rates (e.g., nest and brood site selection, population growth, recruitment). As such, studies that have not accounted for environmental heterogeneity, in this case elevation, may not be reliable (see Fig. 1), as we have demonstrated that either type I (e.g., male survival) or type II (e.g., nest survival, recruitment) error can occur. A specific example of underlying habitat heterogeneity resulting in difficulties in interpretations was found in the nest survival analysis, where we only found support for reduced nest survival related to proximity to a power line in models that included the reference value parameter. We suspect that this was related to patches of high quality nesting habitat, which by happenstance were located relatively near the FG transmission line. In the absence of a line effect, these areas may be highly productive (see Fig. 19). However, the negative effect of its proximity to the FG transmission line negated the benefit of nesting in these habitats, and effectively reduced the spatial variability in nest survival, leading to more support for models that did not consider the effects of common ravens or power lines.

MANAGEMENT IMPLICATIONS

Here, we found support for both hypotheses (i.e., avoidance and demographic suppression) regarding the mechanisms by which power lines influence sage-grouse demographics. Additionally, we found that both the magnitude of the avoidance of utility lines, as well as the extent to which vital rates were suppressed were correlated with common raven abundance, which was, itself, positively associated with utility lines. Therefore, the geographical extent to which utility lines would negatively influence sage-grouse demographic processes is not completely generalizable as it is contingent on local raven abundance and behavior. In this system, however, we found that effects of utility lines extended at least to 10 km, which exceeds

current recommendations for reduced surface use in areas around sage-grouse leks (5-7.5km; Coates et al. 2013).

Our finding that negative impacts of the transmission line were primarily associated with raven abundance, suggests that mitigation of line effects might be accomplished by reducing raven abundance near utility lines. Installation of deterrents to perching and nesting is one approach to such reduction, although perch deterrents on the FG line were not completely effective. Active removal of ravens in the area impacted by utility lines offers another potential approach to mitigation. Across all avian taxa, predator control regimes, on average, have successfully improved individual reproductive parameters (Smith et al. 2010), and tend to be more effective if all predator taxa are removed, as reductions in predation risk from the removed species may be compensated for by increased risk from another predator (Ellis-Felege et al. 2012). Meta-analyses on the effectiveness of predator control, however, have not found that predator removal leads to observable population growth in prey populations (Cote and Sutherland 1997, Smith et al. 2010), which suggest predator-related reductions in reproductive success and survival can be compensatory, potentially related to density-dependent mechanisms that regulate population growth. The effectiveness of raven control, primarily achieved through deployment of poisoned eggs or meat, on sage-grouse demographic rates is also not conclusive (Hagen 2011). Control measures (i.e., poison baits) can effectively reduce raven populations, however numbers of ravens removed are widely overestimated (Coates et al. 2007). Additionally, it is not clear if territorial ravens, which may disproportionately contribute more to both population growth of ravens and reproductive failure in sage-grouse, are as susceptible to control measures relative to migratory or juvenile ravens (Bui et al. 2010, Dinkins 2013). Support for a positive impact of raven removal on individual sage-grouse reproductive vital rates

1109 is variable (Coates and Delehanty 2004, Dinkins 2013), however no studies have currently
1110 quantified the effect of raven removal on population growth (Hagen 2011). As such, efficacy of
1111 direct removal measures requires well designed studies to assess impacts of such removal on
1112 raven populations and sage-grouse (Hagen 2011).

1113 Perch deterrents have been extensively used to reduce the damage cause by perching
1114 birds on power line towers or surrounding structures, reduce electrocutions for species of
1115 conservation concern, as well as disconnect the positive association between avian predators and
1116 elevated structures (Lammers and Collopy 2007, Seamans et al. 2007, Lopez-Lopez et al. 2011,
1117 Dwyer and Leiker 2012). The overall effectiveness of perch deterrents on raven populations,
1118 however, is questionable as some studies have reported short term reductions in perching or
1119 habitat use related to perch deterrents (Slater and Smith 2010, Dwyer and Leiker 2012), while
1120 others failed to find discernable reductions in perching or nesting behavior related to various
1121 types of perch deterrents (Lammers and Collopy 2007, Prather and Messmer 2010). Furthermore,
1122 as we observed reductions in sage-grouse vital rates associated with the portion of the FG
1123 transmission line that was fit with perch deterrents; the use of currently available perch deterrents
1124 as a management strategy for sage-grouse was not supported, especially given their monetary
1125 cost (Dwyer and Doloughan 2014).

1126 Alternatively, mitigation strategies could involve burying existing power lines within
1127 sage-grouse habitat (Fedy et al. 2015, Kirol et al. 2015) or routing new lines through less
1128 'critical' habitat (Bagli et al. 2011). The effectiveness of these two approaches are conditioned
1129 on accurate delineations of 'critical habitat', defined as the "geographic area occupied by the
1130 species" (U.S. Department of the Interior 2014), which are abundant for sage-grouse (Aldridge
1131 and Boyce 2007, Doherty et al. 2008, Kaczor et al. 2011, Fedy et al. 2014). Both of these

measures result in non-trivial initial costs to private industry (Fenrick and Getachew 2012). However, some of these costs may be recouped as underground lines are often more reliable, less susceptible to environmental damage, and require less maintenance (Hall 2009). Furthermore, cost-benefit analyses suggest that realized cost differentials, after accounting for other costs (e.g., aesthetics, wildlife interactions, maintenance) between underground and overhead transmission lines, may be less than previously thought (Navrud et al. 2008), as such many counties in Europe have adopted this strategy (Lehman et al. 2007) . Sage-grouse have positively responded (e.g., reduced avoidance behavior, increased nest survival rates) to mitigation treatments, which included burying power lines and other reductions in surface disturbance (Fedy et al. 2015, Kirol et al. 2015). However, it is unclear what the individual response of removal of transmission towers on individual vital rates was. Additionally, these studies could not quantify the overall impact of mitigation efforts on population growth. As such, and given the costs of burying power lines, additional research is required to determine if burying power lines 1) is an effective strategy for reducing local raven population size or their effectiveness as predators; and 2) results in improved probabilities of sage-grouse population persistence.

Other possible mitigation strategies include collocating proposed transmission lines into existing power line right-of-ways. Although we doubt this approach, singularly, would reduce the influence of existing corridors on sage-grouse demographic rates, it would result in less habitat 'influenced' by a power line, relative to management plans that proposed multiple spatially independent power line corridors. Future work, however, would be needed to assess whether avian predator use of these 'super-corridors' scaled linearly with total number of perching sites, or if other mechanisms influenced its attractiveness as habitat, which would determine the overall effectiveness of this strategy. Mitigation plans should also consider

alternative designs of power lines or poles. Although the design of power lines has been shown to influence avian electrocution rates of primarily large-bodied birds (Janss 2000), studies that demonstrate power line designs with reduced surface area of potential nesting substrate (e.g., no horizontal crossbeams) are used less by avian predators relative to standard power pole line designs are lacking.

In conclusion, there remain gaps in our knowledge of the efficacy of various power line mitigation strategies for management of sage-grouse populations. As such, until the necessary research has been completed, we recommend that 1) management agencies assume a 10km area of disturbance when developing management plans for the placement of new power line corridors, and 2) preferential treatment should be given to mitigation strategies that reduce the number of elevated structures placed within 10km of critical sage-grouse habitat.

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1494 **TABLES**

1495 **Table 1.** Summary of year specific greater sage-grouse and common raven monitoring data from 2003-2012 in Eureka County, NV,

Year	No. Radio-Marked Females	Unique females that nested	Unique females that re-nested	No. Hatched nests	No. Active broods at 6 weeks	No. New Males Captured	No. Males Recaptured (unique)	No. Males Resighted (unique)	Ravens per survey point	Total Max Male Lek Count
2003	15	11	1	5	na	146	26(20)	12(11)	0.87	227
2004	21	16	3	7	na	106	43(36)	41(26)	0.41	266
2005	35	28	8	12	9	104	55(48)	37(25)	1.03	316
2006	62	41	1	20	11	134	37(35)	56(35)	1.93	423*
2007	50	25	1	10	3	113	37(30)	34(12)	2.7	224
2008	41	31	6	7	5	62	30(26)	91(45)	0.79	212*
2009	54	46	17	20	9	46	50(34)	59(23)	1.32	182
2010	68	59	18	20	10	50	35(31)	109(33)	1.49	181
2011	63	48	8	18	10	63	44(30)	107(42)	2.52	193
2012	63	49	5	19	6	68	13(12)	135(40)	2.53	206

1496 USA.

Table 2. Designation of prior information and corresponding Gelman and Rubin convergence diagnostic for Bayesian hierarchical N-mixture models used to estimate common raven population abundance from 2003-2012 in Eureka County, NV, USA.

Priors allowed to vary by:			
Abundance (*n*)	Within Year Growth Rate (*r*)	Detection Probability (*p*)	$\hat{r}$[a]
Site	Site + Primary	Site + Secondary	1.02
Site	Site	Site + Secondary	1.02
Site + Primary	Site + Primary	Site + Secondary	1.03
Site + Primary	Site + Primary	Site + Primary + Secondary	1.17
Likelihood:			
Site + Primary	Site + Primary	Site + Secondary	

[a] $\hat{r}$ represents the Gelman's convergence diagnostic (Brooks and Gelman 1998), which suggests values < 1.1 indicate parameter convergence.

Site represents three survey transects along the Falcon-Gondor transmission line corridor. Primary occasions were comprised of 10 years (2003-2012) and secondary occasions were comprised of eight 10-day intervals from ordinal date 61-140.

Table 3. Designation of prior information and corresponding Gelman and Rubin convergence diagnostic for Bayesian hierarchical dynamic site-occupancy models used to estimate the relative probability of a common raven disturbance during a greater sage-grouse lek observation from 2003-2012 in Eureka County, NV, USA.

Priors allowed to vary by:

Site Occupancy (ψ)	Site Colonization (γ)	Site Survival (φ)	Detection Probability (*p*)	$\hat{\hat{r}}$[a]
Constant	Primary	Primary	Primary	1.01
Constant	Constant	Primary	Primary	1.01
Likelihood:				
Site + Primary	Primary	Primary	Primary	

[a] $\hat{r}$ represents the Gelman's convergence diagnostic (Brooks and Gelman 1998), which suggests values < 1.1 indicate parameter convergence.

Site represents 12 study leks. Primary occasions were comprised of 10 years (2003-2012) and secondary occasions were comprised of four 20-day intervals from ordinal date 61-140. Site occupancy = probability of raven disturbance during a lek observation; Site Colonization = probability that a lek undisturbed in $year_t$ will be disturbed by a raven in $year_{t+1}$; Site Survival = probability that a lek disturbed in in $year_t$ will also be disturbed by a raven in $year_{t+1}$; Detection probability = probability of detecting a disturbance that occurred during a lek observation.

1529 **Table 4.** Performance of all multistate models used to assess the influence of power lines and
1530 common raven demographic structure on greater sage-grouse nesting and re-nesting propensities
1531 in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Nest(NP+RavenOccupancy) ReNest(RNP+RavenOccupancy)	0.00	0.31	24	47436.76
Nest(NP) ReNest(RNP+RavenOccupancy)	1.44	0.15	23	47440.22
Nest(NP) ReNest(RNP+FGLINE^2)	1.90	0.12	24	47438.66
Nest(NP+RavenOccupancy) ReNest(RNP)	2.21	0.10	23	47440.99
Nest(NP) ReNest(RNP+ RavenAbundance)	3.29	0.06	23	47442.08
Nest(NP) ReNest(RNP)	3.64	0.05	22	47444.45
Nest(NP+RavenOccupancy^2) ReNest(RNP)	4.14	0.04	24	47440.90
Nest(NP+FGLINE^2) ReNest(RNP+FGLINE^2)	4.24	0.04	26	47436.95
Nest(NP+RavenAbundance) ReNest(RNP+ RavenAbundance)	5.27	0.02	24	47442.03
Nest(NP+FGLINE) ReNest(RNP+FGLINE)	5.60	0.02	24	47442.36
Nest(NP+Raven) ReNest(RNP)	5.62	0.02	23	47444.40
Nest(NP+FGLINE^2) ReNest(RNP)	5.98	0.02	24	47442.74
Nest(NP*FGLINE) ReNest(RNP)	6.35	0.01	24	47443.11
Nest(NP+AllLines^2) ReNest(RNP)	7.11	0.01	24	47443.87
Nest(NP*AllLine) ReNest(RNP)	7.11	0.01	24	47443.87
Nest(NP) ReNest(RNP+AllLines^2)	7.55	0.01	24	47444.30
Nest(NP+AllLines) ReNest((RNP+AllLines)	7.65	0.01	24	47444.41
Nest(NP+Raven*FGLINE) ReNest(RNP+FGLINE)	9.60	0.00	26	47442.31
Nest(NP+AllLines^2) ReNest(RNP+AllLines^2)	11.02	0.00	26	47443.72

Nest(FGLINE^2) ReNest(FGLINE^2)	195.44	0.00	24	47634.10
Nest(.) ReNest(.)	195.76	0.00	20	47642.51
Nest(FGLINE) ReNest(FGLINE)	196.41	0.00	22	47639.12
Nest(AllLines^2) ReNest(AllLines^2)	198.95	0.00	24	47637.61
Nest(AllLines) ReNest(AllLines)	199.07	0.00	22	47641.78

[a] Model selection notation follows Burnham and Anderson (2002). All models constrained site fidelity, nest failure, and re-nest failure to be constant among and within years (no. par = 3). Detection was allowed to vary by breeding stage (no. par = 3), year (no. par = 10), and fit with a quadratic trend across occasions but within years (no. par = 2). NP represents a covariate developed from the environmental characteristics which were supported to influence nesting propensity (Male Population Size (-); Female Age (+); Female Age^2 (-); Gibson et al. in review-c). RNP represents a covariate developed from the environmental characteristics which were supported to influence re-nesting propensity (Population size (-); Spring precipitation (+); Gibson et al. in review-c). FGLINE and AllLines represents the average distance a female sage-grouse was found from the Falcon-Gondor or any transmission line during a given spring (April 1st-May31st), respectively. RavenOccupancy represents the relative probability of a Common raven disturbing the breeding lek nearest to an individual female. RavenAbundance represents the annual estimated Common raven population abundance associated with the Falcon-Gondor transmission line. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

Table 5. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines and common ravens demographic structure on greater sage-grouse nesting and re-nesting propensities in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
NP	NP	**0.86**	0.76 – 0.93	**0.86**	0.76 – 0.93
NP + Line	Distance	-0.01	-0.10 – 0.08	0.00	-0.10 – 0.08
NP + Line + Line^2	Distance	0.05	-0.06 – 0.16	0.04	-0.09 – 0.16
	Distance^2	-0.07	-0.15 – 0.01	-0.05	-0.15 – 0.05
RNP	RNP	**0.33**	0.09 – 0.56	**0.33**	0.09 – 0.56
RP + Line	Distance	-0.24	-0.48 – 0.01	-0.02	-0.23 – 0.19
RP + Line + Line^2	Distance	**-0.42**	-0.68 – -0.16	0.02	-0.26 – 0.30
	Distance^2	**0.23**	0.07 – 0.39	-0.06	-0.30 – 0.18
Line$_{(Nest\ Prop)}$	Distance	-0.08	-0.16 – 0.01	-0.05	-0.13 – 0.03
Line + Line^2 $_{(Nest\ Prop)}$	Distance	0.00	-0.11 – 0.11	0.06	-0.06 – 0.18
	Distance^2	**-0.08**	-0.16 – 0.00	**-0.12**	-0.22 – -0.03
Line $_{(ReNest\ Prop)}$	Distance	-0.21	-0.45 – 0.03	-0.01	-0.22 – 0.20
Line + Line^2 $_{(ReNest\ Prop)}$	Distance	**-0.36**	-0.61 – -0.10	0.08	-0.2 – 0.35
	Distance^2	**0.19**	0.03 – 0.35	-0.11	-0.35 – 0.13
Model Format	**Parameter**	**β: Raven Abundance**	**85% C.I.**	**β: Raven Disturbance**	**85% C.I.**
NP + Raven	Raven	-0.02	-0.13 – 0.09	**-0.11**	-0.20 – -0.02

RNP + Raven	Raven	**-0.40**	-0.77 – -0.02	**0.30**	0.07 – 0.53

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with either nesting or renesting propensity are noted with NP and RNP, respectively. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven represents models that considered an effect of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6). Subscripts denote the parameter a covariate associated with.

[b] Parameter denotes the format of a given parameter estimate. NP and RNP represent reference values; Distance represents distance from a power line; Raven represents an estimate of common raven demographic structure.

Table 6. Performance of all resource selection function generalized linear mixed effects models used to assess the influence of distance from power lines on greater sage-grouse nest site use at the landscape-scale in Eureka County, NV, from 2004-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
AllLines + Landscape Selection	0.00	0.49	5	1675.97
AllLines * Landscape Selection	1.05	0.29	6	1675.02
$AllLines^2$ + Landscape Selection	2.00	0.18	6	1675.97
$AllLines^2$ * Landscape Selection	5.03	0.04	8	1675.00
Landscape Selection	10.79	0.00	4	1692.78
$FGLINE^2$ + Landscape Selection	10.87	0.00	6	1688.86
FGLINE + Landscape Selection	11.32	0.00	5	1691.31
FGLINE * Landscape Selection	12.06	0.00	6	1690.05
$FGLINE^2$ * Landscape Selection	13.22	0.00	8	1687.21
$FGLINE^2$	542.09	0.00	5	2218.055
$AllLines^2$	546.40	0.00	5	2222.37
AllLines	547.62	0.00	4	2225.59
FGLINE	552.35	0.00	4	2230.32
Null	566.10	0.00	3	2246.07

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse nest or random point was located from the Falcon-Gondor or any transmission line, respectively. Landscape Selection represents a covariate developed from the environmental characteristics which were supported to influence nest site selection at the landscape scale (Distance from Lek (-); Sagebrush Cover Classification (+); Sagebrush Cover Classification * Distance from Lek (-); Slope (-); Elevation (+); Slope * Elevation (-); Distance from Water (-); and $Distance\ from\ Water^2$ (-); Gibson et al. in review-a).

^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

Table 7. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines on greater sage-grouse landscape-scale selection of nesting habitat in Eureka County, NV, 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Landscape	Landscape	**1.22**	1.14 – 1.31	**1.22**	1.14 – 1.31
Landscape + Line	Distance	0.08	-0.02 – 0.19	**0.25**	0.16 – 0.34
Landscape + Line + Line^2	Distance	**0.15**	0.03 – 0.28	**0.25**	0.14 – 0.36
	Distance ^{2}	**-0.10**	-0.19 – 0.00	0.00	-0.09 – 0.08
Landscape * Line	Distance	0.07	-0.03 – 0.18	0.28	0.19 – 0.39
	Landscape	**1.25**	1.16 – 1.34	**1.23**	1.14 – 1.32
	Distance * Landscape	0.08	-0.02 – 0.19	-0.06	-0.14 – 0.03
Landscape * Line^2	Distance	0.10	-0.03 – 0.24	**0.29**	0.16 – 0.41
	Distance ^{2}	**-0.11**	-0.21 – 0.00	0.00	-0.10 – 0.10
	Distance * Landscape	0.05	-0.08 – 0.17	-0.06	-0.17 – 0.05
	Distance ^{2} * Landscape	-0.09	-0.20 – 0.02	0.01	-0.07 – 0.08
	Landscape	**1.28**	1.17 – 1.40	**1.22**	1.11 – 1.34
Line	Distance	**-0.23**	-0.32 – -0.14	**0.24**	0.16 – 0.31
Line + Line^2	Distance	**-0.11**	-0.21 – 0.00	**0.17**	0.08 – 0.26

Distance [2]	**-0.20**	-0.29 – -0.11	**0.09**	0.02 – 0.16

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with nest site selection are denoted with Landscape. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Landscape represents reference value; Distance represents distance from a power line; [2] denotes a quadratic relationship.

Table 8. Performance of all resource selection function generalized linear mixed effects models used to assess the influence of distance from power lines on greater sage-grouse nest site use at the local-scale in Eureka County, NV, from 2004-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
FGLINE + Local Selection	0.00	0.38	5	698.76
FGLINE * Local Selection	1.83	0.15	6	698.58
$FGLINE^2$ + Local Selection	1.97	0.14	6	698.72
$AllLines^2$ + Local Selection	2.29	0.12	6	699.04
AllLines + Local Selection	2.61	0.10	5	701.36
AllLines * Local Selection	4.08	0.05	6	700.84
$FGLINE^2$ * Local Selection	5.28	0.03	8	698.03
$AllLines^2$ * Local Selection	5.73	0.02	8	698.49
Local Selection	14.70	0.00	4	715.46
AllLines	140.22	0.00	4	840.98
$AllLines^2$	142.11	0.00	5	840.87
FGLINE	152.80	0.00	4	853.56
$FGLINE^2$	153.81	0.00	5	852.57
Null	165.82	0.00	3	868.58

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse nest or random point was located from the Falcon-Gondor or any transmission line, respectively. Local Selection represents a covariate developed from the environmental characteristics which were supported to influence nest site selection at the local scale (Sagebrush shrub cover (+); Non-sagebrush shrub cover (+); Sagebrush shrub cover * Non-sagebrush shrub cover (+); average forb height (+); average forb cover (+); average forb height * average forb cover (+); residual grass height (+); live grass height (+); forb richness (+); shrub height (-); Gibson et al. in review-a). ^{2} denotes a quadratic

relationship. Models with interactions consider both the linear and interaction terms. All models considered year as a random effect. Italicized model is the basic reference value model; bold model is the null model.

Table 9. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on greater sage-grouse local-scale selection of nesting habitat in Eureka County, NV, 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Local	Local	**1.25**	1.07 – 1.41	**1.25**	1.07 – 1.41
Local + Line	Distance	**0.40**	0.26 – 0.55	**0.37**	0.23 – 0.52
Local + Line + Line^2	Distance	**0.41**	0.24 – 0.59	**0.30**	0.14 – 0.46
	Distance^2	-0.01	-0.13 – 0.10	**0.15**	0.01 – 0.30
Local * Line	Distance	**0.39**	0.23 – 0.54	**0.35**	0.20 – 0.50
	Local	**1.26**	1.09 – 1.43	**1.20**	1.04 – 1.38
	Distance * Landscape	-0.05	-0.20 – 0.10	-0.08	-0.25 – 0.08
Local * Line^2	Distance	**0.39**	0.21 – 0.57	**0.30**	0.14 – 0.46
	Distance^2	-0.01	-0.12 – 0.11	**0.16**	0.01 – 0.30
	Distance * Local	-0.10	-0.29 – 0.09	-0.09	-0.27 – 0.08
	Distance^2 * Local	0.05	-0.06 – 0.18	0.03	-0.14 – 0.20
	Local	**1.21**	1.00 – 1.42	**1.18**	0.97 – 1.40
Line	Distance	**0.34**	0.21 – 0.46	**0.47**	0.34 – 0.6
Line + Line^2	Distance	**0.39**	0.24 – 0.54	**0.46**	0.31 – 0.6

Distance ^{2}	-0.06	-0.15 – 0.03	0.03	-0.10 – 0.16

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with nest site selection are denoted with Local. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Local represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 10. Performance of all nest survival models used to assess the influence of power lines and common ravens demographic structure on greater sage-grouse nest success in Eureka County, NV, from 2004-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No.	Dev.
Success + FGLINE^2 * RavenAbundance	0.00	0.60	6	1510.08
Success + FGLINE^2	4.38	0.07	4	1518.47
Success * FGLINE^2	4.60	0.06	5	1516.68
Success + AllLines	5.24	0.04	3	1521.33
Success	5.97	0.03	2	1524.06
Success * AllLines	6.05	0.03	4	1520.14
Success + FGLINE^2 + RavenAbundance	6.24	0.03	5	1518.33
Success + FGLINE	6.39	0.02	3	1522.48
Success + RavenDisturbance^2	6.50	0.02	4	1520.59
Success + AllLines^2	6.82	0.02	4	1520.91
Success + RavenAbundance	7.55	0.01	3	1523.64
Success + RavenDisturbance	7.97	0.01	3	1524.06
Success * FGLINE	8.17	0.01	4	1522.26
Success + RavenAbundance^2	8.17	0.01	4	1522.27
Success + FGLINE(Year)	8.55	0.01	11	1508.60
Success * AllLines^2	8.82	0.01	5	1520.91
NULL	24.22	0.00	1	1544.32
AllLines^2	26.07	0.00	3	1542.16
FGLINE	26.12	0.00	2	1544.21
AllLines	26.17	0.00	2	1544.26
FGLINE^2	26.53	0.00	3	1542.62

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the distance a female Greater sage-grouse nest was located from the Falcon-Gondor transmission line or any power line, respectively. Annual FGLINE allowed the parameter

estimate for distance from Falcon-Gondor to vary by year. Success represents the reference value covariate developed from the environmental characteristics that were supported to influence nest survival (Non-sagebrush shrub cover (+); forb cover (+); average shrub height (+); the amount of surrounding habitat classified as pinyon-juniper woodlands (+); population the female was associated with [i.e., Roberts Creek Mountain (+) or Cortez Mountain(-)]; Gibson et al. 2015). RavenOccupancy represents the annual average relative probability of a Common raven disturbing the breeding lek nearest to an individual female. RavenAbundance represents the annual estimated Common raven population abundance associated with the survey transect along the Falcon-Gondor transmission line nearest to an individual female. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms.

Table 11. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines and common raven demographic structure on greater sage-grouse nest survival in Eureka County, NV, from 2004-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Success	Success	**0.27**	0.19 – 0.36	**0.27**	0.19 – 0.36
Success + Line	Distance	0.09	-0.01 – 0.19	**0.11**	0.01 – 0.21
Success + Line + Line^2	Distance	**0.17**	0.5 – 0.28	**0.13**	0.02 – 0.23
	Distance ^{2}	**-0.09**	-0.16 – -0.03	-0.04	-0.13 – 0.05
Line * Success	Distance	0.08	-0.02 – 0.19	0.08	-0.02 – 0.18
	Success	**0.31**	0.21 – 0.40	**0.33**	0.23 – 0.43
	Distance * Success	-0.04	-0.14 – 0.07	-0.08	-0.18 – 0.03
Line^2 * Success	Distance	**0.19**	0.07 – 0.31	**0.13**	0.01 – 0.24
	Distance ^{2}	-0.08	-0.15 – -0.02	-0.4	-0.15 – 0.06
	Distance * Distance * Success	0.08	-0.01 – 0.16	0.00	-0.10 – 0.10
	Success	**0.27**	0.15 – 0.39	**0.32**	0.19 – 0.45
Line	Distance	-0.02	-0.11 – 0.07	-0.01	-0.10 – 0.08
Line + Line^2	Distance	0.03	-0.08 – 0.13	0.03	-0.07 – 0.13
	Distance ^{2}	-0.06	-0.12 – 0.01	**-0.09**	-0.18 – 0.00

Model Format	Parameter-Type	β: Raven Abundance	85% C.I.	β: Raven Disturbance	85% C.I.
Success + Raven	Raven	0.05	-0.06 – 0.16	0.00	-0.17 – 0.17
Success + Raven + Raven^2	Raven	0.05	-0.06 – 0.17	-0.06	-0.22 – 0.11
	Raven^2	0.09	-0.02 – 0.21	-0.21	-0.37 – -0.05

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with nest success are denoted with Success. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven and Raven^2 represent models that considered a linear or quadratic effect, respectively, of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Success represent reference value; Distance represents distance from a power line; Raven represents an estimate of common raven demographic structure. ^{2} denotes a quadratic relationship

Table 12. Performance of all resource selection function generalized linear mixed effects models used to assess the influence of a distance from power lines on greater sage-grouse brood site use at the landscape-scale in Eureka County, NV, from 2005-2012.

Model[a]	ΔAIC_c	AIC_c	No. Par	Dev.
AllLines * Brood Age * AllLines^2 + Landscape Brood	0.00	0.76	9	1995.84
AllLines * Brood Age + AllLines^2 + Landscape Brood Selection	2.67	0.20	8	2000.51
AllLines * Brood Age + Landscape Brood Selection	5.83	0.04	7	2005.67
FGLINE * Brood Age + Landscape Brood Selection	26.41	0.00	7	2026.25
FGLINE * Brood Age + FGLINE^2 + Landscape Brood Selection	27.23	0.00	8	2025.07
FGLINE * Brood Age * FGLINE^2 + Landscape Brood Selection	28.26	0.00	9	2024.10
AllLines^2 + Landscape Brood Selection	29.60	0.00	6	2031.44
AllLines + Landscape Brood Selection	34.42	0.00	5	2038.26
Landscape Brood Selection	50.80	0.00	4	2056.64
FGLINE + Landscape Brood Selection	52.79	0.00	5	2056.63
FGLINE^2 + Landscape Brood Selection	53.50	0.00	6	2055.34
AllLines^2	210.24	0.00	5	2214.08
AllLines	210.70	0.00	4	2216.51
FGLINE^2	236.00	0.00	5	2239.84
NULL	239.99	0.00	3	2247.83
FGLINE	241.06	0.00	4	2246.90

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse brood or random point was located from the Falcon-Gondor or any transmission line, respectively. Landscape Brood Selection represents a covariate developed from the environmental characteristics which were supported to influence brood site selection at the landscape scale (Slope (-); Elevation (+); see Table Sx). Brood Age represented the age (in weeks) since the brood hatched. All models considered individual and

year as random effects. Italicized model is the basic reference value model; bold model is the null model.

Table 13. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines on greater sage-grouse landscape-scale selection of brood rearing habitat in Eureka County, NV, from 2005-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Landscape	Landscape	**0.70**	0.62 – 0.77	**0.70**	0.62 – 0.77
Landscape + Line	Distance	0.01	-0.08 – 0.09	**0.26**	0.17 – 0.34
Landscape + Line +	Distance				
Line^2		0.04	-0.06 – 0.14	**0.15**	0.05 – 0.25
	Distance^2	-0.06	-0.14 – 0.02	**0.16**	0.07 – 0.24
Landscape + Line *	Distance				
Brood Age		0.12	-0.06 – 0.30	**0.45**	0.27 – 0.62
	Brood Age	**-0.19**	-0.24 – -0.14	**-0.18**	-0.23 – -0.13
	Distance *				
	Brood Age	-0.03	-0.08 – 0.02	**-0.06**	-0.11 – -0.01
Landscape + Line *	Distance				
Brood Age+ Line^2		0.16	-0.03 – 0.35	**0.33**	0.15 – 0.52
	Distance^2	-0.06	-0.14 – 0.02	**0.14**	0.05 – 0.22
	Distance *				
	Brood Age	-0.04	-0.09 – 0.01	**-0.05**	-0.10 – -0.01
	Brood Age	**-0.19**	-0.24 – -0.14	**-0.18**	-0.23 – -0.13
Line	Distance	-0.05	-0.13 – 0.03	**0.31**	0.23 – 0.39

Line + Line^2	Distance	0.02	-0.08 – 0.11	**0.36**	0.27 – 0.46
	Distance ^{2}	**-0.14**	-0.22 – -0.07	**-0.09**	-0.16 – -0.01

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with brood site habitat selection are denoted with Landscape. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Brood Age represents models that considered an effect of brood age.

[b] Parameter denotes the format of a given parameter estimate. Landscape represents reference value; Distance represents distance from a power line; Brood Age represents brood age (in weeks); ^{2} denotes a quadratic relationship.

Table 14. Performance of all resource selection function generalized linear mixed models used to assess the influence of a unit of habitat's distance from transmission lines on greater sage-grouse brood site use at the local-scale in Eureka County, NV, from 2005-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
FGLINE^2 * Brood Age + Local Brood Selection	0.00	0.70	8	679.03
FGLINE * Brood Age + Local Brood Selection	2.11	0.24	7	683.14
AllLines* Brood Age + Local Brood Selection	5.89	0.04	7	686.92
AllLines^2 * Brood Age + Local Brood Selection	7.77	0.01	8	686.80
FGLINE^2 + Local Brood Selection	10.16	0.00	6	693.19
AllLines + Local Brood Selection	13.10	0.00	5	698.13
AllLines^2 + Local Brood Selection	14.62	0.00	6	697.65
Local Brood Selection	14.70	0.00	4	701.73
FGLINE + Local Brood Selection	16.33	0.00	5	701.36
AllLines^2	136.58	0.00	5	826.76
AllLines	142.35	0.00	4	834.53
FGLINE^2	150.62	0.00	5	840.80
NULL	159.33	0.00	3	853.51
FGLINE	159.51	0.00	4	851.69

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse brood or random point was located from the Falcon-Gondor or any transmission line, respectively. Local Brood Selection represents reference value covariate developed from the environmental characteristics which were supported to influence brood site selection at the local scale (Total Vegetation Cover (+); Average Residual Grass Height (+); Forb Richness (+); Average Live Grass Height (+); Average Forb height (+); Non-sagebrush shrub cover (-); see Table Sx). Brood Age delineates the early brood rearing from the late brood rearing period. All models considered individual and year as

random effects. Italicized model is the basic reference value model; bold model is the null model.

Table 15. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines on greater sage-grouse local-scale selection of brood rearing habitat in Eureka County, NV, from 2005-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Local	Local	**1.40**	1.20 – 1.60	**1.40**	1.20 – 1.60
Local + Line	Distance	0.07	-0.09 – 0.22	**0.23**	0.05 – 0.40
Local + Line + Line^2	Distance	**0.30**	0.10 – 0.49	**0.26**	0.07 – 0.44
	Distance ^{2}	**-0.28**	-0.43 – -0.14	-0.08	-0.23 – 0.08
Local + Line * Brood Age	Distance	**1.43**	0.91 – 1.98	**1.23**	0.74 – 1.73
	Brood Age	0.13	-0.120 – 0.47	0.17	-0.16 – 0.51
	Distance * Brood Age	**-0.91**	-1.23 – -0.59	**-0.72**	-1.05 – -0.40
Local + Line * Brood Age+ Line^2	Distance	**1.41**	0.90 – 1.92	**1.23**	0.74 – 1.72
	Distance ^{2}	**-0.22**	-0.37 – -0.06	-0.04	-0.21 – 0.13
	Distance * Brood Age	**-0.79**	-1.12 – -0.46	**-0.71**	-1.03 – -0.38
	Brood Age	0.20	-0.14 – 0.53	0.18	-0.16 – 0.51
Line	Distance	0.13	-0.01 – 0.27	**0.47**	0.31 – 0.63
Line + Line^2	Distance	**0.37**	0.20 – 0.55	**0.56**	0.39 – 0.73

Distance [2]	**-0.29**	-0.42 – -0.16	**-0.27**	-0.41 – -0.14

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with brood site habitat selection are denoted with Local. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Brood Age represents models that considered an effect of brood age.

[b] Parameter denotes the format of a given parameter estimate. Local represents reference value; Distance represents distance from a power line; Brood Age delineates between early and late brood rearing periods; [2] denotes a quadratic relationship.

Table 16. Performance of all Lukacs young survival of marked adults models used to assess the influence of power lines and common raven population abundance on pre-fledging greater sage-grouse chick survival in Eureka County, NV, from 2005-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$ * $FGLINE^2_{Weeks1\text{-}2}$	0.00	0.82	18	2076.43
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$ + $FGLINE^2_{Weeks1\text{-}2}$	4.20	0.10	17	2082.81
$Survival_{chick}$ * $FGLINE^2_{Weeks1\text{-}2}$	4.83	0.07	17	2083.44
$Survival_{chick}$ + $FGLINE^2_{Weeks1\text{-}2}$	10.29	0.00	16	2091.07
$Survival_{chick}$ + $FGLINE^2_{Weeks1\text{-}2}$ + $FGLINE_{Weeks3\text{-}6}$	12.16	0.00	17	2090.77
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$ + $RavenAbundance_{Weeks3\text{-}6}$	21.16	0.00	16	2101.94
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$	23.21	0.00	15	2106.15
$Survival_{chick}$ * $AllLines^2_{Weeks1\text{-}2}$	24.70	0.00	17	2103.31
$Survival_{chick}$ + $FGLINE_{Weeks1\text{-}2}$ + $FGLINE_{Weeks3\text{-}6}$	27.54	0.00	16	2108.32
$Survival_{chick}$ + $FGLINE_{Weeks1\text{-}6}$	30.75	0.00	15	2113.70
$Survival_{chick}$	31.29	0.00	14	2116.38
$Survival_{chick}$ + $AllLines^2_{Weeks1\text{-}2}$	32.50	0.00	16	2113.28
$Survival_{chick}$ * $FGLINE_{Weeks1\text{-}6}$	33.32	0.00	15	2116.27
$Survival_{chick}$ + $AllLines_{Weeks1\text{-}6}$	34.16	0.00	16	2114.94
$Survival_{chick}$ + $AllLines^2_{Weeks1\text{-}2}$	34.67	0.00	16	2115.45
$Survival_{chick}$ * $AllLines_{Weeks1\text{-}6}$	35.05	0.00	16	2115.83
$Survival_{chick}$ + $AllLines^2_{Weeks1\text{-}2}$ + $AllLines_{Weeks3\text{-}6}$	36.28	0.00	17	2114.89
$FGLINE^2_{Weeks1\text{-}2}$	38.95	0.00	15	2121.89
$FGLINE_{Weeks1\text{-}2}$	65.87	0.00	14	2150.96
$AllLines_{Weeks1\text{-}2}$	81.00	0.00	14	2166.09
$AllLines^2_{Weeks1\text{-}2}$	81.73	0.00	15	2164.67
NULL	82.19	0.00	13	2169.43

[a] Model selection notation follows Burnham and Anderson (2002). All models allowed detection to vary by year (no. par = 8) and week[b] (no. par = 4). FGLINE and AllLines is a weekly time-

varying covariate which represents the distance a female sage-grouse and her brood was located from the Falcon-Gondor or any transmission line, respectively, in a given week. ^{2} denotes a quadratic relationship. Subscripts denote which weeks a covariate was allowed to influence. Models with interactions consider both the linear and interaction terms. $Survival_{chick}$ represents a covariate developed from the environmental characteristics which were supported to influence pre-fledging chick survival (total vegetation cover (+); distance brood moved in previous week (-); average grass height (-); distance from nearest water source (+); nest site quality (+); female age (+); female age^2 (-); Gibson et al. in review-b). Italicized model is the basic reference value model; bold model is the null model.

[b] the final two weekly detection parameters were constrained to be similar which resulted in the six occasion history having four estimated parameters.

Table 17. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on greater sage-grouse pre-fledging chick survival in Eureka County, NV, from 2005-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
$Survival_{chick}$	$Survival_{chick}$	**0.41**	0.34 – 0.48	**0.41**	0.34 – 0.48
$Survival_{chick}$ + Line	Distance	**-0.09**	-0.16 – -0.02	-0.02	-0.09 – 0.05
$Survival_{chick}$ + $Line_{Week1-2}$ +$Line_{Week3-6}$	$Distance_{Week1-2}$	-0.23	-0.35 – -0.11	-0.05	-0.17 – 0.07
	$Distance_{Week3-6}$	0.09	-0.05 – 0.23	0.06	-0.07 – 0.19
$Survival_{chick}$ +$Line_{Week1-2}^2$	$Distance_{Week1-2}$	0.00	-0.12 – 0.12	-0.08	-0.20 – 0.04
	$Distance_{Week1-2}^2$	-0.26	-0.35 – -0.17	-0.11	-0.21 – -0.01
$Survival_{chick}$ + $Line_{Week1-2}$ + $Line_{Week1-2}^2$ +$Line_{Week3-6}$	$Distance_{Week1-2}$	-0.01	-0.14 – 0.12	-0.10	-0.23 – 0.03
	$Distance_{Week1-2}^2$	-0.26	-0.35 – -0.17	0.07	-0.06 – 0.2
	$Distance_{Week3-6}$	0.05	-0.09 – 0.19	0.02	-0.08 – 0.12
Line * $Survival_{chick}$	Distance	**-0.10**	-0.19 – -0.01	-0.03	-0.10 – 0.04
	$Survival_{chick}$	**0.40**	0.31 – 0.49	**0.41**	0.34 – 0.48
	Distance * $Survival_{chick}$	-0.03	-0.10 – 0.04	-0.04	-0.11 – 0.03
$Line_{Week1-2}^2$ * $Survival_{chick}$	$Distance_{Week1-2}$	-0.03	-0.15 – 0.09	-0.08	-0.20 – 0.04

	Distance $_{\text{Week1-2}}{}^{2}$	**-0.33**	-0.43 – -0.23	**-0.11**	-0.21 – -0.01
	Distance $_{\text{Week1-2}}{}^{2}$ * Survival$_{chick}$	**-0.14**	-0.21 – -0.07	**-0.23**	-0.33 – -0.13
	Survival$_{chick}$	**0.47**	0.37 – 0.57	**0.57**	0.47 – 0.67
Line$_{\text{Week1-2}}$	Distance$_{\text{Week1-2}}$	**-0.36**	-0.47 – -0.24	**-0.15**	-0.27 – -0.03
Line$_{\text{Week1-2}}$ + Line$_{\text{Week1-2}}{}^{2}$	Distance$_{\text{Week1-2}}$	-0.02	-0.14 – 0.11	-0.09	-0.22 – 0.04
	Distance$_{\text{Week1-2}}{}^{2}$	**-0.36**	-0.46 – -0.26	-0.08	-0.18 – 0.01

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with pre-fledging chick survival are denoted with Survival$_{chick}$. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Subscripts following *week* denote covariates were assigned only to the specified weeks of the broods life.

[b] Parameter denotes the format of a given parameter estimate. Survival$_{chick}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 18. Performance of all nest survival models used to assess the influence of power lines on female greater sage-grouse survival in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Survival$_{female}$	0.00	0.27	2	1540.89
Survival$_{female}$ + AllLines	1.12	0.16	3	1540.01
Survival$_{female}$ + FGLINE	1.73	0.12	3	1540.61
Survival$_{female}$ +AllLines^2	1.76	0.12	4	1538.63
Survival$_{female}$ + FGLINE^2	1.95	0.11	4	1538.83
Survival$_{female}$ * FGLINE^2	2.74	0.07	5	1537.61
Survival$_{female}$*AllLines	3.01	0.06	4	1539.89
Survival$_{female}$* AllLines^2	3.44	0.05	5	1538.31
Survival$_{female}$* FGLINE	3.59	0.04	4	1540.46
AllLines^2	46.29	0.00	3	1585.17
FGLINE^2	46.43	0.00	3	1585.31
NULL	47.51	0.00	1	1590.40
AllLines	47.72	0.00	2	1588.60
FGLINE	48.26	0.00	2	1589.15

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines is a monthly time-varying covariate which represents the average distance a female sage-grouse was located from the Falcon-Gondor or any transmission line, respectively, in a given month. ^{2} denotes a quadratic relationship. Survival$_{female}$ represents the reference value covariate developed from the environmental characteristics that were supported to influence female survival (average monthly elevation (-); age (-); nest success in given year (-); brood success (-); seasonal differences: spring (-), summer (+), fall (-); covariate model modified from Blomberg et al. 2013). Italicized model is the basic reference value model; bold model is the null model.

Table 19. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on adult female greater sage-grouse survival in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	**Parameter**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
***Survival*$_{female}$**	*Survival*$_{female}$	**0.59**	0.47 – 0.71	**0.59**	0.47 – 0.71
***Survival*$_{female}$ + Line**	Distance	0.06	-0.11 – 0.23	0.11	-0.06 – 0.28
***Survival*$_{female}$ + Line +**	Distance				
Line^2		0.14	-0.04 – 0.32	**0.18**	0.00 – 0.36
	Distance ^{2}	-0.10	-0.21 – 0.01	-0.11	-0.24 – 0.02
Line * *Survival*$_{female}$	Distance	0.09	-0.11 – 0.29	0.09	-0.10 – 0.28
	Survival$_{female}$	0.04	-0.12 – 0.2	-0.04	-0.20 – 0.12
	Distance *				
	Survival$_{female}$	**0.58**	0.46 – 0.7	**0.58**	0.46 – 0.70
(Line + Line^2) *	Distance				
***Survival*$_{female}$**		0.15	-0.03 – 0.33	0.19	0.01 – 0.37
	Distance ^{2}	-0.07	-0.20 – 0.06	-0.09	-0.24 – 0.06
	Distance *				
	Distance *				
	Survival$_{female}$	0.08	-0.03 – 0.19	0.04	-0.07 – 0.15
	Survival$_{female}$	**0.51**	0.37 – 0.65	**0.54**	0.41 – 0.67
Line	Distance	0.14	-0.04 – 0.31	0.16	-0.02 – 0.34

Line + Line^2	Distance	**0.24**	0.07 – 0.42	**0.27**	0.09 – 0.45
	Distance ^{2}	**-0.15**	-0.25 – -0.05	**-0.17**	-0.30 – -0.04

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with annual female survival are denoted with $Survival_{female}$. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. $Survival_{female}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 20. Performance of all multistate robust design models used to assess the influence of transmission lines on male greater sage-grouse survival (φ) and among-lek movement rates (ψ) in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
$\varphi(Survival_{male})\psi(.)$	0.00	0.21	27	4406.53
$\varphi(Survival_{male})\psi(AllLines^2)$	0.06	0.21	29	4402.43
$\varphi(Survival_{male})\psi(FGLINE)$	0.50	0.17	28	4404.95
$\varphi(Survival_{male})\psi(AllLines)$	1.24	0.11	28	4405.69
$\varphi(Survival_{male}+ FGLINE)\psi(.)$	1.85	0.08	28	4406.30
$\varphi(Survival_{male}+AllLine)\psi(.)$	2.07	0.08	28	4406.52
$\varphi(Survival_{male})\psi(FGLINE^2)$	2.26	0.07	29	4404.62
$\varphi(Survival_{male}+FG^2)\psi(.)$	3.28	0.04	29	4405.64
$\varphi(Survival_{male}+AllLines^2)\psi(.)$	4.14	0.03	29	4406.51
$\varphi(FGLINE)\psi(.)$	11.29	0.00	27	4417.82
$\varphi(.)\psi(.)$	12.31	0.00	26	4420.92
$\varphi(FGLINE^2)\psi(.)$	12.67	0.00	28	4417.12
$\varphi(AllLine)\psi(.)$	12.79	0.00	27	4419.32
$\varphi(AllLines^2)\psi(.)$	14.87	0.00	28	4419.32

[a] Model selection notation follows Burnham and Anderson (2002). All models allowed detection to vary by year (i.e., primary occasion; no. par = 10), month (i.e., secondary occasion; no. par = 2), and lek of capture (no. par. = 12). FGLINE and AllLines is a represents the distance from the lek a male was associated with to Falcon-Gondor or any transmission line, respectively. ^{2} denotes a quadratic relationship. φ represents annual apparent survival. ψ represents the annual probability of a male moving to a new breeding lek among years. (.) denotes constancy, or intercept-only. Italicized model is the basic reference value model; bold model is the null model.

