Impacts of Energy Development on Prairie Grouse Ecology: A Research Synthesis

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As demand has increased for energy resources in recent years (National Petroleum Council 2007), both U.S. federal and state governments have established renewable energy quotas for their energy portfolios (Lu et al. 2009). These quotas are targeted to diversify sources of energy generation and offset the myriad risks associated with climate change. The geographic location of renewable energy sources (e.g., wind, geothermal or bio-mass) has potential to open new markets for generation and transmission of electricity in portions of the U.S. that have not previously been developed for such industrial use (Green and Nix 2006, Lu et al. 2009). The tall and mixed-grass prairies of the Midwest, and sagebrush (*Artemisia* spp.) steppe of the Intermountain West and Great Basin host some of best wind resources in the continental U.S. (Lu et al. 2009). A considerable portion of the Great Basin has significant potential for geothermal energy development (Green and Nix 2006). Much of these native habitats have been lost since European settlement, with reductions of 60 and 70 percent, of sagebrush and prairie types, respectively (Samson et al. 2004, Schroeder et al. 2004).

The remaining native habitats in both of these biomes are home to the iconic prairie grouse species, including greater (*Centrocercus urophasianus*) and Gunnison's sage-grouse (*C. minimus*), greater (*Tympanuchus cupido*) and lesser prairie-chicken (*T. pallidicinctus*), and sharp-tailed grouse (*T. phasianellus*). All of these species require healthy native habitats and generally occupy large landscapes. Because of their dependence on native rangelands and strong site fidelity, the historic loss and degradation of these habitats has led to reduced distributions and in some cases long-term declines in populations of prairie grouse. Thus, the lesser prairie-chicken and both species of sage-grouse are candidates for protection under the Federal Endangered Species Act (www.fws.gov/mountain-prairie/species/birds; accessed 28 February 2009).

Collectively, these endemic game birds often are indicators of ecosystem health for the suite of other avian and mammalian species that occupy these vast regions (Rowland et al. 2005, Hanser and Knick *in press*). There are myriad stressors on these systems: from recreational use to type-conversion for agriculture or industrial uses. Any of these land uses may directly reduce habitat quality or indirectly affect habitat use or demography through avoidance of highly disturbed sites or increased predation rates, respectively (Fuhlendorf et al. 2002, Aldridge and Boyce 2007, Hagen et al. in press, Leu et al. in press). Given projected energy demands and new quotas for energy development portfolios, there is potential risk to significantly reduce and fragment the remaining habitats (Doherty et al. in press, Leu et al in press). However, few data exist regarding the impacts of wind energy development on prairie grouse, and much of the inference on development comes from existing transmission corridors or fossil fuel extraction. Collectively, the body of literature on anthropogenic features and prairie grouse suggests there are negative consequences to populations with this type of development (Robel et al. 2004, Naugle et al. in press). A data synthesis has not been conducted to estimate the generalized effect size of anthropogenic features on prairie grouse space use or demography. Elucidating and quantifying a generalized effect can provide important guidance to conservation efforts (Hagen et al. 2007). Current conservation strategies seek to avoid, minimize or mitigate these impacts on a project-by-project basis, and maintaining sustainable populations using such an approach has been questioned (Doherty et al. in press).

The objectives of this paper are to 1) synthesize current data on the impacts of energy development (and associated infrastructure) on prairie grouse distribution and demography; 2) identify potential mechanisms for population-level responses; 3) address potential future impact to populations; and 4) recommend a conservation strategy for large landscapes to increase the certainty of population persistence of these iconic species.

Methods

I searched peer-refereed articles, graduate research theses and non-refereed reports that pertained to prairie grouse and the impacts of energy development. Because there is a lack of published information on prairie grouse and wind energy development, I chose to include data from two non-peer refereed studies (including three species) on this topic (Young et al. 2003, Vodenhal 2009). Most studies reported several demographic rates or displacement (e.g., distances from features) variables, some of which were non-independent (e.g., brood survival and productivity ratios), in such cases, I chose only one of those variables to include for estimates of effect size. In all cases, each demographic rate was independent from others and treated as a significant unit (e.g., nest initiation rate, nest success). The strength of a meta-analytic approach is that it uses a standardized metric (similar to the coefficient of variation) and enables comparisons

within and among studies that measured different aspects of a population's demography (Hedges and Olkin 1985, Gurevitch and Hedges 1999, Hagen et al. 2007).

