Crowned Ridge Sharp-tailed Grouse Research Study

Final Report

Crowned Ridge I and II Wind Energy Projects

Grant, Codington, and Deuel Counties, South Dakota

Prepared for:

Crowned Ridge Wind I and Crowned Ridge Wind II, LLC

South Dakota Game Fish & Parks
895 Third Street Southwest
Huron, South Dakota 57350

Prepared by:

Kurt Smith[1], Carly Stumpner[1], Chad LeBeau[1], and Alex Solem[2]

[1] Western EcoSystems Technology, Inc.
1610 East Reynolds Street
Laramie, Wyoming 82072

[2] South Dakota Game, Fish & Parks
895 Third Street Southwest
Huron, South Dakota 57350

June 01, 2023

WEST

EXECUTIVE SUMMARY

Crowned Ridge Wind I, an indirect, wholly owned subsidiary of NextEra Energy Resources, LLC (NEER), constructed the Crowned Ridge I Wind Energy Facility (CRI) in Grant and Codington counties, South Dakota, and began commercial operations in December 2019. Crowned Ridge Wind II, LLC, a wholly owned, indirect subsidiary of NEER, began constructing Crowned Ridge II Wind Energy Facility (CRII) immediately to the south of the CRI project boundary in May 2020, and began commercial operations in December 2020. Shortly after CRII began commercial operation, ownership of CRII was transferred from NEER to Northern States Power Company. CRI worked collaboratively with Western Ecosystems Technology, Inc. and South Dakota Game, Fish, and Parks (SDGFP) to develop a plains sharp-tailed grouse (STGR; *Tympanuchus phasianellus jamesi*) research study to better understand the effects of wind energy infrastructure on STGR populations.

While some information exists on the effects of wind energy infrastructure on prairie grouse populations, no studies have directly measured STGR behavioral responses to wind energy infrastructure. The presence of known STGR within CRI and CRII (hereafter, Projects) provided a valuable opportunity to evaluate the potential effects that wind energy infrastructure may have on STGR populations. In accordance with Permit Condition Number 45 of the South Dakota Public Utility Commission order, CRI conducted two years of post-construction prairie grouse lek monitoring to evaluate the project's effects on the local prairie grouse population. In addition, CRI worked collaboratively with SDGFP to develop a Grouse in Lieu Mitigation Plan that incorporated an approved lek monitoring and robust telemetry study plan. The Grouse in Lieu Mitigation Plan outlined goals and objectives of the lek monitoring study and the telemetry study, both of which had the same goal of quantifying the effects of wind energy infrastructure on the local STGR population.

More specifically, the overall goal of this study was to quantify the effects of wind energy infrastructure on STGR lek trends, seasonal habitat selection, and demography. From 2020–2022, monitoring of known leks and surveys for new leks were conducted within six miles (mi; 10 kilometers [km]) of the Projects' boundaries to understand the extent of the local breeding STGR population. Breeding STGR were captured and marked with Global Positioning System transmitters to collect information about habitat selection and demography in relation to wind energy infrastructure. Commonly employed analytical techniques were used to 1) evaluate trends in STGR attending leks located within six miles of the Projects' boundaries, 2) predict the relative probability of female STGR resource selection to estimate potential behavioral avoidance associated with wind energy infrastructure at two scales of selection, and 3) predict nest and female survival during the breeding season relative to wind energy infrastructure. Resource selection was assessed at both the population level (selection of habitat based on the range of all marked female STGR; home-range scale) and the individual level (an individuals' selection of resources based on availability within each individual's seasonal ranges; within home range scale). Resource selection and survival were evaluated across three distinct life stages: nesting, brood-rearing, and breeding.

Lek monitoring and surveys occurred between the middle of March and late April each year. The mean maximum male STGR count at monitored leks was six in 2020, nine in 2021 and eight in 2022. Overall, lek counts appeared to be relatively stable over the study period. Over the course of the study, we monitored 126 female STGR. Resource selection models included locations of 75 nests, 5,364 brood-rearing locations from 17 broods, and 72,452 breeding season locations. Survival analyses included observations from 65 first nest attempts and 112 female STGR.

We did not detect an effect of wind turbine distance or density on nest site selection at the home range or within home range scales, which is consistent with other studies evaluating prairie grouse responses to wind energy development. In addition, we found little evidence to suggest females with broods avoided areas influenced by wind turbines. For example, we found that females with broods selected areas closer to turbines and with more turbines within 1.3 km at the home range scale. At the finer, within home range scale, females with broods selected areas with up to approximately four turbines within 1.0 km. Overall, this provides little evidence that brood-rearing STGR avoided wind turbines given the average number of turbines within 1.0 km of a point on the landscape within the study area was less than one (mean = 0.35; range: 0–8).

In contrast, we found evidence that resource selection by female STGR during the breeding season was associated with wind energy infrastructure. At the home range scale, we found that STGR selected areas farther from wind turbines, but also in areas with greater turbine density within 3.2 km. The spatial predictions of the home range breeding season models, which also accounted for other attributes of STGR habitat, however, provided limited support that wind turbines resulted in avoidance by STGR at this scale. At the within home range scale a count of 20–35 wind turbines within 5.0 km represented a potential threshold where STGR avoidance of wind turbines was greatest. However, there was uncertainty in the response beyond 35 wind turbines within 5.0 km. The within home range breeding season model predicted an approximate 85 to 93% reduction in relative probability of selection when the number of wind turbines increased from zero to 20 or zero to 35 wind turbines within 5.0 km, respectively. To put this response in perspective, the average number of turbines within 5.0 km of a point on the landscape within the study area was 9 (range: 0–57) and approximately 19% of the study area contained more than 20 wind turbines within 5.0 km.

Similar to other studies evaluating grouse responses to wind energy development, we did not detect an effect of wind energy infrastructure on nest survival. Our results provided some evidence that female survival during the breeding season was negatively associated with wind energy infrastructure. However, this effect had weak statistical support and was not considered further. Other studies have found that female survival increased or was not influenced by wind energy infrastructure following construction. Nonetheless, we cannot rule out the possibility that other unmeasured environmental factors influenced both nest and female survival, which could have been potentially uncovered with a longer term dataset.

Although we observed avoidance behavior associated with wind energy infrastructure during the breeding season, relatively stable lek trends over the 3-year study suggest that this behavioral response has not resulted in population level declines. This is based on an assumption that lek counts are suitable indices of population trends, which is supported in the literature. Other prairie grouse research has found that population trends, indexed by lek counts, are not negatively impacted by wind energy infrastructure, although there is some evidence that lek persistence may be lower closer to turbines. Nonetheless, our findings support the existing body of evidence that prairie grouse may not experience population level impacts over the short term following development of wind energy facilities.

REPORT REFERENCE

Smith. K., C. Stumpner, C. LeBeau, and A. Solem. 2023. Crowned Ridge Sharp-tailed Grouse Research Study Final Report for the Crowned Ridge I and II Wind Energy Projects, Grant, Codington, and Deuel Counties, South Dakota. Prepared for Crowned Ridge Wind I and Crowned Ridged Wind II, LLC, Huron, South Dakota. Prepared by Western EcoSystems Technology, Inc., Laramie, Wyoming, and South Dakota Game, Fish & Parks, Huron, South Dakota. June 01, 2023.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Crowned Ridge Wind I, LLC (CRI) an indirect, wholly owned subsidiary of NextEra Energy Resources, LLC (NEER), constructed the Crowned Ridge I Wind Energy Facility in Grant and Codington counties, South Dakota. Construction began on 200 megawatts (MW) of the permitted 300 MW in August 2019 and commercial operations began in December 2019. Crowned Ridge Wind II, LLC (CRII), a wholly owned, indirect subsidiary of NEER, began constructing the Crowned Ridge II Wind Energy Facility immediately to the south of the CRI project boundary in May 2020 and began commercial operations in December 2020. Shortly after CRII began commercial operation, ownership of CRII was transferred from NEER to Northern States Power Company. The presence of known sharp-tailed grouse (*Tympanuchus phasianellus*) within CRI and CRII (hereafter, Projects) and the high probability of lek occurrence surrounding the Projects (Runia et al. 2021), provided a valuable opportunity to evaluate the effects of wind energy development on sharp-tailed grouse (Figure 1). CRI worked collaboratively with South Dakota Game, Fish and Parks (SDGFP) to develop a Grouse In Lieu Mitigation Plan (Mitigation Plan; Crowned Ridge Wind LLC 2019a, 2019b) that incorporated an approved lek monitoring and robust telemetry study plan to better understand the effects of wind energy infrastructure on sharp-tailed grouse populations, with the goal of providing crucial information to assist with future siting and permitting decisions.

Sharp-tailed grouse are a generalist grouse species split into six subspecies distributed across much of central and northwestern North America (Connelly et al. 2020). The most widespread of the subspecies, and focus of this research, the plains sharp-tailed grouse (*Tympanuchus phasianellus jamesi*; STGR), has been recognized as an indicator species for grassland ecosystems (Roersma 2001). Due to their extensive range across areas with high wind capacity, STGR are exposed to the greatest number of wind turbines when compared to prairie chickens (*Tympanuchus* spp.) or greater sage-grouse (*Centrocercus urophasianus*.; Lloyd et al. 2022), and no studies have directly measured potential impacts to STGR.

While information is available regarding impacts of wind energy development and associated infrastructure to grouse, results have generally been mixed. For example, in Wyoming, LeBeau et al. (2014) reported lower greater sage-grouse nest and brood survival in habitats closer to wind turbines two years following development. However, over a 6-year period after development at the same facility, LeBeau et al. (2017b) failed to detect negative effects on greater sage-grouse nest, brood, or summer female survival. In Idaho, Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) nest survival was not influenced by proximity to turbines (Proett et al. 2019); however, turbine density was negatively associated with chick survival (Proett et al. 2022). Greater prairie-chicken (*Tympanuchus cupido*) and lesser prairie-chicken (*Tympanuchus pallidicinctus*) nest and female survival was not influenced by proximity to wind turbines in Nebraska or Kansas (Winder et al. 2014, Harrison et al. 2017, Smith et al. 2017, LeBeau et al. 2023). These studies highlight the variability in effects of survival; however, avoidance behaviors associated with wind energy infrastructure could possibly mask the ability to detect any potential survival consequences.

LeBeau et al. (2017b) found that greater sage-grouse selection for brood-rearing and summer habitats was negatively correlated with surface disturbance associated with wind energy infrastructure. Similar displacement behaviors have also been documented for greater prairie chickens, with avoidance of wind turbines in Kansas (Winder et al. 2014). Lesser prairie-chickens in Kansas avoided areas with high turbine density near large intact grasslands (LeBeau et al. 2023). These findings suggest that there is some level of indirect loss of potentially suitable habitat because of wind energy infrastructure. However, the available literature does not suggest that avoidance behaviors translate to population level effects (LeBeau et al. 2017a, LeBeau et al. 2023).

Power lines (transmission and distribution lines) that are often associated with wind energy infrastructure also have the potential to affect grouse populations directly and indirectly. Although rare, direct mortality caused by collision with power lines has been documented (Beck et al. 2006, Wolfe et al. 2007) and indirect effects could include displacement and survival consequences similar to wind energy infrastructure (Gibson et al. 2018, LeBeau et al. 2019, Londe et al. 2019).

The overall goal of this research was to quantify the effects of a wind energy development on STGR lek trends, habitat selection, and demography over a 3-year period. The study was designed to incorporate the analysis of spatial and demographic data collected from observations of lek trends and marked individuals. The study protocol included data collection during multiple STGR breeding seasons along a distance gradient from wind turbines over a period that included construction and operations of the Projects. Specifically, the objectives were to 1) evaluate trends in STGR attending leks located within six miles (mi; 10 kilometers [km]) of the Projects boundaries, 2) predict the relative probability of female STGR resource selection during nesting, brood-rearing, and the breeding season to estimate potential behavioral avoidance effects associated with wind energy infrastructure at two scales of selection, and 3) predict nest and breeding season survival relative to wind energy infrastructure. The purpose of this report is to summarize data collected during the study period and provide detailed results on the responses of this STGR population to wind energy development, ultimately fulfilling the objectives of the Mitigation Plan (Crowned Ridge Wind LLC 2019a, 2019b).

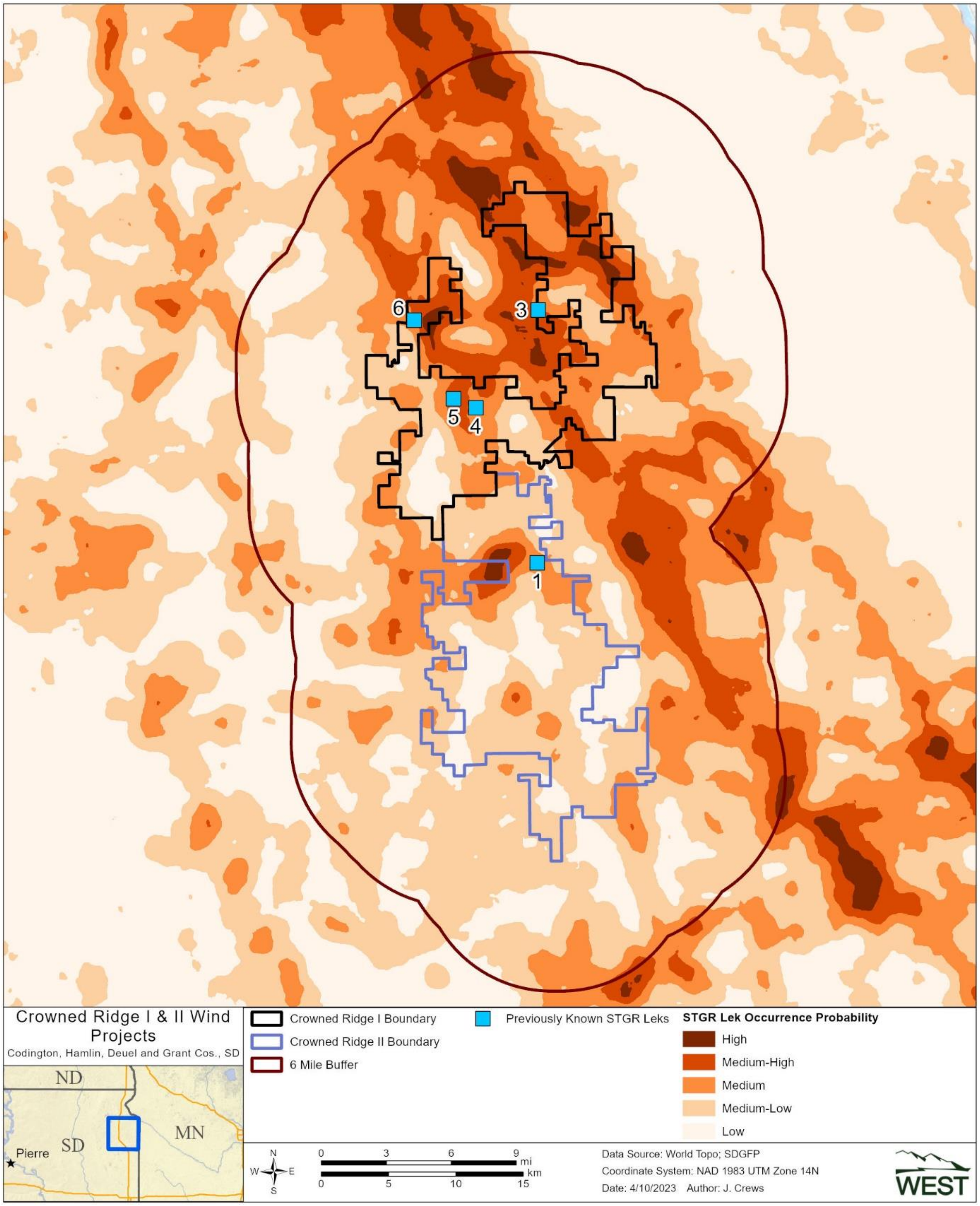

Figure 1. Previously known plains sharp-tailed grouse (STGR) leks within Crowned Ridge I (CRI) and Crowned Ridge II (CRII) Wind Energy Facility boundaries overlaying probability of STGR lek occurrence modeled by South Dakota Game, Fish, and Parks (Runia et al. 2021).