Table 21. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on male greater sage-grouse survival (φ) and among-lek movement rates (ψ) in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	Parameter	β: FG Line	85% C.I.	β: All Line	85% C.I.
φ **Survival$_{male}$**	Survival$_{male}$	0.41	0.25 – 0.57	0.41	0.25 – 0.57
φ **Survival$_{male}$ + Line**	Distance	-0.06	-0.24 – 0.12	-0.01	-0.16 – 0.14
φ **Survival$_{male}$ + Line + Line^2**	Distance	0.04	-0.21 – 0.29	0.02	-0.30 – 0.34
	Distance^2	-0.09	-0.25 – 0.07	-0.01	-0.17 – 0.15
φ **Line**	Distance	**-0.20**	-0.35 – -0.04	-0.13	-0.27 – 0.02
φ **Line + Line^2**	Distance	-0.09	-0.32 – 0.15	-0.13	-0.43 – 0.17
	Distance^2	-0.09	-0.23 – 0.06	0.00	-0.15 – 0.15
ψ **Line**	Distance	-0.45	-1.00 – 0.10	-0.31	-0.84 – 0.22
ψ **Line + Line^2**	Distance	-0.33	-1.00 – 0.34	**-1.01**	-1.68 – -0.34
	Distance^2	-0.21	-0.78 – 0.36	**0.53**	0.13 – 0.93

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with male survival (φ) are denoted with Survival$_{male}$. We could not account for environmental variability associated with male lek movement rates (ψ). Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. $Survival_{male}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 22. Performance of all robust design Pradel models used to assess the influence of power lines and common ravens demographic structure on lek-specific population growth rates of male greater sage-grouse in Eureka County, NV, 2003-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
PopGrowth +AllLines * RavenAbundance^2	0.00	0.35	36	6395.95
PopGrowth +AllLines + RavenAbundance^2	0.04	0.34	35	6398.14
PopGrowth +AllLines^2 + RavenAbundance^2	1.89	0.14	36	6397.84
PopGrowth + FGLINE * RavenAbundance^2	3.27	0.07	36	6399.22
PopGrowth + FGLINE + RavenAbundance^2	3.92	0.05	35	6402.02
PopGrowth + FGLINE^2 + RavenAbundance^2	4.57	0.04	36	6400.53
PopGrowth + RavenAbundance^2	6.49	0.01	34	6406.73
PopGrowth + RavenOccupancy^2	16.55	0.00	34	6416.79
PopGrowth + AllLines	18.65	0.00	33	6421.02
PopGrowth + AllLine + RavenAbundance	20.71	0.00	34	6420.94
PopGrowth + AllLines^2	20.77	0.00	34	6421.01
PopGrowth + FGLINE * RavenAbundance	21.08	0.00	35	6419.18
PopGrowth + FGLINE	22.74	0.00	33	6425.11
PopGrowth	23.27	0.00	32	6427.77
PopGrowth + RavenOccupancy	23.66	0.00	33	6426.04
PopGrowth + FGLINE + RavenAbundance	24.72	0.00	34	6424.96
PopGrowth + FGLINE^2	24.87	0.00	34	6425.10
PopGrowth + RavenAbundance	25.19	0.00	33	6427.57
FGLINE^2	118.95	0.00	33	6521.33
FGLINE	119.13	0.00	32	6523.64
NULL	121.90	0.00	31	6528.54
AllLines	122.61	0.00	32	6527.12
AllLines^2	123.12	0.00	33	6525.50

[a] Model selection notation follows Burnham and Anderson (2002). Apparent survival was allowed to vary by year (no. par = 10). Detection was allowed to vary by year (i.e., primary occasion, no. par = 10) and lek (no. par = 10). PopGrowth represents the reference value covariate developed from the environmental characteristics which were supported to influence lek-specific population growth rates (lek elevation (+); annual precipitation (+); covariate model modified from Blomberg et al. 2012[b]). FGLINE and AllLines represents a leks distance from the Falcon-Gondor or any transmission line during a given spring, respectively. RavenOccupancy represents the annual average relative probability of a Common raven disturbing each lek. RavenAbundance represents the annual estimated Common raven population abundance associated with the survey transect along the Falcon-Gondor transmission line nearest to the lek. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

[b] Models considered two additional years of data and more complex model design. See supplemental material for model results.

Table 23. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines and common raven demographic structure on greater sage-grouse population growth in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	**Parameter-Type**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
PopGrowth	PopGrowth	**0.42**	0.35 – 0.48	**0.42**	0.35 – 0.48
PopGrowth + Line	Distance	**0.02**	0.00 – 0.04	**0.04**	0.02 – 0.06
PopGrowth + Line +	Distance				
Line^2		0.02	-0.01 – 0.05	**0.03**	0.01 – 0.06
	Distance ^{2}	0.00	-0.02 – 0.02	0.00	-0.02 – 0.02
Line	Distance	**-0.03**	-0.04 – -0.01	**-0.02**	-0.03 – 0.00
Line + Line^2	Distance	0.00	-0.03 – 0.03	0.00	-0.02 – 0.03
	Distance ^{2}	**-0.02**	-0.03 – 0.00	**-0.02**	-0.03 – 0.00
Model Format	**Parameter-Type**	**β: Raven Abundance**	**85% C.I.**	**β: Raven Disturbance**	**85% C.I.**
PopGrowth + Raven	Raven	0.02	-0.04 – 0.07	**0.02**	0.00 – 0.04
PopGrowth + Raven	Raven				
+ Raven^2		**-0.14**	-0.21 – -0.07	**-0.03**	-0.06 – 0.00
	Raven^2	**0.18**	0.12 – 0.24	**-0.05**	-0.08 – -0.03
Model	**Parameter**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
PopGrowth +	Distance	-0.01	-0.04 – 0.03	0.00	-0.04 – 0.04
FGLINE *	RavenAbundance	**-0.15**	-0.22 – -0.08	**-0.15**	-0.22 – -0.08

RavenAbundance^2	RavenAbundance^2	**0.19**	0.13 – 0.25	**0.18**	0.11 – 0.24
	Distance	**0.04**	0.01 – 0.08	**0.04**	0.01 – 0.08

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with population growth are denoted with PopGrowth. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven and Raven^2 represent models that considered a linear or quadratic effect, respectively, of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Survival$_{chick}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 24. Performance of all robust design Pradel models used to assess the influence of power lines and common ravens demographic structure on lek-specific per capita recruitment rates of greater sage-grouse in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Recruit + AllLines^2 + RavenAbundance^2	0.00	0.40	36	6431.35
Recruit + AllLines + RavenAbundance^2	0.23	0.36	35	6433.73
Recruit + AllLines * RavenAbundance^2	1.23	0.22	36	6432.58
Recruit + RavenAbundance^2	7.38	0.01	34	6443.02
Recruit + FGLINE + RavenAbundance^2	8.35	0.01	35	6441.85
Recruit + FGLINE * RavenAbundance^2	9.12	0.01	36	6440.47
Recruit + FGLINE^2+ RavenAbundance^2	10.10	0.00	36	6441.45
Recruit + RavenOccupancy^2	10.43	0.00	34	6446.08
Recruit + AllLines^2	10.52	0.00	34	6446.17
Recruit + AllLines	11.68	0.00	33	6449.46
Recruit + AllLines+ RavenAbundance	12.95	0.00	34	6448.59
Recruit	16.88	0.00	32	6456.79
Recruit + RavenAbundance	18.38	0.00	33	6456.16
Recruit + FGLINE	18.43	0.00	33	6456.21
Recruit + RavenOccupancy	18.55	0.00	33	6456.33
Recruit + FGLINE * RavenAbundance	18.71	0.00	35	6452.21
Recruit + FGLINE^2	19.17	0.00	34	6454.81
Recruit + FGLINE + RavenAbundance	19.87	0.00	34	6455.51
FGLINE^2	60.19	0.00	33	6497.97
FGLINE	60.59	0.00	32	6500.50
NULL	61.75	0.00	31	6503.79
AllLines	62.98	0.00	32	6502.89
AllLines^2	63.62	0.00	33	6501.40

[a] Model selection notation follows Burnham and Anderson (2002). Apparent survival was allowed to vary by year (no. par = 10). Detection was allowed to vary by year (i.e., primary occasion, no. par = 10) and lek (no. par = 10). Recruit represents a covariate developed from the

environmental characteristics which were supported to influence lek-specific population growth rates (lek elevation (+); annual precipitation (+); total vegetation cover (+); habitat converted to exotic grassland (+);annual precipitation * habitat converted to exotic grassland; covariate model modified from Blomberg et al. 2012[b]). FGLINE and AllLines represents a leks distance from the Falcon-Gondor or any transmission line during a given spring, respectively. RavenOccupancy represents the annual average relative probability of a Common raven disturbing each lek. RavenAbundance represents the annual estimated Common raven population abundance associated with the survey transect along the Falcon-Gondor transmission line nearest to the lek. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

[b] Models considered two additional years of data and more complex model design. See supplemental material for model results.

Table 25. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines and common raven demographic structure on greater sage-

2008 grouse per capita recruitment in Eureka County, NV, from 2003-2012. Bold values indicate that
2009 the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	**Parameter-Type**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Recruit	Recruit	**0.45**	0.36 – 0.54	**0.45**	0.36 – 0.54
Recruit + Line	Distance	0.04	-0.01 – 0.08	**0.11**	0.06 – 0.17
Recruit + Line +	Distance				
Line^2		0.06	-0.01 – 0.13	**0.17**	0.09 – 0.26
	Distance ^{2}	-0.02	-0.06 – 0.02	**-0.05**	-0.09 – 0.00
Line	Distance	**-0.05**	-0.10 – -0.01	-0.03	-0.07 – 0.02
Line + Line^2	Distance	0.01	-0.05 – 0.08	0.01	-0.06 – 0.08
	Distance ^{2}	-0.04	-0.08 – 0.01	**-0.04**	-0.08 – 0.00
Model Format	**Parameter-Type**	**β: Raven Abundance**	**85% C.I.**	**β: Raven Disturbance**	**85% C.I.**
Recruit + Raven	Raven	0.07	-0.06 – 0.20	0.02	-0.02 – 0.06
Recruit + Raven +	Raven				
Raven^2		**-0.25**	-0.45 – -0.06	**-0.12**	-0.20 – -0.04
	Raven^2	**0.29**	0.17 – 0.40	**-0.14**	-0.21 – -0.08
Model Format	**Parameter**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Recruit + Line *	Distance	-0.01	-0.09 – 0.06	0.06	-0.02 – 0.15
RavenAbundance^2	RavenAbundance	**-0.28**	-0.47 – -0.09	**-0.29**	-0.49 – -0.10
	RavenAbundance^2	**0.28**	0.16 – 0.40	**0.29**	0.17 – 0.41
	Distance	0.04	-0.01 – 0.08	0.04	-0.01 – 0.09

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with population growth are denoted with PopGrowth. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven and Raven^2 represent models that considered a linear or quadratic effect, respectively, of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Recruit represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Figure Headings

Figure 1: Reconstructed analysis from data previously reported in Hall and Haney 1997, which originally suggested leks closer to transmission lines had lower male attendance and decreased population growth. These analyses, like many others, failed to account for latent environmental variability (e.g., elevation) correlated with transmission line placement.

Figure 2: Map of the Falcon-Gondor transmission line (gray line), all other power lines (black hatched line), and state highways (black line) occurring within the study system located primarily in Eureka County, NV, USA (see inset). Sage-grouse were primarily associated with one of 13 study leks (black circles).

Figure 3. Representative images of towers within the Falcon-Gondor transmission line corridor depicting the (**A**) 2-pole H-frame tower and (**B**; foremost) 3-pole guyed angle-transposition tower design. The completed Falcon-Gondor transmission line was approximately 299km long and consisted of 734 towers that varied in height (23-40m), and design (2-3 pole) depending on topography and projection.

Figure 4: Regression of elevation and distance from any power line within Eureka County, NV, USA. Black circles represent 2000 locations randomly generated within the study system delineated in Fig. 2. Error bands represent 95% confidence intervals.

Figure 5: A) Maximum spring common raven abundance (solid black line) associated with the surveyed portion of the Falcon-Gondor transmission line in Eureka County, Nevada from 2003-2012. Construction for the Falcon-Gondor transmission line began in the fall of 2003 and was completed in spring of 2004 (gray line). Regression line (dotted line) suggests an average increase in common raven abundance of 22.7 individuals per year. Error lines (dashed black lines) represent 95% credible intervals. **B**) The relative probability of a raven disturbance during

all lek observations in a given year regressed against annual maximum spring common raven abundance (solid line). Bi-lateral error bars around point estimates represent 95% credible intervals, error lines on regression (dashed lines) represents 95% confidence intervals.

Figure 6: The relative probability of a raven disturbance during all lek observations at a given lek regressed against a study lek's distance from the Falcon-Gondor transmission line (gray circles, solid gray line) or the study lek's distance from the nearest power line (black circles, dashed black line). Error bars around point estimates represent 95% credible intervals.

Figure 7: The influence of the average distance a female greater sage-grouse was from the Falcon-Gondor transmission line during the breeding season (**A**); maximum spring common raven abundance (**B**); and the relative probability of common raven observation at the lek nearest to a female (**C**) and nesting (solid gray line) and re-nesting propensities (solid black line) in Eureka County, Nevada from 2003-2012. Error lines (dashed lines) represent 95% confidence intervals.

Figure 8: The influence of the distance from the Falcon-Gondor (solid gray line) or any power line (solid black line) and the relative probability of selection as a nesting site at the (**A**) landscape scale or (**B**) local scale in Eureka County, Nevada from 2003-2012. Box plots represent the distribution of distances (solid: nests; diagonal lines: available) from the Falcon-Gondor transmission line (gray) or any power line (white). Error lines (dashed lines) represent 95% confidence intervals.

Figure 9: Year-specific beta parameter estimates assessing the influence of distance from the Falcon-Gondor transmission line on nest site selection (filled circles; regression line: dashed line) and nest survival (open circles; regression line: solid line) regressed against the estimated

maximum number of common raven associated with the surveyed portion of the Falcon-Gondor transmission line in Eureka County, Nevada from 2004-2012. Bi-lateral error bars represent standard errors.

Figure 10: The relationship between the distance of a sage-grouse nest from the Falcon-Gondor (solid gray line) and any power line (solid black line) on its overall nest survival (to 37 days) in Eureka County, Nevada from 2004-2012. Box plot represent the distribution of nest distances from the Falcon-Gondor transmission line (gray) or any power line (white). Error lines (dashed lines) represent 95% confidence intervals.

Figure 11: The relationships between use of an area as brood rearing habitat at the landscape scale and its distance from Falcon-Gondor (dashed line, light gray band) and any power line (solid line, dark gray band) across a six week brood rearing period. Avoidance of habitat during the brood rearing period near the Falcon-Gondor was less supported than avoidance of habitat near any power line in Eureka County, Nevada from 2005-2012. Panels represent a shift in the magnitude habitat avoidance, which weakened throughout the brood rearing period as sage-grouse chicks aged. Error bands represent 95% confidence intervals.

Figure 12: The relationships between use of an area as brood rearing habitat at the local scale and its distance from Falcon-Gondor (dashed line, light gray band) and any power line (solid line, dark gray band) during the (**A**) early and (**B**) late brood rearing periods. Panels represent a shift from avoidance of habitat associated with power lines to no selective pressure as sage-grouse chicks aged. Error bands represent 95% confidence intervals.

Figure 13: Influence of an interaction between maximum raven abundance (dashed = low N, solid = average N, short dashed = high N) and a brood's distance from the Falcon-Gondor

transmission line on weekly estimates of apparent pre-fledging chick survival during the first two weeks after hatch. Estimates of raven population size represent a standard deviation below and above the average maximum number of ravens in a given year. Box plots represent the distribution of brood distances from the Falcon-Gondor transmission line the first (gray) and second (white) weeks.

Figure 14: The influence of a female greater sage-grouse's average monthly distance from the Falcon-Gondor (solid gray line) and any power line (solid black line) on true annual female survival. Error lines (dashed) represent 95% confidence intervals.

Figure 15: The influence of a lek's distance from the Falcon-Gondor (solid gray line) and any power line (solid black line) and the apparent annual survival of a male greater sage-grouse associated with that lek. Error lines (dashed) represent 95% confidence intervals.

Figure 16: The influence of a lek's distance from any power line (solid black line) and the annual probability of a male Greater sage-grouse associated with that lek moving to a new lek. Error lines (dashed) represent 95% confidence intervals. Black circles represent the distances from each study lek to the nearest power line.

Figure 17: The influence of a lek's distance from the Falcon-Gondor transmission (**A**) on lek-specific per capita recruitment (f) and population growth (λ) under three levels of estimated numbers of Common ravens per survey transect associated with the Falcon-Gondor transmission line. These estimates represent a standard deviation below (**column 1**), above (**column 3**), and average (**column 2**) number of common ravens per transect. Also, the influence of relative probability of a common raven disturbing a greater sage-grouse lek on lek-specific population

growth (λ) (**B**) and per capita recruitment (*f*) in in Eureka County, Nevada from 2003-2012. Error bands represent 95% confidence intervals.

Figure 18: Beta parameter estimates for models that did not account for environmental variation (gray circles) and models that accounted for environmental variation (black circles) for each analysis that assessed the linear effects of the distance from (**column 1**) any power line and (**column 2**) distance from the Falcon-Gondor transmission line. Error bars represent 85% confidence intervals.

Figure 19: Beta parameter estimates for models that did not account for environmental variation (gray circles) and models that accounted for environmental variation (black circles) for each analysis that assessed the non-linear effects (**column 1**: linear component; **column 2**: quadratic component) of the distance from (**A**) the Falcon-Gondor transmission line and (**B**) distance from any power line. Error bars represent 85% confidence intervals.

Figure 20: Predicted daily survival of a nest (filled circles) based on the surrounding habitat characteristics in the absence of a modeled power line effect (Gibson et al. *in review*) regressed against distance from (**A**) any power line and (**B**) Falcon-Gondor transmission line. Shaded gray ribbon represents 95% confidence intervals around regression parameter.

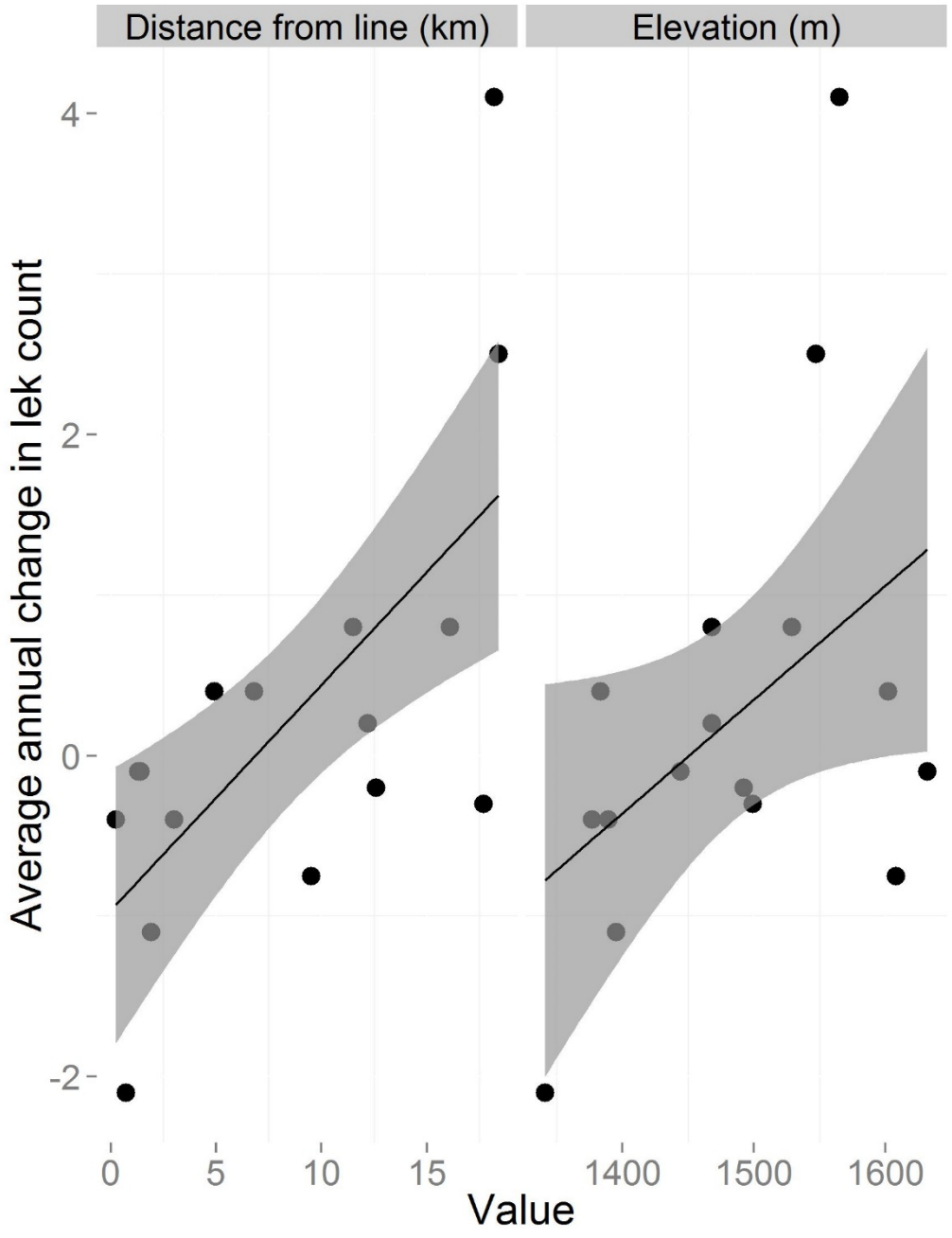

Distance from line (km)
Elevation (m)
Average annual change in lek count
4
2
0
-2
0
5
10
15
1400
1500
1600
Value

Figure 1

2139

2140

2141

2142

2143

2144

2145

2146

2147

2148

2149

2150

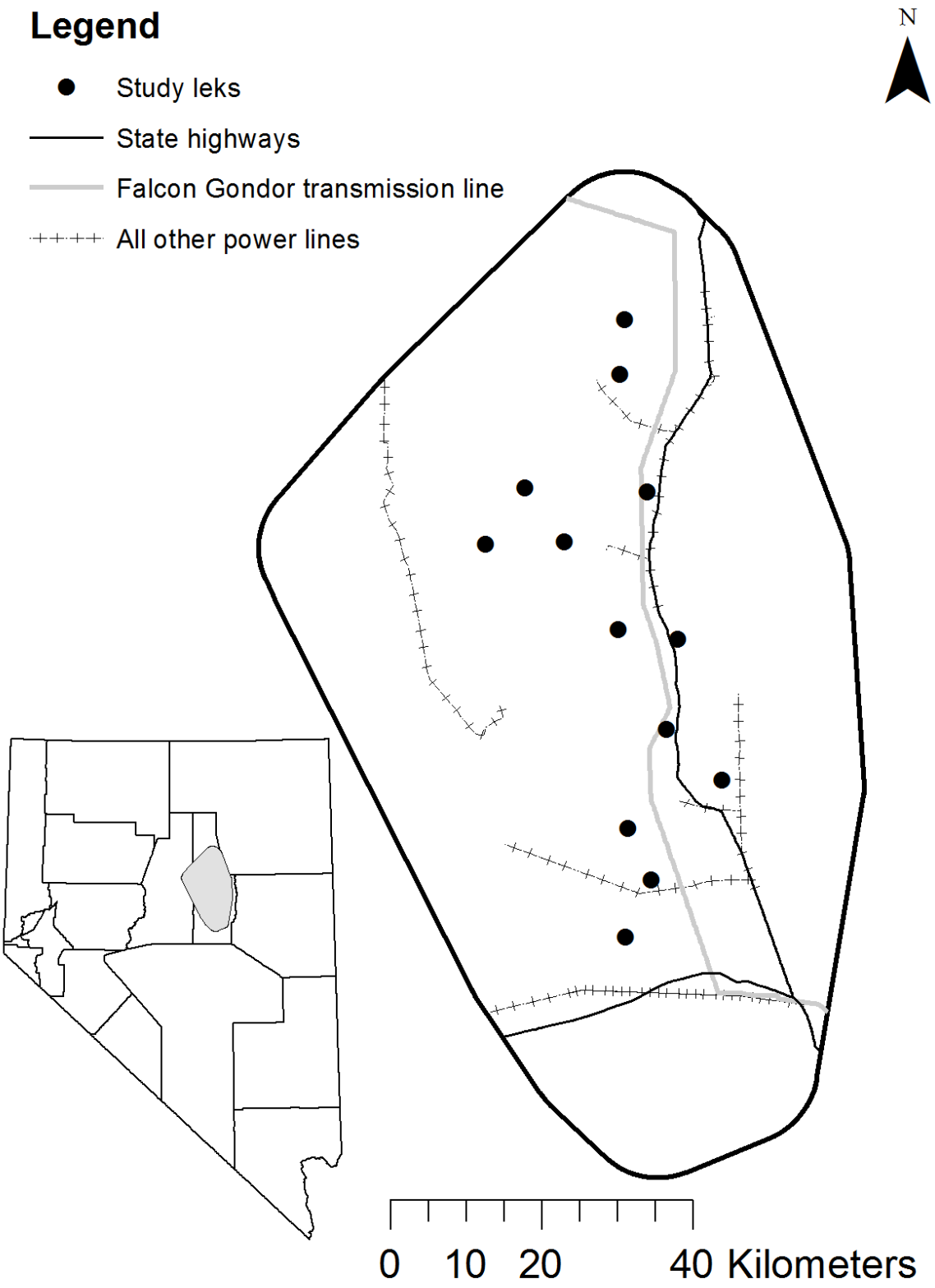
2151

2152

2153

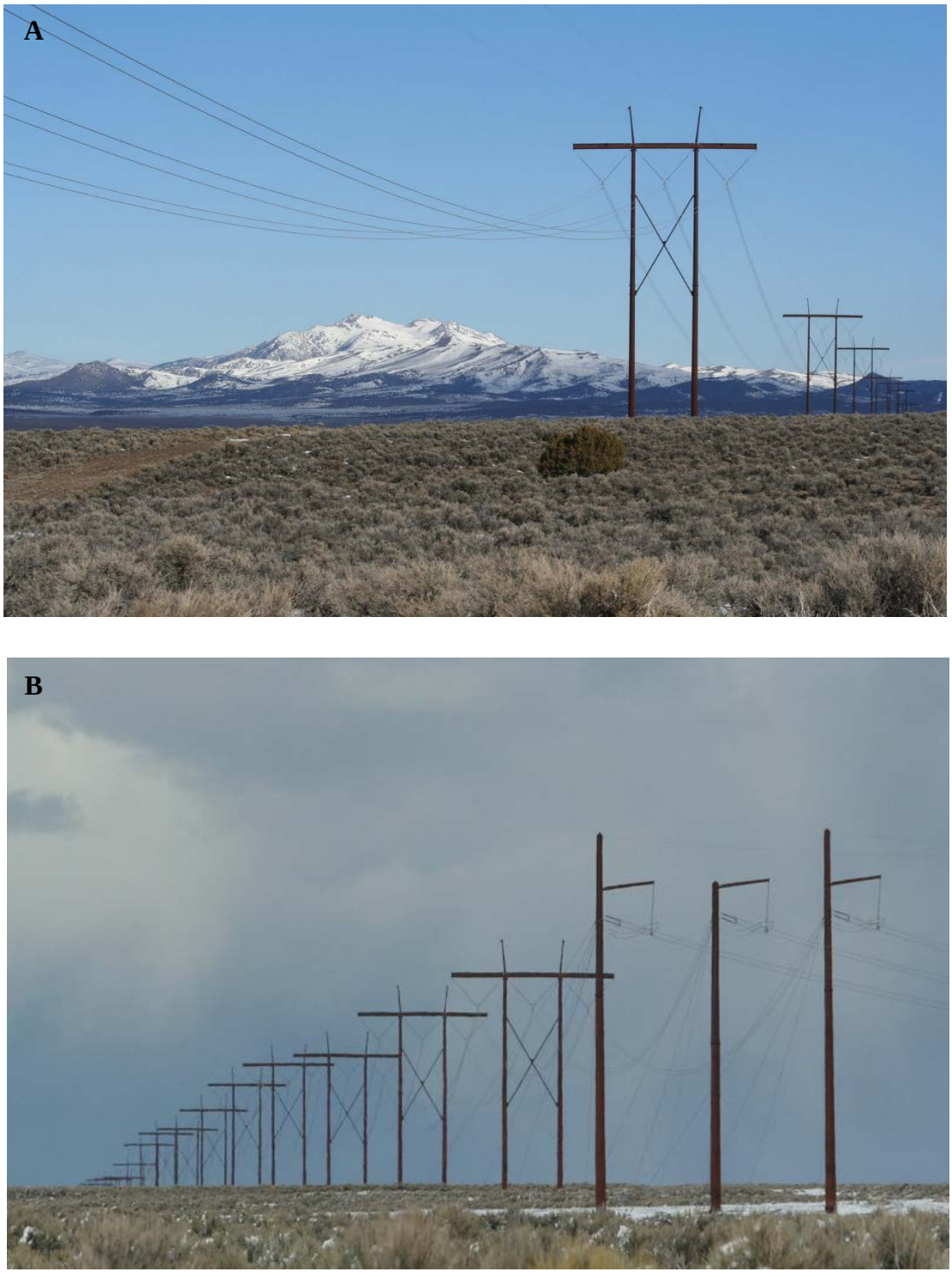
2154

Figure 2



2155

Figure 3



Figur

e 4

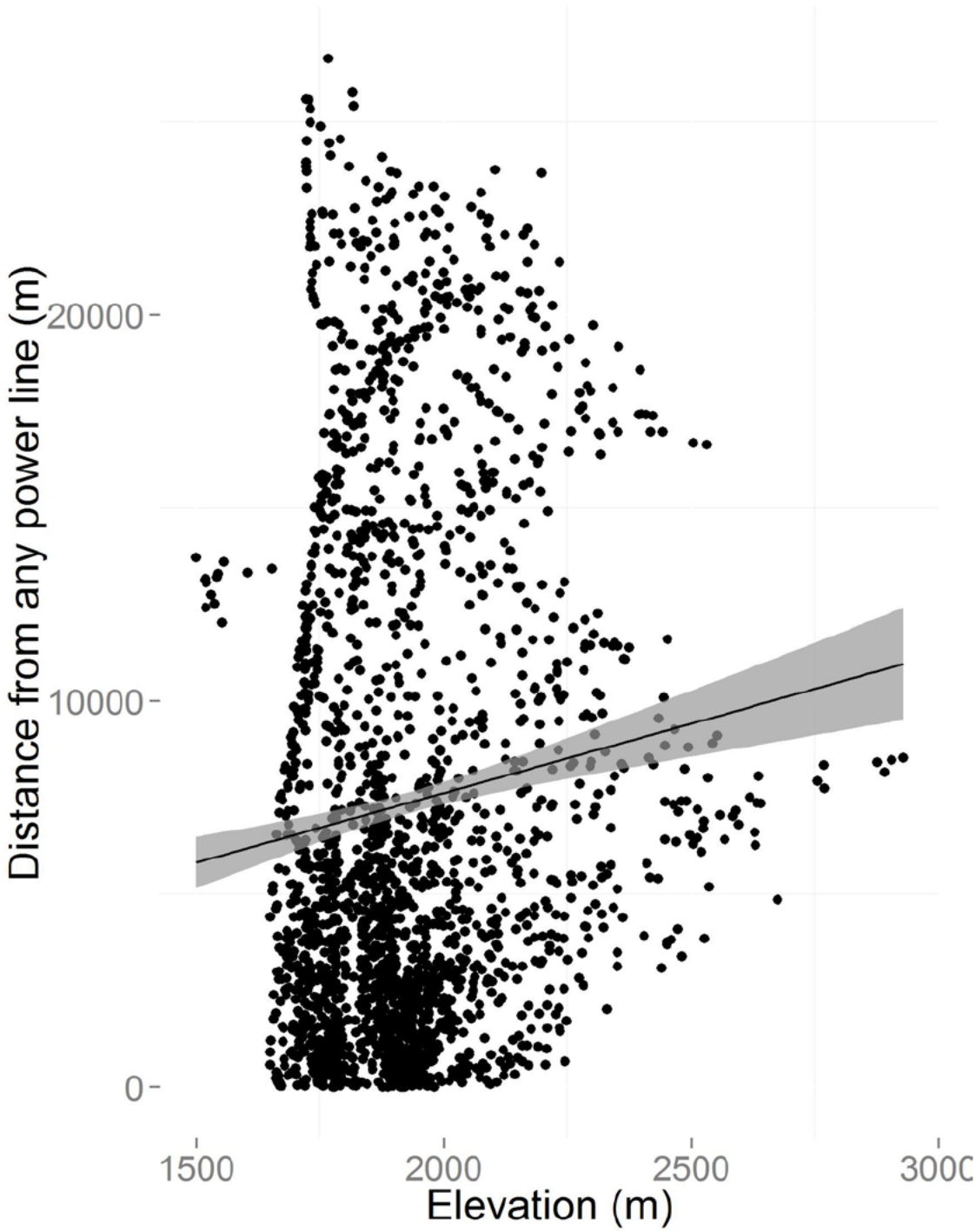


Figure 5

r = 22.7

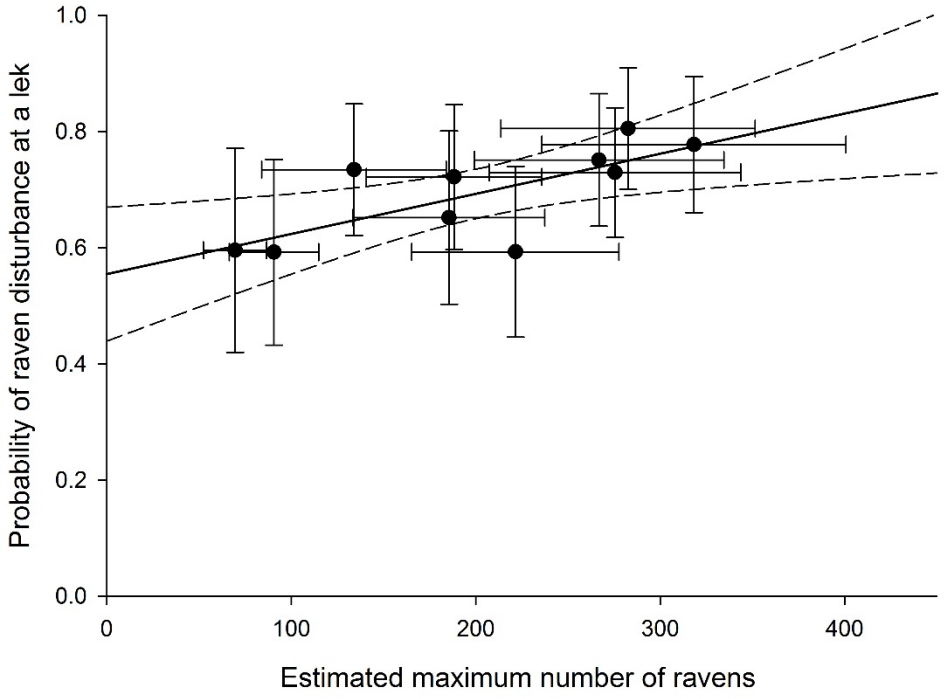
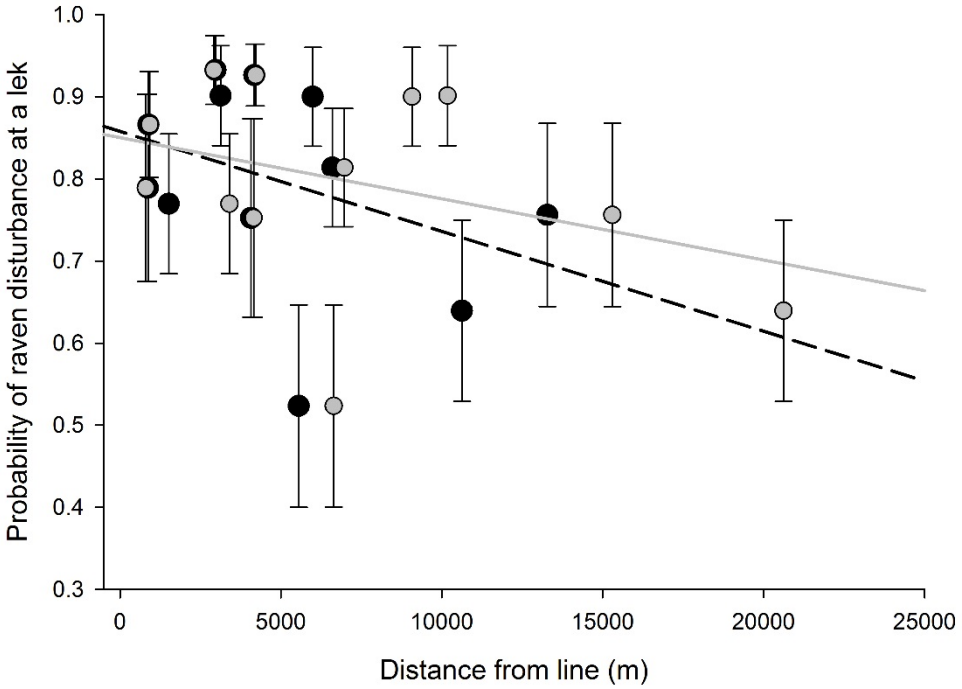
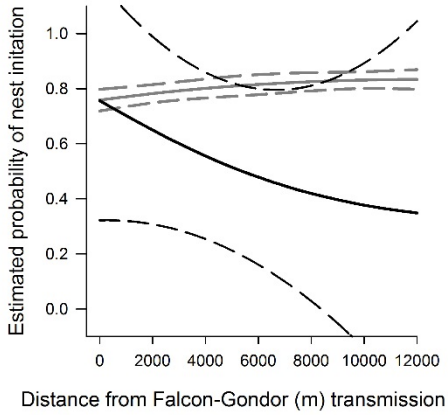

Probability of raven disturbance at a lek
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
Estimated maximum number of ravens

Figure 6


Probability of raven disturbance at a lek
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
5000
10000
15000
20000
25000
Distance from line (m)


Estimated probability of nest initation
1.0
0.8
0.6
0.4
0.2
0.0
0
2000
4000
6000
8000
10000
12000
Distance from Falcon-Gondor (m) transmission line

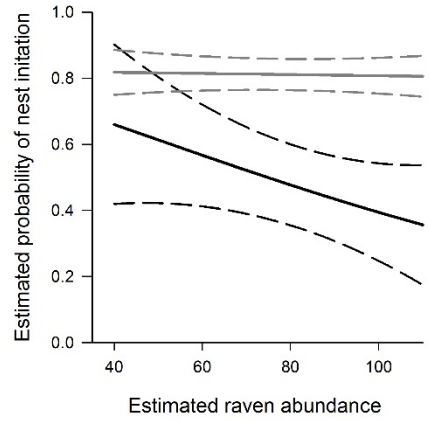
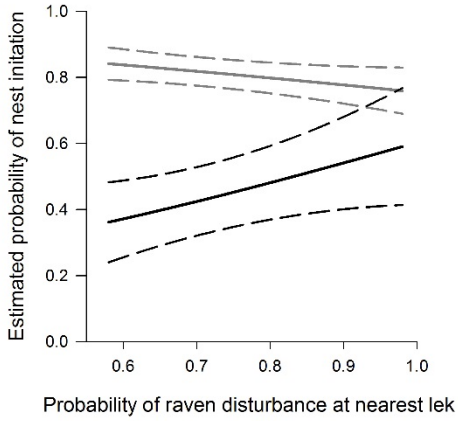

Estimated probability of nest initation
1.0
0.8
0.6
0.4
0.2
0.0
40
60
80
100
Estimated raven abundance

Figure 7


Estimated probability of nest initation
1.0
0.8
0.6
0.4
0.2
0.0
0.6
0.7
0.8
0.9
1.0
Probability of raven disturbance at nearest lek

2222

2223

2224

2225

2226

2227

2228

2229

2230

2231

Figure 8

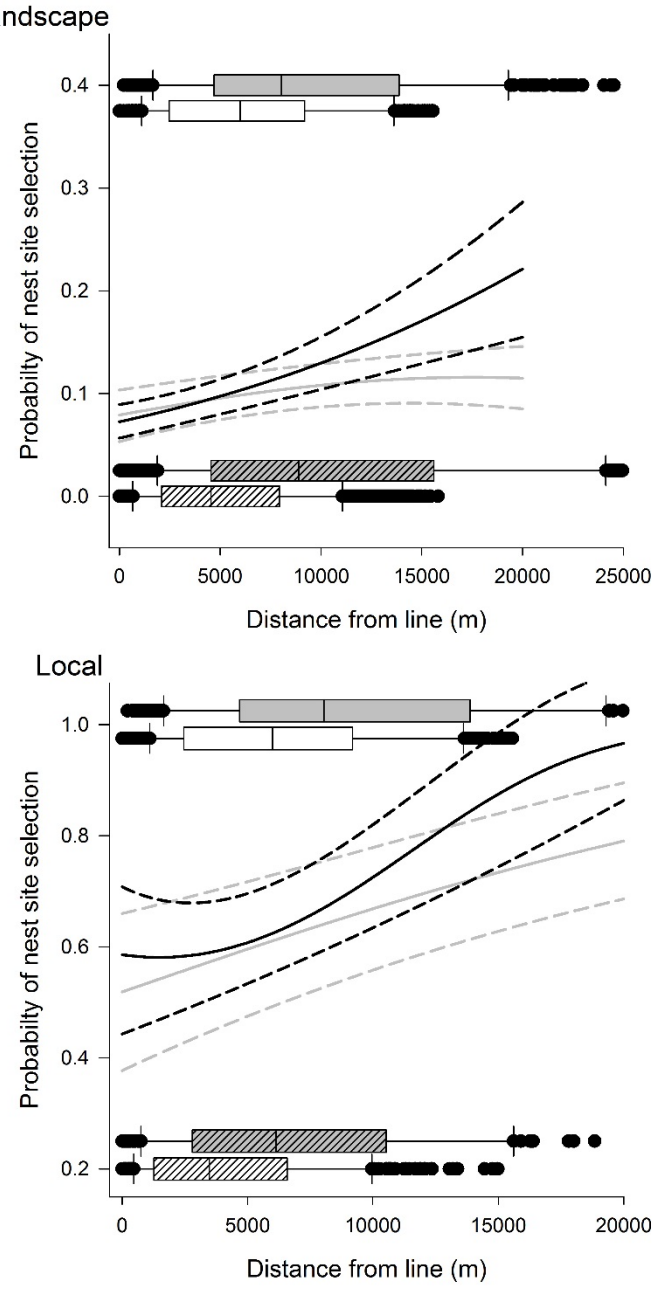

Landscape
Probabilty of nest site selection
0.0
0.1
0.2
0.3
0.4
0
5000
10000
15000
20000
25000
Distance from line (m)
Local
Probabilty of nest site selection
0.2
0.4
0.6
0.8
1.0
0
5000
10000
15000
20000
Distance from line (m)

Figure 9

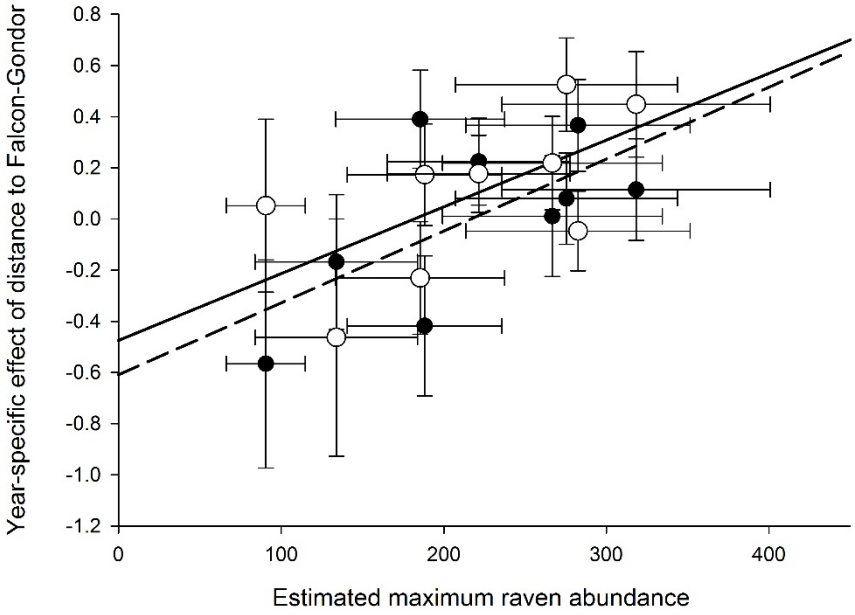

Year-specific effect of distance to Falcon-Gondor
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
0
100
200
300
400
Estimated maximum raven abundance

Figure 10

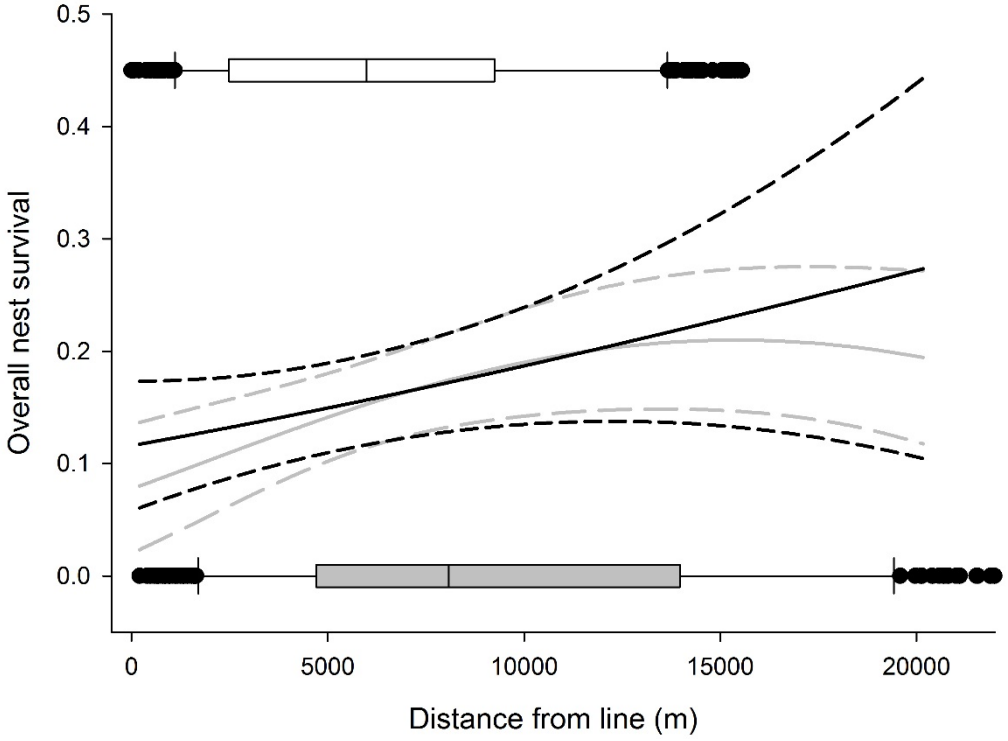

Overall nest survival
0.0
0.1
0.2
0.3
0.4
0.5
0
5000
10000
15000
20000
Distance from line (m)

