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EFFECTS OF WIND POWER DEVELOPMENT ON THE POPULATION BIOLOGY OF GREATER PRAIRIE-CHICKENS IN KANSAS

Executive Summary

1. We investigated the impacts of wind power development on the *demography, movements, and population genetics* of Greater Prairie-Chickens (*Tympanuchus cupido*) at three sites in northcentral and eastern Kansas for a 7-year period. Only 1 of 3 sites was developed for wind power, the 201MW Meridan Way Wind Power Facility at the Smoky Hills site in northcentral Kansas. Our project report is based on population data for prairie chickens collected during a 2-year preconstruction period (2007-2008), a 3-year postconstruction period (2009-2011) and one final year of lek surveys (2012). Where relevant, we present preconstruction data from our field studies at reference sites in the northern Flint Hills (2007-2009) and southern Flint Hills (2006-2008).

2. We addressed *seven potential impacts* of wind power development on prairie chickens: lek attendance, mating behavior, use of breeding habitat, fecundity rates, natal dispersal, survival rates, and population numbers. Our analyses of pre- and postconstruction impacts are based on an analysis of covariance design where we modeled population performance as a function of treatment period, distance to eventual or actual site of the nearest wind turbine, and the interaction of these factors. Our demographic and movement data from the 6-year study period at the Smoky Hills site included 23 lek sites, 251 radio-marked females monitored for 287 bird-years, and 264 nesting attempts. Our genetic data were based on genotypes of 1,760 females, males and chicks that were screened with a set of 27 microsatellite markers that were optimized in the lab.

3. In our analyses of *lek attendance*, the annual probability of lek persistence during the preconstruction period was ~0.9. During the postconstruction period, distance to nearest turbine did not have a significant effect on the probability of lek persistence. However, the probability of lek persistence increased from 0.69 at 0 m to 0.89 at 30 km from turbines, and most abandoned lek sites were located <5 km from turbines. Probability of lek persistence was significantly related to habitat and number of males. Leks had a higher probability of persistence in grasslands than agricultural fields, and increased from ~0.2 for leks of 5 males, to >0.9 for leks of 10 or more males. Large leks in grasslands should be a higher priority for conservation. Overall, wind power development had a weak effect on the annual probability of lek persistence.

3. We used molecular methods to investigate the *mating behavior* of prairie chickens. The prevailing view for lek-mating grouse is that females mate once to fertilize the clutch and that conspecific nest parasitism is rare. We found evidence that females mate multiple times to fertilize the clutch (8-18% of broods, 4-38% of chicks) and will parasitize nests of other females during egg-laying (~17% of nests). Variable rates of parentage were highest in the fragmented landscapes at the Smoky Hills field site, and were lower at the Flint Hills field site. Comparisons of the pre- and postconstruction periods showed that wind energy development did not affect the mating behaviors of prairie chickens.

4. We examined *use of breeding habitats* by radio-marked females and conducted separate analyses for nest site selection, and movements of females not attending nests or broods. The

landscape was a mix of native prairie and agricultural habitats, and nest site selection was not random because females preferred to nest in grasslands. Nests tended to be closer to turbines during the postconstruction period and there was no evidence of behavioral avoidance of turbines by females during nest site selection. Movements of females not attending nests or broods showed that females crossed the site of the wind power development at higher rates during the preconstruction period (20%) than the postconstruction period (11%), and that movements away from turbines were more frequent during the postconstruction period. Thus, wind power development appears to affect movements in breeding habitats but not nest site selection of female prairie chickens during the breeding season.

5. We tested the effects of wind power development on five components of *female fecundity*: timing of clutch initiation, clutch size of first nests and renests, nest survival, and hatchability of eggs. Average date of clutch initiation was 26 April, clutch size was 12.7 and 10.6 eggs for first nests and renests, probability of nest survival was low at 0.18, but egg hatchability was high at 0.79. Wind power development had no impact on reproductive effort or nesting success, and all five components of fecundity were not related to treatment period or distance to turbine. Nest survival was the main factor limiting reproductive output of female prairie chickens and most losses were due to predation. Daily nest survival was strongly related to vegetative cover at the nest. Changes to rangeland management practices that would double nesting cover from 2.5 to 5 dm would triple the probability of nest survival from 0.17 to 0.52. Grass and forb cover had weak positive effects on daily nest survival whereas shrub cover, proximity to woodlands, and recent rainfall had negative effects. Reproductive performance of prairie chickens is low in managed rangelands in northcentral Kansas and efforts to improve range conditions and reduce predator activity would aid recovery of prairie chicken populations.

6. We used molecular methods to investigate patterns of *natal dispersal* in prairie chickens. High rates of nest failure limited the number of young that we could sample. Direct detections of natal dispersal were limited because survival of newly hatched chicks to become adults were low and because we were unable to detect dispersal distances outside of our study area. Direct observations of natal movements were limited and were inadequate to make conclusions about the potential impacts of wind energy development on natal dispersal. Spatial correlograms of genetic distance among males at leks were a more sensitive measure of population structure, and indicated a weak effect of wind energy development on the spatial genetic structure of prairie chickens.

7. We tested the effects of wind power development on *female survival* with time-to-event models, and on *residual body mass of males* with analyses of covariance. Distance to turbine and the interaction of distance and treatment period had no effect on female survival. Contrary to predictions of negative impacts of wind power development, the probability of female was lowest during the preconstruction period (0.274) and increased significantly during the postconstruction period (0.543). Inspection of hazard functions indicated that the difference in annual survival could be attributed to a higher risk of mortality during the lekking season in the preconstruction period. We suggest that wind power development may have improved ecological conditions for prairie chickens by disrupting the foraging behavior of diurnal raptors that kill prairie chickens at lek sites. In support of this idea, raptor kills tended to be farther from turbines during the postconstruction period whereas mammalian kills were closer. Analyses of

the major causes of mortality did not support our hypothesis because the odds of raptor predation were greater after development was completed. Most mortality losses of radio-marked females were due to predation, and losses to collision mortality or harvest were rare events. Low rates of natural mortality during fall and winter imply that harvest is likely to be additive mortality in prairie chickens. Wind energy development reduced the residual body mass of male Greater Prairie-Chickens at lek sites near turbines. Low values of residual body mass could have a negative impact on individual survival or fecundity rates, or may be related to predation risk and flight performance of males displaying at open lek sites.

8. We tested for impacts of wind power development on *population numbers* of prairie chickens with monitoring of male numbers at leks, and with genetic measures of population structure. Lek counts indicated that wind power development did not affect the population size of prairie chickens. Peak counts of males at leks were recorded the first year after construction was completed and the highest rates of population change were observed during the interval when the wind power facility was constructed. Population numbers of prairie chickens near and distant from turbines appeared to covary in parallel, probably because bird numbers were linked by dispersal movements. Estimates of population viability based on genetic diversity, effective population size and rates of population exchange did not show annual changes and were unaffected by wind development during our study. Estimates of relatedness among males at the same and different leks suggested that wind power development has either reduced dispersal rates or changed settlement patterns, leading to higher rates of relatedness among males displaying at the same lek site.

9. Greater Prairie-Chickens were not strongly affected by wind power development in Kansas. *Negative impacts* of wind power development included a trend for reductions in lek persistence near turbines, behavioral avoidance of turbines by females during their breeding season movements, and changes in the genetic structure of males at leks that were consistent with reduced dispersal or recruitment rates. We found *no impacts* of wind power development on nest site selection, female reproductive effort or nesting success, or population numbers. *Positive impacts* of wind power development included an increase in female survival rates. We hypothesized that the unexpected increase in female survival was related to changes in trophic interactions and disruption of the foraging behavior of raptors that kill prairie chickens at lek site.

10. Research funding for this project included a grant from the 20% Wind by 2030 Program of the Department of Energy (*this final report*), and grants from the Kansas Department of Wildlife, Parks and Tourism, the National Fish and Wildlife Federation, and initial funding from the National Wind Coordinating Collaborative. Research products from data collected during the preconstruction period have included *five peer-reviewed research articles* and *two PhD dissertations* at Kansas State University. Additional manuscripts are in review for possible publication in 2013-2014.

Background

Development of wind energy and other renewable energy resources is an important component of U.S. energy policy and economic recovery (DOE 2008). In 2008, the U.S. Department of Energy determined that the U.S. had adequate manufacturing capabilities and wind resources to reach the benchmark of having 20% of U.S. energy demand being met by wind energy by 2030 (DOE 2008). The potential for negative impacts of wind power development on wildlife were identified as one potential limitation for future development of wind as a renewable source of energy (DOE 2008). Wildlife species that could be sensitive to energy development include several species of prairie grouse and migratory tree bats. Listing of sensitive species under the Endangered Species Act would be highly detrimental to reaching the 20% benchmark by 2030 (DOE 2008). The purpose of our long-term research project has been to examine the potential impacts of wind power development on the ecology of a sensitive species of grassland bird.

We conducted a 7-year study (2006-2012) on the potential impacts of wind energy development on Greater Prairie-Chickens (*Tympanuchus cupido;* hereafter prairie chickens) in northcentral Kansas. Prairie chickens are a species of conservation concern because their breeding range has been greatly reduced and the core of their remaining range is located in Kansas, Nebraska, and South Dakota (Busby et al. 2001). Lek count data from monitoring programs of the Kansas Department of Wildlife, Parks, and Tourism indicate that prairie chicken numbers have declined in Kansas during the past 30 years (Rodgers 2008). Prairie chickens are thought to be sensitive to disturbance because they have large home ranges, and females may move up to 30 km from lek sites to nest (Robel et al. 1970, Schroeder 1991, Augustine and Sandercock 2011). Previous studies have provided evidence that female prairie chickens may avoid disturbance from oil and gas development and power lines (Pitman et al. 2005, Pruett et al. 2009, Hagen et al. 2011). Declining population numbers and genetic isolation are of particular concern for Greater Prairie-Chickens because they are one of the few wildlife species where inbreeding depression has been documented in wild populations (Westemeier et al. 1998).

Our 7-year field project was designed as a replicated experiment with three independent study sites to control for spatial and temporal variation in natural systems. We studied prairie chickens at three sites in northcentral and eastern Kansas where wind power development was planned. Field sites included a site in the Smoky Hills (2007-2012), a site in the northern Flint Hills (2007-2009), and a site in the southern Flint Hills (2006-2008, Figure 0.1). Rangeland management and human impacts differed between the two ecoregions where our study sites were located. The Smoky Hills study site (1,642 km^2) was located ~25 km south of Concordia, Kansas and was comprised of 58% grassland land cover, 35% row crop agriculture, 5% Conservation Reserve Program (CRP), 2% woodland (patches >30 m^2), and had a road density of >1.05 km per km^2. Land management at this area was a mixture of row crop agriculture and grazing agriculture with the most common agricultural products being wheat, soy beans, milo, and clover. Native grassland pastures at the Smoky Hills study location were burned less frequently than at the other two field sites (~1 time every 3 years) and cattle were stocked at lower densities for shorter periods (~1 head per 2-4 ha for 90 days). Cattle were turned out to pasture by late March at the other two study locations, but at the Smoky Hills location cattle stocking typically occurred later in the season from late April to early May. The northern Flint Hills location (671 km^2) was located ~20 km south of Manhattan, Kansas and was a grasslanddominated site with 81% grassland and ~10% row crop agriculture, and had a road density of 0.57 km per km^2. Rangelands were managed for cattle with annual burning and a mixture of intensive early stocking of steers or season long stocking of cow-calfs at a rate of 1 head per 1.6 ha for 180 days. The southern Flint Hills location (1,106 km^2) was located ~80 km east of Wichita, Kansas with grassland land cover exceeding 90% with < 3% row crop agriculture and a road density of 0.32 km of road per km^2. A majority of the area was burned annually in the spring and managed for cattle production using intensive early stocking (IESB) at a density of 1 head per 0.8 ha for 90 days.

Research funding for this project included a State Wildlife Grant from the Kansas Department of Wildlife, Parks and Tourism (this report), grants from the Department of Energy and the National Fish and Wildlife Federation, and initial funding from the National Wind Coordinating Collaborative. We collected preconstruction data at three field sites during 2006-2009. Neither of the Flint Hills field sites was developed for wind power and we collected postconstruction data at the Smoky Hills field site from 2009-2012. Our preconstruction data on the demography, movements and population genetics of prairie chickens from the Smoky Hills and Flint Hills sites have been published as four peer-reviewed articles and two dissertations. Our major research results included the following conclusions. Lek sites of Greater Prairie-Chickens in the two ecoregions were usually located on hilltops, surrounded by areas with a high percentage of grassland cover, and >85% of all leks are in habitat strata that comprise <20% of the total landscape (Gregory 2011, Gregory et al. 2011). Compared to northern populations elsewhere in their range, Greater Prairie-Chickens in Kansas start breeding early, have a long breeding season and high renesting rates, resulting in higher reproductive potential (McNew 2010, McNew et al. 2011a). We identified the main demographic mechanisms underlying ongoing population declines of Greater Prairie-Chickens in Kansas. We found that demographic losses were driven by low rates of nest and brood survival, and that females were most vulnerable to predation while attending eggs and young (McNew et al. 2012). The Smoky Hills site showed greater landscape fragmentation than our Flint Hills study sites (McNew et al. 2011a), which has impacted the evolution of life history traits in prairie chickens. High rates of adult mortality have selected for higher reproductive effort and greater clutch volumes among female prairie chickens in the Smoky Hills ecoregion (McNew et al. 2011b). Demographic losses before construction of wind power were related to rangeland management practices where annual burning and intensive cattle grazing reduces the vegetative cover and concealment of nesting females (L.M. Hunt, unpubl. data).

Of our three field sites, only the Smoky Hills field site in northcentral Kansas was developed for wind power energy during our field project. The Meridian Way Wind Power Facility was constructed eight miles south of Concordia in Cloud County, Kansas. The facility was built in two phases with a total of 67 Vestas V90 3.0 MW turbines and an installed capacity of 201MW. Horizon Wind Energy started construction of the facility in April 2008, erected lines of turbines in two phases starting in the eastern portion of the study area, and began commercial operation in December 2008. Our project report is based on population data for Greater Prairie-Chickens collected during a 2-year preconstruction period (2007-2008), a 3-year postconstruction period (2009-2011), and one final year of lek surveys (2012). Here, we report pre- and postconstruction data on the movements, demography and population genetics of prairie chickens at the Smoky Hills field site. Where relevant, we report information from our two Flint Hills study sites as context for our major results.

Our project was originally conceived as a BACI experimental design (before/after: control/impact, Anderson et al. 1999). One challenge for identifying the control sites for use as a reference for impact sites is to determine the threshold distance where energy development begins to have a negative impact. For the analyses in this report, we opted not to use an arbitrary threshold to delineate control and impact areas. Instead, we tested for potential thresholds in demographic and genetic responses by prairie chickens using an experimental design based on analysis of covariance. Treatment period was treated as a categorical variable with two levels (pre- and postconstruction periods) and distance to nearest turbine was treated as a continuous variable. Our spatial data included coordinates of lek sites, nest sites, centroids of female home ranges, and sites of mortality event. For the preconstruction period, we calculated distance from spatial locations to the site where the nearest wind turbine was eventually installed. Distance to an eventual turbine site during the preconstruction period should be a robust measure of baseline conditions because it controls for any preexisting gradients in habitat conditions in a heterogeneous landscape. During the postconstruction period, we used distances from our spatial data to the actual sites of completed wind turbines. Distance to nearest wind turbine should be regarded as an index of proximity to anthropogenic disturbance, because construction of access roads and power substations were also a part of the development project. Distances to nearest access road and power substations were highly correlated with distance to nearest turbine and were not included as separate explanatory factors in our analyses. Major transmission lines were buried underground within the footprint of the completed wind power facility, but a new high capacity transmission line was built to connect the power substations to the infrastructure of the existing transmission lines.

We tested for negative impacts of wind power development under the following hypothetical scenario (Figure 0.2). We predicted that demographic performance of prairie chickens should be unaffected by distance to eventual turbine site during the preconstruction period, and the expected slope of the relationship between distance and performance should be *zero*. If turbines were built in the best habitats that support the greatest demographic performance, it is possible that the baseline relationship could also have a *negative* slope coefficient. If wind energy development has negative impacts on wildlife species, we expected that demographic performance should be reduced at short distances from actual wind turbine sites but should show improvements for individuals and populations at greater distances. Under negative impacts of wind power, we predicted a *positive* slope coefficient for the linear (or curvilinear) relationship between demographic performance and distance from wind turbines.

We had seven objectives for testing the potential impacts of wind energy development on the population viability of Greater Prairie-Chickens**. Objective 1** *Impacts on Lek Attendance*. Lek sites are focal sites for mating activities of prairie chickens and are usually located close to suitable nesting habitats. We tested whether lek persistence was affected by wind-power development. **Objective 2** *Impacts on Mating Behavior*. Disturbance at lek sites could cause changes in mating behavior. We used molecular methods to test for changes in inter- and intra-group relatedness, and changes in the rate of multiple paternity. **Objective 3** *Impacts on Use of Breeding Habitat*. Prairie chickens are open country birds which require native grasslands for nesting and brood-rearing. We tested whether females show behavioral avoidance of wind turbines by examining patterns of nest site selection and movements of radio-marked females during the breeding season. **Objective 4** *Impacts on Fecundity Rates.* Wind power development could increase predation rates on nests or broods if development facilitated predator movements, or if collision mortalities are a food resource for predators. We tested whether proximity to wind turbines affected the nest survival or fecundity rates of female prairie chickens. **Objective 5** *Impacts on Natal Dispersal*. Dispersal is essential for demographic rescue and gene flow among spatially structured populations in a fragmented landscape. We used molecular methods to test for natal dispersal and impacts of development on population structure. **Objective 6** *Impacts on Survival Rates*. We tested for impacts of wind power development on the seasonal and annual survival rates of prairie chickens. **Objective 7** *Impacts on Population Numbers.* We tested for impacts of wind development on prairie chickens by examining counts of males at lek sites and molecular estimates of genetic diversity (H_o), effective population size (N_e/N), and relatedness (r) of males at the same or different leks.

Figure 0.1. Location of field sites for population studies of Greater Prairie-Chickens in northcentral and eastern Kansas, 2006-2012: a) Smoky Hills, b) northern Flint Hills and c) southern Flint Hills, Kansas. This project report focuses on the pre- and postconstruction impacts of wind power development for the 201 MW Meridian Way Wind Power Facility constructed at the Smoky Hills field site in 2008.

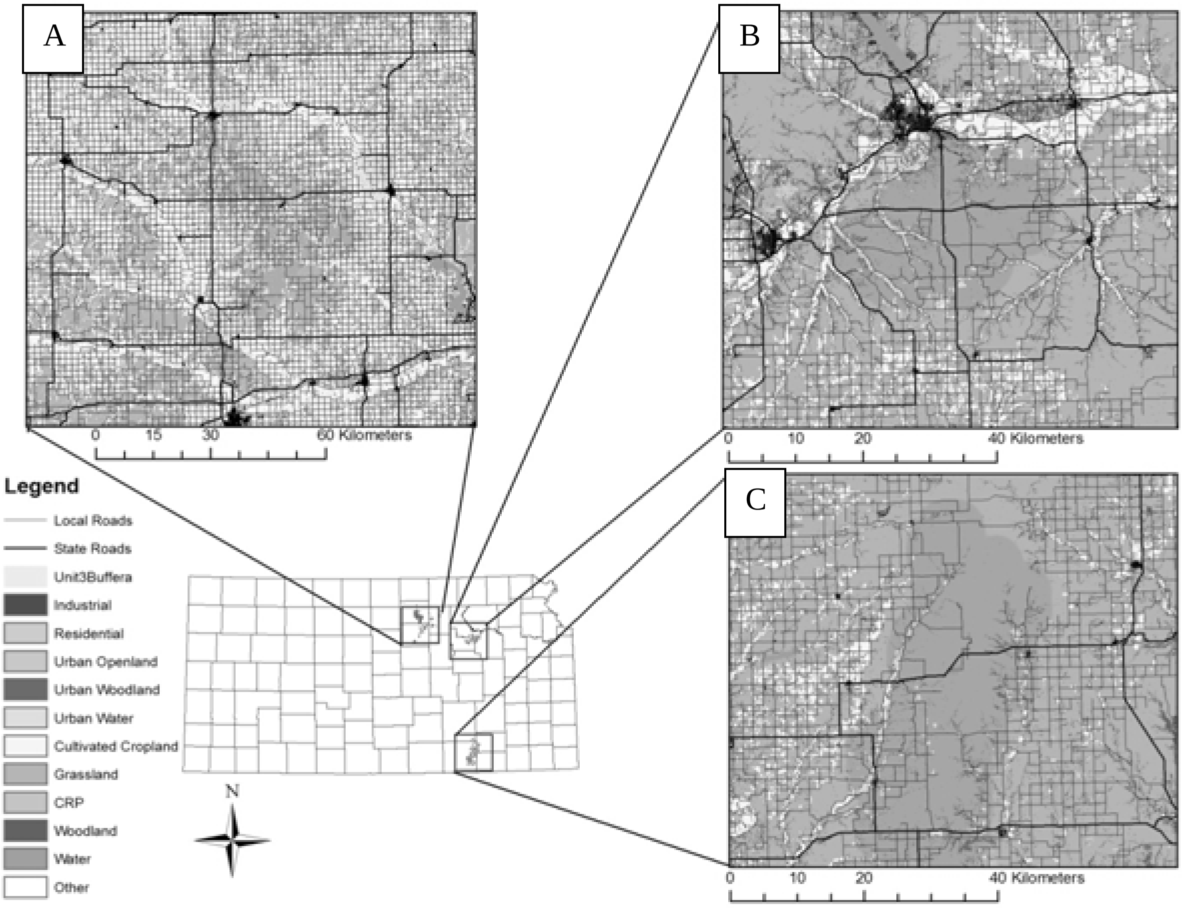
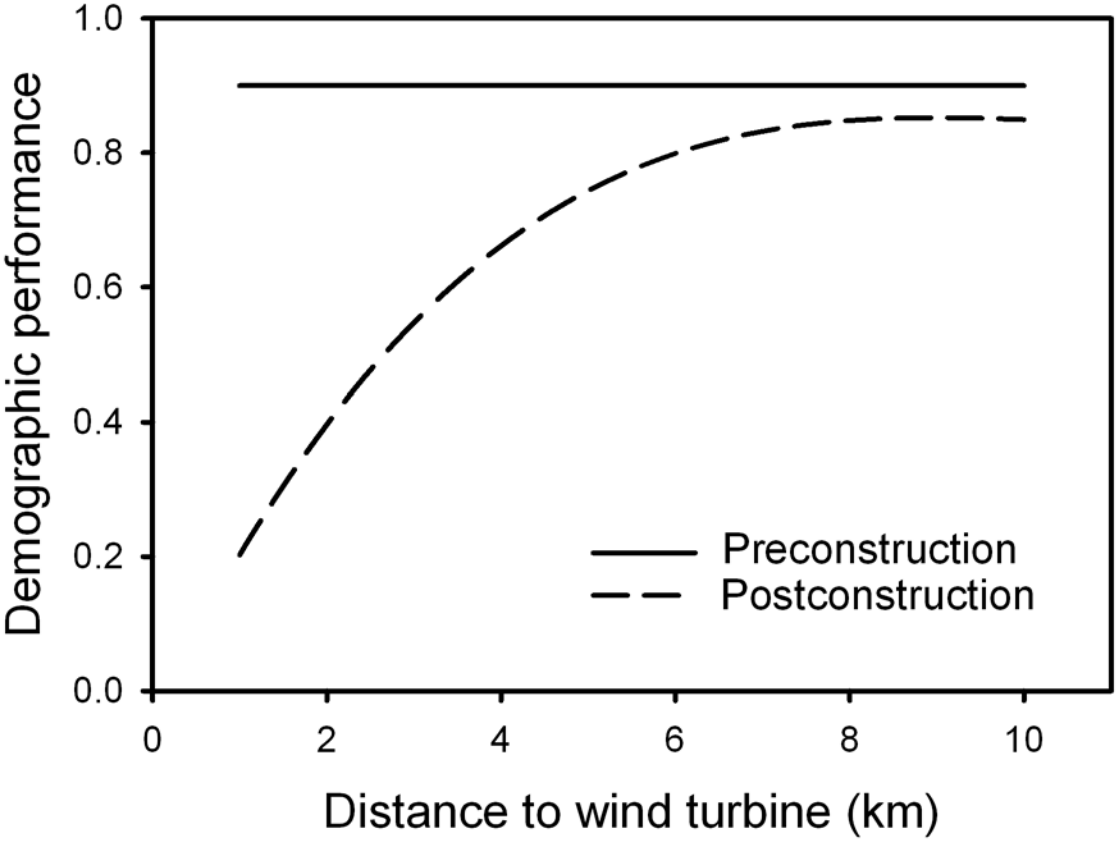


Figure 0.2. Hypothetical changes in the demographic performance of wildlife species predicted under negative impacts of wind power development. Baseline slope coefficients during the preconstruction period should be *zero* or *negative*, and response slope coefficients during the postconstruction period should be *positive*.



