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ARTICLE

Animal Ecology

Resource selection and survival of plains sharp-tailed grouse at a wind energy facility

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Abstract

As the demand for wind energy development increases across much of the Great Plains region, there is a need to understand how this type of energy generation may impact wildlife. Due to their extensive range across areas with high wind resources, plains sharp-tailed grouse (*Tympanuchus phasianellus jamesiTympanuchus phasianellus jamesi*) represent a valuable species to evaluate how selection and survival are associated with existing wind energy infrastructure. We used spatial and demographic data collected from radio-marked female sharp-tailed grouse to evaluate resource selection (nest, brood-rearing, and breeding season) and survival (nest and female) near existing wind energy infrastructure during the April to August breeding season over a 3-year period from 2020 to 2022 in northeastern South Dakota, USA. We monitored 119 GPS-marked females captured at eight leks over the study period. We did not find evidence that females selected nest sites in relation to wind energy infrastructure but found that females with broods and females during the breeding season (April–August) avoided areas near high densities of wind turbines within 1.0 and 5.0 km of their home range, respectively. We found consistent selection for lower lengths of transmission lines across all life stages at the home range scale. We did not detect an effect of wind energy infrastructure on nest or female survival. Based on the results of our study, limiting the siting (the process of selecting the optimal location for a project and the associated features) of wind turbines within 5.0 km of sharp-tailed grouse breeding habitat may represent an important siting tool to minimize avoidance of otherwise suitable habitats.

KEYWORDS

energy development, grouse, renewable energy, resource selection, survival, *Tympanuchus phasianellus*

INTRODUCTION

Concerns about global climate change have placed mounting pressure on transitioning from conventional to renewable sources of energy generation in the United States. A reduction in carbon emissions by increased use of alternative renewable energy sources, such as wind energy generation, has important implications for wildlife inhabiting the Great Plains region of the central United States, which contains more than 75% of the total US wind energy generating capacity (Ott et al., 2021). The increased demand for wind energy has sparked concerns surrounding habitat loss, degradation, and fragmentation of remaining grassland ecosystems in the Great Plains (Pruett et al., 2009); yet, uncertainty remains regarding how wildlife may respond to the development of renewable energy infrastructure (Northrup & Wittemyer, 2013). Approximately 70% of eastern South Dakota's native mixed-grass prairie has been lost, amplifying concern for the possibility of further reduction and fragmentation (Bauman et al., 2016; Wright & Wimberly, 2013). Each wind turbine, associated turbine pad, and access road requires approximately 1.2 ha of land (Ott et al., 2021), which, if not properly sited, may increase loss and fragmentation of important habitat occupied by wildlife in this region.

Steep declines in grassland bird populations have prompted efforts to better understand how to mitigate the effects of rapidly changing landscapes (NABCI, 2022; Pavlacky et al., 2022). Obligate grassland birds are sensitive to fragmentation and require large, contiguous intact habitats (Herkert, 1994). Fragmentation may decrease species richness (Herkert, 1994; Herse et al., 2020) and increase nest predation (Herkert et al., 2003) and displacement of obligate grassland birds (Brennan & Kuvlesky Jr., 2005; Shaffer & Buhl, 2015). Grassland birds may be displaced by and avoid wind energy infrastructure, although the effects of development may vary by life history strategy (Hale et al., 2014; Shaffer & Buhl, 2015; Stevens et al., 2013). However, the magnitude of responses to energy infrastructure may vary by habitat quality (Hatchett et al., 2013; Mahoney & Chalfoun, 2016), potentially confounding our ability to detect potential negative impacts associated with energy infrastructure.

Multiple species of North American grouse (tribe Tetraonini) reside in grassland habitats and have received considerable conservation attention because of recent population declines (Storch, 2007). Studying grouse can increase the current understanding of potential impacts of wind energy infrastructure to nonmigratory wildlife and may also inform wildlife managers on how to better conserve grassland species as a whole. Direct effects of energy infrastructure, such as collisions, on prairie grouse are likely low, although indirect effects, such as avoidance of otherwise suitable habitat have been documented (Hovick et al., 2014). Generally, impacts to nest and adult survival for prairie grouse and greater sage-grouse (*Centrocercus urophasianus*) from wind energy infrastructure have not been detected (Harrison et al., 2017; McNew et al., 2014; Proett et al., 2019; Smith et al., 2017; Winder et al., 2014). However, brood survival may be lower in areas with wind turbines, at least over a short period after development (LeBeau et al., 2014; LeBeau, Johnson, et al., 2017; Proett et al., 2022). A decrease in nest and brood survival may occur after the construction of a wind energy facility if predators (e.g., meso-carnivores and raptors) are attracted to the area due to an increase in food resources or if habitat fragmentation from access roads promote movement of mammalian predators (Dickie et al., 2017; LeBeau et al., 2014). Avoidance behaviors by grouse in relation to their exposure to wind energy infrastructure could possibly mask the ability to detect potential survival consequences. Such behaviors have been documented during the breeding season (LeBeau, Johnson, et al., 2017; Winder et al., 2014) and suggest that avoidance of wind energy infrastructure could result in indirect loss of potentially suitable habitats. Power lines (transmission and distribution lines) also can directly and indirectly affect grouse populations. Although rare, direct mortality caused by collisions with power lines has been documented (Beck et al., 2006; Wolfe et al., 2007) and indirect effects could include displacement, similar to wind energy infrastructure, and demographic consequences (Gibson et al., 2018; LeBeau et al., 2019; Londe et al., 2019).

Previous research on grouse and wind energy infrastructure has primarily focused on habitat specialists or species with narrow geographic ranges. For example, greater sage-grouse are considered sagebrush (*Artemisia* spp.) obligates (Baker et al., 1976) and greater prairie-chicken (*Tympanuchus cupido*) require large, contiguous tallgrass prairie (McNew et al., 2013, 2015). Predicting an individual's perceived predation risk because of anthropogenic habitat change for these specialist species may be easier due to their obligate relationships with specific habitats (Owens & Bennett, 2000). Predicting how habitat generalist species may respond to human-induced habitat changes, however, may be challenging because they are widespread and can utilize a variety of habitats to fulfill their life history needs. The sharp-tailed grouse (*Tympanuchus phasianellus*) is a generalist grouse species comprising 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*; hereafter "sharp-tailed grouse") has an extensive range across areas with high wind resources, exposing the species to the most wind energy development relative to other grouse species (Lloyd et al., 2022). However, no studies have directly measured the relationship between existing wind energy development and sharp-tailed grouse.

Although sharp-tailed grouse are a species of least conservation concern (IUCN, 2023), their preservation is of economic importance for the rural areas comprising the Northern Great Plains. The Great Plains are a popular destination for upland game bird hunting where the sport has consistently contributed millions of dollars annually to the economy through hunting license sales, lodging, dining, and sporting goods (Erickson & Wiebe, 1973; Gascoigne et al., 2021; Loomis et al., 2015; South Dakota Game Fish and Parks, 2017). Therefore, an understanding of sharp-tailed grouse survival and selection near existing wind energy development will be necessary for stakeholders tasked with conserving this important species. By identifying potential effects of wind turbine placement in grassland habitats on sharp-tailed grouse, wildlife managers will be better equipped to manage resources and create scientifically informed development guidelines. The goal of our study was to evaluate the relationship between existing wind energy infrastructure and sharp-tailed grouse resource selection and survival over a 3-year period from 2020 to 2022. We used spatial and demographic data collected from observations of lek trends and GPS-marked females. Specifically, our objectives were to evaluate (1) resource selection by female sharp-tailed grouse associated with wind energy infrastructure during nesting, brood-rearing, and the breeding season and (2) nest and female survival relative to wind energy infrastructure.