Figure 11

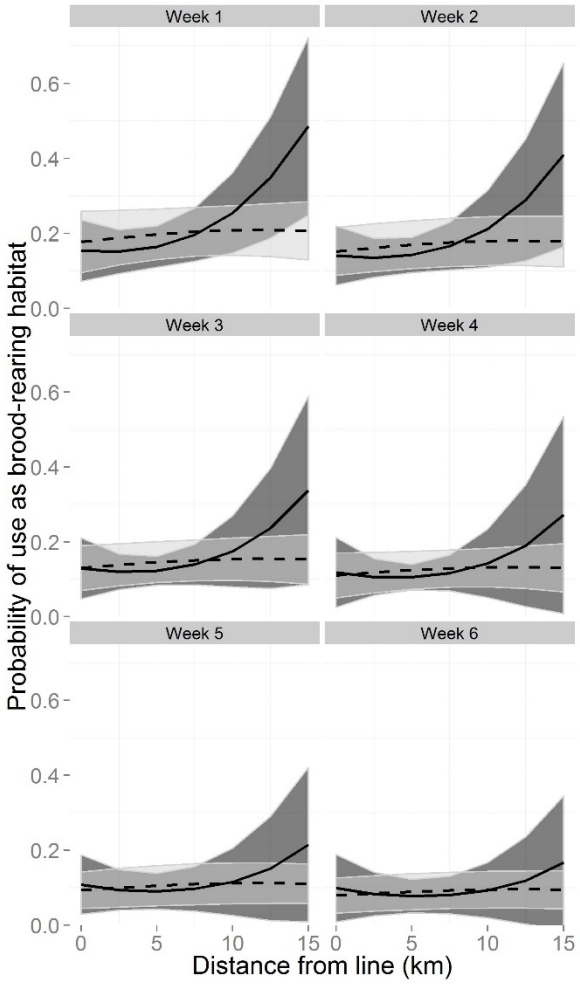

Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Probability of use as brood-rearing habitat
0.0
0.2
0.4
0.6
0
5
10
15
Distance from line (km)

Figure 12

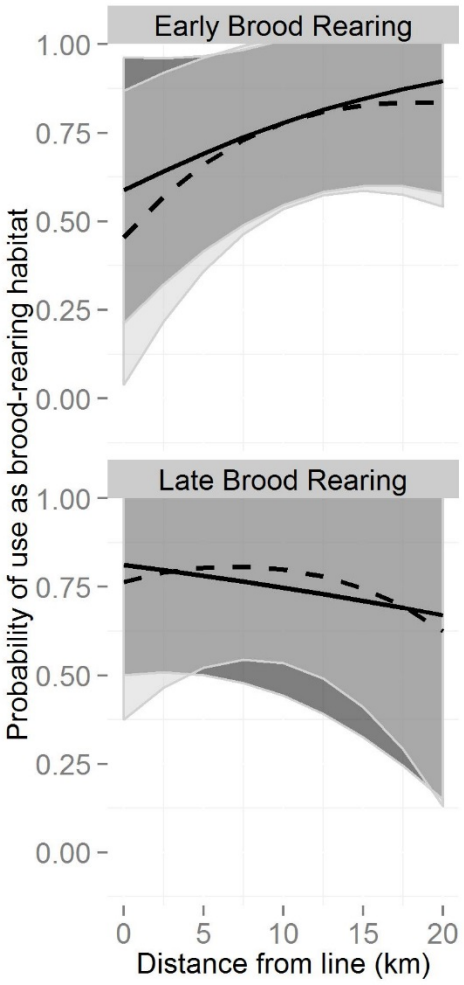

Early Brood Rearing
Late Brood Rearing
Probability of use as brood-rearing habitat
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
Distance from line (km)

Figure 13

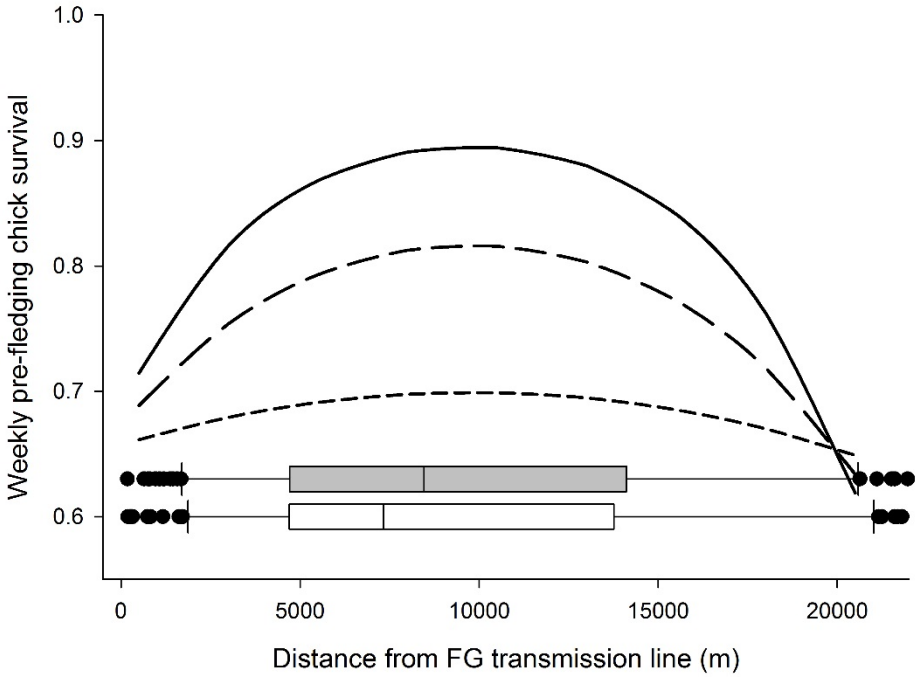
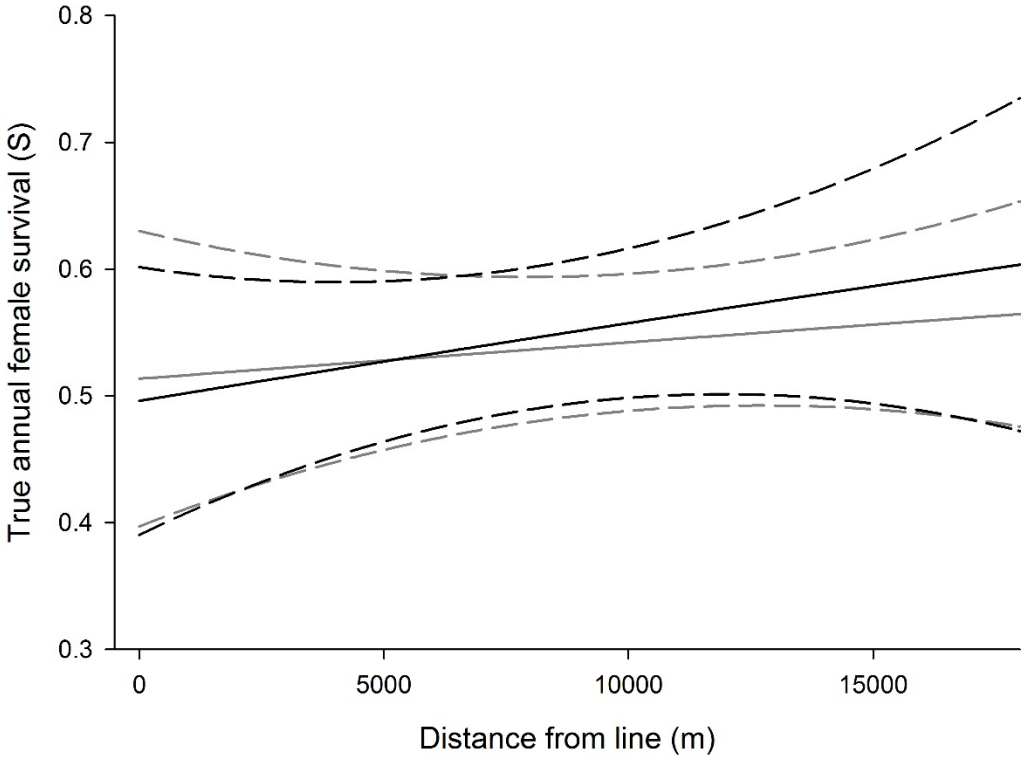

Weekly pre-fledging chick survival
1.0
0.9
0.8
0.7
0.6
0
5000
10000
15000
20000
Distance from FG transmission line (m)

Figure 14


True annual female survival (S)
0.8
0.7
0.6
0.5
0.4
0.3
0
5000
10000
15000
Distance from line (m)

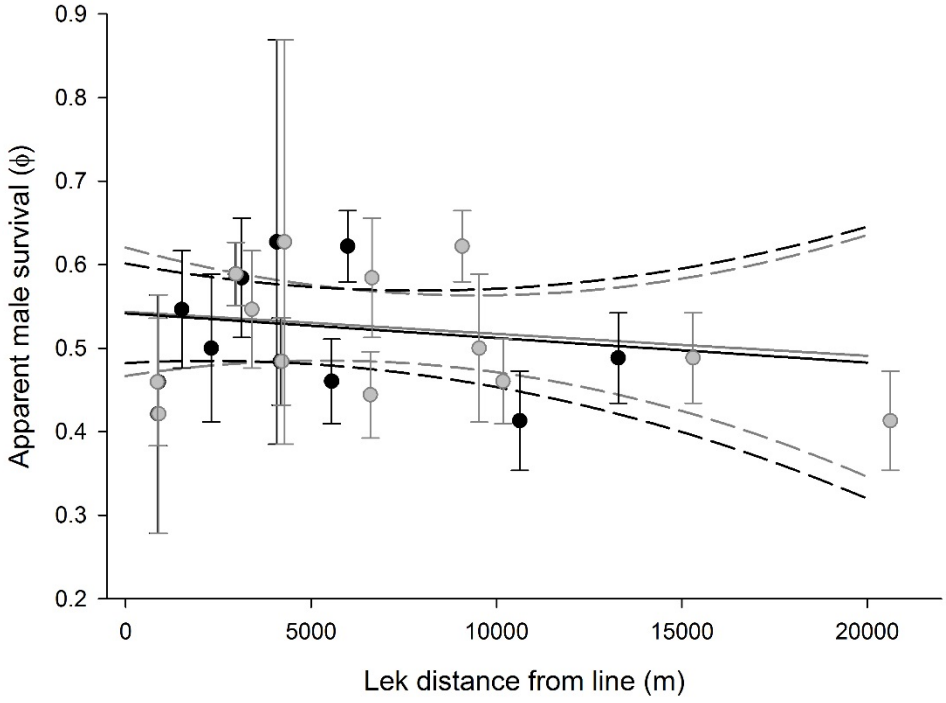
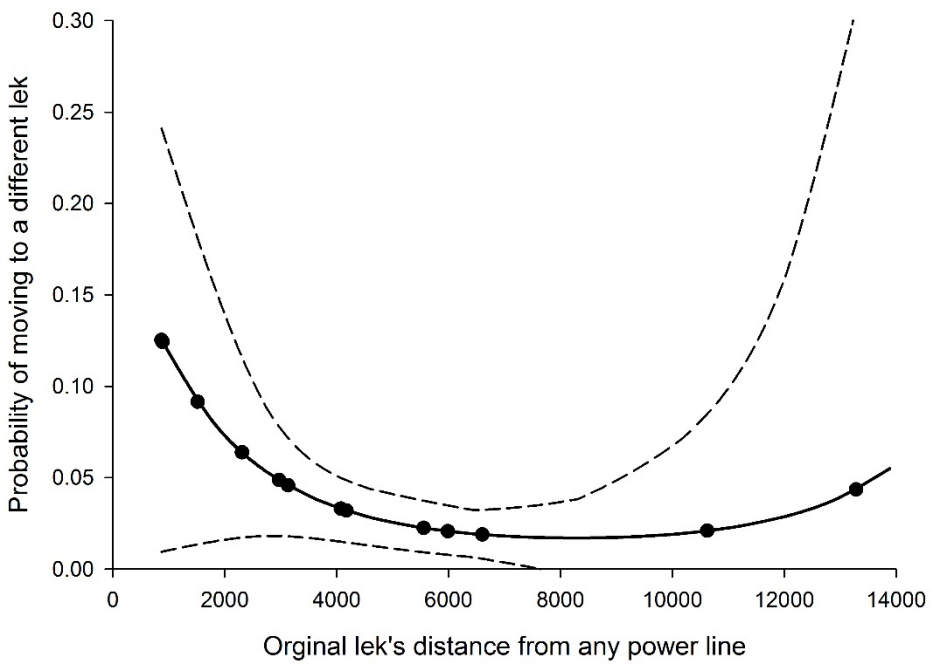

Apparent male survival (ϕ)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
5000
10000
15000
20000
Lek distance from line (m)

Figure 15

Figure 16


Probability of moving to a different lek
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
2000
4000
6000
8000
10000
12000
14000
Orginal lek's distance from any power line

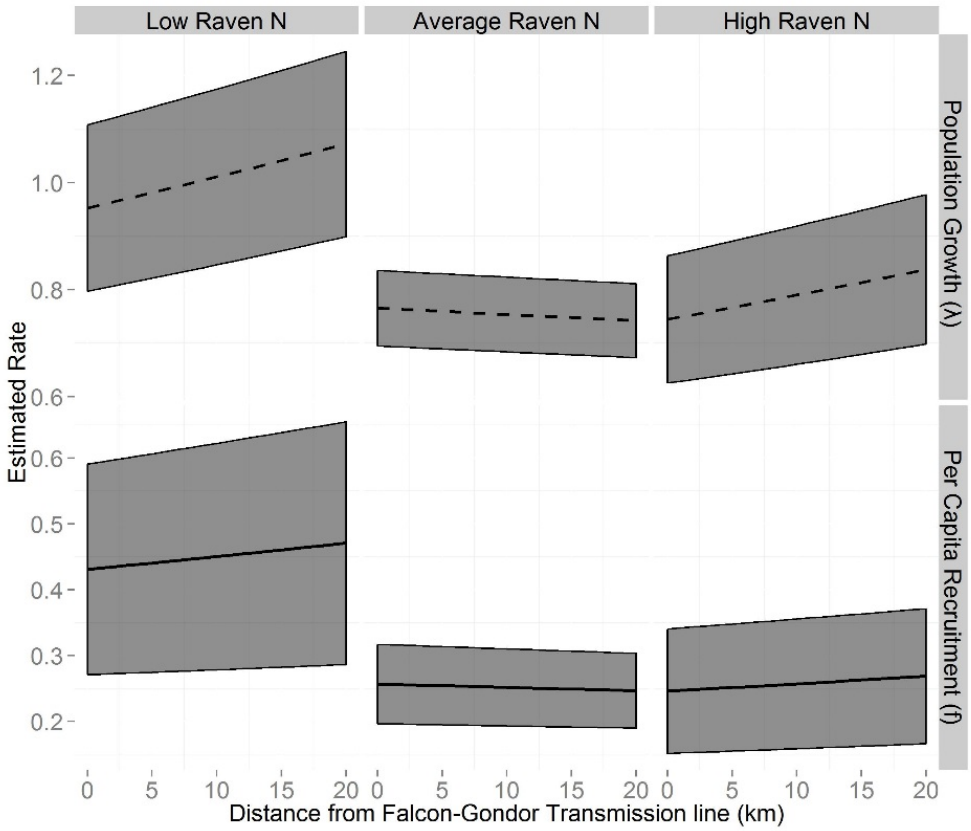

Low Raven N
Average Raven N
High Raven N
Population Growth (λ)
Per Capita Recruitment (f)
Estimated Rate
1.2
1.0
0.8
0.6
0.6
0.5
0.4
0.3
0.2
0
5
10
15
20
Distance from Falcon-Gondor Transmission line (km)

Figure 17

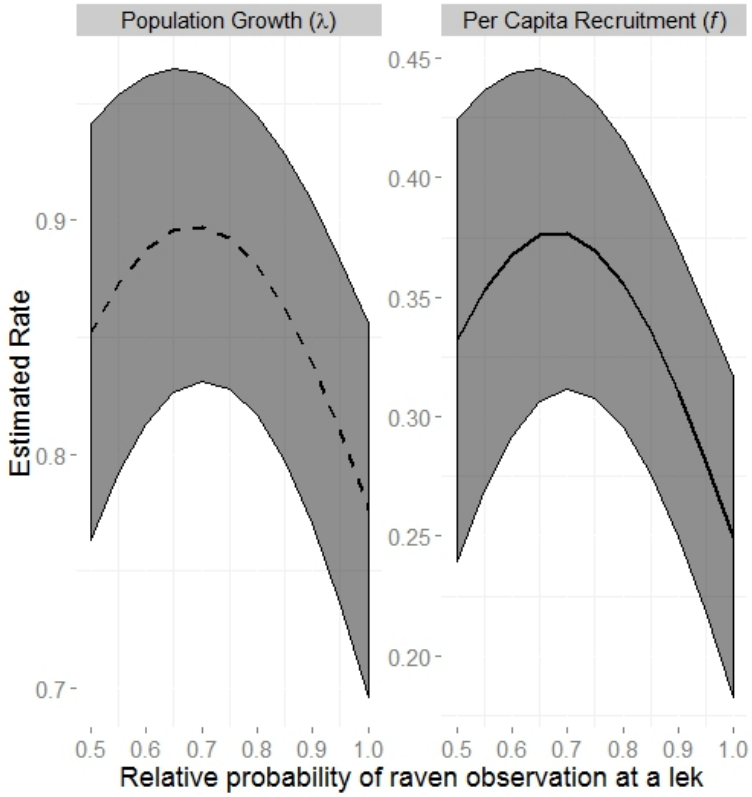

Population Growth (λ)
Per Capita Recruitment (f)
Estimated Rate
0.9
0.8
0.7
0.45
0.40
0.35
0.30
0.25
0.20
0.5 0.6 0.7 0.8 0.9 1.0
0.5 0.6 0.7 0.8 0.9 1.0
Relative probability of raven observation at a lek

Figure 18

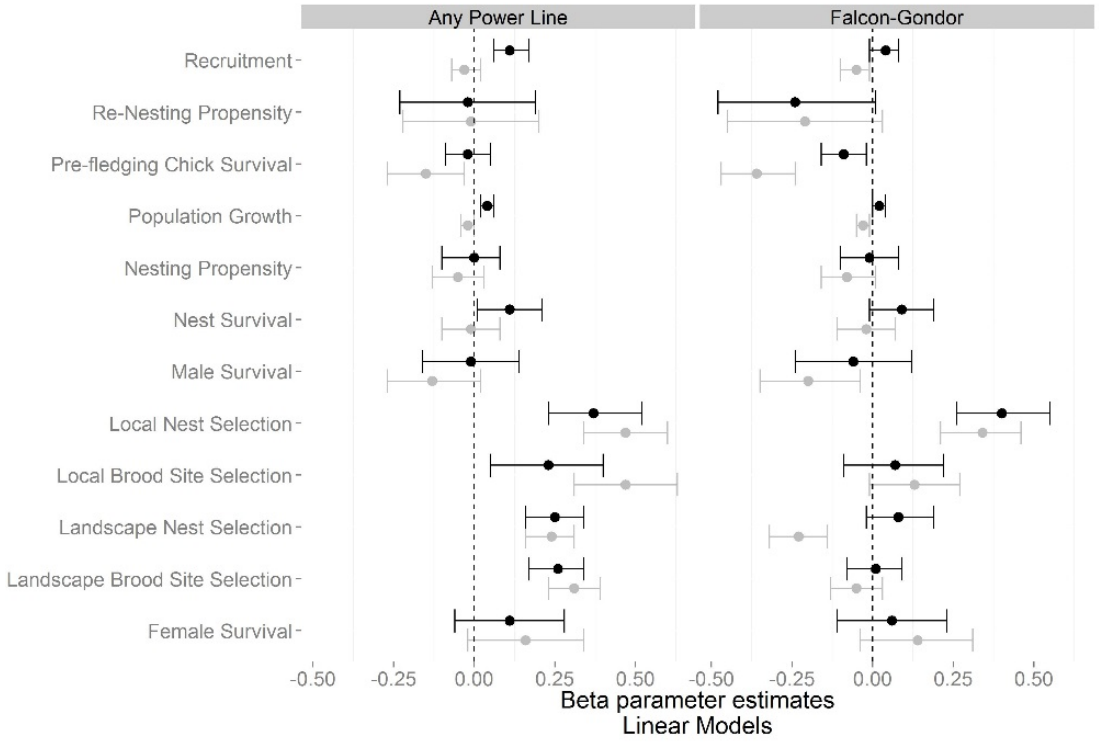

Any Power Line
Falcon-Gondor
Recruitment
Re-Nesting Propensity
Pre-fledging Chick Survival
Population Growth
Nesting Propensity
Nest Survival
Male Survival
Local Nest Selection
Local Brood Site Selection
Landscape Nest Selection
Landscape Brood Site Selection
Female Survival
-0.50 -0.25 0.00 0.25 0.50
-0.50 -0.25 0.00 0.25 0.50
Beta parameter estimates
Linear Models

Figure 19

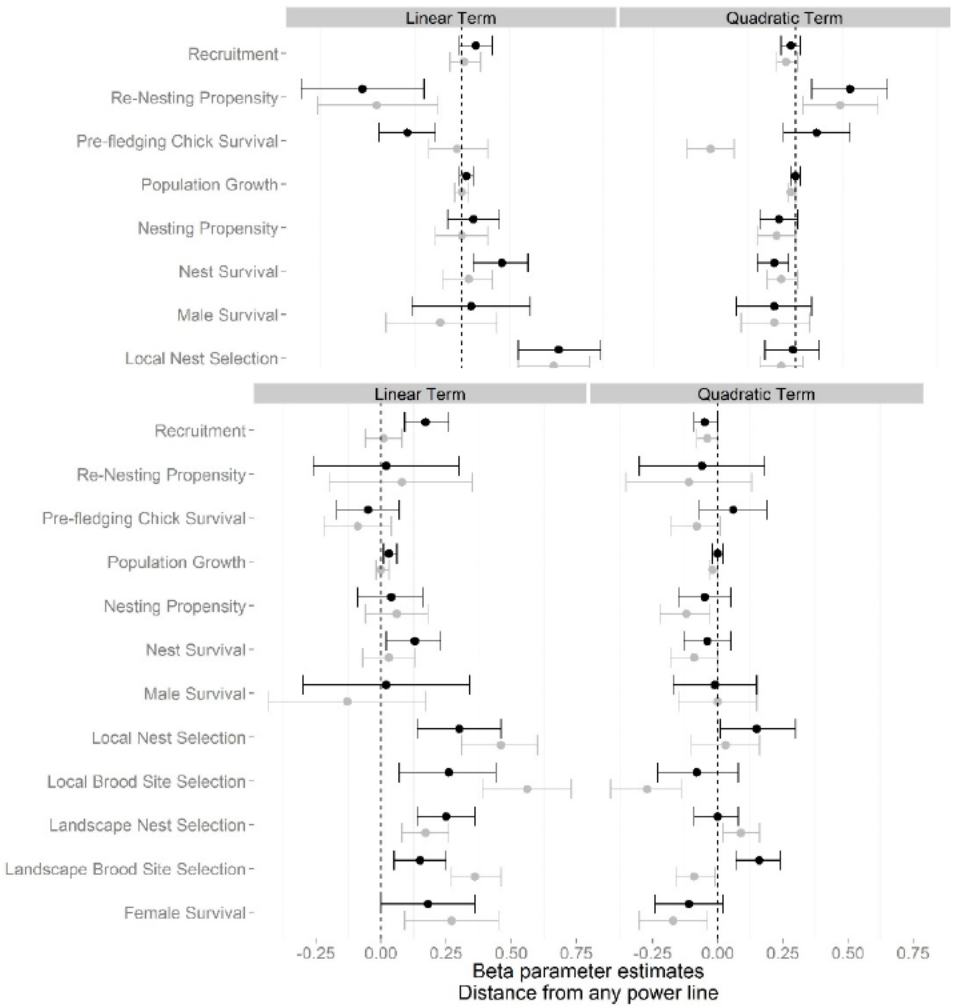
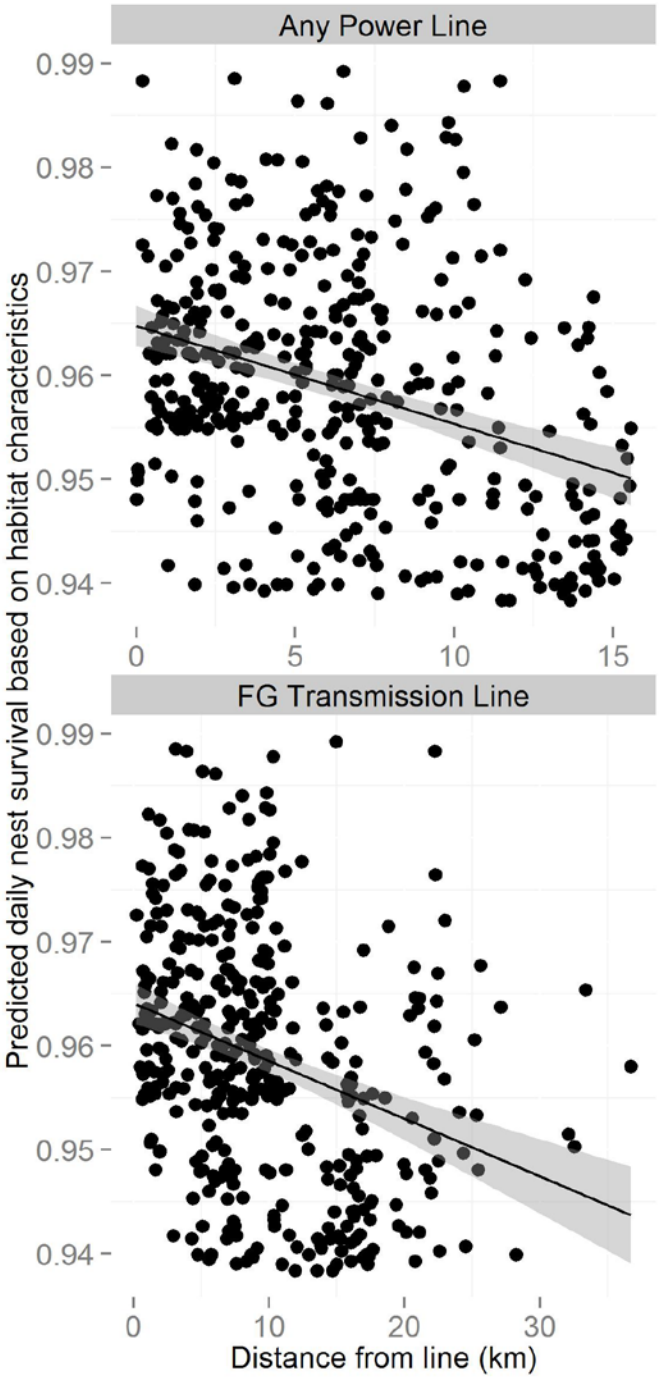

Linear Term
Quadratic Term
Recruitment
Re-Nesting Propensity
Pre-fledging Chick Survival
Population Growth
Nesting Propensity
Nest Survival
Male Survival
Local Nest Selection
Linear Term
Quadratic Term
Recruitment
Re-Nesting Propensity
Pre-fledging Chick Survival
Population Growth
Nesting Propensity
Nest Survival
Male Survival
Local Nest Selection
Local Brood Site Selection
Landscape Nest Selection
Landscape Brood Site Selection
Female Survival
-0.25
0.00
0.25
0.50
0.75
-0.25
0.00
0.25
0.50
0.75
Beta parameter estimates
Distance from any power line

Figure 20


Any Power Line
FG Transmission Line
Predicted daily nest survival based on habitat characteristics
0.99
0.98
0.97
0.96
0.95
0.94
0
5
10
15
20
30
Distance from line (km)

SUPPLEMENTAL MATERIAL

A) Methods and model results for specified reference value analyses

B) JAGS Code – Raven Abundance Model

C) JAGS Code – Raven Site Occupancy Model

2500

2501

2502

2503

2504

SUPPLEMENTAL MATERIAL

Table S1. List of all covariates considered to account for background environmental variation in an individual vital rate. Variables in italics were supported to influence a particular demographic rate of Greater sage-grouse in Eureka County, NV, USA from 2003-2012.

Variable	Nesting (and re-nesting) propensity	Nest Site Selection	Nest Survival	Brood Site Selection	Pre-fledging chick survival	Adult female survival	Adult male Survival	Recruitment	Population Growth
Percent non-sagebrush shrub cover		*x*	*x*	x	x			x	x
Percent forb cover		*x*	*x*	x	x			x	x
Percent total shrub cover		x	x	x	x			x	x
Average shrub height		*x*	*x*	x	x			x	x
Total percent vegetation cover		x	x	*x*	*x*			*x*	x
Percent grass cover		x	x	x	x			x	x
Percent sagebrush shrub cover		*x*	x	*x*	x			x	x

Forb taxa richness	*x*	x	*x*	x			x	x
Average live grass height	*x*	x	*x*	*x*			x	x
Average residual grass height	*x*	x	*x*	x			x	x
Average forb height	*x*	x	*x*	x			x	x
Proportion of surrounding area classified as exotic grasslands	x	x	x	x	x		*x*	*x*
Distance from nearest road	x	x	x	x	x		x	x
Proportion of surrounding area classified as Pinyon-Juniper woodlands	*x*	*x*	x	x	x			
Proportion of surrounding area classified as sagebrush	*x*	x	x	x	x			
Elevation	*x*	x	*x*	x	*x*	*x*	*x*	*x*
Distance to nearest active lek	*x*	x	x	x				
Distance to nearest	*x*	x	x	*x*		x	x	x

spring or water source									
Slope		*x*	x	*x*	x				
Northness :									
cosine(aspect)		x	x	x	x				
Eastness: sine(aspect)		x	x	x	x				
Minimum age	*x*				x	*x*			
Estimated male									
population size	*x*								
Precipitation	*x*				*x*		*x*	*x*	*x*
Summer temperature	x				*x*		x		
Nest hatch date			**x**		x				
Nesting success						*x*			
Fledging success						*x*			
Nest quality					*x*				
Distance brood moved					*x*				
Population	x		***x***		x	x	*x*	x	x

Table S2. Performance of all nest survival models used to assess the influence of habitat features selected for as nest sites on Greater sage-grouse nest survival in Eureka County, NV, 2004-2012. Tables are organized by individual heterogeneity (A), disturbance (B), landscape-scale habitat features (C), temporal characteristics (D), local-scale vegetation features (E), and multivariable models (F).

Individual Heterogeneity Models[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Base + Pop	0.00	0.84	5	1268.21
Base	6.19	0.04	4	1276.40
Base + ID^2	6.71	0.03	6	1272.91
Base + Season	6.88	0.03	5	1275.08
Base + Age Class	7.46	0.02	5	1275.67
Base + MinAge	8.09	0.01	5	1276.30
Base + ID	8.11	0.01	5	1276.32
Base + NestAttempt	8.18	0.01	5	1276.39

Disturbance Models[b]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Base + WF_{2000}	0.00	0.31	5	1274.06
Base	0.33	0.26	4	1276.40

Base + WF_{1000}	1.26	0.17	5	1275.32
Base + WF_{500}	1.68	0.14	5	1275.75
Base + DRoad	2.01	0.12	5	1276.07

Geo-Spatial Models[c]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Base + PJ_{2000}	0.00	0.71	5	1265.60
Base + Elev	4.20	0.09	5	1269.80
Base + PJ_{1000}	4.22	0.09	5	1269.81
Base + Dlek	5.62	0.04	5	1271.21
Base + $DLek^2$	7.51	0.02	6	1271.11
Base + All_{2000}	8.11	0.01	5	1273.71
Base + PJ_{500}	8.13	0.01	5	1273.72
Base	8.80	0.01	4	1276.40
Base + DSpring	8.82	0.01	5	1274.42
Base + North	8.83	0.01	5	1274.43
Base + Slope	8.96	0.01	5	1274.56
Base + $Sagebrush_{1000}$	9.76	0.01	5	1275.36
Base + $Sagebrush_{500}$	10.56	0.00	5	1276.16

Base +East	10.61	0.00	5	1276.20
Base + DSpring^2	10.82	0.00	6	1274.42
Base + North * East	11.78	0.00	7	1273.37

Temporal Models[d]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Stage + Incubation Trend (Base)	0.00	0.23	4	1276.40
(.)	0.64	0.17	1	1283.04
Stage	0.64	0.16	3	1279.05
Snowpack	1.54	0.11	2	1281.95
Raven Index	2.02	0.08	2	1282.42
Weekly Trend	2.50	0.07	2	1282.90
Daily Trend	2.60	0.06	2	1283.00
Precipitation	2.60	0.06	2	1283.00
Week Quadratic Trend	4.50	0.02	3	1282.90
Day Quadratic Trend	4.56	0.02	3	1282.96
Week	5.65	0.01	6	1278.04
Year + Stage + Incubation Trend	9.18	0.00	12	1269.53
Year	10.24	0.00	9	1276.61

Local Vegetation Models[e]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Base + NSC_5	0.00	0.79	5	1264.68
Base + FC_5	4.88	0.07	5	1269.56
Base + $TC_{0.5}$	6.54	0.03	5	1271.22
Base + TSC_5	6.64	0.03	5	1271.32
Base + SH_5	6.95	0.02	5	1271.63
Base + TC_5	8.39	0.01	5	1273.07
Base + FH_5	8.67	0.01	5	1273.34
Base + $SH_{0.5}$	9.53	0.01	5	1274.21
Base	9.72	0.01	4	1276.40
Base + $GH_{0.5}$	10.87	0.00	5	1275.55
Base + GH_5	11.24	0.00	5	1275.92
Base + GC_5	11.32	0.00	5	1276.00
Base + SC_5	11.57	0.00	5	1276.24
Base + $FRich_5$	11.71	0.00	5	1276.39
Base + RGH_5	11.72	0.00	5	1276.39
Base + $FH_{0.5}$	11.72	0.00	5	1276.40

2519

Multivariable Model[f]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Base + NSC_5 + FC_5 + Pop	0.00	0.29	7	1253.92
Base + NSC_5 + FC_5 + Pop + PJ_{2000}	0.56	0.22	8	1252.47
Base + NSC_5 + FC_5 + PJ_{2000}	1.29	0.15	7	1255.20
Base + NSC_5 + FC_5	3.29	0.06	6	1259.21
Base + NSC_5 + FC_5 + SH_5	3.96	0.04	7	1257.88
Base + NSC_5 + PJ_{2000}	4.19	0.04	6	1260.12
Base + NSC_5 + FC_5 + Dlek	4.29	0.03	7	1258.21
Base + NSC_5 + FC_5 + Elev	4.88	0.03	7	1258.80
Base + NSC_5 + FC_5 + $TC_{0.5}$	4.93	0.02	7	1258.85
Base + NSC_5 + Pop	5.13	0.02	6	1261.05
Base + NSC_5 + $TC_{0.5}$	6.50	0.01	6	1262.42
Base + NSC_5 + Dlek	6.50	0.01	6	1262.42
Base + NSC_5 + SH_5	6.58	0.01	6	1262.50
Base + NSC_5 + Elev	6.63	0.01	6	1262.56
Base + NSC_5	6.75	0.01	5	1264.68
Base + NSC_5 + DSpring	7.05	0.01	6	1262.97

Base + NSC_5 + TC_5	7.13	0.01	6	1263.05
Base + NSC_5 + WF_{2000}	7.66	0.01	6	1263.59
Base + PJ_{2000}	7.67	0.01	5	1265.60
Base + NSC_5 + TSC	8.08	0.01	6	1264.00
Base + NSC_5 + $SH_{0.5}$	8.46	0.00	6	1264.38
Base + NSC_5 + $FH_{0.5}$	8.72	0.00	6	1264.65
Base + Pop	10.28	0.00	5	1268.21
Base + FC_5	11.63	0.00	5	1269.56
Base + Elev	11.87	0.00	5	1269.80
Base + Dlek	13.28	0.00	5	1271.21
Base + $TC_{0.5}$	13.29	0.00	5	1271.22
Base + TSC_5	13.39	0.00	5	1271.32
Base + SH_5	13.70	0.00	5	1271.63
Base + TC_5	15.14	0.00	5	1273.07
Base + WF_{2000}	16.13	0.00	5	1274.06
Base + $SH_{0.5}$	16.28	0.00	5	1274.21
Base + DSpring	16.49	0.00	5	1274.42
Base + $FH_{0.5}$	18.47	0.00	5	1276.40

[a,b,c,d,e,f] Model selection notation follows Burnham and Anderson (2002). Base represents a competitive four parameter design to account for variation in nest survival related to nest age; we allowed the laying period for the average nest (occasions 1-10), early incubation/late laying period (occasions 11-15), and the primary incubation period (occasions 16-44) to estimate independently from each other, with the linear trend (daily) on the primary incubation period. Subscripts denote the scale of the variable (i.e., within 0.5m, 5m or within a radius of 500m, 1000m, or 2000m of a point). Horizontal cover variables included non-sagebrush shrub cover of all size classes (NSC), sagebrush shrub cover at all size classes (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represented forb taxa richness within a given plot. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sagebrush represent the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; Slope represented the slope (in degrees) of a point. North is the cosine of aspect, East is the sin of aspect. Pop was a binomial covariate delineating nests from females associated from the Cortez Mountains from females associated with Roberts Creek Mountain. AgeClass was a binomial covariate which delineated second year females from after second year females, MinAge was a continuous covariate which represented the females minimum age. Season was a binomial covariate which delineated females captured in the spring from females captured in the fall. ID represented estimate nest initiation date. (.) denotes intercept-only model. Year denotes

full annual variation. We also considered annual constraints related to annual precipitation (precipitation), raven population size (raven index), and winter snowpack (snowpack). Week allowed for variation among 7 day fixed periods. Stage allowed for the laying, early incubation, and primary incubation phases to estimate separately. Linear and quadratic daily and weekly trends are clearly denoted. All covariates were z-standardized prior to analysis

Table S3. Model parameter estimates, associated error, and measure of significance from single variable nest survival (Nest Survival) models.

Variable	β	S.E.	Sig.?	units
NSC_5	0.29	0.09	*	Prop. cover
FC_5	0.21	0.09	*	Prop. cover
$TC_{0.5}$	0.15	0.06	*	Prop. cover
TSC_5	0.16	0.07	*	Prop. cover
SH_5	0.15	0.07	*	cm
TPC_5	0.12	0.07	*	Prop. cover
$FH_{0.5}$	0.12	0.07	*	cm
$SH_{0.5}$	0.11	0.08	*	cm
G0.5	0.07	0.07		cm
GC_5	-0.05	0.07		Prop. cover
SC_5	-0.03	0.07		Prop. cover
$FRich_5$	0.01	0.07		taxa
GH_5	0.05	0.07		cm
RGH_5	-0.01	0.07		cm
FH_5	0.00	0.07		cm
WF_{2000}	-0.11	0.07	*	Prop. classified
WF_{1000}	-0.07	0.07		Prop. classified
WF_{500}	-0.06	0.07		Prop. classified
Road	0.04	0.07		m
PJ_{2000}	0.25	0.08	*	Prop. classified

PJ_{1000}	0.20	0.08	*	Prop. classified
PJ_{500}	0.12	0.08	*	Prop. classified
$Sage_{2000}$	-0.13	0.08	*	Prop. classified
$Sage_{1000}$	-0.08	0.08		Prop. classified
$Sage_{500}$	-0.04	0.08		Prop. classified
Elev	0.18	0.07	*	m
Dlek	0.17	0.08	*	m
DSpring	0.10	0.07	*	m
Slope	0.10	0.07		°
Northness	-0.10	0.07	*	°
Eastness	0.03	0.07		°

(*) denotes significance at 85 percent confidence intervals (Arnold 2010) in single variable models. Subscripts denote the scale of the variable (i.e., within 0.5m, 5m, or within a radius of 500m, 1000m, or 2000m of a point). Horizontal cover variables included non-sagebrush shrub cover of all size classes (NSC), sagebrush shrub cover at all size classes (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represented forb taxa richness within a given plot. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sagebrush represent the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the

elevation (in m) of a point; Slope represented the slope (in degrees) of a point. North is the cosine of aspect, East is the sin of aspect.

Table S3. Performance of all resource selection function generalized linear mixed models used to assess the influence of landscape-scale vegetation habitat features on Greater sage-grouse brood site selection in Eureka County, NV, 2005-2012.

Model[a]	**ΔAIC_c**	**AIC_c w_i**	**No. Par**	**Dev.**
Elevation + Slope	0.00	0.37	5	2063.75
Elevation * Slope	0.21	0.34	6	2061.96
$Elevation^2$ + Slope	0.50	0.29	6	2062.25
$Elevation^2$	21.00	0.00	5	2084.75
Elevation	21.99	0.00	4	2087.74
$All\ Sagebrush_{500}$	73.83	0.00	4	2139.58
$All\ Sagebrush_{1000}$	75.42	0.00	4	2141.17
$Pinyon\text{-}Juniper_{500}$	78.89	0.00	4	2144.64
$All\ Sagebrush_{2000}$	88.29	0.00	4	2154.04
$Pinyon\text{-}Juniper_{1000}$	93.19	0.00	4	2158.94
$Pinyon\text{-}Juniper_{2000}$	136.71	0.00	4	2202.46
Slope	163.51	0.00	4	2229.26
$Wildfire_{1000}$	179.60	0.00	4	2245.35
$Wildfire_{500}$	179.95	0.00	4	2245.70
Null	180.08	0.00	3	2247.83
$Wildfire_{2000}$	180.50	0.00	4	2246.25
Distance from $spring^2$	180.77	0.00	5	2244.52
Distance from spring	181.88	0.00	4	2247.63

[a] Model selection notation follows Burnham and Anderson (2002). All models include random intercepts for year and individual. Subscripts denote the scale of the variable (i.e., radius of 500m, 1000m, or 2000m from a point), superscripts denote quadratic relationships. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. All Sagebrush represented the proportion of area classified as sagebrush at a specified scale; WF represented the proportion of area converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of area classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; Slope represented the slope (in degrees) of a point. Null denotes intercept-only model. All variables were z-standardized prior to analysis.

Table S4. Performance of all resource selection function generalized linear mixed models used to assess the influence of local-scale vegetation habitat features on Greater sage-grouse brood site selection in Eureka County, NV, 2005-2012.

Model[a]	**ΔAIC_c**	**AIC_c w_i**	**No. Par**	**Dev.**
TC + RGH + FRich + GH + NSC	0.00	0.58	9	713.64
TC + RGH + FRich + GH + NSC + SC	1.05	0.35	10	712.69
TC + RGH + FRich + GH + SC	6.37	0.02	9	720.01
TC + RGH + FRich + GH + FH	7.29	0.02	8	722.93
TC + RGH + FRich + GH + FC	7.70	0.01	9	721.34
TC + RGH + FRich + GH + FC	8.51	0.01	8	724.15
TC + RGH + FRich + GH	9.87	0.00	7	727.52
TC + RGH + FRich + FH	10.50	0.00	7	728.14
TC + RGH + FRich + GH + TRich	11.87	0.00	8	727.51
TC + RGH + FRich + FC	16.27	0.00	7	733.91
TC + RGH + FRich	17.81	0.00	6	737.45
TC + RGH + FRich + GRich	17.84	0.00	7	735.48
TC + RGH + FRich + TRich	19.69	0.00	7	737.33
TC + RGH + TR	21.68	0.00	6	741.33
TC + RGH + FH	31.10	0.00	6	750.74
TC + RGH + FC	34.14	0.00	6	753.79
TC + RGH + GH	36.35	0.00	6	756.00
TC + RGH + GRich	39.83	0.00	6	759.48
TC + RGH	42.93	0.00	5	764.57

TC + FRich	47.90	0.00	5	769.54
TC + TR	50.71	0.00	5	772.35
TC + FH	57.21	0.00	5	778.85
TC + GH	57.90	0.00	5	779.54
TC + FC	63.52	0.00	5	785.16
TC + GRich	65.10	0.00	5	786.75
TC	69.27	0.00	4	792.92
TC + GC	70.24	0.00	5	791.88
FRich	83.05	0.00	4	806.70
FH	83.76	0.00	4	807.40
TRich	86.97	0.00	4	810.61
FC	89.78	0.00	4	813.43
GH	92.28	0.00	4	815.92
RGH	94.48	0.00	4	818.12
GRich	121.69	0.00	4	845.34
SC	122.94	0.00	4	846.58
GC	124.53	0.00	4	848.17
TSC	126.96	0.00	4	850.60
Null	127.87	0.00	3	853.51
NSC	128.95	0.00	4	852.59
SH	129.08	0.00	4	852.72
SRich	129.59	0.00	4	853.23

[a] Model selection notation follows Burnham and Anderson (2002). All models include random intercepts for year and individual. Horizontal cover variables included non-sagebrush shrub cover (NSC), sagebrush shrub cover (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich, GRich, SRich, and TRich represented forb, grass, shrub, and total taxa richness within a given plot, respectively. Null denotes intercept-only model. All variables were z-standardized prior to analysis.

Table S5. Parameter estimates from resource selection functions based on generalized linear mixed models to assess the influence of habitat characteristics on greater sage-grouse brood site selection in Eureka County, NV, 2005-2012.

Parameters	β	Lower 85% Confidence Interval	Upper 85% Confidence Interval
FC_{10}	0.71	0.54	0.89
$FRich_{10}$	0.78	0.61	0.95
GC_{10}	0.24	0.09	0.39
$GRich_{10}$	0.30	0.15	0.45
RGH_{10}	0.66	0.48	0.83
FH_{10}	0.75	0.58	0.93
GH_{10}	0.70	0.52	0.87
NSC_{10}	-0.09	-0.24	0.05
SC_{10}	0.26	0.12	0.41
SH_{10}	0.09	-0.06	0.24
$ShrubRich_{10}$	0.05	-0.09	0.19
TC_{10}	0.86	0.69	1.03
$TotalRich_{10}$	0.77	0.60	0.95
TSC_{10}	0.18	0.03	0.33
Elev	0.67	0.60	0.75
Slope	0.23	0.15	0.30
DSpring	0.03	-0.05	0.10
WF_{500}	-0.08	-0.17	0.00

WF_{1000}	-0.09	-0.18	-0.01
WF_{2000}	-0.07	-0.15	0.01
$Sage_{500}$	0.72	0.62	0.83
$Sage_{1000}$	0.75	0.64	0.87
$Sage_{2000}$	0.76	0.64	0.88
PJ_{500}	-0.87	-1.03	-0.70
PJ_{1000}	-0.74	-0.88	-0.60
PJ_{2000}	-0.45	-0.55	-0.34

Parameter estimates are each from a single variable model. Subscripts denote the scale of the variable (i.e., within 10m, or a radius of 500m, 1000m, or 2000m from a point), superscripts denote quadratic relationships. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sage represented the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; Slope represented the slope (in degrees) of a point. Horizontal cover variables included non-sagebrush shrub cover (NSC), sagebrush shrub cover (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich, GRich, SRich, and TRich represented forb, grass, shrub, and total taxa richness within a given plot, respectively. All covariates were z-standardized prior to analysis.