STUDY AREA

The study area is located in Grant, Codington, and Deuel counties, South Dakota, and was demarcated as the area encompassing a six mile buffer around the Projects (549,177 acres [222,244 hectares]; Figure 2). A six mile buffer was used to delineate the area for initial STGR lek searches and subsequent captures (described below). CRI consisted of 87, 2.3-MW turbines that were constructed prior to the study in 2019. CRII consisted of 88, 2.3-MW turbines that became operational in 2020. Twenty-six CRI or CRII turbines (14.8%) were sited in grassland according to National Land Cover Database. The proportion of grassland within 1.0 km of each turbine varied (mean = 0.29; range = 0.00–0.85; Figure 2). Other wind energy facilities in the region included Dakota Range I and II (72, 2.2–4.5-MW turbines operational in 2021) and Dakota Range III (32, 4.5-MW turbines operational in 2021) to the northwest, and Deuel Harvest North (101, 2.8-MW turbines operational in 2019) and Tatanka Ridge (50, 2.8-MW turbines and six, 2.3-MW turbines operational in 2021) to the southeast (Figure 2). The number of turbines in the study area ranged from 102 in April 2020 to 258 at the end of the study in August 2022. The study area is almost entirely privately owned land. However, several small state and federally managed wildlife management areas and waterfowl production areas intersperse the region. Annual precipitation ranged from 24.0–28.0 inches (61.0–71.1 centimeters; 30-year average; PRISM Climate Group 2021). Elevation ranged from 965–2,083 feet (294–635 meters; US Geological Survey [USGS] 2023). The study area is classified as tallgrass prairie within the Northern Great Plains Region (Johnson and Larson 2016) comprising a matrix of grassland and cultivated cropland (Figure 2).

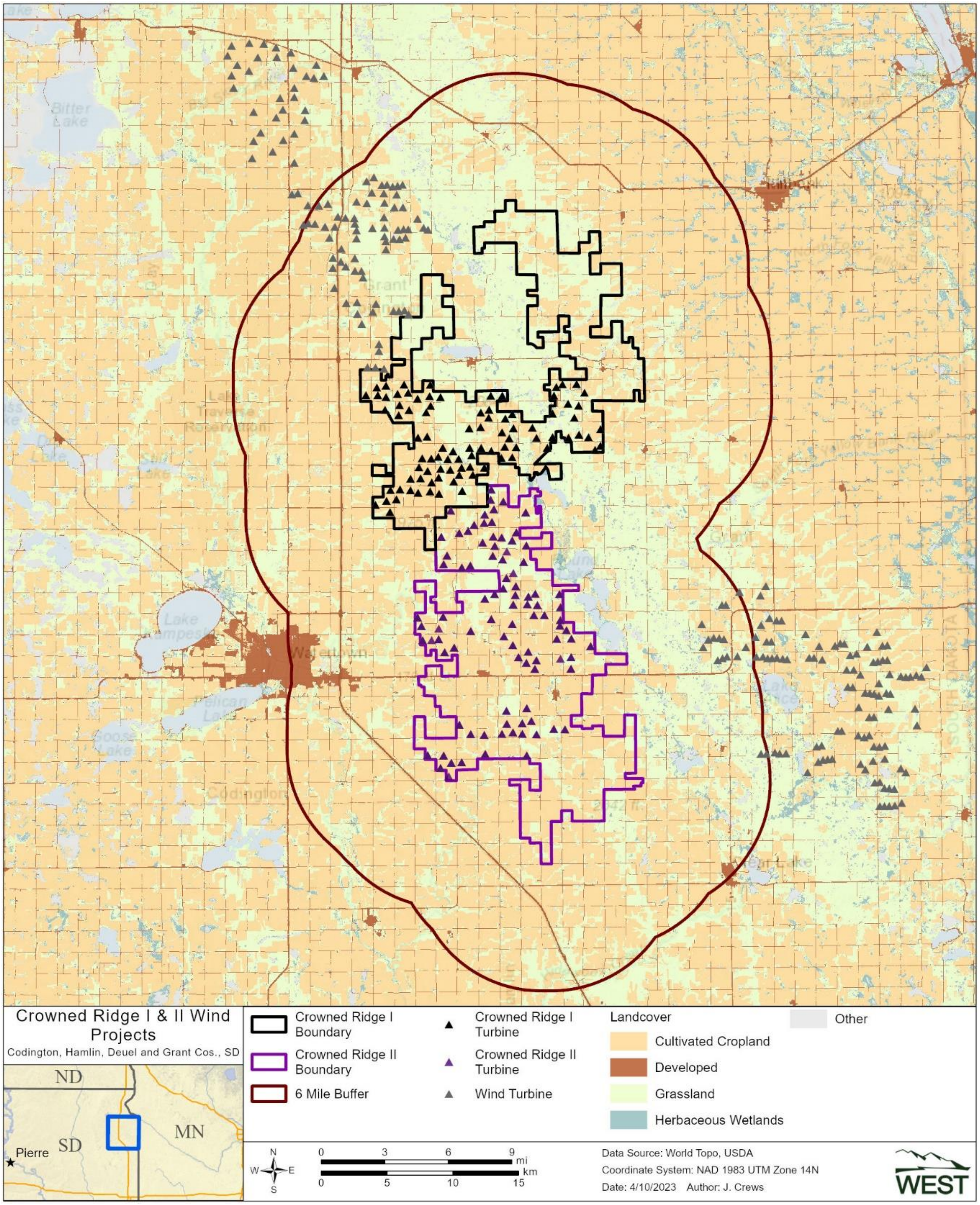

Figure 2. Study area located in Grant, Codington, and Deuel counties, South Dakota, including locations of wind turbines and land cover types.

METHODS

Lek Counts and Surveys

Previously known lek locations within the study area were provided by SDGFP and NEER. During each spring, biologists searched for previously undocumented leks (i.e., two or more displaying males) and visited known leks to count the number of individual STGR in attendance. Biologists conducted ground-based lek counts during three or four mornings each year at all known leks during the lekking period. An aerial lek survey was conducted in 2020 to search for previously unknown leks to help supplement ground-based survey efforts. Counts were spaced approximately seven days apart and occurred between 30 minutes (min) before sunrise and 90 min after sunrise. Observers scanned each lek for a minimum of 10 min and counted the total number of individuals attending the lek. In the event a known lek was not located, observers searched within 1.9 km, when landowner access was possible, to determine if the lek moved. The 1.9 km search area was based on inter-annual movement of lek locations documented in prairie grouse populations (Hovick et al. 2015). Lek counts were only conducted when conditions included clear to partly cloudy skies, wind speeds less than 32 km per hour, and no moderate or heavy precipitation. The maximum number of male STGR observed at each lek during each survey was recorded.

Capture and Monitoring

Results from the lek surveys were used to identify which leks would be targeted for capturing STGR. Targeted leks for capture were based on the number of males observed on a lek, proximity to turbines, and landowner access. Female STGR were targeted for captures, given their contribution to population growth rates (Milligan et al. 2018), but males were targeted after peak female lek attendance passed. However, male STGR were not included in subsequent analyses, but may be used to address additional questions in the future. STGR were captured from leks using walk-in drift traps during the spring lekking period, March – late April (Haukos et al. 1990). STGR were sexed based on tail feather striation and color of crown feathers, aged as juveniles or adults based on the shape and condition of the ninth and tenth primary features (Ammann 1944, Henderson et al. 1967). Individuals were fit with a Global Positioning System (GPS)-Ultra High Frequency (UHF) solar-powered telemetry unit (Ecotone Harrier GPS-UHF, Saker GPS-GSM model L) with a modified rump-mounting harness (Bedrosian and Craighead 2009). Telemetry units were approximately 0.6 ounces (17.0 grams) in mass (less than 3% body weight; Phillips et al. 2003). STGR were captured following procedures under a SDGFP scientific collection permit (Permit No. 14) to capture, mark and monitor grouse. Captures were conducted to minimize stress and individuals were released as soon as possible following capture.

The solar-powered GPS units fit to each individual uploaded locations via cellular transmission (3G). This enabled near real-time assessment of location data. GPS units were programmed to collect locations every 15 min. We masked locations recorded from each individual immediately following capture and assumed that individuals acclimated to the GPS transmitters following two days post capture. In addition, these units had Very High Frequency (VHF) capability to allow for manual tracking. Each year, individuals were tracked on the ground beginning in late May using a R4000 Advanced Telemetry Systems (Isanti, Minnesota) receiver and 3- or 5-element Yagi antennas to evaluate demographic parameters (described below). We used fixed-wing aircraft flights to locate individuals that went missing. In the event locations were localized for more than a day indicating a mortality, a biologist visited the location to retrieve the GPS unit and determine cause of death, if possible. In mid-June of 2022, major cell phone carriers disabled their 3G networks (South Dakota Public Utilities Commission 2021). This resulted in GPS units no longer able to upload locations remotely. Biologists recognized the failure for data to be uploaded using 3G networks within a week of networks being disabled. Biologists began locating grouse on the ground using VHF telemetry and downloading data utilizing the UHF capabilities of the transmitters where possible.

Nests were located by visually inspecting location data that indicated homing by females to a single location (± GPS location error). STGR have an approximately 23-day incubation period (Johnsgard 1983). If a female left the nest location prior to 23-days, we considered the nest to have failed. Nests were visited to confirm nest fate and nests were considered successful when at least one egg hatched (Rotella et al. 2004). A biologist also manually tracked the bird with VHF telemetry to confirm nest fate by visually observing chicks or brooding behavior by the female (e.g., distraction displays or injury feigning). When a female successfully hatched a nest, brood fate was determined during the initial telemetry visit by either visually observing the female with at least one chick, or observing the female exhibiting brooding behavior. Brood status was confirmed with telemetry visits at approximately 35 days post-hatch, and a female was considered to have successfully reared a brood when at least one chick was present with the female during the 35-day post-hatch visit. If brood status could not be determined during the 35-day visit, a second visit was conducted the following day. All females were monitored throughout the study period regardless of nest or brood fate.

Spatial Predictor Variables

We investigated both habitat and wind energy infrastructure variables to assess STGR habitat selection and survival (Table 1). We used land cover data from the US Department of Agriculture (USDA) National Agricultural Statistical Service (USDA 2023) to estimate the proportion of canopy cover of alfalfa (*Medicago sativa*), corn (*Zia mays*), herbaceous wetland, grassland, soybeans (*Glycine max*), total crop cover (included alfalfa, corn, and soybeans), and developed areas (included roads, dwellings, and associated infrastructure [USDA 2023]). Major crop cover variables (corn, alfalfa, and soybeans) were selected based on their abundance on the landscape and visual observations of STGR utilizing specific cover types by biologists in the field. Land cover data were available each year. Therefore, STGR location data were temporally matched to the appropriate year to most accurately reflect conditions when locations were recorded.

A digital elevation model (USGS 2023) was used to create a Terrain Roughness Index (TRI) and Terrain Positioning Index (TPI). TRI was calculated as the mean difference between a raster cell and the eight surrounding cells (Wilson et al. 2007). TPI compared the elevation of each cell to the mean elevation of the eight surrounding cells. Positive and negative TPI values represent areas that are higher or lower than their surrounding areas, respectively (Guisan et al. 1999). Distance to roads was calculated using data from the South Dakota Department of Transportation (2022), Minnesota Department of Transportation (2012), as well as service roads to turbines that were manual digitized. Distance to roads was calculated using the Euclidean Distance tool in ArcGIS Desktop version 10.8.

Wind energy and transmission line covariates (hereafter, collectively referred to as wind energy infrastructure variables) included distance to turbine (km), distance to transmission line (km), turbine density (count of turbines), and length of transmission lines (km; transmission line density). Locations of turbines were obtained from the United States Wind Turbine database (Hoen et al. 2018) and information on timing of construction and commercial operation dates were verified with direct communication with the wind energy facility operators. Transmission and distribution line data was obtained from the Department of Homeland Security (2022). Transmission and distribution line voltage ranged from 69 to 345 kilovolts. Wind energy covariates were time-stamped to accurately reflect when infrastructure was present on the landscape.

We assessed all habitat covariates (excluding Euclidean-distance based covariates) within six radii circular scales; 0.2-km, 0.5-km, 1.0-km, 1.3-km, 3.2-km, and 5.0-km radii. Wind energy infrastructure variables were assessed within 1.0-km, 1.3-km, 3.2-km, and 5.0-km. TPI and TRI were also assessed at local scale (raster pixel). Scales were determined based on previous research on spatial use patterns (Milligan et al. 2020b, Runia et al. 2021) and current management recommendations for wind energy development siting (North Dakota Game and Fish 2021). Variables were created using the Focal Statistics tool in ArcGIS Desktop version 10.8.

Table 1. Spatial predictor variables used to assess sharp-tailed grouse (STGR) habitat selection and survival at the Crowned Ridge I and Crowned Ridge II Wind Energy Project, 2020–2022.

Covariate[1]	Description
Habitat variables	
Alfalfa	Alfalfa canopy cover (%; US Department of Agriculture [USDA] 2023)
Corn	Corn canopy cover (%; USDA 2023)
Grassland	Grassland canopy cover (%; USDA 2023)
Herbaceous wetland	Herbaceous wetland (%; USDA 2023)
Soybeans	Soybean canopy cover (%; USDA 2023)
Total crop	Combined canopy cover of alfalfa, corn, miscellaneous crop, and soybeans (%; USDA 2023)
Distance to roads	Euclidean-distance to road (km; South Dakota Department of Transportation 2022, Minnesota Department of Transportation 2012)
Terrain Positioning Index	Mean terrain positioning index (Positive values = area higher than surroundings; negative values = area lower than surroundings; Guisan et al. 1999) derived from a digital elevation model (US Geological Survey [USGS] 2023).
Terrain Roughness Index	Mean topographic ruggedness index (Positive values = area more rugged than surroundings, example: ridges; negative values = area less rugged than surroundings, example: depressions; Wilson et al. 2007) derived from a digital elevation model (USGS 2023).
Wind energy infrastructure variables	
Distance to transmission line	Euclidean-distance to transmission or distribution line (69–345 kilovolt; km; Department of Homeland Security [DHS] 2022)
Distance to turbine	Euclidean-distance to turbine (km; Hoen et al. 2018)
Transmission line length	Length of transmission line (km; DHS 2022)
Turbine density	Count of wind turbines (Hoen et al. 2018)

[1] Non-Euclidean distance habitat variables were estimated across 0.2, 0.5, 1.0, 1.3, 3.2, and 5.0-kilometer (km) radii circular scales. Wind energy infrastructure variables were estimated across 1.0, 1.3, 3.2, and 5.0 km radii scales.

Experimental Design and Analysis

The potential influence of wind energy infrastructure on STGR behavior and demography was assessed using resource selection and survival analyses. We evaluated resource selection of STGR nests, broods, and females during the breeding season (April 1 to August 15), and survival of nests and females. We did not evaluate survival of broods due to insufficient information regarding the timing of brood failure and relatively small sample sizes. In all analyses, we related STGR locations to spatially explicit covariates (Table 1). All statistical analyses were performed in R version 4.1.3 (R Core Team 2022). Second-order Akaike Information Criterion (AICc) was used to assess model support for all models (Burnham and Anderson 2002). Prior to model development, we ran univariate models and retained variables when they were more informative than random intercept only models. Variables were also removed from further consideration if 85% confidence intervals surrounding coefficient estimates included zero (Hosmer and Lemeshow 2000). For non-Euclidean distance based variables that were assessed at multiple radii scales, we retained the variable scale that had the lowest AICc score. Variable screening procedures were done independently for each model.