STUDY AREA

Our study took place in Grant, Codington, and Deuel counties, South Dakota (Figure 1). Sharp-tailed grouse in the study area were exposed to six wind energy facilities over the 3-year period. Crowned Ridge I consisted of 87, 2.3-MW turbines that were operational prior to the study in 2019. Crowned Ridge II consisted of 88, 2.3-MW turbines that were constructed from July to August 2020 and became operational in November 2020. Other wind energy facilities in the region included Dakota Range I, II (72, 2.2–4.5-MW; constructed August to December 2020 and June to September 2021, turbines operational in 2021), and III (32, 4.5-MW; constructed August to December 2020 and June to September 2021, turbines operational in 2021), Deuel Harvest North (101, 2.8-MW turbines operational in 2019), and Tatanka Ridge (50, 2.8-MW turbines and 6, 2.3-MW turbines; constructed April 2020 to July 2021, operational in January 2021). 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 classified as tallgrass prairie within the Northern Great Plains Region (Johnson & Larson, 2007) and consisted of almost entirely privately owned land managed for cattle grazing and crop agriculture production. Several small state and federally managed wildlife management areas and waterfowl production areas interspersed the study area. Topography was characteristic of the Prairie Coteau ecoregion, consisting of rolling hills and numerous wetlands (Johnson & Larson, 2007). Elevations ranged from 294 to 635 m (US Geological Survey [USGS], 2023), and annual precipitation during the study was 51.8 cm in 2020, 71.0 cm in 2021, and 63.9 cm in 2022. Mean yearly precipitation in the study area was 62.2 cm (National Oceanic and Atmospheric Administration, 2024). Common grasses included big bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), porcupine grass (*Hesperostipa spartea*), sideoats grama (*Bouteloua curtipendula*), and switchgrass (*Panicum virgatum*). Common forbs included American licorice (*Glycyrrhiza lepidota*), blazing star (*Liatris pycnostachya*), Canada goldenrod (*Solidago canadensis*), common sunflower (*Helianthus annuus*), downy phlox (*Phlox pilosa*), false boneset (*Brickellia eupatorioides*), giant goldenrod (*Solidago gigantea*), ground plum (*Astragalus crassicarpus*), heath aster (*Symphyotrichum ericoides*), New England aster (*Symphyotrichum novae-angliae*), purple prairie clover (*Dalea purpurea*), purple coneflower (*Echinacea purpurea*), pussytoes (*Antennaria neglecta*), and silverleaf scurfpea (*Pediomelum argophyllum*). Dominant shrubs included lead plant (*Amorpha canescens*) and prairie rose (*Rosa arkansana*; Johnson & Larson, 2007). Common crops included alfalfa (*Medicago sativa*), corn (*Zea mays*), soybeans (*Glycine max*), and wheat (*Triticum*).

METHODS

Field methods

We searched for previously undocumented leks (i.e., two or more displaying males) each spring and visited known leks to count the number of individual sharp-tailed grouse in attendance. We surveyed all known leks three to four times each spring using ground-based lek counts during the lekking period. We conducted aerial lek surveys in 2020 to search for previously unknown leks and to supplement ground-based surveys. Lek surveys followed standardized protocols (South Dakota Game Fish and Parks, 2022). We targeted leks for capture based on the number of males observed on leks (≥6 males), proximity to turbines (to ensure leks were spaced along a gradient from turbines), and landowner access. Capture leks were selected at random to the extent possible, but lek capture selection was limited by landowner access constraints and availability of known leks to trap. We were unable to capture grouse at leks in the southern portion of the study area because these leks were small (<6 males per lek) and did not adequately represent the local population.

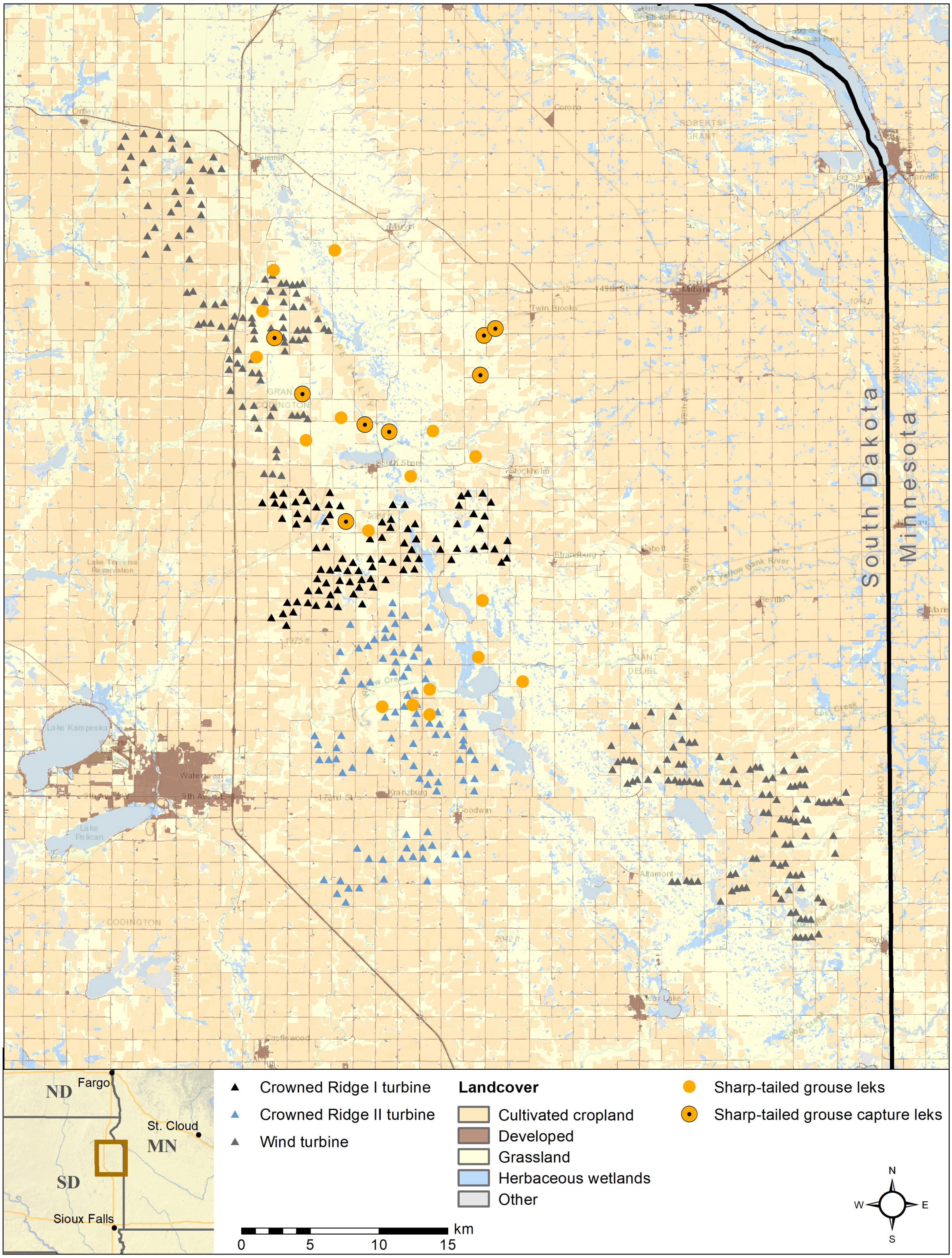

FIGURE 1 Study area located in Grant, Codington, and Deuel counties, South Dakota, USA, including locations of wind turbines, land cover types, sharp-tailed grouse leks monitored during the 2020–2022 breeding seasons, and leks where grouse captures occurred within the study area.