Objective 1. *Impacts on Lek Attendance*

Greater Prairie-Chickens are an example of a lek-mating bird with a promiscuous mating system. Leks are display arenas used by groups of males to display and advertise for mates. Females visit leks to mate with males but receive no other resources from males other than gametes. Parental care is uniparental and females lay the clutch, incubate the eggs, and attend the brood on their own. Prairie chickens attend leks from March to May and lek monitoring is an important tool for monitoring the status of prairie grouse populations. Despite relatively low annual survival and high turnover among males, leks are often traditional sites that are used by different groups of males for multiple years. Lek sites are often located in open areas on hilltops (Gregory et al. 2011). Open areas allow males to project their vocalizations and display behaviors while being vigilant for approaching females, but can be risky sites if group size is small and fewer birds are available to scan for predators. Wind power development planning usually places turbines on ridgetops to take advantage of stronger prevailing winds. We predicted that presence of turbines might have a negative impact on lek attendance if male prairie chickens avoided tall structures or if construction activity led to disturbance at lek sites.

We located leks by searching for displaying prairie chickens at sunrise on calm days with low winds during early spring. Landowners and conservation officers assisted us with locating leks with their local knowledge of the study area. We systematically visited each lek multiple times during each breeding season and counted numbers of males at each lek with two methods. During *trap counts*, we set up blinds at the edge of lek sites while trap sets were deployed for bird capture. We used scan sampling to tally the maximum number of males and females observed during a morning observation period, and the sexes were readily distinguished by plumage. During *flush counts*, we visited the lek within the 3-hour period after sunrise and counted all birds flushed from the lek site. It was not possible to distinguish between males and females during flush counts. McNew et al. (2011a) showed that disturbance from trapping did not negatively impact lek attendance by males. If we compared trap to flush counts for leks sampled with both techniques, the maximum number of males observed during trapping averaged 90% of the maximum count of birds observed during flush counts. To combine information from the two techniques, we took the maximum count of males per lek per technique, weighted it by the number of visits that counted birds with each technique, and discounted maximum flush count by 10%. We took the weighted average as the average number of male at the lek site per year.

We modeled the annual probability of lek persistence with logistic regression in Program R (ver. 2.13.11, R Foundation for Statistical Computing, Vienna, Austria). We considered a lek to be *active* if the maximum count of males in a season was a group of four or more males. We considered a lek to be *inactive* if we detected <4 males during repeated visits to a lek during a breeding season. Lek persistence was calculated as the transitional probability of a group of males returning to the same lek site between two consecutive years. We treated observations of the same lek in different year intervals as independent, and used lek-years as the sample unit in this analysis. We had one complete transition before wind power construction commenced (2007-2008). In most analyses in this report, 2008 was included as part of the preconstruction period. In analyses of lek persistence, the transition from 2008-2009 was included in the postconstruction period because the transition spanned the period when the wind turbines were erected in our study area. We modeled the annual probability of lek persistence as a function of four factors: treatment (pre and postconstruction), distance to nearest turbine (eventual and actual sites), habitat (grassland vs. agricultural fields), and the maximum number of males observed per year.

In total, we located and monitored 23 lek sites in the 6-year period from 2007-2012 (Figure 1.1). Leks could be as close as 0.5 km apart but we treated nearby leks as independent if individually marked males did not move between adjacent sites. Most lek sites were located in native grasslands (n = 14), but prairie chickens also displayed in agricultural fields planted to crops, including corn stubble and early winter wheat (n = 9). The median lek size in our study area was 12 males (range = 3 to 32 males, n = 76 lek-years), but numbers of males per lek were dynamic and changed year-to-year during our 6-year study (Table 1.1). If we examined lek locations during the pre- and postconstruction periods, the median distance to the eventual or actual site of the nearest wind turbine was 4.8 km (range = 0.04 to 27.6 km, n = 23 leks). Thus, more than half of all lek sites were within the 8 km (5 mile) buffer zone usually recommended as an offset for siting of wind turbines during development (USFWS 2003).

The probability of lek persistence was not statistically different between the pre- and postconstruction periods (Table 1.2), but the power of our test was relatively weak because we had only one transition period for lek monitoring before construction commenced. Similarly, the probability of lek persistence increased with distance from the nearest turbine but the slope was not significant in either a main effects model (Table 1.2), or a factorial model that included the effects of treatment and an interaction term (results not shown). The probability of lek persistence was ~0.9 at all distances from eventual turbine sites during the preconstruction interval of 2007-2008 (Figure 1.1). The probability of lek persistence increased from 0.69 at 0 m to 0.89 at 30 km from actual turbine sites during the postconstruction intervals of 2008-2012 (Figure 1.1). Most of the abandoned leks were located <5 km from the site of a wind turbine, although at least four leks at distances of 5 to 28 km were also abandoned during the postconstruction period (leks A, B, S, and W, Table 1.1).

Two factors had a significant effect on the probability of lek persistence (Table 1.2). Leks located in grasslands had a significantly higher probability of persistence compared to leks located in agricultural fields. The number of males recorded at a lek at the start of a transition interval had the strongest effect on the probability of lek persistence. During the postconstruction period, the probability of lek persistence was ~0.2 for leks of 5 males, 0.5 for leks of 7-8 males, and >0.9 for leks of 10 or more males (Figure 1.3). Thus, leks are abandoned when poor recruitment or low survival of males reduces group size below 7-8 males.

Lek attendance by Greater Prairie-Chickens is a dynamic process and changes in male numbers and lek abandonment are a natural feature of the species' population dynamics. Distance to wind turbines did not have a significant effect on the probability of lek persistence. However, abandonment of lek sites < 5 km from turbines and a positive slope coefficient for the effects of distance on lek persistence are consistent with negative impacts of wind energy development. The probability of lek persistence was highest for lek sites located in grasslands and with 10 or more males and lek locations with these characteristics should be a high priority for conservation.

Table 1.1. Maximum count of male Greater Prairie-Chickens per year at 23 leks in the Smoky Hills study area, 2007-2012.

			2007		2008		2009		2010		2011		2012	
Lek	Habitat	Turbine dist. (km)	Males	n	Males	n	Males	n	Males	n	Males	n	Males	n
A	G	6.39	-	-	12	10	17	29	7	13	8	11	2	4
B	G	6.06	-	-	14	18	13	16	15	11	10	31	3	4
C	G	3.16	-	-	10	17	0	1	3	4	0	2	0	2
D	A	2.46	-	-	-	-	19	3	25	2	14	3	15	2
E	A	0.11	13	7	9	10	3	6	0	3	1	3	0	2
F	A	0.22	-	-	-	-	22	28	10	16	1	3	0	2
G	G	0.11	-	-	-	-	-	-	-	-	7	21	4	3
H	G	0.04	6	6	8	5	7	7	3	4	0	3	0	2
I	A	2.01	17	15	10	12	4	5	1	3	1	3	0	2
J	A	2.57	-	-	-	-	-	-	-	-	12	1	3	2
K	G	0.68	-	-	9	20	14	17	10	16	12	15	9	3
L	G	0.12	-	-	-	-	13	14	16	20	14	20	7	4
M	G	3.18	4	3	6	6	8	7	9	8	7	10	2	2
N	G	3.95	16	7	24	18	26	26	15	21	22	37	21	3
O	G	4.16	-	-	-	-	15	9	8	7	6	12	0	3
P	G	4.84	-	-	-	-	15	10	13	18	11	30	10	4
Q	G	6.57	-	-	25	19	17	19	15	15	14	33	11	3
R	G	22.04	15	11	13	6	24	2	-	-	-	-	-	-
S	A	15.92	12	7	3	2	0	1	-	-	8	1	0	2
T	A	16.64	21	6	26	17	17	11	12	9	21	16	18	3
U	A	18.15	14	8	13	8	10	10	7	13	8	9	6	3
V	A	27.07	12	10	16	9	18	16	29	8	32	8	14	4
W	G	27.64	18	3	-	-	10	2	10	2	4	2	1	2

Notes: Habitat: A = agricultural field, G = native grassland. Distance to turbine in km. Males: maximum count per year, where dashes indicate no sampling was conducted. n = number of mornings the lek was observed from a blind or flushed. Leks were considered active with four or more males and inactive with 0-3 males present. Leks A-D, F, J-L, and O-Q were discovered after the start of the study. Gaps in monitoring at leks S, and W were caused by restricted access to private lands.

Table 1.2. Logistic regression models for the probability of lek persistence of prairie chickens as a function of four factors in the Smoky Hills study area, 2007-2012.

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-4.94	1.61	-3.07	0.002
trt(PRE)	1.28	1.29	0.99	0.321
dturb	0.05	0.05	1.01	0.314
habitat(GRASS)	1.75	0.87	2	0.045
male	0.46	0.13	3.52	0.001

Notes: trt = treatment where the preconstruction period is the baseline for comparison, dturb = distance to nearest turbine, habitat = lek habitat where grassland is the baseline for comparison, and male = number of males attending the lek at the start of the transition interval.

Figure 1.1. Map of lek locations for 23 leks of Greater Prairie-Chickens monitored at the Smoky Hills field site in northcentral Kansas, 2007-2012.

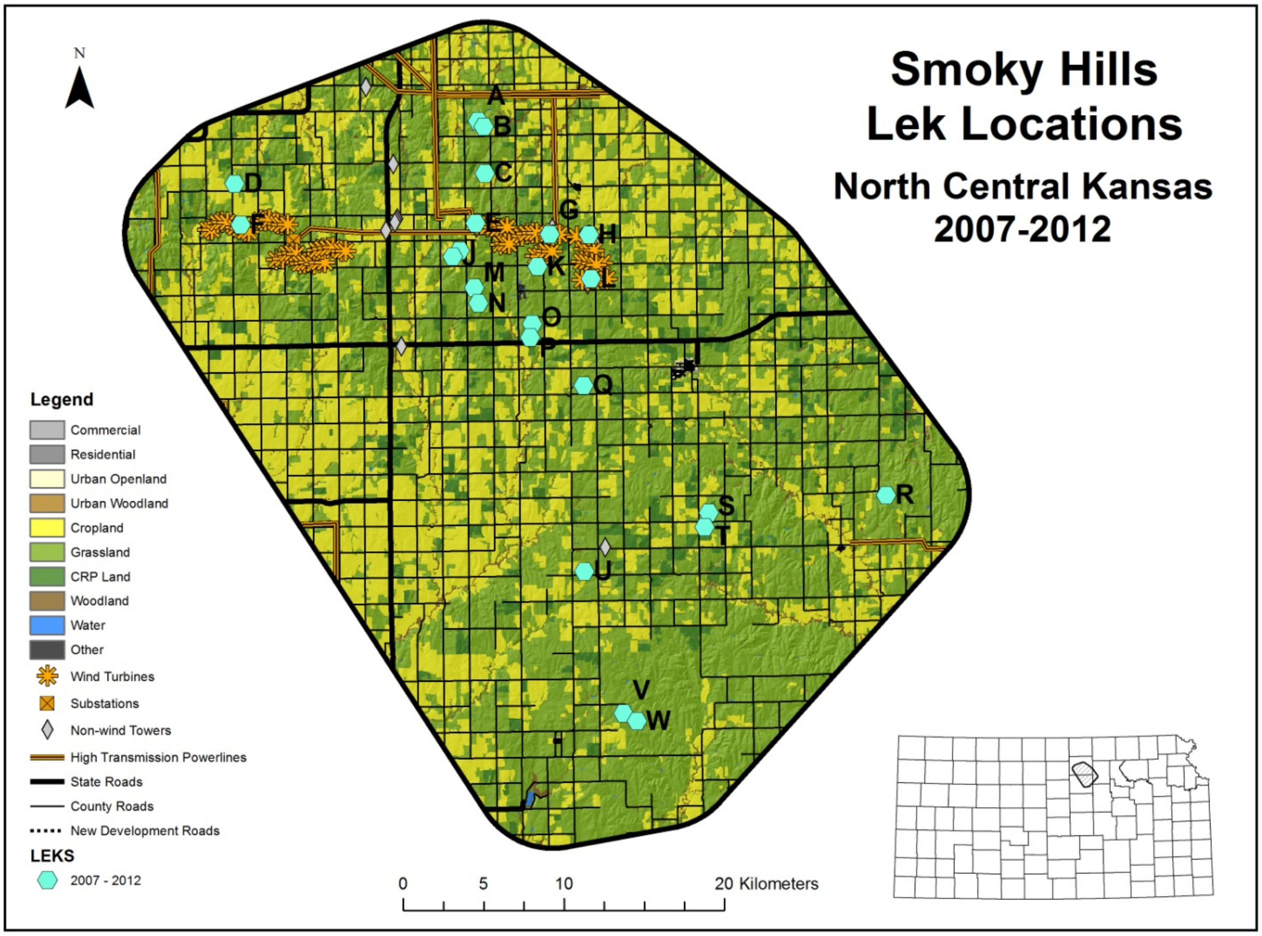


Figure 1.2. Probability of lek persistence for Greater Prairie-Chickens as a function of distance to nearest turbine during the preconstruction (2007-2008, top panel) and postconstruction periods (2008-2012, bottom panel) at the Smoky Hills field site, 2007-2012. Points are jittered for clarity.

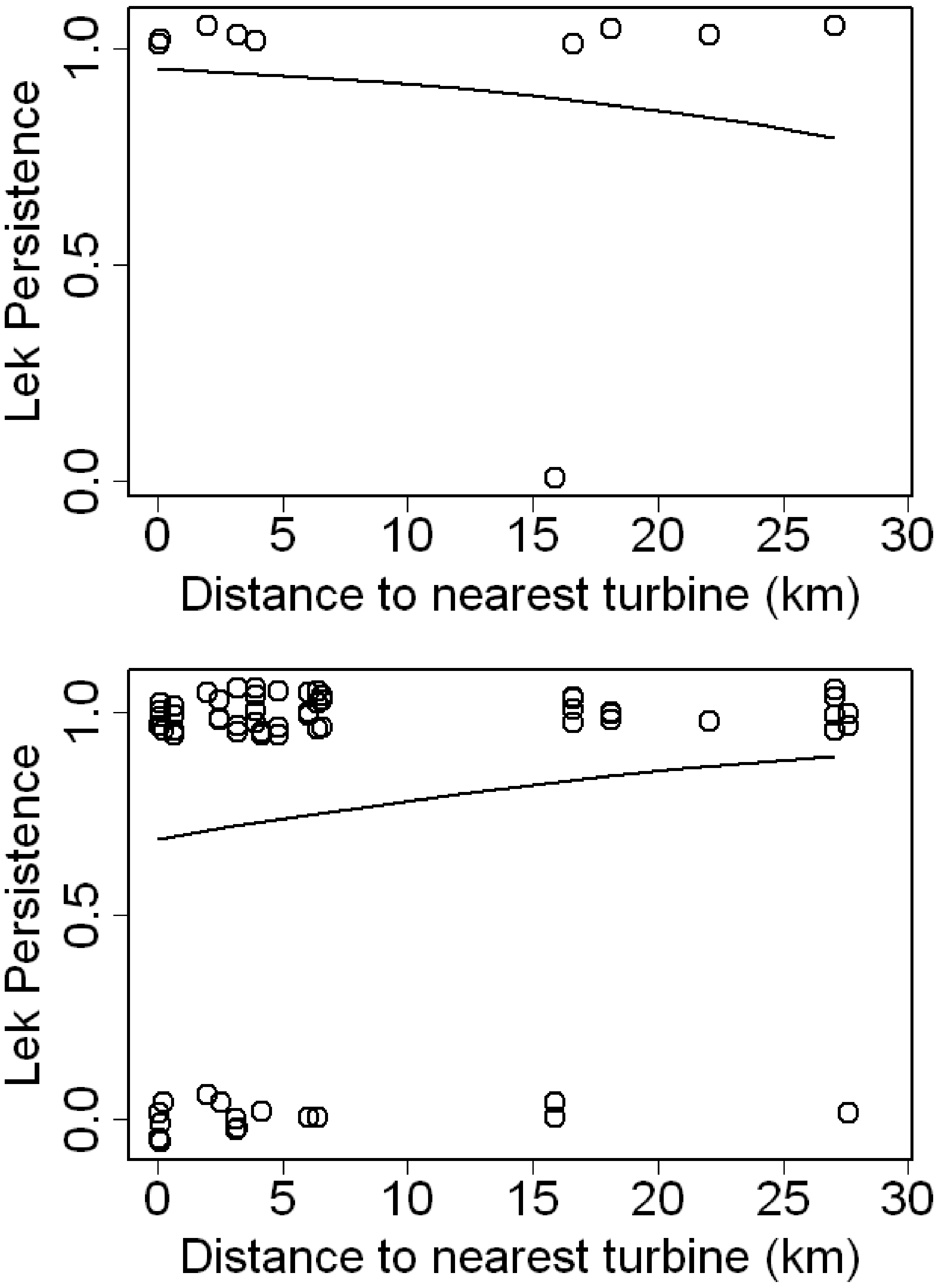
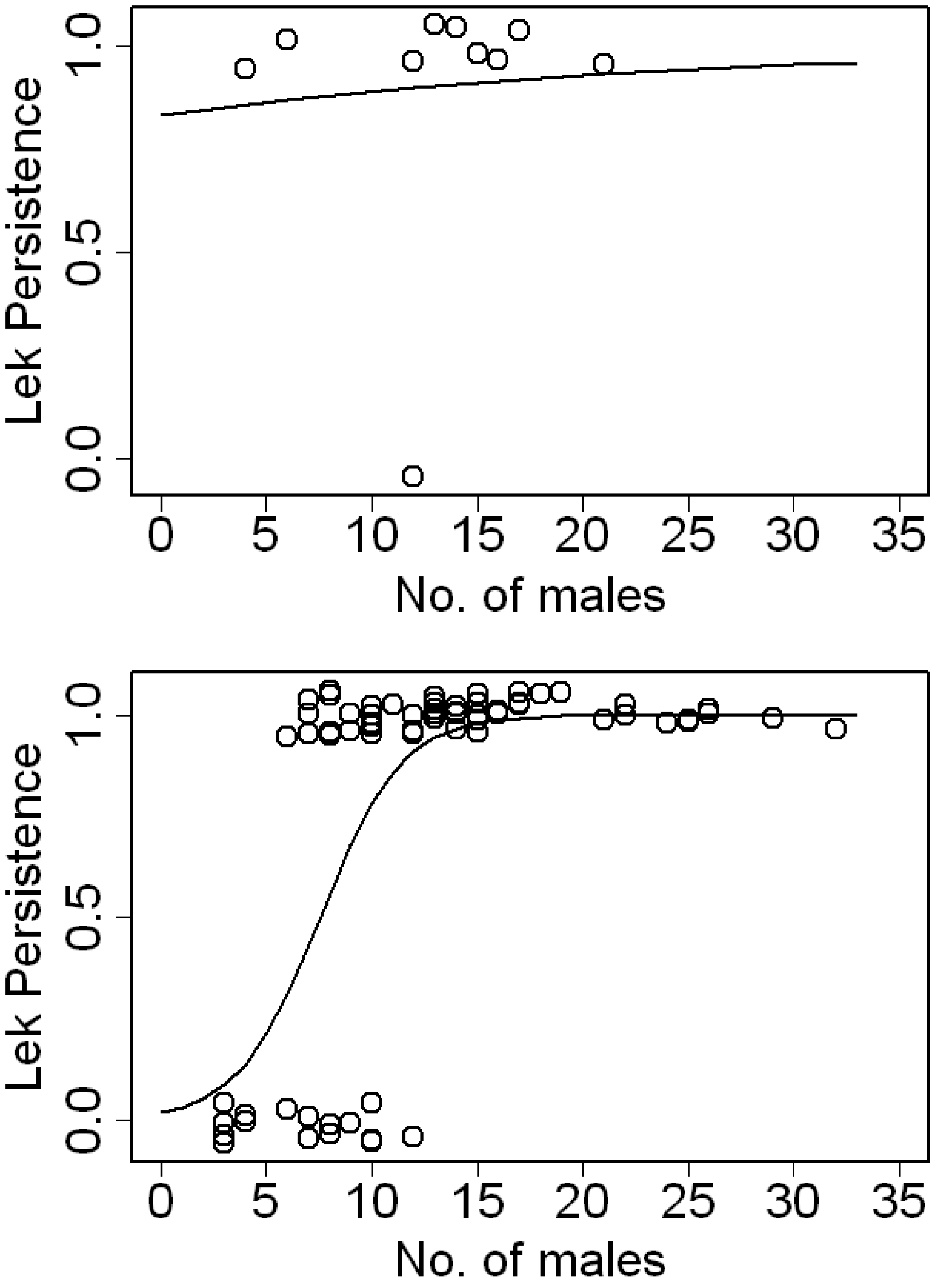


Figure 1.3. Probability of lek persistence for Greater Prairie-Chickens as a function of number of males at a lek site during the preconstruction (2007-2008, top panel) and postconstruction periods (2008-2012, bottom panel) at the Smoky Hills field site, 2007-2012. Points are jittered for clarity.