Data Analysis

A general equation for an effect size (d) of a single study is the treatment mean minus control mean divided by the pooled variance (Hedges 1982). The effect size for each independent variable in a study serves as a dependent variable that can be modeled as a function of discrete or continuous explanatory variables or used to estimate a cumulative effect size (d_{++}) across multiple studies. As a general guideline, effect size magnitude can be ranked as small (0.2), medium (0.5) or large (0.8) standard deviations from a null effect size of zero (Cohen 1969).

I used Hedges' d because it is conducive to estimating an effect between paired treatments or observational groups, and estimated cumulative effect size d_{++} for each demographic and displacement effect (Hedges 1982). I used pre-construction, reference sites, areas of less disturbance (where there was a gradient of development levels) areas outside of development buffers and control sites, to collectively define the "control" group. I used post-construction sites, areas of greater disturbance (where there was a gradient of development levels), and areas inside of development buffers collectively to define the "treatment" group; thus, a positive estimate of d and 95-percent confidence intervals (CIs) non-inclusive of zero indicated a distance or demographic variable was positively influenced (benefited) by energy development. Whereas a negative estimate of d and 95-percent CIs non-inclusive of zero indicated a distance (hereafter displacement) or demographic variable was negatively influenced by energy development, and any estimate of d with 95-percent CIs that included zero no measurable effect could be inferred.

I chose bias corrected bootstrap sampling to estimate 95-percent CIs for d_{++}, to account for replicate years, areas or multiple variables being measured within studies. I evaluated the plausibility of using additional explanatory variables to explain the observed differences in effect sizes among studies. I used mixed models to identify a common effect size (or lack thereof) across species, studies and seasons (categorical data) for each demographic or displacement effect. The basic assumption for this analysis is that random variation occurs among effect sizes within a species (or study site), but may differ between them (Gurevitch and Hedges 1999). Here, the statistic Q_B can be used to assess the amount of variation in effect sizes accounted for between groups. If Q_B is greater than would be expected at random (χ^2 - distribution) it suggests that effect sizes are larger between groups than expected from random. If Q_B was non-significant, then a random effects model was used to estimate a cumulative effect size for each demographic or displacement effect for all studies and species. All meta-analytic calculations were conducted in MetaWin 2.0 (Rosenberg et al. 2000).

The quality of a research synthesis hinges on the quality of publications available to analyze, as well as studies not published because of a lack of significant results (Rosenberg 2005). Such bias is referred to as publication bias and can overestimate the effect size if a large number of non-significant studies are not published or accessible. The preferred method to evaluate the potential impact of publication bias is the calculation of a fail-safe number (N_+; Rosenberg 2005). A fail-safe number indicates the number of nonsignificant, unpublished (or missing) studies that would need to be added to a meta-analysis to reduce an overall statistically significant observed result to non-significance (Rosenberg 2005). The limitation to this approach is there is no fail-safe number for mixed model estimates. I estimated fail-safe numbers for each significant effect size using Fail-Safe Number Calculator (Rosenberg 2005), and considered an effect size robust if $N_+ > 5N + 10$, where N is the observed number of studies used to estimate the effect size. Because I used mixed models to estimate effect sizes, I report fail-safe numbers for both fixed and random effects models.

Results

I located 22 studies (13 peer-refereed, 5 graduate studies and 3 non-refereed reports) that reported quantitative data on prairie grouse responses to energy development (Table 1). Four studies did not report data in a format that could be used for a meta-analysis using Hedges' d (Braun et al. 2002, Aldridge and Boyce 2007, Doherty et al. 2008, Pruett et al. 2009), and two others were synthesis papers that did not report original data (Robel et al. 2004, Naugle et al. in press). One article on the European black grouse (*Tetrao tetrix*) was included as it directly measured the impacts of wind farm development on lek attendance (Zeiler et al. 2009). Black grouse occupy a similar niche to that of the Columbian sharp-tailed grouse (*Tympanuchs phasianellus columbianus*), using montane shrub communities but also occupying wooded or forested habitats. Five studies provided information on displacement distances to 6 types of features resulting in 26 estimates of d (Table 1). Thirteen studies provided estimates of demographic rates as they related to development resulting in 41 estimates of d.