We targeted female sharp-tailed grouse for captures, given their contribution to population growth rates (Milligan et al., 2018). We captured females from leks using walk-in drift traps during the spring lekking period, March–late April (Haukos et al., 1990). We sexed each grouse based on tail feather striation and color of crown feathers and aged them as juveniles or adults based on the shape and condition of the ninth and tenth primary feathers (Ammann, 1944; Henderson et al., 1967). We fit all captured adult and yearling females with GPS-ultra-high-frequency (UHF) solar-powered telemetry units (Ecotone Harrier GPS-UHF, Saker GPS-GSM model L) with a modified rump-mounting harness (Kirol et al., 2020). Telemetry units weighed approximately 17 g (less than 3% body mass; Phillips et al., 2003).

GPS units were programmed to collect locations every 15 min and uploaded via 3G cellular transmission to an online server, allowing for near real time assessment. We masked locations recorded from each individual immediately following capture and assumed that individuals acclimated to the GPS transmitters after 2 days (C. Kelly, unpublished data). GPS units were also equipped with VHF transmitters (model RI-2B, Holohil Systems Ltd., Ontario, Canada) to allow for manual tracking when necessary. We manually located sharp-tailed grouse on the ground beginning in May each year using a R4000 (Isanti, MN, USA) receiver (Advanced Telemetry Systems, Isanti, MN, USA) and three- or five-element Yagi antennas. We used fixed-wing aircraft flights to locate any individuals that went missing. In the event locations were localized for more than a day indicating a mortality, we visited the location to retrieve the GPS transmitter and determine cause of death when possible.

We located nests by visually inspecting location data that indicated homing by females to a single location (±GPS location error). We considered the nest to have failed if a female permanently left the nest location prior to the 23-day incubation period (Johnsgard, 1983). We visited each nest to confirm fate and considered a nest successful when at least one egg hatched (Rotella et al., 2004). We manually tracked the bird immediately following confirmation of nest fate and 35 days after hatch using VHF telemetry to confirm brood fate by visually observing chicks or brooding behavior by the female (e.g., distraction displays or injury feigning; Kirol et al., 2015). We monitored all females throughout the study period irrespective of nest fate.

Resource selection and survival analyses

We used binomial generalized linear mixed models to estimate the relative probability of female sharp-tailed grouse nest site, brood-rearing (from hatch to 5 weeks), and breeding season (1 April–15 August) resource selection within the study area. Breeding season models included locations from the nesting and brood-rearing periods. Models included a random intercept term identifying individual grouse nested within year to account for variation among individuals and across years (Gillies et al., 2006). We randomly selected 10 used locations per day to minimize spatial autocorrelation (Valcu & Kempenaers, 2010). We evaluated resource selection at the home range (second order) and within home range (third order) scales 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 of all marked females), whereas the within home range analyses evaluated resource selection at the individual level (an individual's selection given habitat within each female's seasonal range). For all home range scale analyses, we restricted available locations to a 99% fixed kernel density estimator (KDE; Worton, 1989) surrounding all sharp-tailed grouse locations during the life stage being evaluated. For within home range analyses, we generated available points 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 to generate available locations. We assumed that a 3-week period represented the time period 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. We restricted the brood-rearing resource selection analysis to individuals that were known to have broods. Prior to model development, we ran and tested model fit on a series of models using 5, 10, 15, 20, and 25 available locations per used location of females during the breeding season. We determined the rate of 25 times the number of used locations for home range and within home range analyses was the best fit. Coefficients consistently converged with 25 available locations per used location (Northrup et al., 2013).

Spatial predictors

We considered both habitat and energy infrastructure variables to assess sharp-tailed grouse resource 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, corn, herbaceous wetland, grassland, soybeans, total crop cover (including alfalfa, corn, and soybeans), and developed areas (including roads, dwellings, and associated infrastructure; USDA, 2023). We selected major crop cover variables (corn, alfalfa, and soybeans) based on their abundance in the study area and visual observations of sharp-tailed grouse use. Land cover

TABLE 1 Spatial predictor variables used to assess sharp-tailed grouse resource selection and survival in Grant, Codington, and Deuel counties, South Dakota, USA, from 2020 to 2022.

Covariate[a]	Description	Biological significance	Citation
Habitat variables			
Alfalfa	Alfalfa canopy cover (%; USDA, 2023)	May act as preferred forage	Goddard et al. (2009), Sullins et al. (2018)
Corn	Corn canopy cover (%; USDA, 2023)	May act as a preferred forage	Roy and Chen (2023)
Grassland	Grassland canopy cover (%; USDA, 2023)	Prairie grouse have strong selection for grasslands across all life stages	Milligan et al. (2020a), Proett et al. (2019), Runia et al. (2021)
Herbaceous wetland	Herbaceous wetland (%; USDA, 2023)	May provide dense vegetation for concealment and a source of invertebrates	McDonald and Reese (1998)
Soybeans	Soybean canopy cover (%; USDA, 2023)	May act as a preferred forage	Roy and Chen (2023)
Total crop	Combined canopy cover of alfalfa, corn, miscellaneous crop, and soybeans (%; USDA, 2023)	Higher proportions of cropland may result in decreases in survival	Milligan et al. (2020b)
Distance to roads	Euclidean distance to road (km; Minnesota Department of Transportation, 2012; South Dakota Department of Transportation, 2022)	Vehicle noise may increase perceived risk	Harrison et al. (2017), Londe et al. (2022), Pitman et al. (2005), Pruett et al. (2009)
TPI	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 (USGS, 2023).	Lower TPI values may act as concealment and provide thermal refugia	Raynor et al. (2018)
TRI	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).	Lower TRI values (depressions) may catch water resulting in higher soil moisture and more vegetation growth for concealment	Raynor et al. (2018)
Energy infrastructure variables			
Distance to transmission line	Euclidean-distance to transmission or distribution line (69–345 kV; km; DHS, 2022)	May act as perches for aerial predators and increase risk and avoidance by grouse	Hagen et al. (2011), Londe et al. (2019), Plumb et al. (2019), Pruett et al. (2009)
Distance to turbine	Euclidean-distance to turbine (km; Hoen et al., 2018)	Presence of turbines may result in avoidance of otherwise suitable habitat	LeBeau, Johnson, et al. (2017), Winder et al. (2014)
Transmission line length	Length of transmission lines (km; DHS, 2022)	Higher densities may result in higher perceived risk	Sullins et al. (2019)
Turbine density	Count of wind turbines (Hoen et al., 2018)	No. turbines may affect the strength of avoidance behaviors	LeBeau et al. (2023)

Abbreviations: DHS, Department of Homeland Security; USDA, US Department of Agriculture; USGS, US Geological Survey; TPI, terrain positioning index; TRI, terrain roughness index.

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

data were available each year; therefore, we temporally matched sharp-tailed grouse locations to the appropriate year to reflect land cover when locations were recorded.

We used a 30-m resolution digital elevation model (USGS, 2023) to create a terrain roughness index (TRI) and terrain positioning index (TPI). We calculated TRI 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 were higher or lower than their surrounding areas, respectively (Guisan et al., 1999). We calculated distance to roads using spatial data that included all public roads from the Minnesota Department of Transportation (2012), South Dakota Department of Transportation (2022), and service roads to wind turbines that were manually digitized.