Objective 2. *Impacts on Mating Behavior*

Our field effort focused on live capture and radio-marking of female prairie chickens to collect data on movements and demographic performance. Direct investigations of mating behavior and other aspects of the behavioral ecology of Greater Prairie-Chickens require intensive focal observations of birds at undisturbed leks (Nooker and Sandercock 2008), which was not possible in this project. Thus, we used a population genetic approach to investigate the potential impacts of wind power development on the mating behavior of male and female prairie chickens. We examined two components of mating behavior: variation in paternity and maternity. Paternity rates assess the number of males that father young in a female's clutch, and are a function of male mating success and rates of multiple mating by females. The prevailing view for prairie chickens is that dominant males mate with multiple females but that females copulate once only to fertilize the clutch. Prairie chickens are solitary nesters and confidence of maternity is expected to be high because intraspecific nest parasitism is rare in grouse. Maternity rates less than one would provide evidence for conspecific nest or brood parasitism where individual females lay eggs in the nests of other females, or cases of brood-mixing where chicks are exchanged among unrelated broods of different females. If wind power development disrupts natural mating behavior, we predicted that rates of paternity and maternity should be higher among the young of females exposed to disturbance.

Population Genetics.–To create multi-locus genotypic profiles for individual birds, adult prairie chickens were captured at lek sites from March-May of each year from 2006-2011. Chicks were captured by hand during brood monitoring once the nest had hatched and the female departed the nest. A 40 µL blood sample was collected in 1,000 µL of Queens Lysis Buffer from each adult bird and a 10 µL sample was collected in 200 µL of Queen's Lysis Buffer from each chick (Seutin et al. 1991). DNA extraction was conducted with Qiagen DNEasy extraction kits (Qiagen Inc. Valencia, CA, USA).

We genotyped prairie chickens with microsatellite markers which have been successfully amplified for other populations. Amplification via PCR took place on an Eppendorf epgradient thermocycler (Brinkman Inc. Westbury, NY, USA) in standard 10 µL PCR cocktails containing: 30 ng of template DNA, 2.5 µM MgCl, 0.2 µM dNTP's, 0.12 µg/µl BSA, 0.8 M betaine, 0.05 µM of each forward and reverse primer, 0.2 µM of M-13 universal primers labeled with a fluorescent dye attached to the 5' end, and 0.05 units of Taq polymerase (Go Taq Flexi, Promega, Madison, WI, USA; Schuelke 2000). Fragment analysis was conducted using an ABI 3730 automated sequencer, and alleles were scored using GeneMarker 1.6 software (Applied Biosystems; Foster City, CA). We re-analyzed all homozygotes and 10% of all heterozygotes to determine rates of genotypic error and allelic dropout. The presence of null alleles can confound estimates of genetic diversity and can be particularly problematic for parentage assessments (Chakraborty et al. 1992). We tested all polymorphic loci used in genetic diversity estimates and parentage assessments for the presence of null alleles using Micro-Checker (Oosterhout et al. 2004). All microsatellites were found to be at Hardy Weinberg Equilibrium and to be unlinked (Table 2.1). Genetic diversity, Hardy-Weinberg Equilibrium (HWE), and linkage disequilibrium were assessed using GenePop 4.0.10 (Raymond and Rousset 1995). Population pairwise estimates of genetic distance, F_{ST}, and within population estimates of F_{IS} and spatial autocorrelation were calculated using GenAlEx6.41 (Peakall and Smouse 2006). Probability of identity, probability to assign parentage, parentage, and identity analysis were calculated using Program Cervus 3.0.3 (Marshal 1998). Effective population size (N_e) was estimated using Waples (2007) linkage disequilibrium method as implemented in Program LDNE. We tested for population bottlenecks using Program Bottleneck (Cornuet and Luikart 1996).

Multiple Mating and Patterns of Paternity.–Based on our paternity analysis, between 8-18% of broods and 4-38% of the chicks were the result of multiple mating by females. Variation in the rate of multiple paternity covaried with degree of human impact (Table 2.4). The fragmented Smoky Hills site had the highest multiple paternity rate whereas the undisturbed southern Flint Hills site had the lowest rate of multiple paternity rate. Of females that mated with multiple males, 63% of them did so during their first nesting attempt. Males with greater genetic diversity had higher reproductive performance, and we found that heterozygosity of individual males was significantly correlated with number of offspring fathered ($r = 0.251$, $P = 0.007$).

Conspecific Nest Parasitism.–Our genetic analyses indicated that no or limited conspecific nest parasitism occurred at either of the two Flint Hills locations, which were characterized by predominantly intact grassland habitat and high adult survival. At the northern Flint Hills site, the observed rate of nest parasitism of 0.5% was the result of a single parasitic chick. The parasitic chick had an equal probability of assignment to two females, the female it was captured with and another female that was a sister to the putative mother with whom the chick was captured. These two females also nested within 36 m of each other and had broods which hatched within two days of each other. Thus, for this single brood we cannot rule out brood mixing. Consequently, our evidence for nest parasitism applies only to the Smoky Hills site.

Seven of 42 (~17%) females on the Smoky Hills site had broods with multiple maternity. These seven females had clutches an average of 2.1 eggs larger than other females within the Smoky Hills (parasitized = 13.4 ± 2.5, n = 7, non-parasitized clutch = 11.3 ± 2.6, n = 41); however, this difference was not significant (Two-sample *t*-test, $P = 0.28$). Host nests had an average of 2.7 ± 1.4 parasitic eggs per nest. Parasitic events were evenly distributed across three years of this study where we collected samples from chicks (2008 = 2, 2009 = 2, 2010 = 3). In two cases, we detected maternity from females who had been captured in a previous year, but had not been captured in the year for which parasitic egg laying was detected. We determined that these females were laying parasitically but we lacked complete reproductive data because their radio-collars had failed. However, both of the parasitic females successfully hatched nests in previous years, and in one case the female hatched her own nest and laid parasitic eggs within the same year. Thus, we were able to confirm that all parasitic females laid and incubated their own clutch in addition to laying eggs parasitically. Six of seven host females (86%) were yearlings, which successfully hatched clutches during their first nesting attempt (n = 5) or a renest (n = 1) containing both host and parasitic eggs. One host was an adult female who successfully fledged her first nest. Five of seven parasitized nests contained eggs from the host and at least two additional females (number of parasitic females per nest = 2.14 ± 0.89), suggesting that the probability of conspecific parasitism increases once a nest has already been parasitized.

For six of the seven parasitic events, we were able to unambiguously assign maternity to seven females sampled in the population. We also identified two chicks that were the offspring of parasitic females for which we could not identify the mothers. We detected three females that parasitized a single nest one time, two females which parasitized two nests, and two females which parasitized the nests of three different females. The average number of parasitic eggs laid per parasitized nest was 1.3 ± 0.47 and the average number of parasitic chicks produced per parasitic female was 2.17 ± 1.41. Parasitic female clutches were smaller than average for the population (nests of facultative parasites = 9.86 ± 2.7 eggs, n = 14, unparasitized nests = 11.3 ± 2.6, n = 306, two-sample *t*-test, *P* = 0.004). However, once parasitic and non-parasitic eggs were accounted for, parasitic females actually hatched significantly more eggs than the average female in the population (eggs laid by facultative parasites = 15.8 ± 2.3 eggs, n = 14, unparasitized nests = 11.3 ± 2.6, n = 41, two-sample *t*-test, *P* = 0.004). In total, there were 21 parasitic chicks detected which accounted for ~9% of the chicks in the Smoky Hills population and at least 25% of the fecundity of parasitic laying females.

Five of the seven parasitic females were known as adults based on age at capture one or more years prior to detection as a parasitic egg-layer, for the remaining two females age was unknown. Thus, a minimum of 71% of the parasitic females were ≥2-year olds when they were parasitizing nests. In addition, 5 of 7 (71%) of the females laying parasitically had their first nest fail as a result of nest predation. During the time which parasitic females were laying parasitic eggs they were also initiating their own nests, as parasitic female nests were initiated within ±6.4 days of the nests that they parasitized. However, parasitic female nests all hatched 6-9 days after the nests they parasitized suggesting that breeding synchrony plays a role in prairie chickens ability to engage in CBP behavior. Last, the average distance between parasitic female nests and host nests was 1.5 ± 0.9 km with a median of 1 km. Based on the chronology of nest initiation and hatch dates, two parasitic females apparently first laid eggs parasitically, and then moved > 3 km (3.3 km and 5.2 km respectively) from their host's nests to establish their own nests. The two females represented 30% of our observations. If we discarded these two individuals, the average distance between parasite nest and parasitized nest was 702.6 ± 54.1 meters and a median distance of 303 meters. Having mixed paternity for 18% of the broods is significantly greater than would be expected by random chance (Binomial Test, *P* = 0.70; Gregory et al., unpubl. manuscript).

All facultative parasitic events took place within the area of the wind energy facility, but half of the events occurred prior to wind energy development. Multiple paternity rates prior to wind energy development was 19.5% of broods whereas after wind energy development the observed rate of multiple paternity was 20.7% of broods. Of seven putative instances of conspecific nest parasitism, four events occurred during the preconstruction period, and three events occurred after construction of the wind energy facility was completed.

The prevailing view of the mating behavior of prairie chickens is that females mate once to fertilize the clutch and that conspecific nest parasitism is a rare event. Our genetic data show that multiple mating and nest parasitism are more common among female prairie chickens than previously thought. Variable rates of parentage were highest in the fragmented landscapes at the Smoky Hills field site and were lower at the Flint Hills field sites. Comparisons of the pre-

and postconstruction periods show that wind energy development did not affect the mating behaviors of Greater Prairie-Chickens.

Table 2.1. Microsatellite markers selected for use in population genetic analyses of Greater Prairie-Chickens, Kansas, 2006-2011.

Marker	NA	AR	HO	HWE	Species	Source
ADL-146	7	5	0.57	0.051	A	Cheng et al. 1995
ADL-230	9	4	0.56	0.932	A	
BG-**1**2	7	4	0.44	0.388	B	
BG-16	9	5	0.82	1.000	B	
BG-18	14	6	0.78	0.277	B	
BG-10	8	3	0.41	0.800	B	Piertney and Hoglund 2001
BG-14	12	5	0.55	0.673	B	
BG-19	23	17	0.90	0.789	B	
BG-20	Failed				B	
LLSD-3	12	5	0.57	0.836	C	
LLSD-4	24	14	0.87	0.405	C	
LLSD-7	32	18	0.94	0.959	C	
LLST-1	11	9	0.92	0.049	C	Piertney and Dallas 1997
LLSD-2	29	19	0.89	0.123	C	
SGCA-6	33	25	0.72	0.104	D	
SGCA-9	8	5	0.73	0.229	D	
SGCA-11	10	2	0.55	0.181	D	Taylor et al. 2003
TTD-1	12	7	0.85	0.061	E	
TTD-2	26	18	0.93	0.834	E	
TTD-3	6	2	0.44	0.060	E	
TTT-1	8	4	0.46	0.270	E	Caizergues et al. 2001
TTT-2	9	5	0.82	0.153	E	

Species letter codes are as follows: A = Domestic Chicken (*Gallus gallus*), B = Black Grouse (*Tetrao tetrix*), C = Red Grouse (*Lagopus lagopus scoticus*), D = Sage Grouse (*Centrocercus urophasianus*).

Table 2.4. Results of parentage analysis for Greater Prairie-Chickens at three sites in the Smoky Hills and Flint Hills ecoregions of northcentral and eastern Kansas, 2006-2010.

Location	Sample Size (Broods | Chicks)	Probability of miss-assigning parentage using our set of loci	Rate of Paternity Assignment (Broods | Chicks)	Rate of Maternity Assignment (Broods | Chicks)	Multiple Paternity Rate (Broods | Chicks)	Multiple Maternity Rate (Broods)
Smoky Hills	29 | 179	1.1×10^{-8}	56% | 78%	99% | 1.0%	18% | 38%	17%
Northern Flint Hills	18 | 212	7.9×10^{-6}	20% | 31%	100% | 1.0%	17% | 6.0%	0.5%
Southern Flint Hills	8 | 24	1.0×10^{-5}	100% | 100%	100% 100%	14% | 4.0%	0%

Notes: Sample sizes are reported separately for number of broods and chicks, and are based on families where paternity assignments were successfully made. Rates of multiple paternity were calculated as the percentage of total individuals found to be of multiple paternity out of the total number of individuals for which paternity could be unambiguously determined.

Objective 3. ***Impacts on Use of Breeding Habitat***

Movement is a fundamental, yet poorly understood ecological process that has great potential to structure populations and drive demographic performance (Turchin 1998). Our analyses of impacts on wind power development on use of breeding habitat were based on movements of female Greater Prairie-Chickens marked with radio transmitters. Females were captured and marked with transmitters at leks in March and April, and battery life of the transmitters allowed monitoring for 1-2 years. Locations of nest sites for radio-marked prairie chickens should be an unbiased index of female space use of breeding habitats because they are not affected by variation in search effort by observers or detectability of nests in different habitats. Preliminary analyses showed that females had restricted movements while attending active nests or broods but moved greater distances when not attending young and during the nonbreeding season. Accordingly, we examined the impacts of wind power development separately for nest site selection, and then for the movement behavior of females when they were not attending nests or broods. If wind power development has a negative impact on use of breeding habitat, we predicted that females should nest farther from wind turbines after construction, and that female movements should show evidence of behavioral avoidance of turbines and other structures.

Nest Site Selection.-To test for impacts of development on nest site selection, we compared nest placement by female prairie chickens during the pre- (2007-2008) and postconstruction periods (2009-2011). We restricted our analysis to first nesting attempts (n = 186) because females usually renest within their home range if their first clutch is destroyed by predators. We used distance to nearest turbine as an index of exposure to disturbance from the wind power facility. If nests are distributed at random in the landscape, the expected cumulative distribution of nests should be linear (Figure 3.1). However, we expected a nonrandom distribution of nests because our study area was a heterogeneous mixture of grasslands and agricultural lands. As the baseline for comparison, we took the subset of nests monitored during the preconstruction period and calculated the distance from the nest site to the eventual location of the nearest turbine after the wind power facility was constructed. During the preconstruction period (2007-2008), the median distance from nest site to the eventual site of the nearest wind turbine was 5.8 km (range = 0.02 to 27.1 km, n = 63 nests). Overall, ~75% of all nests located during the preconstruction period were <16 km from the eventual site of a wind turbine (Figure 3.1). During the postconstruction period (2009-2011), the median distance from nest site to the actual site of the nearest wind turbine was 4.8 km (range = 0.08 to 29.4 km, n = 123 nests). Overall, ~75% of all nests located during the postconstruction period were <7 km from the actual site of a wind turbine (Figure 3.1). The cumulative distributions of distance from nest to turbine did not differ between the pre- and postconstruction periods (2-sample Kolmogorov-Smirnov test, D = 0.208, $P = 0.054$). If anything, there was a nonsignificant trend for female prairie chickens to nest closer to turbines during the postconstruction period. Our conclusions were unchanged if we truncated our distance data and tested for differences in nest selection by females within 5, 10 or 15 km of the turbines (results not shown).

Movements of Breeding Females.–Nest site selection is a critical aspect of prairie chicken demography, but movements of female prairie chickens during the nesting period may resemble central place foragers because females repeatedly return to the nest sites for long bouts of nest attendance during incubation. Movements of females incubating nests may not fully capture the complexity of animal habitat use during the critical period of breeding. To investigate the effects of wind energy development on the movements of female prairie chickens, we applied three different quantitative methods for analyzing movement data. Our previous demographic analyses showed that population dynamics of prairie chickens are determined by events during the breeding season (McNew et al. 2012). Accordingly, we restricted our sample of movement data to the breeding and nesting periods, and did not include movement data after hatching or failure of each female's last nesting attempt in July or August to March of the following year. To maximize our ability to detect possible effects of wind power development, we restricted our analysis to females which nested within 10 km of the wind energy infrastructure footprint. Our analyses were based on a sample of 88 females during the pre- (2007-2008, n = 27) and postconstruction periods (2009-2011, n = 61). Some preparations for wind power development were initiated in April 2008. Development was completed in two phases at our study site in 2008, and the eastern portion of the study site area was not impacted by wind power during the breeding season of 2008. We treated 2008 nests in the eastern portion of our study area as preconstruction nests because ecological conditions were the same as 2007. For preconstruction analyses, we considered movements in relation to the eventual sites of where wind turbines were located after construction. Postconstruction movement analyses considered movement in relation to the actual locations of the wind power infrastructure once construction was completed.

The first method we applied was a State Space Model (SSM) approach (Jonsen et al. 2005). The SSM approach uses information on the behavioral state of the animal at its current location to determine the probability of movement toward or away from a particular resource, based on the frequency with which the individual has moved toward or away from the resource in previous situations. From this information, the models then extrapolate the degree to which certain landscape features are favored or avoided (Patterson et al. 2008). Second, we modeled the movements of female prairie chickens with a Brownian Bridge Movement Arc (BBM) analysis (Horne et al. 2006). The BBM approach uses the arc distance and rotational angle between location nodes as the assessment unit. BBM measures the directionality and distance of observed movement data as compared to a similar data set generated via a random walks procedure. The arc length and angles for the random walks procedure are parameterized from the distribution of these values from the observed movement path data set. The BBM then assesses the degree to which observed movement paths are directional compared to a random walks model, and preference or avoidance of structures can be determined by *post hoc* comparisons (Horne et al. 2006).

Using all locations recorded for a female during the breeding season, the SSM and BBM models indicated that movements of female prairie chickens during the nesting season were random, but did not indicate avoidance of any feature on the landscape. Preliminary analyses of our movement data showed a high spatial autocorrelation between female locations and their nest sites during the breeding season (Moran's I = 0.17, $P = 0.014$). Most movements of radio-marked females during the nesting period were short movements away from and back to the nest site, resulting in a star-like pattern of movement arcs around the location of the nest (Figure 3.2). Thus, movements and resource selection of females attending nests were determined by their initial behavioral decisions made during nest site selection.

Female movements during the breeding season that occurred prior to nest establishment or immediately after nest failure and before renesting were longer and more directional. Breeding season movements of females not attending nests addressed the landscape features that females were sampling when visiting leks to mate with males to fertilize the clutch, and sampling of suitable areas for nesting or renesting before settlement for egg-laying. Thus, we restricted our analyses to long distance movements of females not associated with a nest, which we termed 'major breeding season events' (MBSE; Figure 3.3). Using this restricted criteria, we reduced the number of locations per female from >20 to an average of 5.3 locations per female. Reductions in sample size limited our options because SSM and BBM procedures are not statistically valid for small sample sizes (Horne et al. 2006, Patterson et al. 2008). To test for potential behavioral avoidance of wind power infrastructure, we examined each MBSE and calculated two different metrics. After each MBSE, we tested whether a female's next movement would be either toward or away from wind energy infrastructure, and the relative frequency her next movement would cross wind energy infrastructure. We examined female movements separately during the pre- and postconstruction periods.

We confined our analysis to female prairie chickens which nested within 10 km of wind energy infrastructure development. Our criteria provided a dataset of 27 females during the preconstruction period, and 61 females monitored during the postconstruction period. The first parameter we measured was the average distance between female location and wind energy infrastructure during the pre- and postconstruction periods. There was no difference in the average distance between female locations and wind energy infrastructure during the pre- (3.8 ± 2.1 km) and postconstruction periods (3.8 ± 2.2 km, $P = 0.78$). Second, we measured the frequency with which MBSE movements would cross wind energy infrastructure pre- and postconstruction. We found that 20% of the preconstruction movements would have crossed the eventual sites where wind energy infrastructure was located, but only 11% of the postconstruction movements crossed the actual sites of wind energy infrastructure. Last, we evaluated the probability that movements of female prairie chickens would be away from wind energy infrastructure during pre- and postconstruction periods. We modeled the probability of directional movement as a function of the distance of females from the wind energy infrastructure during the beginning of the time-step before movement. Females were more likely to move away from the wind power infrastructure during the postconstruction period than during the preconstruction period, but movements away from wind turbines was not strongly related to distance to the nearest wind turbines (Figure 3.3). If wind infrastructure impacts female movements, it could act as an agent of population fragmentation, which could have future impacts on demographic performance and gene flow for prairie chickens.

Nest site selection by female prairie chickens was not random because females preferred to nest in native grasslands and the landscape was a heterogeneous mix of prairie and agricultural habitats. Nest site selection by female Greater Prairie-Chickens was not affected by wind power development. There was a nonsignificant trend for females to nest closer to wind turbines during the postconstruction period. If we examined females nesting within 10 km of the wind turbines, our movement data provide weak evidence for behavioral avoidance of wind turbines by females when they are not attending nests or broods during the breeding season.

Figure 3.1. Nest site selection of female prairie chickens in relation to wind power development at the Smoky Hills site, Kansas, 2007-2011. Analyses were based on 63 first nests during the preconstruction period (2007-2008) and 123 first nests during the postconstruction period (2009-2011). The diagonal line is the expected distribution if nests are placed at random. The solid line indicates nest placement preconstruction, and the dashed line is nest placement after construction of the Meridian Way Wind Power facility.