FEMALE SURVIVAL

Model Modifications

We modified the analyses reported in Blomberg et al. (2013) by the following: 1) inclusion of an additional year of data [i.e., 2012]; 2) inclusion of additional predictor variables; and 3) transitioning the modeling framework from a known-fate analysis to that of a nest survival model.

Table S6. Performance of all nest survival models used to assess the influence of environmental characteristics on adult female Greater sage-grouse survival in Eureka County, NV, 2003-2012.

Model[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Elev + Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	0.00	0.26	9	1511.44
Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	0.51	0.20	8	1513.96
PJ + Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	1.01	0.16	9	1512.45
Road + Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	1.40	0.13	9	1512.84
Month + Winter + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	5.50	0.02	13	1508.90
Month + Winter + PreBreeding + Age_{min}	10.36	0.00	11	1517.77
Seasons	11.77	0.00	4	1533.25
Month + Winter + $Hatch_{summer}$ + $Fledge_{fall}$	13.62	0.00	11	1521.04
Month + Winter + Elev	14.55	0.00	10	1523.98
Month + Winter + $Fledge_{fall}$	14.60	0.00	10	1524.03
Month + Winter + $Hatch_{summer}$	15.48	0.00	10	1524.91
Month + Winter + PreBreeding + Age_{min}^2	15.74	0.00	12	1521.14
Month + Winter + PreBreeding	16.01	0.00	10	1525.44
Month + Winter + PJ	16.75	0.00	10	1526.17
Month + Winter + Age_{min}	16.76	0.00	10	1526.19
Month + Winter	17.15	0.00	9	1528.59

Month + Winter + Fire	17.71	0.00	10	1527.14
Year + Month + Winter	25.69	0.00	18	1519.00
(.)	62.91	0.00	1	1590.40
Year	73.17	0.00	10	1582.60

[a] Model selection notation follows Burnham and Anderson (2002). Month + Winter (no. par = 9) allows survival during March – October to estimate independently but constrained to estimate together from November – February. Seasons (no. par = 4) constrains monthly survival into seasonal blocks (i.e., March-May, June-July, August-October, and November – February) that estimate independently from each other. Year (no. par = 10) allows survival each year (2003-2012) to estimate independently from another. Elev is a monthly (March- October) time-varying covariate that represents the average elevation from all locations of a radio-marked female during that month. PJ is a monthly (March- October) time-varying covariate that represents the average proportion of area classified as Pinyon-Juniper within 5km from all locations of a radio-marked female during that month. Fire is a monthly (March- October) time-varying covariate that represents the average proportion of area classified as exotic grasslands within 5km from all locations of a radio-marked female during that month. Road is a monthly (March- October) time-varying covariate that represents the average distance between each location of a radio-marked female and the nearest road. PreBreeding is a binomial (yes/no) variable modeled on post-breeding months (August-February) that delineates young-of-year individuals from females that have survived at least one breeding season. Age_{min} represents the minimum age for each female each year. $Hatch_{summer}$ is a binomial (yes/no) variable modeled on the season immediately following hatching (June-July) that delineates females that successfully hatched a nest from those that did not. $Fledge_{fall}$ is a binomial (yes/no) variable modeled on the season immediately

following fledging (August-October) that delineates females that successfully fledged at least one chick from those that did not.

RECRUITMENT AND POPULATION GROWTH

Model Modifications

We modified the analyses reported in Blomberg et al. (2012) by the following: 1) inclusion of two additional year of data [i.e., 2011-2012]; 2) inclusion of additional predictor variables; and 3) including increased model parameterization that allowed for lek specific estimates of per capita recruitment and lambda. Additional predictor variables included various metrics of vegetation composition (e.g., total percent vegetation cover, percent sagebrush cover) derived from vegetation surveys generated from random locations within 5km from each lek. Each lek was assigned the average value for each vegetation variable from all random surveys completed within 5km from the lek.

Table S7. Performance of all Pradel models used to assess the influence of environmental characteristics on per capita recruitment in Eureka County, NV, 2003-2012.

Model[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
r(Prec * WF_{1000} + TC + Elev)	0.00	1.00	35	6414.16
r(Prec + TC + Elev + WF_{1000})	26.67	0.00	34	6442.98
r(Prec + PC + Elev)	27.38	0.00	33	6445.82
r(Prec + TC + RD + FRich + WF + FC)	28.65	0.00	36	6440.67
r(Year + TC + FRich)	29.65	0.00	37	6439.52
r(Prec + TC + FRich)	30.21	0.00	33	6448.66
r(Year + TC + WF_{1000})	32.06	0.00	36	6444.08
r(Year + Lek)	32.40	0.00	43	6429.29
r(Year + TC + FC)	32.54	0.00	37	6442.41
r(Year + TC)	33.06	0.00	36	6445.08
r(Prec + TC + WF_{1000})	34.21	0.00	33	6452.65
r(Year + TC + SH)	34.85	0.00	37	6444.72
r(Year + Elev)	42.08	0.00	36	6454.10
r(Prec + Elev + WF_{1000})	45.49	0.00	33	6463.94
r(Year + WF_{1000})	46.39	0.00	36	6458.41
r(Year + RD)	49.07	0.00	36	6461.09
r(Year + FC)	49.54	0.00	36	6461.56
r(Year + SH)	50.47	0.00	35	6464.63
r(Lek)	55.80	0.00	39	6461.35
r(Year + FRich)	60.34	0.00	36	6472.36

r(Year)	61.76	0.00	34	6478.06
r(Year + DSpring)	61.93	0.00	36	6473.95
r(Year + FH)	62.24	0.00	36	6474.26
r(Prec)	62.47	0.00	31	6485.18
r(Year + RGH)	62.50	0.00	36	6474.52
r(Year + Pop)	63.04	0.00	36	6475.06
r(Year + GC)	64.40	0.00	36	6476.42
r(Year + TSC)	64.93	0.00	36	6476.95
r(Year + SC)	65.00	0.00	36	6477.02
r(Year + NSC)	65.10	0.00	36	6477.12
r(Year + GH)	65.22	0.00	36	6477.24
r(Elev)	72.35	0.00	31	6495.05
r(.)	84.10	0.00	30	6508.93

[a] Model selection notation follows Burnham and Anderson (2002). All models had identical constraints on survival and detection that allowed survival to vary by year (no. par = 9) and detection to vary by year (no. par = 10) and lek (no. par = 10). Elev Horizontal cover variables included average non-sagebrush shrub cover (NSC), average sagebrush shrub cover (SC), average total shrub cover (TSC), average forb cover (FC), average grass cover (GC), and average total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represents average forb taxa richness across all vegetation surveys associated with each lek. (.) denotes intercept-only model. All variables were z-standardized prior to analysis.

Table S8. Performance of all Pradel models used to assess the influence of environmental characteristics on population growth in Eureka County, NV, 2003-2012.

Model[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
λ(TC + Prec * WF + Elev)	0.00	0.37	35	6404.81
λ(TC + RD + Prec * WF + Elev)	0.69	0.26	36	6403.35
λ(TC + RD + Prec * WF)	0.79	0.25	35	6405.59
λ(TC + RD + Prec * WF + DSpring + Elev)	2.37	0.11	36	6405.03
λ(FC + Prec * WF + DSpring + Elev)	9.83	0.00	35	6414.64
λ(FC + SH + Prec * WF + DSpring + Elev)	11.86	0.00	36	6414.52
λ(WF * Prec + Elev)	12.23	0.00	34	6419.18
λ(WF * Prec)	25.70	0.00	33	6434.79
λ(Elev * Prec + WF)	31.28	0.00	34	6438.22
λ(Lek + Prec)	39.80	0.00	41	6431.67
λ(TPC + Prec + RD)	41.11	0.00	33	6450.19
λ(TPC + Prec + RD + WF)	41.72	0.00	34	6448.66
λ(TPC + Prec)	42.29	0.00	32	6453.50
λ(TPC + Prec + RD + WF + DSpring)	43.40	0.00	35	6448.21
λ(Year + Lek)	52.25	0.00	48	6428.83
λ(Elev + Prec)	53.35	0.00	32	6464.57
λ(Lek)	56.03	0.00	40	6450.07
λ(TPC)	58.01	0.00	31	6471.36
λ(Year + Elev)	65.32	0.00	39	6461.51
λ(Prec)	65.38	0.00	31	6478.73

λ(Elev)	68.75	0.00	31	6482.09
λ(Slope)	69.42	0.00	31	6482.76
λ(SH)	71.73	0.00	31	6485.08
λ(FH)	76.20	0.00	31	6489.54
λ(RD)	76.35	0.00	31	6489.70
λ(FC)	76.73	0.00	31	6490.07
λ(Year)	77.50	0.00	38	6475.86
λ(Year + WF)	79.15	0.00	39	6475.35
λ(.)	80.20	0.00	30	6495.67
λ(DSpring)	80.28	0.00	31	6493.62
λ(FRich)	81.75	0.00	31	6495.09
λ(SC)	82.01	0.00	31	6495.36
λ(WF)	82.06	0.00	31	6495.41
λ(GC)	82.08	0.00	31	6495.42
λ(TSC)	82.11	0.00	31	6495.45
λ(RGH)	82.11	0.00	31	6495.46
λ(NSC)	82.29	0.00	31	6495.64
λ(GH)	82.31	0.00	31	6495.66

[a] Model selection notation follows Burnham and Anderson (2002). All models had identical constraints on survival and detection that allowed survival to vary by year (no. par = 9) and detection to vary by year (no. par = 10) and lek (no. par = 10). Elev Horizontal cover variables included average non-sagebrush shrub cover (NSC), average sagebrush shrub cover (SC), average total shrub cover (TSC), average forb cover (FC), average grass cover (GC), and average

total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represents average forb taxa richness across all vegetation surveys associated with each lek. (.) denotes intercept-only model. All variables were z-standardized prior to analysis.

SUPPLEMENTAL MATERIAL – B

JAGS Code:

SUPPLEMENTAL MATERIAL – C

JAGS Code

Running Head: Influence of power lines on sage-grouse

Effects of transmission lines on demography and population dynamics of greater sage-grouse (*Centrocercus urophasianus*)

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ABSTRACT

Energy infrastructure has been associated with altering wildlife community dynamics by influencing survival, reproduction, and movements of individuals. Power lines, specifically, may indirectly impact habitat selection, beyond the immediate footprint of the corridor, through avoidance behaviors related to increased harassment of predators that are positively associated with elevated structures. In addition to avoidance responses, power lines may indirectly suppress various vital rates for certain species as a function of increased predator abundance or predator foraging performance along power line corridors. Greater sage-grouse (*Centrocercus urophasianus*), a species of conservation concern across western North America, have been suspected to be indirectly affected by power lines related to changes in predator dynamics associated with power lines. Previous studies, however, have failed to provide evidence regarding the causal mechanism directly influencing vital rates, nor have they controlled for variation in demographic rates related to environmental heterogeneity. Here, our primary objective was to assessing the influence of power lines on multiple sage-grouse vital rates, based on Greater sage-grouse and Common raven (*Corvus corax*) demographic data collected from 2003-2012 in central Nevada, that accounted for various sources of underlying environmental heterogeneity. We focused primarily on a single transmission line that was constructed at the beginning of our monitoring efforts, however, we also determined if similar patterns were observed with all other nearby power lines. We found that numerous demographic rates (e.g., nest site selection, nest survival, recruitment, and population growth) were indirectly affected by power lines, and that these negative effects were predominantly explained by variation in Common raven abundance or distribution. More importantly, we found that latent environmental heterogeneity in this system, if unaccounted for, could either mask or exacerbate the negative

effects attributed to power lines for half of the analyses considered, highlighting the importance of both study and analytical design.

Keywords: power lines, indirect anthropogenic effects, sage-grouse, common ravens, elevated structures, environmental heterogeneity

INTRODUCTION

Energy infrastructure has been associated with altering wildlife population dynamics by influencing survival, reproduction, and habitat use, as well as the spread of invasive species and acerbating habitat fragmentation (Naugle et al. 2011a, Northrup and Wittemyer 2013). Overhead power lines, specifically, can negatively influence wildlife populations directly through the immediate loss of habitat (i.e., the physical footprint of power line towers and line rights of way; Jones et al. 2015) or increased mortality (e.g., bird collisions with guy wires, towers, or lines; Bevanger 1998, Janss 2000, Bevanger and Broseth 2001, Loss et al. 2014). Power line towers, however, may also enhance habitat for some organisms by creating nesting (Steenhof et al. 1993, Howe et al. 2014) and perching habitat for bird species, such as raptors and ravens (Coates et al. 2014b). Additionally, construction and tower footprints can disturb the underlying soil and vegetation, promoting the spread of non-native species (Lathrop and Archbold 1980). Although less studied, power lines are hypothesized to indirectly impact habitat selection through avoidance behaviors beyond the physical footprint of the structure potentially related to the increased presence of electromagnetic fields (Balmori and Hallberg 2007), avoidance of elevated structures, or increased harassment of predators associated with elevated structures (Pruett et al. 2009, Silva et al. 2010).

In addition to avoidance responses, power lines may indirectly suppress various vital rates [e.g., nest success (DeGregorio et al. 2014); adult survival (Hovick et al. 2014)] for certain species as a function of increased predator abundance or predator foraging behavior (Plumpton and Andersen 1997) along power line corridors. Beyond species-specific susceptibilities, the overall impact of power lines on wildlife populations may be influenced by surrounding environmental characteristics. For example, relative to woodlands, transmission lines may have a

85 greater effect in open habitats (e.g., shrub- or grasslands), which may be related to differences in
86 flight behavior (Rollan et al. 2010), power line visibility (Benitez-Lopez et al. 2010), or changes
87 in local predator densities (Howe et al. 2014).

88 Placement of power lines on the landscape is not random, as it is influenced by local
89 topography and geology (Vajjhala and Fischbeck 2007). In the absence of conservation
90 constraints utility corridors are typically placed along least cost routes, which usually minimize
91 changes in slope and elevation (Bagli et al. 2011). This non-random distribution of power lines
92 across a landscape, results in covariance between proximity to, or density of, power lines and
93 other environmental features (e.g., elevation, slope, hydrology) that may influence the structure
94 of surrounding habitat, thereby complicating assessment of impacts of power lines themselves.
95 For example, changes in demographic rates in proximity to a power line could result from a
96 gradient in habitat features, rather than an impact of the line itself but such potential covariances
97 between environmental conditions and anthropogenic disturbances are often ignored.

98 Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are of
99 conservation concern that have been negatively influenced by anthropogenic disturbances,
100 including energy development and its supporting infrastructure (Naugle et al. 2011b, Hovick et
101 al. 2014). Sage-grouse are endemic to sagebrush (*Artemisia spp*.) ecosystems of western North
102 America (Connelly et al. 2011), which are characterized by large expanses of woody shrubs,
103 with trees occurring in either low densities or localized patches. In these systems, anthropogenic
104 structures including utility lines can provide novel perches or nest sites otherwise unavailable in
105 the local landscape (Steenhof et al. 1993, Coates et al. 2014b, Howe et al. 2014).

106 Although sage-grouse, like other Galliformes, are susceptible to fatal collisions with
107 power lines (Borell 1939, Bevanger 1998), numerous telemetry based studies (Connelly et al.

2000, Beck et al. 2006, Blomberg et al. 2013a, Dinkins et al. 2014b) have reported low numbers of bird strikes of radio-marked individuals, which suggest this source of mortality is unlikely to be meaningful at the population level. Site-specific mortality may be appreciable, however, if elevated structures are placed perpendicular to a corridor of high sage-grouse use during crepuscular periods (Stevens et al. 2011). Recent work has suggested that indirect effects of elevated structures, such as either causing avoidance of habitat near lines (Doherty et al. 2008, Dinkins et al. 2014b), or lower vital rates due to increased predation (Ellis 1984, Bui et al. 2010), may important at the population level. Sage-grouse and other grouse species have been reported to avoid habitat near elevated structures, primarily other types of energy infrastructure (Doherty et al. 2008, Pruett et al. 2009, Silva et al. 2010, Hovick et al. 2014, Lebeau et al. 2014). Authors have speculated that the perceived threat of predation associated near power lines may explain this potential avoidance of habitat (Hall and Haney 1997, Braun 1998, Holloran et al. 2015).

Common ravens (*Corvus corax;* hereafter, raven) are important predators of sage-grouse nests and chicks throughout the species range (Coates et al. 2008, Hagen 2011, Lockyer et al. 2013). Raven populations have steadily increased across western North America over the last 50 years, associated with increases in anthropogenic subsidies (Bui et al. 2010, Webb et al. 2011). Power poles, and other elevated structures have increased nesting substrate in shrublands and grasslands where nest sites are typically less abundant (Steenhof et al. 1993, Howe et al. 2014). Consequently, raven densities are higher near elevated structures compared to the surrounding landscape (Knight and Kawashima 1993, Coates et al. 2014b). Therefore, we expect that effects of power lines on sage-grouse habitat use or reproductive success should depend on raven abundance near power lines.

Relatively few studies have addressed impacts of elevated structures on sage-grouse (e.g.; Johnson et al. 2011, Dinkins et al. 2014a) , in contrast to the case of oil and gas development (e.g.; Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2010, Naugle et al. 2011a, Fedy et al. 2015, Holloran et al. 2015). Effects of oil and gas development cannot be extrapolated to those of utility lines because the former is often associated with substantial human activity and noise (Blickley et al. 2012) and the infrastructure differs between the two kinds of disturbance (Copeland et al. 2011). Although some studies have reported negative effects of distances from elevated structures on individual vital rates (e.g., adult survival, nest success, brood survival; Dinkins et al. 2014, Lebeau et al. 2014), these studies have not generally controlled for confounding effects of variation in habitat. Additionally, no studies have causally linked utility lines, predator abundance and behavior, with sage-grouse demography and population trajectories (Hagan et al. 2011). Furthermore, large-scale patterns in population dynamics in relation to utility lines are not consistent (Johnson et al. 2011, Wisdom et al. 2011).

As avoidance of habitat near power lines is the most consistently reported effect, the lack of evidence for negative effects of power lines on vital rates may be may be related to reduced statistical power owing to low numbers of individuals using habitat near power lines (Kirol et al. 2014). A corollary is that potential negative effects of power lines are partially mediated by sage-grouse behavior, and the absolute cost of power lines on the landscape is related to the extent of avoidance. Interpreting previously reported patterns in habitat use or reproductive success related to power lines are complicated by the fact that earlier studies did not control for potential confounding habitat effects. Therefore, we cannot be certain that negative effects of power lines are not an artifact of an association between location of utility lines and habitat quality (see Fig. 1 for a reconstruction analysis of data originally presented in Hall and Haney 1997) or spatial

153 autocorrelation (e.g., including multiple individuals from a single breeding area; Gillan et al.
154 2013).

155 Here, we define transmission line as any overhead structure that is capable of transmitting
156 voltages > 69 kV (Hamilton and Schwann 1995), and overheard structures transmitting < 69 kV
157 as subtransmission and distribution lines. We use the term 'power line' to refer to all elevated
158 energy transmission structures (i.e., transmission, subtransmission, and distribution lines)
159 regardless of voltage. Our primary objective was to assess the influence of power lines on
160 multiple sage-grouse demographic rates after accounting for other sources of environmental
161 heterogeneity in demography. Our goal was to provide as complete an assessment as possible of
162 influences of utility lines on population dynamics of sage-grouse. We used ten years of data on
163 sage-grouse demography following construction of a 345 kilovolt transmission line in central
164 Nevada in our assessment. Because recent studies have indicated that impacts of utility lines on
165 grouse may occur largely through the association of avian predators with such lines (Doherty et
166 al. 2008, Lebeau et al. 2014, Fedy et al. 2015, Holloran et al. 2015), we also determined if
167 variation in sage-grouse reproductive success was related to raven abundance or distribution.

168 **STUDY AREA**

169 The study site was located in east central Nevada within Eureka County (Fig. 2). The
170 study area encompasses approximately 7000 km^2 of sagebrush steppe and pinyon-juniper
171 mountain ranges. Within this system, sage-grouse occur in habitat that varies along an elevation
172 gradient. At lower elevations (< 2000m), the shrub community is dominated by Wyoming big
173 sagebrush (*Artemisa tridentata wyomingensis*), with localized patches of black sagebrush (*A.*
174 *nova*) and basin big sagebrush (*A. tridentata tridentata*). Rubber rabbitbrush (*Chrysothamnus*
175 *nauseosus*), greasewood (*Sarcobatus vermiculatus*), and scattered Utah juniper (*Juniperus*

176 *osteosperma*) were also relatively common. At higher elevations (> ~2000m), the dominant
177 shrub community is a mixture of mountain big sagebrush (*A. tridentata vaseyana*) and low
178 sagebrush (*A. arbuscula*), with some intermixed common snowberry (*Symphoricarpos albus*),
179 western serviceberry (*Amelanchier alnifolia*), and bitterbrush (*Purshia tridentata*). Large
180 expanses of singleleaf pinyon (*Pinus monophylla*)/Utah Juniper forest often occurs at mid-
181 elevation sites between the low and high elevation sagebrush communities. Structure and
182 composition of understory vegetation, primarily grasses and forbs (e.g., richness and biomass)
183 was also positively correlated with elevation (Gibson et al. in review-a). Common annual and
184 perennial forb taxa included phlox (*Phlox* spp.), lupine (*Lupinus* spp.), mustard (*Descurainia*
185 spp.), and vetch (*Astragalus* spp.). Common grasses consisted of blue grass (*Poa* spp.),
186 cheatgrass (*Bromus tectorum*), crested wheat (*Agropyron cristatum*), Indian rice grass
187 (*Achnatherum hymenoides*), and squirrel tail (*Elymus elymoides*). Patterns in seasonal habitat use
188 (Atamian et al. 2010) and genetic structure (Jahner et al. in review) indicate that sage-grouse in
189 our study system can be classified into at least two distinct populations: individuals associated
190 with the Cortez mountains or the Roberts Creek Mountain (hereafter Cortez or Roberts).

191 *Falcon-Gondor transmission line*

192 In fall 2003, Sierra Pacific Power Company (now NV Energy) began construction of a
193 345 kilovolt transmission line between the Falcon and Gondor (hereafter FG transmission line)
194 substations located in White Pine and Lander Counties, respectively, in Nevada, U.S.A.
195 Construction of the FG transmission line was completed in the spring of 2004 and was energized
196 in May of that year. The completed FG transmission line was approximately 299km long and
197 consisted of 734 towers that varied in height (23-40m), and design (2-pole H-frame or 3-pole
198 guyed angle-transposition towers; Fig. 3), depending on topography and projection. Towers in

areas of historic or active sage-grouse habitat were fit with experimental perch deterrents that were fixed on sections of towers where avian predators were most likely to perch. Deterrents consisted of 16-gauge steel in an inverted-Y design fit on horizontal tower arms, and steel plate deterrents fit on the tops of vertical tower arms and crossarms (Lammers and Collopy 2007).

The FG transmission line runs through the middle Eureka County's prime sage-grouse habitat (M. Podborny, NDOW, personal communication). We defined our study area as anything within a 10km buffer surrounding the minimum convex-hull polygon that encompassed all female sage-grouse telemetry locations from 2003–2012 (Fig. 2). The study area includes 134km of the FG transmission line and focuses primarily on individuals associated with 13 leks at various distances from the FG transmission line. Six study leks were within 5km of the Falcon-Gondor transmission line, and ten study leks were within 10km of the Falcon-Gondor transmission line.

Study lek descriptions

We monitored 10 to 13 breeding areas, or leks located within 20 km of the Falcon-Gondor transmission line (see below) from 2003-2012. Male sage-grouse establish territories within these leks and attempt to attract potential mates with a mating display (Wiley 1973). Lek activity began in late February and ceased in mid-May, with male lek attendance peaking in both early and late April associated with high female attendance (Blomberg et al. *unpublished data*). Leks were selected by evaluating previously collected data from the Bureau of Land Management (BLM) and the Nevada Department of Wildlife (NDOW). Five leks were monitored by NDOW and BLM over the past thirty years. Long term data show male lek attendance at these leks has declined over the last five decades (NDOW *unpublished data*). Although long term lek monitoring suggested that populations stabilized during the 1990's, the

abundance of sage-grouse within this system declined over the course of this study (Gibson et al. 2014), similar to population trends across the southern Great Basin (Garton et al. 2011, Garton et al. 2015).

Other anthropogenic disturbances

Other power lines

The study area also included approximately 243km of additional power lines, of which 42km were associated with a second transmission line, and 201km were either subtransmission or distribution lines. The other transmission line, which runs east-west through the southern portion of the study system, was substantially older (~circa 1980), but of similar design and structure to the FG transmission line. Subtransmission and distribution lines were similarly older, and were typically one- or two-pole structures that facilitated transmission to mines, ranches, and residences. Eight study leks were within 5km of any power line.

Highways and roads

The study area included two major paved roads, which were both two lane state highways that intersected in the southeast portion of the study area, and combined were 162km in length. Four study leks were within 5km of a highway. There was an additional 430km of maintained gravel or dirt roads, and 3,500km of unmaintained single-lane dirt access roads (two-tracks). All study leks were within 5km of a maintained or unmaintained road. In this system, each transmission line corridor ran parallel (although not always immediately adjacent to) one of the two previously established highways, creating spatial correlation between highways and transmission lines.

Mining

Mineral extraction (primarily gold or other rare earth metals) is common throughout northern Nevada. Approximately 46,000 ha (~6.6%) of the study system was currently, or had recently been, within the physical footprint of mining activities (Nevada Department of Wildlife, *unpublished data*). The level of disturbance associated with mining is spatially heterogeneous, and ranges from complete loss of functional habitat (e.g., creation of open pit mines) to minor disturbances (e.g., increased noise; Blickley et al. 2012). However, it was unclear what percentage of the study area was comprised of actual surface disturbance, versus less intrusive activities (e.g., prospecting) or previously mined areas with no current disturbance. Additionally, the area associated with mining was not completely additive to other forms of disturbance, as the acreage associated with mining typically included roads, power lines, and/or recent wildfire.

Wildfire

Wildfires have disturbed approximately 85,000 ha (~12.1%) of our study system since 1999, with 90% of this disturbance occurring before the onset of this study. Burned areas were primarily colonized by exotic grasses, predominantly cheatgrass, but also planted crested wheatgrass. Exotic grasslands typically suppress the suppresses establishment of native vegetation (Miller et al. 2011), and are negatively associated with sage-grouse population trajectories (Blomberg et al. 2012).

Ranching and agricultural use

The majority (88%; ~619,000 ha) of the study system was federal lands that were primarily managed by the BLM. Livestock grazing (primarily cattle and to a lesser extent sheep) were prevalent on BLM managed lands. Of the ~ 82,500 ha of study system under private ownership, approximately 10,500 ha (1.5% of total study area) had been converted to cropland

agriculture, primarily irrigated fields planted with alfalfa (*Medicago sativa* cv.) or grass hay. These areas were generally located in the southeastern portion of the system. Alfalfa fields that bordered by sagebrush were used as early brood rearing habitat, however radio-marked sage-grouse were never observed in the interior of fields (D. Gibson et al., *unpublished data*). The remaining private land holdings were primarily in a checkboard pattern intermixed with BLM land localized in the northern portion of the study system, or were associated with mesic, lower elevation sites scattered throughout the system, often associated with grazing operations.

METHODS

Field Methods

Mark-Capture

We captured male and female sage-grouse on, or near, 10 to 13 leks during the mating season (March-May) from 2003–2012 and in seasonal high-elevation habitat during the fall from 2005–2011. Upon capture, birds were aged, sexed, weighed, and a series of morphological measurements were taken (i.e., length of 1st primary, 5th primary, wing chord, tarsus, foot, and number of tail feathers). Each female was banded with a size 14 National Band and Tag metal band, and most females were equipped with either a 22g or 12g radio with necklace-style attachment (A4060, A3950, Advanced Telemetry Systems, Isanti, MN). Radios were equipped with a mortality sensor that doubled the signal pulse rate if the transmitter remained motionless for >8 h. Each male was banded with a size 16 National Band and Tag metal band, and all adults and those young that were large enough were banded with a colored plastic tarsal band engraved with a unique three character alpha-numeric code for re-sighting during lek observations (described below). Individually marked male sage-grouse were re-encountered by recapture, re-

sightings of tarsal bands during morning lek observations, or from images of tarsal bands recorded by trail cameras placed on leks (Gibson et al. 2013).

Lek observations

Each study lek was observed approximately once weekly during the mating season (March- May) from 2003–2012. Observers arrived on the leks 1/2 hour before morning nautical twilight, and remained until strutting activity ceased or birds dispersed. During these periods, observers monitored leks from trucks or mobile blinds with spotting scopes and binoculars. We occasionally included a mobile observation tower to facilitate band reading where terrain permitted and vegetation characteristics required it. Observers counted the number of males and females, marked and unmarked, on leks every 30 minutes during each observation period. Observers also recorded individual tarsal band codes (resights) and behavioral interactions with potential predators. Observers recorded all disturbances at the lek, which included sage-grouse reaction, time of day, number of birds affected, and type of predator/disturbance (e.g., visual or audible detection of a mammalian or avian predator).

Female monitoring

Radio-marked females were located at least once weekly during the nesting season (end March – mid June) from 2003–2012 using a handheld receiver and YAGI antenna. Once nesting was confirmed, observers visited nests approximately twice a week until the nest hatched or failed. Our full nest monitoring protocols are described in (Gibson et al. 2015). From 2005–2012, we continued to monitor females that successfully hatched a nest to assess brood status and habitat use. We assessed brood foraging habitat by locating brood-rearing females weekly during diurnal hours (i.e., 700–1700). We monitored each female's current brood status through weekly

brood flush counts conducted the morning after the diurnal location. We performed weekly flush counts until 42 days after hatch (hereafter, pre-fledging period) or after two weeks of consecutive counts of zero chicks, which ever occurred first. Our full brood monitoring protocols are described in (Gibson et al. in review-b). After all radio-collared females had fledged young or failed, we continued to monitor survival of radio-marked females approximately once a month using fixed-wing aircraft.

Vegetation surveys

We measured vegetation at each nest site, weekly diurnal brood locations, and at random points temporally associated with the nesting and brood rearing periods, which all followed similar protocols. We measured nest vegetation at all monitored nest sites within 3 days of either the predicted or actual date of hatch. Nest site vegetation was sampled along 10m intersecting transects centered at the nest bowl (Gregg et al. 1994), using the line-intercept (Canfield 1941) and Daubenmire (1959) frame methods. The line-intercept method was used to estimate total shrub cover, sagebrush shrub cover, and non-sagebrush shrub cover. We used Daubenmire frames placed along each transect to classify ground cover of grass, forbs, and total cover (grass, forb, and shrub). See Gibson et al. (2015) for detailed nest vegetation protocols. We also measured vegetation at each weekly diurnal brood location, which were conducted approximately one week after the initial brood location, and centered approximately (± 5 m) where the brood was located the week prior. Brood vegetation surveys followed the same protocols as nest vegetation surveys, however from 2008–2012, brood vegetation surveys were sampled along 20m intersecting transects. See Gibson et al. (in review-b) for detailed brood vegetation protocols. Lastly, we randomly selected four points each year for each monitored study lek that were generated within a 5 km buffer around each study lek. We began random

vegetation surveys after the first predicted hatch date in a given year, and completed them haphazardly throughout the nesting and brood rearing seasons to coincide with sampling at nest and brood locations.

Raven monitoring

During March-May from 2003–2012, we performed avian point counts along three transects (i.e., south, central, north) that paralleled the Falcon-Gondor transmission line corridor. The average distance between two points within a single transect was 3.36 km (sd = 0.70 km). The north and central transects had 9 points, and the south transect had 5 points. The nearest points in the central and north transects were 10.9 km apart, and the nearest points in the the central and south transects were 20.2 km apart. Observers attempted to survey each transect once every 10 days from March - May. We alternated transect start times (between 1 hour after sunrise and at 13:00 hrs), and survey start point (between northernmost and southernmost point of a transect). Surveys were not conducted if there was precipitation, fog, or if wind speeds exceeded 19 km/hr. Observers spent 10 minutes at each point, identified all observed raptor and corvid species, number of individuals, and whether the observed individual was within 400m of the line or beyond.

Quantitative Methods

Sage-grouse demographic processes

We estimated the following demographic rates from radio-telemetered female sage-grouse data: 1) nesting propensity; 2) re-nesting propensity; 3) nest site selection; 4) nest success; 5) brood site selection; 6) pre-fledging chick survival; and 7) adult female survival. We estimated the following demographic rates from capture-mark-recapture data of male sage-

grouse: 1) adult male survival; 2) male lek movements; 3) per capita recruitment; and 4) population growth. Each analysis is outlined in detail within the Demographic Analyses sub-section.

Approach to inference

The underlying hypothesis for each analysis was that a particular demographic rate (e.g., nest success, female survival) was not influenced by an individual's proximity to either the FG transmission line or any other power line. Environmental impact studies often employ a Before-After-Control-Impact (BACI) study design to account for correlations between various temporal or spatial variables and the potential disturbance. Such an experimental design presumably accounts for factors that may otherwise mask or inflate impacts. Although BACI study designs are ideal for disentangling variables that are spatially confounded (Green 1993), the pace at which disturbances occur, even those of anthropogenic origin, often occur prior to sufficient data collection, which precludes BACI approaches. In such cases, post-disturbance data sampled across sufficient spatial and temporal scales represent the only viable approach to assessing disturbance (Johnson et al. 2005).

We developed a two stage approach for assessing impacts of power lines on sage-grouse habitat use and demography. First, we developed functional relationships between habitat variables (e.g., elevation, shrub cover, etc.) and the response variable of interest (e.g., daily nest survival), which allowed us to establish a predictive surface for each response variable for the entire study area based entirely on features of the natural environment. We refer to values from this surface as reference values, as they represent estimates of demographic rates based solely on features of the natural environment. Second, we compared the predicted value of each response variable to the estimated value, including effects of distance to anthropogenic features in models.

The second set of models allowed us to assess the impact of anthropogenic features on potential demographic rates, while controlling for habitat and other environmental effects. Spatial correlation between anthropogenic features and habitat variables has the potential to render our approach conservative but the approach we adopted produces less biased assessments of the impacts of anthropogenic disturbance than approaches that do not account for effects of habitat.

For this study, a BACI study design was not possible because the period between permitting and construction of the FG transmission line did not allow for adequate collection of pre-construction data. Additionally, other anthropogenic disturbances (e.g., highways, other transmission lines), as well as other natural environmental variation (e.g., elevation, Fig. 4), were associated with the location of power lines. Therefore, our modeling approach had to account for potential correlations between an individual's distance from all power lines and other confounding sources of variation. Although modeling interactions between covariates can be an appropriate method for accounting for correlations in models with a few covariates, complex models with numerous parameters and multiple interactions are both difficult to interpret and are sensitive to sparse or outlier data (Zuur et al. 2010).

Accounting for confounding sources of variance in demographic data

Our approach to account for demographic heterogeneity among individuals, while minimizing the number of estimated parameters and interactions among parameters, was to use the parameter coefficients from the most competitive model structure that did not consider the distance from the FG transmission line covariate, to create a reference value, and use this value as a weighting factor. This reference value represented the predicted demographic probability (e.g., survival) for an individual, given the characteristics of the individual and its environmental (e.g. associated habitat), in the absence of any transmission line effects. Reference values were

401 then used as an individual covariate in a second analysis where we considered a series of models
402 designed to evaluate whether an individual's proximity to a utility line influenced their
403 demographic rates, while explicitly accounting for the individual's underlying demographic
404 state.

405 Demographic analyses used to generate reference values were conducted in the Program
406 MARK (White and Burnham 1999) or in R (R Core Team 2012) using generalized linear mixed
407 effects models with the lme4 package (Bates and Maechler 2009). We primarily developed
408 analysis-specific reference values from ecological relationships based on analyses previously
409 conducted in this study system (Blomberg et al. 2012, Blomberg et al. 2013a, Gibson et al. 2014,
410 Gibson et al. 2015, Gibson et al. in review-a;b, Gibson et al. in review-c). However, we modified
411 some analyses by considering additional environmental variables that were not included in the
412 original publications. We were not able to use a uniform suite of environmental variables across
413 all analyses because spatial (e.g., landscape- versus local-scale), organizational (e.g., individual-
414 versus lek-specific) and temporal resolution (e.g., daily versus annual time-steps) varied among
415 analyses. See supplemental material for all covariates considered (Table S1) for each reference
416 value analysis.

417 *Description of primary disturbance covariates*

418 We were primarily interested in assessing if sage-grouse demographic rates varied as a
419 function of their distance from the FG transmission line. We digitized the FG transmission line
420 corridor from UTM coordinates of all tower locations in our study system, and created a spatial
421 surface that represented the Euclidian distance each pixel was from the FG transmission line
422 using the spatial analyst toolbox in ArcMap 10.0 (Environmental Systems Research Institute,
423 Redlands, CA). We used this surface to assign individuals a distance from FG transmission line

value, where assignment depended on temporal resolution of each analysis. We were also interested in whether individuals responded to a new transmission line differently than previously existing power lines, and thus we considered two power line covariates for each analysis; 1) distance from the FG transmission line; and 2) distance from any power line. We digitized all known power lines from satellite imagery, and created a spatial surface of Euclidian distances from any power line for our study system, which was assigned to each individual in each analysis. We also allowed for diminishing effects on demographic rates of distance to a power line by considering models containing both linear and quadratic effects of distance from utility lines.

Lastly, as an important hypothesis underlying the influence of power lines on sage-grouse demography is that power lines positively influence sage-grouse predators (e.g., reproductive success, foraging efficiency), we used estimates of raven abundance and raven disturbance (see below) as covariates to investigate the linkage between utility lines, the distribution and abundance of avian predators, and sage-grouse.

Raven abundance

We used a modified robust design N-mixture model in a Bayesian hierarchical framework (Kery and Schaub 2012) in JAGS accessed through program R using the rjags package (Plummer 2013) to estimate raven abundance (n), finite rate of increase (*r*), and detection (*p*) from avian point count data collected along the FG transmission line corridor from 2003–2012. We summarized point count data to represent the maximum number of ravens observed within 400m of the FG transmission line per transect survey. Each survey was assigned to a transect group (i.e., north, central, south), and to a 10-day secondary occasion based on the ordinal date of the survey (OD: 61–140; no. secondary occasions = 8) within each year, and a

primary occasion based on year (no. primary occasions = 10). For this analysis, we allowed raven populations to be open among years (primary occasions), but closed within primary occasions; however, as raven territory behavior is heterogeneous, and individuals range along a continuum from permanent residents to seasonal transients (Webb et al. 2011). We, therefore, acknowledge that we likely violated the assumption of population closure inherent to the secondary occasions of the robust design, because some counted individuals were most likely transients and thus not available for detection during all secondary occasions within a primary occasion. However, we suggest that the violation of this assumption results in our estimates of raven abundance nevertheless represent the superpopulation size, or the total number of ravens that were available for detection at least once during a single year near the FG transmission line (Kéry and Schaub 2012). Furthermore, even though the overall estimate of raven abundance shifts as a function of a models constraints on population closure, patterns in population trajectories across years (e.g., lambda), which we were primarily interested in, should remain unaffected. We report the mean and standard errors for each parameter. The model code and specifications can be found in Supplemental Material B.

Raven disturbance

We used a site-dynamic occupancy model in a Bayesian hierarchical framework (Kéry and Schaub 2012) in JAGS accessed through program R using the rjags package, based on raven observation data collected during morning sage-grouse lek observations from 2003–2012 to estimate the following: probability 1) of a lek being visited by a raven (ψ_{Dis}) in year$_t$; 2) that a lek not visited by a raven in year$_t$ would be visited in year$_{t+1}$ (γ_{Dis}); 3) that a lek visited by a raven in year$_t$ would not be visited in year$_{t+1}$ (φ_{Dis}), and 4) of detecting of a raven visitation (p_{Dis}). We summarized raven visitations recorded during lek observations as a Bournoulli

(presence or absence) response variable describing whether a lek was disturbed at least once by a raven during a morning lek observation. Each study lek was considered to be independent (no. leks = 13), and each lek observation was assigned to a to a 20-day secondary occasion based on the ordinal date of the survey (OD: 61–140; no. secondary occasions = 4) within each year, and a primary occasion based on year (no. primary occasion = 10). We used 20-day lengths for secondary periods to both increase the probability that at least one full survey per lek was completed per occasion (e.g., not cancelled due to weather) and decrease the absolute variation in survey observation length. Although both raven analysis share an assumption of closure among secondary occasions, this analysis was less sensitive to violations of this assumption, because it was highly likely that each lek was available to be visited by at least one raven during each secondary occasion. We report the mean and standard errors for each parameter. The model code and specifications can be found in Supplemental Material C

Model selection - maximum likelihood

We used an information theoretic approach to evaluate support for competitive models preformed in a maximum-likelihood framework (Burnham and Anderson 2002), and considered covariate effects to be meaningful if 85% confidence intervals of β coefficients did not overlap 0.0 (Arnold 2010). For generation of the reference values, we used an iterative process in model creation whereby we applied individual covariates to assess various potential sources of heterogeneity in each demographic rate. Covariates were added to a model one covariate at time, and those that improved model fit were retained in the model structure. Covariates that were correlated with each other (Pearson's r >0.50) were not included simultaneously in models. We then performed backwards model selection; each covariate in the current model structure was removed singularly to assess its influence on model performance in the presence of other

493 covariates. If exclusion of a single covariate improved model performance, that covariate was
494 removed from consideration. All covariates in all analyses were z-standardized (mean = 0.0, SD
495 = 1.0; White and Burnham 1999).

496 *Model selection – Bayesian hierarchical model*

497 The appropriate methods for model selection in Bayesian hierarchical model framework
498 are still under debate (Hooten and Hobbs 2015). However, we were not interested in assessing
499 model support for explanatory variables in either Bayesian analysis, but instead only interested in
500 developing less-biased estimates of raven abundance and spatial distribution. Therefore, it was
501 only necessary that our models were both realistic and reached convergence. As such, we
502 developed a series of models of increasing prior parameter complexity, and derived demographic
503 estimates from the most complex model that was both biologically reasonable and converged
504 based on Gelman's diagnostic (Brooks and Gelman 1998).

505 *Modeling power line covariates*

506 For each analysis, we considered linear effects of distance from the FG transmission line
507 and any power line. Additionally, if the underlying data was sufficient we considered the effect
508 of distance from either any power line or FG transmission line, specifically, as a non-linear
509 relationship (i.e., quadratic) or allowed for interactions between the reference valueand each
510 distance variable. Post-hoc, we report the inflection point for all supported non-linear effects of
511 distance from a power line or FG transmission line to provide an estimate of the distance at
512 which an effect began to dissipate. For analyses that measured metrics of reproductive success
513 (e.g., nesting propensity, nest success, population growth), we also considered linear and
514 quadratic effects of estimated maximum raven population size and raven disturbance as well as

interactions between raven population size or disturbance and distance from power lines. Lastly, post-hoc, for the nest site selection and nest survival models, we considered models that allowed for full annual variation in the effects of distance from the FG transmission line to assess if female nesting behavior or hatching success was influenced by annual shifts in raven population size. We considered disturbance effects to be meaningful if 85% confidence intervals of β coefficients did not overlap 0.0 (Arnold 2010).

Demographic Analyses

Nesting propensity

We used spring (April 1s –May 31st) locations from radio-marked female sage-grouse from 2003–2012 in multi-state framework in Program MARK to assess the influence of power lines on probabilities of nest initiation. We formatted encounter histories and model state specifications following methods outlined in Gibson et al. (in review-c), which used the recorded nesting state from each check of a radio-marked female to generate an encounter history for each female in each study year. In this analysis, year-specific nesting states were defined as a female not yet observed on a nest (PreNest), a female observed on her first nest ($Nest_1$), a female observed not on a nest following failure of a first nest (PostNest), and a female observed on a second nest ($Nest_2$). We were primarily interested in estimating the probabilities of transitioning (ψ_{Nest}) among nesting states, which can be used to derive an overall probability of nest initiation and re-nest initiation conditioned on failure of a first nest. We developed the reference value variable (NP) for nest initiation as an occasion specific covariate (30 2-day occasions) and included the following variables (and direction of effect): 1) male population size (-); 2) minimum female age (+); 3) minimum female age^2 (-), and 4) a quadratic time trend. The reference value variable (RNP) for re-nest initiation was modeled with no temporal variation

within years and included the following variables (and direction of effect): 1) male population size (-); and 2) total precipitation recorded for the previous year (August-July). See (Gibson et al. in review-c) for methods, parameter estimates, and model results for the reference value analysis.

For the power line component of this analysis, we calculated the average distance to the closest power line or the FG transmission line, for all unique locations for each female (i.e. a single nest was only considered once, and not for every visit) during each spring. We used these values as a covariates for both the nest and re-nest initiation parameters. We also assigned each individual a covariate that represented the estimate raven population size for that year, as well as a covariate that represented the average probability of raven disturbance associated with the study lek that a female was most often closest to each spring.

Nest site and brood site selection

We used vegetation and location data collected from nest sites, brood sites, and random locations from 2004–2012 (nest site selection) and 2005–2012 (brood site selection) to assess the influence of power lines on probabilities of habitat use during the nesting and brood rearing periods at multiple scales using resource selection functions implemented with methods described by Boyce and McDonald (1999) and Hebblewhite and Merrill (2008). We performed two separate resource selection analyses based on the spatial scale of the habitat characteristics considered for the both nesting and brood rearing periods. The local scale selection analyses considered predictor variables derived from fine-scale vegetation surveys, and the landscape scale selection analyses used predictor variables derived from more broad-scale Geographic Information Systems data. We performed each resource selection function analysis in a generalized linear mixed model framework (Zuur et al. 2009) using the lme4 package (Bates and Maechler 2010) in R. The reference value variable (Landscape Nest Site Selection) for nest site

561 selection at the landscape scale included the following variables (and direction of effect): 1) nest
562 site elevation (+); 2) slope (+); 3) slope * elevation (-); 4) amount of habitat classified as
563 sagebrush with 1000m (+); 5) distance from nearest lek (-); 6) amount of habitat classified as
564 sagebrush * distance to lek (-); 7) amount of habitat classified as pinyon-juniper woodlands (+);
565 8) amount of habitat classified as pinyon-juniper woodlands^2 (-); 9) distance from nearest water
566 source (-); and 10) distance from nearest water source^2 (-).The reference value variable (Local
567 Nest Site Selection) for nest site selection at the local scale included the following variables (and
568 direction of effect): 1) sagebrush shrub cover (+); 2) non-sagebrush shrub cover (+); 3)
569 sagebrush shrub cover * non-sagebrush shrub cover (+); 4) forb cover (+); 5) forb height (+); 6)
570 forb cover * forb height (+); 7) forb taxa richness (+); 8) live grass height (+); 9) residual grass
571 height (+); and 10) shrub height (-). See (Gibson et al. in review-a) for methods, parameter
572 estimates, and model results for the nest site selection analyses used to generate reference values.