A variable subsetting approach (Arnold 2010) was used to evaluate the influence of wind energy infrastructure variables on STGR. We first explored all combinations of uncorrelated ($|r| > 0.6$) habitat variables retained after univariate screening that excluded wind energy infrastructure variables. The maximum number of habitat variables in any model was set to six in order to limit potential model overfitting (Burnham and Anderson 2002). We used AICc to rank models and considered the most parsimonious model to be the base model for comparison with models containing wind energy infrastructure variables wind energy covariates. A similar variable screening procedure was used for wind energy infrastructure variables. The base model was then compared to models that included habitat variables in the base model plus all combinations of uncorrelated ($|r| > 0.6$) wind energy infrastructure variables. This modelling approach determined whether models containing wind energy infrastructure variables were more predictive of STGR resource selection or survival compared to models only containing habitat covariates. Candidate models were fitted with package *MuMIn* in R (Bartoń 2022). We allowed each model to compete and selected the most parsimonious model based on AICc (Burnham and Anderson 2004). Covariates in final models that had 95% confidence intervals that included zero were considered uninformative.

Final models that contained wind energy infrastructure variables and had parameter estimates that suggested behavioral avoidance or survival consequences were further evaluated to test for potential thresholds in STGR responses. We investigated quadratic and ramped thresholds for all wind energy infrastructure variables. A ramped threshold describes a gradient of the effect of a specified covariate and identifies a break point where the response to the covariate plateaus (Powell et al. 2017). To determine potential ramped threshold values to assess, we used 10% quantile intervals (ranging from 10 to 90%) based on the distribution of STGR use locations relative to wind energy infrastructure. Therefore, we tested up to nine ramped thresholds and one quadratic threshold for each wind energy infrastructure variable included in the final model. AICc was used to assess support for including nonlinear responses in final models.

Resource selection design and analysis

We used binomial generalized linear mixed models to estimate the relative probability of female STGR nest site, brood-rearing (from hatch to five weeks), and breeding season (April 1 to August 15) resource selection within the study area. Models included the random effect of individual grouse nested within year to account for variation among individuals and across years. Used locations from GPS-marked individuals were rarified to 10 locations per day to minimize spatial autocorrelation (Valcu and Kempenaers 2010). Resource selection was evaluated at the home-range scale (second-order) and within home ranges (third-order) using resource selection functions (RSFs; Johnson 1980, Manly et al. 2002). The home-range scale analyses evaluated resource selection at the population level (selection given available habitat occupied by all marked females), whereas the within home range analyses evaluated resource selection at the individual level (an individual's selection given habitat within each females seasonal range; Figure 3). For all home-range scale analyses, we used 25 times the number of available locations per used (STGR) location. At this scale, available locations were restricted to a 99% fixed kernel (KDE; Worton 1989) surrounding all STGR locations during the breeding season. For within home range analyses, available points were generated within a 99% KDE that was created using locations used by each individual. For the within home range nest analysis, we used locations obtained during the 3-week period preceding nest incubation to determine the area with which to generate available locations. We used a 3-week period to establish the seasonal home range for females that nested as we assumed that this period represented the time when a female was choosing a nest location prior to initiation. We used locations obtained during the 5-week period following hatch or during the breeding season to determine the area to generate available locations for the within home range brood-rearing and breeding season analyses, respectively. Brood-rearing resource selection analyses were restricted to individuals that were known to have broods. Available locations were also generated at a rate of 25 times the number of used locations for within home range analyses.

The predictability of the most parsimonious home range scale breeding season RSF was evaluated using a 5-fold cross-validation (Boyce et al. 2002, Johnson et al. 2006). Predictions were binned into five equal-area (quartile) intervals (Wiens et al. 2008). Validations were performed by running linear regressions on the number of observed locations from test groups compared to expected locations generated from each RSF bin. We considered models to be good predictors when linear regressions had high coefficients of determination ($r^2 > 0.9$) and 95% confidence intervals of slope estimates excluded zero and included one (Howlin et al. 2004). The most predictive RSF model was mapped across the study area using coefficients from the top model and predictions were distributed into five equal area bins corresponding with increasing relative probability of selection from zero (low relative probability of selection) to five (high relative probability of selection). If the most predictive resource selection function model included wind energy infrastructure variables, we also mapped the most predictive base model to visually compare spatial predictions that did not include the additive effects of wind energy infrastructure variables. Base models were mapped in the same way as the final RSF. We based inference on variables when they had 95% confidence intervals that did not overlap zero.

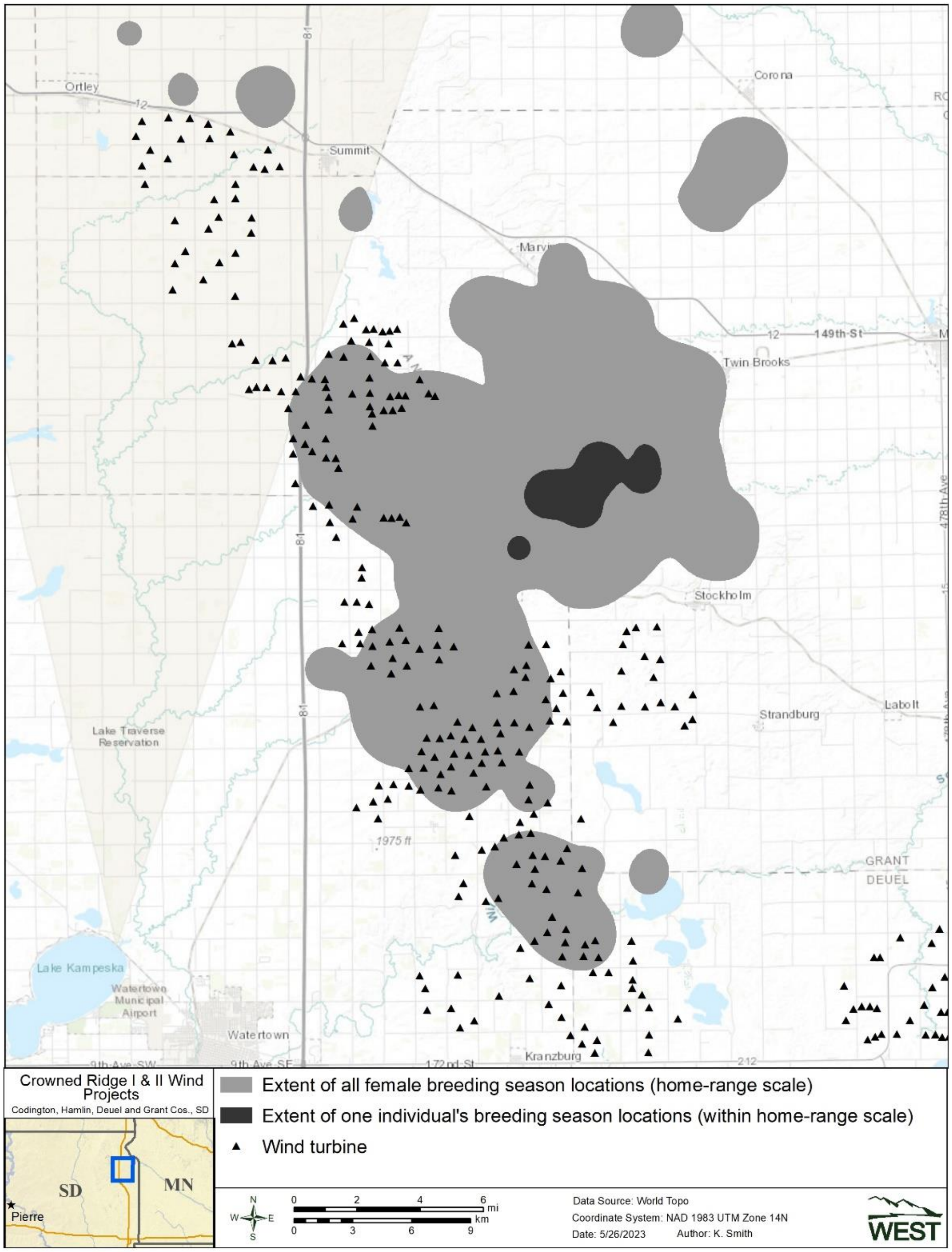

Figure 3. A 99% fixed kernel surrounding all female sharp-tailed grouse locations during the breeding season (gray) and an example of a 99% fixed kernel surrounding one individual's locations (black) used to assess home-range scale and within home-range scale resource selection near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons. For each scale of selection, available locations used to evaluate resource selection were restricted to respective fixed kernel regions.

Survival design and analysis

Nest and breeding season survival was evaluated using Cox proportional hazards regression models to relate survival and hazard of death to predictor variables using the *coxme* package in R (Cox 1972, Therneau and Grambsch 2000). We assessed nest survival over a 23-day incubation period (Johnsgard 1983) and included only first nest attempts. Second nest attempts were excluded because these nests may not have been independent of first nests and comprised a relatively small sample. Breeding season survival was assessed from April 1 to August 15 (19 weeks) to be consistent with other studies (Manzer and Hannon 2008, Milligan et al. 2020b). Individuals that died within two days of capture were excluded from analyses to remove potential bias in survival estimates and assumed to be capture-related mortality. Breeding season survival was analyzed using the Andersen-Gill formulation of the Cox proportional hazards regression to accommodate left and right censoring of data (Andersen and Gill 1982). For each survival model, we tested the proportional hazards assumptions using Schoenfeld residuals of the covariates included in the top model (Schoenfeld 1982).

RESULTS

Lek Counts and Surveys

During lek surveys in 2020, 11 previously undocumented leks were located using ground-based and helicopter surveys. No previously undocumented leks were found during the 2021 lek surveys. One undocumented lek was located in 2022.

We obtained landowner permission to monitor 13 of the 19 leks that were known at the beginning of the 2020 field season, 20 of 30 leks in 2021, and 26 of 31 known leks in 2022 (Figure 4, Table 2). Lek counts occurred between March 11 and April 25 each year. The mean maximum male STGR count at leks was six (range = 0–23), nine (range = 0–31), and eight (range = 0–29) in 2020, 2021, and 2022, respectively. Overall, male lek counts appeared to be relatively stable over the study period (Figure 5).

Table 2. Summary of male sharp-tailed grouse lek attendance near Crowned Ridge I and Crowned Ridge II Wind Energy Projects surveyed during the 2020–2022 breeding seasons.

Lek number	Max count 2020[1]	Max count 2021[1]	Max Count 2022[1]
1	2 (0–2)	6 (0–6)	2 (0–2)
2	NA[2]	NA[2]	NA[2]
3	0	0	10 (0–10)
4	2 (0–2)	7 (0–7)	3 (0–3)
5	20 (18–20)	22 (14–22)	15 (10–15)
6	2 (0–2)	0	6 (0–6)
7	0	3 (0–3)	0
8	NA[2]	NA[2]	0
9	5 (1–5)	12 (7–12)	10 (0–10)
10	0	2 (0–2)	4 (0–4)
11	12 (0–12)	27 (19–27)	7 (6–7)
12	NA[2]	NA[2]	NA[2]
13	0	0	0
14	0	8 (0–8)	0
15	NA[2]	NA[2]	26 (22–26)
16	11 (8–11)	13 (12–13)	11 (7–11)
17	0	6 (0–6)	0
18	NA[2]	4 (2–4)	6 (0–6)
19	NA[2]	NA[2]	1 (0–1)
20	7 (5–7)	5 (0–5)	5 (0–5)
21	23 (18–23)	31 (24–31)	17 (11–17)
22	5 (3–5)	NA[2]	NA[2]
23	6 (1–6)	2 (0–2)	0
24	5[3]	6 (0–6)	5 (0–5)
25	9[3]	NA[2]	NA[2]
26	5[3]	NA[2]	29 (5–29)
27	4[3]	13 (0–13)	8 (0–8)
28	9[3]	NA[2]	16 (13–16)
29	5 (1–5)	NA[2]	NA[2]
30	16 (12–16)	8 (5–8)	9 (5–9)
31	NA[4]	NA[4]	24 (18–24)

[1] Range of counts in parenthesis.

[2] No landowner permission.

[3] Located via helicopter survey and were unable to obtain landowner permission for subsequent visits.

[4] Lek discovered in 2022.

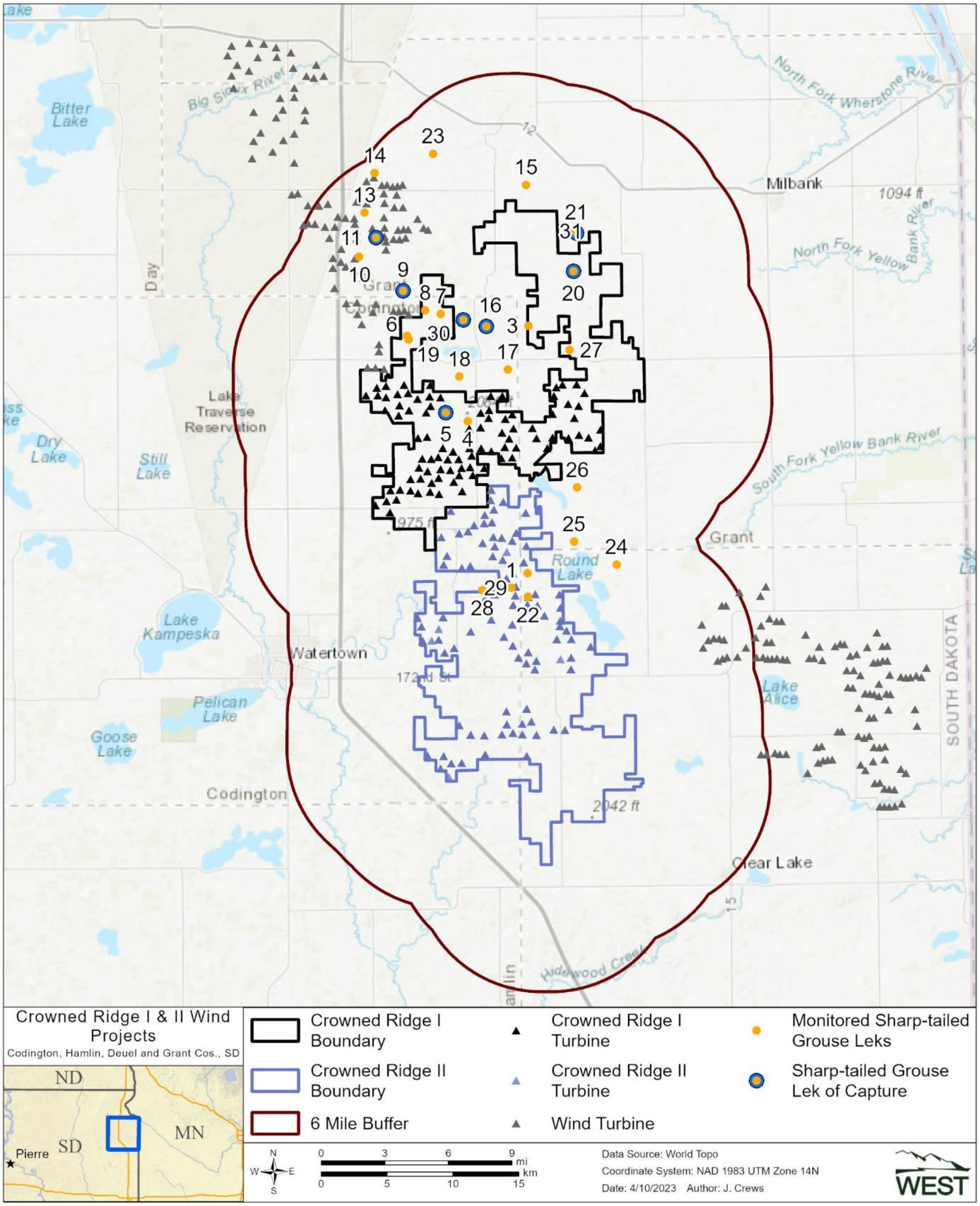

Figure 4. Sharp-tailed grouse (STGR) leks monitored during 2020–2022 breeding seasons and STGR capture leks within the 6-mile buffer (study area) surrounding the Crowned Ridge I and Crowned Ridge II Wind Energy Projects.