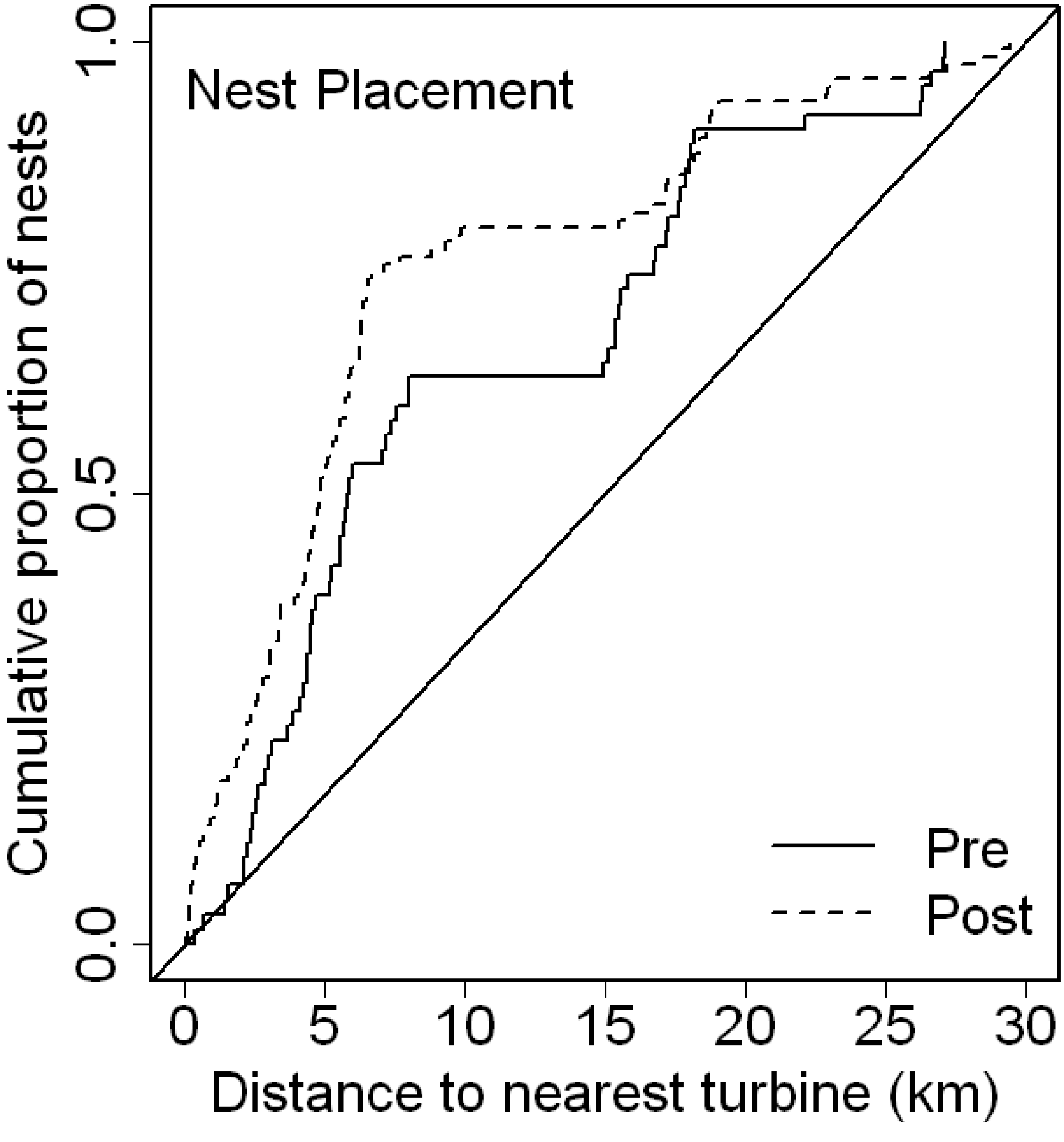


Figure 3.2. Example of movement arcs of a nesting female prairie chicken at the Smoky Hills study site. *Yellow* circles denote the location of two nesting attempts within a breeding season. *Blue* lines show the limited movements of females away from the nest during daily incubation breaks. Movement arcs highlighted in *red* are examples of 'major breeding season events' (MBSE) used for analyses of female movements.

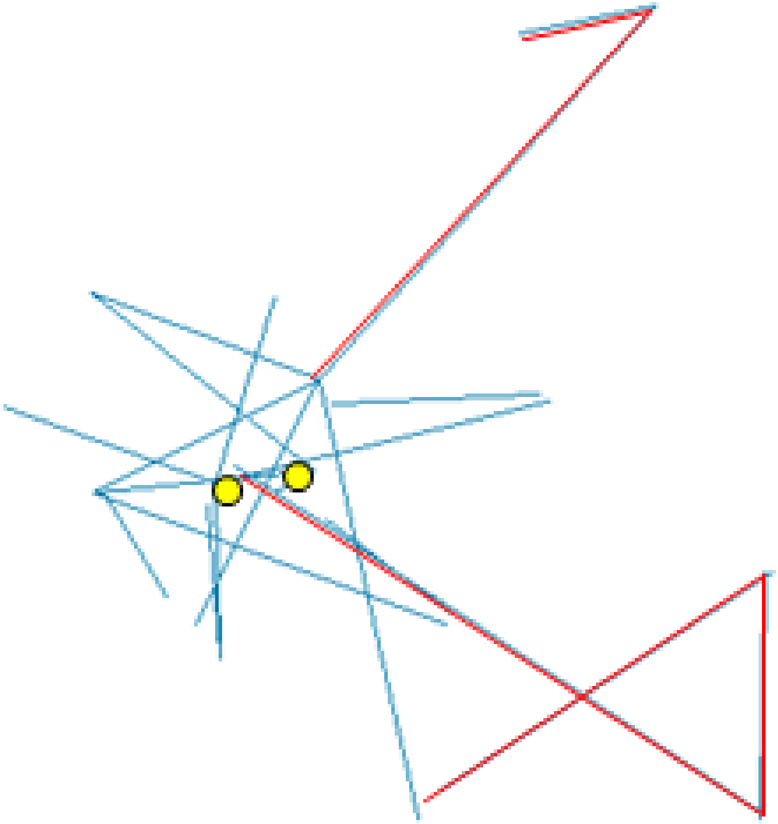
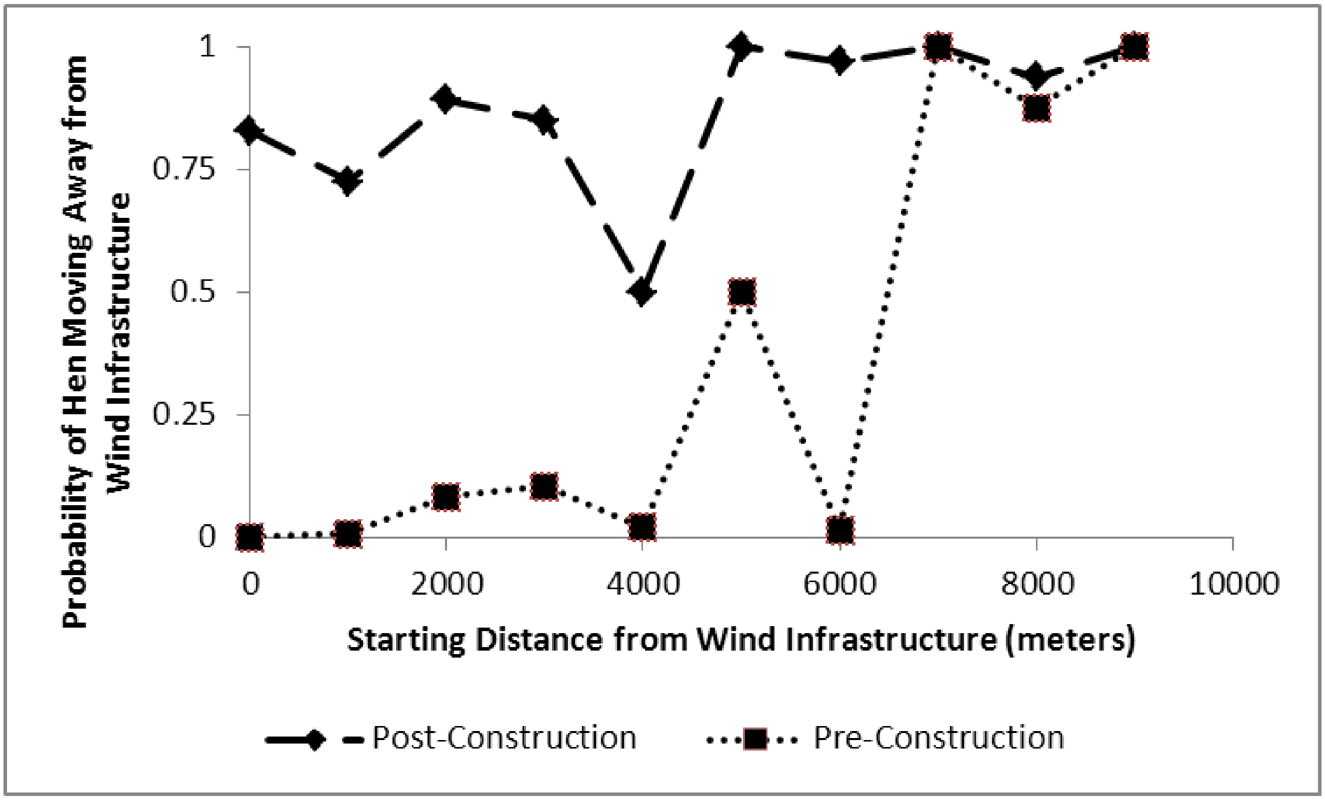


Figure 3.3. Probability that the direction of the next movement after a major breeding season event (MSBE) will be away from wind energy development as a function of female's distance from the wind power development. Analyses were based on a sample of 88 females during the pre- (2007-2008, n = 27) and postconstruction periods (2009-2011, n = 61).



Objective 4. *Impacts on Fecundity Rates*

Greater Prairie-Chickens are characterized by a life-history strategy with relatively high reproductive effort, early age at maturity, and low annual survival rates. Disturbance of nesting females could have negative impacts on reproductive performance if females have less resources for egg-laying or if changes in incubation behavior lead to reduced rates of nest attendance during incubation. If fecundity of prairie chickens is negatively impacted by wind power development, we predicted that females might nest later in the breeding season, lay smaller clutches with fewer eggs, or lay lower quality eggs that had lower rates of hatchability. Our previous work has shown that nest survival is the main demographic parameter affecting seasonal productivity of prairie chickens in Kansas (McNew et al. 2012). We modeled nest survival in relation to distance to the nearest wind turbine and other anthropogenic features, and as a function of a series of ecological covariates that described habitat quality at the local nest site or in the surrounding area. If wind power development affects nest survival, we predicted lower rates of daily survival for the nests closest to turbines during the postconstruction period.

Field Methods.–Prairie chickens were captured with walk-in traps and drop-nets at lek sites during March to April. A few females were captured at the nest or with broods to replace failing transmitters. Females were outfitted with 10-11 g radio transmitters attached with an elastic or wire necklace harness (ATS or Holohil). Females were relocated 3-4 times a week during the breeding, nesting, and brood-rearing seasons (Mar-Aug) to locate nests and broods. Once a female localized in an area for three successive days, we located the nest by tracking the female with portable radio receivers and handheld antennas. We flushed the female once in early incubation to count eggs, determine stage of incubation by floating the eggs in a cup of lukewarm wanter, and record nest location with a handheld GPS in UTM coordinates. To minimize disturbance, incubating females were monitored by triangulation with radio telemetry at distances ≥100 m until the nest failed or successfully hatched. We considered a nest to have *failed* if movements showed that a female had ceased incubation, and we revisited the nest to determine whether the nest contents were destroyed or removed before the expected hatch date. We continued to monitor females who lost their first nest to locate any renesting attempts during the breeding season. We considered nests to be *successful* if the nestbowl contained pipped eggshells or if at least one egg hatched and produced a chick. For successful nests, we conducted systematic brood flushes within one hour of sunrise at 14, 24, 34, and 60-d post-hatch by radio-tracking the brood female.

Components of Fecundity.–We examined five components of the reproductive effort of female prairie chickens at the Smoky Hills field site. *Date of clutch initiation* was estimated by backdating from stage of egg-laying or incubation, assuming an egg-laying rate of one egg per day. We examined timing of clutch initiation for first nests only because timing of laying for renests is affected by timing and stage of loss of first nests. *Clutch size* of first nests and renests were estimated as the maximum number of eggs observed in the nest at the completion of egg-laying. *Nest survival* was the probability that a nest survived a ~35-day period that included egg-laying and incubation, and was estimated with nest survival modeling (see below). Last, we calculated *egg hatchability* as the number of chicks produced per egg for the subset of nests that survived incubation and successfully hatched. Reductions in hatchability less than one were mainly due to inviable eggs that failed to hatch. We monitored survival of broods and juveniles but due to high rates of nest mortality, our samples were small and inadequate for testing for effects of wind power development.

Ecological Covariates.–Vegetation structure was quantified at each nest site within three days of hatching or failure. Two perpendicular, 9 m sampling transects were centered on the nest bowl in a north-south and east-west orientation. Using a Robel pole, four visual obstruction readings (VOR) of the vegetative cover screening 1 dm segments of the pole were estimated at the nest from a distance of 2 m and a height of 0.5 m along each of the four transect arms (Robel et al. 1970). Non-overlapping vegetation cover (% grass, forbs, shrub, detritus and bare ground) was estimated at three equally spaced sub-sampling locations along each transect arm using a 20 x 50-cm Daubenmire sampling frame. Distance and height of the nearest grass, forb and shrub were also measured. Nest elevations were collected using a handheld GPS unit.

Habitat characteristics associated with each nest were evaluated at three additional spatial scales: the core use area (13 ha), the home range area (310 ha), and the study site area (160,000 ha). Core use and home range area buffers were centered around each nest at a radius of 200 and 1000 meters; respectively. Buffer circumferences were determined based on the approximate core use area (13 ha) and home range size (310 ha) of a breeding prairie chicken (Osborne et al. 2001, Poirazidis et al. 2004, Robel 1970). The portion of the entire study site available to nesting prairie chickens was designated by a 5 km buffer around the minimum convex polygon of all nest locations. Habitat and landscape variables were acquired using a Geographic Information System (GIS) in ArcMap 9.3 (ESRI, Redlands, CA). The locations of 244 successful and unsuccessful nests (n = 74 and n = 170; respectively), collected from 2007 to 2011, were uploaded into a geodatabase. Kansas Landcover Patterns dataset (2005) depicting 11 landcover classes at 30-m resolution was used for landcover analysis (Kansas Applied Remote Sensing Program, Lawrence, Kansas). A Kansas roads and highways dataset (2006) from the Kansas Department of Transportation, and an electric transmission lines dataset from the Kansas Corporation Commission were also obtained. Locations of wind turbines, substations, associated high-capacity transmission lines, newly constructed wind park access roads, and non-wind related vertical towers were collected *in situ* with a hand held GPS unit and uploaded into the database. Tools available in ArcMap 9.3 were used to quantify the proportion of grassland, cropland, and Conservation Reserve Program (CRP) landcover types within each nest buffer. Euclidian distances were calculated from each nest to the nearest transitional edge habitat (woodland, water body, agriculture), wind power feature (turbine, substation, transmission line), road (state, county, wind turbine access road) and other classified disturbances (non-wind related towers).

Average daily precipitation (cm) and average daily temperature (°C) were obtained from the National Climatic Data Center (NCDC) and summarized for each day of the 86-day nesting season (18 April-12 July) for each year in our 5-year study (2007-2011). For each weather covariate, daily readings from three local weather stations were averaged to obtain one daily estimate for the entire study site. Daily estimates were then adjusted to account for possible influence of previous days' weather patterns on nest survival as well as potential gaps in the nest monitoring period. Failed nests had an average 2.5 day interval between last day active and date of detected failure. Thus, we calculated the average daily climatic conditions for a moving 3-day interval and modeled daily nest survival as a function of conditions in the previous 3-day period.

Reproductive Effort.–We collected detailed demographic data on the reproductive performance of female prairie chickens over a 5-year period (2007-2011). If radio-marked females survived the 2-4 week period from capture at the lek to the onset of egg-laying, almost all birds initiated at least one nesting attempt. Early failure of nests before discovery likely accounted for the few females where we did not locate nests (McNew et al. 2012). In total, we located and monitored 264 nests between 2007-2011. Analysis of covariance showed that the effects of treatment period, distance to turbine, and the interaction of these two factors were nonsignificant for four key components of reproductive effort: clutch initiation date, clutch size of first nests and renests, and egg hatchability (Table 4.1). The linear relationships of these demographic variables with distance to turbine were consistently flat and showed no evidence of reductions in reproductive effort for females near turbines during the postconstruction period (Figure 4.1).

Nest Survival.–We modeled the daily survival of nests of prairie chickens with the nest survival procedure in Program Mark. The nest survival procedure is a known fate model that allows modeling of nest survival and ragged telemetry data where check rates may vary. Here, nests were monitored remotely by triangulation of the radio-marked females every 2-3 days while the nest remained active. We created encounter histories for each nest that included four input variables, the date of first discovery, the date the nest was last active, the date the nest was completed, and the nest fate (1 = failed, 0 = successful). If the nest failed, the last two dates bracketed the timing of failure, whereas if the nest successfully hatched, the last two dates were set to be the same. We included 16 individual covariates for each nest (Table 4.2). Covariates included potential effects of wind power development (treatment period, distance to turbines, substations, county roads or state roads), environmental conditions (daily precipitation), temporal variables (year), and spatial variables related to the local conditions at the nest (visual obstruction reading or VOR, percent grass, forb and shrub) or the surrounding area (distances to nearest shrub, woodland or water, percent agriculture in 200 m or 1 km buffers). We used AIC_c for model selection because the variance inflation factor (c-hat) is nonidentifiable for known fate models. All models were constructed using design matrices and the logit link function. We extrapolated daily survival rates to expected rates of nest survival using a 35-day exposure period based on an average clutch size of 12 eggs and a 23-day incubation period. We calculated the SE of the expected rate of nest survival using the delta method and partial derivatives.

We located a total of 264 nests but censored 20 nests from this sample for the nest survival analyses because of abandonment due to observer activity or unknown causes (n = 13), nests destroyed by hay cutting or trampling by livestock (n = 3), and nests with incomplete data (n = 4). Our nest survival modeling was based on a total of 244 nests including 59 nesting attempts during the 2-year preconstruction period (2007-2008, first nests: n = 48, renests: n =11) and 185 nesting attempts during the postconstruction period (2009-2011, first nests: n = 142, renests: n = 43). Of this sample, 74 nests (30.3%) were successful and produced young, and 170 nests (69.7%) were destroyed by predators. Miniature nest cameras were deployed at 29 nests in 2010-2011 and recorded 20 predation events and 9 nests that successfully hatched. The most important predators of prairie chicken nests included coyotes (*Canis latrans*, n = 8 losses), badger (*Taxidea taxus*, n = 3), skunks (*Mephitis mephitis*, n = 3), and gopher snakes (*Pituophis catenifer*, n = 5).

Nest survival models with the effects of treatment period and distance to turbine were among the worst fit models in our candidate set ($\Delta AIC_c \geq 37$, $w_i \leq 0.001$, Table 4.2). Consistent with a potential impact of wind power development, the relationship between daily nest survival and distance to turbine was negative during the preconstruction period and positive during the postconstruction period (Figure 4.3). However, most of the change in daily survival rates occurred at distances > 15 km with little change in nest survival at distances < 5 km. Moreover, the 95%CI of the slope coefficients were large and included zero. Overall, the probability of nest survival for a 35-day exposure period was 0.16 to 0.18 during the pre- and postconstruction periods (Table 4.3).

The ecological factor with the single strongest effect on the daily nest survival of prairie chickens was the visual obstruction readings (VOR) at the nest site (Table 4.2). VOR readings were a measure of the height of vegetation structure around the nest and were an index of concealment for the clutch and the incubating female. Rangeland management practices based on prescribed fire and cattle grazing are expected to reduce values of VOR through removal of aboveground vegetation. Together, models that treated daily nest survival as a quadratic or a linear function of the visual obstruction readings [$S(VOR^2)$, $S(VOR)$] accounted for essentially all of the support among the different candidate models that we tested ($\Sigma w_i > 0.99$, Table 4.2). Daily survival rates increased from a low of ~0.8 at VOR readings <0.5 to an asymptote of ~0.97 at VOR readings >4 (Figure 4.4). If we compared VOR values between random points and nest sites, we found a consistent pattern in all years of the study that vegetation height was ranked random < failed nests < successful nests (Table 4.4). Thus, female prairie chickens are selecting nest sites with greater vegetative cover, and cover has an important effect on subsequent nest survival. The ecological relationship between nest survival and vegetative cover will be critical for conservation of prairie chickens because the average VOR among nests in our sample was 2.5 which yielded an expected probability of nest survival of only 0.17 (Table 4.5, Figure 4.4). Rangeland management practices that would double VOR values for nesting females from 2.5 to 5 would effectively triple the probability of nest survival from 0.17 to 0.52.

Alternative models of nest survival with other ecological covariates received little support in our candidate set ($w_i < 0.001$), but indicated that other factors may influence daily survival of prairie chicken nests. Consistent with the important effects of vegetative cover, the next best model in our candidate set showed a positive relationship between daily survival and the percent coverage of grass around the nest site (Table 4.2). Daily nest survival increased from 0.91 with 0% cover to 0.97 with 100% grass cover (Figure 4.5). Percent coverage of broad-leafed forbs showed a similar relationship although the 95%CI of the slope coefficient included zero. In contrast, percent cover of shrub and proximity to woodlands both had negative but weak impacts on nest survival.

Video surveillance with miniature cameras identified mesocarnivores as the main predators of prairie chicken nests. Consistent with this result, we found that precipitation during the preceding three days had a negative effect on the daily survival of nests (Figure 4.6). Low rates of nest survival following heavy rains may be related to the activity of scent-based predators locating incubating females by the scent emanating from wet feathers soaked with water. Alternatively, female may take more incubation breaks following heavy rains and local movements may attract predators to nest sites.