573 The reference value variable (Landscape Brood Site Selection) for brood site selection at
574 the landscape scale included the following variables (and direction of effect): 1) nest site
575 elevation (+); and 2) slope (-). The reference value variable (Local Brood Site Selection) for
576 brood site selection at the local scale included the following variables (and direction of effect): 1)
577 non-sagebrush shrub cover (-); 2) total vegetation cover (+); 3) forb height (+); 4) forb taxa
578 richness (+); 5) live grass height (+); and 6) residual grass height (+). See Supplemental Material
579 (Tables S4-6) for parameter estimates and model results for the brood site selection analyses
580 used to generate reference values.

581 For each of power line components of these analyses, we used the distance each nest,
582 brood location, or a random location was from any power line and the FG transmission line as
583 covariates. Additionally, for the brood rearing habitat selection models, we allowed the effect of

distance from either power line covariate to vary as a function of survey date to assess if habitat selection varied as a function of brood age. Landscape brood-rearing selection models allowed for weekly variation, however we only allowed local brood-rearing selection models to vary by early and late brood-rearing, which was delineated by the median survey date. Post hoc, we estimated the effect of distance to FG transmission line variable to estimate independently for each year of the study in the landscape-level nest site selection analysis to assess how patterns in nest site selection changed over time. We only considered a year by distance from FG interaction for the landscape nest site selection analysis due to data limitations in other analyses.

Nest survival

We used the 'nest survival' module in Program MARK to model the influence of power lines on daily nest survival probabilities based on data collected from nests monitored from 2004–2012. We did not censor research related abandonments for this analysis, which biased our estimates of overall nest survival low (~0.07; Gibson et al. 2015), however, this bias should not substantially influence observed covariate relationships. The reference value variable (Success) for nest survival analysis included the following variables (and the direction of the effect): 1) percent non-sagebrush shrub cover (+); 2) percent forb cover (+); 3) average shrub height (+); 4) the amount of surrounding habitat classified as pinyon–juniper woodlands (+); and 5) the population the female was associated with [i.e. Roberts (+) or Cortez (-)]. See Supplemental material (Tables S2-3) for parameter estimates and model results for the reference value analysis.

For the power line component, we used the distance each nest was from either a power line or the FG transmission line as covariates. Post hoc, we also allowed the distance to FG transmission line variable to be estimated independently for each year of the study to assess how patterns in nest survival changed over time. We also assigned each nest a covariate that

607 represented the estimated raven population size for that year, as well as a covariate that
608 represented the average probability of raven disturbance associated with the study lek nearest to
609 the nest.

610 *Pre-fledging chick survival*

611 We used the Lukacs young survival of marked adults module (Lukacs-survival; Lukacs et
612 al. 2004)) in Program MARK to assess the influence of power lines on the pre-fledging chick
613 survival based on brood flush count and brood-site vegetation survey data collected from 2005–
614 2012. Lukacs's et al. (2004) model uses repeated counts of unmarked individuals (i.e., chicks)
615 that are completely associated with a marked individual (i.e., radio-marked female) who is
616 available for detection, to estimate apparent offspring survival (φ) accounting for imperfect
617 detection (p) of offspring. We modeled the reference value variable ($Survival_{chick}$) for the pre-
618 fledging chick survival analysis as a weekly time-varying covariate (no. weeks = 6) and included
619 the following variables (and the direction of the effect): 1) total percent vegetative cover (+); 2)
620 average grass height (-); 3) distance from spring or water source (+); 4) distance brood moved
621 during previous week (-); 5) mean maximum summer temperature (-); 6) nest site quality (+);
622 and 7) a quadratic effect (+) of minimum female age (+). Each weekly value for $Survival_{chick}$,
623 which is an interval-specific survival probability, was estimated using habitat characteristics
624 from the previous weeks brood location, as well as additive terms for current week (i.e., chick
625 age) and year. See Gibson et al. (in review-b) for methods, parameter estimates, and model
626 results for the reference value component for this analysis.

627 For the power line component, we calculated the distance a female and her brood was
628 located from either the nearest power line or FG transmission line at the beginning each week,
629 and used each of these values as a weekly time-varying covariate. Additionally, we also assigned

each brood a covariate that represented the estimated raven abundance for that year. We did not use probability of raven disturbance as a covariate in this analysis as broods tended to congregate, and were not spatially associated with leks, which together reduced variation in possible covariate values.

Adult Female survival

We used the 'nest survival' module in Program MARK to assess the influence of proximity to power lines on monthly female survival probabilities (*S*) based on year round telemetry data collected from radio-marked females from 2003–2012. We used nest survival models as they more appropriately assign timing of mortality when telemetry data is collected at irregular intervals (Dinsmore et al. 2002, Mong and Sandercock 2007, Blomberg et al. 2014). Individual encounter histories were 12 intervals (months) long, beginning March 1st in $year_t$, and terminating February 28/29th in $year_{t+1}$. Each year ($n_{years} = 10$) was defined as a group; females that were monitored across multiple years had a unique 12-occasion encounter history for each year they were monitored. We modeled the reference value variable ($Survival_{female}$) for the female survival analysis as a monthly time-varying covariate during the months we had ground-based telemetry locations (March–August; $n_{month} = 6$), and included the following variables (and the direction of the effect): 1) average monthly elevation (-); 2) minimum female age (-); 3) nest success (- ; a binomial variable (yes/no) modeled on June-July survival); and 4) brood success (- ; a binomial variable (yes/no) modeled on August survival). Elevation was the average monthly value from all telemetry locations during each monthly occasion. The reference value model also consisted of additive terms for the current season [i.e., spring (Mar-May); summer (June-July); fall (August)]. The reference value covariate was based on results published in (Blomberg et al. 2013b), but see Supplemental Material (Table S7) for model modifications.

For the power line component, we calculated the average distance a female was located from either the nearest power line or FG transmission line based on all ground-based telemetry locations collected for each female during a given month (March–August), and used each of these values as a monthly time-varying covariate. We did not assess the influence of distance from a power line or FG transmission line from the beginning of September to the end of February because we lacked precise location data for these months during all study years. Additionally, we did not use either metric of raven abundance in this analysis, as ravens are not known predators of adult sage-grouse.

Male survival and movement rates

We used the multistate robust design model in Program MARK to assess the influence of proximity to power lines on annual male survival (φ_{male}) and male lek-lek movement rates ($\psi_{movement}$) based on mark-recapture data collected from 2003–2012 during trapping events on leks (captures/recaptures) and during lek observations (resights). Encounter histories were generated from physical recaptures and band resights, and used in a two state, multistate robust design framework, where males were grouped together by lek of capture ($n_{leks} = 13$). As in Gibson et al. (2014), state transition probabilities represented the annual probability of a male moving to a lek different from it's lek of original capture. To fit criteria necessary for robust design analyses, we defined primary occasions as an annual breeding season, and subdivided each breeding season into two 35-day secondary occasions. The reference value variable ($Survival_{male}$) for the male survival analysis was based on spatial covariate values at the lek-scale (as opposed to individual), and should be interpreted as the average annual male survival for each lek. The variables in $Survival_{male}$ (and the direction of the effect) included the following: 1) lek elevation (+); 2) population the lek was associated with [(Roberts (+); Cortez (-)]; and 3) the

676 total precipitation recorded for the year prior (+). We did not calculate a reference value variable
677 for $\psi_{movement}$ as the data were too sparse to reliably assess model structures more complicated
678 than the intercept-only model. See Gibson et al. (2014) for methods, parameter estimates, and
679 model results of the reference value component of this analysis.

680 We assigned each male was assigned annual time-varying covariates that represented the
681 distance between the lek he attended in year$_t$ and the nearest power line or FG transmission line
682 to assess the influence of power lines on either φ_{male} or $\psi_{movement}$ from year$_t$ to year$_{t+1.}$ We did
683 not use either metrics of raven abundance on either φ_{male} or $\psi_{movement}$ for this analysis as ravens
684 are not known predators of adult sage-grouse.

685 *Recruitment and population growth*

686 We used robust design Pradel models in the Program MARK to assess the influence of
687 proximity to power lines on lek-specific population growth (λ) and recruitment rates (f) based on
688 male encounters from 2003–2012 during trapping events on leks. Encounter histories were
689 generated from only physical captures of males at leks that were monitored from the entire
690 length of the study (n_{leks} = 11). Similar to the multistate robust design analysis, we defined
691 primary occasions as an annual breeding season, and subdivided each breeding season into two
692 35-day secondary occasions. Additionally, both the reference value variables for λ (PopGrowth)
693 and f (Recruit) were based on spatial covariate values at the lek-scale, and should be interpreted
694 as the average demographic rate for each lek. The variables in PopGrowth (and the direction of
695 effect) included the following: 1) lek elevation (+); 2) total precipitation recorded for the year
696 prior (+); and 3) proportion of surrounding habitat converted to exotic grasslands (-). The
697 variables in Recruit (and direction of effect) included the following: 1) lek elevation (+); 2) total
698 precipitation recorded for the year prior (+); 3) proportion of surrounding habitat converted to

699 exotic grasslands (-); 4) an interaction between precipitation and exotic grasslands (-); and 5)
700 average percent vegetation cover from all random vegetation surveys performed within 5km of a
701 lek (+). The reference value models were based on results published in Blomberg et al. (2012),
702 but see Supplemental Material (Tables S8-9) for model modifications.

703 Each male was assigned annual time-varying covariates that represented the distance
704 between the lek he attended in year$_t$ and the nearest power line or FG transmission line to assess
705 the influence of power lines on λ or f between years t and $t+1$. We also assigned each male a
706 time-varying covariate that represented the estimated raven population size for that year, as well
707 as a covariate that represented the average probability of raven disturbance at the study lek each
708 male was associated with to assess whether variation in raven abundance influenced sage-grouse
709 recruitment and population trajectories.

710 **RESULTS**

711 **Descriptive Results**

712 We captured and radio-marked 361 female sage-grouse and captured and banded 988
713 male sage-grouse over the course of the study (Table 1). Over the ten year period, we did not
714 attribute any mortalities of radio-marked individuals to a collision with a power line or pole. We
715 discovered and monitored 427 nests from 249 unique females from 2003-2012, of which 138
716 nests from 116 unique females were successful. We classified 355 of the nests as first nests, 66
717 as second nests, and 6 as third nest attempts. Adults initiated 312 of the nests, juveniles initiated
718 96, and 19 nests were from unknown-age females. We monitored 120 broods after hatch from 99
719 unique females, and observed 862 chicks at hatch, of which 163 chicks were associated with
720 their mothers at approximately 6 weeks after hatch. We completed 1364 vegetation surveys, of

721 which 423 were associated with nests, 452 were associated with brood locations, and 488 were at
722 random sites. We completed 1067 lek observations at our 13 study leks ($\bar{x}$ = 8.73 observations
723 per lek per year).

724 **Quantitative Results**

725 *Raven abundance*

726 The most complex model we considered that converged allowed n (raven abundance) and
727 *r* (within-year growth rate) to vary independently among transects and years, and *p* (detection) to
728 vary independently among transects and secondary occasions, but constrained *p* to be constant
729 among years (Table 2). Raven populations in Eureka County, NV, have increased approximately
730 5-fold since the construction of the FG transmission line in 2004 (range: 69.50 – 318.39; Fig.
731 4A). On average, the annual rate of increase was 22.7 ravens/year, however this represents the
732 increase in the superpopulation of ravens, which relative to a geographic area we cannot spatially
733 delineate. Annual estimates of raven population size were used in subsequent models to assess
734 the influence of changes in common raven abundance on various sage-grouse demographic rates.

735 *Raven occupancy*

736 We had sufficient data to estimate probability of raven disturbance at 12 of the 13
737 monitored leks. After censoring data from the lek that failed to converge (i.e., Pony Express), the
738 most complex model that converged allowed ψ_{Dis} to vary independently among leks and years,
739 where γ_{Dis}, φ_{Dis}, p_{Dis} were allowed to vary independently among years, but were constrained to
740 be similar among secondary occasions and leks (Table 3). We found that, across all leks, annual
741 probabilities of raven disturbances generally increased from 2003-2012, and were positively
742 associated with our annual estimates of raven abundance (Fig. 4B; $\beta_{Abun\text{-}Occ}$ = 0.73; 85% C.I.:

743 0.38 – 1.08). Lek-specific probabilities of raven disturbances were variable across space, and
744 negatively covaried with distance from a power line or FG transmission line (Fig. 5). These
745 relationships, however, were based on limited data and were not well supported ($\beta_{Occ\text{-}Power}$ = -
746 0.046; 85% C.I.: -0.098 – 0.005; $\beta_{Occ\text{-}FG}$ = -0.044; 85% C.I.: -0.096 – 0.007) (Table Sx).
747 Nevertheless, the overall synchrony between our independently generated estimates of raven
748 abundance (i.e., abundance and disturbance rates) through time supported the use of these
749 metrics as variables in subsequent analyses.

750 *Nesting propensity*

751 Reference value variables for the nesting propensity analyses were predictive for both
752 probabilities of nest initiation (β_{NP} = 0.86; 85% C.I.: 0.76 – 0.93) and re-nest initiation (β_{RNP} =
753 0.33; 85% C.I.: 0.09 – 0.56). We found that an individual's distance from either the FG
754 transmission line or any power line did not influence her nesting propensity (Table 4); however
755 we found that probabilities of re-nesting (conditioned on initial failure) were highest in areas
756 most proximate to the FG transmission line (Fig. 6A). Annual estimated raven population size
757 was positively associated with re-nesting propensity but not nesting propensity (Fig.6B; Table 5).
758 We also found that the estimated probability of raven disturbance at the lek nearest to an
759 individual female was positively associated with nesting propensity, but was negatively
760 associated with re-nesting propensity (Fig. 6C).

761 *Nest site selection*

762 The reference value variables for the nest site selection analyses were predictive at both
763 the landscape ($\beta_{landscape}$ = 1.22; 85% C.I.: 1.13 – 1.30) and local (β_{local} = 1.24; 85% C.I.: 1.07 –
764 1.42) scales. Contrary to our hypothesis, at the landscape scale, we found support for a positive

765 linear effect of distance to any power line on nest site selection (Fig. 7A; Tables 6, 7), indicative
766 of avoidance. We also found support for a quadratic effect of distance from the FG transmission
767 line, which suggested that avoidance of the FG transmission line begins to dissipate, based on the
768 inflection point of the non-linear function, at approximately 10.5km from the line. At the local
769 scale, we found the most support for a positive linear effect of the FG transmission line on nest
770 site selection (Fig. 7B; Tables 8, 9), also indicative of avoidance behavior. We also found
771 support for a quadratic effect of distance from any power line, which suggested that avoidance of
772 power lines, based on the inflection point of the function, began to dissipate approximately
773 11.6km from the line.

774 Post hoc, we assessed whether the magnitude of the effects of distance from the FG
775 transmission line on nest site selection at the landscape scale was dependent on the current raven
776 population by developing a model that allowed for year-specific estimates of distance from the
777 FG transmission line. We found that year-specific parameter estimates for distance from the FG
778 transmission line on nest site selection positively covaried with estimated raven abundance (Fig.
779 8). This result indicates that females were more likely to nest further away from the line in years
780 with greater numbers of ravens present in the study landscape.

781 *Nest survival*

782 The reference value variable for the nest survival analysis was predictive of nest success
783 ($\beta_{success}$ = 0.27; 85% C.I.: 0.19 – 0.36). The best supported models included a quadratic effect of
784 distance from the FG transmission line on nest survival (Fig. 9; Tables 10, 11), which suggested
785 nests within 9.2km of the FG transmission line had reduced probabilities of hatching. We also
786 found support for a positive linear effect of distance from any power line on nest survival, which
787 suggested that nests distant from any elevated structures had higher probabilities of hatching. We

did not find support for a non-linear effect of distance to any power line, which is most likely related to the limited amount of habitat, and therefore nests, that were sufficiently distant from all power lines to observe a threshold. We did not find that, individually, annual raven abundance influenced nest survival, however we found support for an interaction (β_{FG}^2-$_{RavenAbun}$ = 0.21; 85% C.I.: 0.11 – 0.31) between a non-linear effect of distance to FG transmission line (β_{FG} = 0.13; 85% C.I.: 0.01 – 0.25; β_{FG}^2 = -0.17; 85% C.I.: -0.01 – -0.35) and raven abundance ($\beta_{RavenAbun}$ = -0.13; 85% C.I.: -0.27 – 0.01), which suggested nest survival near the FG transmission line was decreased when raven abundance was higher.

Post hoc, we further assessed whether the magnitude of the effects of a nest's distance from the FG transmission line was dependent on the current raven population size by developing a model that allowed for year-specific estimates of nest distance from the FG transmission line. Similar to results from the nest site selection analysis, we found that year-specific parameter estimates for distance effects nest survival positively covaried with estimated raven abundance (Fig. 8). This suggests that either the reduction in nest survival, or the distance from the FG transmission line in which nest survival was reduced, was positively correlated with annual raven abundance.

Brood site selection

The reference value variables for the brood site selection analyses were predictive at both the landscape ($\beta_{broodlandscape}$ = 0.70; 85% C.I.: 0.62 – 0.77) and local ($\beta_{broodlocal}$ = 1.40; 85% C.I.: 1.20 – 1.60) scales. At the landscape scale, we found the most support for an interaction between brood age and a quadratic effect of distance from any power line on brood site selection (Tables 12, 13), which suggested avoidance of habitat near power lines when chicks were very young. The magnitude of effect of power lines, however, declined as chicks aged (Fig. 10). We

did not find that distance from the Falcon-Gondor transmission line influenced site selection at the landscape scale. However, at the local scale, we found strong support for an interaction between chick age and a quadratic effect of distance from the FG transmission line, as well as interaction between chick age and a linear effect of distance from any power line (Fig. 11). Both effects suggested early avoidance of power lines, and that this effect dissipated as broods aged.

Pre-fledging chick survival

The reference value variable for the pre-fledging chick survival analysis was predictive of pre-fledging chick survival ($\beta_{survival\text{-}chick}$ = 0.41; 85% C.I.: 0.34 – 0.48). We found that early pre-fledging chick survival (i.e., first two weeks) was reduced near the FG transmission line (Table 14, 15). Furthermore, the effect of the FG transmission line on brood survival was greater in in habitats associated with higher probabilities of chick survival than on broods in lower quality habitat. We did not find that pre-fledging survival in later weeks (i.e., 3-6 weeks after hatch) was substantially influenced by distance from the FG transmission line. Support for an effect of distance to any power line on pre-fledging chick survival was marginal during both the early and late pre-fledging period. We did find that chick survival during the first two weeks after hatch was negatively impacted by raven abundance ($\beta_{RavenChickEarly}$ = -0.46; 85% C.I.: -0.63 – -0.28), however chick survival during subsequent weeks was positively associated with raven abundance ($\beta_{RavenChickLate}$ = 0.23; 85% C.I.: 0.07 – 0.39). We also found support for an interaction ($\beta_{Raven*FG}$ = 0.26; 85% C.I.: 0.11 – 0.41) between raven abundance ($\beta_{RavenAbundance}$ = -0.65; 85% C.I.: -0.90 – -0.41) and a non-linear effect of distance from the FG transmission line ($\beta_{FGChick}$ = 0.00; 85% C.I.: -0.12 – 0.12; $\beta_{FGChick}^{2}$ = -0.35; 85% C.I.: -0.45 – -0.25) (Fig. 12). This suggests that when raven abundance was high, chick survival was low regardless of brood location relative to the FG transmission line. However, during years of average or low raven abundances,

834 chicks further from the FG transmission line survived at substantially higher rates than chicks
835 located near the FG transmission line.

836 *Female survival*

837 The reference value variable for the female survival analysis was predictive of monthly
838 female survival ($\beta_{survival\text{-}female}$ = 0.59; 85% C.I.: 0.47 – 0.71). We found evidence of a weak
839 quadratic effect of distance from any power line on survival, however, in general, we found little
840 support for an influence of distance to the FG transmission line or any power line on female
841 survival (Fig. 13; Tables 16, 17).

842 *Male survival and lek movement rates*

843 The reference value variable for the male survival analysis was predictive of annual male
844 survival ($\beta_{survival\text{-}male}$ = 0.41; 85% C.I.: 0.25 – 0.57). We did not find that distance to FG
845 transmission line or any power line influenced male survival (Fig. 14; Tables 18, 19). Due to
846 rarity of observed movements among leks (Gibson et al. 2014), we did not estimate a reference
847 value variable for the male lek movement parameter. We found support for a marginal quadratic
848 effect of distance to any power line on male movement rates, which suggested that males
849 originally captured on leks closer to the transmission line were more likely to move to a different
850 lek than individuals from leks further away from transmission lines (Fig. 15). Overall, we did not
851 find that a lek's distance to the FG transmission line influenced male movement rates.

852 *Lek-specific recruitment and population growth rates*

853 The reference value variable for the population growth analysis ($\beta_{PopGrowth}$ = 0.42; 85%
854 C.I.: 0.35 – 0.48) was predictive of population change within our study system. After accounting
855 for the effect of surrounding habitat quality on population growth, we found leks more distant

from either the FG transmission line or any power line had higher population growth rates (Fig 16A; Tables 20, 21). The reference value variable for the recruitment analysis ($\beta_{Recruit}$ = 0.45; 85% C.I.: 0.36 – 0.54) was predictive of per capita recruitment. Overall, we found similar patterns between the recruitment and population growth analyses. After accounting for environmental conditions that influence recruitment, we found per capita recruitment was substantially higher at leks more distance from any power line (Figs 16A; Tables 22, 23). Alternatively, we did not find conclusive support for a relationship between distance of the FG transmission line and per capita recruitment.

Our findings indicated that among year estimates of population growth and recruitment were negatively influenced by annual raven abundance, and lek-specific estimates of population growth and recruitment were negatively influenced by the probability of raven disturbance at each lek (Fig. 16B). Models that included an interaction between distance from either the FG transmission line or any power line and a non-linear effect of raven abundance were supported in both analyses. Additionally, parameter estimates for distance from line variables in these interaction models were reduced, relative to the additive model, and were not supported. However, the raven abundance terms as well as the interaction between distance from line and raven abundance term were consistently supported, which suggests the negative effect of power lines on sage-grouse demographic rates were associated with raven population abundance and spatial distribution.

Influence of latent environmental heterogeneity on detection of power line effects

Numerous analyses demonstrated substantial differences in parameter estimates for distance from line covariates between models that accounted for environmental heterogeneity and those that did not. The direction of effect switched signs for a third of the analyses that

879 considered linear effects of distance to the FG transmission line (i.e., landscape-scale nest site
880 selection, nest survival, recruitment, population growth) between models that did, or did not,
881 include the reference value variable (Figs. 17, 18A,B). Additionally, confidence intervals
882 between estimates did not overlap for multiple analyses (i.e., recruitment, pre-fledging chick
883 survival, population growth, landscape-scale nest site selection). Similar inconsistencies were
884 also observed between models assessing the linear influence of distance to any power line in the
885 nest survival, recruitment, and population growth analyses. The effect of inclusion of the
886 reference value variable, however, was not consistent across all analyses, as it reduced the
887 observed negative effects of proximity to power lines (e.g., local nest site and brood selection),
888 as well as, negated support for an effect (e.g., female survival), but also suggested the existence
889 of a cryptic negative effect (e.g., nest survival, recruitment, population growth). As an example,
890 predicted nest survival based on habitat conditions were suggested, on average, to be higher near
891 power lines (Fig. 19A, B), which inhibited more simple model designs from detecting a
892 deleterious effect of utility lines (Fig. 17, 18A,B).

893 **DISCUSSION**

894 We found contrary to our initial hypotheses, that many demographic processes were
895 negatively influenced by an individual's proximity to either the FG transmission line or any
896 power line. However across the 10 year study period, we did not attribute a single mortality
897 event of a radio-marked individual to a direct collision with a power line, pole, or guy wire.
898 Although collisions between Galliformes and power lines have been suggested to be
899 disproportionately high relative to other birds (Bevanger 1998). The observed lack of mortality
900 was consistent with other long term studies that have recorded low numbers of mortalities
901 associated with power lines, relative to other sources, of radio-marked sage-grouse (Connelly et

al. 2000, Beck et al. 2006, Dinkins et al. 2014b) or other North American Galliformes (Pruett et al. 2009). Thus, effect of power lines on sage-grouse population dynamics was associated with indirect mechanisms, such as avoidance of habitat or suppressed vital rates, near power lines.

Avoidance of Habitat near Utility Lines

We found consistent support across spatial scales and seasonal habitat requirements that female sage-grouse selected habitat more distant from power lines. That is, we found that areas proximate to either the FG transmission line or any power line, which were otherwise predicted to be appropriate habitats for either nesting or brood-rearing, were less likely to used by female sage-grouse. Most notably, we found that the extent of avoidance during the nesting period was positively associated with annual raven abundance. This novel result suggests that changes in predator distribution across the landscape is the direct mechanism driving the avoidance of nesting in habitat near power lines. Raven populations have been positively associated with power lines (Knight and Kawashima 1993, Knight et al. 1995, Coates et al. 2014a, Howe et al. 2014), and sage-grouse have been found to avoid nesting in areas with high densities of avian nest predators (Dinkins et al. 2012). To our knowledge this is the first study that both demonstrates that sage-grouse avoid nesting near power lines, and that the magnitude of the avoidance is related to abundance of nest predators.

Avoidance of habitat near power lines during the nesting period was greater than during the brood-rearing period (Fig. 17). As selection for nesting habitat occurs before selection of brood rearing habitat, and support for avoidance of power lines during the brood rearing period dissipated as a function of chick age, it is likely that avoidance of power lines during the early brood rearing period was an artifact of avoidance of nesting near power lines. That is, we expect that reduced nest initiation and lower nest success near power lines would result in a distribution

of initial brood locations across a landscape that appear to reflect avoidance of power lines. We clearly cannot separate effects of lower nesting and nest success near lines from the potential that females avoided using habitats near utility lines during early brood rearing. Regardless, even in the absence of true avoidance behaviors during the brood rearing period, the combined effects of avoidance during nesting and or reduced reproductive performance near power lines results in a reduction in 'quality' of brood rearing habitat near power lines as brood rearing habitat is only functional if it is physically accessible (i.e., near successful nests) by broods (Gibson et al. in review-b) . Furthermore, as seasonal brood rearing habitat in our study system was rare (Atamian et al. 2010), and its abundance and condition influence sage-grouse chick survival (Guttery et al. 2013), which strongly influences population growth (Blomberg et al. 2012), relatively small losses of existing functional brood rearing habitat may result in substantial reductions in recruitment and population growth.

Lastly, we found support for a marginal effect of distance a lek was from any power line on the probability a breeding-aged male would move to a new lek the following year. Confidence intervals associated with these estimates were wide due to the rarity of observed lek movements within this system (Gibson et al. 2014), which also prevented us from developing more sophisticated models that could partition the direction of lek movements (e.g., towards or away from a power line) from absolute movements. Although these relationships indicate that power lines may, over time, lead to lek abandonments through habitat avoidance alone, it is far more likely extirpation of a lek would be a function of reduced recruitment of new individuals and reduced survival of adults in addition to greater male lek movement rates (Wisdom et al. 2011, Hess and Beck 2012).

Suppression of Individual Vital Rates

948 We found variable support for reductions of vital rates as a function of distance from
949 power lines. Some vital rates (e.g., nesting propensity, male survival) were not influenced by an
950 individual's distance from either FG transmission line or any power line. We found marginal
951 support for greater re-nesting rates near the FG transmission line, which was not observed with
952 other power lines. This relationship was not directly related to reduced nest survival near the FG
953 transmission line, as our model's estimates of re-nesting propensity were conditional on nest
954 failure, and as such, did not directly increase as a function of increased nest failure. However,
955 increased nest predation may result in more nests failing earlier in the nesting season, which
956 could indirectly increase re-nesting propensity as the average unsuccessful female would have
957 more time to attempt a second nest, or be in better body condition for such an attempt. Although
958 sage-grouse nesting propensity has been found to be negatively influenced by other
959 anthropogenic disturbances (e.g., oil development; Lyon and Anderson 2003), these estimates
960 were reported as apparent nesting propensity and are not directly comparable with our results
961 (Gibson et al. in review-c).

962 Nest survival, on the other hand, was negatively impacted by proximity to both the FG
963 transmission line and any power line. Similar to the pattern of avoidance of habitats near utility
964 lines for nesting, the effect of the distance to FG transmission line covariate in the nest survival
965 analysis positively covaried with annual raven abundance. Together, these results suggests that
966 females selected nesting habitat more distant from power lines, because nesting near power lines
967 resulted in reduced nest survival. Additionally, both the reduction in nest survival and the
968 amount of habitat avoided was correlated with temporal changes in raven abundance, which to
969 the best of our knowledge are the first results to also demonstrate a negative relationship between
970 raven abundance and sage-grouse reproductive success. Furthermore, we observed a sharp

971 increase in raven abundance associated with the FG transmission line corridor following its
972 construction and an increasing trend in raven abundance during our study. Having only one year
973 of pre-construction data limits our ability to draw inferences regarding raven responses to utility
974 lines but the patterns we observed are consistent with hypothesized responses of ravens to
975 elevated structures or other anthropogenic features (Knight et al. 1995, Kristan and Boarman
976 2003, Howe et al. 2014).

977 We also found reduced chick survival near the FG transmission line during the first two
978 weeks after hatch and the extent of the reduction varied as a function of raven abundance. Chick
979 survival was lower when raven abundance was higher, potentially related to increased predation.
980 Raven densities have been reported to be greater near sage-grouse brood rearing areas (Bui et al.
981 2010), indicative of increased predation pressure. However, female sage-grouse have also
982 exhibited avoidance of brood rearing habitat associated with greater raven densities (Dinkins et
983 al. 2012), which suggests behavioral mechanisms exist that reduce predation pressure.
984 Furthermore, and counterintuitively, we also found that chick survival during the end of the pre-
985 fledging period positively covaried with raven abundance, which we suspect may be related to
986 shared covariance between ravens and young-of-year sage-grouse with respect to how various
987 environmental conditions (e.g., forage conditions) affect productivity.

988 Similar to Dinkins et al. (2014a), we found a slight reduction in adult female survival for
989 females that occupied habitat associated with power lines, however we found no support for an
990 influence of power lines on adult male survival. We did not have sufficient data to estimate
991 variation in the abundances of predators of adult sage-grouse (e.g., raptors, coyotes, badgers)
992 within this system, therefore we could not design more targeted models related to adult survival.
993 Raptor abundances, however, were generally low and did not appear to increase following the

994 construction of the FG transmission line (Lammers and Collopy 2007, Gibson et al. unpublished
995 data)

996 *Did Power Lines Lead To Population-Level Effects?*

997 Although increased raven density or abundance has been associated with reduced nest
998 survival across many taxa (Andren 1992, Kurki et al. 1997, Klausen et al. 2010), overall, support
999 is lacking for population-level effects of ravens on avian population trajectories in general
1000 (Madden et al. 2015). We found that both habitat use (e.g., nest and brood site selection) and
1001 reproductive success (e.g., nest survival, chick survival) were reduced for female sage-grouse
1002 within ~10km of any power line, and this effect was clearly linked to raven abundance. Most
1003 importantly, our male-centered analyses suggested that these negative relationships observed in
1004 the female-centered analyses led to observable reductions in both recruitment of individuals into
1005 the breeding population and population growth. We found lek-specific recruitment and overall
1006 population growth rates were reduced near all power lines, and similar to results from the female
1007 analyses, these relationships were primarily associated with raven abundance or distribution.
1008 Although, we did not find the same level of support for reductions in lek-specific recruitment and
1009 overall population growth rates as a function of distance from the FG transmission line compared
1010 to distance from any power line, the patterns were consistent. Additionally, our ability to
1011 observe a correlation between sage-grouse population trajectories and distance from the FG
1012 transmission line was reduced, as leks more distant (>10km) from the FG transmission line
1013 predominantly remained within 10 km of, and therefore negatively influenced by, other power
1014 lines (Figs. 2, 6).

1015 In summary, we found that multiple vital rates estimated from independent data sources
1016 had the same general pattern; in that vital rates were reduced near utility lines. However, support

for the distance from power line parameters waned when models also considered interactions with raven abundance or distribution. Together, these analyses indicated utility lines indirectly influenced various sage-grouse vital rates, and ultimately population growth, through the positive association of ravens with utility lines. In other words, utility lines create an artificial selection pressure on sage-grouse, which have instilled behavioral responses in sage-grouse (e.g., avoidance), however the long term consequences of this selective pressure are currently unclear.

Importance of Accounting for Environmental Conditions

Our results highlight the importance of considering the underlying, latent environmental variability when assessing the influence of anthropogenic (or other) features. Here, we observed inconsistencies in the effect size or direction of the influence of either the distance from the FG line or any utility line. Over half of the analyses supported an effect of utility lines only with the inclusion of a reference value parameter that represented variation in environmental conditions. That is, we were substantially less likely to detect impacts of utility lines when we did not control for other environmental variables. In our study, these patterns resulted from the fact that the FG transmission line (and other lines) was placed in habitats that, would otherwise, be of high quality for sage-grouse. Additionally, support for models that included interactions between environmental conditions (e.g., shrub cover) and distance from power lines suggest complex relationships exist, in which certain individuals, or individuals associated with certain environmental conditions are more, or less, affected by their proximity to a power line. Furthermore, accounting for environmental heterogeneity produced different effects across demographic analyses, even within analyses based on similar data (e.g., landscape versus local scale nest site selection), as environmental heterogeneity was observed to both mask and exacerbate effects ultimately assigned to proximity to power lines.

We suspect inconsistencies related to environmental heterogeneity were driven primarily by two mechanisms; 1) study design (i.e., sampling variance), and 2) covariance among environmental conditions (i.e., process covariance). First, contrary to the reference models assessing the influence of distance to the FG transmission line at the landscape scale, models that did not consider the reference value variable suggested individuals selected habitat closer to the FG transmission line. This, however, was most likely an artifact of study design as this study was primarily developed to assess the effects of the FG transmission line on sage-grouse demographic rates. As such, study leks were selected (and therefore females were captured) as a function of their proximity the FG line corridor relative to available area within the study system. However, if leks nearest to the FG line were over represented as study leks relative to leks more distant from the FG line (Fig 14), then regardless of the true effect of the FG transmission line on nest site selection, models based on these data would inherently suggest females were attracted to the FG line corridor (Fig 17). Alternatively, if leks had not been selected relative to their proximity to power lines, we would have expected the bias in nest site selection (tending to be nearer the line) would have disappeared. Inclusion of the reference value variable, which was based on our earlier work using widely accessible environmental data allowed us to parsimoniously account for this source of sampling variance associated with study design, and provide less biased estimates of nest site selection.

Second, we suspect covariance among distance from either the FG transmission line or any power line variables and other environmental variables both obfuscated and exacerbated the true relationships between a vital rate and distance from a power line. For example, we have illustrated that distance from power lines was correlated with site elevation (Fig. 2; Fig. 4), and that elevation was correlated with habitat characteristics that influenced certain sage-grouse

demographic rates (Gibson et al. in review-a*;* Figure S6), and therefore, was correlated with those demographic rates (e.g., nest and brood site selection, population growth, recruitment). As such, studies that have not accounted for environmental heterogeneity, in this case elevation, may not be reliable (see Fig. 1), as we have demonstrated that either type I (e.g., male survival) or type II (e.g., nest survival, recruitment) error can occur. A specific example of underlying habitat heterogeneity resulting in difficulties in interpretations was found in the nest survival analysis, where we only found support for reduced nest survival related to proximity to a power line in models that included the reference value parameter. We suspect that this was related to patches of high quality nesting habitat, which by happenstance were located relatively near the FG transmission line. In the absence of a line effect, these areas may be highly productive (see Fig. 19). However, the negative effect of its proximity to the FG transmission line negated the benefit of nesting in these habitats, and effectively reduced the spatial variability in nest survival, leading to more support for models that did not consider the effects of common ravens or power lines.

MANAGEMENT IMPLICATIONS

Here, we found support for both hypotheses (i.e., avoidance and demographic suppression) regarding the mechanisms by which power lines influence sage-grouse demographics. Additionally, we found that both the magnitude of the avoidance of utility lines, as well as the extent to which vital rates were suppressed were correlated with common raven abundance, which was, itself, positively associated with utility lines. Therefore, the geographical extent to which utility lines would negatively influence sage-grouse demographic processes is not completely generalizable as it is contingent on local raven abundance and behavior. In this system, however, we found that effects of utility lines extended at least to 10 km, which exceeds

current recommendations for reduced surface use in areas around sage-grouse leks (5-7.5km; Coates et al. 2013).

Our finding that negative impacts of the transmission line were primarily associated with raven abundance, suggests that mitigation of line effects might be accomplished by reducing raven abundance near utility lines. Installation of deterrents to perching and nesting is one approach to such reduction, although perch deterrents on the FG line were not completely effective. Active removal of ravens in the area impacted by utility lines offers another potential approach to mitigation. Across all avian taxa, predator control regimes, on average, have successfully improved individual reproductive parameters (Smith et al. 2010), and tend to be more effective if all predator taxa are removed, as reductions in predation risk from the removed species may be compensated for by increased risk from another predator (Ellis-Felege et al. 2012). Meta-analyses on the effectiveness of predator control, however, have not found that predator removal leads to observable population growth in prey populations (Cote and Sutherland 1997, Smith et al. 2010), which suggest predator-related reductions in reproductive success and survival can be compensatory, potentially related to density-dependent mechanisms that regulate population growth. The effectiveness of raven control, primarily achieved through deployment of poisoned eggs or meat, on sage-grouse demographic rates is also not conclusive (Hagen 2011). Control measures (i.e., poison baits) can effectively reduce raven populations, however numbers of ravens removed are widely overestimated (Coates et al. 2007). Additionally, it is not clear if territorial ravens, which may disproportionately contribute more to both population growth of ravens and reproductive failure in sage-grouse, are as susceptible to control measures relative to migratory or juvenile ravens (Bui et al. 2010, Dinkins 2013). Support for a positive impact of raven removal on individual sage-grouse reproductive vital rates

1109 is variable (Coates and Delehanty 2004, Dinkins 2013), however no studies have currently
1110 quantified the effect of raven removal on population growth (Hagen 2011). As such, efficacy of
1111 direct removal measures requires well designed studies to assess impacts of such removal on
1112 raven populations and sage-grouse (Hagen 2011).

1113 Perch deterrents have been extensively used to reduce the damage cause by perching
1114 birds on power line towers or surrounding structures, reduce electrocutions for species of
1115 conservation concern, as well as disconnect the positive association between avian predators and
1116 elevated structures (Lammers and Collopy 2007, Seamans et al. 2007, Lopez-Lopez et al. 2011,
1117 Dwyer and Leiker 2012). The overall effectiveness of perch deterrents on raven populations,
1118 however, is questionable as some studies have reported short term reductions in perching or
1119 habitat use related to perch deterrents (Slater and Smith 2010, Dwyer and Leiker 2012), while
1120 others failed to find discernable reductions in perching or nesting behavior related to various
1121 types of perch deterrents (Lammers and Collopy 2007, Prather and Messmer 2010). Furthermore,
1122 as we observed reductions in sage-grouse vital rates associated with the portion of the FG
1123 transmission line that was fit with perch deterrents; the use of currently available perch deterrents
1124 as a management strategy for sage-grouse was not supported, especially given their monetary
1125 cost (Dwyer and Doloughan 2014).

1126 Alternatively, mitigation strategies could involve burying existing power lines within
1127 sage-grouse habitat (Fedy et al. 2015, Kirol et al. 2015) or routing new lines through less
1128 'critical' habitat (Bagli et al. 2011). The effectiveness of these two approaches are conditioned
1129 on accurate delineations of 'critical habitat', defined as the "geographic area occupied by the
1130 species" (U.S. Department of the Interior 2014), which are abundant for sage-grouse (Aldridge
1131 and Boyce 2007, Doherty et al. 2008, Kaczor et al. 2011, Fedy et al. 2014). Both of these

measures result in non-trivial initial costs to private industry (Fenrick and Getachew 2012). However, some of these costs may be recouped as underground lines are often more reliable, less susceptible to environmental damage, and require less maintenance (Hall 2009). Furthermore, cost-benefit analyses suggest that realized cost differentials, after accounting for other costs (e.g., aesthetics, wildlife interactions, maintenance) between underground and overhead transmission lines, may be less than previously thought (Navrud et al. 2008), as such many counties in Europe have adopted this strategy (Lehman et al. 2007) . Sage-grouse have positively responded (e.g., reduced avoidance behavior, increased nest survival rates) to mitigation treatments, which included burying power lines and other reductions in surface disturbance (Fedy et al. 2015, Kirol et al. 2015). However, it is unclear what the individual response of removal of transmission towers on individual vital rates was. Additionally, these studies could not quantify the overall impact of mitigation efforts on population growth. As such, and given the costs of burying power lines, additional research is required to determine if burying power lines 1) is an effective strategy for reducing local raven population size or their effectiveness as predators; and 2) results in improved probabilities of sage-grouse population persistence.

Other possible mitigation strategies include collocating proposed transmission lines into existing power line right-of-ways. Although we doubt this approach, singularly, would reduce the influence of existing corridors on sage-grouse demographic rates, it would result in less habitat 'influenced' by a power line, relative to management plans that proposed multiple spatially independent power line corridors. Future work, however, would be needed to assess whether avian predator use of these 'super-corridors' scaled linearly with total number of perching sites, or if other mechanisms influenced its attractiveness as habitat, which would determine the overall effectiveness of this strategy. Mitigation plans should also consider

alternative designs of power lines or poles. Although the design of power lines has been shown to influence avian electrocution rates of primarily large-bodied birds (Janss 2000), studies that demonstrate power line designs with reduced surface area of potential nesting substrate (e.g., no horizontal crossbeams) are used less by avian predators relative to standard power pole line designs are lacking.

In conclusion, there remain gaps in our knowledge of the efficacy of various power line mitigation strategies for management of sage-grouse populations. As such, until the necessary research has been completed, we recommend that 1) management agencies assume a 10km area of disturbance when developing management plans for the placement of new power line corridors, and 2) preferential treatment should be given to mitigation strategies that reduce the number of elevated structures placed within 10km of critical sage-grouse habitat.

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1494 **TABLES**

1495 **Table 1.** Summary of year specific greater sage-grouse and common raven monitoring data from 2003-2012 in Eureka County, NV,

Year	No. Radio-Marked Females	Unique females that nested	Unique females that re-nested	No. Hatched nests	No. Active broods at 6 weeks	No. New Males Captured	No. Males Recaptured (unique)	No. Males Resighted (unique)	Ravens per survey point	Total Max Male Lek Count
2003	15	11	1	5	na	146	26(20)	12(11)	0.87	227
2004	21	16	3	7	na	106	43(36)	41(26)	0.41	266
2005	35	28	8	12	9	104	55(48)	37(25)	1.03	316
2006	62	41	1	20	11	134	37(35)	56(35)	1.93	423*
2007	50	25	1	10	3	113	37(30)	34(12)	2.7	224
2008	41	31	6	7	5	62	30(26)	91(45)	0.79	212*
2009	54	46	17	20	9	46	50(34)	59(23)	1.32	182
2010	68	59	18	20	10	50	35(31)	109(33)	1.49	181
2011	63	48	8	18	10	63	44(30)	107(42)	2.52	193
2012	63	49	5	19	6	68	13(12)	135(40)	2.53	206

1496 USA.

Table 2. Designation of prior information and corresponding Gelman and Rubin convergence diagnostic for Bayesian hierarchical N-mixture models used to estimate common raven population abundance from 2003-2012 in Eureka County, NV, USA.

Priors allowed to vary by:			
Abundance (*n*)	Within Year Growth Rate (*r*)	Detection Probability (*p*)	$\hat{r}$[a]
Site	Site + Primary	Site + Secondary	1.02
Site	Site	Site + Secondary	1.02
Site + Primary	Site + Primary	Site + Secondary	1.03
Site + Primary	Site + Primary	Site + Primary + Secondary	1.17
Likelihood:			
Site + Primary	Site + Primary	Site + Secondary	

[a] $\hat{r}$ represents the Gelman's convergence diagnostic (Brooks and Gelman 1998), which suggests values < 1.1 indicate parameter convergence.

Site represents three survey transects along the Falcon-Gondor transmission line corridor. Primary occasions were comprised of 10 years (2003-2012) and secondary occasions were comprised of eight 10-day intervals from ordinal date 61-140.

Table 3. Designation of prior information and corresponding Gelman and Rubin convergence diagnostic for Bayesian hierarchical dynamic site-occupancy models used to estimate the relative probability of a common raven disturbance during a greater sage-grouse lek observation from 2003-2012 in Eureka County, NV, USA.

Priors allowed to vary by:

Site Occupancy (ψ)	Site Colonization (γ)	Site Survival (φ)	Detection Probability (*p*)	$\hat{\hat{r}}$[a]
Constant	Primary	Primary	Primary	1.01
Constant	Constant	Primary	Primary	1.01
Likelihood:				
Site + Primary	Primary	Primary	Primary	

[a] $\hat{r}$ represents the Gelman's convergence diagnostic (Brooks and Gelman 1998), which suggests values < 1.1 indicate parameter convergence.

Site represents 12 study leks. Primary occasions were comprised of 10 years (2003-2012) and secondary occasions were comprised of four 20-day intervals from ordinal date 61-140. Site occupancy = probability of raven disturbance during a lek observation; Site Colonization = probability that a lek undisturbed in $year_t$ will be disturbed by a raven in $year_{t+1}$; Site Survival = probability that a lek disturbed in in $year_t$ will also be disturbed by a raven in $year_{t+1}$; Detection probability = probability of detecting a disturbance that occurred during a lek observation.