Wind energy and transmission line covariates included distance to turbine (in kilometers), distance to transmission line (in kilometers), turbine density (count of turbines within each circular scale), and length of transmission lines (in kilometers; transmission line density). We obtained locations of turbines from the US Wind Turbine database (Hoen et al., 2018). We verified the timing of construction and commercial operation dates through direct communication with wind energy facility operators. We obtained transmission line data from the Department of Homeland Security (2022). Transmission line voltage ranged from 69 to 345 kV within the study area. We time-stamped wind energy covariates to accurately reflect when infrastructure was present on the landscape.

We assessed all habitat covariates (excluding those describing Euclidean distance) within six circular scales: 0.2-, 0.5-, 1.0-, 1.3-, 3.2-, and 5.0-km radii. We assessed wind energy infrastructure and transmission line variables within 1.0, 1.3, 3.2, and 5.0 km. We also assessed TPI and TRI at the local scale (raster pixel). Scales were determined based on previous research on survival and spatial use patterns of sharp-tailed grouse (Milligan et al., 2020b; Runia et al., 2021) and current management recommendations for wind energy development siting (the process of selecting the optimal location for a project and the associated features; North Dakota Game and Fish Department, 2021; South Dakota Game Fish and Parks, 2022).

Experimental design and analysis

We assessed the potential influence of wind energy infrastructure and transmission lines on sharp-tailed grouse behavior and demography using resource selection and survival analyses. We evaluated resource selection of sharp-tailed grouse nests, broods, and adult females during the breeding season (1 April to 15 August). We assessed survival of nests over the 23-day incubation period and female survival during the breeding season (1 April to 15 August). In each analysis, we related sharp-tailed grouse locations to spatially explicit habitat and energy infrastructure covariates (Table 1). We performed all statistical analyses in R version 4.1.3 (R Core Team, 2022). We used second order Akaike information criterion (AIC_c) to assess model support for all models (Burnham & Anderson, 2002). Prior to model development, we ran univariate models and retained variables when they were more informative than random intercept only models. We removed variables from further consideration if 85% CIs surrounding coefficient estimates included 0 (Arnold, 2010). For non-Euclidean distance-based variables that were assessed at multiple scales, we retained the variable scale that had the lowest AIC_c score. We completed variable screening procedures independently for each model.

We used a variable subsetting approach (Arnold, 2010), where we first explored all combinations of uncorrelated (Pearson's correlation analysis $|r| > 0.6$) habitat variables retained after univariate screening that excluded wind energy infrastructure and transmission line variables. We set the maximum number of habitat variables in any model to six to limit potential model overfitting (Burnham & Anderson, 2002). We used AIC_c to rank models and considered the most parsimonious model to be the base model for comparison with models containing energy infrastructure variables. We used a similar variable screening procedure for wind energy and transmission line variables. We then compared the base model to models that included habitat variables in the base model plus all combinations of uncorrelated (Pearson's correlation analysis $|r| < 0.6$) wind energy and transmission line variables. This modeling approach allowed us to determine whether models containing energy infrastructure variables were more predictive of sharp-tailed grouse resource selection or survival compared with models only containing habitat covariates in the base model. Our approach also allowed us to account for underlying environmental factors influential to sharp-tailed grouse resource selection and survival to better isolate the potential effects of wind energy infrastructure. We fit candidate models with package *MuMIn* in R (Bartoń, 2022). We allowed each model to compete and selected the most parsimonious model based on AIC_c (Burnham & Anderson, 2004). We considered covariates in final models that had 95% CIs that included 0 to be uninformative.

We further evaluated final models that contained wind energy and transmission line variables with parameter estimates that indicated behavioral avoidance or survival consequences to test for potential thresholds in sharp-tailed grouse responses. We investigated quadratic and ramped thresholds separately for all energy infrastructure variables present in the final model. 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). A quadratic or ramped threshold may be detected if sharp-tailed grouse are not avoiding infrastructure at low densities but do exhibit avoidance once a certain density has been reached. To determine potential ramped threshold values to assess, we used 10% quantile intervals (ranging from 10% to 90%) based on the distribution of sharp-tailed grouse use locations relative to the wind energy or transmission line variable of interest. Therefore, we tested up to nine ramped thresholds and one quadratic threshold for each energy infrastructure variable included in final models. We used AIC_c to assess support for including nonlinear terms in final models.

We evaluated the predictability of the most parsimonious home range scale breeding season RSF using a 5-fold cross-validation (Boyce et al., 2002; Johnson et al., 2006), where we spatially predicted the RSF within a 10-km buffer of the Crowned Ridge I and Crowned Ridge II facilities. We binned predictions into five equal-area (quartile) intervals (Wiens et al., 2008). We performed model validations with linear regressions run on the number of observed locations from test groups compared with 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% CIs of slope estimates that excluded 0 and included 1 (Howlin et al., 2004). We mapped the most predictive RSF across the study area using coefficients from the top model and distributed predictions into five equal-area bins corresponding to low, moderate-low, moderate, moderate-high, and high relative probability of selection. We also mapped the most predictive base model RSF to visually compare spatial predictions that did not include the additive effects of wind energy infrastructure variables.

We evaluated nest and breeding season female survival using Cox proportional hazards regression models to relate hazard of death to predictor variables using the *coxme* package in R (Cox, 1972; Therneau & Grambsch, 2000). Cox models relate hazard of death to multiple covariates that may influence hazard rate. Hazard ratios produced by Cox models can be used to compare different levels of a variable of interest on the risk of failure or death. By estimating hazard ratios, we can gain insights into how specific variables may influence nest success and survival. We assessed nest survival over a 23-day incubation period (Johnsgard, 1983). We only included first nest attempts because renests may not have been independent of first nests and comprised a relatively small sample ($n = 8$). We assessed female survival from 1 April to 15 August (19 weeks) to be consistent with other studies (Manzer & Hannon, 2008; Milligan et al., 2020b). We excluded individuals that died within 2 days of capture from the analysis to remove possible bias associated with potential capture-related mortality. We modeled female risk during the breeding season using the Anderson–Gill formulation of the Cox proportional hazards regression to accommodate left and right censoring of data (Anderson & Gill, 1982). We tested the assumption of proportional hazards using Schoenfeld residuals of the covariates included in the final model (Schoenfeld, 1982).

RESULTS

We completed lek counts from 11 March to 25 April each year. The locations of 19 sharp-tailed grouse leks were known prior to initial surveys in 2020, and 12 previously undocumented leks were identified during ground- and aerial-based surveys (Figure 1). Consistent surveys were not conducted at the 19 leks prior to 2020. The average maximum male sharp-tailed grouse count at leks was six (range = 0–23), nine (range = 0–31), and eight (range = 0–29) in 2020, 2021, and 2022, respectively (Figure 2). We captured 130 female sharp-tailed grouse (2020: $n = 51$, 2021: $n = 50$, 2022: $n = 29$) at eight leks over the study period. We monitored 25 females for multiple years of the study. The average distance of a capture lek to the nearest wind turbine was 5.6 km (range = 0.7–11.7 km). We removed 11 individuals from our analyses because they died within 2 days of capture. Resource selection models included 75 nests, 5364 brood–rearing locations from 17 broods, and 72,453 breeding season locations (Figure 3). In our study, 95% of female breeding season locations (including nest and brood-rearing) occurred within 4.3 km of an active lek (50% of locations were within 1.4 km) and 95% were located in areas that contained greater than 28% grassland (50% of locations contained greater than 52% grassland) within all scales that we assessed. Our survival analyses included 65 first nest attempts and 112 females with complete survival histories. Of the 75 nests included in the analysis, eight were within 1.0 km of a wind turbine, eight within 1.3 km, 12 within 3.2 km, and 19 within 5.0 km of a turbine. The remaining 56 nests were 5.0–24.5 km from turbines.