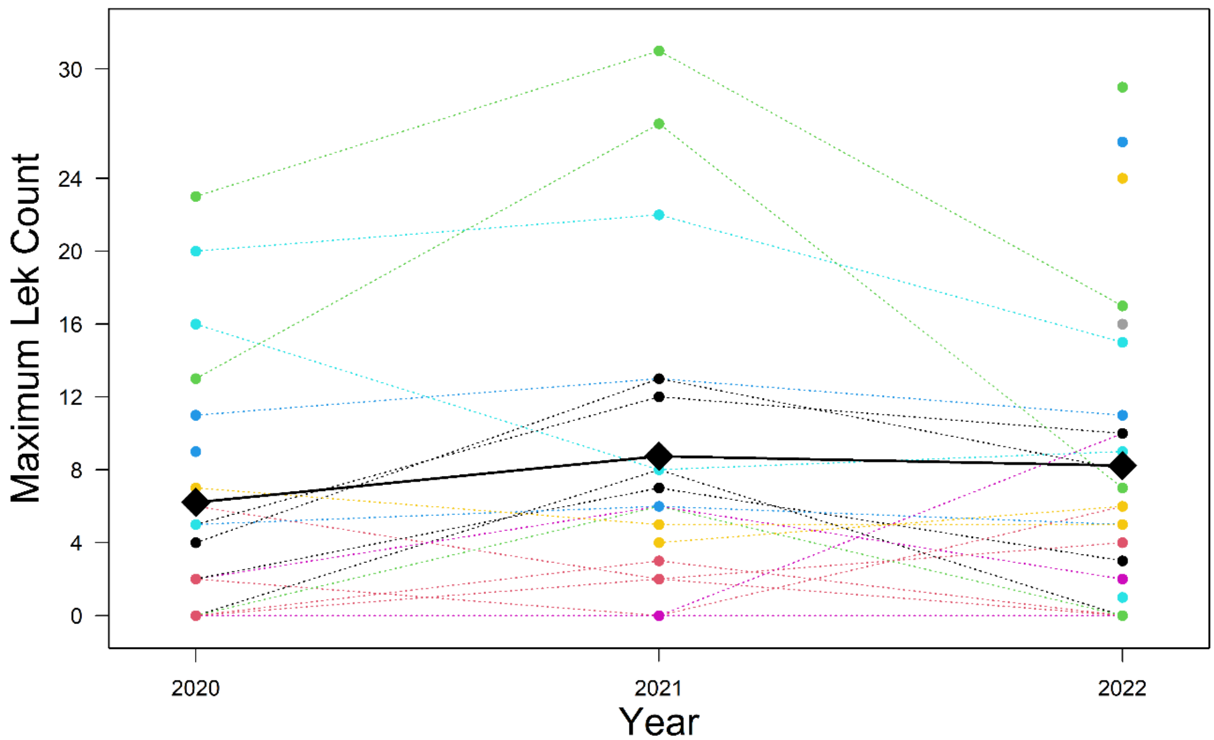

Figure 5. Trends in sharp-tailed grouse leks monitored during the 2020–2022 breeding seasons near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects. Points connected by dashed lines represent individual leks. The solid black line connects the mean maximum lek count for each year. Points that are not connected by dashed lines were not monitored in previous years (see Table 2 for details).

Capture and Monitoring

In 2020, we captured 51 females at six leks throughout the study area (Figure 4, Table 3). In 2021, we captured 49 females at four leks, and in 2022 we captured 26 females at six leks throughout the study area. In total, we monitored 126 female STGR over the study period. Resource selection models included 75 nests, 5,364 brood rearing-locations from 17 broods, and 72,452 breeding season locations (Figure 6). A total of 32 broods were identified over the study, however, we excluded 15 broods from resource selection models due to insufficient data, brood failure, or we were unable to confirm brood fate to ensure that locations of females were with broods. Survival analyses included 65 first nest attempts, and 112 female STGR. We excluded eight second nest attempts from the nest survival analysis. The density of used and available locations in relation to wind infrastructure covariates used to assess breeding season resource selection at the home range and within home range scales are located in Appendix A (Figures 1 and 2).

Table 3. Summary of female sharp-tailed grouse captured at leks near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons.

Lek number	# Females	Distance to nearest turbine (km)
5	15	1.2
9	1	1.5
16	3	5.4
20	4	8.6
21	21	11.3
30	7	4.2
5	15	1.2
11	9	0.7
16	10	5.4
21	15	11.3
5	17	1.2
11	1	0.7
16	1	5.4
21	0	11.3
30	1	4.2
32	6	11.7

Note: distance to nearest wind turbine was based on locations of wind turbines in 2022.
km = kilometer.

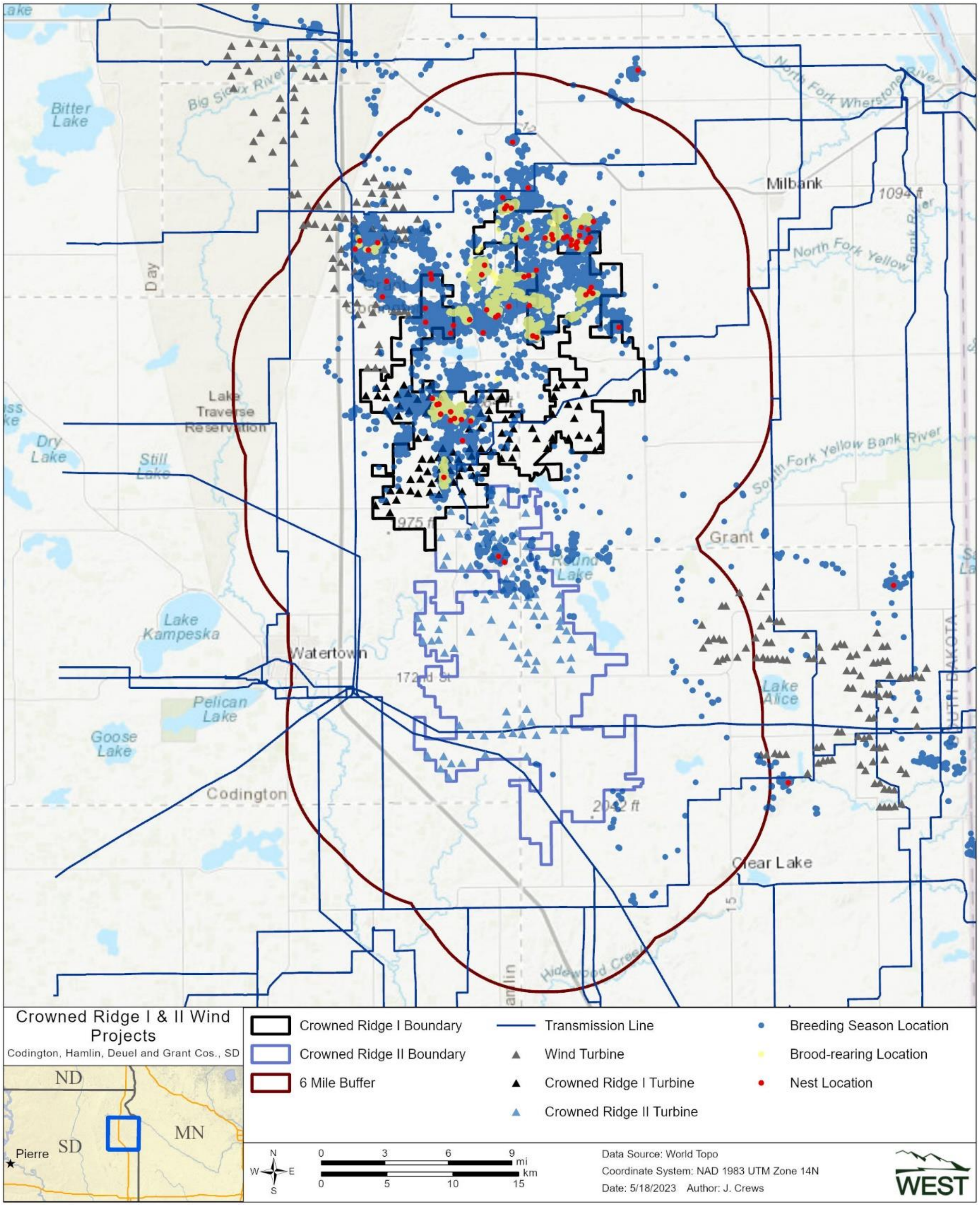

Figure 6. Nest, brood-rearing, and breeding season locations of female sharp-tailed grouse near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons.

Nest Site Selection

Home range scale (second order) nest site selection

The addition of wind energy infrastructure variables improved model fit compared to base models (Appendix A, Table 1), suggesting that wind energy infrastructure was associated with nest site selection at the home range scale. The final model suggested that STGR selected nest sites with greater proportion of grassland within 0.2 km, less herbaceous wetland within 3.2 km, lower TPI within 5.0 km, lower TRI within 3.2 km, and lower length of transmission lines within 5.0 km (Table 4). The addition of threshold terms to describe length of transmission lines within 5.0 km did not improve model fit compared to models that only contained linear covariates.

Within home range scale (third order) nest site selection

The base model suggested that STGR selected nest sites with greater proportion of grassland within 0.2 km, and lower TPI at the local scale (Table 4). Models containing wind energy infrastructure variables did not improve model fit compared to base models (Appendix A, Table 1).

Table 4. Coefficient estimates and 95% confidence intervals (CI) for covariates in models describing sharp-tailed grouse nest site selection at home range (second order) and within home range (third order) scales at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022.

Model and variable	Scale (km)	Coefficient	Lower CI	Upper CI
Home range scale (second order)				
Corn	0.2	-1.31	-2.77	0.15
Developed	0.5	-0.36	-0.73	0.02
Grassland	0.2	1.11	0.65	1.57
Herbaceous wetland	3.2	-0.40	-0.72	-0.08
TPI	5.0	-0.63	-0.93	-0.32
TRI	3.2	-0.70	-1.12	-0.28
Transmission line length	5.0	-0.80	-1.23	-0.37
Within home range scale (third order)				
Corn	0.2	-0.56	-1.34	0.22
Grassland	0.2	0.44	0.09	0.79
TPI	NA	-0.23	-0.45	-0.01

km = kilometer; TPI = Terrain Positioning Index; TRI = Terrain Roughness Index.

Brood Site Selection

Home range scale (second order) brood selection

Models that contained wind energy infrastructure variables were more informative than base models (Appendix A, Table 2). The final model suggested that STGR selected brood-rearing locations with more alfalfa within 5.0 km, less corn within 5.0 km, less developed land within 1.3 km, greater proportion of grassland within 0.5 km, greater proportion of herbaceous wetland within 1.0 km, lower TPI within 5.0 km, lower length of transmission lines within 5.0 km, closer to turbines, and higher density of turbines within 1.3 km (Table 5). A nonlinear relationship of length of transmission lines within 5.0 km suggested that females with broods avoided areas once the length of transmission lines exceeded approximately 1.9 mi (3.0 km) within 5.0 km (Figure 7). Threshold terms considered for turbine density did not improve model fit.

Within home range scale (third order) brood selection

The addition of wind energy infrastructure variables improved model fit compared to the base model (Appendix A, Table 2). The final model suggested that female STGR selected brood-rearing locations within home ranges with greater proportion of developed land within 1.0 km, greater proportion of grassland within 0.2 km, greater proportion of herbaceous wetland within 1.3 km, lower TPI, higher TRI, and areas closer to transmission lines (Table 5). A quadratic term describing wind turbine density within 1.0 km suggested that brood rearing STGR avoided areas once the number of turbines within 1.0 km exceeded approximately four (Figure 7).

Table 5. Coefficient estimates and 95% confidence intervals (CI) for covariates in models describing sharp-tailed grouse brood-rearing site selection at the home range (second order) and within home range (third order) scales at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022.

Model and variable	Scale (km)	Coefficient	Lower CI	Upper CI
Home range scale (second order)				
Alfalfa	5.0	0.21	0.20	0.23
Corn	5.0	-1.31	-1.34	-1.29
Developed	1.3	-0.58	-0.59	-0.56
Grassland	0.5	1.03	1.01	1.05
Herbaceous wetland	1.0	0.34	0.32	0.35
TPI	5.0	-0.82	-0.84	-0.80
Distance to turbine	NA	-0.26	-0.29	-0.23
Transmission line length	5.0	1.15	1.02	1.27
Transmission line length[1]	5.0	-10.02	-10.48	-9.57
Turbine density	1.3	0.46	0.43	0.48
Within home range scale (third order)				
Developed	1.0	0.07	0.04	0.09
Grassland	0.2	0.21	0.20	0.23
Herbaceous wetland	1.3	0.71	0.64	0.77
Soybeans	1.3	-0.02	-0.05	0.01
TPI	NA	-0.31	-0.32	-0.30
TRI	NA	0.18	0.16	0.19
Distance to transmission line	NA	-0.51	-0.59	-0.44
Turbine density	1.0	0.73	0.67	0.79
Turbine density[1]	1.0	-0.34	-0.39	-0.29

km = kilometer; TPI = Terrain Positioning Index; TRI = Terrain Roughness Index.

[1] Quadratic term.

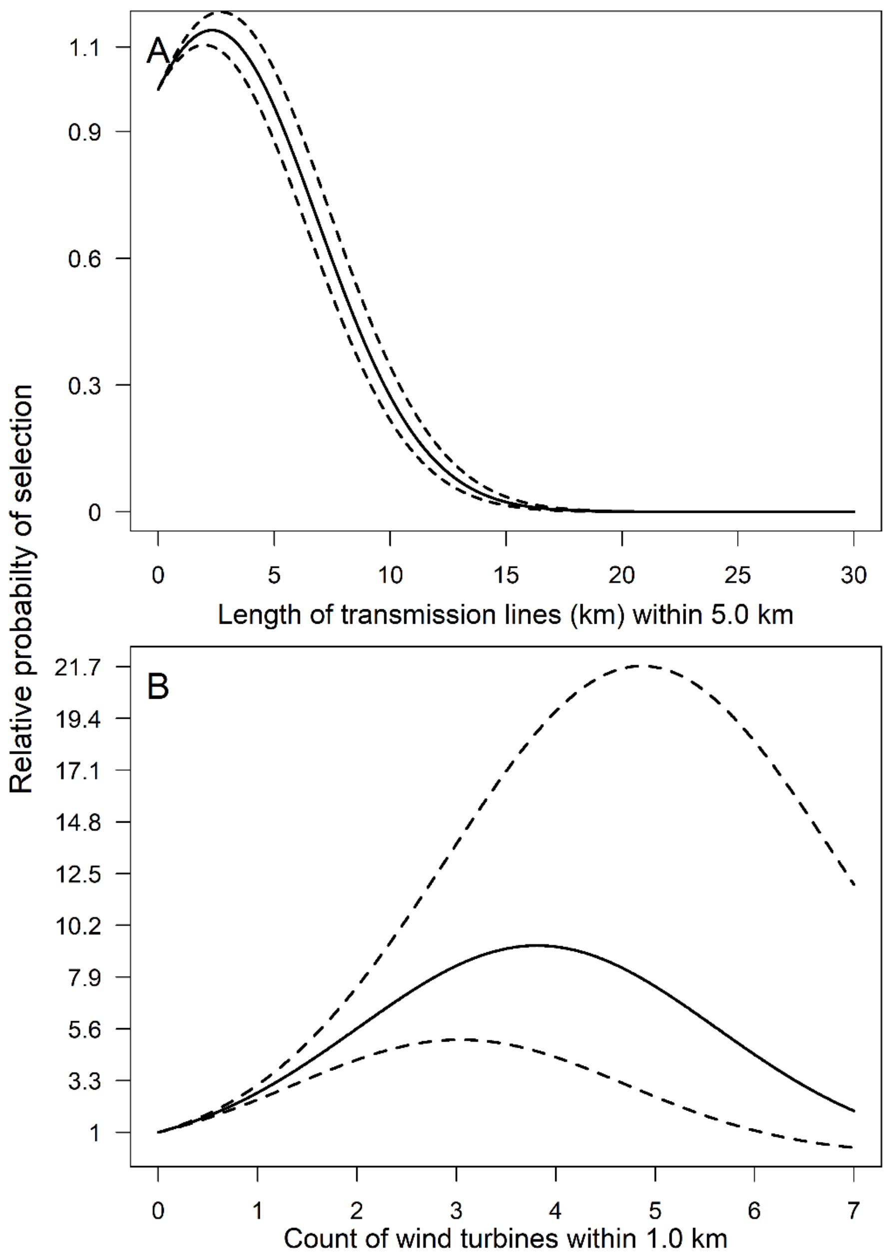

Figure 7. Relative probability of brood-rearing female sharp-tailed grouse selection at the home range (A) and within home range (B) scales as a function of length of transmission lines within 5.0 kilometers (km) and count of wind turbines within 1.0 km near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons. Dashed lines represent 95% confidence intervals surrounding predictions.