1529 **Table 4.** Performance of all multistate models used to assess the influence of power lines and
1530 common raven demographic structure on greater sage-grouse nesting and re-nesting propensities
1531 in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Nest(NP+RavenOccupancy) ReNest(RNP+RavenOccupancy)	0.00	0.31	24	47436.76
Nest(NP) ReNest(RNP+RavenOccupancy)	1.44	0.15	23	47440.22
Nest(NP) ReNest(RNP+FGLINE^2)	1.90	0.12	24	47438.66
Nest(NP+RavenOccupancy) ReNest(RNP)	2.21	0.10	23	47440.99
Nest(NP) ReNest(RNP+ RavenAbundance)	3.29	0.06	23	47442.08
Nest(NP) ReNest(RNP)	3.64	0.05	22	47444.45
Nest(NP+RavenOccupancy^2) ReNest(RNP)	4.14	0.04	24	47440.90
Nest(NP+FGLINE^2) ReNest(RNP+FGLINE^2)	4.24	0.04	26	47436.95
Nest(NP+RavenAbundance) ReNest(RNP+ RavenAbundance)	5.27	0.02	24	47442.03
Nest(NP+FGLINE) ReNest(RNP+FGLINE)	5.60	0.02	24	47442.36
Nest(NP+Raven) ReNest(RNP)	5.62	0.02	23	47444.40
Nest(NP+FGLINE^2) ReNest(RNP)	5.98	0.02	24	47442.74
Nest(NP*FGLINE) ReNest(RNP)	6.35	0.01	24	47443.11
Nest(NP+AllLines^2) ReNest(RNP)	7.11	0.01	24	47443.87
Nest(NP*AllLine) ReNest(RNP)	7.11	0.01	24	47443.87
Nest(NP) ReNest(RNP+AllLines^2)	7.55	0.01	24	47444.30
Nest(NP+AllLines) ReNest((RNP+AllLines)	7.65	0.01	24	47444.41
Nest(NP+Raven*FGLINE) ReNest(RNP+FGLINE)	9.60	0.00	26	47442.31
Nest(NP+AllLines^2) ReNest(RNP+AllLines^2)	11.02	0.00	26	47443.72

Nest(FGLINE^2) ReNest(FGLINE^2)	195.44	0.00	24	47634.10
Nest(.) ReNest(.)	195.76	0.00	20	47642.51
Nest(FGLINE) ReNest(FGLINE)	196.41	0.00	22	47639.12
Nest(AllLines^2) ReNest(AllLines^2)	198.95	0.00	24	47637.61
Nest(AllLines) ReNest(AllLines)	199.07	0.00	22	47641.78

[a] Model selection notation follows Burnham and Anderson (2002). All models constrained site fidelity, nest failure, and re-nest failure to be constant among and within years (no. par = 3). Detection was allowed to vary by breeding stage (no. par = 3), year (no. par = 10), and fit with a quadratic trend across occasions but within years (no. par = 2). NP represents a covariate developed from the environmental characteristics which were supported to influence nesting propensity (Male Population Size (-); Female Age (+); Female Age^2 (-); Gibson et al. in review-c). RNP represents a covariate developed from the environmental characteristics which were supported to influence re-nesting propensity (Population size (-); Spring precipitation (+); Gibson et al. in review-c). FGLINE and AllLines represents the average distance a female sage-grouse was found from the Falcon-Gondor or any transmission line during a given spring (April 1st-May31st), respectively. RavenOccupancy represents the relative probability of a Common raven disturbing the breeding lek nearest to an individual female. RavenAbundance represents the annual estimated Common raven population abundance associated with the Falcon-Gondor transmission line. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

Table 5. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines and common ravens demographic structure on greater sage-grouse nesting and re-nesting propensities in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
NP	NP	**0.86**	0.76 – 0.93	**0.86**	0.76 – 0.93
NP + Line	Distance	-0.01	-0.10 – 0.08	0.00	-0.10 – 0.08
NP + Line + Line^2	Distance	0.05	-0.06 – 0.16	0.04	-0.09 – 0.16
	Distance^2	-0.07	-0.15 – 0.01	-0.05	-0.15 – 0.05
RNP	RNP	**0.33**	0.09 – 0.56	**0.33**	0.09 – 0.56
RP + Line	Distance	-0.24	-0.48 – 0.01	-0.02	-0.23 – 0.19
RP + Line + Line^2	Distance	**-0.42**	-0.68 – -0.16	0.02	-0.26 – 0.30
	Distance^2	**0.23**	0.07 – 0.39	-0.06	-0.30 – 0.18
Line$_{(Nest\ Prop)}$	Distance	-0.08	-0.16 – 0.01	-0.05	-0.13 – 0.03
Line + Line^2 $_{(Nest\ Prop)}$	Distance	0.00	-0.11 – 0.11	0.06	-0.06 – 0.18
	Distance^2	**-0.08**	-0.16 – 0.00	**-0.12**	-0.22 – -0.03
Line $_{(ReNest\ Prop)}$	Distance	-0.21	-0.45 – 0.03	-0.01	-0.22 – 0.20
Line + Line^2 $_{(ReNest\ Prop)}$	Distance	**-0.36**	-0.61 – -0.10	0.08	-0.2 – 0.35
	Distance^2	**0.19**	0.03 – 0.35	-0.11	-0.35 – 0.13
Model Format	**Parameter**	**β: Raven Abundance**	**85% C.I.**	**β: Raven Disturbance**	**85% C.I.**
NP + Raven	Raven	-0.02	-0.13 – 0.09	**-0.11**	-0.20 – -0.02

RNP + Raven	Raven	**-0.40**	-0.77 – -0.02	**0.30**	0.07 – 0.53

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with either nesting or renesting propensity are noted with NP and RNP, respectively. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven represents models that considered an effect of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6). Subscripts denote the parameter a covariate associated with.

[b] Parameter denotes the format of a given parameter estimate. NP and RNP represent reference values; Distance represents distance from a power line; Raven represents an estimate of common raven demographic structure.

Table 6. Performance of all resource selection function generalized linear mixed effects models used to assess the influence of distance from power lines on greater sage-grouse nest site use at the landscape-scale in Eureka County, NV, from 2004-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
AllLines + Landscape Selection	0.00	0.49	5	1675.97
AllLines * Landscape Selection	1.05	0.29	6	1675.02
$AllLines^2$ + Landscape Selection	2.00	0.18	6	1675.97
$AllLines^2$ * Landscape Selection	5.03	0.04	8	1675.00
Landscape Selection	10.79	0.00	4	1692.78
$FGLINE^2$ + Landscape Selection	10.87	0.00	6	1688.86
FGLINE + Landscape Selection	11.32	0.00	5	1691.31
FGLINE * Landscape Selection	12.06	0.00	6	1690.05
$FGLINE^2$ * Landscape Selection	13.22	0.00	8	1687.21
$FGLINE^2$	542.09	0.00	5	2218.055
$AllLines^2$	546.40	0.00	5	2222.37
AllLines	547.62	0.00	4	2225.59
FGLINE	552.35	0.00	4	2230.32
Null	566.10	0.00	3	2246.07

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse nest or random point was located from the Falcon-Gondor or any transmission line, respectively. Landscape Selection represents a covariate developed from the environmental characteristics which were supported to influence nest site selection at the landscape scale (Distance from Lek (-); Sagebrush Cover Classification (+); Sagebrush Cover Classification * Distance from Lek (-); Slope (-); Elevation (+); Slope * Elevation (-); Distance from Water (-); and $Distance\ from\ Water^2$ (-); Gibson et al. in review-a).

^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

Table 7. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines on greater sage-grouse landscape-scale selection of nesting habitat in Eureka County, NV, 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Landscape	Landscape	**1.22**	1.14 – 1.31	**1.22**	1.14 – 1.31
Landscape + Line	Distance	0.08	-0.02 – 0.19	**0.25**	0.16 – 0.34
Landscape + Line + Line^2	Distance	**0.15**	0.03 – 0.28	**0.25**	0.14 – 0.36
	Distance ^{2}	**-0.10**	-0.19 – 0.00	0.00	-0.09 – 0.08
Landscape * Line	Distance	0.07	-0.03 – 0.18	0.28	0.19 – 0.39
	Landscape	**1.25**	1.16 – 1.34	**1.23**	1.14 – 1.32
	Distance * Landscape	0.08	-0.02 – 0.19	-0.06	-0.14 – 0.03
Landscape * Line^2	Distance	0.10	-0.03 – 0.24	**0.29**	0.16 – 0.41
	Distance ^{2}	**-0.11**	-0.21 – 0.00	0.00	-0.10 – 0.10
	Distance * Landscape	0.05	-0.08 – 0.17	-0.06	-0.17 – 0.05
	Distance ^{2} * Landscape	-0.09	-0.20 – 0.02	0.01	-0.07 – 0.08
	Landscape	**1.28**	1.17 – 1.40	**1.22**	1.11 – 1.34
Line	Distance	**-0.23**	-0.32 – -0.14	**0.24**	0.16 – 0.31
Line + Line^2	Distance	**-0.11**	-0.21 – 0.00	**0.17**	0.08 – 0.26

Distance [2]	**-0.20**	-0.29 – -0.11	**0.09**	0.02 – 0.16

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with nest site selection are denoted with Landscape. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Landscape represents reference value; Distance represents distance from a power line; [2] denotes a quadratic relationship.

Table 8. Performance of all resource selection function generalized linear mixed effects models used to assess the influence of distance from power lines on greater sage-grouse nest site use at the local-scale in Eureka County, NV, from 2004-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
FGLINE + Local Selection	0.00	0.38	5	698.76
FGLINE * Local Selection	1.83	0.15	6	698.58
$FGLINE^2$ + Local Selection	1.97	0.14	6	698.72
$AllLines^2$ + Local Selection	2.29	0.12	6	699.04
AllLines + Local Selection	2.61	0.10	5	701.36
AllLines * Local Selection	4.08	0.05	6	700.84
$FGLINE^2$ * Local Selection	5.28	0.03	8	698.03
$AllLines^2$ * Local Selection	5.73	0.02	8	698.49
Local Selection	14.70	0.00	4	715.46
AllLines	140.22	0.00	4	840.98
$AllLines^2$	142.11	0.00	5	840.87
FGLINE	152.80	0.00	4	853.56
$FGLINE^2$	153.81	0.00	5	852.57
Null	165.82	0.00	3	868.58

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse nest or random point was located from the Falcon-Gondor or any transmission line, respectively. Local Selection represents a covariate developed from the environmental characteristics which were supported to influence nest site selection at the local scale (Sagebrush shrub cover (+); Non-sagebrush shrub cover (+); Sagebrush shrub cover * Non-sagebrush shrub cover (+); average forb height (+); average forb cover (+); average forb height * average forb cover (+); residual grass height (+); live grass height (+); forb richness (+); shrub height (-); Gibson et al. in review-a). ^{2} denotes a quadratic

relationship. Models with interactions consider both the linear and interaction terms. All models considered year as a random effect. Italicized model is the basic reference value model; bold model is the null model.

Table 9. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on greater sage-grouse local-scale selection of nesting habitat in Eureka County, NV, 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Local	Local	**1.25**	1.07 – 1.41	**1.25**	1.07 – 1.41
Local + Line	Distance	**0.40**	0.26 – 0.55	**0.37**	0.23 – 0.52
Local + Line + Line^2	Distance	**0.41**	0.24 – 0.59	**0.30**	0.14 – 0.46
	Distance^2	-0.01	-0.13 – 0.10	**0.15**	0.01 – 0.30
Local * Line	Distance	**0.39**	0.23 – 0.54	**0.35**	0.20 – 0.50
	Local	**1.26**	1.09 – 1.43	**1.20**	1.04 – 1.38
	Distance * Landscape	-0.05	-0.20 – 0.10	-0.08	-0.25 – 0.08
Local * Line^2	Distance	**0.39**	0.21 – 0.57	**0.30**	0.14 – 0.46
	Distance^2	-0.01	-0.12 – 0.11	**0.16**	0.01 – 0.30
	Distance * Local	-0.10	-0.29 – 0.09	-0.09	-0.27 – 0.08
	Distance^2 * Local	0.05	-0.06 – 0.18	0.03	-0.14 – 0.20
	Local	**1.21**	1.00 – 1.42	**1.18**	0.97 – 1.40
Line	Distance	**0.34**	0.21 – 0.46	**0.47**	0.34 – 0.6
Line + Line^2	Distance	**0.39**	0.24 – 0.54	**0.46**	0.31 – 0.6

Distance ^{2}	-0.06	-0.15 – 0.03	0.03	-0.10 – 0.16

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with nest site selection are denoted with Local. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Local represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 10. Performance of all nest survival models used to assess the influence of power lines and common ravens demographic structure on greater sage-grouse nest success in Eureka County, NV, from 2004-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No.	Dev.
Success + FGLINE^2 * RavenAbundance	0.00	0.60	6	1510.08
Success + FGLINE^2	4.38	0.07	4	1518.47
Success * FGLINE^2	4.60	0.06	5	1516.68
Success + AllLines	5.24	0.04	3	1521.33
Success	5.97	0.03	2	1524.06
Success * AllLines	6.05	0.03	4	1520.14
Success + FGLINE^2 + RavenAbundance	6.24	0.03	5	1518.33
Success + FGLINE	6.39	0.02	3	1522.48
Success + RavenDisturbance^2	6.50	0.02	4	1520.59
Success + AllLines^2	6.82	0.02	4	1520.91
Success + RavenAbundance	7.55	0.01	3	1523.64
Success + RavenDisturbance	7.97	0.01	3	1524.06
Success * FGLINE	8.17	0.01	4	1522.26
Success + RavenAbundance^2	8.17	0.01	4	1522.27
Success + FGLINE(Year)	8.55	0.01	11	1508.60
Success * AllLines^2	8.82	0.01	5	1520.91
NULL	24.22	0.00	1	1544.32
AllLines^2	26.07	0.00	3	1542.16
FGLINE	26.12	0.00	2	1544.21
AllLines	26.17	0.00	2	1544.26
FGLINE^2	26.53	0.00	3	1542.62

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the distance a female Greater sage-grouse nest was located from the Falcon-Gondor transmission line or any power line, respectively. Annual FGLINE allowed the parameter

estimate for distance from Falcon-Gondor to vary by year. Success represents the reference value covariate developed from the environmental characteristics that were supported to influence nest survival (Non-sagebrush shrub cover (+); forb cover (+); average shrub height (+); the amount of surrounding habitat classified as pinyon-juniper woodlands (+); population the female was associated with [i.e., Roberts Creek Mountain (+) or Cortez Mountain(-)]; Gibson et al. 2015). RavenOccupancy represents the annual average relative probability of a Common raven disturbing the breeding lek nearest to an individual female. RavenAbundance represents the annual estimated Common raven population abundance associated with the survey transect along the Falcon-Gondor transmission line nearest to an individual female. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms.

Table 11. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines and common raven demographic structure on greater sage-grouse nest survival in Eureka County, NV, from 2004-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Success	Success	**0.27**	0.19 – 0.36	**0.27**	0.19 – 0.36
Success + Line	Distance	0.09	-0.01 – 0.19	**0.11**	0.01 – 0.21
Success + Line + Line^2	Distance	**0.17**	0.5 – 0.28	**0.13**	0.02 – 0.23
	Distance ^{2}	**-0.09**	-0.16 – -0.03	-0.04	-0.13 – 0.05
Line * Success	Distance	0.08	-0.02 – 0.19	0.08	-0.02 – 0.18
	Success	**0.31**	0.21 – 0.40	**0.33**	0.23 – 0.43
	Distance * Success	-0.04	-0.14 – 0.07	-0.08	-0.18 – 0.03
Line^2 * Success	Distance	**0.19**	0.07 – 0.31	**0.13**	0.01 – 0.24
	Distance ^{2}	-0.08	-0.15 – -0.02	-0.4	-0.15 – 0.06
	Distance * Distance * Success	0.08	-0.01 – 0.16	0.00	-0.10 – 0.10
	Success	**0.27**	0.15 – 0.39	**0.32**	0.19 – 0.45
Line	Distance	-0.02	-0.11 – 0.07	-0.01	-0.10 – 0.08
Line + Line^2	Distance	0.03	-0.08 – 0.13	0.03	-0.07 – 0.13
	Distance ^{2}	-0.06	-0.12 – 0.01	**-0.09**	-0.18 – 0.00

Model Format	Parameter-Type	β: Raven Abundance	85% C.I.	β: Raven Disturbance	85% C.I.
Success + Raven	Raven	0.05	-0.06 – 0.16	0.00	-0.17 – 0.17
Success + Raven + Raven^2	Raven	0.05	-0.06 – 0.17	-0.06	-0.22 – 0.11
	Raven^2	0.09	-0.02 – 0.21	-0.21	-0.37 – -0.05

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with nest success are denoted with Success. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven and Raven^2 represent models that considered a linear or quadratic effect, respectively, of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Success represent reference value; Distance represents distance from a power line; Raven represents an estimate of common raven demographic structure. ^{2} denotes a quadratic relationship

Table 12. Performance of all resource selection function generalized linear mixed effects models used to assess the influence of a distance from power lines on greater sage-grouse brood site use at the landscape-scale in Eureka County, NV, from 2005-2012.

Model[a]	ΔAIC_c	AIC_c	No. Par	Dev.
AllLines * Brood Age * AllLines^2 + Landscape Brood	0.00	0.76	9	1995.84
AllLines * Brood Age + AllLines^2 + Landscape Brood Selection	2.67	0.20	8	2000.51
AllLines * Brood Age + Landscape Brood Selection	5.83	0.04	7	2005.67
FGLINE * Brood Age + Landscape Brood Selection	26.41	0.00	7	2026.25
FGLINE * Brood Age + FGLINE^2 + Landscape Brood Selection	27.23	0.00	8	2025.07
FGLINE * Brood Age * FGLINE^2 + Landscape Brood Selection	28.26	0.00	9	2024.10
AllLines^2 + Landscape Brood Selection	29.60	0.00	6	2031.44
AllLines + Landscape Brood Selection	34.42	0.00	5	2038.26
Landscape Brood Selection	50.80	0.00	4	2056.64
FGLINE + Landscape Brood Selection	52.79	0.00	5	2056.63
FGLINE^2 + Landscape Brood Selection	53.50	0.00	6	2055.34
AllLines^2	210.24	0.00	5	2214.08
AllLines	210.70	0.00	4	2216.51
FGLINE^2	236.00	0.00	5	2239.84
NULL	239.99	0.00	3	2247.83
FGLINE	241.06	0.00	4	2246.90

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse brood or random point was located from the Falcon-Gondor or any transmission line, respectively. Landscape Brood Selection represents a covariate developed from the environmental characteristics which were supported to influence brood site selection at the landscape scale (Slope (-); Elevation (+); see Table Sx). Brood Age represented the age (in weeks) since the brood hatched. All models considered individual and

year as random effects. Italicized model is the basic reference value model; bold model is the null model.

Table 13. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines on greater sage-grouse landscape-scale selection of brood rearing habitat in Eureka County, NV, from 2005-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Landscape	Landscape	**0.70**	0.62 – 0.77	**0.70**	0.62 – 0.77
Landscape + Line	Distance	0.01	-0.08 – 0.09	**0.26**	0.17 – 0.34
Landscape + Line +	Distance				
Line^2		0.04	-0.06 – 0.14	**0.15**	0.05 – 0.25
	Distance^2	-0.06	-0.14 – 0.02	**0.16**	0.07 – 0.24
Landscape + Line *	Distance				
Brood Age		0.12	-0.06 – 0.30	**0.45**	0.27 – 0.62
	Brood Age	**-0.19**	-0.24 – -0.14	**-0.18**	-0.23 – -0.13
	Distance *				
	Brood Age	-0.03	-0.08 – 0.02	**-0.06**	-0.11 – -0.01
Landscape + Line *	Distance				
Brood Age+ Line^2		0.16	-0.03 – 0.35	**0.33**	0.15 – 0.52
	Distance^2	-0.06	-0.14 – 0.02	**0.14**	0.05 – 0.22
	Distance *				
	Brood Age	-0.04	-0.09 – 0.01	**-0.05**	-0.10 – -0.01
	Brood Age	**-0.19**	-0.24 – -0.14	**-0.18**	-0.23 – -0.13
Line	Distance	-0.05	-0.13 – 0.03	**0.31**	0.23 – 0.39

Line + Line^2	Distance	0.02	-0.08 – 0.11	**0.36**	0.27 – 0.46
	Distance ^{2}	**-0.14**	-0.22 – -0.07	**-0.09**	-0.16 – -0.01

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with brood site habitat selection are denoted with Landscape. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Brood Age represents models that considered an effect of brood age.

[b] Parameter denotes the format of a given parameter estimate. Landscape represents reference value; Distance represents distance from a power line; Brood Age represents brood age (in weeks); ^{2} denotes a quadratic relationship.

Table 14. Performance of all resource selection function generalized linear mixed models used to assess the influence of a unit of habitat's distance from transmission lines on greater sage-grouse brood site use at the local-scale in Eureka County, NV, from 2005-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
FGLINE^2 * Brood Age + Local Brood Selection	0.00	0.70	8	679.03
FGLINE * Brood Age + Local Brood Selection	2.11	0.24	7	683.14
AllLines* Brood Age + Local Brood Selection	5.89	0.04	7	686.92
AllLines^2 * Brood Age + Local Brood Selection	7.77	0.01	8	686.80
FGLINE^2 + Local Brood Selection	10.16	0.00	6	693.19
AllLines + Local Brood Selection	13.10	0.00	5	698.13
AllLines^2 + Local Brood Selection	14.62	0.00	6	697.65
Local Brood Selection	14.70	0.00	4	701.73
FGLINE + Local Brood Selection	16.33	0.00	5	701.36
AllLines^2	136.58	0.00	5	826.76
AllLines	142.35	0.00	4	834.53
FGLINE^2	150.62	0.00	5	840.80
NULL	159.33	0.00	3	853.51
FGLINE	159.51	0.00	4	851.69

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines represents the average distance a female sage-grouse brood or random point was located from the Falcon-Gondor or any transmission line, respectively. Local Brood Selection represents reference value covariate developed from the environmental characteristics which were supported to influence brood site selection at the local scale (Total Vegetation Cover (+); Average Residual Grass Height (+); Forb Richness (+); Average Live Grass Height (+); Average Forb height (+); Non-sagebrush shrub cover (-); see Table Sx). Brood Age delineates the early brood rearing from the late brood rearing period. All models considered individual and year as

random effects. Italicized model is the basic reference value model; bold model is the null model.

Table 15. Parameter estimates (β), and 85% confidence intervals for all covariates used to assess the influence of power lines on greater sage-grouse local-scale selection of brood rearing habitat in Eureka County, NV, from 2005-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Local	Local	**1.40**	1.20 – 1.60	**1.40**	1.20 – 1.60
Local + Line	Distance	0.07	-0.09 – 0.22	**0.23**	0.05 – 0.40
Local + Line + Line^2	Distance	**0.30**	0.10 – 0.49	**0.26**	0.07 – 0.44
	Distance ^{2}	**-0.28**	-0.43 – -0.14	-0.08	-0.23 – 0.08
Local + Line * Brood Age	Distance	**1.43**	0.91 – 1.98	**1.23**	0.74 – 1.73
	Brood Age	0.13	-0.120 – 0.47	0.17	-0.16 – 0.51
	Distance * Brood Age	**-0.91**	-1.23 – -0.59	**-0.72**	-1.05 – -0.40
Local + Line * Brood Age+ Line^2	Distance	**1.41**	0.90 – 1.92	**1.23**	0.74 – 1.72
	Distance ^{2}	**-0.22**	-0.37 – -0.06	-0.04	-0.21 – 0.13
	Distance * Brood Age	**-0.79**	-1.12 – -0.46	**-0.71**	-1.03 – -0.38
	Brood Age	0.20	-0.14 – 0.53	0.18	-0.16 – 0.51
Line	Distance	0.13	-0.01 – 0.27	**0.47**	0.31 – 0.63
Line + Line^2	Distance	**0.37**	0.20 – 0.55	**0.56**	0.39 – 0.73

Distance [2]	**-0.29**	-0.42 – -0.16	**-0.27**	-0.41 – -0.14

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with brood site habitat selection are denoted with Local. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Brood Age represents models that considered an effect of brood age.

[b] Parameter denotes the format of a given parameter estimate. Local represents reference value; Distance represents distance from a power line; Brood Age delineates between early and late brood rearing periods; [2] denotes a quadratic relationship.

Table 16. Performance of all Lukacs young survival of marked adults models used to assess the influence of power lines and common raven population abundance on pre-fledging greater sage-grouse chick survival in Eureka County, NV, from 2005-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$ * $FGLINE^2_{Weeks1\text{-}2}$	0.00	0.82	18	2076.43
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$ + $FGLINE^2_{Weeks1\text{-}2}$	4.20	0.10	17	2082.81
$Survival_{chick}$ * $FGLINE^2_{Weeks1\text{-}2}$	4.83	0.07	17	2083.44
$Survival_{chick}$ + $FGLINE^2_{Weeks1\text{-}2}$	10.29	0.00	16	2091.07
$Survival_{chick}$ + $FGLINE^2_{Weeks1\text{-}2}$ + $FGLINE_{Weeks3\text{-}6}$	12.16	0.00	17	2090.77
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$ + $RavenAbundance_{Weeks3\text{-}6}$	21.16	0.00	16	2101.94
$Survival_{chick}$ + $RavenAbundance_{Weeks1\text{-}2}$	23.21	0.00	15	2106.15
$Survival_{chick}$ * $AllLines^2_{Weeks1\text{-}2}$	24.70	0.00	17	2103.31
$Survival_{chick}$ + $FGLINE_{Weeks1\text{-}2}$ + $FGLINE_{Weeks3\text{-}6}$	27.54	0.00	16	2108.32
$Survival_{chick}$ + $FGLINE_{Weeks1\text{-}6}$	30.75	0.00	15	2113.70
$Survival_{chick}$	31.29	0.00	14	2116.38
$Survival_{chick}$ + $AllLines^2_{Weeks1\text{-}2}$	32.50	0.00	16	2113.28
$Survival_{chick}$ * $FGLINE_{Weeks1\text{-}6}$	33.32	0.00	15	2116.27
$Survival_{chick}$ + $AllLines_{Weeks1\text{-}6}$	34.16	0.00	16	2114.94
$Survival_{chick}$ + $AllLines^2_{Weeks1\text{-}2}$	34.67	0.00	16	2115.45
$Survival_{chick}$ * $AllLines_{Weeks1\text{-}6}$	35.05	0.00	16	2115.83
$Survival_{chick}$ + $AllLines^2_{Weeks1\text{-}2}$ + $AllLines_{Weeks3\text{-}6}$	36.28	0.00	17	2114.89
$FGLINE^2_{Weeks1\text{-}2}$	38.95	0.00	15	2121.89
$FGLINE_{Weeks1\text{-}2}$	65.87	0.00	14	2150.96
$AllLines_{Weeks1\text{-}2}$	81.00	0.00	14	2166.09
$AllLines^2_{Weeks1\text{-}2}$	81.73	0.00	15	2164.67
NULL	82.19	0.00	13	2169.43

[a] Model selection notation follows Burnham and Anderson (2002). All models allowed detection to vary by year (no. par = 8) and week[b] (no. par = 4). FGLINE and AllLines is a weekly time-

varying covariate which represents the distance a female sage-grouse and her brood was located from the Falcon-Gondor or any transmission line, respectively, in a given week. ^{2} denotes a quadratic relationship. Subscripts denote which weeks a covariate was allowed to influence. Models with interactions consider both the linear and interaction terms. $Survival_{chick}$ represents a covariate developed from the environmental characteristics which were supported to influence pre-fledging chick survival (total vegetation cover (+); distance brood moved in previous week (-); average grass height (-); distance from nearest water source (+); nest site quality (+); female age (+); female age^2 (-); Gibson et al. in review-b). Italicized model is the basic reference value model; bold model is the null model.

[b] the final two weekly detection parameters were constrained to be similar which resulted in the six occasion history having four estimated parameters.

Table 17. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on greater sage-grouse pre-fledging chick survival in Eureka County, NV, from 2005-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format[a]	**Parameter**[b]	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
$Survival_{chick}$	$Survival_{chick}$	**0.41**	0.34 – 0.48	**0.41**	0.34 – 0.48
$Survival_{chick}$ + Line	Distance	**-0.09**	-0.16 – -0.02	-0.02	-0.09 – 0.05
$Survival_{chick}$ + $Line_{Week1-2}$ +$Line_{Week3-6}$	$Distance_{Week1-2}$	-0.23	-0.35 – -0.11	-0.05	-0.17 – 0.07
	$Distance_{Week3-6}$	0.09	-0.05 – 0.23	0.06	-0.07 – 0.19
$Survival_{chick}$ +$Line_{Week1-2}^2$	$Distance_{Week1-2}$	0.00	-0.12 – 0.12	-0.08	-0.20 – 0.04
	$Distance_{Week1-2}^2$	-0.26	-0.35 – -0.17	-0.11	-0.21 – -0.01
$Survival_{chick}$ + $Line_{Week1-2}$ + $Line_{Week1-2}^2$ +$Line_{Week3-6}$	$Distance_{Week1-2}$	-0.01	-0.14 – 0.12	-0.10	-0.23 – 0.03
	$Distance_{Week1-2}^2$	-0.26	-0.35 – -0.17	0.07	-0.06 – 0.2
	$Distance_{Week3-6}$	0.05	-0.09 – 0.19	0.02	-0.08 – 0.12
Line * $Survival_{chick}$	Distance	**-0.10**	-0.19 – -0.01	-0.03	-0.10 – 0.04
	$Survival_{chick}$	**0.40**	0.31 – 0.49	**0.41**	0.34 – 0.48
	Distance * $Survival_{chick}$	-0.03	-0.10 – 0.04	-0.04	-0.11 – 0.03
$Line_{Week1-2}^2$ * $Survival_{chick}$	$Distance_{Week1-2}$	-0.03	-0.15 – 0.09	-0.08	-0.20 – 0.04

	Distance $_{\text{Week1-2}}{}^{2}$	**-0.33**	-0.43 – -0.23	**-0.11**	-0.21 – -0.01
	Distance $_{\text{Week1-2}}{}^{2}$ * Survival$_{chick}$	**-0.14**	-0.21 – -0.07	**-0.23**	-0.33 – -0.13
	Survival$_{chick}$	**0.47**	0.37 – 0.57	**0.57**	0.47 – 0.67
Line$_{\text{Week1-2}}$	Distance$_{\text{Week1-2}}$	**-0.36**	-0.47 – -0.24	**-0.15**	-0.27 – -0.03
Line$_{\text{Week1-2}}$ + Line$_{\text{Week1-2}}{}^{2}$	Distance$_{\text{Week1-2}}$	-0.02	-0.14 – 0.11	-0.09	-0.22 – 0.04
	Distance$_{\text{Week1-2}}{}^{2}$	**-0.36**	-0.46 – -0.26	-0.08	-0.18 – 0.01

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with pre-fledging chick survival are denoted with Survival$_{chick}$. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Subscripts following *week* denote covariates were assigned only to the specified weeks of the broods life.

[b] Parameter denotes the format of a given parameter estimate. Survival$_{chick}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 18. Performance of all nest survival models used to assess the influence of power lines on female greater sage-grouse survival in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Survival$_{female}$	0.00	0.27	2	1540.89
Survival$_{female}$ + AllLines	1.12	0.16	3	1540.01
Survival$_{female}$ + FGLINE	1.73	0.12	3	1540.61
Survival$_{female}$ +AllLines^2	1.76	0.12	4	1538.63
Survival$_{female}$ + FGLINE^2	1.95	0.11	4	1538.83
Survival$_{female}$ * FGLINE^2	2.74	0.07	5	1537.61
Survival$_{female}$*AllLines	3.01	0.06	4	1539.89
Survival$_{female}$* AllLines^2	3.44	0.05	5	1538.31
Survival$_{female}$* FGLINE	3.59	0.04	4	1540.46
AllLines^2	46.29	0.00	3	1585.17
FGLINE^2	46.43	0.00	3	1585.31
NULL	47.51	0.00	1	1590.40
AllLines	47.72	0.00	2	1588.60
FGLINE	48.26	0.00	2	1589.15

[a] Model selection notation follows Burnham and Anderson (2002). FGLINE and AllLines is a monthly time-varying covariate which represents the average distance a female sage-grouse was located from the Falcon-Gondor or any transmission line, respectively, in a given month. ^{2} denotes a quadratic relationship. Survival$_{female}$ represents the reference value covariate developed from the environmental characteristics that were supported to influence female survival (average monthly elevation (-); age (-); nest success in given year (-); brood success (-); seasonal differences: spring (-), summer (+), fall (-); covariate model modified from Blomberg et al. 2013). Italicized model is the basic reference value model; bold model is the null model.

Table 19. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on adult female greater sage-grouse survival in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	**Parameter**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
***Survival*$_{female}$**	*Survival*$_{female}$	**0.59**	0.47 – 0.71	**0.59**	0.47 – 0.71
***Survival*$_{female}$ + Line**	Distance	0.06	-0.11 – 0.23	0.11	-0.06 – 0.28
***Survival*$_{female}$ + Line +**	Distance				
Line^2		0.14	-0.04 – 0.32	**0.18**	0.00 – 0.36
	Distance ^{2}	-0.10	-0.21 – 0.01	-0.11	-0.24 – 0.02
Line * *Survival*$_{female}$	Distance	0.09	-0.11 – 0.29	0.09	-0.10 – 0.28
	Survival$_{female}$	0.04	-0.12 – 0.2	-0.04	-0.20 – 0.12
	Distance *				
	Survival$_{female}$	**0.58**	0.46 – 0.7	**0.58**	0.46 – 0.70
(Line + Line^2) *	Distance				
***Survival*$_{female}$**		0.15	-0.03 – 0.33	0.19	0.01 – 0.37
	Distance ^{2}	-0.07	-0.20 – 0.06	-0.09	-0.24 – 0.06
	Distance *				
	Distance *				
	Survival$_{female}$	0.08	-0.03 – 0.19	0.04	-0.07 – 0.15
	Survival$_{female}$	**0.51**	0.37 – 0.65	**0.54**	0.41 – 0.67
Line	Distance	0.14	-0.04 – 0.31	0.16	-0.02 – 0.34

Line + Line^2	Distance	**0.24**	0.07 – 0.42	**0.27**	0.09 – 0.45
	Distance ^{2}	**-0.15**	-0.25 – -0.05	**-0.17**	-0.30 – -0.04

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with annual female survival are denoted with $Survival_{female}$. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. $Survival_{female}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 20. Performance of all multistate robust design models used to assess the influence of transmission lines on male greater sage-grouse survival (φ) and among-lek movement rates (ψ) in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
$\varphi(Survival_{male})\psi(.)$	0.00	0.21	27	4406.53
$\varphi(Survival_{male})\psi(AllLines^2)$	0.06	0.21	29	4402.43
$\varphi(Survival_{male})\psi(FGLINE)$	0.50	0.17	28	4404.95
$\varphi(Survival_{male})\psi(AllLines)$	1.24	0.11	28	4405.69
$\varphi(Survival_{male}+ FGLINE)\psi(.)$	1.85	0.08	28	4406.30
$\varphi(Survival_{male}+AllLine)\psi(.)$	2.07	0.08	28	4406.52
$\varphi(Survival_{male})\psi(FGLINE^2)$	2.26	0.07	29	4404.62
$\varphi(Survival_{male}+FG^2)\psi(.)$	3.28	0.04	29	4405.64
$\varphi(Survival_{male}+AllLines^2)\psi(.)$	4.14	0.03	29	4406.51
$\varphi(FGLINE)\psi(.)$	11.29	0.00	27	4417.82
$\varphi(.)\psi(.)$	12.31	0.00	26	4420.92
$\varphi(FGLINE^2)\psi(.)$	12.67	0.00	28	4417.12
$\varphi(AllLine)\psi(.)$	12.79	0.00	27	4419.32
$\varphi(AllLines^2)\psi(.)$	14.87	0.00	28	4419.32

[a] Model selection notation follows Burnham and Anderson (2002). All models allowed detection to vary by year (i.e., primary occasion; no. par = 10), month (i.e., secondary occasion; no. par = 2), and lek of capture (no. par. = 12). FGLINE and AllLines is a represents the distance from the lek a male was associated with to Falcon-Gondor or any transmission line, respectively. ^{2} denotes a quadratic relationship. φ represents annual apparent survival. ψ represents the annual probability of a male moving to a new breeding lek among years. (.) denotes constancy, or intercept-only. Italicized model is the basic reference value model; bold model is the null model.

Table 21. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines on male greater sage-grouse survival (φ) and among-lek movement rates (ψ) in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	Parameter	β: FG Line	85% C.I.	β: All Line	85% C.I.
φ **Survival$_{male}$**	Survival$_{male}$	0.41	0.25 – 0.57	0.41	0.25 – 0.57
φ **Survival$_{male}$ + Line**	Distance	-0.06	-0.24 – 0.12	-0.01	-0.16 – 0.14
φ **Survival$_{male}$ + Line + Line^2**	Distance	0.04	-0.21 – 0.29	0.02	-0.30 – 0.34
	Distance^2	-0.09	-0.25 – 0.07	-0.01	-0.17 – 0.15
φ **Line**	Distance	**-0.20**	-0.35 – -0.04	-0.13	-0.27 – 0.02
φ **Line + Line^2**	Distance	-0.09	-0.32 – 0.15	-0.13	-0.43 – 0.17
	Distance^2	-0.09	-0.23 – 0.06	0.00	-0.15 – 0.15
ψ **Line**	Distance	-0.45	-1.00 – 0.10	-0.31	-0.84 – 0.22
ψ **Line + Line^2**	Distance	-0.33	-1.00 – 0.34	**-1.01**	-1.68 – -0.34
	Distance^2	-0.21	-0.78 – 0.36	**0.53**	0.13 – 0.93

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with male survival (φ) are denoted with Survival$_{male}$. We could not account for environmental variability associated with male lek movement rates (ψ). Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. $Survival_{male}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 22. Performance of all robust design Pradel models used to assess the influence of power lines and common ravens demographic structure on lek-specific population growth rates of male greater sage-grouse in Eureka County, NV, 2003-2012.

Model[a]	ΔAIC_c	AIC_c w_i	No. Par	Dev.
PopGrowth +AllLines * RavenAbundance^2	0.00	0.35	36	6395.95
PopGrowth +AllLines + RavenAbundance^2	0.04	0.34	35	6398.14
PopGrowth +AllLines^2 + RavenAbundance^2	1.89	0.14	36	6397.84
PopGrowth + FGLINE * RavenAbundance^2	3.27	0.07	36	6399.22
PopGrowth + FGLINE + RavenAbundance^2	3.92	0.05	35	6402.02
PopGrowth + FGLINE^2 + RavenAbundance^2	4.57	0.04	36	6400.53
PopGrowth + RavenAbundance^2	6.49	0.01	34	6406.73
PopGrowth + RavenOccupancy^2	16.55	0.00	34	6416.79
PopGrowth + AllLines	18.65	0.00	33	6421.02
PopGrowth + AllLine + RavenAbundance	20.71	0.00	34	6420.94
PopGrowth + AllLines^2	20.77	0.00	34	6421.01
PopGrowth + FGLINE * RavenAbundance	21.08	0.00	35	6419.18
PopGrowth + FGLINE	22.74	0.00	33	6425.11
PopGrowth	23.27	0.00	32	6427.77
PopGrowth + RavenOccupancy	23.66	0.00	33	6426.04
PopGrowth + FGLINE + RavenAbundance	24.72	0.00	34	6424.96
PopGrowth + FGLINE^2	24.87	0.00	34	6425.10
PopGrowth + RavenAbundance	25.19	0.00	33	6427.57
FGLINE^2	118.95	0.00	33	6521.33
FGLINE	119.13	0.00	32	6523.64
NULL	121.90	0.00	31	6528.54
AllLines	122.61	0.00	32	6527.12
AllLines^2	123.12	0.00	33	6525.50

[a] Model selection notation follows Burnham and Anderson (2002). Apparent survival was allowed to vary by year (no. par = 10). Detection was allowed to vary by year (i.e., primary occasion, no. par = 10) and lek (no. par = 10). PopGrowth represents the reference value covariate developed from the environmental characteristics which were supported to influence lek-specific population growth rates (lek elevation (+); annual precipitation (+); covariate model modified from Blomberg et al. 2012[b]). FGLINE and AllLines represents a leks distance from the Falcon-Gondor or any transmission line during a given spring, respectively. RavenOccupancy represents the annual average relative probability of a Common raven disturbing each lek. RavenAbundance represents the annual estimated Common raven population abundance associated with the survey transect along the Falcon-Gondor transmission line nearest to the lek. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

[b] Models considered two additional years of data and more complex model design. See supplemental material for model results.

Table 23. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines and common raven demographic structure on greater sage-grouse population growth in Eureka County, NV, from 2003-2012. Bold values indicate that the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	**Parameter-Type**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
PopGrowth	PopGrowth	**0.42**	0.35 – 0.48	**0.42**	0.35 – 0.48
PopGrowth + Line	Distance	**0.02**	0.00 – 0.04	**0.04**	0.02 – 0.06
PopGrowth + Line +	Distance				
Line^2		0.02	-0.01 – 0.05	**0.03**	0.01 – 0.06
	Distance ^{2}	0.00	-0.02 – 0.02	0.00	-0.02 – 0.02
Line	Distance	**-0.03**	-0.04 – -0.01	**-0.02**	-0.03 – 0.00
Line + Line^2	Distance	0.00	-0.03 – 0.03	0.00	-0.02 – 0.03
	Distance ^{2}	**-0.02**	-0.03 – 0.00	**-0.02**	-0.03 – 0.00
Model Format	**Parameter-Type**	**β: Raven Abundance**	**85% C.I.**	**β: Raven Disturbance**	**85% C.I.**
PopGrowth + Raven	Raven	0.02	-0.04 – 0.07	**0.02**	0.00 – 0.04
PopGrowth + Raven	Raven				
+ Raven^2		**-0.14**	-0.21 – -0.07	**-0.03**	-0.06 – 0.00
	Raven^2	**0.18**	0.12 – 0.24	**-0.05**	-0.08 – -0.03
Model	**Parameter**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
PopGrowth +	Distance	-0.01	-0.04 – 0.03	0.00	-0.04 – 0.04
FGLINE *	RavenAbundance	**-0.15**	-0.22 – -0.08	**-0.15**	-0.22 – -0.08

RavenAbundance^2	RavenAbundance^2	**0.19**	0.13 – 0.25	**0.18**	0.11 – 0.24
	Distance	**0.04**	0.01 – 0.08	**0.04**	0.01 – 0.08

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with population growth are denoted with PopGrowth. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven and Raven^2 represent models that considered a linear or quadratic effect, respectively, of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Survival$_{chick}$ represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Table 24. Performance of all robust design Pradel models used to assess the influence of power lines and common ravens demographic structure on lek-specific per capita recruitment rates of greater sage-grouse in Eureka County, NV, from 2003-2012.

Model[a]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Recruit + AllLines^2 + RavenAbundance^2	0.00	0.40	36	6431.35
Recruit + AllLines + RavenAbundance^2	0.23	0.36	35	6433.73
Recruit + AllLines * RavenAbundance^2	1.23	0.22	36	6432.58
Recruit + RavenAbundance^2	7.38	0.01	34	6443.02
Recruit + FGLINE + RavenAbundance^2	8.35	0.01	35	6441.85
Recruit + FGLINE * RavenAbundance^2	9.12	0.01	36	6440.47
Recruit + FGLINE^2+ RavenAbundance^2	10.10	0.00	36	6441.45
Recruit + RavenOccupancy^2	10.43	0.00	34	6446.08
Recruit + AllLines^2	10.52	0.00	34	6446.17
Recruit + AllLines	11.68	0.00	33	6449.46
Recruit + AllLines+ RavenAbundance	12.95	0.00	34	6448.59
Recruit	16.88	0.00	32	6456.79
Recruit + RavenAbundance	18.38	0.00	33	6456.16
Recruit + FGLINE	18.43	0.00	33	6456.21
Recruit + RavenOccupancy	18.55	0.00	33	6456.33
Recruit + FGLINE * RavenAbundance	18.71	0.00	35	6452.21
Recruit + FGLINE^2	19.17	0.00	34	6454.81
Recruit + FGLINE + RavenAbundance	19.87	0.00	34	6455.51
FGLINE^2	60.19	0.00	33	6497.97
FGLINE	60.59	0.00	32	6500.50
NULL	61.75	0.00	31	6503.79
AllLines	62.98	0.00	32	6502.89
AllLines^2	63.62	0.00	33	6501.40

[a] Model selection notation follows Burnham and Anderson (2002). Apparent survival was allowed to vary by year (no. par = 10). Detection was allowed to vary by year (i.e., primary occasion, no. par = 10) and lek (no. par = 10). Recruit represents a covariate developed from the

environmental characteristics which were supported to influence lek-specific population growth rates (lek elevation (+); annual precipitation (+); total vegetation cover (+); habitat converted to exotic grassland (+);annual precipitation * habitat converted to exotic grassland; covariate model modified from Blomberg et al. 2012[b]). FGLINE and AllLines represents a leks distance from the Falcon-Gondor or any transmission line during a given spring, respectively. RavenOccupancy represents the annual average relative probability of a Common raven disturbing each lek. RavenAbundance represents the annual estimated Common raven population abundance associated with the survey transect along the Falcon-Gondor transmission line nearest to the lek. ^{2} denotes a quadratic relationship. Models with interactions consider both the linear and interaction terms. Italicized model is the basic reference value model; bold model is the null model.

[b] Models considered two additional years of data and more complex model design. See supplemental material for model results.

Table 25. Parameter estimates (β), and 85% confidence intervals for selected parameters used to assess the influence of power lines and common raven demographic structure on greater sage-

2008 grouse per capita recruitment in Eureka County, NV, from 2003-2012. Bold values indicate that
2009 the 85% confidence intervals associated with a parameter estimate did not overlap zero.

Model Format	**Parameter-Type**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Recruit	Recruit	**0.45**	0.36 – 0.54	**0.45**	0.36 – 0.54
Recruit + Line	Distance	0.04	-0.01 – 0.08	**0.11**	0.06 – 0.17
Recruit + Line +	Distance				
Line^2		0.06	-0.01 – 0.13	**0.17**	0.09 – 0.26
	Distance ^{2}	-0.02	-0.06 – 0.02	**-0.05**	-0.09 – 0.00
Line	Distance	**-0.05**	-0.10 – -0.01	-0.03	-0.07 – 0.02
Line + Line^2	Distance	0.01	-0.05 – 0.08	0.01	-0.06 – 0.08
	Distance ^{2}	-0.04	-0.08 – 0.01	**-0.04**	-0.08 – 0.00
Model Format	**Parameter-Type**	**β: Raven Abundance**	**85% C.I.**	**β: Raven Disturbance**	**85% C.I.**
Recruit + Raven	Raven	0.07	-0.06 – 0.20	0.02	-0.02 – 0.06
Recruit + Raven +	Raven				
Raven^2		**-0.25**	-0.45 – -0.06	**-0.12**	-0.20 – -0.04
	Raven^2	**0.29**	0.17 – 0.40	**-0.14**	-0.21 – -0.08
Model Format	**Parameter**	**β: FG Line**	**85% C.I.**	**β: All Line**	**85% C.I.**
Recruit + Line *	Distance	-0.01	-0.09 – 0.06	0.06	-0.02 – 0.15
RavenAbundance^2	RavenAbundance	**-0.28**	-0.47 – -0.09	**-0.29**	-0.49 – -0.10
	RavenAbundance^2	**0.28**	0.16 – 0.40	**0.29**	0.17 – 0.41
	Distance	0.04	-0.01 – 0.08	0.04	-0.01 – 0.09

[a] Model format describes the parameter structure associated with a series of parameter estimates (β). Models that account for environmental variability associated with population growth are denoted with PopGrowth. Line and Line^2 represent models that considered a linear and quadratic effect, respectively, influence of the FG transmission line (columns 3-4) or any power line (columns 5-6). Raven and Raven^2 represent models that considered a linear or quadratic effect, respectively, of annual common raven abundance (columns 3-4) or the relative probability of a common raven disturbing the breeding lek nearest to an individual female (columns 5-6).

[b] Parameter denotes the format of a given parameter estimate. Recruit represents reference value; Distance represents distance from a power line; ^{2} denotes a quadratic relationship.