Resource selection

Nest site selection at the home range scale was improved with the addition of transmission line variables compared with base models (Appendix S1: Table S1). The final model suggested that female sharp-tailed grouse selected nest sites with a greater proportion of grassland within 0.2 km, less herbaceous wetland within 3.2 km, lower TPI within

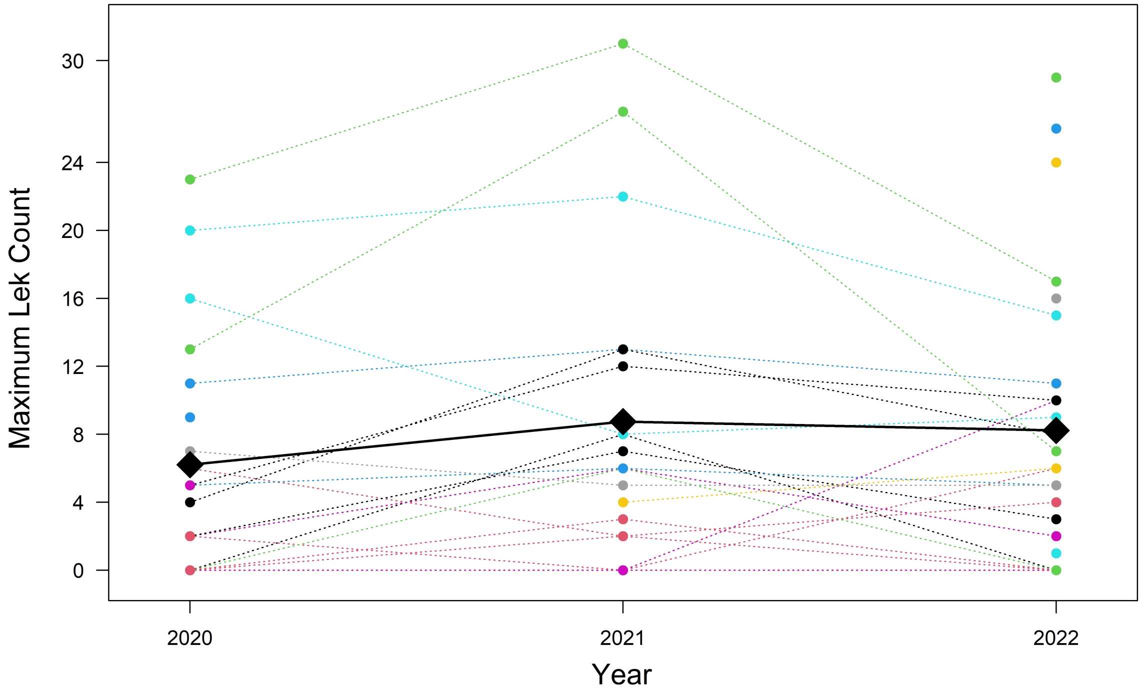

FIGURE 2 Trends in sharp-tailed grouse leks monitored during the 2020–2022 breeding seasons within the study area in Grant, Codington, and Deuel counties, South Dakota, USA. Points connected by dashed lines represent individual leks. The solid black line connects the mean maximum lek count for each year. Points not connected by dashed lines were not monitored in previous years.

5.0 km, lower TRI within 3.2 km, and a lower length of transmission lines within 5.0 km (Table 2). The addition of threshold terms to describe the length of transmission lines within 5.0 km did not improve model fit compared with a model that only contained the linear model term. At the within home range scale, sharp-tailed grouse selected nest sites with greater proportion of grassland within 0.2 km and lower TPI at the local scale (Table 2). Models containing wind energy and transmission line variables did not improve model fit compared with base models (Appendix S1: Table S1).

Models describing brood-rearing resource selection at both scales of selection were improved by the addition of wind energy and transmission line variables compared with base models at both scales of selection (Appendix S1: Table S2). The final model describing brood site selection at the home range scale suggested that brood-rearing females selected locations with more alfalfa within 5.0 km, less corn within 5.0 km, less developed land within 1.3 km, a greater proportion of grassland within 0.5 km, a greater proportion of herbaceous wetland within 1.0 km, lower TPI within 5.0 km, a lower length of transmission lines within 5.0 km, areas closer to turbines, and a higher density of turbines within 1.3 km (Table 3). A nonlinear relationship of the length of transmission lines within 5.0 km suggested that females with broods avoided areas once the length of transmission lines exceeded approximately 3.0 km within 5.0 km (Figure 4). Threshold terms considered for wind turbine density did not improve model fit. At the within home range scale, females selected brood-rearing locations with a greater proportion of developed land within 1.0 km, a greater proportion of grassland within 0.2 km, a greater proportion of herbaceous wetland within 1.3 km, lower TPI, higher TRI, and areas closer to transmission lines (Table 3). A quadratic term describing wind turbine density within 1.0 km suggested that brood-rearing sharp-tailed grouse did not avoid areas until the number of turbines within 1.0 km exceeded approximately 4 (Figure 4).

The density of used and available locations in relation to wind energy infrastructure covariates to assess breeding season resource selection at the home range and within home range scales are in Appendix S1: Figures S1 and S2. Models that contained wind energy and transmission line variables were more informative than base models during the breeding season (Appendix S1: Table S3). The final home range scale model suggested that female sharp-tailed grouse selected areas with less developed land within 0.5 km, closer to roads, a 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 4). The addition of a quadratic term describing distance to turbines suggested