Breeding Season Site Selection

Home range scale (second order) breeding season selection

Models that contained wind energy infrastructure variables were more informative than base models (Appendix A, Table 3). The final model suggested that female STGR selected areas with less developed land within 0.5 km, closer to roads, greater proportion of grassland within 0.2 km, less herbaceous wetland within 3.2 km, less soybean within 3.2 km, lower TPI within 5.0 km, areas farther from turbines and transmission lines, but greater turbine densities within 3.2 km (Table 6). The addition of a quadratic term describing distance to turbines suggested that the relative probability of selection by STGR during the breeding season increased positively as distance to turbines increased up to approximately 14 km, after which relative probability of selection declined (Figure 8). Of note, however is that only 6% of used locations were further than 14 km from a turbine.

The spatial prediction of the RSF was a strong predictor of female home range resource selection during the breeding season (Figure 9). When we partitioned validation testing and training groups by individual, average r^2 = 0.98 ± < 0.01 (standard error [SE]). In general, the relative probability of selection increased slightly in areas near turbines based on final model predictions (Figure 9B) relative to base model predictions (Figure 9A). There was a general shift where areas around turbines were considered to have higher predicted relative probability of selection when turbine covariates were included in final model predictions, suggested that relative probability of selection was not reduced in areas near wind turbines at the home range scale (Figure 10).

Within home range scale (third order) breeding season selection

The addition of turbine covariates improved model fit compared to base models (Appendix A, Table 3). The final model suggested that females selected breeding season locations within home ranges with less corn within 0.2 km, less developed land within 0.5 km, greater proportion of grassland within 0.2 km, less herbaceous wetland within 3.2 km, lower TPI, lower TRI within 3.2 km, areas closer to transmission lines, but lower lengths of transmission lines within 1.0 km. A quadratic term describing turbine density within 5.0 km suggested that during the breeding season STGR avoided areas within their home ranges that contained wind turbines within 5.0 km. The strongest avoidance occurred once an area exceeded approximately 20–35 wind turbines within 5.0 km (Figure 8).

Table 6. Coefficient estimates and 95% confidence intervals (CI) for covariates in models describing female sharp-tailed grouse breeding season (April 1 through August 15) site selection at the home range (second order) and within home range (third order) scales at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022.

Model and variable	Scale (km)	Coefficient	Lower CI	Upper CI
Home range scale (second order)				
Developed	0.5	-0.61	-0.62	-0.59
Distance to road	NA	-0.25	-0.26	-0.24
Grassland	0.2	0.54	0.53	0.55
Herbaceous wetland	3.2	-0.28	-0.30	-0.27
Soybeans	3.2	-0.34	-0.36	-0.33
TPI	5.0	-0.16	-0.17	-0.15
Distance to transmission line	NA	0.60	0.59	0.61
Distance to turbine	NA	1.73	1.68	1.78
Distance to turbine[1]	NA	-1.52	-1.58	-1.46
Turbine density	3.2	0.80	0.79	0.82
Within home range scale (third order)				
Corn	0.2	-0.25	-0.26	-0.24
Developed	0.5	-0.26	-0.27	-0.25
Grassland	0.2	0.24	0.23	0.26
Herbaceous wetland	3.2	-0.17	-0.18	-0.16
TPI	NA	-0.08	-0.08	-0.07
TRI	3.2	-0.04	-0.06	-0.03
Distance to transmission line	NA	-0.18	-0.20	-0.17
Transmission line length	1.0	-0.02	-0.03	-0.01
Turbine density	5.0	-0.78	-0.83	-0.72
Turbine density[1]	5.0	0.59	0.54	0.65

km = kilometer; TPI = Terrain Positioning Index.

[1] Quadratic term.

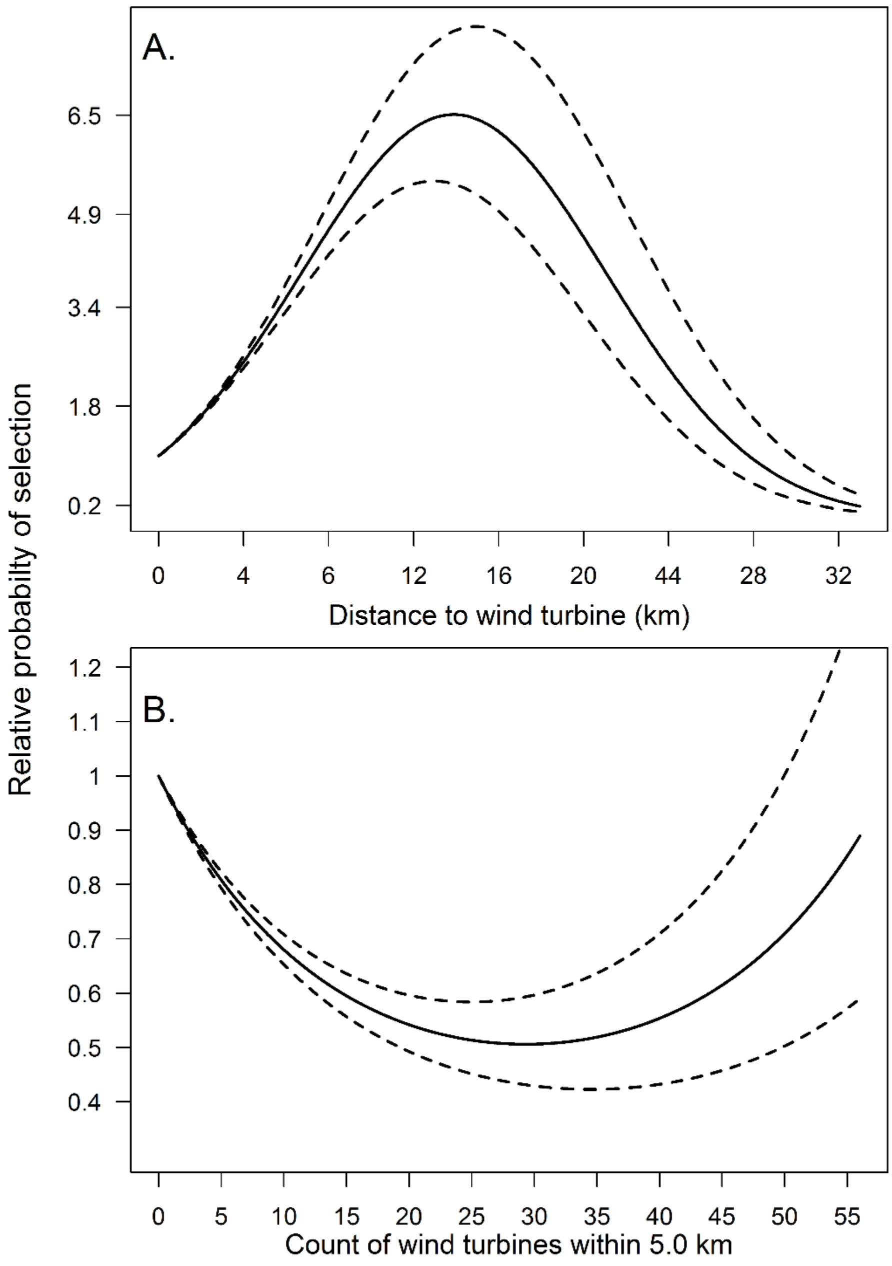

Figure 8. Relative probability of female sharp-tailed grouse breeding season selection at the home range (A) and within home range (B) scales as a function of distance to transmission lines and count of wind turbines within 5.0 kilometers near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons. Dashed lines represent 95% confidence intervals surrounding predictions.

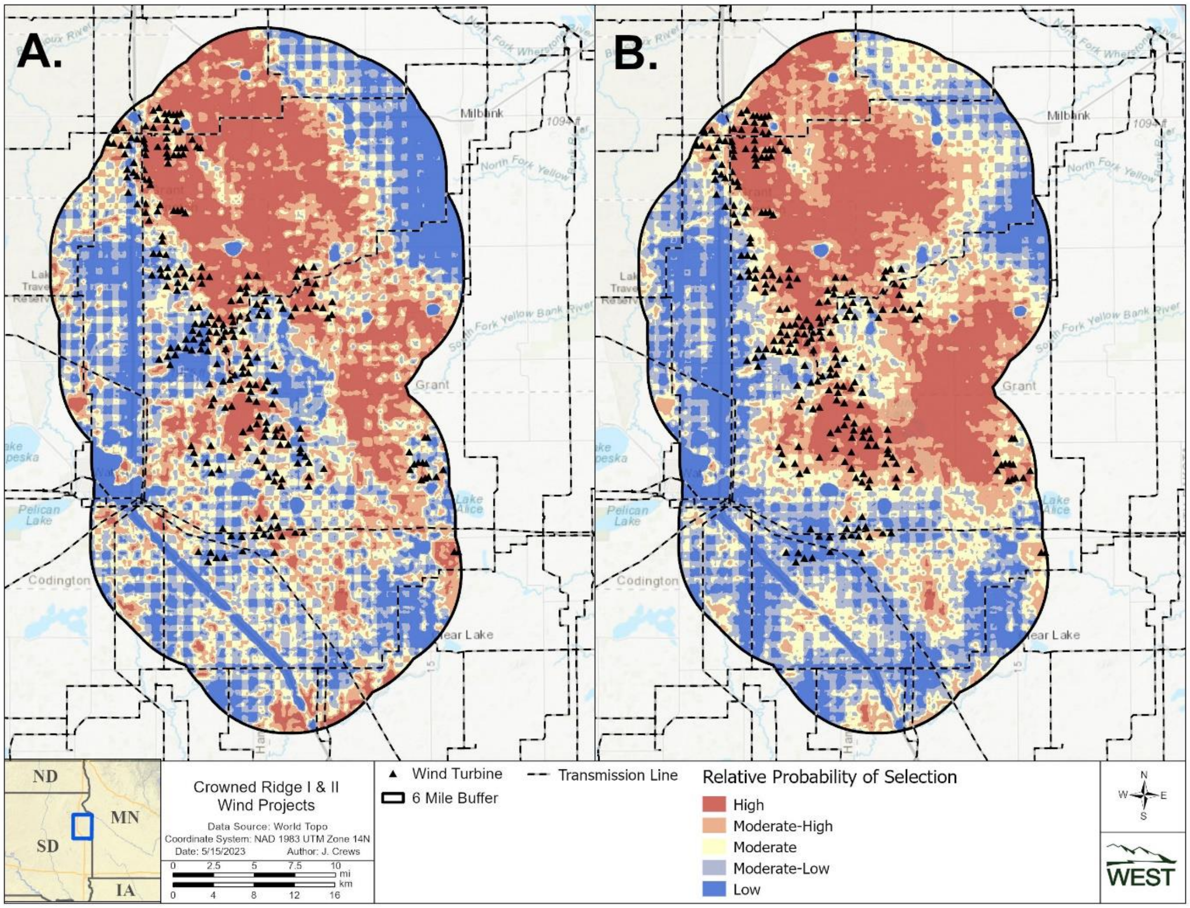

Figure 9. Predicted relative probability of female sharp-tailed grouse breeding season selection at the home range scale from models that did not (A) and models that did (B) include wind energy infrastructure variables during the 2020–2022 breeding season. Predictions were generated within a 6-mile buffer (study area) surrounding the Crowned Ridge I and Crowned Ridge II Wind Energy Projects.

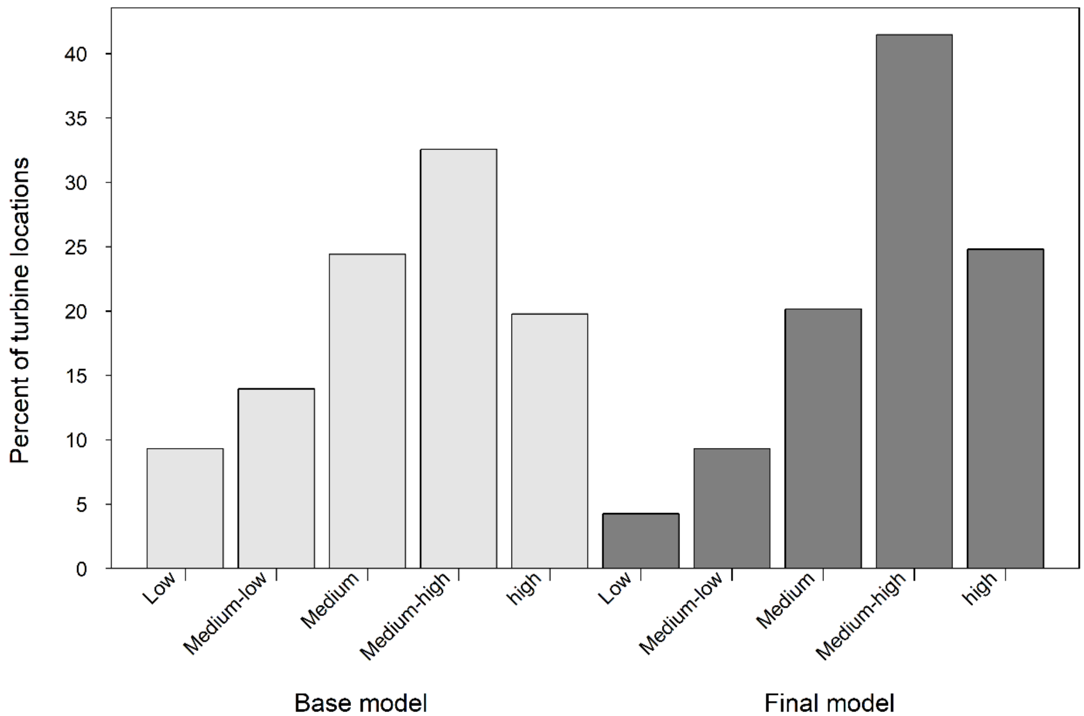

Figure 10. Percent of Crowned Ridge I and Crowned Ridge II wind turbine locations within each resource selection function (RSF) model-predicted bin from the lowest predicted probability of selection (left-most bins) to the highest predicted probability of selection (right-most bins). RSF models were developed using female sharp-tailed grouse locations during the 2020–2022 breeding seasons and represented models that included (final model) or did not include (base model) wind energy covariates.

Survival

Nest survival

The final nest survival model suggested that survival was negatively associated with the proportion of grassland within 1.3 km (Table 7). The addition of wind energy infrastructure did not improve model fit (Appendix A, Table 4).

Sharp-tailed grouse survival

The addition of wind energy infrastructure covariates improved the model fit compared to the most parsimonious base model (Appendix A, Table 4). The final model suggested that female sharp-tailed grouse survival was positively associated with the proportion of soybeans within 0.5 km, and negatively associated with the proportion of developed land within 3.2 km, positively associated with the proportion of soybeans within 0.5 km, negatively associated with TPI within 5.0 km, and negatively associated with the density of wind turbines within 5.0 km (Table 7). However, turbine density within 5.0 km was not considered further because confidence intervals surrounding the parameter estimate overlapped zero.

Table 7. Coefficient estimates and 95% confidence intervals (CI) for covariates in models describing sharp-tailed grouse nest and female survival at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022. A positive coefficient indicated a greater risk of nest failure or female mortality.

Model and variable	Scale (km)	Coefficient	Lower CI	Upper CI
Nest survival				
Grassland	1.3	2.89	0.02	5.77
Adult survival				
Developed	3.2	88.15	42.97	133.32
Soybeans	0.5	-3.14	-5.56	-0.72
TPI	5.0	0.91	0.06	1.75
Turbine density	5.0	0.01	-0.02	0.03

km = kilometer.