Table 1. Studies reviewed and included in a meta-anlysis examining the displacement and demographic effects of energy development on prairie grouse species.

Study	Species[a]	Development type[b]	Design[c]	Displacement[d]	Demography	Report
Aldridge and Boyce 2007	GRSG	OG	GR	Y	Y	Peer refereed
Braun et al. 2002	GRSG	OG	GR	N	Y	Peer refereed
Doherty et al. 2008	GRSG	NG	GR	Y	N	Peer refereed
Ellis 1984	GRSG	PL	TC	Y	Y	Peer refereed
Hagen et al. 2009	LPCH	DV	OR	Y	N	Peer refereed
Holloran 2005	GRSG	NG	TC	Y	Y	Thesis
Holloran et al. 2007	GRSG	NG	TC	Y	Y	Report
Holloran et al. 2010	GRSG	NG	TC	Y	Y	Peer refereed
Hunt 2004	LPCH	OG	PP	Y	N	Thesis
Johnson et al. in press	GRSG	DV	GR	Y	Y	Peer refereed
Kaiser 2006	GRSG	NG	BF	Y	Y	Thesis
Lyon and Anderson 2003	GRSG	NG	TC	Y	Y	Peer refereed
Pitman et al. 2005	LPCH	DV	OR	Y	N	Peer refereed
Pruett et al. 2009	LPCH, GPCH	PL, RD	OR	Y	N	Peer refereed
Robel et al. 2004	LPCH	DV	OR	Y	N	Peer refereed
Tack 2010	GRSG	OG	GR	Y	Y	Thesis
Vodenhal 2009	SHTG, GPCH	WD	OB	N	Y	Report
Walker et al. 2007	GRSG	NG	TC	Y	Y	Peer refereed
Williamson 2009	SHTG	OG	TC	N	Y	Thesis
Young et al. 2003	GRSG	WD	PP	Y	N	Report
Zeiler and Berger 2009	BLGR	WD	PP	Y	Y	Peer refereed

[a] Grouse species include: greater sage-grouse (GRSG), greater prairie-chicken (GPCH), lesser prairie-chicken (LPCH), sharp-tailed grouse (SHTG) and black grouse (BLGR).
[b] Development type includes: oil/gas (OG), multiple forms of development (DV), wind energy (WD), natural gas (NG), power lines (PL) and roads (RD).
[c] Study design generally characterized as pre- and post construction (PP), treatment and control sites (TC), observed compared to random (OB), distance gradients using regression (GR), and impacts compared inside and outside of development buffer (BF).
[d] Type of data reported in an article, displacement or habitat use, or demography, indicated by a yes (Y) or no (N).

Effect Sizes

There was a general effect for prairie grouse displacement by anthropogenic features ($d_{++} = -0.671$, 95 percent CI: –1.105, –0.341). An examination of Q_B indicated that the effect (d) of anthropogenic features was similar among studies ($P > 0.199$), species ($P = 0.124$) and seasons ($P = 0.406$) for each variable (Table 2). The mixed model examining the similarity of effect sizes among features indicated there was measurable heterogeneity among classes of features ($P = 0.020$). However, features only measured in one study were not included in this model, because at least two effect sizes are needed to define a class in the mixed-model analysis. Thus, I evaluated an overall random effects model which included data from all studies that measured distances to anthropogenic features, and the overall model indicated that drawing inference from an average effect size was reasonable ($P = 0.433$). Anthropogenic features had a negative effect on displacement in all biological seasons for which d could be estimated (Table 2), with the largest effect on nesting season ($d = -1.026$, 95 percent CI: –1.889, –0.307). The presence of power lines had the largest measurable effect on displacement ($d = -1.526$, 95 percent CI: –2.052, –0.974), followed by roads ($d = -0.736$, 95 percent CI: –1.867, –0.126).