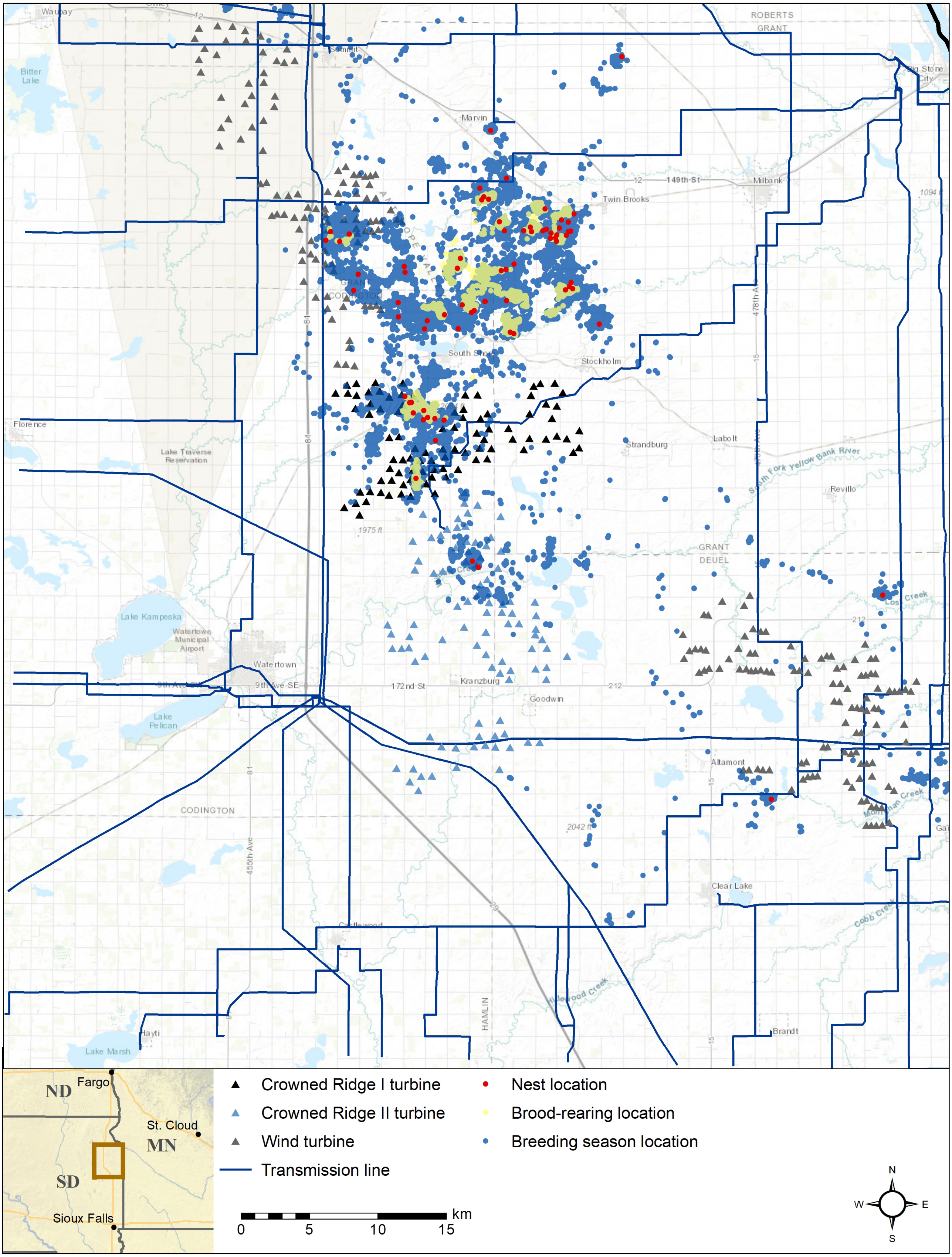

FIGURE 3 Nest, brood-rearing, and breeding season locations of female sharp-tailed grouse within the study area in Grant, Codington, and Deuel counties, South Dakota, USA, during the 2020–2022 breeding seasons.

TABLE 2 Coefficient estimates and 95% CIs for covariates in models describing sharp-tailed grouse nest site selection at home range (second order) and within home range (third order) scales in Grant, Codington, and Deuel counties, South Dakota, USA, 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[a]	−0.23*	−0.45	−0.01

Note: An asterisk (*) indicates which variables were significant at the 95% CI.
Abbreviations: NA, not available; TPI, terrain positioning index; TRI, terrain roughness index.
[a]The variable was measured at the local scale.

TABLE 3 Coefficient estimates and 95% CIs 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 in Grant, Codington, and Deuel counties, South Dakota, USA, 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[a]	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[a]	1.0	−0.34*	−0.39	−0.29

Note: An asterisk (*) indicates which variables were significant at the 95% CI.
Abbreviations: NA, not available; TPI, terrain positioning index; TRI, terrain roughness index.
[a]Quadratic term.

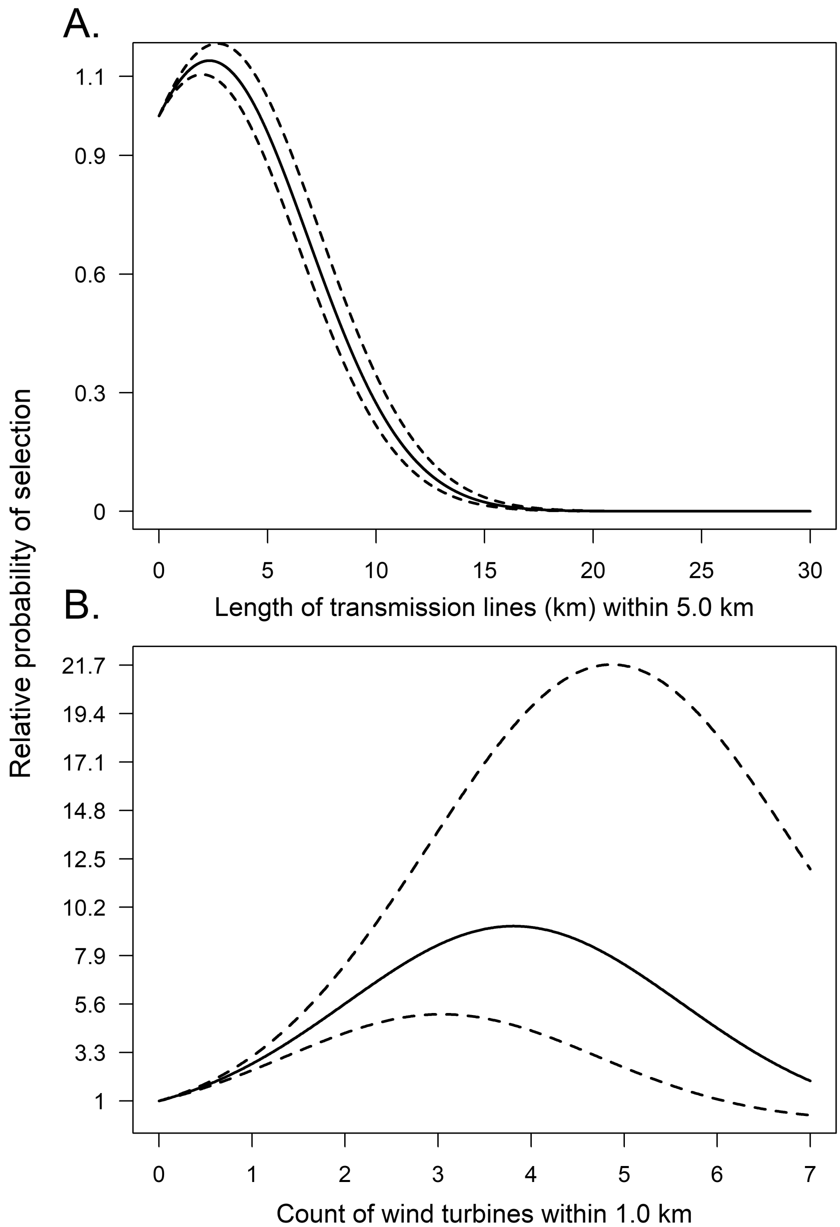

FIGURE 4 Relative probability of brood-rearing female sharp-tailed grouse selection (A) at the home range and (B) within home range scales as a function of length of transmission lines within 5.0 km and count of wind turbines within 1.0 km near the study area in Grant, Codington, and Deuel counties, South Dakota, USA, during the 2020–2022 breeding seasons. Dashed lines represent 95% CIs surrounding predictions.

that the relative probability of selection by sharp-tailed grouse during the breeding season increased positively as distance to turbines increased up to approximately 14 km, after which relative probability of selection declined (Figure 5A). Of note, however, is that only 6% of used locations were farther 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 (Appendix S1: Figure S3). When we partitioned validation testing and training groups by individual, average $r^2 = 0.98 \pm <0.01$ SE. In general, the relative probability of selection increased slightly in areas near turbines based on final model predictions (Appendix S1: Figure S3B) relative to base model predictions (Appendix S1: Figure S3A). 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, suggesting that relative probability of selection was not reduced in areas near wind turbines at the home range scale (Appendix S1: Figures S4 and S5).