DISCUSSION

Resource selection and survival were evaluated across three distinct life stages: nesting, brood-rearing, and breeding. In addition, resource selection was assessed at two scales to evaluate selection at the population level (selection given available habitat of all marked individuals) as well as the individual level (selection given habitat within individual seasonal ranges). Overall, we found evidence that female STGR selected habitat types that were previously known to influence resource selection. We did not find evidence that females avoided wind energy infrastructure during nesting, but found that females avoided areas near high densities of wind turbines during the brood-rearing and breeding season at the finer, within home range scale. We found no evidence that nest and weak evidence that female survival during the breeding season was associated with wind energy infrastructure. Given the relative stability of the local STGR population, as indexed by yearly lek counts, potential avoidance behaviors in areas with relatively high densities of wind turbines (e.g., 20-35 within 5.0 km) does not appear to result in population level declines, at least over the short-term following development of wind energy infrastructure.

Consistent with other studies, female STGR selected areas with higher amounts of grassland across all life stages and orders of selection (McNew et al. 2014, Proett et al. 2019, LeBeau et al. 2023), highlighting the importance of the overall STGR conservation strategy of conserving large intact grassland habitats (Runia et al. 2021). In this study, the median proportion of grassland used by STGR during the breeding season was relatively high and greater than 0.52 at used locations within all circular regions we assessed (ranged from 0.52 within 5.0-km to 0.91 within 0.2 km; Figure 11). The percent of grassland and pasture hay within a 0.7-mi (1.2-km) radius was a strong positive predictor of STGR occurrence and density in North and South Dakota (Runia et al. 2021). Resource selection of STGR was also positively correlated with grassland habitats. In Montana and western North Dakota, female STGR selected a greater proportion of grassland habitats within their home ranges during the breeding season (Milligan et al. 2020a). In this study, STGR selected areas with more alfalfa during brood-rearing. This was similar to the findings of Goddard et al. (2009) who found that STGR selected early brood-rearing habitats near agriculture.

Forb rich cultivated crop fields may function as preferred forage (Sullins et al. 2018) and potential cover from predators. We found STGR selected nesting and brood-rearing habitat in depressions on the landscape (as indexed by TPI and TRI), characteristic of the prairie pothole region, which may further act as concealment from predators, provide higher soil moisture and concomitant vegetation productivity, and potentially provide thermal refugia (Raynor et al. 2018). Although other studies have found prairie grouse to avoid roads (Pitman et al. 2005, Pruett et al. 2009, Harrison et al. 2017, LeBeau et al. 2017b), we found that STGR selected areas near roads during the breeding season at the home-range scale. This could be because the study area contained mostly gravel roads used primarily by residential traffic as opposed to more heavily traveled roads.

An effect of wind turbine distance or density on nest site selection was not detected at either scale of selection, which is consistent with other studies evaluating prairie grouse response to wind energy development (McNew et al. 2014, Harrison et al. 2017, Proett et al. 2019, LeBeau et al. 2023). In addition, we found little evidence to suggest females with broods avoided areas influenced by wind turbines at both scales of selection. For example, we found that females with broods selected areas closer to turbines and with more turbines within 1.3 km at the home range scale. At the smaller, within home range scale, females with broods selected areas with up to approximately four turbines within 1.0 km. Overall, this provides little evidence that brood-rearing STGR avoided wind turbines because there were few areas with in the study area that contained more than four turbines within 1.0 km. The average number of turbines within 1.0 km of a point on the landscape within the study area was less than one (mean = 0.35; range: 0–8). We are unaware of any prairie grouse studies that have evaluated brood-rearing habitat selection relative to wind turbines, but LeBeau et al. (2017b) found female greater sage-grouse with broods avoided areas with higher density of wind turbines.

In contrast, we found some evidence that resource selection by female STGR during the breeding season was influenced by wind energy infrastructure. At the home range scale, we found that STGR selected areas farther from wind turbines, but in areas with greater turbine density within 3.2 km. However, the spatial predictions of the home range breeding season RSF models, which also accounted for other attributes of STGR habitat, provide limited support that wind turbines resulted in avoidance by STGR at this scale. When considering the base RSF, 52.3% of wind turbines were in areas that were predicted to be in areas of medium-high or high relative probability of female STGR breeding season selection. Based on final model predictions that included wind energy infrastructure variables, 66.3% of wind turbines were in areas predicted to be in medium-high or high relative probability of selection, indicating that the additive effect of wind energy infrastructure did not reduce the relative probability of STGR selection at the home-range scale. At the within home range scale, a count of 20–35 wind turbines within 5.0 km represented a potential threshold where STGR avoidance of wind turbines was most pronounced (i.e., relative probability of selection was lowest). The within home range breeding season model predicted an approximate 85 to 93% reduction in relative probability of selection when the number of wind turbines increased from zero to 20 or zero to 35 wind turbines within 5.0 km, respectively. This indicates that wind turbines could affect within home-range breeding season selection. However, the marginal effects plot (Figure 8) indicates that there is uncertainty in the response once the count of turbines exceed approximately 40 turbines within 5.0 km. To put this response in perspective, the average number of turbines within 5.0 km of a point on the landscape within the study area was 9 (range: 0–57) and areas with greater than 20 wind turbines represented approximately 19% of the study area.

We found consistent selection for lower length of transmission lines across all life stages at the population level but not at the individual level. Avoidance of transmission lines appears to be a consistent behavior by prairie grouse species at multiple spatial scales (Pruett et al. 2009, Londe et al. 2019, Plumb et al. 2019). It is hypothesized that grouse may avoid transmission lines because they can act as perches for avian predators, increasing raptor abundance and predation risk for grouse (Hagen et al. 2011, Gibson et al. 2018). That we generally failed to detect a consistent effect of transmission line length or distance across life stages at the within home range scale likely indicates that STGR were primarily selecting habitats at the larger scale, wherein fewer transmission lines were available to be avoided within home ranges. At the finer scale, vegetation characteristics and topography appeared to be more important to STGR when selecting habitats. While most studies have evaluated prairie grouse responses as a function of distance to transmission lines, Sullins et al. (2019) found a similar avoidance of length of transmission lines by lesser prairie-chickens when assessed within a 1.2 mi (2.0 km) radius.

Similar to other studies evaluating grouse responses to wind energy development, we did not detect an effect of wind energy infrastructure on nest survival (McNew et al. 2014, Harrison et al. 2017, LeBeau et al. 2017b, Proett et al. 2019, LeBeau et al. 2023). Other studies at wind energy facilities have documented vegetation characteristics related to concealment or visual obstruction to influence nest survival, suggesting the importance of concealment from predators and foraging opportunities (McNew et al. 2014, Proett et al. 2019, LeBeau et al. 2023). Interestingly, we found that nest survival was negatively associated with the amount of grassland within 1.3 km. This relationship is contrary to other research and may be an artifact of the spatial scales that were assessed (e.g., unmeasured factors such as grassland patch sizes or habitat heterogeneity) in this study system. Our results provide some evidence that female survival during the breeding season was associated with wind energy infrastructure. However, the confidence interval surrounding this effect overlapped zero and we therefore considered this a weak effect and indicates uncertainty in the overall effect of turbine density on female survival. In both nest and female survival analyses, we cannot rule out the possibility that unmeasured environmental factors influenced survival, which could have potentially been uncovered with a longer term dataset. Other studies have found that adult survival increased (Winder et al. 2014, LeBeau et al. 2017b) or was not influenced by wind energy infrastructure (Smith et al. 2017, LeBeau et al. 2023) following construction.

Although we observed avoidance behavior associated with wind energy infrastructure during the breeding season, stable lek trends over the 3-year study suggest that this behavioral response has not resulted in population level declines. This is based on an assumption that lek counts are suitable indices of grouse population trends, which is supported by greater sage-grouse population modeling (Dahlgren et al. 2016). Other prairie grouse research has found that population trends, indexed by lek counts, are not negatively impacted by wind energy infrastructure (LeBeau et al. 2017b), although there is some evidence that lek persistence may be lower closer to turbines (Winder et al. 2015). Nonetheless, our findings support the existing body of evidence that prairie grouse may not experience population level impacts over the short-term following development of wind energy facilities (Lloyd et al. 2022).

The lack of other studies investigating the effects of wind energy development on STGR resource selection and survival limits our ability to make predictions about how STGR may respond to wind energy development over a longer time period. In addition, we lacked pre-development data to understand how STGR utilized this landscape prior to the construction of the Projects, which is an unfortunate shortcoming in most wildlife-impact studies (Hebblewhite 2011, Conkling et al. 2020). It has been suggested that grouse may exhibit a three or more year lagged response to renewable and conventional energy development (e.g., Walker et al. 2007, Green et al. 2017, LeBeau et al 2017b), and 10 or more years of data may be necessary to fully understand and detect population level impacts (Harju et al. 2010). While most studies have failed to detect negative effects of wind energy on grouse populations, long-term replicated studies are necessary to adequately address the impacts associated with wind energy development (Coppes et al. 2020, Lloyd et al. 2022).

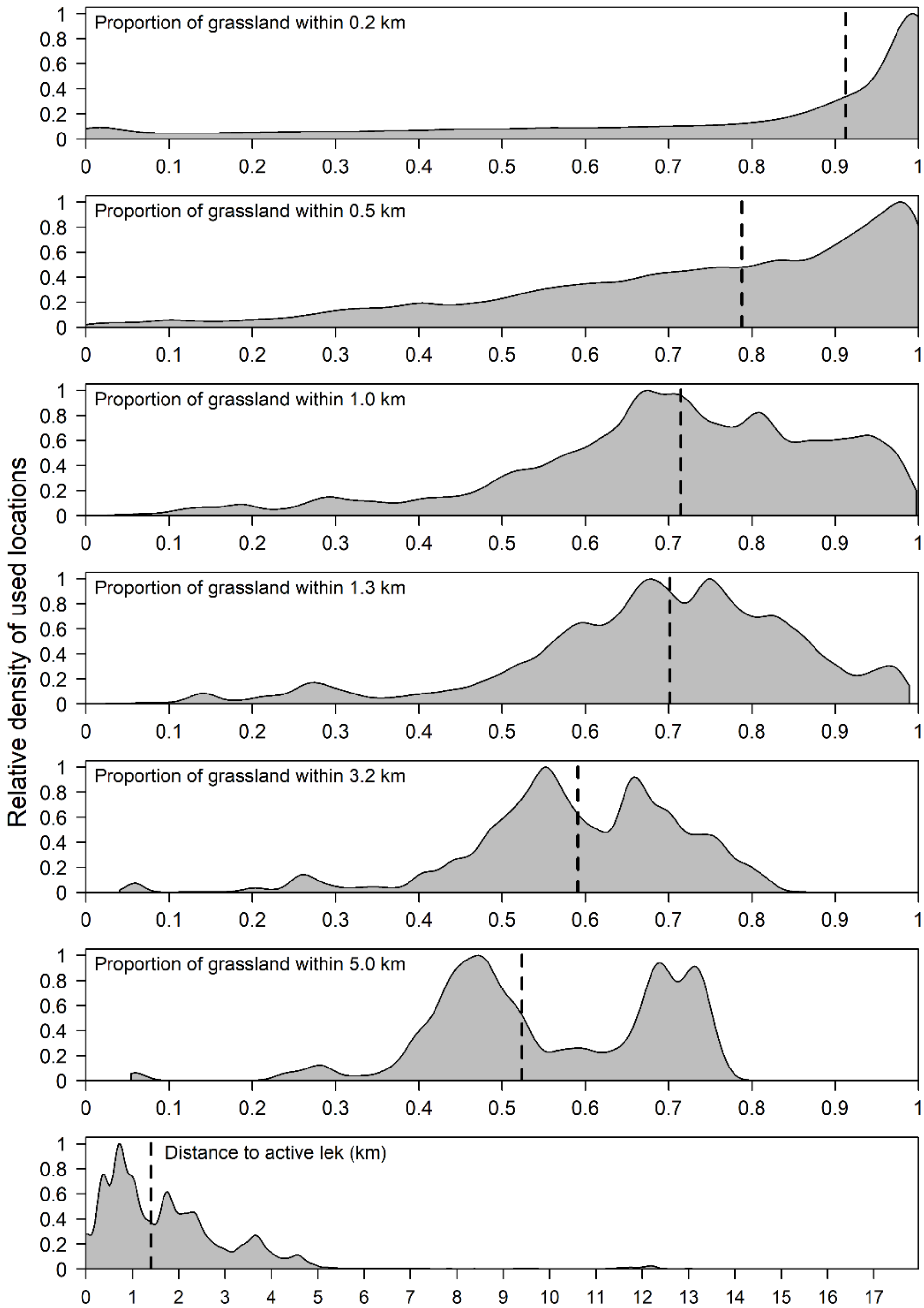

Figure 11. Density of locations used by female sharp-tailed grouse (STGR) during the breeding season relative to the proportion of grassland within 0.2, 0.5, 1.0, 1.3, 3.2, and 5.0-km radii scales as well as distance to active leks near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons. The vertical dashed lines within each panel represent the average value of STGR use locations within respective buffers.

REFERENCES

Ammann, G. A. 1944. Determining the Age of Pinnated and Sharp-Tailed Grouse. Journal of Wildlife Management 8(2): 170-171. doi: 10.2307/3796451.

Anderson, P. K. and R. D. Gill. 1982. Cox's Regression Model for Counting Processes: A Large Sample Study. Annals of Statistics 10(4): 1100-1120.

Arnold, T. W. 2010. Uninformative Parameters and Model Selection Using Akaike's Information Criterion. Journal of Wildlife Management 74(6): 1175-1178.

Bartoń, K. 2022. MuMIn: Multi-Model Inference. R package, version 1.46.0. September 1, 2022. Accessed April 2023. Available online: https://cran.r-project.org/web/packages/MuMIn/index.html

Beck, J. L., K. P. Reese, J. W. Connelly, and M. B. Lucia. 2006. Movements and Survival of Juvenile Greater Sage-Grouse in Southeastern Idaho. Wildlife Society Bulletin 34: 1070-1078.

Bedrosian, B. and D. Craighead. 2009. Solar Powered Gps Transmitter Use on Sage Grouse: Methods of Attachment, Influences of Survival, and Success Rates of the Transmitters. July 22, 2009. Craighead Beringia South, Kelly, Wyoming. Available online: https://www.fs.fed.us/t-d/programs/im/satellite_gps_telemetry/_assets/Grouse%20GPS%20Attachment_Craighead%20Beringia%20South.pdf

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating Resource Selection Functions. Ecological Modelling 157(2-3): pp. 281-300. doi: 10.1016/S0304-3800(02)00200-4.

Burnham, K. P. and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Second Edition. Springer, New York, New York.

Burnham, K. P. and D. R. Anderson. 2004. Multimodel Inference: Understanding Aic and Bic in Model Selection. Sociological Methods and Research 33(2): 261-304.

Conkling, T. J., S. R. Loss, J. E. Diffendorfer, A. E. Duerr, and T. E. Katzner. 2020. Limitations, Lack of Standardization, and Recommended Best Practices in Studies of Renewable Energy Effects on Birds and Bats. Conservation Biology 35(1): 64-76. doi: 10.1111/cobi.13457.

Connelly, J. W., M. W. Gratson, and K. P. Reese. 2020. Sharp-Tailed Grouse (*Tympanuchus phasianellus*), Version 1.0. *In*: A. F. Poole and F. B. Gill, eds. Birds of the World. Cornell Lab of Ornithology, Ithaca, New York. doi: 10.2173/bow.shtgro.01. Available online: http://birdsoftheworld.org/bow/species/shtgro/cur/

Coppes, J., V. Braunisch, K. Bollmann, I. Storch, P. Mollet, V. Grünschachner-Berger, J. Taubmann, R. Suchant, and U. Nopp-Mayr. 2020. The Impact of Wind Energy Facilities on Grouse: A Systematic Review. Journal of Ornithology 161(1): 1-15. 10.1007/s10336-019-01696-1.

Cox, D. R. 1972. Regression Models and Life-Tables. Journal of the Royal Statistical Society, Series B 34: 187-220.