Figure Headings

Figure 1: Reconstructed analysis from data previously reported in Hall and Haney 1997, which originally suggested leks closer to transmission lines had lower male attendance and decreased population growth. These analyses, like many others, failed to account for latent environmental variability (e.g., elevation) correlated with transmission line placement.

Figure 2: Map of the Falcon-Gondor transmission line (gray line), all other power lines (black hatched line), and state highways (black line) occurring within the study system located primarily in Eureka County, NV, USA (see inset). Sage-grouse were primarily associated with one of 13 study leks (black circles).

Figure 3. Representative images of towers within the Falcon-Gondor transmission line corridor depicting the (**A**) 2-pole H-frame tower and (**B**; foremost) 3-pole guyed angle-transposition tower design. The completed Falcon-Gondor transmission line was approximately 299km long and consisted of 734 towers that varied in height (23-40m), and design (2-3 pole) depending on topography and projection.

Figure 4: Regression of elevation and distance from any power line within Eureka County, NV, USA. Black circles represent 2000 locations randomly generated within the study system delineated in Fig. 2. Error bands represent 95% confidence intervals.

Figure 5: A) Maximum spring common raven abundance (solid black line) associated with the surveyed portion of the Falcon-Gondor transmission line in Eureka County, Nevada from 2003-2012. Construction for the Falcon-Gondor transmission line began in the fall of 2003 and was completed in spring of 2004 (gray line). Regression line (dotted line) suggests an average increase in common raven abundance of 22.7 individuals per year. Error lines (dashed black lines) represent 95% credible intervals. **B**) The relative probability of a raven disturbance during

all lek observations in a given year regressed against annual maximum spring common raven abundance (solid line). Bi-lateral error bars around point estimates represent 95% credible intervals, error lines on regression (dashed lines) represents 95% confidence intervals.

Figure 6: The relative probability of a raven disturbance during all lek observations at a given lek regressed against a study lek's distance from the Falcon-Gondor transmission line (gray circles, solid gray line) or the study lek's distance from the nearest power line (black circles, dashed black line). Error bars around point estimates represent 95% credible intervals.

Figure 7: The influence of the average distance a female greater sage-grouse was from the Falcon-Gondor transmission line during the breeding season (**A**); maximum spring common raven abundance (**B**); and the relative probability of common raven observation at the lek nearest to a female (**C**) and nesting (solid gray line) and re-nesting propensities (solid black line) in Eureka County, Nevada from 2003-2012. Error lines (dashed lines) represent 95% confidence intervals.

Figure 8: The influence of the distance from the Falcon-Gondor (solid gray line) or any power line (solid black line) and the relative probability of selection as a nesting site at the (**A**) landscape scale or (**B**) local scale in Eureka County, Nevada from 2003-2012. Box plots represent the distribution of distances (solid: nests; diagonal lines: available) from the Falcon-Gondor transmission line (gray) or any power line (white). Error lines (dashed lines) represent 95% confidence intervals.

Figure 9: Year-specific beta parameter estimates assessing the influence of distance from the Falcon-Gondor transmission line on nest site selection (filled circles; regression line: dashed line) and nest survival (open circles; regression line: solid line) regressed against the estimated

maximum number of common raven associated with the surveyed portion of the Falcon-Gondor transmission line in Eureka County, Nevada from 2004-2012. Bi-lateral error bars represent standard errors.

Figure 10: The relationship between the distance of a sage-grouse nest from the Falcon-Gondor (solid gray line) and any power line (solid black line) on its overall nest survival (to 37 days) in Eureka County, Nevada from 2004-2012. Box plot represent the distribution of nest distances from the Falcon-Gondor transmission line (gray) or any power line (white). Error lines (dashed lines) represent 95% confidence intervals.

Figure 11: The relationships between use of an area as brood rearing habitat at the landscape scale and its distance from Falcon-Gondor (dashed line, light gray band) and any power line (solid line, dark gray band) across a six week brood rearing period. Avoidance of habitat during the brood rearing period near the Falcon-Gondor was less supported than avoidance of habitat near any power line in Eureka County, Nevada from 2005-2012. Panels represent a shift in the magnitude habitat avoidance, which weakened throughout the brood rearing period as sage-grouse chicks aged. Error bands represent 95% confidence intervals.

Figure 12: The relationships between use of an area as brood rearing habitat at the local scale and its distance from Falcon-Gondor (dashed line, light gray band) and any power line (solid line, dark gray band) during the (**A**) early and (**B**) late brood rearing periods. Panels represent a shift from avoidance of habitat associated with power lines to no selective pressure as sage-grouse chicks aged. Error bands represent 95% confidence intervals.

Figure 13: Influence of an interaction between maximum raven abundance (dashed = low N, solid = average N, short dashed = high N) and a brood's distance from the Falcon-Gondor

transmission line on weekly estimates of apparent pre-fledging chick survival during the first two weeks after hatch. Estimates of raven population size represent a standard deviation below and above the average maximum number of ravens in a given year. Box plots represent the distribution of brood distances from the Falcon-Gondor transmission line the first (gray) and second (white) weeks.

Figure 14: The influence of a female greater sage-grouse's average monthly distance from the Falcon-Gondor (solid gray line) and any power line (solid black line) on true annual female survival. Error lines (dashed) represent 95% confidence intervals.

Figure 15: The influence of a lek's distance from the Falcon-Gondor (solid gray line) and any power line (solid black line) and the apparent annual survival of a male greater sage-grouse associated with that lek. Error lines (dashed) represent 95% confidence intervals.

Figure 16: The influence of a lek's distance from any power line (solid black line) and the annual probability of a male Greater sage-grouse associated with that lek moving to a new lek. Error lines (dashed) represent 95% confidence intervals. Black circles represent the distances from each study lek to the nearest power line.

Figure 17: The influence of a lek's distance from the Falcon-Gondor transmission (**A**) on lek-specific per capita recruitment (f) and population growth (λ) under three levels of estimated numbers of Common ravens per survey transect associated with the Falcon-Gondor transmission line. These estimates represent a standard deviation below (**column 1**), above (**column 3**), and average (**column 2**) number of common ravens per transect. Also, the influence of relative probability of a common raven disturbing a greater sage-grouse lek on lek-specific population

growth (λ) (**B**) and per capita recruitment (*f*) in in Eureka County, Nevada from 2003-2012. Error bands represent 95% confidence intervals.

Figure 18: Beta parameter estimates for models that did not account for environmental variation (gray circles) and models that accounted for environmental variation (black circles) for each analysis that assessed the linear effects of the distance from (**column 1**) any power line and (**column 2**) distance from the Falcon-Gondor transmission line. Error bars represent 85% confidence intervals.

Figure 19: Beta parameter estimates for models that did not account for environmental variation (gray circles) and models that accounted for environmental variation (black circles) for each analysis that assessed the non-linear effects (**column 1**: linear component; **column 2**: quadratic component) of the distance from (**A**) the Falcon-Gondor transmission line and (**B**) distance from any power line. Error bars represent 85% confidence intervals.

Figure 20: Predicted daily survival of a nest (filled circles) based on the surrounding habitat characteristics in the absence of a modeled power line effect (Gibson et al. *in review*) regressed against distance from (**A**) any power line and (**B**) Falcon-Gondor transmission line. Shaded gray ribbon represents 95% confidence intervals around regression parameter.

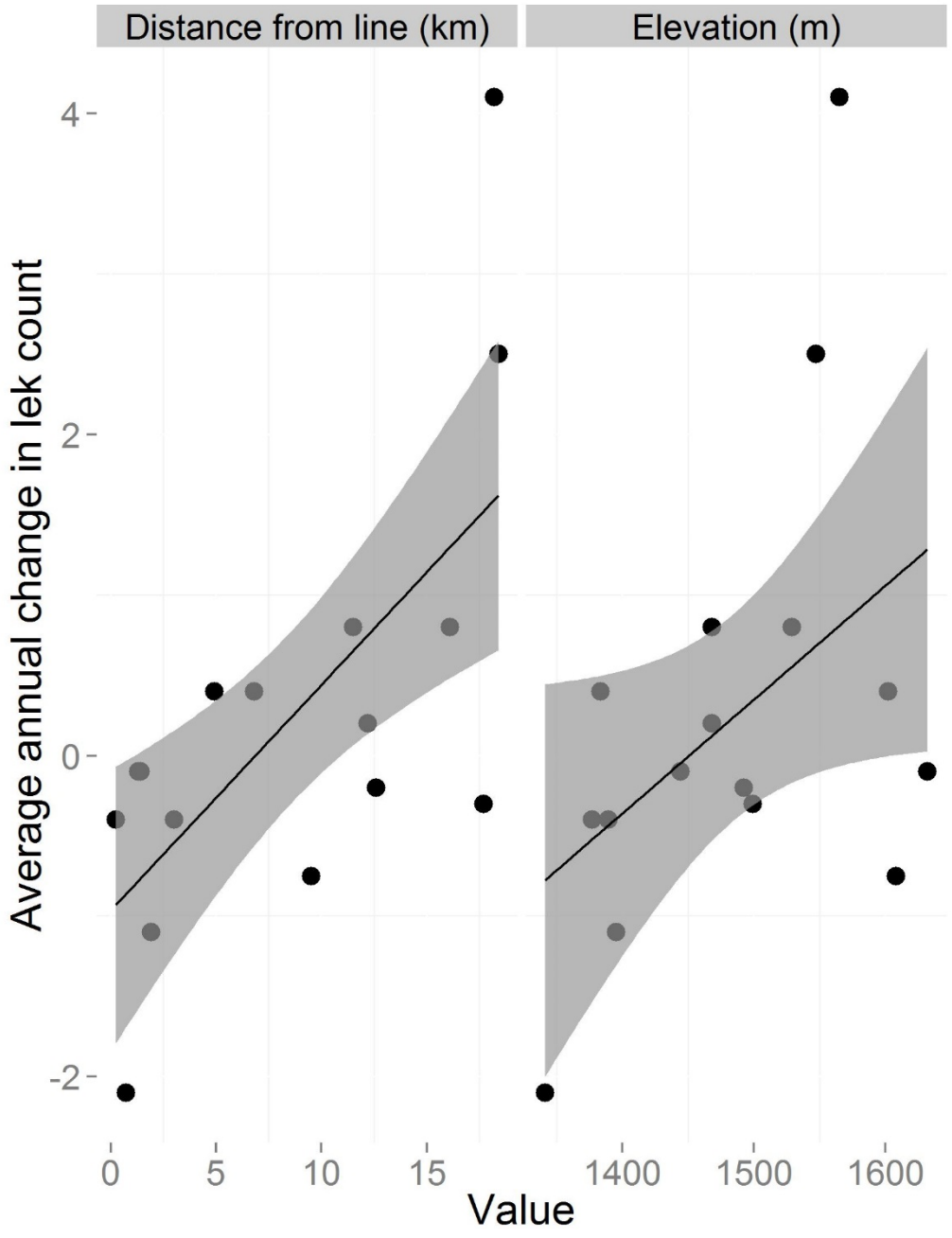
Distance from line (km)
Elevation (m)
Average annual change in lek count
4
2
0
-2
0
5
10
15
1400
1500
1600
Value

Figure 1

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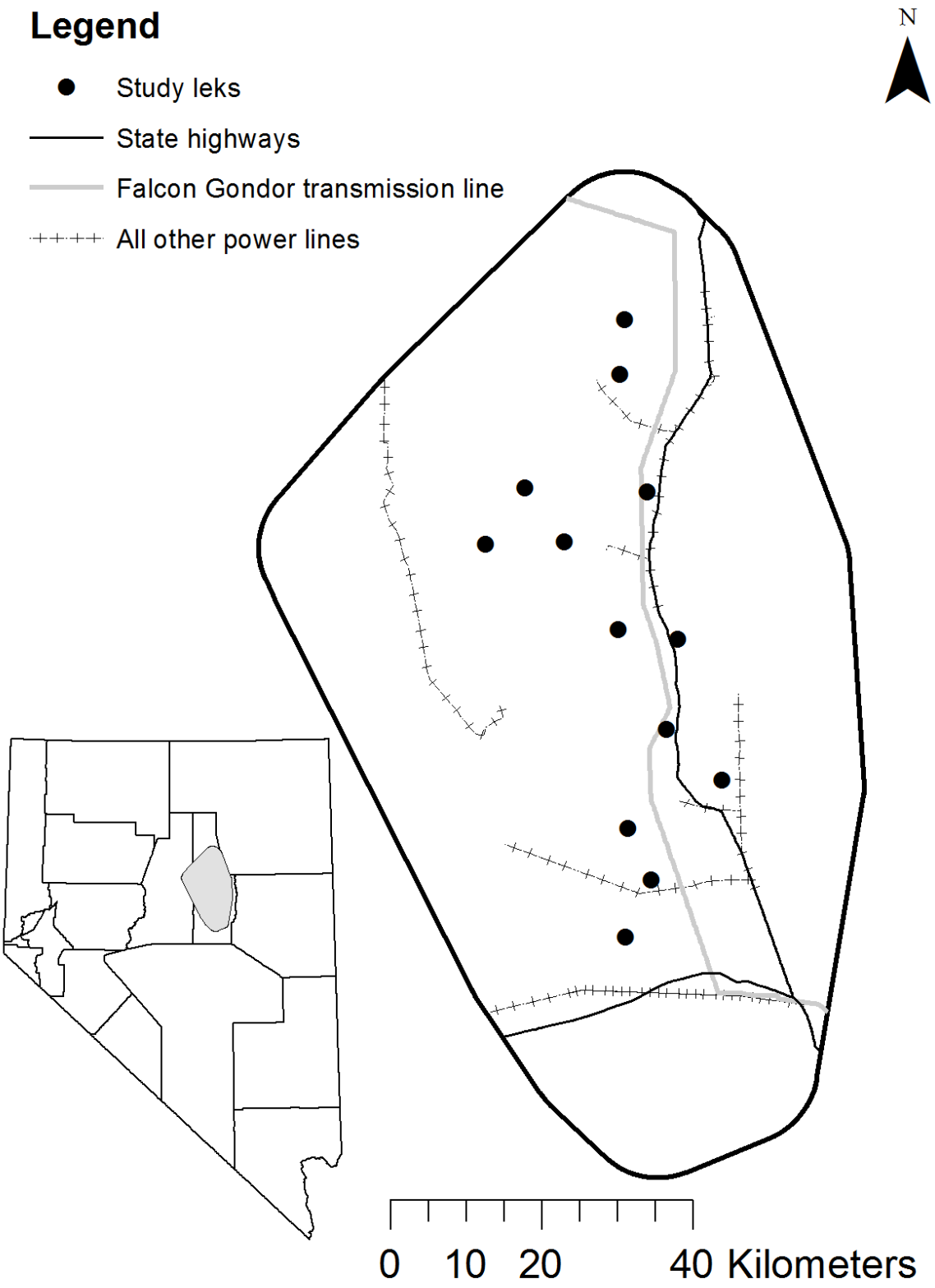
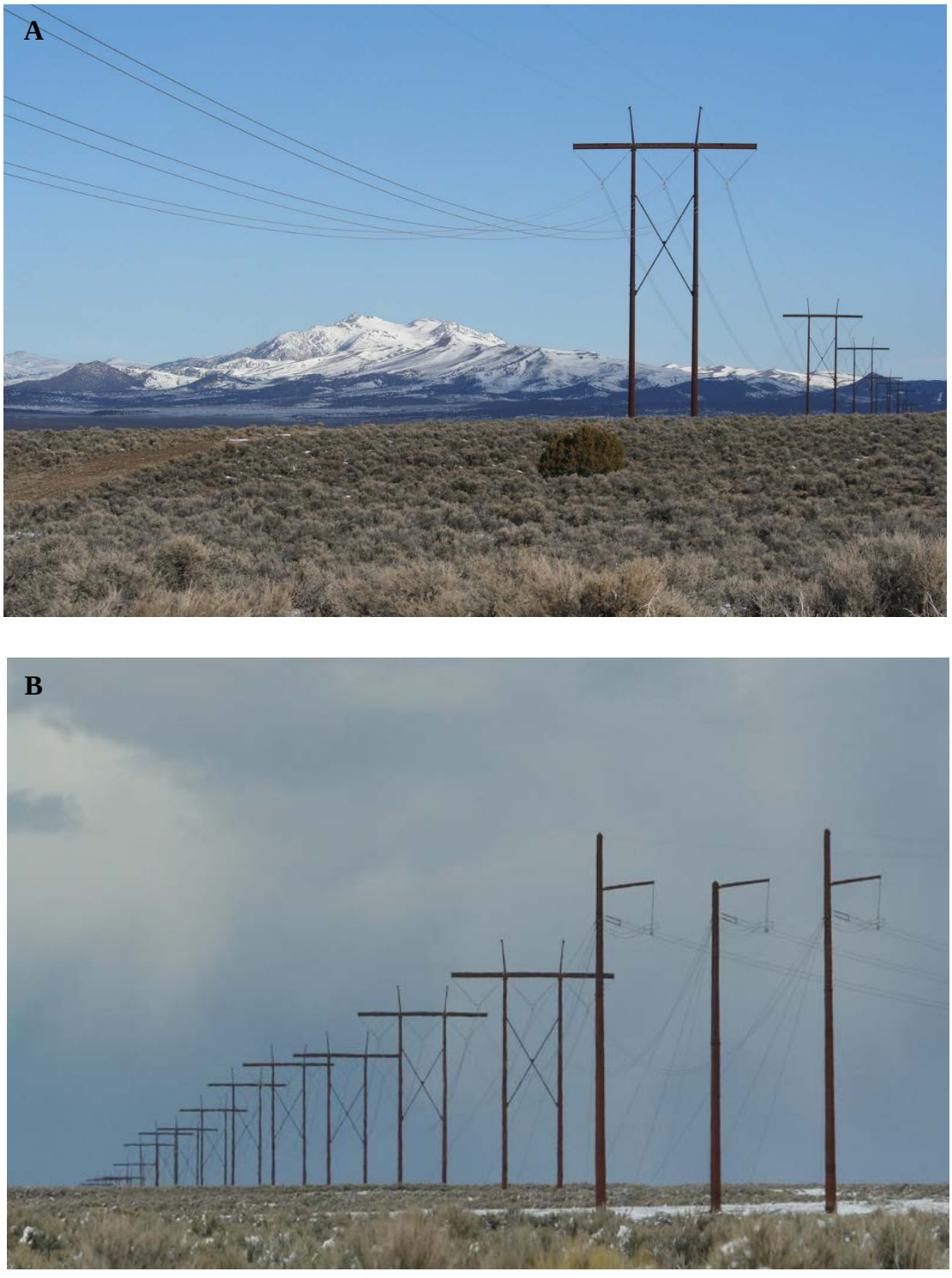
Figure 2



2155

Figure 3



Figur

e 4

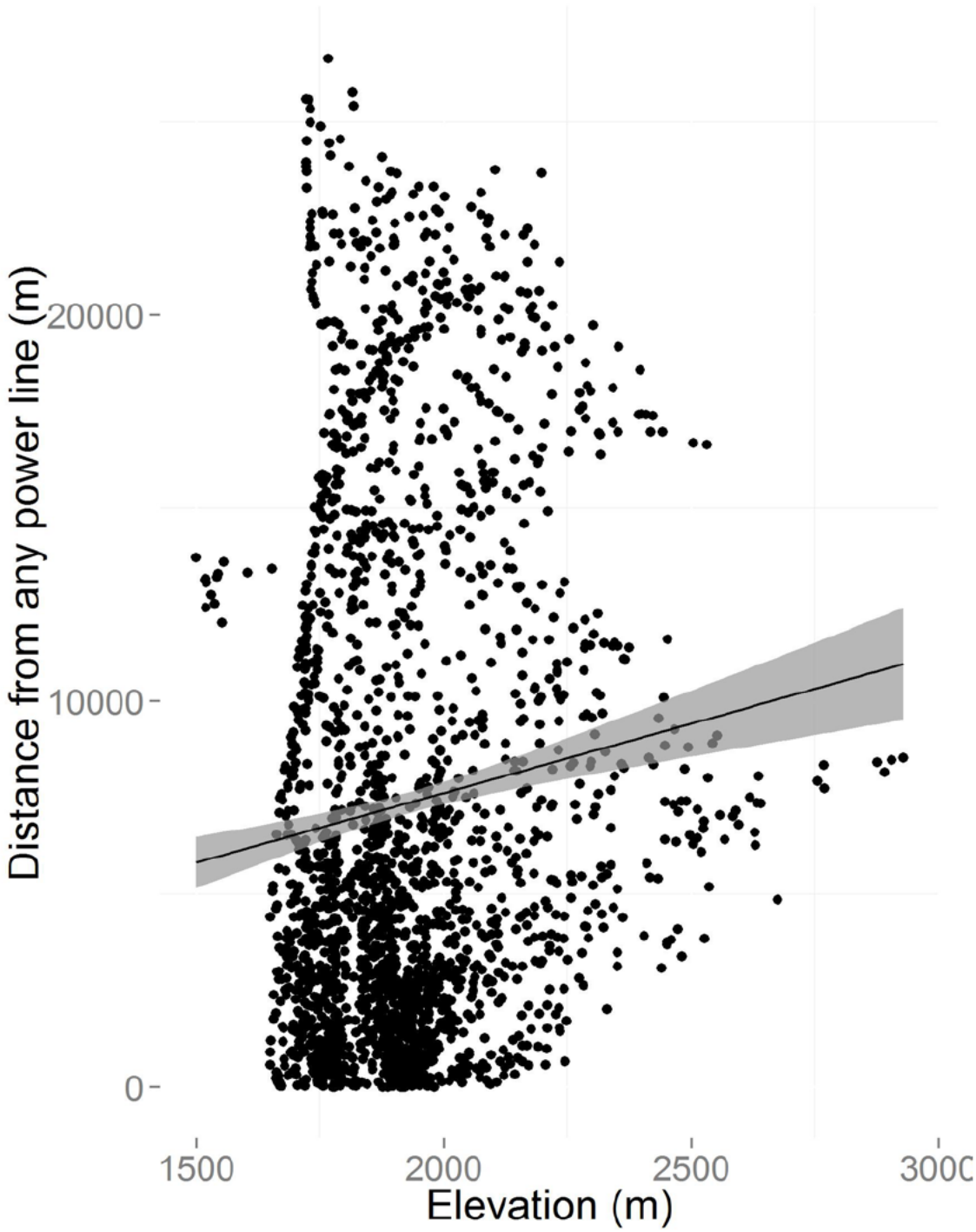


Figure 5

r = 22.7

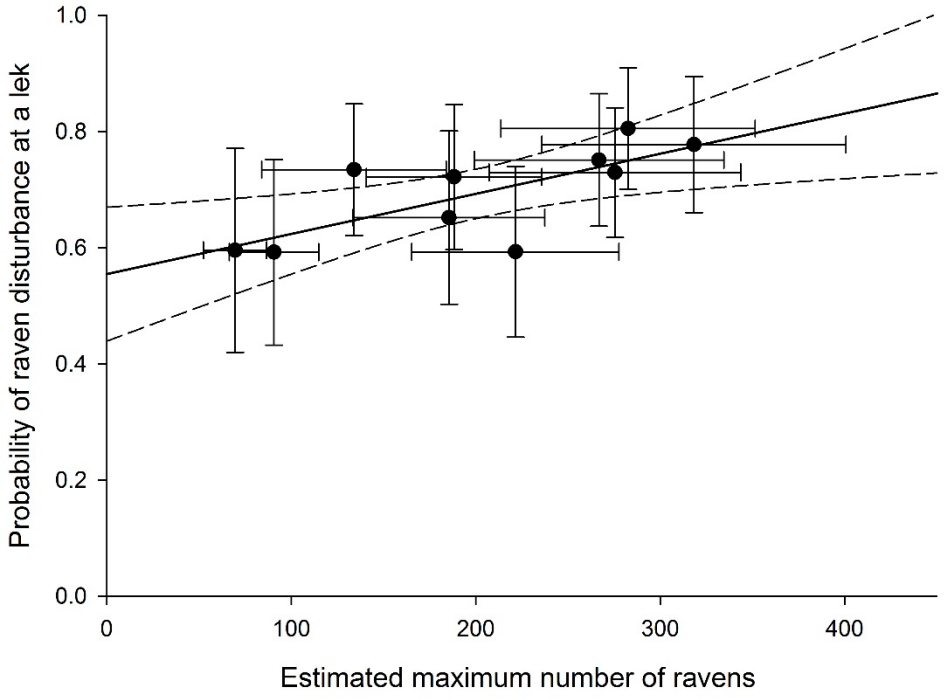
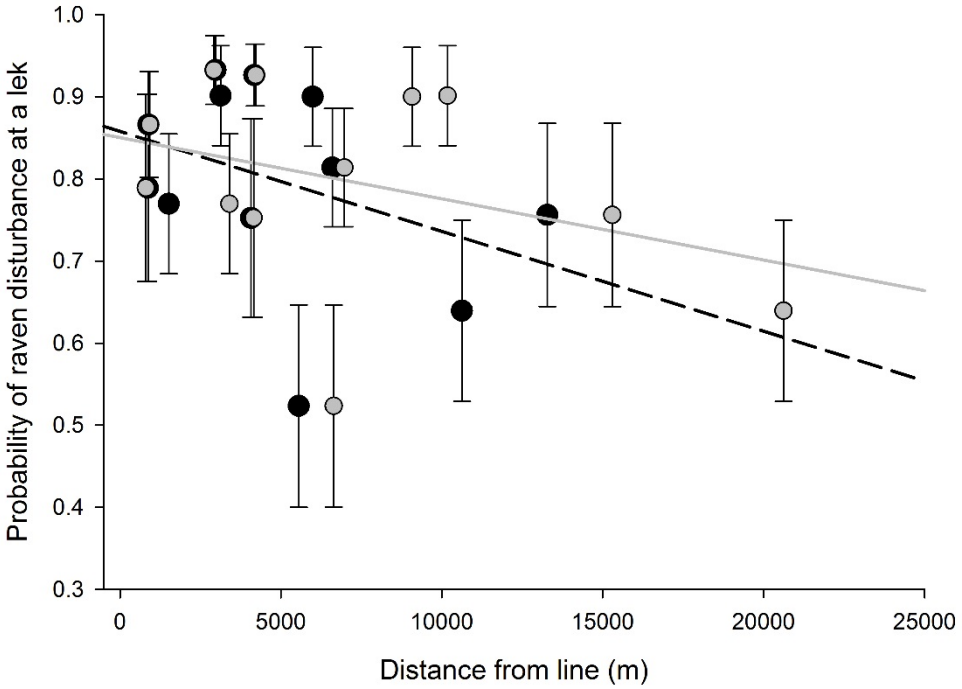
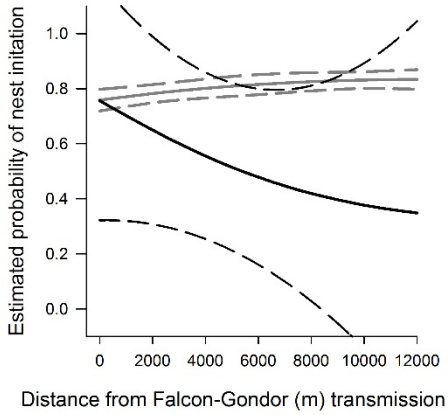

Probability of raven disturbance at a lek
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
Estimated maximum number of ravens

Figure 6


Probability of raven disturbance at a lek
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
5000
10000
15000
20000
25000
Distance from line (m)


Estimated probability of nest initation
1.0
0.8
0.6
0.4
0.2
0.0
0
2000
4000
6000
8000
10000
12000
Distance from Falcon-Gondor (m) transmission line

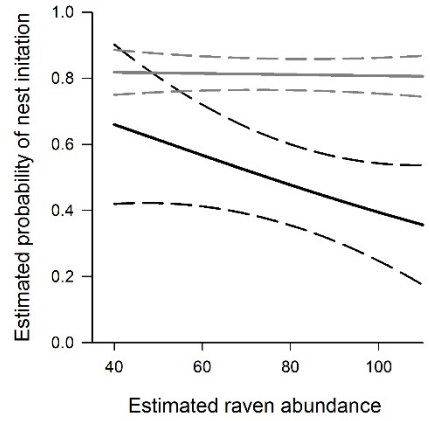
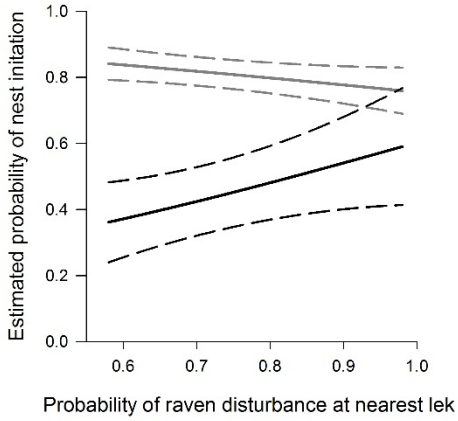

Estimated probability of nest initation
1.0
0.8
0.6
0.4
0.2
0.0
40
60
80
100
Estimated raven abundance

Figure 7


Estimated probability of nest initation
1.0
0.8
0.6
0.4
0.2
0.0
0.6
0.7
0.8
0.9
1.0
Probability of raven disturbance at nearest lek

2222

2223

2224

2225

2226

2227

2228

2229

2230

2231

Figure 8

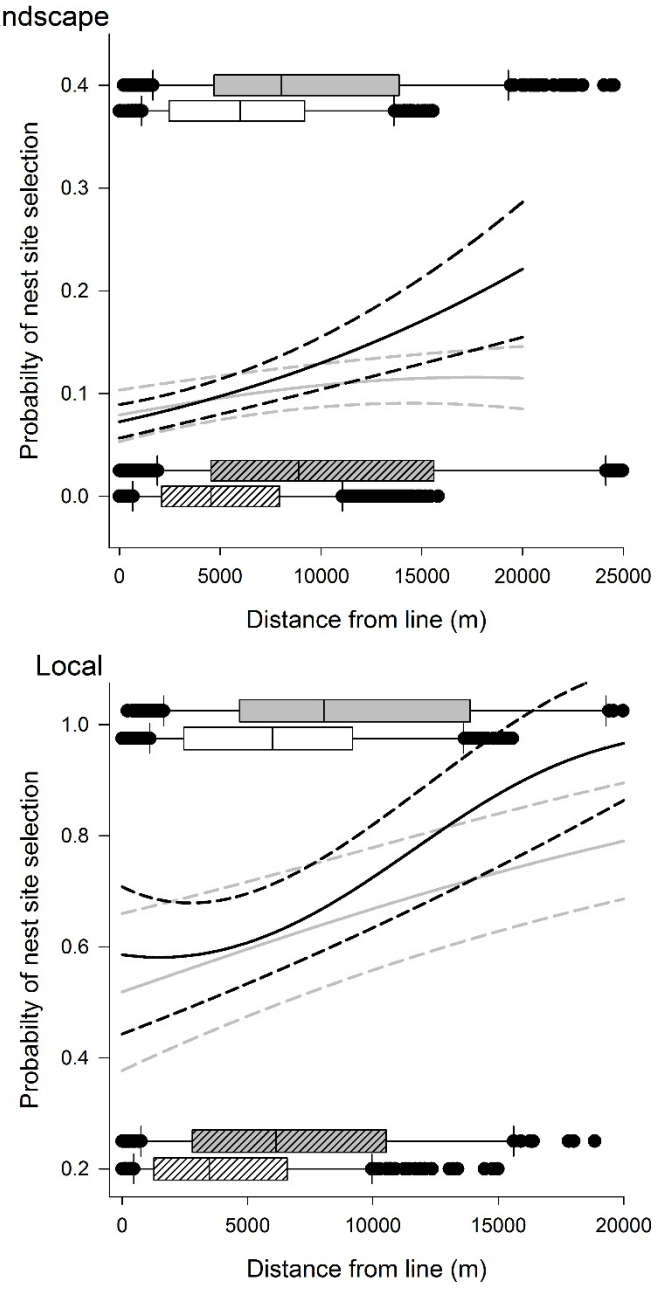

Landscape
Probabilty of nest site selection
0.0
0.1
0.2
0.3
0.4
0
5000
10000
15000
20000
25000
Distance from line (m)
Local
Probabilty of nest site selection
0.2
0.4
0.6
0.8
1.0
0
5000
10000
15000
20000
Distance from line (m)

Figure 9

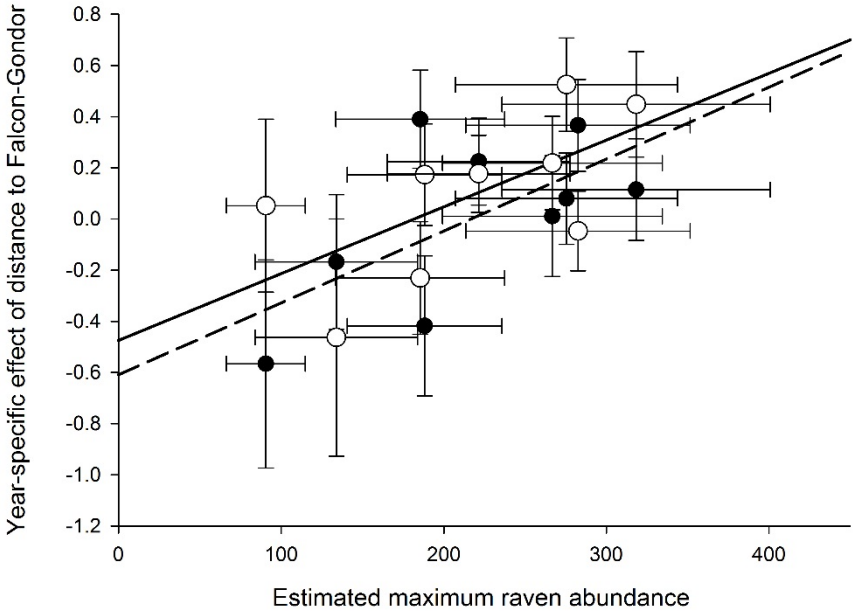

Year-specific effect of distance to Falcon-Gondor
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
0
100
200
300
400
Estimated maximum raven abundance

Figure 10

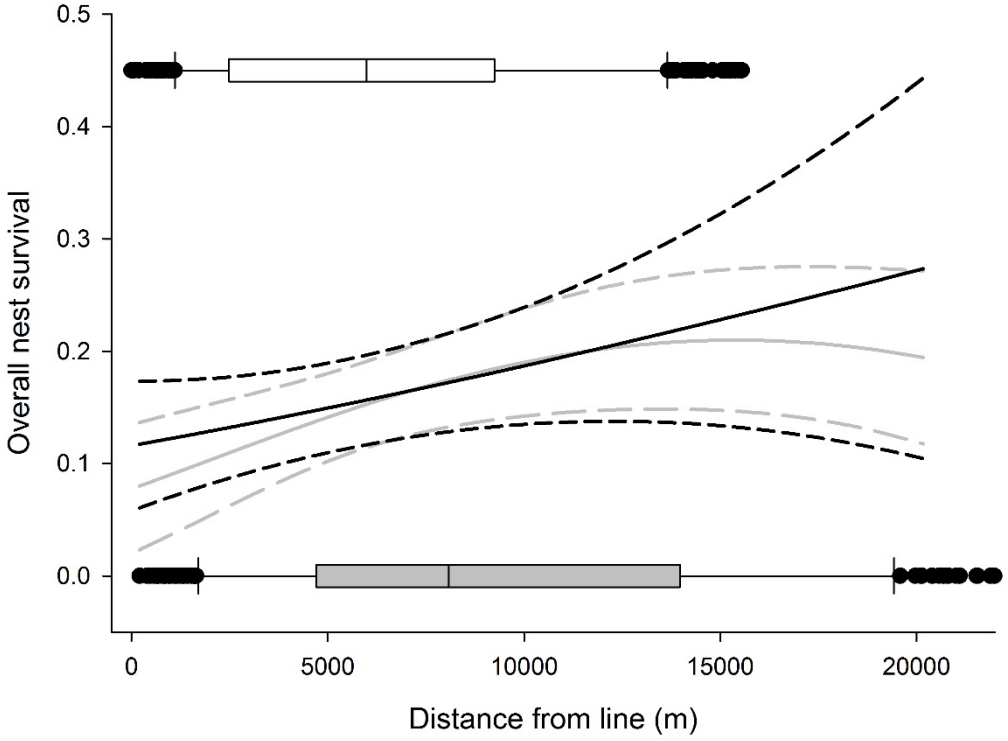

Overall nest survival
0.0
0.1
0.2
0.3
0.4
0.5
0
5000
10000
15000
20000
Distance from line (m)

Figure 11

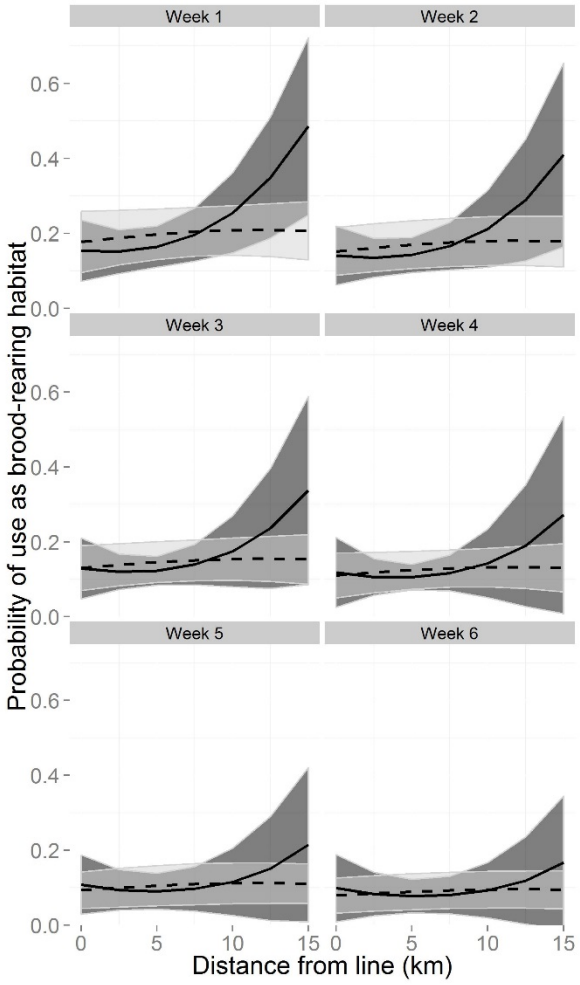

Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Probability of use as brood-rearing habitat
0.0
0.2
0.4
0.6
0
5
10
15
Distance from line (km)

Figure 12

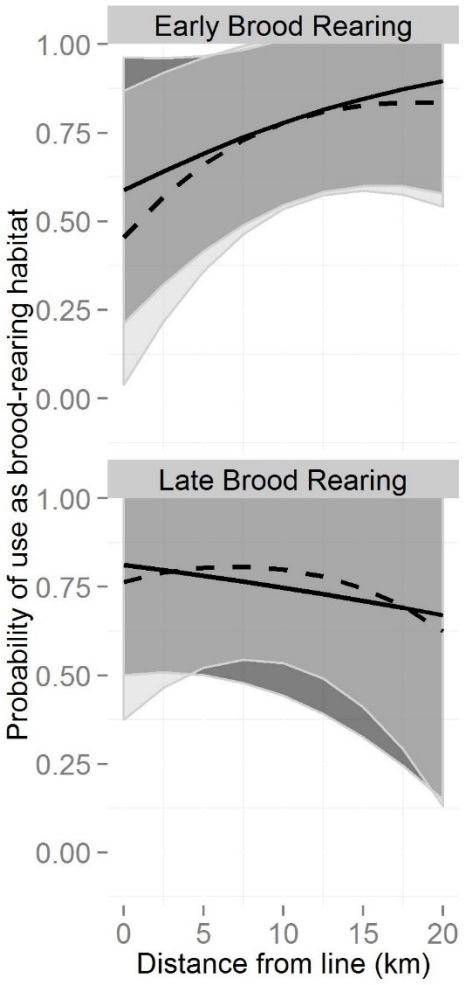

Early Brood Rearing
Late Brood Rearing
Probability of use as brood-rearing habitat
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
Distance from line (km)

Figure 13

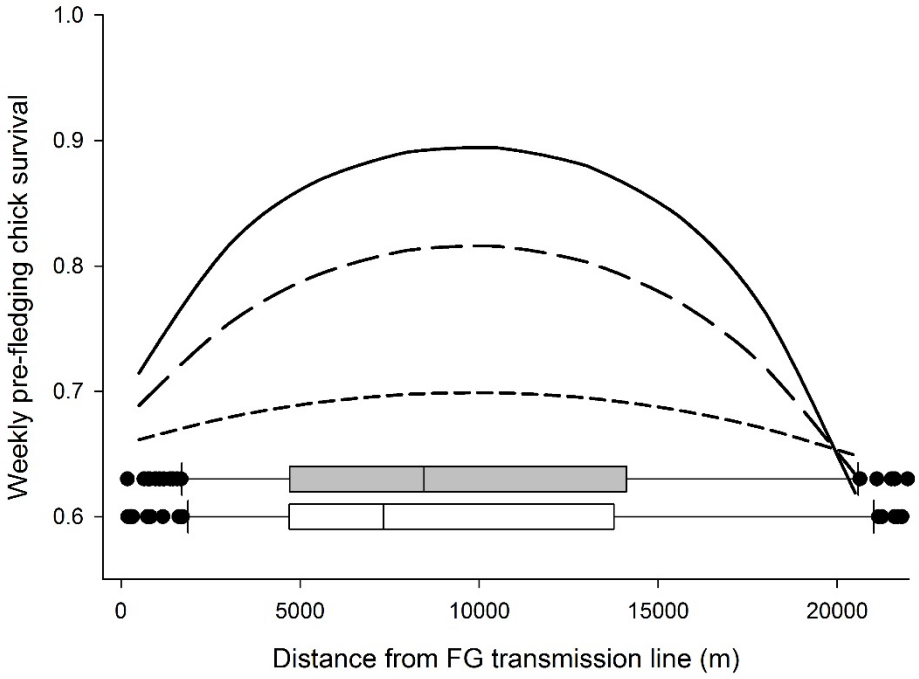
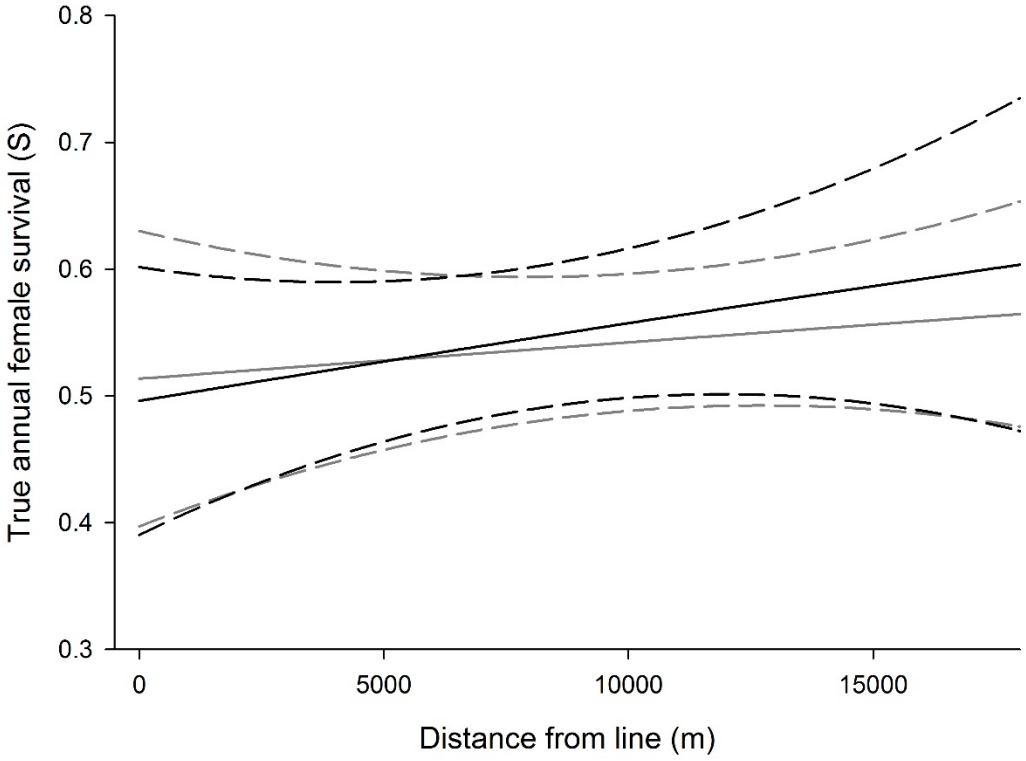

Weekly pre-fledging chick survival
1.0
0.9
0.8
0.7
0.6
0
5000
10000
15000
20000
Distance from FG transmission line (m)

Figure 14


True annual female survival (S)
0.8
0.7
0.6
0.5
0.4
0.3
0
5000
10000
15000
Distance from line (m)

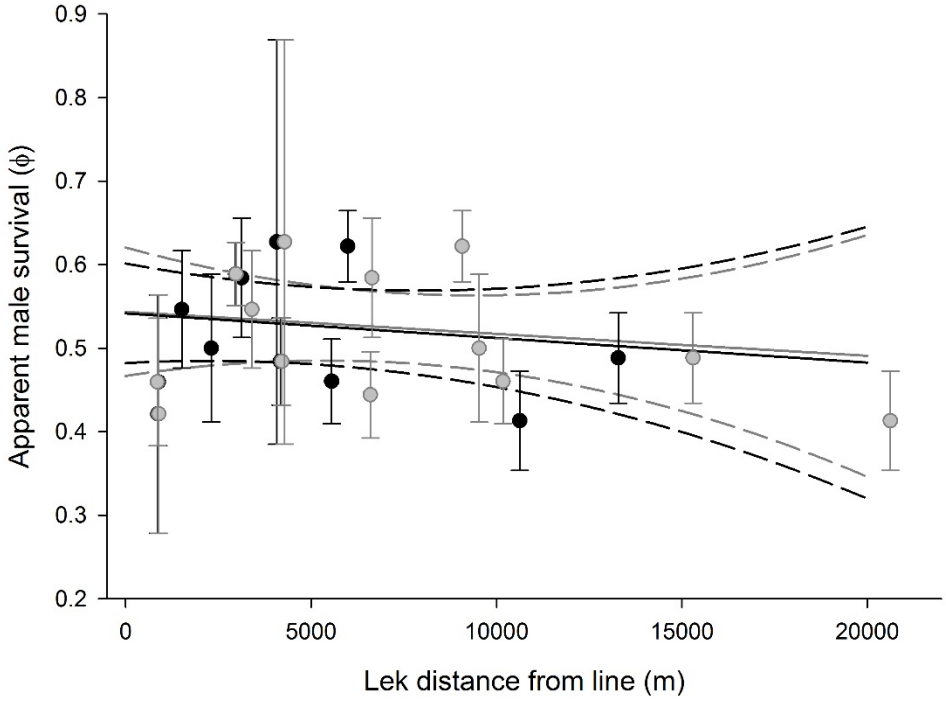
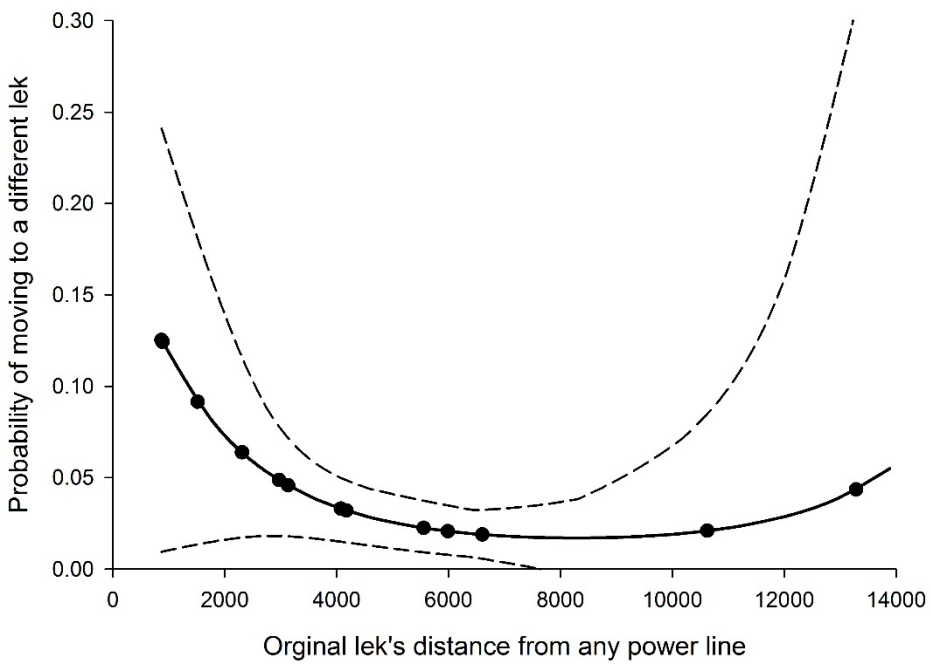