At the within home range scale during the breeding season, the addition of wind energy and transmission line covariates improved model fit compared with base models

TABLE 4 Coefficient estimates and 95% CIs for covariates in models describing female sharp-tailed grouse breeding season (1 April through 15 August) site selection at the home range (second order) and within home range (third order) scales in Grant, Codington, and Deuel counties, South Dakota, USA, 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[a]	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[a]	5.0	0.59*	0.54	0.65

Note: An asterisk (*) indicates which variables were significant at the 95% CI.
Abbreviations: NA, not available; TPI, terrain positioning index; TRI, terrain roughness index.
[a]Quadratic term.

(Appendix S1: Table S3). 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, a 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, and with a lower density of turbines within 5.0 km. A quadratic term describing turbine density within 5.0 km suggested that during the breeding season, sharp-tailed grouse showed the strongest avoidance in areas with approximately 20–35 wind turbines within 5.0 km (Figure 5B).

Nest and adult survival

The final nest survival model indicated that nest survival during the incubation period was negatively associated with the proportion of grassland within 1.3 km (Table 5). The addition of wind energy infrastructure did not improve model fit (Appendix S1: Table S4). The addition of wind energy infrastructure improved the female survival model fit compared with the base model (Appendix S1: Table S4). Nest survival estimates for the 3 years of the study were 0.57 (95% CI = 0.43 to 0.80) in 2020, 0.52 (95% CI = 0.36 to 0.74) in 2021, and 0.44 (95% CI = 0.21 to 0.92) in 2022. The base model suggested that female survival was negatively associated with the proportion of developed land within 3.2 km, positively associated with the proportion of soybeans within 0.5 km, and negatively associated with TPI within 5.0 km, whereas the final model also included a negative association with the density of wind turbines within 5.0 km (Table 5). However, we considered turbine density within 5.0 km to be uninformative because CIs surrounding this parameter estimate overlapped 0 (95% CI = −0.2 to 0.03). Female survival estimates during the breeding season were 0.43 (95% CI = 0.31 to 0.61)

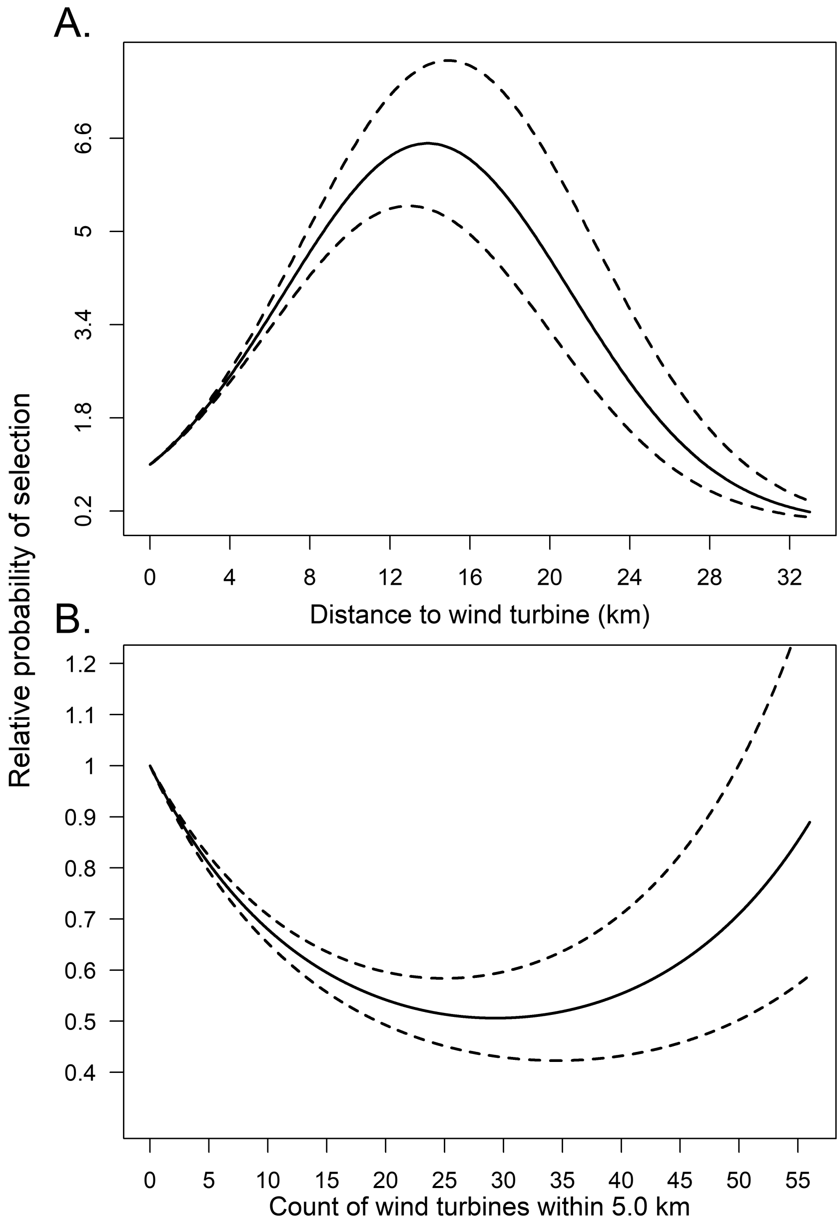

FIGURE 5 Relative probability of female sharp-tailed grouse breeding season selection (A) at the home range and (B) within home range scales as a function of distance to transmission lines and count of wind turbines within 5.0 km in Grant, Codington, and Deuel counties, South Dakota, USA, during the 2020–2022 breeding seasons. Dashed lines represent 95% CIs surrounding predictions.

in 2020, 0.27 (95% CI = 0.17 to 0.43) in 2021, and 0.27 (95% CI = 0.14 to 0.55) in 2022.

DISCUSSION

Wildlife managers have been tasked with understanding how energy development may impact grassland bird populations. Current literature evaluating grassland bird responses to wind energy infrastructure is generally mixed and provides limited context for conservation planning. Our study addressed an important knowledge gap focused on the plains sharp-tailed grouse. We did not find evidence that females selected nest sites in relation to wind energy infrastructure but found that females with broods and during the breeding season avoided areas near high densities of wind turbines within their home ranges. We found consistent selection for lower lengths of transmission lines across all life stages at the home range scale. We did not detect an effect of wind energy infrastructure on nest or female survival. Our findings will be useful for identifying management practices to minimize impacts to sharp-tailed grouse exposed to future wind energy facilities.

TABLE 5 Coefficient estimates and 95% CIs for covariates in models describing sharp-tailed grouse nest and female survival in Grant, Codington, and Deuel counties, South Dakota, USA, 2020–2022.

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

Note: A positive coefficient indicates a greater risk of nest failure or female mortality. An asterisk (*) indicates which variables were significant at the 95% CI. Abbreviation: TPI, terrain positioning index.