Wind power development had no impact on the fecundity rates of female prairie chickens. Four components of reproductive effort, timing of clutch initiation, clutch size of first and renests, and hatchability of eggs were unaffected by treatment period or distance to nearest turbine. The probability of nest survival was low overall at 0.18, and video surveillance showed that most demographic losses were due to mammalian predators. Wind power development had no effect on nest survival, instead local environmental conditions at the nest site were more important drivers of nest survival. Nest survival was most strongly related to vegetative cover and concealment at the nest site. Grass and forb cover had weak positive effects on daily nest survival whereas shrub cover, proximity to woodlands, and recent rainfall had negative effects. Reproductive performance of prairie chickens is low in managed rangelands in northcentral Kansas and efforts to improve range conditions and reduce predator activity would aid recovery of prairie chicken populations.

Table 4.1. Analysis of covariance for four components of fecundity for female prairie chickens in response to wind power development at the Smoky Hills field site, 2007-2011. Sample size of nests in the preconstruction period (first nests: n = 48, renests: n =11) and the postconstruction period (first nests: n = 142, renests: n = 43).

Variable	Factor	df	*F*	*P* ≤
Date of laying for first nests	Treatment	1	0.12	0.73
	Distance	1	0.25	0.62
	Interaction	1	0.50	0.48
	Model	3	0.52	0.67
Clutch size of first nests	Treatment	1	0.00	0.96
	Distance	1	0.03	0.86
	Interaction	1	1.39	0.24
	Model	3	1.14	0.33
Clutch size of renests	Treatment	1	1.01	0.32
	Distance	1	1.28	0.26
	Interaction	1	0.31	0.58
	Model	3	0.63	0.60
Egg hatchability of successful nests	Treatment	1	0.15	0.69
	Distance	1	0.04	0.84
	Interaction	1	1.43	0.24
	Model	3	0.81	0.49

Notes: Treatment = preconstruction vs. postconstruction periods. Distance = distance to eventual or actual site of the nearest wind turbine.

Table 4.2. Model selection for ecological covariates of daily survival rates (S) of prairie chicken nests at the Smoky Hills field site, Kansas, 2007-2011. Sample size included n = 59 nests during the preconstruction period and n = 185 nests during the postconstruction period.

Model structure	*K*	Deviance	AIC_c	ΔAIC_c	$w_i \leq$
S(VOR^2)	3	1099.4	1105.4	0.0	0.872
S(VOR)	2	1105.3	1109.3	3.8	0.128
S(pgrass)	2	1126.4	1130.4	24.9	0.000
S(pforb)	2	1136.0	1140.0	34.6	0.000
S(c)	1	1139.2	1141.2	35.8	0.000
S(ag1000)	2	1137.7	1141.7	36.3	0.000
S(dwood)	2	1137.8	1141.8	36.4	0.000
S(dshr)	2	1137.8	1141.8	36.4	0.000
S(dwatr)	2	1138.2	1142.2	36.7	0.000
S(pshr)	2	1138.3	1142.3	36.9	0.000
S(year)	5	1132.5	1142.5	37.1	0.000
S(precip)	2	1138.6	1142.6	37.2	0.000
S(dstrd)	2	1138.6	1142.6	37.2	0.000
S(dcord)	2	1138.7	1142.7	37.3	0.000
S(ag200)	2	1138.8	1142.8	37.4	0.000
S(dsubs)	2	1138.9	1142.9	37.5	0.000
S(treatment)	2	1139.1	1143.1	37.6	0.000
S(treatment × dturb)	3	1136.6	1144.6	39.2	0.000
S(treatment + dturb)	4	1138.9	1144.9	39.5	0.000

Notes: Dependent variable (S) = daily nest survival. Model factors include: c = constant model; year = 2007-2011; treatment = pre (2007-2008) vs. post-construction periods (2009-2011); ag200/ag1000 = proportion of agriculture within core use (200m) and home range buffer areas (1000m); VOR, VOR2 = linear and quadratic functions for the visual obstruction reading at the nest site; pgrass/pforb/pshr = percentage of grass, forb, and shrub canopy cover at nest site; precip = average daily precipitation during the three previous days; dwood/dwater = Euclidian distance measurements from nest to nearest woodland edge habitat or water body; dstrd/dcord/dturb = Euclidian distance measurements from nest to nearest state road, county road, and wind turbine.

Table 4.3. Reproductive effort of prairie chickens during the pre- and postconstruction periods at the Smoky Hills field site, Kansas, 2007- 2011.

		Preconstruction		Postconstruction		Total	
Parameter	NA	*n*	Mean	*n*	Mean	*n*	Mean
n		59	-	185	-	244	-
Clutch size	1	48	12.3 (0.34)	140	12.8 (0.20)	188	12.7 (0.17)
	2+	10	10.7 (0.52)	40	10.6 (0.27)	50	10.6 (0.24)
Nest success	All	59	0.27	185	0.31	244	0.30
	1	48	0.25	142	0.30	190	0.28
	2+	11	0.36	16	0.37	20	0.37
Daily nest survival	All (1 d)	59	0.95 (0.01)	185	0.95 (0.00)	244	0.95 (0.00)
Nest survival	All (35 d)	59	0.16 (0.05)	185	0.18 (0.03)	244	0.18 (0.02)
Chicks per egg	1	12	0.81 (0.05)	41	0.87 (0.02)	53	0.86 (0.02)
	2+	4	0.81 (0.11)	16	0.78 (0.05)	20	0.79 (0.05)
Brood survival	All (2 d)	16	0.81	55	0.96	71	0.93
	All (14 d)	16	0.56	47	0.48	63	0.50
	All (25 d)	16	0.50	44	0.38	60	0.42
Fledglings per chick	All (2 d)	13	0.66 (0.07)	53	0.65 (0.04)	66	0.65 (0.03)
	All (14 d)	9	0.58 (0.06)	22	0.32 (0.05)	32	0.39 (0.05)
	All (25 d)	8	0.58 (0.06)	17	0.35 (0.05)	25	0.42 (0.04)

Notes: NA = nesting attempt where 1 = first nests, 2+ = renesting attempts, and All = first nests and renests combined. Means are presented with standard errors (SE). Overall rates of apparent nest success do not control for losses prior to nest discovery. Parameter estimates for daily nest survival taken from model S(trt). Probability of nest survival was calculated by extrapolating daily survival rates to a 35-day nest exposure period. SE(NS) was calculated with the delta method. Probability of brood survival and number of fledglings per chick were calculated from brood flush counts at 2, 14 and 25 days after hatching.

Table 4.4. Visual obstruction readings (dm, mean ± SE) for vegetation structure at prairie chicken nests and paired random points at the Smoky Hills Field site, Kansas, 2007-2011.

Point Type	*n*	2007	*n*	2008	*n*	2009	*n*	2010	*n*	2011	*n*	All Years
Successful	4	3.97 (0.92)	11	3.18 (0.56)	22	2.62 (0.27)	19	3.00 (0.27)	13	2.84 (0.32)	69	2.93 (0.17)
Failed	6	3.15 (0.75)	31	2.16 (0.34)	41	1.92 (0.20)	33	1.93 (0.20)	53	2.11 (0.16)	164	2.07 (0.11)
Random	65	2.50 (0.23)	44	1.79 (0.28)	64	1.74 (0.16)	69	1.48 (0.14)	80	1.53 (0.13)	322	1.79 (0.08)
F-value		1.33		8.04		6.01		12.28		12.50		36.20
$P \leq$		0.271		0.001		0.003		0.001		0.001		0.001

Table 4.5. Daily survival rates (DSR) and predicted nest survival (NS) for prairie chicken nests at six potential levels of vegetative obstruction readings (VOR, 1-10 dm) at the Smoky Hills field site, Kansas, 2007- 2011. Parameter estimates taken from model S(VOR^2).

VOR	DSR	SE(DSR)	NS	SE(NS)
1	0.88	0.024	0.01	0.012
2.5	0.95	0.010	0.17	0.060
4	0.97	0.006	0.41	0.090
5	0.98	0.005	0.52	0.098
7	0.98	0.007	0.59	0.136
10	0.97	0.027	0.37	0.123

Notes: Probability of nest survival was calculated by extrapolating daily survival rates to a 35-day nest exposure period. SE(NS) was calculated with the delta method. A VOR reading of 2.5 dm was the average nesting cover for nests at our study site, where mean VOR readings for failed and successful nests ranged from 2.07 to 2.93 (Table 4.2).

Figure 4.1. Components of fecundity for radio-marked females in relation to the wind power development at the Smoky Hills field site, 2007-2011. Fecundity data are presented separately for the preconstruction (2007-2008, black squares, solid lines) and postconstruction periods (2009, 2011, open circles, dashed lines). We monitored 59 nests in the preconstruction period (first nests: n = 48, renests: n =11) and 185 nests in the postconstruction period (first nests: n = 142, renests: n = 43). Average date of clutch initiation was 26 April (Julian date = 116).

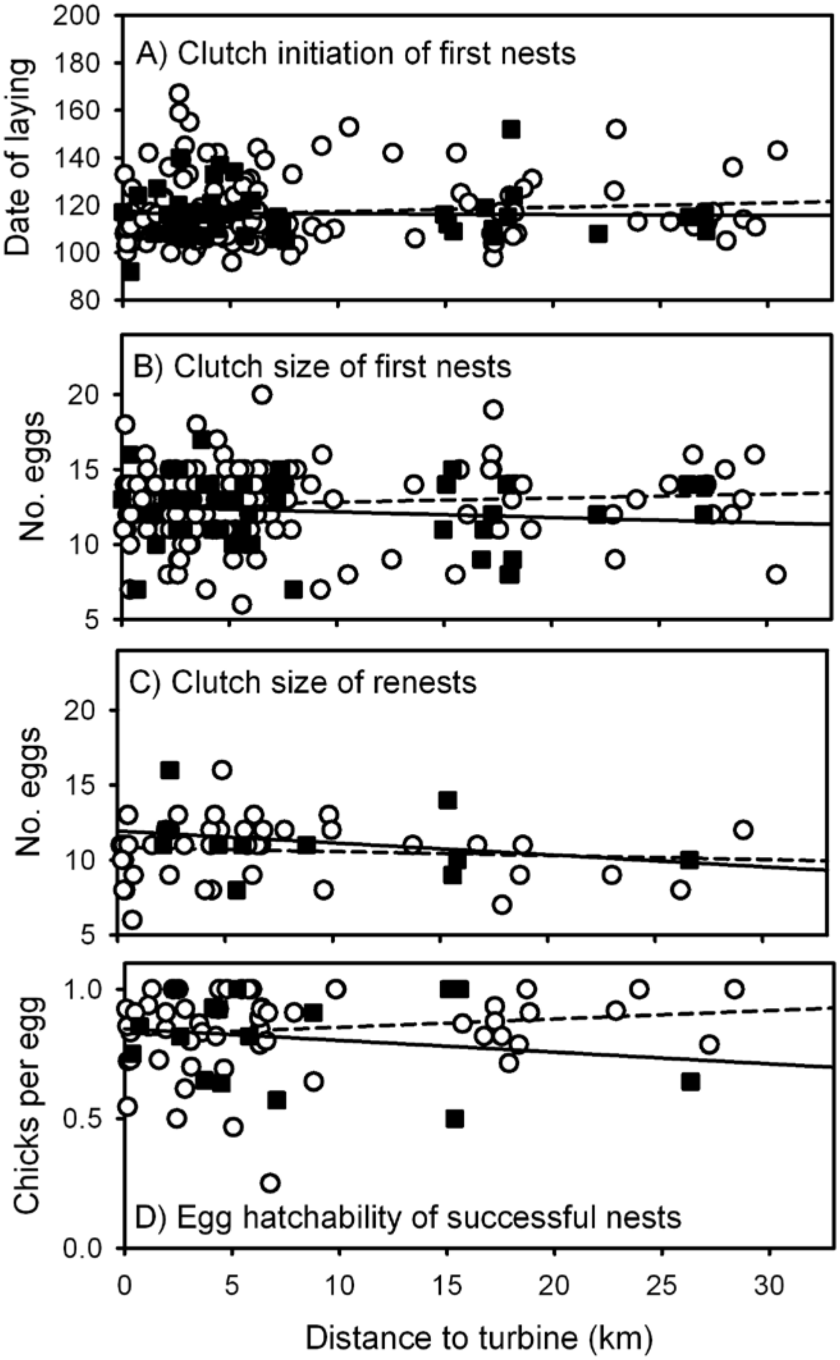


Figure 4.2. Location of nest sites of radio-marked females in relation to the wind power development at the Smoky Hills site, 2007-2011. Nest locations are shown separately for the pre- (circles) and postconstruction periods (triangles), and for successful (light purple) and unsuccessful nests (dark purple). Boundaries of the study area were set by the distribution of nests with a 5 km buffer.

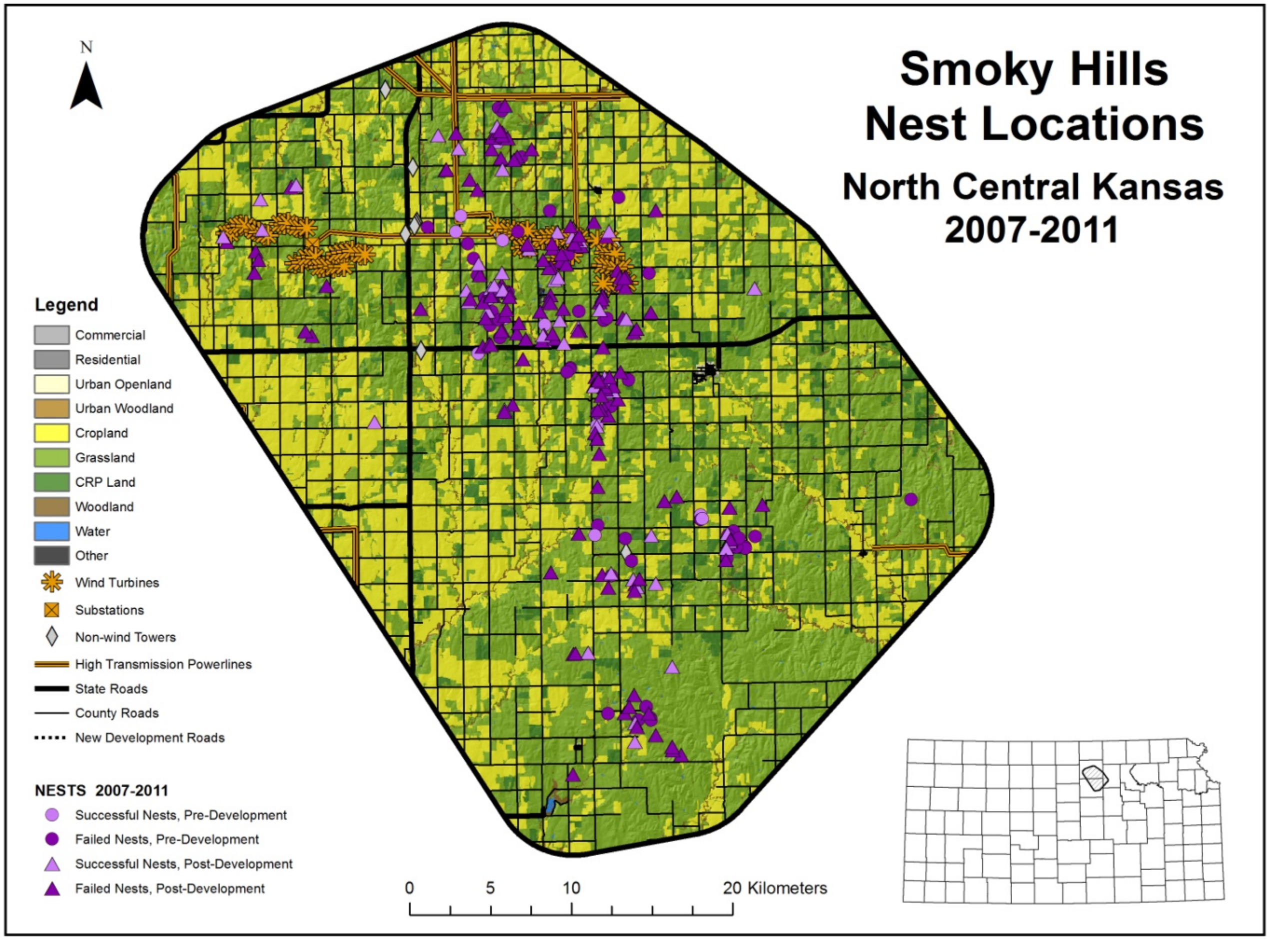
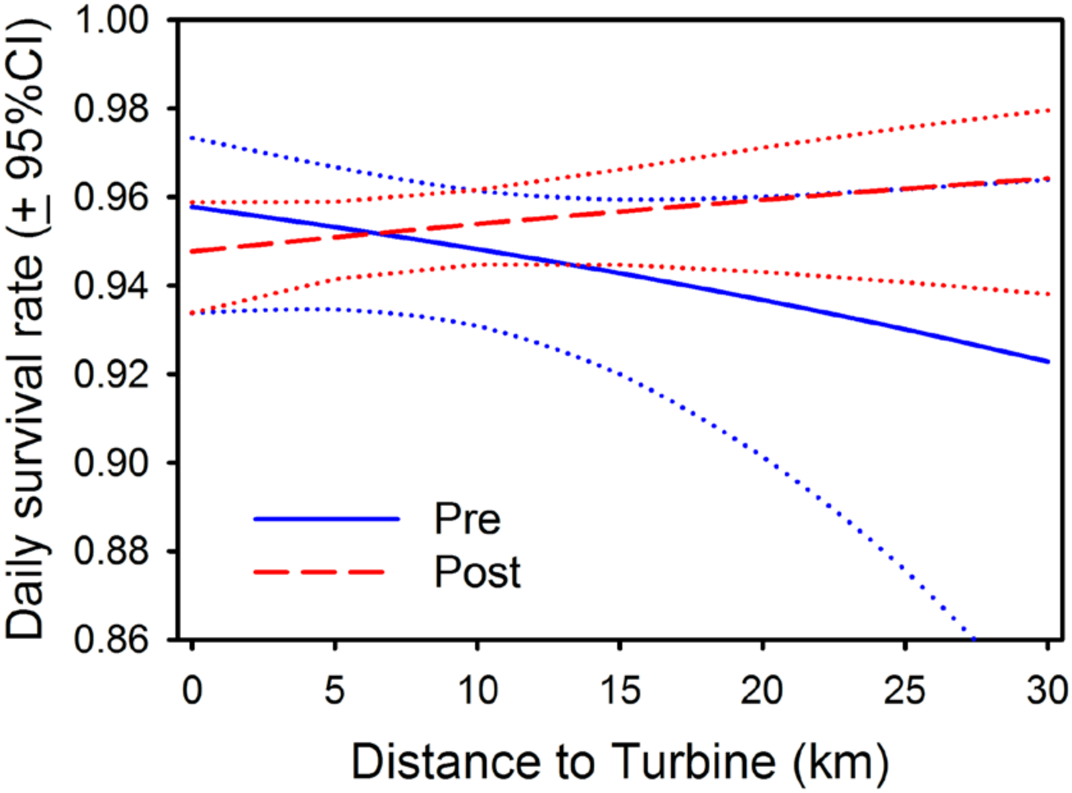
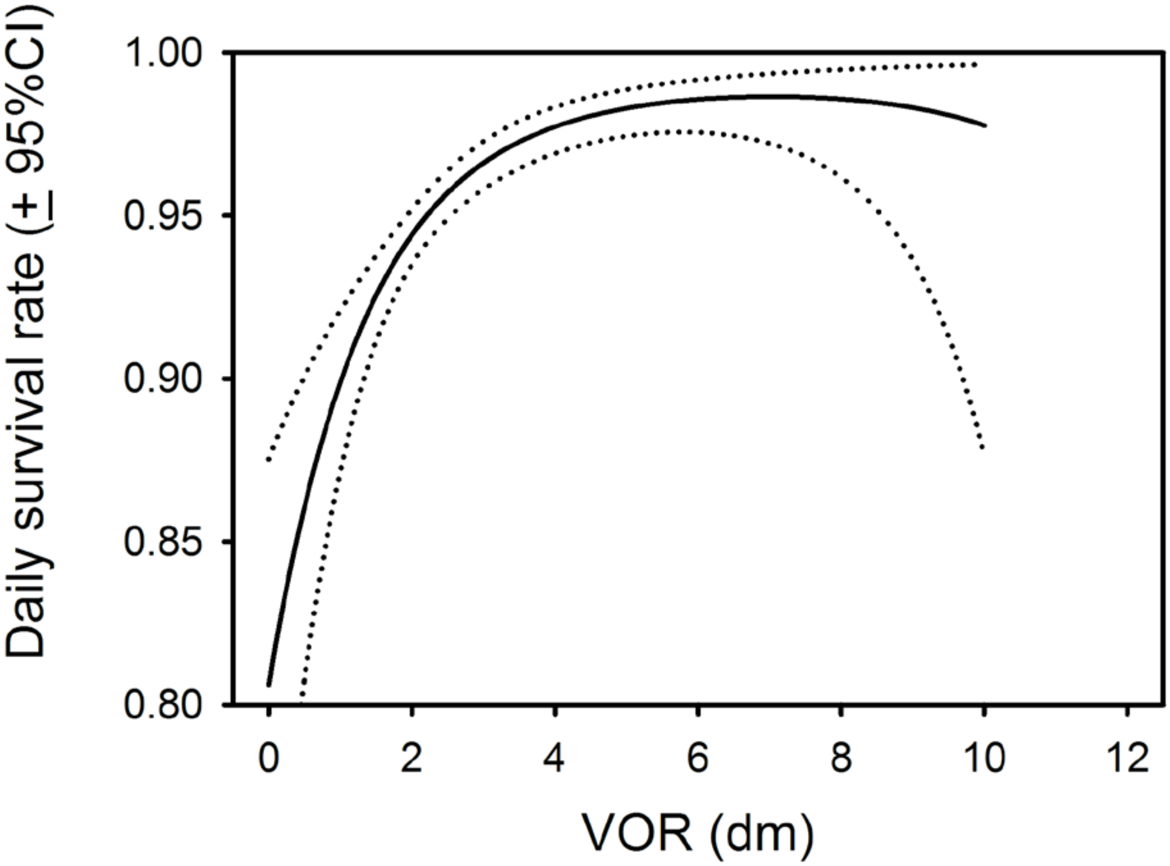


Figure 4.3. The effect of distance to nearest wind turbine (km) on daily nest survival rate in pre-construction (2007-2008) and post-construction periods (2009-2011) at the Smoky Hills field site, Kansas, 2007- 2011. Parameter estimates taken from model S(trt × dturb).