Crowned Ridge Wind LLC. 2019a. Technical Memorandum: Crowned Ridge I Grouse Lek Monitoring Study Plan. Prepared for South Dakota Public Utilities Commission. Prepared by Crowned Ridge Wind, LLC; South Dakota Game, Fish, and Parks; SWCA Environmental Consultants; and Western Ecosystems Technology, Inc. October 29, 2019. Available online: https://puc.sd.gov/commission/dockets/electric/2019/EL19-003/grouse.pdf

Crowned Ridge Wind LLC. 2019b. Technical Memorandum: Permit Condition 45 Crowned Ridge I: In Lieu Mitigation Plan. Prepared for South Dakota Public Utilities Commission. Prepared by Crowned Ridge Wind, LLC: South Dakota Game, Fish, and Parks: and Western Ecosystems Technology, Inc. December 6, 2019. Available online: https://puc.sd.gov/commission/dockets/electric/2019/el19-003/grousemig.pdf

Dahlgren, D. K., T. A. Messmer, B. A. Crabb, R. T. Larsen, T. A. Black, S. N. Frey, E. T. Thacker, R. J. Baxter, and J. D. Robinson. 2016. Seasonal Movements of Greater Sage-Grouse Populations in Utah: Implications for Species Conservation. Wildlife Society Bulletin 40(2): 288-299. doi: 10.1002/wsb.643.

Department of Homeland Security (DHS). 2022. Electric Power Transmission Lines. Homeland Infrastructure Foundation-Level Data (HIFLD), DHS, Washington, D.C. Updated February 15, 2022. Accessed April 2023. Available online: https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines-1/about

Esri. 2023. World Imagery and Aerial Photos (World Topo). ArcGIS Resource Center. Environmental Systems Research Institute (Esri), producers of ArcGIS software, Redlands, California. Accessed April 2023. Available online: https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=10df2279f9684e4a9f6a7f08febac2a9

Gibson, D., E. J. Blomberg, M. T. Atamian, S. P. Espinosa, and J. S. Sedinger. 2018. Effects of Power Lines on Habitat Use and Demography of Greater Sage-Grouse (*Centrocercus urophasianus*). Wildlife Monographs 200: 1-41. doi: 10.1002/wmon.1034.

Goddard, A. D., R. D. Dawson, and M. P. Gillingham. 2009. Habitat Selection by Nesting and Brood-Rearing Sharp-Tailed Grouse. Canadian Journal of Zoology 87(4): 326-336. doi: 10.1139/Z09-016.

Green, A. W., C. L. Aldridge, and M. S. O'Donnell. 2017. Investigating Impacts of Oil and Gas Development on Greater Sage-Grouse. Journal of Wildlife Management 81(1): 46-57. doi: 10.1002/jwmg.21179.

Guisan, A., S. B. Weiss, and A. D. Weiss. 1999. GLM Versus CCA Spatial Modeling of Plant Species Distribution. Plant Ecology 143(1): 107-122. DOI: 10.1023/A:1009841519580.

Hagen, C. A., J. C. Pitman, T. M. Loughin, B. K. Sandercock, R. J. Robel, and R. D. Applegate. 2011. Impacts of Anthropogenic Features on Habitat Use by Lesser Prairie-Chickens. Pp. 63-75. *In*: B. K. Sandercock, K. Martin, and G. Segelbacher, eds. Ecology, Conservation, and Management of Grouse. Studies in Avian Biology, Vol. 39. University of California Press, Berkeley, California.

Harrison, J. O., M. Bomberger Brown, L. A. Powell, W. H. Schacht, and J. A. Smith. 2017. Nest Site Selection and Nest Survival of Greater Prairie-Chickens near a Wind Energy Facility. Condor 119: 659-672. doi: 10.1650/CONDOR-17-51.1.

Haukos, D. A., L. M. Smith, and G. S. Broda. 1990. Spring Trapping of Lesser Prairie-Chickens. Journal of Field Ornithology 61(1): 20-25.

Hebblewhite, M. 2011. Effects of Energy Development on Ungulates in Western North America. Pp. 71-94. *In*: D. Naugle, ed. Energy Development and Wildlife Conservation in Western North America. Island Press, New York.

Henderson, F. R., F. W. Brooks, R. E. Wood, and R. B. Dahlgren. 1967. Sexing of Prairie Grouse by Crown Feather Patterns. Journal of Wildlife Management 31(4): 764-769. doi: 10.2307/3797981.

Hoen, B. D., J. E. Diffendorfer, J. T. Rand, L. A. Kramer, C. P. Garrity, and H. E. Hunt. 2018. United States Wind Turbine Database (Ver. 5.3, January 2023). U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release. Published April 19, 2018. Last revision January 13, 2023. doi: 10.5066/F7TX3DN0.

Hosmer, D. W. and S. Lemeshow. 2000. Applied Logistic Regression. John Wiley and Sons, New York.

Hovick, T. J., B. W. Allred, R. D. Elmore, S. D. Fuhlendorf, and R. G. H. A. Breland. 2015. Dynamic Disturbance Processes Create Dynamic Lek Site Selection in Prairie Grouse. PLoS ONE 10(9): e0137882.

Howlin, S., W. P. Erickson, and R. M. Nielson. 2004. A Proposed Validation Technique for Assessing Predictive Abilities of Resource Selection Functions. Presented at the Resource Selection Methods and Applications: 1st International Conference on Resource Selection, Laramie Wyoming. S. V. Huzurbazar, ed. Pp. 40-51. January 13-15, 2003.

Johnsgard, P. A. 1983. The Grouse of the World. University of Nebraska Press, Lincoln, Nebraska.

Johnson, C. J., S. E. Nielsen, E. H. Merrill, T. L. McDonald, and M. S. Boyce. 2006. Resource Selection Functions Based on Use-Availability Data: Theoretical Motivation and Evaluation Methods. Journal of Wildlife Management 70(2): 347-357. doi: 10.2193/0022-541X(2006)70[347:RSFBOU]2.0.CO;2.

Johnson, D. H. 1980. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology 61(1): 65-71.

Johnson, J. R. and G. E. Larson. 2016. Grassland Plants of South Dakota and Northern Great Plains. South Dakota State University, Brookings, South Dakota. 288 pp.

LeBeau, C., J. L. Beck, G. D. Johnson, and M. J. Holloran. 2014. Short-Term Impacts of Wind Energy Development on Greater Sage-Grouse Fitness. Journal of Wildlife Management 78(3): 522-530.

LeBeau, C. W., J. L. Beck, G. D. Johnson, R. M. Nielson, M. J. Holloran, K. G. Gerow, and T. L. McDonald. 2017a. Greater Sage-Grouse Male Lek Counts Relative to a Wind Energy Development. Wildlife Society Bulletin 41(1): 17-26. doi: 10.1002/wsb.725.

LeBeau, C. W., G. D. Johnson, M. J. Holloran, J. L. Beck, R. M. Nielson, M. E. Kauffman, E. J. Rodemaker, and T. L. McDonald. 2017b. Greater Sage-Grouse Habitat Selection, Survival, and Wind Energy Infrastructure. Journal of Wildlife Management 81(4): 690-711. doi: 10.1002/jwmg.21231.

LeBeau, C. W., K. T. Smith, M. J. Holloran, J. L. Beck, M. E. Kauffman, and G. D. Johnson. 2019. Greater Sage-Grouse Habitat Function Relative to 230-Kv Transmission Lines. Journal of Wildlife Management 83(8): 1173-1786. doi: 10.1002/jwmg.21749.

LeBeau, C., K. Smith, and K. Kosciuch. 2023. Lesser Prairie-Chicken Habitat Selection and Survival Relative to a Wind Energy Facility Located in a Fragmented Landscape.Wildlife Biology doi: 10.1002/wlb3.01091

Lloyd, J. D., C. L. Aldridge, T. D. Allison, C. W. LeBeau, L. B. McNew, and V. L. Winder. 2022. Prairie Grouse and Wind Energy: The State of the Science and Implications for Risk Assessment. Journal of Wildlife Management 46(3): e1305. doi: 10.1002/wsb.1305.

Londe, D. W., S. D. Fuhlendorf, R. D. Elmore, C. A. Davis, and J. Rutledge. 2019. Female Greater Prairie-Chicken Response to Energy Development and Rangeland Management. Ecosphere 10(12): e02982. DOI: 10.1002ecs2.2982.

Manly, B. F., L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies. Second edition. Kluwer Academic Publishers, Dordrecht, the Netherlands. 216 pp.

Manzer, D. L. and S. J. Hannon. 2008. Survival of Sharp-Tailed Grouse Tympanuchus Phasianellus Chicks and Hens in a Fragmented Prairie Landscape. Wildlife Biology 14: 16-25. doi: 10.2981/0909-6396(2008)14[16:SOSGTP]2.0.CO;2.

McNew, L. B., L. M. Hunt, A. J. Gregory, S. M. Wisely, and B. K. Sandercock. 2014. Effects of Wind Energy Development on Nesting Ecology of Greater Prairie-Chickens in Fragmented Grasslands. Conservation Biology 28(4): 1089-1099.

Milligan, M. C., L. I. Berkeley, and L. B. McNew. 2020a. Effects of Rangeland Management on the Nesting Ecology of Sharp-Tailed Grouse. Rangeland Ecology and Management 73: 128-137.

Milligan, M. C., L. I. Berkeley, and L. B. McNew. 2020b. Survival of Sharp-Tailed Grouse under Variable Livestock Grazing Management. Journal of Wildlife Management 84: 1296-1305.

Milligan, M. C., S. L. Wells, and L. B. McNew. 2018. A Population Viability Analysis for Sharp-Tailed Grouse to Inform Reintroductions. Journal of Fish and Wildlife Management 9:565–581.

Minnesota Department of Transportation (MDOT). 2012. Roads, Minnesota, 2012. Accessed April 2023. Available online: https://gisdata.mn.gov/dataset/trans-roads-mndot-tis

National Land Cover Database (NLCD). 2016. *As cited* includes:

Yang, L., S. Jin, P. Danielson, C. Homer, L. Gass, S. M. Bender, A. Case, C. Costello, J. Dewitz, J. Fry, M. Funk, B. Granneman, G. C. Liknes, M. Rigge, and G. Xian. 2018. A New Generation of the United States National Land Cover Database: Requirements, Research Priorities, Design, and Implementation Strategies. ISPRS Journal of Photogrammetry and Remote Sensing 146: 108-123. doi: 10.1016/j.isprsjprs.2018.09.006.

and

Multi-Resolution Land Characteristics (MRLC). 2019. National Land Cover Database (NLCD) 2016. Multi-Resolution Land Characteristics (MRLC) Consortium. US Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, MRLC Project, Sioux Falls, South Dakota. May 10, 2019. Available online: https://www.mrlc.gov/data.

North American Datum (NAD). 1983. NAD83 Geodetic Datum.

North Dakota Game and Fish Department (NDGFD). 2021. Keywind Energy Development in North Dakota: Best Management Practices. June 2021. Available online: https://gf.nd.gov/sites/default/files/publications/wind-energy-development-bmp.pdf

Phillips, R. A., J. C. Xavier, and J. P. Croxall. 2003. Effects of Satellite Transmitters on Albatrosses and Petrels. The Auk 120(4): 1082-1090. doi: 10.2307/4090279.

Pitman, J. C., C. A. Hagen, R. J. Robel, T. M. Loughlin, and R. D. Applegate. 2005. Location and Success of Lesser Prairie-Chicken Nests in Relation to Vegetation and Human Disturbance. Journal of Wildlife Management 69(3): 1259-1269. doi: 10.2193/0022-541X(2005)069[1259:LASOLP]2.0.CO;2.

Plumb, R. T., J. M. Lautenbach, S. G. Robinson, D. A. Haukos, V. L. Winder, C. A. Hagen, D. S. Sullins, J. C. Pitman, and D. K. Dahlgren. 2019. Lesser Prairie-Chicken Space Use in Relation to Anthropogenic Structures. Journal of Wildlife Management 83(1): 215-230. doi: 10.1002/jwmg.21561.

Powell, L. A., M. B. Brown, J. A. Smith, J. O. Harrison, and C. E. Whalen. 2017. Modeling the Spatial Effects of Disturbance: A Constructive Critique to Provide Evidence of Ecological Thresholds. Wildlife Biology 2017(SP1): doi: 10.2981/wlb.00245.

PRISM Climate Group. 2021. 30-yr Normal Precipitation. Oregon State University, Corvallis, Oregon, USA. Accessed April 2023. Available online: http://prism.oregonstate.edu/

Proett, M., S. B. Roberts, J. S. Horne, D. N. Koons, and T. A. Messmer. 2019. Columbian Sharp-Tailed Grouse Nesting Ecology: Wind Energy and Habitat. Journal of Wildlife Management 83: 1214-1225. doi: 10.1002/jwmg.21673.

Proett, M., S. B. Roberts, and T. A. Messmer. 2022. Columbian Sharp-Tailed Grouse Brood Success and Chick Survival in a Wind-Energy Landscape. Journal of Wildlife Management 86(7): e22287. doi: 10.1002/jwmg.22287.

Pruett, C. L., M. A. Patten, and D. H. Wolfe. 2009. Avoidance Behavior by Prairie Grouse: Implications for Wind Energy Development. Conservation Biology 23(5): 1253-1259. doi: 10.1111/j.1523-1739.2009.01254.x.

R Development Core Team. 2022. R: A Language and Environment for Statistical Computing. Version 4.2.0. R Foundation for Statistical Computing, Vienna, Austria. Last updated March 4, 2022. Accessed April 2023. Available online: https://www.R-project.org/

Raynor, E. J., L. A. Powell, and W. H. Schacht. 2018. Present and Future Thermal Environments Available to Sharp-Tailed Grouse in an Intact Grassland. PLoS ONE 13(2): e0191233. doi: 10.1371/journal.pone.0191233.

Roersma, S. J. 2001. Nesting and Brood Rearing Ecology of Plains Sharp-Tailed Grouse (*Tympanuchus phasianellus jamesi*) in a Mixed-Grass Fescue Ecoregion of Southern Alberta. University of Manitoba, Winnipeg, Manitoba. Available online: https://mspace.lib.umanitoba.ca/xmlui/handle/1993/2687

Rotella, J., J., S. J. Dinsmore, and T. L. Shaffer. 2004. Modeling Nest-Survival Data: A Comparison of Recently Developed Methods That Can Be Implemented in Mark and Sas. Animal Biodiversity and Conservation 27(1): 187-205.

Runia, T. J., A. J. Solem, N. D. Niemuth, and K. W. Barnes. 2021. Spatially Explicit Habitat Models for Prairie Grouse: Implications for Improved Population Monitoring and Targeted Conservation. Wildlife Society Bulletin 45: 36-54.

Schoenfeld, D. 1982. Partial Residuals for the Proportional Hazards Regression Model. Biometrika 69(1): 239-241. doi: 10.1093/biomet/69.1.239.

Smith, J. A., M. B. Brown, J. O. Harrison, and L. A. Powell. 2017. Predation Risk: A Potential Mechanism for Effects of a Wind Energy Facility on Greater Prairie-Chicken Survival. Ecosphere 8(6): e01835. doi: 10.1002/ecs2.1835.

South Dakota Department of Transportation (SDDOT). 2022. Local Roads. Published March 29, 2022. Last updated June 29, 2022. Accessed April 2023. Available online: https://opendata2017-09-18t192802468z-sdbit.opendata.arcgis.com/datasets/ed3b489797754aa0a60ce3896bea4681_0/explore?location=44.246317%2C-100.249450%2C7.31

South Dakota Public Utilities Commission (SD PUC). 2021. Plan Ahead for 3G Phase out in 2022. November 3, 2021. Accessed April 2023. Available online: https://puc.sd.gov/News/2021/11032021.aspx

Sullins, D. S., D. A. Haukos, J. M. Craine, J. M. Lautenbach, S. G. Robinson, J. D. Lautenbach, J. D. Kraft, R. T. Plumb, J. H. Reitz, B. K. Sandercock, and N. Fierer. 2018. Identifying the Diet of a Declining Prairie Grouse Using DNA Metabarcoding. The Auk 135(3): 583-608. doi: 10.1642/AUK-17-199.1.