Demographic rates were generally reduced by energy development ($d_{++} = -0.303$, 95 percent CI: –0.609, –0.064). An examination of Q_B indicated that the effect (d) of anthropogenic features was similar among studies ($P = 0.115$), species ($P = 0.288$), features ($P = 0.216$) and seasons ($P = 0.540$), for each variable (Table 3). Demographic rates were lower in developed areas for all biological seasons for which d could be estimated (Table 3), with the largest effect on annual survival ($d = -0.523$, 95 percent CI: –1.042, –0.250). Buffer areas around natural gas wells and turbines had the largest two effect size estimates, but neither was precise enough to conclude a measurable effect. Only gas fields had a measurable effect on demography of prairie grouse. However, per the Q_B test, drawing inference from the overall random effects model Q_T($P = 0.712$) was reasonable and indicated a small to moderate negative effect (Table 3).

Table 2. Effect size estimates (*d*) and 95-percent CI for displacement of prairie grouse by anthropogenic features from five studies, and diagnostic statistics (Q_T, N_+) from mixed model meta-analyses. Mixed models were used to explore potential relationships between features, and biological season, even though a generalized random model (Overall) did not detect heterogeneity in effect sizes among features or seasons. An asterisk indicates a fail-safe number (N_+) is robust (>5*N* + 10). The fail-safe number is equivalent to the number of studies of null effect and mean weight necessary to reduce the observed significance level to $\alpha = 0.05$.

	Parameter estimates			Diagnostics	
Feature	N	*d*	95-percent CI	Fail-safe (N_+) fixed effects	Fail-safe (N_+) random effects
Power lines	6	–1.526	–2.052, –0.974	1,936*	1
Wells	6	–0.299	–0.652, –0.046	75*	1
Buildings	4	–0.169	–0.500, 0.109	NA	NA
Roads	6	–0.736	–1.867, –0.126	198*	1
Total[a]	22	–0.724	–1.160, –0.372	Non-est	Non-est
Season					
Lekking	2	–0.066	–0.131, 0.015	NA	NA
Nesting	9	–1.027	–1.915, –0.263	1,335*	1
Brood	3	–0.209	–0.311, –0.058	1	1
Annual	10	–0.591	–0.925, –0.273	773*	1
Total[a]	24	–0.671	–1.065, –0.348	Non-est	Non-est
Overall[a]	24	–0.671	–1.065, –0.348	4,801*	1

[a] Diagnostics for mixed model of feature type $Q_T = 34.17$ df = 21 $P = 0.03$; season of use and random effects model included all studies $Q_T = 22.48$ df = 23 $P = 0.49$.

Table 3. Effect size estimates (*d*) and 95-percent CI for demographic impacts of prairie grouse by anthropogenic features from 13 studies, and diagnostic statistics (Q_T, N_+) from mixed model meta-analyses. Mixed models were used to explore potential relationships between features, and biological season, even though a generalized random model (Overall) did not detect heterogeneity in effect sizes among features or seasons. An asterisk indicates a fail-safe number (N_+) is robust (>5*N* + 10). The fail-safe number is equivalent to the number of studies of null effect and mean weight necessary to reduce the observed significance level to $\alpha = 0.05$.

	Parameter estimates			Diagnostics	
Feature	N	*d*	95-percent CI	Fail-safe (N_+) fixed effects	Fail-safe (N_+) random effects
Wells	2	–0.280	–0.560, 0.000	NA	NA
Gas Field	21	–0.202	–0.415, –0.003	84*	1
Turbine	4	–0.774	–1.543, 0.027	258*	NA
Buffered dis.	4	–0.736	–1.967, 0.187	17	1
Total[a]	31	–0.347	–0.620, –0.116	Non-est	Non-est
Season					
Lekking	10	–0.097	–0.467, 0.269	NA	NA
Nesting	5	–0.432	–2.095, 0.521	NA	NA
Brood	10	–0.104	–0.246, 0.029	NA	NA
Annual	6	–0.573	–1.035, –0.250	42	1

Table 3 continued

Total[a]	31	–0.246	–0.558, –0.028	Non-est	Non-est
Overall[a]	32	–0.303	–0.557, –0.073	1,512*	1

[a] Diagnostics for mixed model of feature type $Q_T = 35.94$ df = 30 $P = 0.21$; season of use $Q_T = 33.79$ df = 30 $P = 0.29$; and for random effects model across all studies $Q_T = 26.17$ df = 31 $P = 0.71$.