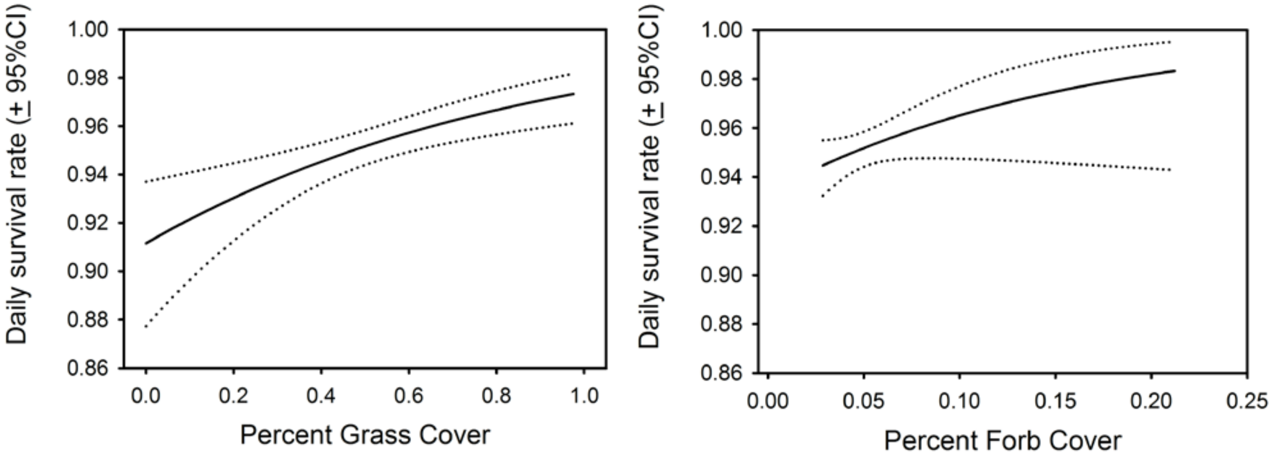
β_{pre} = -0.27 (95% CI = -0.61 to 0.72)
β_{post} = 0.10 (95% CI = -0.08 to 0.29)

Figure 4.4. The effect of vegetative cover on the daily survival rate of prairie chicken nests at the Smoky Hills field site, Kansas, 2007- 2011. Vegetative cover was measured by visual obstruction readings and was modeled as a quadratic relationship. Parameter estimates taken from model S(VOR^2).



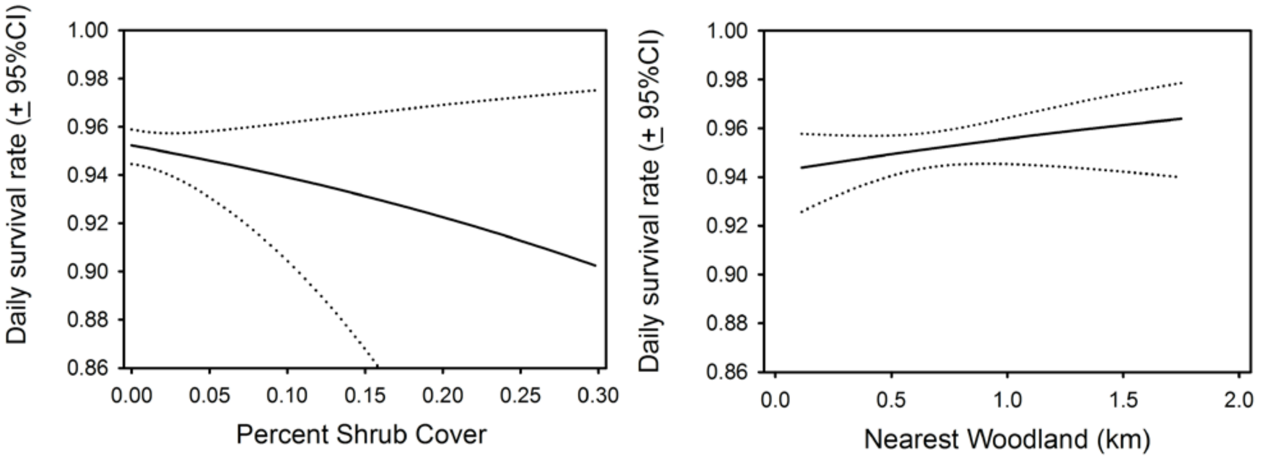
β_1 = 0.72 (95% CI = 0.49 to 0.95)
β_2 = -0.11 (95% CI = -0.18 to -0.03)

Figure 4.5. The effects of habitat on the daily nest survival rates of prairie chicken nests at the Smoky Hills field site, Kansas, 2007- 2011. Habitat parameters included percentage of forb, grass and shrub canopy cover near the nest, and distance to nearest woodland edge (km). Parameter estimates taken from models S(pgrass), S(pforb), S(pshr), and S(dwood).



β = 0.29 (95% CI = 0.13 to 0.45)

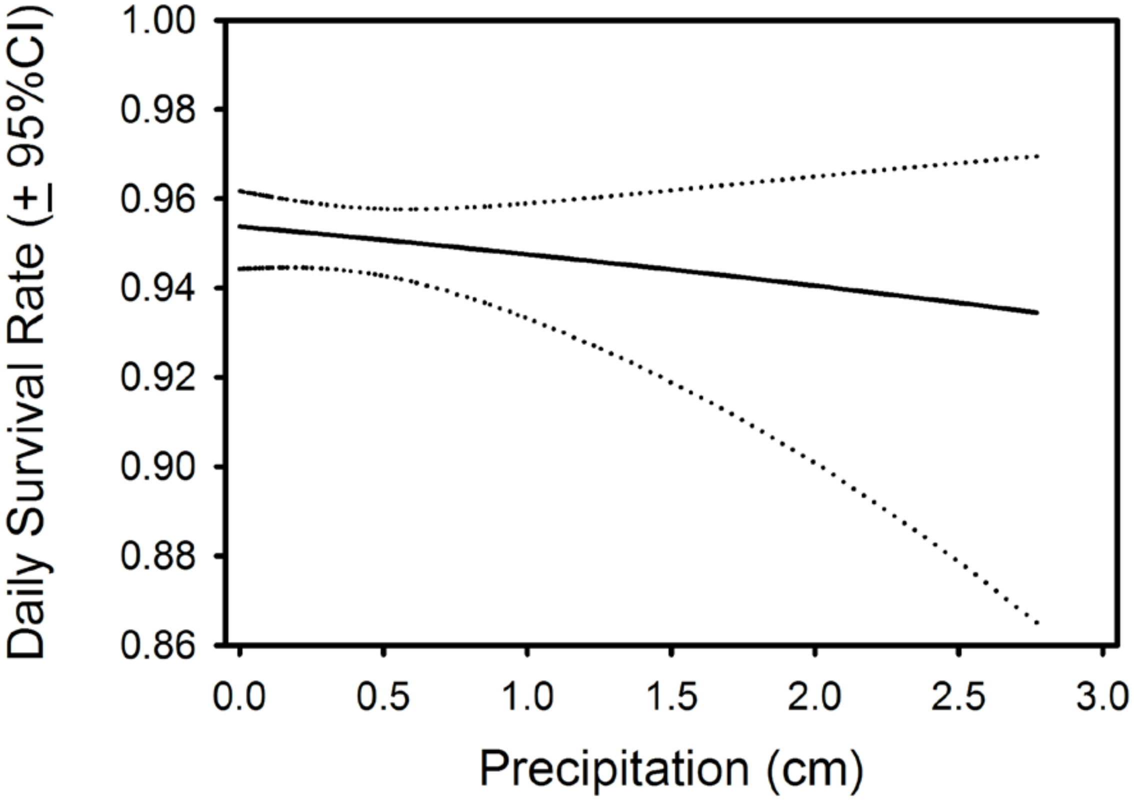
β = 0.15 (95% CI = -0.02 to 0.33)



β = -0.06 (95% CI = -0.19 to 0.06)

β = 0.09 (95% CI = -0.06 to 0.25)

Figure 4.6. The effect of rainfall on the daily nest survival rates of prairie chicken nests at the Smoky Hills field site, Kansas, 2007- 2011. Precipitation was modeled as a moving window with average rainfall received during the previous three days of exposure (cm). Parameter estimates taken from model S(precip).



β = -0.13 (95% CI = -0.46 to 0.19)

Objective 5. *Impacts on Natal Dispersal*

In natural and modified landscapes, dispersal is a fundamental ecological process that shapes distribution patterns, affects population viability via demographic rescue, influences extinction and re-colonization rates, and controls patterns of gene flow (Peakall et al. 2003). Ecologists typically differentiate between two types of dispersal events: *natal dispersal*, which is the movement of an individual organism away from a natal site to settle in a new breeding range vs. *breeding dispersal*, which is the movement of mature individuals among sites used in consecutive breeding attempts (Greenwood 1980). Natal and breeding dispersal movements of prairie chickens are female-biased with males tending to be the sex with greater philopatry and breeding site fidelity (Schroeder and Robb 1993). However, given the observed high skew in male reproductive success and costs of inbreeding depression in prairie chickens, natal dispersal of males and lek recruitment might exert greater influence on the population genetic structure of the Greater Prairie-Chicken (Westemeier et al. 1998, Nooker and Sandercock 2008, Gregory 2011). One approach for assessing natal dispersal is to mark juveniles during a sampling period prior to dispersal and then search among the cohort of sampled adults in subsequent sampling periods for individuals marked as juveniles. It is possible to mark juvenile grouse with patagial wing tags as an individual marker but tags must be applied with care to avoid injury to newly hatched young. To minimize risk of injury in a sensitive species, we opted to use a population genetic approach and genotyped individual birds to examine dispersal rates of prairie chickens

We first used genetic analyses to directly examine dispersal of young from their natal sites. We used molecular identity analysis to positively identify individuals sampled as both chicks and adults by comparing multi-locus genetic profiles. Using 20 microsatellite markers, we genotyped all adult prairie chickens and chicks captured at the Smoky Hills study site (Table 2.1). Our suite of markers provided high confidence in molecular identification in our genetic analysis with a probability of identity of 6.3×10^{-15}, and a probability of identity among siblings of 3.6×10^{-9}. With our genotypic data, there was a $<4 \times 10^{-10}$ % chance we would misidentify different siblings as the same individual, and $<4 \times 10^{-13}$ % chance that we would misidentify unrelated individuals as the same bird.

A second method for identifying changes in dispersal patterns is to evaluate changes to the extent to which significant spatial autocorrelation among genetic and geographic distance occurs (Peakall et al. 2003). Under restricted gene flow and neutral selection, the focal population should be characterized by positive spatial genetic autocorrelation at short distances, which should decline to zero and become negative with increasing distance between individuals or populations (Smouse and Peakall 1999). If wind power development or other landscape perturbations affect dispersal behavior, we would predict rapid changes in the patterns of spatial genetic autocorrelation. Changes in patterns of relatedness can provide evidence of changing dispersal habits and breeding ecology of the species leading to restricted gene flow and increasing patchiness in local species distribution (Scribner and Chesser 1993). Thus, we also evaluated spatial autocorrelation among male prairie chickens during the pre- and postconstruction periods of wind energy development, and tested for thresholds in the distances at which spatial autocorrelation in genetic structure approached zero or negative values. Changes in distance threshold between pre- and postconstruction periods could indicate changes in mating behavior, altered dispersal patterns, or changes in habitat use or less connectivity in a fragmented landscape.

Sexing of chicks.–Prairie chicken chicks are not sexually dimorphic. We used genetic markers to sex young with introns of the sex-linked CHD gene (2550F and 2718R, Fridolfsson and Ellegren 1999). DNA fragments were amplified in a 10 µL PCR cocktails (see above) and molecular sexing was visualized via electrophoresis on high resolution agarose gels (3%). The observed juvenile sex ratio among chicks based on molecular sexing was 1.1:1.0 females per male, which did not differ significantly from an expected 1:1 sex ratio (Binomial Test: $P = 0.86$). Sex ratios of prairie chicken young did not change between the pre- and postconstruction period.

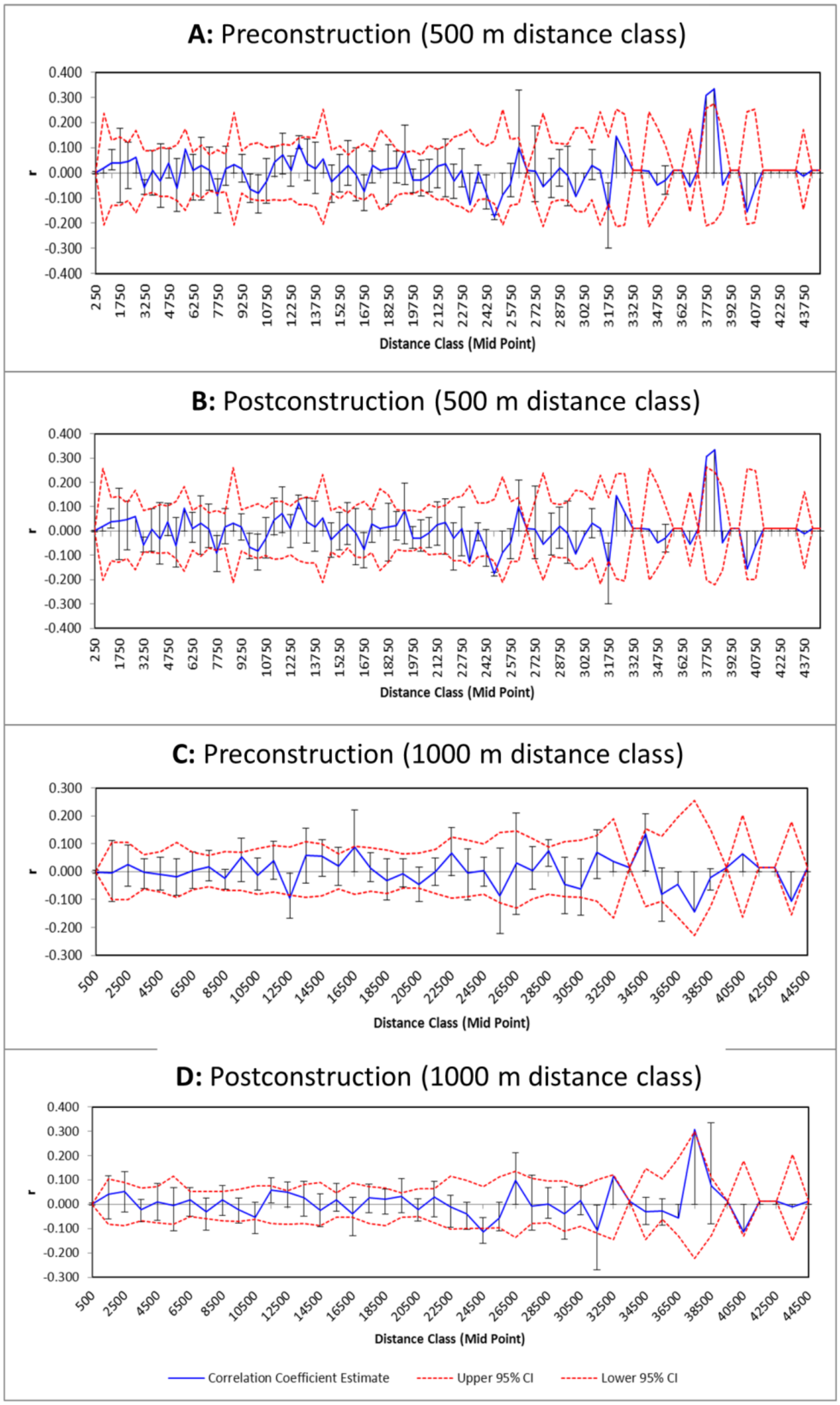
Direct evidence for natal dispersal.–Using molecular techniques, we were able to unambiguously assign identity to nine individuals (Smoky Hills: n = 6, northern Flint Hills: n = 3). The nine birds were originally captured as chicks and then later recaptured as adults, and were identified by genotyping with microsatellite markers. In the Smoky Hills, all dispersing birds were recaptured during the postconstruction period following wind energy development. However, at least four birds were first captured as chicks in 2008 or prior to 2008. Five of these chicks were male, and one was female. On average, males dispersed 1.2 ± 0.8 km from their capture location as a chick just after hatching to the lek to which they later recruited. The female dispersed 13.5 km from her point of capture as a chick to the lek she was later re-captured at as an adult. At the northern Flint Hills site, one disperser was a male and two birds were females. On average, males at the northern Flint Hills site dispersed 321 ± 0.0 meters from their capture location as a chick just after hatching to the lek to which they later recruited. Two females dispersed 11.5 ± 0.1 km from their capture locations as chicks to the leks where they were captured as adults. Pooling data for direct measures of natal dispersal across our two study units, females captured as chicks had an average natal dispersal distance of 12.5 km whereas males had dispersed and recruited to leks that were 0.6 km from their natal nest site. Natal dispersal distance was significantly different between females and males (two sample *t*-test, $P < 0.01$), but the power of our analysis was low with our small sample sizes.

Dispersal neighborhoods and spatial autocorrelation among males.–Given our evidence for sex bias in the natal dispersal distances of juvenile prairie chickens, we predicted that males would be more sensitive to disturbance from wind power development because males are the philopatric sex. Thus, we focused on changes in the patterns of genetic distance (r) among males at leks as a second genetic index of potential disruption of natal dispersal caused by construction of the wind power facility at the Smoky Hills field site.

During the preconstruction period (2007-2008), we sampled 175 male prairie chickens at 22 lek sites which were spaced 0.3 to 45 km apart. During the postconstruction period (2009-2011), we sampled 222 males at the same 22 lek locations. Spatial autocorrelation analyses were conducted for male prairie chickens before and after wind power construction using distance classes of 0.5 and 1 km (Figure 5.1). During the preconstruction period, the preconstruction correlations were positive using 500 meter distance classes. Individual estimates were significantly greater than zero up to the 1,750 meter distance class, which was consistent with the 1,166 meter average dispersal distance detected with the identity analysis above. During the postconstruction period, the correlogram with 500 meter distance class shows that the individual estimates overlap with zero within the first 250 meter distance class. Comparing the change in thresholds between the pre- and postconstruction periods suggests that the average natal distance of males in the changing landscape was 4-7 times greater during the preconstruction than the postconstruction periods.

Direct detections of natal dispersal were limited because survival of newly hatched chicks to adults were low and because we were unable to detect dispersal distances outside of our study area. Direct observations of natal movements were limited and were inadequate to make conclusions about the potential impacts of wind energy development on natal dispersal. Spatial correlograms of genetic distance among males at leks were a more sensitive measure of population structure, and indicated a weak effect of wind energy development on the spatial genetic structure of prairie chickens.

Figure 5.1. Spatial autocorrelation correlograms for genetic distance (*r*) among males vs. distance to turbine among prairie chickens captured at 22 lek sites before (A,C) and after (B,D) wind energy development at the Smoky Hills field site in northcentral Kansas, 2007-2011. Correlation coefficients denoted in blue, 95%CI with dashed red lines.



Objective 6. *Impacts on Survival Rates*

Wind power development could affect survival of prairie chickens through several possible mechanisms. The mechanism that has received the most attention in studies of wildlife impacts has been the risk of collision mortality if flying birds are at risk of injury or death from striking turbine blades, power lines, fence lines, or other infrastructure associated with energy development. Most losses in natural populations of prairie chickens are due to predation and wind power development could also affect survival rates if numbers or foraging behavior of key predators is altered. If collision mortality from turbines generates carrion that is a supplemental food resource for coyotes, badgers and other mesocarnivores, predation risk may be increased on lekking males or nesting females near turbines. Both males and females are vulnerable to predation while displaying and visiting open lek sites in the spring. If presence of turbines improves the foraging opportunities for mammalian predators hunting prairie chickens at lek sites, mortality rates due to predation could be elevated. On the other hand, presence of turbines might reduce predation risk for prairie chickens if Northern Harriers (*Circus cyaneus*), Red-tailed Hawks (*Buteo jamaicensis*), and other raptors avoid wind turbines while hunting (Hoover and Morrison 2005).

Seasonal Survival of Females.–Prairie chickens were captured with walk-in traps and drop-nets at lek sites during March to April. A few females were captured at the nest or with broods to replace failing transmitters. At first capture, we marked all birds with a numbered metal leg band and three colored leg bands and sexed them by plumage. Females were outfitted with 10-11 g radio transmitters attached with an elastic or wire necklace harness (ATS or Holohil). Radios had an expected battery life of 1-2 years and were equipped with mortality switches that changed pulse rate when a bird was killed. Females were relocated 3-4 times a week during the breeding, nesting, and brood-rearing seasons (Mar-Aug) and weekly during the post-breeding and winter periods (Sep-Feb). Following the timing of our capture effort, we created encounter histories for each female per year for an annual period from Mar 1 to Feb 28/29 the following year (i.e., Mar 1-7 = week 1). Encounter histories consisted of three items: week of entry, week of exit, and event (1 = mortality, 0 = survived). Our data were both left- and right-censored with staggered entry of birds into the sample, and surviving birds which were censored after failure of an attachment harness or battery of the radio transmitter.

If the pulse rate from the mortality switch indicated that a female had died, observers relocated the carcass within 1-2 days and attempted to determine cause of death from evidence at the mortality location. Radios with broken harnesses but no other damage, and no sign of bird remains were considered to be *dropped collars* and were treated as surviving birds. In 2010, our Holohil radios were constructed with faulty elastic harnesses, and many of the dropped collars had harnesses with evidence of stretching and other damage. Bird carcasses with evidence of tooth marks or scat were considered to be the result of *mammalian* predation by coyotes, badgers or other mesocarnivores. Carcasses that were plucked at a perch site, decapitated remains where breast muscles were removed with no evidence of tooth marks, or presence of white fecal matter were considered to be the result of *avian* predation by raptors or owls. Carcasses that had broken necks or wings, long open gashes, and no other evidence of predator activity that were found <200 m from fence or power lines were considered to be the result of *collision* mortality. Birds shot by hunters where leg bands were reported to our field team or to KDWPT were considered to be *harvest* mortality. Most carcasses were recovered within 1-2 days of death, but causes of mortality are tentative because we cannot discount the possible effects of scavenging of dead birds. If we were unable to determine cause of mortality because carcasses were too degraded when recovered or if multiple signs of evidence were present, we considered the event to be an *unknown* cause of mortality.