Apparent male survival (ϕ)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
5000
10000
15000
20000
Lek distance from line (m)

Figure 15

Figure 16


Probability of moving to a different lek
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
2000
4000
6000
8000
10000
12000
14000
Orginal lek's distance from any power line

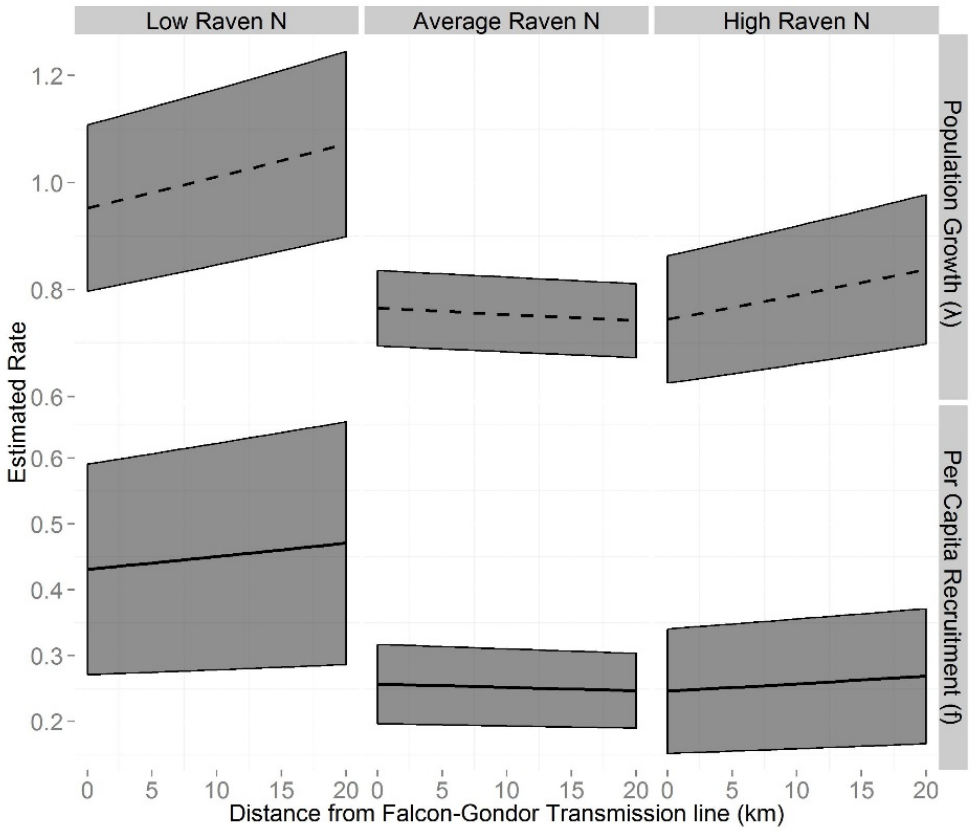

Low Raven N
Average Raven N
High Raven N
Population Growth (λ)
Per Capita Recruitment (f)
Estimated Rate
1.2
1.0
0.8
0.6
0.6
0.5
0.4
0.3
0.2
0
5
10
15
20
Distance from Falcon-Gondor Transmission line (km)

Figure 17

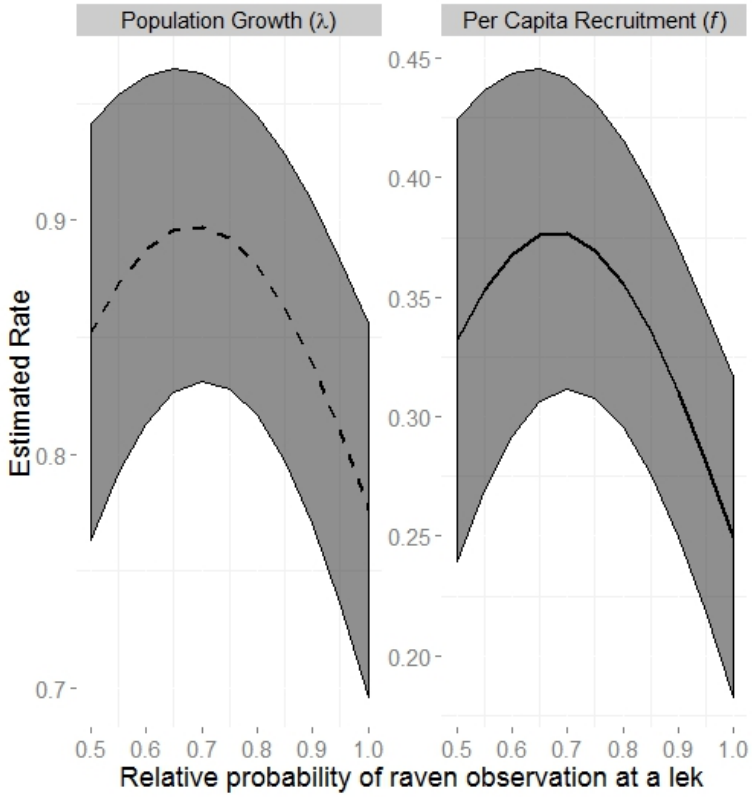

Population Growth (λ)
Per Capita Recruitment (f)
Estimated Rate
0.9
0.8
0.7
0.45
0.40
0.35
0.30
0.25
0.20
0.5 0.6 0.7 0.8 0.9 1.0
0.5 0.6 0.7 0.8 0.9 1.0
Relative probability of raven observation at a lek

Figure 18

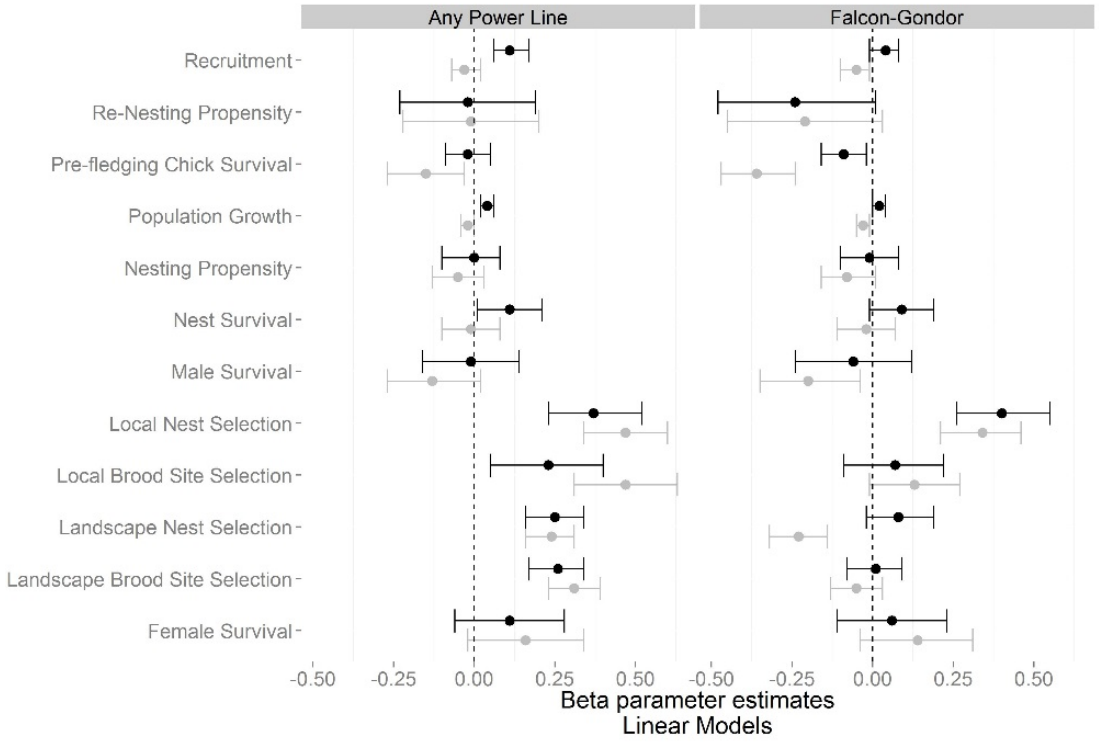

Any Power Line
Falcon-Gondor
Recruitment
Re-Nesting Propensity
Pre-fledging Chick Survival
Population Growth
Nesting Propensity
Nest Survival
Male Survival
Local Nest Selection
Local Brood Site Selection
Landscape Nest Selection
Landscape Brood Site Selection
Female Survival
-0.50 -0.25 0.00 0.25 0.50
-0.50 -0.25 0.00 0.25 0.50
Beta parameter estimates
Linear Models

Figure 19

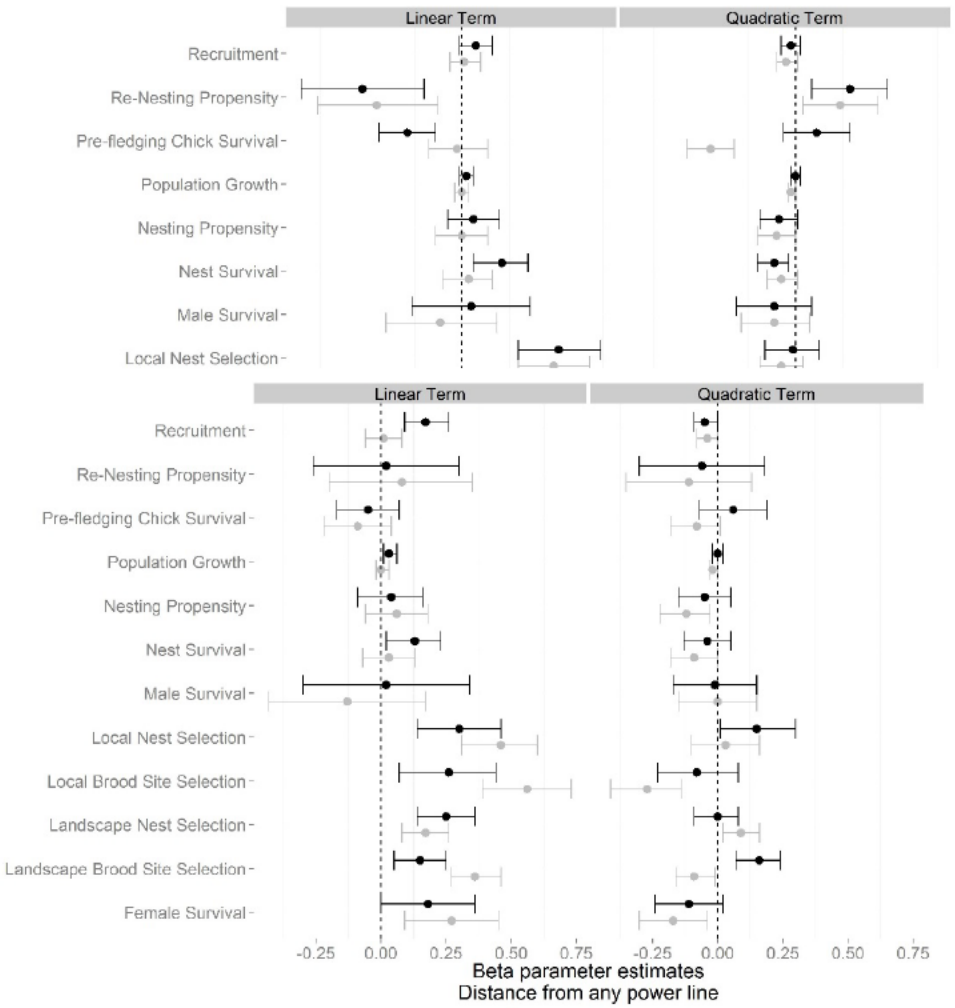
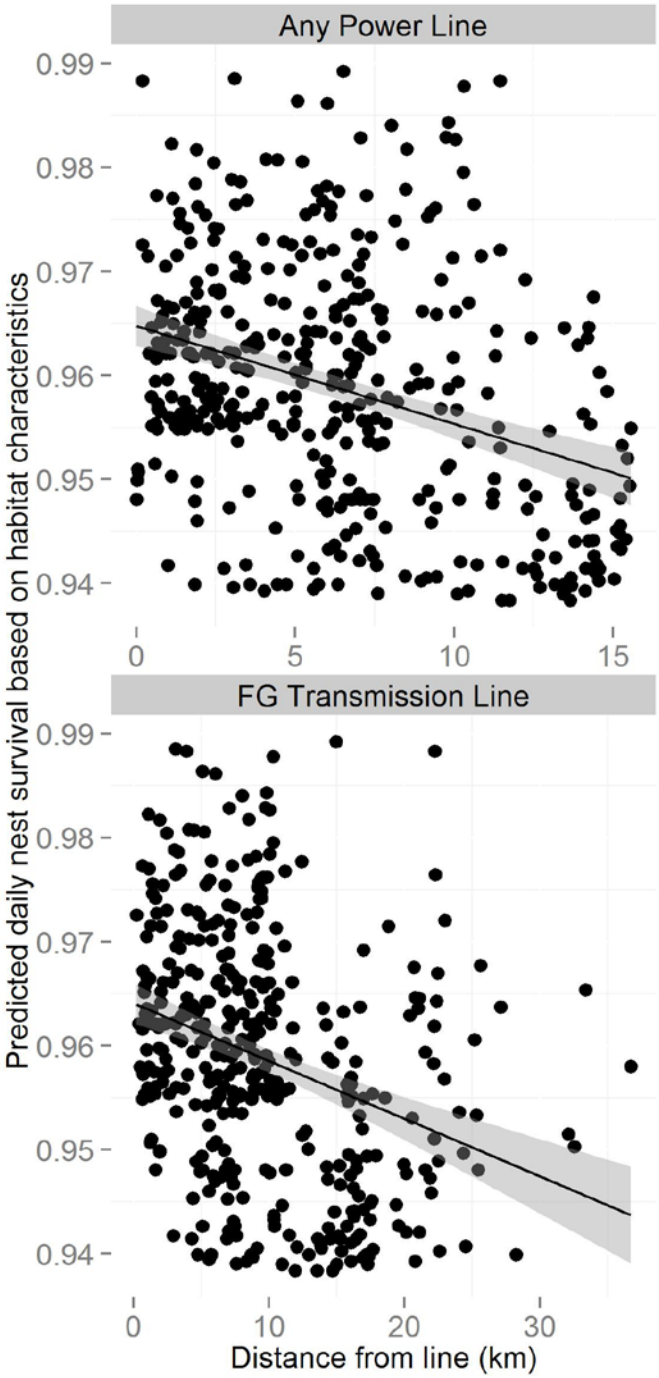

Linear Term
Quadratic Term
Recruitment
Re-Nesting Propensity
Pre-fledging Chick Survival
Population Growth
Nesting Propensity
Nest Survival
Male Survival
Local Nest Selection
Linear Term
Quadratic Term
Recruitment
Re-Nesting Propensity
Pre-fledging Chick Survival
Population Growth
Nesting Propensity
Nest Survival
Male Survival
Local Nest Selection
Local Brood Site Selection
Landscape Nest Selection
Landscape Brood Site Selection
Female Survival
-0.25
0.00
0.25
0.50
0.75
-0.25
0.00
0.25
0.50
0.75
Beta parameter estimates
Distance from any power line

Figure 20


Any Power Line
FG Transmission Line
Predicted daily nest survival based on habitat characteristics
0.99
0.98
0.97
0.96
0.95
0.94
0
5
10
15
20
30
Distance from line (km)

SUPPLEMENTAL MATERIAL

A) Methods and model results for specified reference value analyses

B) JAGS Code – Raven Abundance Model

C) JAGS Code – Raven Site Occupancy Model

2500

2501

2502

2503

2504

SUPPLEMENTAL MATERIAL

Table S1. List of all covariates considered to account for background environmental variation in an individual vital rate. Variables in italics were supported to influence a particular demographic rate of Greater sage-grouse in Eureka County, NV, USA from 2003-2012.

Variable	Nesting (and re-nesting) propensity	Nest Site Selection	Nest Survival	Brood Site Selection	Pre-fledging chick survival	Adult female survival	Adult male Survival	Recruitment	Population Growth
Percent non-sagebrush shrub cover		*x*	*x*	x	x			x	x
Percent forb cover		*x*	*x*	x	x			x	x
Percent total shrub cover		x	x	x	x			x	x
Average shrub height		*x*	*x*	x	x			x	x
Total percent vegetation cover		x	x	*x*	*x*			*x*	x
Percent grass cover		x	x	x	x			x	x
Percent sagebrush shrub cover		*x*	x	*x*	x			x	x

Forb taxa richness	*x*	x	*x*	x			x	x
Average live grass height	*x*	x	*x*	*x*			x	x
Average residual grass height	*x*	x	*x*	x			x	x
Average forb height	*x*	x	*x*	x			x	x
Proportion of surrounding area classified as exotic grasslands	x	x	x	x	x		*x*	*x*
Distance from nearest road	x	x	x	x	x		x	x
Proportion of surrounding area classified as Pinyon-Juniper woodlands	*x*	*x*	x	x	x			
Proportion of surrounding area classified as sagebrush	*x*	x	x	x	x			
Elevation	*x*	x	*x*	x	*x*	*x*	*x*	*x*
Distance to nearest active lek	*x*	x	x	x				
Distance to nearest	*x*	x	x	*x*		x	x	x

spring or water source									
Slope		*x*	x	*x*	x				
Northness :									
cosine(aspect)		x	x	x	x				
Eastness: sine(aspect)		x	x	x	x				
Minimum age	*x*				x	*x*			
Estimated male									
population size	*x*								
Precipitation	*x*				*x*		*x*	*x*	*x*
Summer temperature	x				*x*		x		
Nest hatch date			**x**		x				
Nesting success						*x*			
Fledging success						*x*			
Nest quality					*x*				
Distance brood moved					*x*				
Population	x		***x***		x	x	*x*	x	x

Table S2. Performance of all nest survival models used to assess the influence of habitat features selected for as nest sites on Greater sage-grouse nest survival in Eureka County, NV, 2004-2012. Tables are organized by individual heterogeneity (A), disturbance (B), landscape-scale habitat features (C), temporal characteristics (D), local-scale vegetation features (E), and multivariable models (F).

Individual Heterogeneity Models[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Base + Pop	0.00	0.84	5	1268.21
Base	6.19	0.04	4	1276.40
Base + ID^2	6.71	0.03	6	1272.91
Base + Season	6.88	0.03	5	1275.08
Base + Age Class	7.46	0.02	5	1275.67
Base + MinAge	8.09	0.01	5	1276.30
Base + ID	8.11	0.01	5	1276.32
Base + NestAttempt	8.18	0.01	5	1276.39

Disturbance Models[b]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Base + WF_{2000}	0.00	0.31	5	1274.06
Base	0.33	0.26	4	1276.40

Base + WF_{1000}	1.26	0.17	5	1275.32
Base + WF_{500}	1.68	0.14	5	1275.75
Base + DRoad	2.01	0.12	5	1276.07

Geo-Spatial Models[c]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Base + PJ_{2000}	0.00	0.71	5	1265.60
Base + Elev	4.20	0.09	5	1269.80
Base + PJ_{1000}	4.22	0.09	5	1269.81
Base + Dlek	5.62	0.04	5	1271.21
Base + $DLek^2$	7.51	0.02	6	1271.11
Base + All_{2000}	8.11	0.01	5	1273.71
Base + PJ_{500}	8.13	0.01	5	1273.72
Base	8.80	0.01	4	1276.40
Base + DSpring	8.82	0.01	5	1274.42
Base + North	8.83	0.01	5	1274.43
Base + Slope	8.96	0.01	5	1274.56
Base + $Sagebrush_{1000}$	9.76	0.01	5	1275.36
Base + $Sagebrush_{500}$	10.56	0.00	5	1276.16

Base +East	10.61	0.00	5	1276.20
Base + DSpring^2	10.82	0.00	6	1274.42
Base + North * East	11.78	0.00	7	1273.37

Temporal Models[d]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Stage + Incubation Trend (Base)	0.00	0.23	4	1276.40
(.)	0.64	0.17	1	1283.04
Stage	0.64	0.16	3	1279.05
Snowpack	1.54	0.11	2	1281.95
Raven Index	2.02	0.08	2	1282.42
Weekly Trend	2.50	0.07	2	1282.90
Daily Trend	2.60	0.06	2	1283.00
Precipitation	2.60	0.06	2	1283.00
Week Quadratic Trend	4.50	0.02	3	1282.90
Day Quadratic Trend	4.56	0.02	3	1282.96
Week	5.65	0.01	6	1278.04
Year + Stage + Incubation Trend	9.18	0.00	12	1269.53
Year	10.24	0.00	9	1276.61

Local Vegetation Models[e]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Base + NSC_5	0.00	0.79	5	1264.68
Base + FC_5	4.88	0.07	5	1269.56
Base + $TC_{0.5}$	6.54	0.03	5	1271.22
Base + TSC_5	6.64	0.03	5	1271.32
Base + SH_5	6.95	0.02	5	1271.63
Base + TC_5	8.39	0.01	5	1273.07
Base + FH_5	8.67	0.01	5	1273.34
Base + $SH_{0.5}$	9.53	0.01	5	1274.21
Base	9.72	0.01	4	1276.40
Base + $GH_{0.5}$	10.87	0.00	5	1275.55
Base + GH_5	11.24	0.00	5	1275.92
Base + GC_5	11.32	0.00	5	1276.00
Base + SC_5	11.57	0.00	5	1276.24
Base + $FRich_5$	11.71	0.00	5	1276.39
Base + RGH_5	11.72	0.00	5	1276.39
Base + $FH_{0.5}$	11.72	0.00	5	1276.40

2519

Multivariable Model[f]	ΔAIC_c	$AIC_c\ w_i$	No. Par	Dev.
Base + NSC_5 + FC_5 + Pop	0.00	0.29	7	1253.92
Base + NSC_5 + FC_5 + Pop + PJ_{2000}	0.56	0.22	8	1252.47
Base + NSC_5 + FC_5 + PJ_{2000}	1.29	0.15	7	1255.20
Base + NSC_5 + FC_5	3.29	0.06	6	1259.21
Base + NSC_5 + FC_5 + SH_5	3.96	0.04	7	1257.88
Base + NSC_5 + PJ_{2000}	4.19	0.04	6	1260.12
Base + NSC_5 + FC_5 + Dlek	4.29	0.03	7	1258.21
Base + NSC_5 + FC_5 + Elev	4.88	0.03	7	1258.80
Base + NSC_5 + FC_5 + $TC_{0.5}$	4.93	0.02	7	1258.85
Base + NSC_5 + Pop	5.13	0.02	6	1261.05
Base + NSC_5 + $TC_{0.5}$	6.50	0.01	6	1262.42
Base + NSC_5 + Dlek	6.50	0.01	6	1262.42
Base + NSC_5 + SH_5	6.58	0.01	6	1262.50
Base + NSC_5 + Elev	6.63	0.01	6	1262.56
Base + NSC_5	6.75	0.01	5	1264.68
Base + NSC_5 + DSpring	7.05	0.01	6	1262.97

Base + NSC_5 + TC_5	7.13	0.01	6	1263.05
Base + NSC_5 + WF_{2000}	7.66	0.01	6	1263.59
Base + PJ_{2000}	7.67	0.01	5	1265.60
Base + NSC_5 + TSC	8.08	0.01	6	1264.00
Base + NSC_5 + $SH_{0.5}$	8.46	0.00	6	1264.38
Base + NSC_5 + $FH_{0.5}$	8.72	0.00	6	1264.65
Base + Pop	10.28	0.00	5	1268.21
Base + FC_5	11.63	0.00	5	1269.56
Base + Elev	11.87	0.00	5	1269.80
Base + Dlek	13.28	0.00	5	1271.21
Base + $TC_{0.5}$	13.29	0.00	5	1271.22
Base + TSC_5	13.39	0.00	5	1271.32
Base + SH_5	13.70	0.00	5	1271.63
Base + TC_5	15.14	0.00	5	1273.07
Base + WF_{2000}	16.13	0.00	5	1274.06
Base + $SH_{0.5}$	16.28	0.00	5	1274.21
Base + DSpring	16.49	0.00	5	1274.42
Base + $FH_{0.5}$	18.47	0.00	5	1276.40

[a,b,c,d,e,f] Model selection notation follows Burnham and Anderson (2002). Base represents a competitive four parameter design to account for variation in nest survival related to nest age; we allowed the laying period for the average nest (occasions 1-10), early incubation/late laying period (occasions 11-15), and the primary incubation period (occasions 16-44) to estimate independently from each other, with the linear trend (daily) on the primary incubation period. Subscripts denote the scale of the variable (i.e., within 0.5m, 5m or within a radius of 500m, 1000m, or 2000m of a point). Horizontal cover variables included non-sagebrush shrub cover of all size classes (NSC), sagebrush shrub cover at all size classes (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represented forb taxa richness within a given plot. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sagebrush represent the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; Slope represented the slope (in degrees) of a point. North is the cosine of aspect, East is the sin of aspect. Pop was a binomial covariate delineating nests from females associated from the Cortez Mountains from females associated with Roberts Creek Mountain. AgeClass was a binomial covariate which delineated second year females from after second year females, MinAge was a continuous covariate which represented the females minimum age. Season was a binomial covariate which delineated females captured in the spring from females captured in the fall. ID represented estimate nest initiation date. (.) denotes intercept-only model. Year denotes

full annual variation. We also considered annual constraints related to annual precipitation (precipitation), raven population size (raven index), and winter snowpack (snowpack). Week allowed for variation among 7 day fixed periods. Stage allowed for the laying, early incubation, and primary incubation phases to estimate separately. Linear and quadratic daily and weekly trends are clearly denoted. All covariates were z-standardized prior to analysis

Table S3. Model parameter estimates, associated error, and measure of significance from single variable nest survival (Nest Survival) models.

Variable	β	S.E.	Sig.?	units
NSC_5	0.29	0.09	*	Prop. cover
FC_5	0.21	0.09	*	Prop. cover
$TC_{0.5}$	0.15	0.06	*	Prop. cover
TSC_5	0.16	0.07	*	Prop. cover
SH_5	0.15	0.07	*	cm
TPC_5	0.12	0.07	*	Prop. cover
$FH_{0.5}$	0.12	0.07	*	cm
$SH_{0.5}$	0.11	0.08	*	cm
G0.5	0.07	0.07		cm
GC_5	-0.05	0.07		Prop. cover
SC_5	-0.03	0.07		Prop. cover
$FRich_5$	0.01	0.07		taxa
GH_5	0.05	0.07		cm
RGH_5	-0.01	0.07		cm
FH_5	0.00	0.07		cm
WF_{2000}	-0.11	0.07	*	Prop. classified
WF_{1000}	-0.07	0.07		Prop. classified
WF_{500}	-0.06	0.07		Prop. classified
Road	0.04	0.07		m
PJ_{2000}	0.25	0.08	*	Prop. classified

PJ_{1000}	0.20	0.08	*	Prop. classified
PJ_{500}	0.12	0.08	*	Prop. classified
$Sage_{2000}$	-0.13	0.08	*	Prop. classified
$Sage_{1000}$	-0.08	0.08		Prop. classified
$Sage_{500}$	-0.04	0.08		Prop. classified
Elev	0.18	0.07	*	m
Dlek	0.17	0.08	*	m
DSpring	0.10	0.07	*	m
Slope	0.10	0.07		°
Northness	-0.10	0.07	*	°
Eastness	0.03	0.07		°

(*) denotes significance at 85 percent confidence intervals (Arnold 2010) in single variable models. Subscripts denote the scale of the variable (i.e., within 0.5m, 5m, or within a radius of 500m, 1000m, or 2000m of a point). Horizontal cover variables included non-sagebrush shrub cover of all size classes (NSC), sagebrush shrub cover at all size classes (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represented forb taxa richness within a given plot. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sagebrush represent the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the

elevation (in m) of a point; Slope represented the slope (in degrees) of a point. North is the cosine of aspect, East is the sin of aspect.

Table S3. Performance of all resource selection function generalized linear mixed models used to assess the influence of landscape-scale vegetation habitat features on Greater sage-grouse brood site selection in Eureka County, NV, 2005-2012.

Model[a]	**ΔAIC_c**	**AIC_c w_i**	**No. Par**	**Dev.**
Elevation + Slope	0.00	0.37	5	2063.75
Elevation * Slope	0.21	0.34	6	2061.96
$Elevation^2$ + Slope	0.50	0.29	6	2062.25
$Elevation^2$	21.00	0.00	5	2084.75
Elevation	21.99	0.00	4	2087.74
$All\ Sagebrush_{500}$	73.83	0.00	4	2139.58
$All\ Sagebrush_{1000}$	75.42	0.00	4	2141.17
$Pinyon\text{-}Juniper_{500}$	78.89	0.00	4	2144.64
$All\ Sagebrush_{2000}$	88.29	0.00	4	2154.04
$Pinyon\text{-}Juniper_{1000}$	93.19	0.00	4	2158.94
$Pinyon\text{-}Juniper_{2000}$	136.71	0.00	4	2202.46
Slope	163.51	0.00	4	2229.26
$Wildfire_{1000}$	179.60	0.00	4	2245.35
$Wildfire_{500}$	179.95	0.00	4	2245.70
Null	180.08	0.00	3	2247.83
$Wildfire_{2000}$	180.50	0.00	4	2246.25
Distance from $spring^2$	180.77	0.00	5	2244.52
Distance from spring	181.88	0.00	4	2247.63

[a] Model selection notation follows Burnham and Anderson (2002). All models include random intercepts for year and individual. Subscripts denote the scale of the variable (i.e., radius of 500m, 1000m, or 2000m from a point), superscripts denote quadratic relationships. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. All Sagebrush represented the proportion of area classified as sagebrush at a specified scale; WF represented the proportion of area converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of area classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; Slope represented the slope (in degrees) of a point. Null denotes intercept-only model. All variables were z-standardized prior to analysis.

Table S4. Performance of all resource selection function generalized linear mixed models used to assess the influence of local-scale vegetation habitat features on Greater sage-grouse brood site selection in Eureka County, NV, 2005-2012.

Model[a]	**ΔAIC_c**	**AIC_c w_i**	**No. Par**	**Dev.**
TC + RGH + FRich + GH + NSC	0.00	0.58	9	713.64
TC + RGH + FRich + GH + NSC + SC	1.05	0.35	10	712.69
TC + RGH + FRich + GH + SC	6.37	0.02	9	720.01
TC + RGH + FRich + GH + FH	7.29	0.02	8	722.93
TC + RGH + FRich + GH + FC	7.70	0.01	9	721.34
TC + RGH + FRich + GH + FC	8.51	0.01	8	724.15
TC + RGH + FRich + GH	9.87	0.00	7	727.52
TC + RGH + FRich + FH	10.50	0.00	7	728.14
TC + RGH + FRich + GH + TRich	11.87	0.00	8	727.51
TC + RGH + FRich + FC	16.27	0.00	7	733.91
TC + RGH + FRich	17.81	0.00	6	737.45
TC + RGH + FRich + GRich	17.84	0.00	7	735.48
TC + RGH + FRich + TRich	19.69	0.00	7	737.33
TC + RGH + TR	21.68	0.00	6	741.33
TC + RGH + FH	31.10	0.00	6	750.74
TC + RGH + FC	34.14	0.00	6	753.79
TC + RGH + GH	36.35	0.00	6	756.00
TC + RGH + GRich	39.83	0.00	6	759.48
TC + RGH	42.93	0.00	5	764.57

TC + FRich	47.90	0.00	5	769.54
TC + TR	50.71	0.00	5	772.35
TC + FH	57.21	0.00	5	778.85
TC + GH	57.90	0.00	5	779.54
TC + FC	63.52	0.00	5	785.16
TC + GRich	65.10	0.00	5	786.75
TC	69.27	0.00	4	792.92
TC + GC	70.24	0.00	5	791.88
FRich	83.05	0.00	4	806.70
FH	83.76	0.00	4	807.40
TRich	86.97	0.00	4	810.61
FC	89.78	0.00	4	813.43
GH	92.28	0.00	4	815.92
RGH	94.48	0.00	4	818.12
GRich	121.69	0.00	4	845.34
SC	122.94	0.00	4	846.58
GC	124.53	0.00	4	848.17
TSC	126.96	0.00	4	850.60
Null	127.87	0.00	3	853.51
NSC	128.95	0.00	4	852.59
SH	129.08	0.00	4	852.72
SRich	129.59	0.00	4	853.23

[a] Model selection notation follows Burnham and Anderson (2002). All models include random intercepts for year and individual. Horizontal cover variables included non-sagebrush shrub cover (NSC), sagebrush shrub cover (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich, GRich, SRich, and TRich represented forb, grass, shrub, and total taxa richness within a given plot, respectively. Null denotes intercept-only model. All variables were z-standardized prior to analysis.

Table S5. Parameter estimates from resource selection functions based on generalized linear mixed models to assess the influence of habitat characteristics on greater sage-grouse brood site selection in Eureka County, NV, 2005-2012.

Parameters	β	Lower 85% Confidence Interval	Upper 85% Confidence Interval
FC_{10}	0.71	0.54	0.89
$FRich_{10}$	0.78	0.61	0.95
GC_{10}	0.24	0.09	0.39
$GRich_{10}$	0.30	0.15	0.45
RGH_{10}	0.66	0.48	0.83
FH_{10}	0.75	0.58	0.93
GH_{10}	0.70	0.52	0.87
NSC_{10}	-0.09	-0.24	0.05
SC_{10}	0.26	0.12	0.41
SH_{10}	0.09	-0.06	0.24
$ShrubRich_{10}$	0.05	-0.09	0.19
TC_{10}	0.86	0.69	1.03
$TotalRich_{10}$	0.77	0.60	0.95
TSC_{10}	0.18	0.03	0.33
Elev	0.67	0.60	0.75
Slope	0.23	0.15	0.30
DSpring	0.03	-0.05	0.10
WF_{500}	-0.08	-0.17	0.00

WF_{1000}	-0.09	-0.18	-0.01
WF_{2000}	-0.07	-0.15	0.01
$Sage_{500}$	0.72	0.62	0.83
$Sage_{1000}$	0.75	0.64	0.87
$Sage_{2000}$	0.76	0.64	0.88
PJ_{500}	-0.87	-1.03	-0.70
PJ_{1000}	-0.74	-0.88	-0.60
PJ_{2000}	-0.45	-0.55	-0.34

Parameter estimates are each from a single variable model. Subscripts denote the scale of the variable (i.e., within 10m, or a radius of 500m, 1000m, or 2000m from a point), superscripts denote quadratic relationships. DLek, DRoad, and DSpring represent distance (in m) from nearest active lek, nearest road, and nearest spring or water source, respectively. Sage represented the proportion of habitat classified as sagebrush at a specified scale; WF represented the proportion of habitat converted to exotic grasslands due to wildfire at a specified scale; PJ represented the proportion of habitat classified as pinyon-juniper woodlands at a specified scale. Elev represented the elevation (in m) of a point; Slope represented the slope (in degrees) of a point. Horizontal cover variables included non-sagebrush shrub cover (NSC), sagebrush shrub cover (SC), total shrub cover (TSC), forb cover (FC), grass cover (GC), and total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich, GRich, SRich, and TRich represented forb, grass, shrub, and total taxa richness within a given plot, respectively. All covariates were z-standardized prior to analysis.

FEMALE SURVIVAL

Model Modifications

We modified the analyses reported in Blomberg et al. (2013) by the following: 1) inclusion of an additional year of data [i.e., 2012]; 2) inclusion of additional predictor variables; and 3) transitioning the modeling framework from a known-fate analysis to that of a nest survival model.

Table S6. Performance of all nest survival models used to assess the influence of environmental characteristics on adult female Greater sage-grouse survival in Eureka County, NV, 2003-2012.

Model[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
Elev + Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	0.00	0.26	9	1511.44
Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	0.51	0.20	8	1513.96
PJ + Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	1.01	0.16	9	1512.45
Road + Seasons + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	1.40	0.13	9	1512.84
Month + Winter + PreBreeding + Age_{min} + $Hatch_{summer}$ + $Fledge_{fall}$	5.50	0.02	13	1508.90
Month + Winter + PreBreeding + Age_{min}	10.36	0.00	11	1517.77
Seasons	11.77	0.00	4	1533.25
Month + Winter + $Hatch_{summer}$ + $Fledge_{fall}$	13.62	0.00	11	1521.04
Month + Winter + Elev	14.55	0.00	10	1523.98
Month + Winter + $Fledge_{fall}$	14.60	0.00	10	1524.03
Month + Winter + $Hatch_{summer}$	15.48	0.00	10	1524.91
Month + Winter + PreBreeding + Age_{min}^2	15.74	0.00	12	1521.14
Month + Winter + PreBreeding	16.01	0.00	10	1525.44
Month + Winter + PJ	16.75	0.00	10	1526.17
Month + Winter + Age_{min}	16.76	0.00	10	1526.19
Month + Winter	17.15	0.00	9	1528.59

Month + Winter + Fire	17.71	0.00	10	1527.14
Year + Month + Winter	25.69	0.00	18	1519.00
(.)	62.91	0.00	1	1590.40
Year	73.17	0.00	10	1582.60

[a] Model selection notation follows Burnham and Anderson (2002). Month + Winter (no. par = 9) allows survival during March – October to estimate independently but constrained to estimate together from November – February. Seasons (no. par = 4) constrains monthly survival into seasonal blocks (i.e., March-May, June-July, August-October, and November – February) that estimate independently from each other. Year (no. par = 10) allows survival each year (2003-2012) to estimate independently from another. Elev is a monthly (March- October) time-varying covariate that represents the average elevation from all locations of a radio-marked female during that month. PJ is a monthly (March- October) time-varying covariate that represents the average proportion of area classified as Pinyon-Juniper within 5km from all locations of a radio-marked female during that month. Fire is a monthly (March- October) time-varying covariate that represents the average proportion of area classified as exotic grasslands within 5km from all locations of a radio-marked female during that month. Road is a monthly (March- October) time-varying covariate that represents the average distance between each location of a radio-marked female and the nearest road. PreBreeding is a binomial (yes/no) variable modeled on post-breeding months (August-February) that delineates young-of-year individuals from females that have survived at least one breeding season. Age_{min} represents the minimum age for each female each year. $Hatch_{summer}$ is a binomial (yes/no) variable modeled on the season immediately following hatching (June-July) that delineates females that successfully hatched a nest from those that did not. $Fledge_{fall}$ is a binomial (yes/no) variable modeled on the season immediately

following fledging (August-October) that delineates females that successfully fledged at least one chick from those that did not.

RECRUITMENT AND POPULATION GROWTH

Model Modifications

We modified the analyses reported in Blomberg et al. (2012) by the following: 1) inclusion of two additional year of data [i.e., 2011-2012]; 2) inclusion of additional predictor variables; and 3) including increased model parameterization that allowed for lek specific estimates of per capita recruitment and lambda. Additional predictor variables included various metrics of vegetation composition (e.g., total percent vegetation cover, percent sagebrush cover) derived from vegetation surveys generated from random locations within 5km from each lek. Each lek was assigned the average value for each vegetation variable from all random surveys completed within 5km from the lek.

Table S7. Performance of all Pradel models used to assess the influence of environmental characteristics on per capita recruitment in Eureka County, NV, 2003-2012.

Model[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
r(Prec * WF_{1000} + TC + Elev)	0.00	1.00	35	6414.16
r(Prec + TC + Elev + WF_{1000})	26.67	0.00	34	6442.98
r(Prec + PC + Elev)	27.38	0.00	33	6445.82
r(Prec + TC + RD + FRich + WF + FC)	28.65	0.00	36	6440.67
r(Year + TC + FRich)	29.65	0.00	37	6439.52
r(Prec + TC + FRich)	30.21	0.00	33	6448.66
r(Year + TC + WF_{1000})	32.06	0.00	36	6444.08
r(Year + Lek)	32.40	0.00	43	6429.29
r(Year + TC + FC)	32.54	0.00	37	6442.41
r(Year + TC)	33.06	0.00	36	6445.08
r(Prec + TC + WF_{1000})	34.21	0.00	33	6452.65
r(Year + TC + SH)	34.85	0.00	37	6444.72
r(Year + Elev)	42.08	0.00	36	6454.10
r(Prec + Elev + WF_{1000})	45.49	0.00	33	6463.94
r(Year + WF_{1000})	46.39	0.00	36	6458.41
r(Year + RD)	49.07	0.00	36	6461.09
r(Year + FC)	49.54	0.00	36	6461.56
r(Year + SH)	50.47	0.00	35	6464.63
r(Lek)	55.80	0.00	39	6461.35
r(Year + FRich)	60.34	0.00	36	6472.36

r(Year)	61.76	0.00	34	6478.06
r(Year + DSpring)	61.93	0.00	36	6473.95
r(Year + FH)	62.24	0.00	36	6474.26
r(Prec)	62.47	0.00	31	6485.18
r(Year + RGH)	62.50	0.00	36	6474.52
r(Year + Pop)	63.04	0.00	36	6475.06
r(Year + GC)	64.40	0.00	36	6476.42
r(Year + TSC)	64.93	0.00	36	6476.95
r(Year + SC)	65.00	0.00	36	6477.02
r(Year + NSC)	65.10	0.00	36	6477.12
r(Year + GH)	65.22	0.00	36	6477.24
r(Elev)	72.35	0.00	31	6495.05
r(.)	84.10	0.00	30	6508.93

[a] Model selection notation follows Burnham and Anderson (2002). All models had identical constraints on survival and detection that allowed survival to vary by year (no. par = 9) and detection to vary by year (no. par = 10) and lek (no. par = 10). Elev Horizontal cover variables included average non-sagebrush shrub cover (NSC), average sagebrush shrub cover (SC), average total shrub cover (TSC), average forb cover (FC), average grass cover (GC), and average total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represents average forb taxa richness across all vegetation surveys associated with each lek. (.) denotes intercept-only model. All variables were z-standardized prior to analysis.

Table S8. Performance of all Pradel models used to assess the influence of environmental characteristics on population growth in Eureka County, NV, 2003-2012.

Model[a]	**ΔAIC_c**	**$AIC_c\ w_i$**	**No. Par**	**Dev.**
λ(TC + Prec * WF + Elev)	0.00	0.37	35	6404.81
λ(TC + RD + Prec * WF + Elev)	0.69	0.26	36	6403.35
λ(TC + RD + Prec * WF)	0.79	0.25	35	6405.59
λ(TC + RD + Prec * WF + DSpring + Elev)	2.37	0.11	36	6405.03
λ(FC + Prec * WF + DSpring + Elev)	9.83	0.00	35	6414.64
λ(FC + SH + Prec * WF + DSpring + Elev)	11.86	0.00	36	6414.52
λ(WF * Prec + Elev)	12.23	0.00	34	6419.18
λ(WF * Prec)	25.70	0.00	33	6434.79
λ(Elev * Prec + WF)	31.28	0.00	34	6438.22
λ(Lek + Prec)	39.80	0.00	41	6431.67
λ(TPC + Prec + RD)	41.11	0.00	33	6450.19
λ(TPC + Prec + RD + WF)	41.72	0.00	34	6448.66
λ(TPC + Prec)	42.29	0.00	32	6453.50
λ(TPC + Prec + RD + WF + DSpring)	43.40	0.00	35	6448.21
λ(Year + Lek)	52.25	0.00	48	6428.83
λ(Elev + Prec)	53.35	0.00	32	6464.57
λ(Lek)	56.03	0.00	40	6450.07
λ(TPC)	58.01	0.00	31	6471.36
λ(Year + Elev)	65.32	0.00	39	6461.51
λ(Prec)	65.38	0.00	31	6478.73

λ(Elev)	68.75	0.00	31	6482.09
λ(Slope)	69.42	0.00	31	6482.76
λ(SH)	71.73	0.00	31	6485.08
λ(FH)	76.20	0.00	31	6489.54
λ(RD)	76.35	0.00	31	6489.70
λ(FC)	76.73	0.00	31	6490.07
λ(Year)	77.50	0.00	38	6475.86
λ(Year + WF)	79.15	0.00	39	6475.35
λ(.)	80.20	0.00	30	6495.67
λ(DSpring)	80.28	0.00	31	6493.62
λ(FRich)	81.75	0.00	31	6495.09
λ(SC)	82.01	0.00	31	6495.36
λ(WF)	82.06	0.00	31	6495.41
λ(GC)	82.08	0.00	31	6495.42
λ(TSC)	82.11	0.00	31	6495.45
λ(RGH)	82.11	0.00	31	6495.46
λ(NSC)	82.29	0.00	31	6495.64
λ(GH)	82.31	0.00	31	6495.66

[a] Model selection notation follows Burnham and Anderson (2002). All models had identical constraints on survival and detection that allowed survival to vary by year (no. par = 9) and detection to vary by year (no. par = 10) and lek (no. par = 10). Elev Horizontal cover variables included average non-sagebrush shrub cover (NSC), average sagebrush shrub cover (SC), average total shrub cover (TSC), average forb cover (FC), average grass cover (GC), and average

total vegetation cover (TC). Vertical cover variables included average shrub height (SH), average forb height (FH), average live grass height (GH), and average residual grass height (RGH). FRich represents average forb taxa richness across all vegetation surveys associated with each lek. (.) denotes intercept-only model. All variables were z-standardized prior to analysis.

SUPPLEMENTAL MATERIAL – B

JAGS Code:

SUPPLEMENTAL MATERIAL – C

JAGS Code