Consistent with other studies, female sharp-tailed grouse selected areas with higher amounts of grassland across all life stages we assessed (Milligan et al., 2020a; Proett et al., 2019), highlighting the importance of conserving large intact grassland habitats for sharp-tailed grouse conservation (Runia et al., 2021). The median proportion of grassland used by sharp-tailed grouse during the breeding season in our study was relatively high and greater than 0.52 at used locations within all circular regions that were assessed (Appendix S1: Figure S6). Other studies have reported that the percentage of grassland and pasture hay within a 1.2-km radius was a strong positive predictor of sharp-tailed grouse occurrence and density in North and South Dakota (Runia et al., 2021). In Montana and western North Dakota, female sharp-tailed grouse selected a greater proportion of grassland habitats within their home ranges during the breeding season (Milligan et al., 2020a). Contrary to other studies, we found that sharp-tailed grouse nest survival decreased with higher proportions of grassland within 1.3 km. This negative relationship may be related to the local predator population, which we did not measure. For example, red foxes (*Vulpes vulpes*) forage more often in pastureland, compared to cropland (Phillips et al., 2004). We also found that sharp-tailed grouse selected areas with more alfalfa during brood-rearing, a finding consistent with other studies (Goddard et al., 2009). Forb-rich cultivated crop fields may function as preferred forage (Sullins et al., 2018) and potentially provide concealment structure. We found that sharp-tailed grouse selected nesting and brood-rearing habitats 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 that prairie grouse generally avoid roads (Harrison et al., 2017; Londe et al., 2022; Pitman et al., 2005; Pruett et al., 2009), we found that sharp-tailed grouse selected areas near roads during the breeding season at the home range scale. A potential explanation is that our study area contained mostly gravel roads used primarily by residential traffic as opposed to more heavily traveled roads.

We did not detect an effect of wind turbine distance or density on nest site selection at either scale that we assessed, a finding consistent with other studies evaluating prairie grouse response to wind energy infrastructure (Harrison et al., 2017; LeBeau et al., 2023; McNew et al., 2014; Proett et al., 2019). In addition, we found little evidence that females with broods avoided areas influenced by wind turbines at either scale of selection. Females with broods selected areas closer to turbines and with more turbines within 1.3 km at the home range scale. At the within home range scale, females with broods selected areas with up to approximately four turbines within 1.0 km. We are unaware of any prairie grouse studies that have evaluated brood-rearing resource selection relative to wind turbines, but LeBeau, Johnson, et al. (2017) found that female greater sage-grouse with broods avoided areas with a higher density of wind turbines.

During the breeding season, females selected areas farther from wind turbines, but in areas with greater turbine density within 3.2 km at the home range scale. The spatial predictions of the home range breeding season RSF model, which also accounted for other attributes of sharp-tailed grouse habitat, however provided limited support that wind turbines resulted in strong avoidance by sharp-tailed grouse at this scale. When considering the base RSF, 52.3% of wind turbines were in areas predicted to be in areas of medium-high or high relative probability of breeding season resource 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 sharp-tailed grouse selection.

In contrast, we found that female sharp-tailed grouse resource selection was negatively associated with the count of wind turbines within 5.0 km at the within home range scale. This is contrary to the responses of lesser prairie chickens (*Tympanuchus pallidicinctus*), which selected habitats closer to wind turbines when turbine densities were low (LeBeau et al., 2023). A count of 20–35 wind turbines within 5.0 km represented a potential threshold where sharp-tailed grouse relative probability of selection was lowest. The model predicted an approximate 85% to 93% reduction in relative probability of selection when the number of wind turbines increased from 0 to 20 or 0 to 35 within 5.0 km, respectively. 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 lengths of transmission lines at the home range scale during the nesting and brood-rearing stages and at the within home range scale during the breeding season. Mounting evidence indicates that avoidance of transmission lines is a consistent behavior by prairie grouse at multiple spatial scales (Londe et al., 2019; Plumb et al., 2019; Pruett et al., 2009). 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 (Gibson et al., 2018; Hagen et al., 2011). We generally failed to detect a consistent effect of transmission line length or distance to transmission line across life stages at the within home range scale. This likely indicates that sharp-tailed grouse were primarily selecting habitats at the larger scale, possibly resulting in fewer transmission lines available within home ranges. Vegetation characteristics and topography appeared to be more important to sharp-tailed grouse when selecting habitats at the finer scale. 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 2.0-km radius.

Similar to other studies evaluating associations between grouse survival and wind energy infrastructure, we did not detect an effect of wind energy infrastructure on nest survival (Harrison et al., 2017; LeBeau et al., 2023; LeBeau, Johnson, et al., 2017; McNew et al., 2014; Proett et al., 2019). 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 (LeBeau et al., 2023; McNew et al., 2014; Proett et al., 2019). 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. We did not evaluate brood survival relative to wind energy infrastructure; however, there is evidence that brood success and chick survival of Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) are negatively associated with wind turbine density (Proett et al., 2022), warranting further investigation. Based on our analysis criteria, we did not find evidence that female survival during the breeding season was associated with wind energy infrastructure. 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 (LeBeau, Johnson, et al., 2017; Winder et al., 2014) or was not influenced by wind energy infrastructure (LeBeau et al., 2023; Smith et al., 2017) following construction. Addressing the uncertainty in the effect of turbine density on female survival will be necessary to fully understand how wind energy infrastructure may impact sharp-tailed grouse.

Although we observed avoidance behavior associated with wind energy infrastructure during the breeding season, we did not detect significant changes to overall male lek counts over the 3-year study. Other prairie grouse research has found that population trends, indexed by lek counts, are not negatively impacted by wind energy infrastructure (LeBeau, Beck, et al., 2017), although there is 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 relationship between wind energy infrastructure and sharp-tailed grouse resource selection and survival limits our ability to make predictions about how sharp-tailed grouse may respond to wind energy development over a longer period. In addition, we lacked pre-development data to understand how sharp-tailed grouse utilized our study area prior to construction of the wind energy facilities, which is an unfortunate shortcoming in most wildlife-impact studies (Conkling et al., 2020; Hebblewhite, 2011). It has been suggested that grouse may exhibit a 3-year or more year lagged response to renewable and conventional energy development (e.g., Green et al., 2017; LeBeau, Beck, et al., 2017; Walker et al., 2007), and 10 or more years of data may be necessary to fully understand and detect population level impacts (sensu 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). Furthermore, our study area was a grassland landscape highly fragmented with row crop agriculture, unique to this region of South Dakota (Wimberly et al., 2018). Due to the relatively limited availability of intact grasslands in our study area, additional research will be necessary to fully understand how sharp-tailed grouse select habitats in proximity to wind energy development.

Based on the results of our study, siting wind turbines within 5.0 km of sharp-tailed grouse breeding habitat (e.g., areas within 4.3 km of a lek and containing greater than 28% grassland) should be limited to minimize sharp-tailed grouse avoidance. As the number of wind turbines within 5 km increased from 0 to 10, 0 to 20, and 0 to 35, the relative probability that sharp-tailed grouse selected these areas was reduced by 31.9%, 45.8%, and 48.1%, respectively. If development of new transmission lines is necessary for a wind energy facility, collocation with existing infrastructure and in areas outside of sharp-tailed grouse breeding habitat should be encouraged to minimize sharp-tailed grouse avoidance. Sharp-tailed grouse breeding habitat occurs near lek locations, which are typically centered on large intact grasslands (Hanowski et al., 2000; Merrill et al., 1999; Niemuth, 2000). Research employing long-term datasets and robust study designs will be necessary to determine management prescriptions especially in areas where available habitat differs from our study.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

All grouse captures adhered to protocols of a South Dakota Game, Fish, and Parks scientific collection permit (Permit No. 14) to minimize handling time and capture-related stress.

DATA AVAILABILITY STATEMENT

Data (Kelly et al., 2025) are available from Dryad: https://doi.org/10.5061/dryad.r2280gbnw.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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