We calculated cumulative survival rates of radio-marked females with staggered entry Kaplan-Meier models with package survival in Program R (ver. 2.13.11, R Foundation for Statistical Computing, Vienna, Austria). As first step, we checked whether the assumption of proportional hazards was met by our survival data with model diagnostics based on scaled Schoenfeld residuals (cox.zph function, Fox 2002). We then used Cox proportional hazards models to test for differences in survival among years within each treatment period, between treatments (i.e., pre- and postconstruction periods), and as a function of distance from the centroid of the female home range to the nearest turbine (Figure 6.1, Murray 2006, Sandercock et al. 2011). We calculated distances for eventual sites of turbines during the preconstruction period, and actual sites of turbines during the postconstruction period. We report effects of year, treatment and other factors as hazard ratios ($\exp(\beta)$) where a hazard ratio of one is expected if there is no difference between different groups in the risk of mortality. Some females were monitored in multiple years and we modeled individual identity as a random effect to control for a potential lack of independence among different encounter histories for the same female (with the cluster() function). Hazard functions (or the instantaneous risk of mortality per week) were estimated with smoothing spline functions in package gss (DelGiudice et al. 2006). We used the default value of 1.2 for the smoothing parameter and did not modify this value to avoid overfitting of splines.

During the preconstruction period, we monitored 25 females in 2007 (n = 15 mortalities) and 56 females in 2008 (n = 26 mortalities, Figure 6.2). The assumption of proportional hazards was met ($\rho = 0.117$, $\chi^2 = 0.701$, $P = 0.402$). The probability of annual survival was 0.215 in 2007 (95%CI = 0.089 to 0.520 and 0.303 in 2008 (95%CI = 0.173 to 0.533). There was no difference in female survival between years during the preconstruction period (Cox proportional hazards, HR = 0.656, 95%CI = 0.323 to 1.335, z = -1.163, $P = 0.245$). During the postconstruction period, we monitored 74 females in 2009 (n = 20 mortalities), 70 females in 2010 (n = 18 mortalities), and 62 females in 2011 (n = 25 mortalities, Figure 6.2). The assumption of proportional hazards was again met ($\rho = -0.086$, $\chi^2 = 0.503$, $P = 0.478$). The probability of annual survival was 0.566 in 2009 (95%CI = 0.435 to 0.737), 0.521 in 2010 (95%CI = 0.360 to 0.753), and 0.551 in 201 (95%CI = 0.435 to 0.698). There was no difference in female survival between years during the postconstruction period (HR = 1.130, 95%CI = 0.831 to 1.537, z = 0.781, $P = 0.435$). Accordingly, we combined information from different years within each treatment period and proceeded with further analyses.

Analyses of female survival were based on 74 females monitored for 81 bird-years (41 mortalities) during the 2-year preconstruction period (2007-2008), and 177 females monitored for 206 bird-years (63 mortalities) during 3-year postconstruction period (2009-2011). Average distance from centroid of female home ranges to nearest turbine was 8.4 km (range = 0.02 to 26.8 km) in the preconstruction period and 7.8 km (range = 0.18 to 32.1 km) in the postconstruction model. We modeled female survival as a factorial model with the main effects of treatment period, distance to turbine, and the interaction between these two factors. The assumption of proportional hazards was met for our global model (ρ = n/a, $\chi^2 = 6.94$, $P = 0.074$). The interaction between treatment and distance to turbine was not significant (Cox proportional hazards, HR = 1.010, 95%CI = 0.953 to 1.072, z = 0.344, $P = 0.731$). Similarly, distance to turbine had no significant effect on female survival (HR = 0.994, 95%CI = 0.957 to 1.031, z = -0.339, $P = 0.734$). A hazard ratio <1 indicated that female mortality rates declined at greater distances from turbines but the confidence interval of the hazard ratio included one and this factor was not significant. We did find a nonsignificant trend for a difference in female survival between the pre- and postconstruction periods (HR = 1.777, 95%CI = 0.988 to 3.197, z = 1.92, $P = 0.055$). Contrary to predictions of negative impacts of wind power development, annual survival of female prairie chickens increased almost two-fold after the turbines were installed. The probability of annual survival for female prairie chickens at the Smoky Hills field site was 0.274 (95%CI = 0.167 to 0.452) in the preconstruction period (2007-2008) and increased to 0.543 (95%CI = 0.459 to 0.642) in the postconstruction period (2009-2011, Figure 6.3).

To investigate the mechanisms leading to higher survival of female prairie chickens after wind power development, we calculated hazard functions for the pre- and postconstruction periods. During the lekking period of March to May (weeks 1-12), the instantaneous risk of mortality for females was ~4 times higher during the preconstruction period (0.040 to 0.110) than during the postconstruction period (0.015 to 0.025, Figure 6.3). During the nesting and brood-rearing periods of June to September (weeks 13 to 30), the risk of mortality for females remained high. Females rely upon cryptic coloration and concealment to avoid predators and were vulnerable to predation while attending eggs and young. If a female survived the breeding season, there was limited natural mortality during the nonbreeding period from October to February (weeks 31 to 52). The cumulative survival in Kaplan-Meier plots was a flat line in fall and winter, and the instantaneous risk of mortality was < 0.01 per week (Figure 6.3).

Prairie chickens are vulnerable to attacks by avian predators at lek sites and predation risk is an important factor affecting lek site selection, lek persistence and vigilant behavior of displaying birds. One possible explanation for our observed higher hazard rates during the preconstruction period is that construction of wind turbines may have disrupted the foraging behavior of raptors during the lek-mating season of prairie chickens. To test this idea, we examine cause of mortality for 90 females that were found dead during our 5-year study. Nine females were coded as dead of unknown causes (n = 5) or killed by an unknown predator (n = 4). We restricted our analysis to females where cause of mortality could be determined. Our data on cause of mortality should be treated with caution because we were unable to assess rates of scavenging.

Of 25 female mortalities recorded during the preconstruction period (2007-2008), 72% were killed by mammalian predators, 16% by avian predators, and 12% were collision mortalities. Of 56 female mortalities recorded during the postconstruction period (2009-2011), 54% were killed by mammalian predators, 38% by avian predators, and 7% were collision mortalities. Comparisons of rates of mammalian vs. avian predation were not consistent with our working hypothesis that wind power might have negative impacts on raptor foraging. Risk of mortality from avian predators was lower during the preconstruction than the postconstruction period (odds ratio = 0.30, 95%CI = 0.09 to 1.02, ($\chi^2 = 3.89$, df = 1, $P = 0.048$). However, if we calculated the distance from mortality location to nearest turbine by cause of mortality, female prairie chickens killed by raptors tended to be closer to turbines during the preconstruction (median = 2.9 km, range = 2.6 to 14.7 km, n = 3) than the postconstruction period (median = 5.9 km, range = 0.7 to 28.8 km , n = 23, chi-square approximation to Mann-Whitney U-test, χ^2 = 0.015, df = 1, *P* = 0.904). Conversely, female prairie chickens killed by mammalian predators tended to be closer to turbines during the postconstruction (median = 3.7 km, range = 0.13 to 28.2 km, n = 30) than the preconstruction period (median = 7.8 km, range = 0.07 to 27.0 km, n = 18, χ^2 = 3.12, df = 1, *P* = 0.077).

Contrary to predictions of negative impacts of wind power development, the risk of collision mortality tended to be higher during the pre- than the postconstruction period (odds ratio = 1.5, 95%CI = 0.3 to 7.2), but the difference was nonsignificant (χ^2 = 0.25, df = 1, *P* = 0.613). Female mortality events attributed to collision mortality were often a long distance from wind turbines and usually associated with fence lines (Figure 6.4). Distance to turbines for collision mortalities did not differ between the preconstruction (median = 4.2 km, range = 0.8 to 4.3 km, n = 3) and postconstruction periods (median = 2.9 km, range = 0.16 to 28.4 km, n = 4, χ^2 = 0, df = 1, *P* = 1.0). No females were killed by hunters during our study and harvest mortality was limited. The low rates of natural mortality during the fall and winter periods imply that any harvest during the regular 3-month hunting season from November to January would likely be additive mortality for prairie chickens.

Body Condition of Males.–In the above analysis, we examined direct impacts of wind power development on the survival of radio-marked females. We did not deploy radios on males and investigated variation in male body condition as a possible correlate of annual survival rates. Female body mass dynamics include large increases when females are gravid with eggs, followed by loss of body mass during the incubation period. Thus, we restricted this analysis to males only. Changes in body condition are an indirect measure of the possible impacts of wind energy if disturbance has a negative impact on habitat conditions or individual performance. Reductions in body condition are expected to have negative impacts on the survival and reproductive performance of birds.

To obtain an index of male body condition, we regressed body mass vs. the first principal component of body size and used residuals as an index of body condition. We then regressed residual body mass against the distance of lek of capture to the nearest wind turbine for all male prairie chickens during the pre- and postconstruction periods. The first Principal Component of body size (PC1) was calculated from six morphometric measures recorded for each chicken at capture (wing length, tarsus length, comb length, comb height, right and left pinnae length). We conducted the Principal Component Analyses, linear regression of the first PC1 of body size against individual body mass, and calculations of residual body mass for each individual in Program R (ver. 2.13.11, R Foundation for Statistical Computing, Vienna, Austria). However, some authors have questioned the validity of using principal components of several different morphometric variables as a metric of body size (Green 2001). We also regressed body mass against tarsus length and used residuals from this relationship as an alternative index of body condition.

We assumed that residual body mass reflected variation in nutrient stores was an index of male body condition. A positive residual body mass would indicate that body mass is greater than expected given the individual bird's size compared to other individuals in the population. If a residual value was negative, the body mass of the individual was less than expected given the bird's size, and the bird may be in poor condition relative to other individuals in the population. For the preconstruction period, we regressed residual body mass against distance to the eventual location where turbines were later constructed. We used 2007 as a preconstruction year and 2009-2011 as postconstruction years. We opted to exclude 2008 because construction of Phase 1 started in April 2008 in the eastern portion of our study area but inclusion of 2008 as a preconstruction year did not qualitatively affect the results of this analysis. Similarly, if we used tarsus length instead of the first principal component as an indicator of body size, our conclusions were unaffected (results not shown).

We found that pre- and postconstruction regressions of body condition vs. distance to eventual or actual sites of wind turbines had significant relationships; however, the slope coefficients were opposite. Prior to wind energy development, the relationship was negative and males with better body condition were located in habitat patches closer to sites where wind energy infrastructure was eventually developed ($\beta = -0.20$, $r^2 = 0.42$, $P = 0.048$, df =113). Conversely, after wind energy development, the relationship was positive and birds at greater distances from the actual sites of wind turbines were in better condition ($\beta = 0.13$, $r^2 = 0.67$, $P = 0.003$, df = 108, Figure 6.5). The slope coefficient was of greater magnitude during the preconstruction period but the linear regression explained less of the observed variation in residual body mass.

Analyses of female survival with time-to-event models show that wind energy development does not have a negative effect on the survival of female prairie chickens. Unexpectedly, females realized higher survival rates during the lekking season in the postconstruction period. Our working hypothesis for this result is that wind power infrastructure may have disrupted the foraging behavior of diurnal raptors that kill prairie chickens at lek sites. In support of this idea, raptor kills tended to be farther from turbines during the postconstruction period whereas mammalian kills were closer. However, analyses of the major causes of mortality did not support this hypothesis because the odds of raptor predation were greater after development was completed. Overall, a majority of mortality losses of radio-marked females were due to predation, and losses to collision mortality or harvest were rare events. Low rates of natural mortality during fall and winter imply that harvest is likely to be additive mortality in prairie chickens. Wind energy development reduced the residual body mass of male Greater Prairie-Chickens at lek sites near turbines. Low values of residual body mass could have a negative impact on individual survival or fecundity rates, or may be related to predation risk and flight performance of males displaying at open lek sites.

Figure 6.1. Location of the home ranges of radio-marked females in relation to the wind power development at the Smoky Hills field site in northcentral Kansas, 2007-2011. Home ranges were calculated separately by year for each female and centroids of female home ranges are marked with pink circles (n = 287 bird-years). Boundaries of the study area were determined by the distribution of nests with a 5 km buffer.

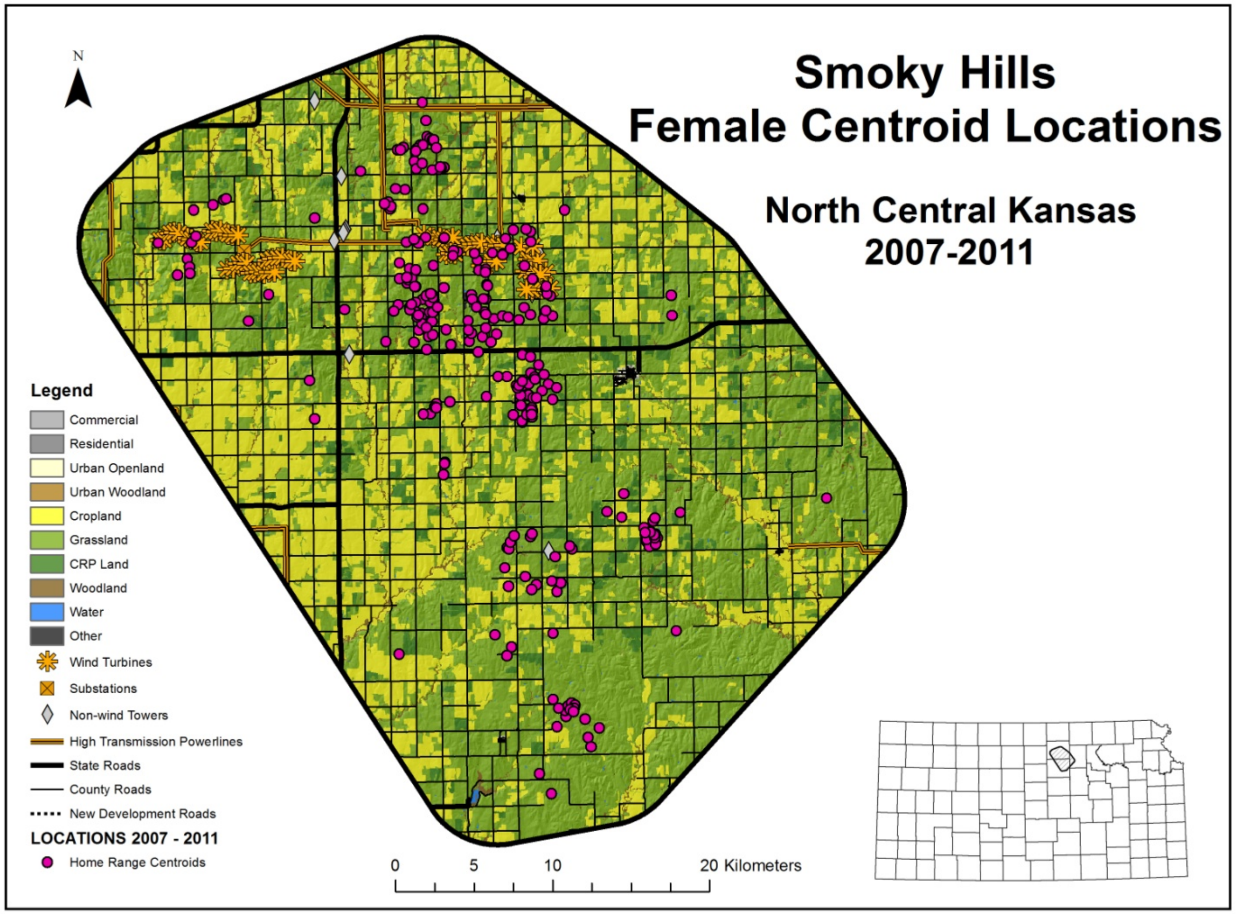


Figure 6.2. Kaplan-Meier plots showing annual variation in the survival of radio-marked females during the pre- (2007-2008) and postconstruction periods (2009-2011) of wind power development. Analyses were based on a weekly time step where Week 1 = 1-7 March. Confidence intervals omitted for clarity.

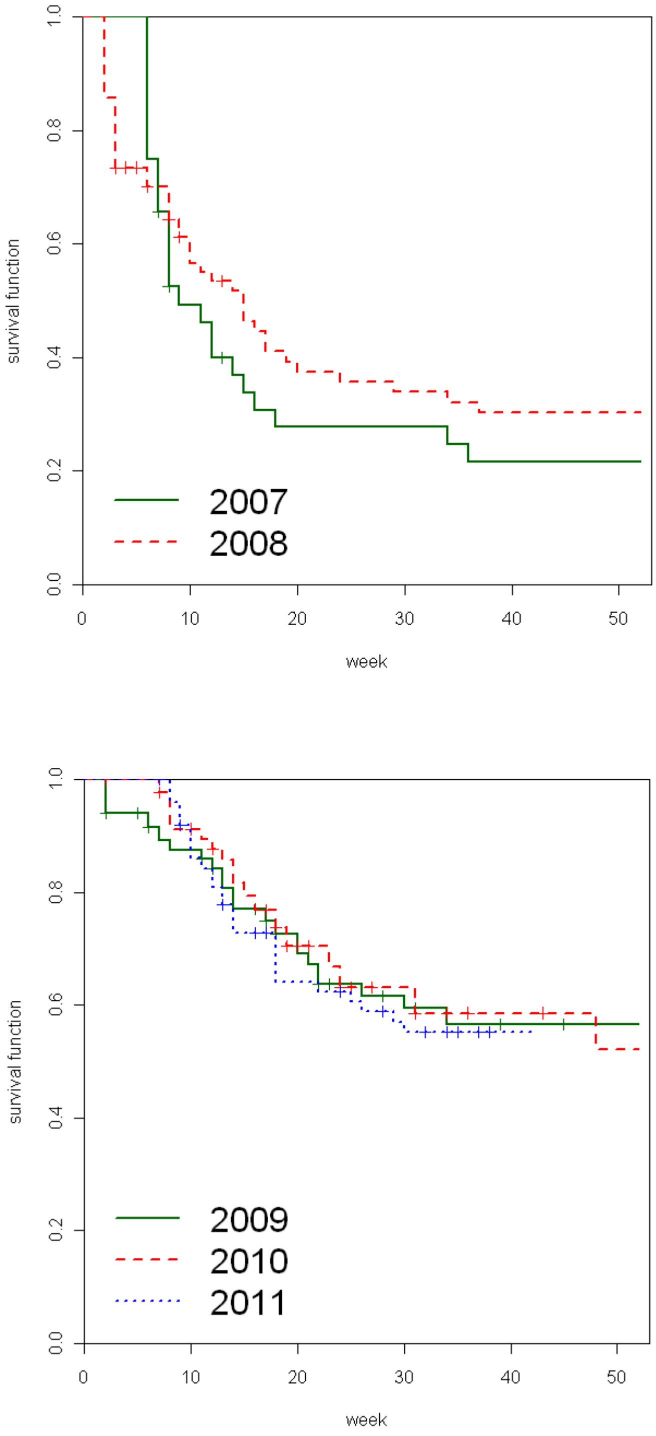


Figure 6.3. Kaplan-Meier plots of survival and hazard functions for radio-marked females during the pre- (2007-2008) and postconstruction periods (2009-2011) of wind power development. Analyses were based on a weekly time step where Week 1 = 1-7 March. Confidence intervals omitted for clarity.

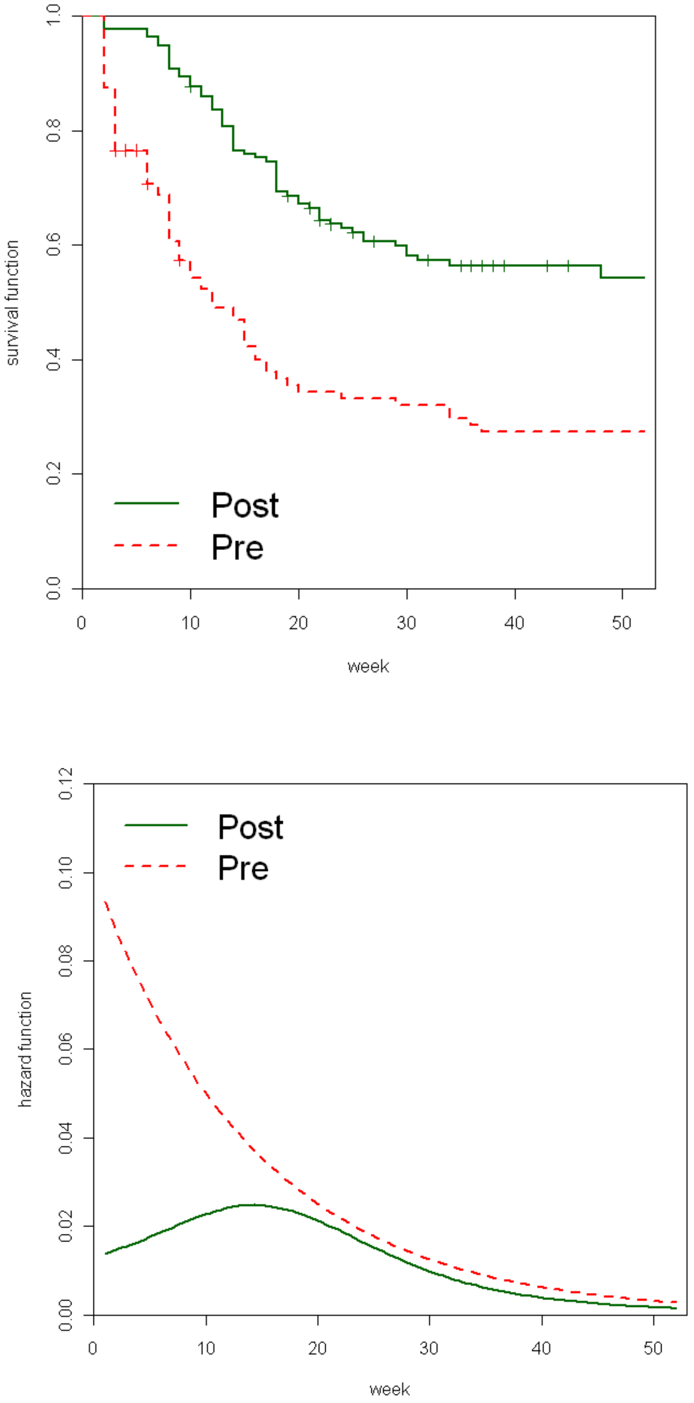


Figure 6.4. Location of mortality sites of radio-marked females (n = 81) in relation to the wind power development at the Smoky Hills field site in northcentral Kansas, 2007-2011. Collision mortalities are denoted by starts, mammalian predation by triangles, and avian predation by circles. Pre and postconstruction periods are light and dark pink, respectively.