Sullins, D. S., D. A. Haukos, J. M. Lautenbach, J. D. Lautenbach, S. G. Robinson, M. B. Rice, B. K. Sandercock, J. D. Kraft, R. T. Plumb, J. H. Reitz, J. M. S. Hutchinson, and C. A. Hagen. 2019. Strategic Conservation for Lesser Prairie-Chickens among Landscapes of Varying Anthropogenic Influence. Biological Conservation 238(2019): Article 108213. doi: 10.1016/j.biocon.2019.108213.

Therneau, T. M. and P. M. Grambsch. 2000. Modeling Survival Data: Extending the Cox Model. Springer-Verlag, New York.

US Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). 2023. USDA's National Agricultural Statistics Service South Dakota Field Office. Last updated January 5, 2023. Accessed April 2023. Available online: https://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.php

US Geological Survey (USGS). 2023. The National Map. TNM Download V2.0. Topo Map data, 3DEP products, Lidar, IfSAR, NHD (Hydrography Dataset), NAIP Plus Imagery, National Structures Dataset. Accessed April 2023. Available online: https://apps.nationalmap.gov/downloader/#/

Valcu, M. and B. Kempenaers. 2010. Spatial Autocorrelation: An Overlooked Concept in Behavioral Ecology. Behavioral Ecology 21(5): 902-905. doi: 10.1093/beheco/arq107.

Walker, B. L., D. E. Naugle, and K. E. Doherty. 2007. Greater Sage-Grouse Population Response to Energy Development and Habitat Loss. Journal of Wildlife Management 71(8): 2644-2654. doi: 10.2193/2006-529.

Wiens, T. S., B. C. Dale, M. S. Boyce, and G. P. Kershaw. 2008. Three Way K-Fold Cross-Validation of Resource Selection Functions. Ecological Modelling 212(3-4): 244-255. doi: 10.1016/j.ecolmodel.2007.10.005.

Wilson, M. F. J., B. O'Connell, C. Brown, J. C. Guinan, and A. J. Grehan. 2007. Multiscale Terrain Analysis of Multibeam Bathymetry Data for Habitat Mapping on the Continental Slope. Marine Geodesy 30: 3-35.

Winder, V., L. B. McNew, L. M. Hunt, A. J. Gregory, S. M. Wisely, and B. K. Sandercock. 2014. Effects of Wind Energy Development on Seasonal Survival of Greater Prairie-Chickens. Journal of Applied Ecology 51: 395-405.

Winder, V. L., A. J. Gregory, L. B. McNew, and B. K. Sandercock. 2015. Responses of Male Greater Prairie-Chickens to Wind Energy Development. Condor 117: 284-296. doi: 10.1650/CONDOR-14-98.1.

Wolfe, D. H., M. A. Patten, E. Shochat, C. L. Pruett, and S. K. Sherrod. 2007. Causes and Patterns of Mortality in Lesser Prairie-Chickens *Tympanuchus pallidicinctus* and Implications for Management. Wildlife Biology 13 (Suppl. 1): 95-104.

Worton, B. J. 1989. Kernel Methods for Estimating the Utilization Distribution in Home-Range Studies. Ecology 70(1): 164-168.

Appendix A. Additional supporting information

Table 1. Top 5 (if applicable) models used to assess sharp-tailed grouse nest site selection at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022. Base models were included for comparison if not in the top 5 models.

	Model fit statistics[a]		
Model	**K**	**ΔAIC**	w_i
Home range scale[b]			
Base model parameters + length of transmission line$_{5.0km}$	8	0.00	0.68
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{1.3km}$	9	2.00	0.25
Base model parameters + distance to transmission line	8	5.34	0.05
Base model parameters + distance to transmission line + turbine density$_{1.3km}$	9	7.31	0.02
Base model parameters	7	19.58	0.00
Within home range scale[c]			
Base model parameters[d]	4	NA	NA

[a]Number of parameters (K), change in AICc (ΔAICc), and Akaike weights (w_i).

[b]Base model parameters include proportion corn within 0.2 km, proportion developed within 0.5 km, proportion grassland within 0.2 km, proportion herbaceous wetland within 3.2 km, TPI within 5.0 km, and TRI within 3.2 km.

[c]Base model parameters include proportion corn within 0.2 km, proportion grassland within 0.2 km, and TPI at the local scale.

[d]No wind energy infrastructure variables were retained following initial variable screening.

Table 2. Top 5 (if applicable) models used to assess female sharp-tailed grouse brood-rearing resource selection at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022. Base models were included for comparison if not in the top 5 models.

	Model fit statistics[a]		
Model	**K**	**ΔAIC**	w_i
Home range scale[b]			
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{1.3km}$ + distance to turbine	10	0.00	1.00
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{1.3km}$	9	155.47	0.00
Base model parameters + length of transmission line$_{5.0km}$ + distance to turbine	9	1,613.21	0.00
Base model parameters + length of transmission line$_{5.0km}$	8	2,348.78	0.00
Base model parameters + distance to transmission line + turbine density$_{1.3km}$ + distance to turbine	10	6,210.53	0.00
Base model parameters	7	17,320.18	0.00
Within home range scale[c]			
Base model parameters + distance to transmission line + turbine density$_{1.0km}$	9	0.00	0.70
Base model parameters + distance to transmission line + turbine density$_{1.0km}$ + distance to turbine	10	1.71	0.30
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{1.0km}$ + distance to turbine	10	74.42	0.00
Base model parameters + turbine density$_{1.0km}$ + distance to turbine	9	84.83	0.00
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{1.0km}$	9	111.53	0.00
Base model parameters	7	920.11	0.00

[a]Number of parameters (K), change in AICc (ΔAICc), and Akaike weights (w_i).

[b]Base model parameters include proportion alfalfa within 5.0 km, proportion corn within 5.0 km, proportion developed within 1.3 km, proportion grassland within 0.5 km, proportion herbaceous wetland within 1.0 km, and TPI within 5.0 km.

[c]Base model parameters include proportion developed within 1.0 km, proportion grassland within 0.2 km, proportion herbaceous wetland within 1.3 km, proportion soybeans within 1.3 km, TPI at the local scale, and TRI at the local scale.

Table 3. Top 5 (if applicable) models used to assess female sharp-tailed grouse breeding season resource selection at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022. Base models were included for comparison if not in the top 5 models.

Model	Model fit statistics[a]		
	K	ΔAIC	w_i
Home range scale[b]			
Base model parameters + distance to transmission line + turbine density$_{3.2km}$ + distance to turbine	10	0.00	1.00
Base model parameters + distance to transmission line + turbine density$_{3.2km}$	9	2,218.26	0.00
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{3.2km}$ + distance to turbine	10	3,490.71	0.00
Base model parameters + length of transmission line$_{5.0km}$ + turbine density$_{3.2km}$	9	4,317.01	0.00
Base model parameters + distance to transmission line + distance to turbine	9	5,903.48	0.00
Base model parameters	7	22,200.54	0.00
Within home range scale[c]			
Base model parameters + length of transmission line$_{1.0km}$ + distance to transmission line + turbine density$_{5.0km}$	10	0.00	1.00
Base model parameters + distance to transmission line + turbine density$_{5.0km}$	9	18.34	0.00
Base model parameters + length of transmission line$_{1.0km}$ + distance to transmission line + distance to turbine	10	181.66	0.00
Base model parameters + distance to transmission line + distance to turbine	9	191.01	0.00
Base model parameters + length of transmission line$_{1.0km}$ + distance to transmission line	9	365.63	0.00
Base model parameters	7	700.34	0.00

[a]Number of parameters (K), change in AICc (ΔAICc), and Akaike weights (w_i).

[b]Base model parameters include proportion developed within 0.5 km, proportion grassland within 0.2 km, proportion herbaceous wetland within 3.2 km, distance to road, proportion soybean within 3.2 km, and TPI within 5.0 km.

[c]Base model parameters include proportion corn within 0.2 km, proportion developed within 0.5 km, proportion grassland with 0.2 km, proportion herbaceous wetland within 3.2 km, TPI at the local scale, and TRI within 3.2 km.

Table 4. Top 5 (if applicable) models used to assess sharp-tailed nest and female survival at the Crowned Ridge I and Crowned Ridge II Wind Energy Projects, 2020–2022. Base models were included for comparison if not in the top 5 models.

	Model fit statistics[a]		
Model	**K**	**ΔAIC**	***w*i**
***Nest survival*[b]**			
Base model parameters	1	0.00	0.57
Base model parameters + distance to turbine	2	0.53	0.43
***Female survival*[c]**			
Base model parameters + turbine density$_{5.0km}$	4	0.00	0.60
Base model parameters	3	1.95	0.23
Base model parameters + distance to turbine	4	2.49	0.17

[a]Number of parameters (K), change in AICc (ΔAICc), and Akaike weights (w_i).

[b]Base model parameters include proportion grassland within 1.3 km.

[c]Base model parameters include proportion developed within 3.2 km, proportion soybean within 0.5 km, and TPI within 5.0 km.

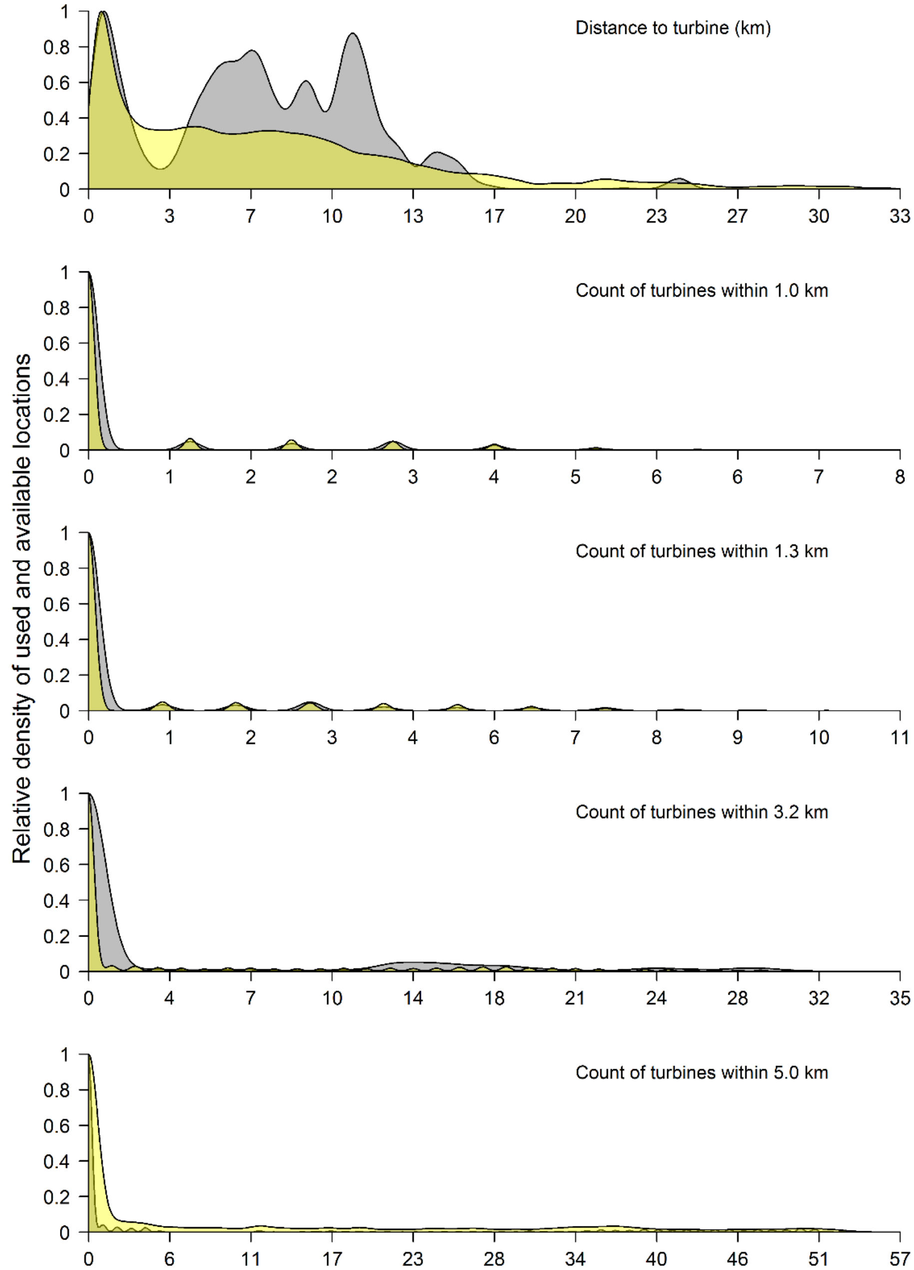

Figure 1. Relative density of locations used by female sharp-tailed grouse (gray) and what was available at the home range scale (yellow) relative to distance to wind turbines and count of wind turbines within 1.0, 1.3, 3.2, and 5.0 km near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons.

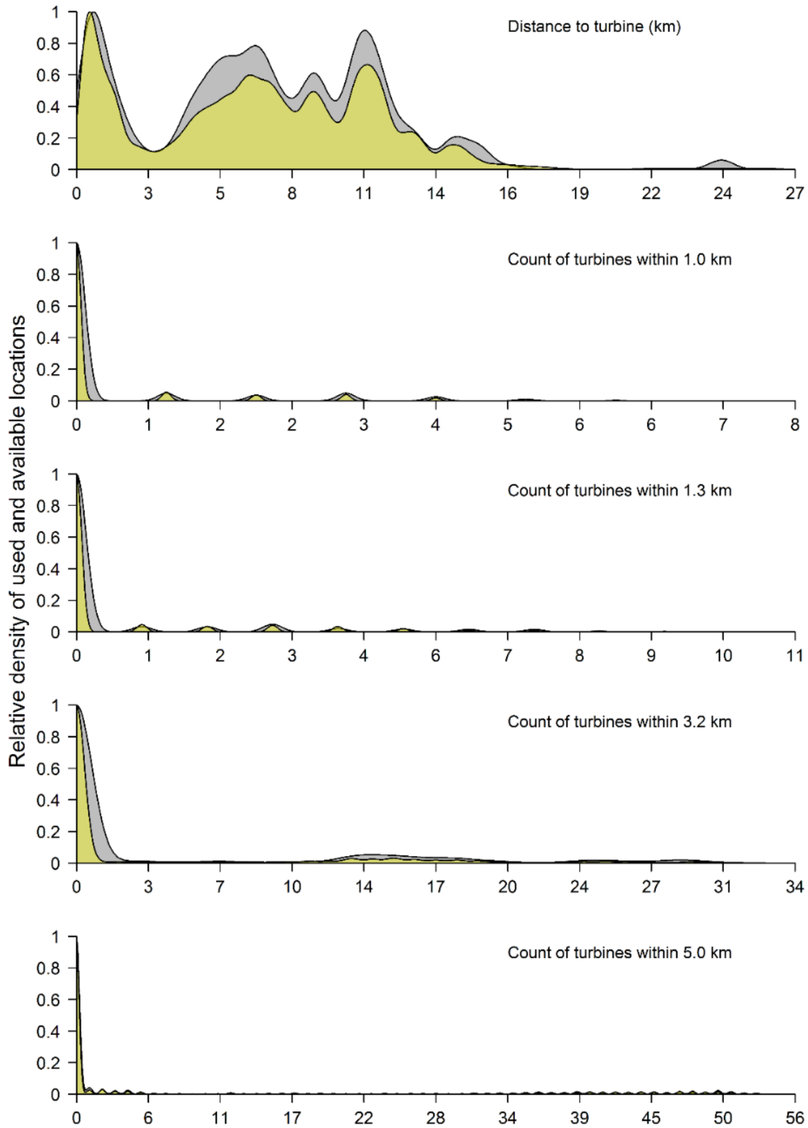

Figure 2. Relative density of locations used by female sharp-tailed grouse (gray) and what was available at the within home range scale (yellow) relative to distance to wind turbines and count of wind turbines within 1.0, 1.3, 3.2, and 5.0 km near the Crowned Ridge I and Crowned Ridge II Wind Energy Projects during 2020–2022 breeding seasons.