Publication Bias

The relatively small number of studies included in these analyses resulted in fail-safe calculations under a random-effects model indicated that only one additional study was needed to reduce the observed effect sizes to a non-significant level under the random-effects model. However, estimating fail-safe calculations under the assumption of fixed effects, most estimates of d and d_{++} were robust to publication bias (Tables 2 and 3). Given the extreme differences in these outcomes, it is likely that truth is somewhere in the middle of these two estimates.

Discussion

I provide the first quantitative assessment of available data on the impacts of anthropogenic features on displacement and demography of prairie grouse. I found a general effect for displacement and reduced demographic rates, as evidenced by low levels of variation in effect sizes across studies and species. Most of the effect size estimates were not robust to the potential impacts of publication bias, suggesting additional research is needed to better understand biological mechanisms underlying these patterns. Notwithstanding, the best available data indicates moderate to large displacement effects and small to moderate demographic effects on prairie grouse populations. Together, these effect size estimates add to the growing body of evidence indicating that anthropogenic features displace and may reduce demographic rates in prairie grouse species. However, limitations of these generalized impacts should be addressed. There were relatively few studies from which to draw data, and as a result, multiple measurements from a single study were often included and assumed to be independent data points. Nevertheless, I included only those variables (or estimates) that were independent of one another (e.g., nest initiation, nest success, brood survival, annual survival) to avoid overestimating an effect size and to minimize underestimating variances. Similarly, distances and displacement data relative to features were drawn from a relatively small set of studies, and some of those measurements may have been correlated. However, I had no way of determining the level of correlation and had to assume they were independent measures. Ideally, as the impact-study body of literature grows, these meta-analytic techniques can be directed at questions regarding specific demographic rates and specific types of development or anthropogenic features.

Overall, the displacement effect size of anthropogenic features on prairie grouse space use was nearly one standard deviation (–0.7) and would be considered a medium to large effect (Cohen 1969). The displacement effect varied by feature type; power lines and roads had the largest effects. However, recent work in the oil and gas fields that used regression techniques further supports the levels of displacement by gas field development synthesized in my study (Holloran 2005, Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2010, Tack 2010).

Regression analyses and Monte Carlo simulations have identified distance thresholds of avoidance as well as demographic responses to energy development. Avoidance of energy development for greater sage-grouse can occur out to approximately 3.1 miles (5 km) for nesting and lekking (Holloran 2005, Johnson et al. in press). Both species of prairie chicken appear to be more tolerant of these disturbances with minimum distances of less than 1.1 mile (1.8 km) in many cases (Pitman et al. 2005, Pruett et al. 2009, Hagen et al. in press). However, Hagen et al. (*in press*) caution that the apparent tolerance to these features may represent populations occupying habitat sinks (Aldridge and Boyce 2007, Hagen et al. 2009). Simple distances to features is not always the best indicator of avoidance (Holloran 2005), and elucidating the patterns of habitat use relative to the density of features can be more informative. The density of oil, natural gas and coal-bed methane gas infrastructure was negatively correlated with nest locations, winter habitat use, lek attendance and number of active leks (Hunt 2004, Holloran 2005, Walker et al. 2007, Doherty et al. 2008, Tack 2010).

Presence of anthropogenic features tended to negatively affect prairie grouse demographic rates (–0.3), and would be considered a small to moderate effect size (Cohen 1969). The 95-percent CIs for largest point estimates of d (turbines and gas field buffers) both overlapped zero. Thus, the presence of turbines relative to black grouse leks and demographic rates of greater sage-grouse inside a 6-kilometer buffer of natural gas fields were the factors behind these effect size estimates. Seasonal variation in demographic effects was not measurable, but an exploratory examination of those results indicated that the largest effects were to annual survival and nesting season rates (e.g., nest initiation, nest success).

However, the effect on nesting season rates ($d = -0.4$) was not measurably different from zero, but the effect on annual survival was moderate ($d = -0.5$).