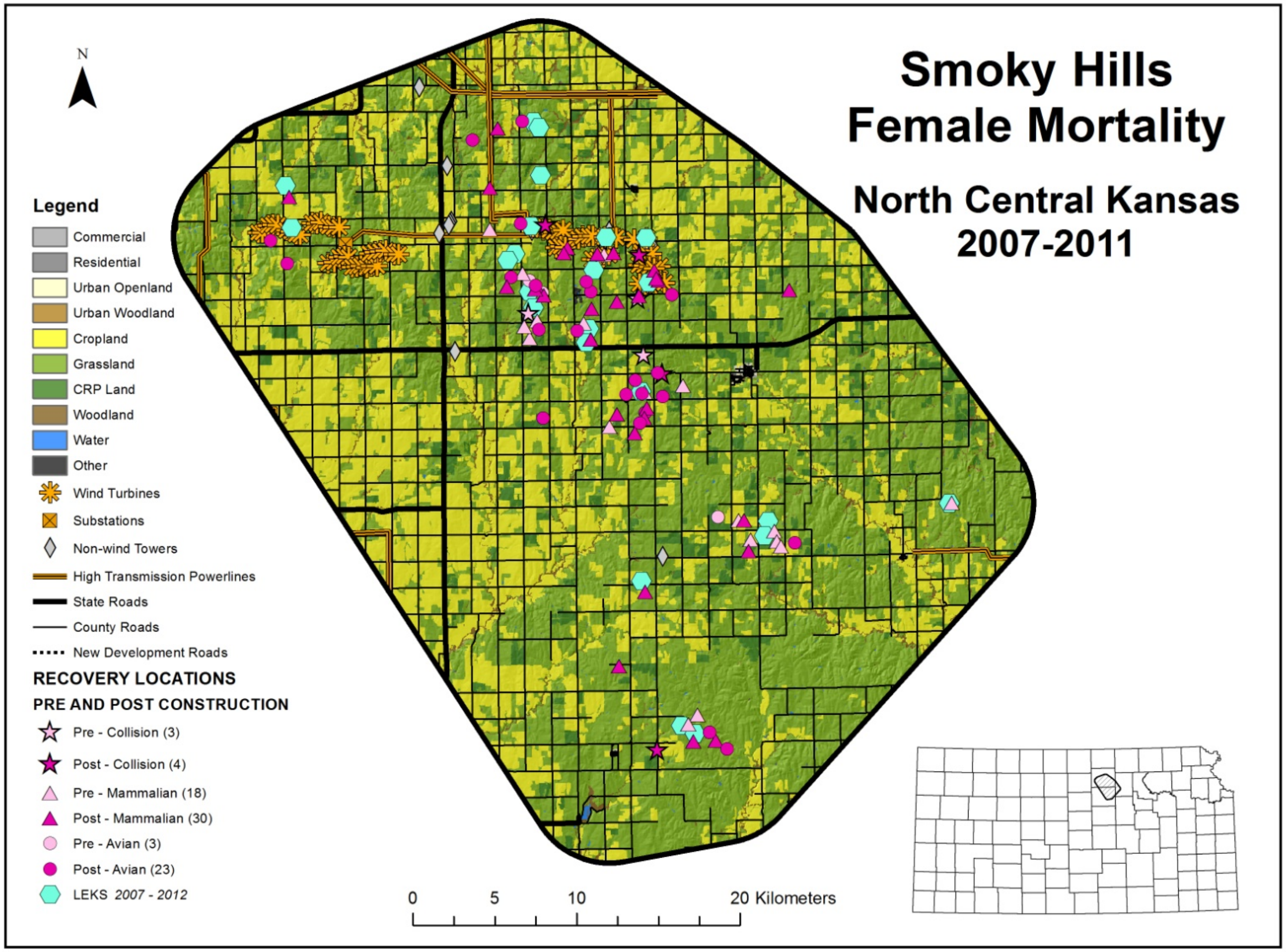
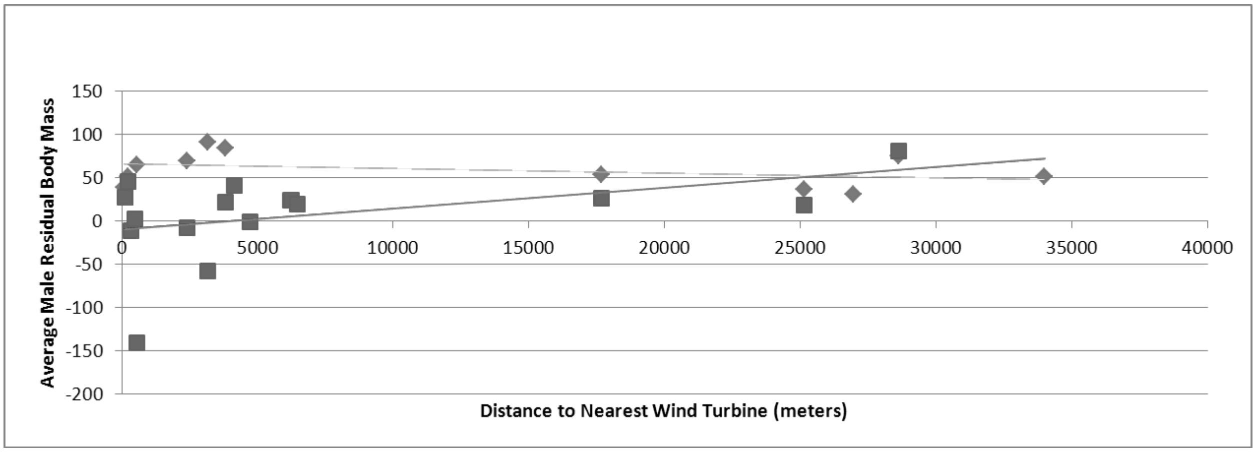


Figure 6.5. Plot of residual body mass of male prairie chickens vs. the distance between lek of capture and nearest wind turbine. Residual mass in the preconstruction period is denoted by grey diamonds (dashed line), and the postconstruction period by black squares (black line).



Objective 7. *Impacts on Population Numbers*

We assessed impacts of wind power development on prairie chickens with complementary approaches based on lek count surveys and population genetics. We predicted that the negative impacts of wind power development could potentially include reductions in number of males at lek sites or changes in effective population size caused by population bottlenecks.

Lek Counts.–We used lek surveys as an index of population size for prairie chickens at the Smoky Hills field site. To investigate impacts of wind power development on lek attendance, we treated lek activity as a binary variable and modeled the probability of lek persistence (see Objective 1). Here, we modeled changes in population size using lek counts where we combined information from flush and trap visits to determine the maximum number of males per year at each lek site (Table 1.1). First, we calculated the median number of males per active lek for lek sites that were <5 km and >5 km from the nearest turbine. We used 5 km as a conservative threshold value because 8 km (5 miles) was a recommended offset distance for siting of wind turbines (U.S. Fish and Wildlife Service 2003), and because most or our abandoned lek sites appeared to be <5 km from wind turbines (Figure 1.2). Second, we calculated the total population size of males for each region as the product of the number of leks monitored and median lek size per region per year. Lek sites were difficult to locate at the start of the study and we continue to add newly discovered leks to our sample over the first couple of years. To control for leks that we missed in the first two years of the study, we used the number of leks present in 2009 to calculate the total number of males present in 2007 and 2008 for regions <5 and >5 km from wind turbines. Last, we calculated the finite rate of population change as the ratio of the estimated number of males present in consecutive years ($\lambda = N_{t+1}/N_t$). Populations are predicted to be stable if $\lambda \geq 1$ and decreasing if $\lambda < 1$.

The median number of males per active lek tended to be 2-4 birds greater at distant leks during the preconstruction years of 2007-2008 but was comparable in the last three years of our project (Figure 7.1A). The estimated population size of males ranged from 60-170 males at leks close to the turbines (<5 km) and from 60-130 males at distant leks (>5 km, Figure 7.1B). Estimation of total population size from male numbers requires an estimate of the sex ratio among prairie chickens. We found that sex ratio among chicks at hatching was 1:1 but differential survival could have led to a different sex ratio among adults. Nevertheless, if the adult sex ratio was close to a 1:1 ratio, the total population size would effectively be double the estimated number of males. The estimated rates of population change based on male numbers were highly variable and tended to fluctuate in parallel at leks that were close and distant from wind turbines (Figure 7.1C).

Construction of the Meridian Way Wind Power facility was completed at the Smoky Hills field site in December 2008. If wind power development negatively impacted the population numbers of prairie chickens, we expected to record high numbers of birds during the preconstruction years of 2007-2008 and greater reductions at leks <5 km from turbines during the postconstruction years of 2009-2012. Instead, we observed the highest lek counts of males in the year after construction (2009), and the highest rates of population growth were recorded during the transition when the wind power facility was constructed (2008-2009). From our peak population counts in 2009, both the median number of males per lek and the total number of males has continued to decline over the next three years, resulting in rates of population change that were consistently $\lambda < 1$. Declines were not any greater at lek sites close to turbines and appeared to covary in parallel at leks <5 and >5 km from turbines. Parallel patterns of variation in population numbers across all leks is consistent with our data on natal dispersal. Juvenile prairie chickens can disperse long distances during their natal year, and dynamics of males at leks <5 and > 5 km from wind turbines are likely linked by long distance movements of birds across our study area.

Population Genetics.–Methods of DNA extraction, optimization of microsatellite markers and genotyping of prairie chickens were completed and previously described for our investigations of the impacts of wind power development on mating behavior (see Objective 2). Bayesian clustering analysis using Program Structure confirmed that the three study sites were each a distinct population (LN(P) = -40,322; Pritchard et al. 2000). More spatially explicit estimates of population genetic structure based on a Bayesian clustering analysis using Program Geneland also indicated greatest support for there being three distinct prairie chicken subpopulations (LN(P) = -37,211; Guillot et al. 2008). Based on these results we calculated separate population genetic parameters and effective population size estimates for each study site (Table 7.1). Overall we have 293 alleles and a high power of identity (PI) at all three study sites (Smoky Hills: PI = 5.5×10^{-27}, northern Flint Hills: PI = 4.3×10^{-20}, southern Flint Hills: PI = 6.6×10^{-15}). Similarly, genetic diversity was high at all three study sites (Smoky Hills: $H_o = 0.88$, northern Flint Hills: $H_o = 0.88$, and southern Flint Hills: $H_o = 0.80$). Using Wilcoxon sign rank tests we detected no evidence of population bottlenecks at any of our study sites (Smoky Hills: $P = 0.279$, northern Flint Hills: $P = 0.711$, southern Flint Hills: $P = 0.351$).

N_e and relatedness impacts.–Genetic diversity and effective population size are indirect measures of population status that can be calculated from molecular data. Genotyping of prairie chickens showed no evidence of significant changes in observed heterozygosity (H_o) or effective population size (N_e) throughout the duration of this study (Table 7.2). However, global estimates of genetic diversity and effective population size might be expected to change slowly, and take a long time to reach equilibrium in a contemporary landscape (Crow and Akoi 1984). Unlike estimates of heterozygosity and F_{ST}, genetic relatedness is based on the percent genetic similarity among individuals and is much more temporally sensitive to contemporary landscape conditions (Hartl and Clark 2007). At the Smoky Hills study site, we compared the average pairwise relatedness of males within a lek and the average pairwise relatedness of males among leks during the pre- and postconstruction periods. Wind energy development started in the eastern portion of our site in phase 1 and proceeded to the western edge of phase 2, effectively bisecting the northern and southern halves of our study site. To control for isolation by distance (Slatkin 1993), we included leks north and south of the wind power facility in two separate spatial neighborhoods.

Relatedness among males at the Smoky Hills site during the preconstruction period indicated that the sampled birds were from a genetically diverse, panmictic population (average pairwise relatedness among individuals : $r = -0.016 \pm 0.13$). Moreover, relatedness among males captured at the same lek was significantly less than would be expected by chance ($r = -0.33 \pm 0.05$) and significantly less than the pairwise relatedness among males at different leks (two sample t-test, $P = 0.03$). During the postconstruction period, genetic relatedness between males among different leks remained essential zero (*r* = 0.012 ± 0.12). However, pairwise relatedness among males within leks increased to about the level of relatedness one would expect to observe among half siblings (*r* = 0.28 ± 0.08). An increase in relatedness among individuals associated at the same lek may be an indicator of disrupted gene flow and more limited rates of natal dispersal, with groups of siblings showing greater philopatry and settling at the same lek together.

Estimates of population numbers from counts of males at leks do not indicate that wind power development has a negative impact on population size of prairie chickens. The highest rates of population change were observed during the interval that the wind power facility was constructed and peak counts of males at leks were recorded the first year after construction was completed. Estimates of population viability based on genetic diversity, effective population size and rates of population exchange did not show annual changes during our study. Estimates of relatedness among males at the same and different leks suggested that wind power development has either reduced dispersal rates or changed settlement patterns, leading to higher rates of relatedness among males displaying at the same lek site.

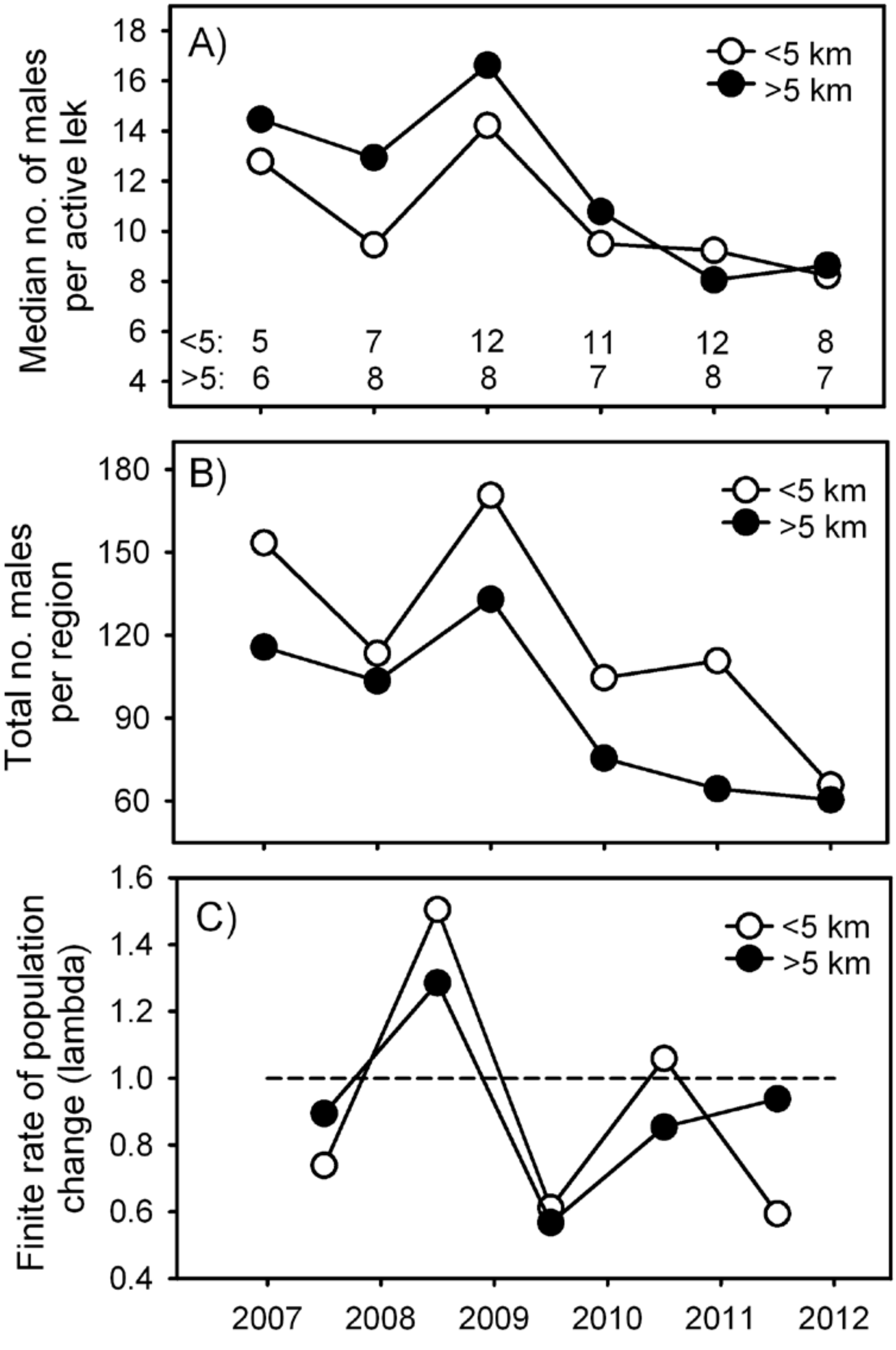
Table 7.1. Descriptive population genetic statistics for Greater Prairie-Chickens at the three study sites in Kansas, 2006-2011.

Location or Paired Comparison	**N**	**95% CI N_e**	**H_E**	**H_O**	**F_{ST}**	**F_{IS}**	**# Broods**	**# Chicks**
Smoky Hills	927	268.9-309.9	0.89	0.88		0.17	42	46
Northern Flint Hills	609	190.3-365.8	0.89	0.88		0.18	20	114
Southern Flint Hills	164	137.4-182.6	0.81	0.80		0.16	12	243
Smoky Hills vs. Northern Flint Hills					0.005			
Smoky Hills vs. Southern Flint Hills					0.013			
Northern Flint Hills vs. Southern Flint Hills					0.012			
Cumulative	1,700		0.86	0.85			74	403

Table 7.2. Annual variation in observed heterozygosity (H_o) and effective population size (N_e) for three populations of Greater Prairie-Chickens in Kansas, 2006-2011.

	Smoky Hills	Northern Flint Hills	Southern Flint Hills
2006 95% CI H_O	NA	NA	0.72 ± 0.062
2007 95% CI H_O	0.69 ± 0.041	0.72 ± 0.057	0.69 ± 0.068
2008 95% CI H_O	0.69 ± 0.044	0.70 ± 0.068	0.64 ± 0.092
2009 95% CI H_O	0.69 ± 0.043	0.71 ± 0.046	NA
2010 95% CI H_O	0.65 ± 0.042	NA	NA
2011 95% CI H_O	0.79 ± 0..27	NA	NA
2006 95% CI N_e	NA	NA	122.0 – 271.3
2007 95% CI N_e	200.2 – 281.6	211.2 – 325.9	127.1 – 182.9
2008 95% CI N_e	164.6 – 197.5	251.8 – 524.8	45.4 – 114.9
2009 95% CI N_e	215.5 – 282.1	103.8 – 175.4	NA
2010 95% CI N_e	322.6 – 489.2	NA	NA
2011 95% CI N_e	336.4 – 1140.2	NA	NA

Figure 7.1. Population trends for male Greater Prairie-Chickens at the Smoky Hills field site, 2007-2012. Wind power development was completed between 2008 and 2009, and we present counts of males at leks <5 km and >5 km from wind turbines. A) Median number of males per active lek, B) Total number of males per area, and C) Finite rate of population change for males where the dashed line indicates a stationary population (λ = 1).



Accomplishments

Research products from this project include five peer-reviewed publications and two dissertations. Five manuscripts are currently in review.

Peer-reviewed Journal Articles and Dissertations (PDF at www.ksu.edu/bsanderc)

McNew, L.B., A.J. Gregory, and B.K. Sandercock. 2013. Spatial heterogeneity in habitat selection: nest site selection by Greater Prairie-Chickens. Journal of Wildlife Management 77:791-801.

McNew, L.B., A.J. Gregory, S.M. Wisely, and B.K. Sandercock. 2012. Demography of Greater Prairie-Chickens: regional variation in vital rates, sensitivity values, and population dynamics. Journal of Wildlife Management 76:987-1000.

Gregory, A.J., L.B. McNew, T.J. Prebyl, B.K. Sandercock, and S.M. Wisely. 2011. Hierarchical modeling of lek habitats of Greater Prairie-Chickens. Studies in Avian Biology 39:21-32.

McNew, L.B., A.J. Gregory, S.M. Wisely, and B.K. Sandercock. 2011a. Reproductive biology of a southern population of Greater Prairie-Chickens. Studies in Avian Biology 39:209-221.

McNew, L.B., A.J. Gregory, S.M. Wisely, and B.K. Sandercock. 2011b. Human-mediated selection on life-history traits of Greater Prairie-Chickens. Studies in Avian Biology 39:255-266.

McNew, L.B. 2010. An analysis of Greater Prairie-chicken demography in Kansas: the effects of human land use on the population ecology of an obligate grassland species. Ph.D. dissertation, Kansas State University, 149 pages.

Gregory, A.J. 2011. Landscape genetics and behavioral ecology of Greater Prairie-Chickens (*Tympanuchus cupido*). PhD Dissertation, Kansas State University, Manhattan, Kansas, 159 pages.

Manuscripts in Review

Blanco-Fontao, B., J.R. Obeso, M. Quevedo, L.B. McNew, and B.K. Sandercock. Effects of sexual dimorphism and habitat composition on the trophic behavior of Greater Prairie-Chickens revealed through analysis of stable isotopes. PLoS One, submitted May 2013.

Gregory, A.J., L.B. McNew, B.K. Sandercock and S.M. Wisely. Genetic prospecting and bet-hedging: breeding behavior of female Greater Prairie-Chickens (*Tympanuchus cupido*) across a gradient of anthropogenic landscape disturbance. Evolutionary Ecology, submitted February 2012.

Gregory, A.J., L.B. McNew, B.K. Sandercock and S.M. Wisely. Optimizing landscape resistance surfaces to understand gene flow: a case study of Greater Prairie-Chickens. Molecular Ecology, submitted March 2012.

McNew, L.B., L.M. Hunt, A.J. Gregory, S.M. Wisely, and B.K. Sandercock. Wind energy development does not impact the nesting ecology of an obligate grassland bird in a fragmented landscape. Conservation Biology, submitted April 2013.

Winder, V.L., L.B. McNew, A.J. Gregory, L.M. Hunt, S.M. Wisely, and B.K. Sandercock. Effects of wind energy development on the survival of Greater Prairie-Chickens. Journal of Applied Ecology, submitted January 2013.

Conclusions

A Research Brief that provides a nontechnical synopsis of the research results from this project was prepared by staff with the National Wind Coordinating Collaborative and is posted at the NWCC website (www.nationalwind.org). The 4-page Research Brief is included as an Appendix to this Final Technical Report.

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