Female prairie grouse are capable of successfully hatching nests despite various levels of development (Lyon and Anderson 2003, Pitman et al. 2005, Kaiser 2006, Williamson 2009). The impacts on nest initiation rates and brood survival are more variable, with sharp-tailed grouse demography seemingly the least affected based on a two-year study (Williamson 2009). Reduced chick survival and annual survival have been documented in greater sage-grouse occupying energy development sites (Ellis 1985, Kaiser 2006, Aldridge and Boyce 2007, Holloran et al. 2010). A portion of the increased mortality can be attributed to predation and vehicle collisions (Ellis 1984, Aldridge and Boyce 2007). Chick survival and adult female survival are generally the drivers in population dynamics of prairie grouse, and reductions to these rates may have population level effect (Wisdom and Mills 1997, Johnson and Braun 1999, Holloran 2005, Hagen et al. 2009, Walker et al. in press).

Lek attendance and persistence were variable with respect to energy development (Walker et al. 2007, Vodenhal 2009, Johnson et al. in press). The two examples of lek attendance relative to wind energy development demonstrate this variation. Zeiler and Grunschnacher-Berger (2009) documented the local displacement and near extirpation (from preconstruction counts) of black grouse display grounds in the vicinity of a 13-turbine wind farm over an eight-year period. In contrast, greater prairie-chicken and sharp-tailed grouse continued to display at leks in an area with 36 turbines four years post construction (Vodenhal 2009). Unfortunately, there were no preconstruction data to allow comparisons of population trends (or distributions) to the larger region pre- and post construction, but greater prairie-chicken lek attendance increased at a slower rate (6 versus 9 percent annual rate of change), and sharp-tailed grouse lek attendance decreased at a slower rate (–5 versus –11 percent annual rate of change) relative to the larger Sandhills region (Nebraska Game and Fish Commission unpublished data).

Together, these effect sizes suggest that displacement of prairie grouse may lead to reduced demographic rates. Individual studies have drawn similar conclusions but few have examined these impacts at the scale of this review (Holloran 2005, Hagen et al. 2009, Johnson et al. in press, Walker et al. in press). Several anecdotal reports are available that record the behaviors of individual grouse or small flocks relative to these disturbances (Young et al. 2003, Washington Department of Fish and Wildlife 2008). For example, a greater sage-grouse nest was located within 656 feet (200 m) of the nearest wind turbine, and males were roosting on a turbine pad (Washington Department of Fish and Wildlife 2008). Often, such observations suggest that avoidance is not an issue, but it is critical to differentiate between observations of individuals and population level effects (Aldridge and Boyce 2007). Individuals may still occupy habitats in developed areas because of site fidelity or because they are remnants of suitable habitat (or both). However, there is a biological cost to occupying such sites (i.e., an ecological sink), if predator communities have been altered and increase mortality risks or if new stressors are introduced to the system that reduce primary productivity (Holloran 2005, Aldridge and Boyce 2007, Hagen et al. 2009). Aldridge and Boyce (2007) provide evidence that oil and gas fields in Alberta are habitat sinks and pose a significant threat to local populations of greater sage-grouse. Thus, it is probable that individual prairie grouse will occupy habitats proximate to anthropogenic features, but their fitness may be compromised, and consequently their contribution to the sustainability of a local or regional population is uncertain.

Conservation Implications

The results of my synthesis suggest general effects of displacement and subsequently reduced demographic rates in landscapes impacted by energy development. Thus, strategies to protect large landscapes (i.e., refugia) and increase the likelihood of persistence of prairie grouse populations therein are paramount (Doherty et al. in press, Naugle et al. in press). I concur with Naugle et al. (in press) and the analysis of Doherty et al. (in press), both of which advocate for landscape-scale prioritization of grouse habitats based on the breeding density and biology of the species. If implemented, this framework would protect the highest quality areas from associated risks of energy development, but would provide some flexibility in the siting of energy development in less important habitat areas and a context for habitat mitigation. Currently, regional or rangewide maps that prioritize habitats for prairie grouse are needed. Thoughtful planning to conserve the high-priority habitat areas for prairie grouse should enable goals of sustainable wildlife populations and energy generation to be met.

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